Study of transverse spherocity as event shape variable in charged-particle productions in pp collisions at $\sqrt{s}$= 13 TeV using EPOS event generator

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Introduction

Studying the behavior of matter under extreme temperature and energy density conditions is crucial for gaining insights into the phase transitions of matter within Quantum Chromodynamics (QCD). Specialized experiments such as the Relativistic Heavy Ion Collider (RHIC) in BNL, USA, and the Large Hadron Collider in CERN, Geneva, Switzerland have been designed for precisely this purpose. The findings from these experiments indicate the formation of a highly interactive deconfined state comprising quarks and gluons, known as Quark-Gluon Plasma (QGP), during ultra-relativistic heavy-ion collisions. This QGP represents an ephemeral, intensely hot, and dense state.

Transverse Spherocity serves as a variable within event structures, offering an efficient means to distinguish between hard and soft components in data [1]. These components correspond to events involving either a small number of multi-parton interactions (MPI) or a large number of MPI [2], respectively. By calculating event-by-event event shape observables, we can effectively segregate events into two categories: jetty-like events featuring high transverse momentum (p_T) jets and isotropic events representing partonic scattering with low Q^2. Recent findings from the LHC in small-scale systems underscore the significance of the transverse spherocity variable in event classification. In this contribution, we investigate the dynamics of identified particle production in pp-collisions at a center-of-mass energy of $\sqrt{s}$ = 13 TeV using the EPOS event generator. We analyze the transverse momentum spectra of identified particles in soft (isotropic) and hard (jetty-like) events across two centrality intervals.

EVENT GENERATION AND ANALYSIS METHODOLOGY

This section will be devoted to discussions related to the event generator EPOS3. About 10 million minimum bias events have been generated for pp collision at $\sqrt{s}$= 13 TeV. Each event is required to have at least one primary charged particle. A discussion will also be presented for transverse spherocity.

A. EPOS3 event generator

EPOS stands for Energy conserving quantum mechanical approach, based on Partons, parton ladders, strings, Off-shell remnants, and Splitting of parton ladders, represents a specialized event generator tailored for simulating high-energy collisions. Its primary objective is to replicate a wide spectrum of observables, encompassing phenomena such as jets, multiplicity, and transverse momentum, typically observed in collisions occurring at extremely high energies, such as those witnessed at RHIC or LHC for diverse systems like pp, PbPb, and AuAu when the baryon potential μ_B is approximately 0.

This model represents a complex hybrid system where the development of this newly established system during initial collisions, including proton-proton (pp) and heavy-ion interactions, follows the principles of the Parton-Based Gribov-Ragge theory.

B. Transverse Spherocity

Transverse spherocity (S_o) is a characteristic of an event, determined by employing a unit vector denoted as $\widehat{n}$ ($\widehat{n}_T$, 0). This vector

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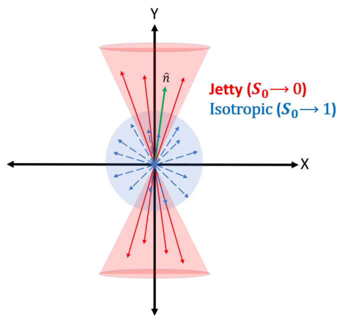

FIG. 1:

is selected from the entire set of feasible unit transverse vectors [26, 27], minimizing a specific ratio.

$$S_o = \frac{\pi^2}{4} \min_{\widehat{n}=(n_x,n_y,n_y)} \left(\frac{\sum_i |\vec{p}_{T_i} \times \widehat{n}_T|}{\sum_i p_{T_i}} \right)^2 \quad (1)$$

The coefficient $\frac{\pi^2}{4}$ serves to standardize the minimum value to 1 in the case of isotropy. Consequently, the transverse spherocity ranges from 0 to 1, reflecting the transition from a distribution of particles resembling jets to a more isotropic structure. respectively, i.e.

$$S_o = \begin{cases} 0 & \text{pencil-like limit (hard events)} \\ 1 & \text{isotropic limit (soft events)} \end{cases} \quad (2)$$

Fig. 1 shows the distribution of particles in both the scenarios

Results

The Multiplicity as well as transverse spherocity (S_o) distributions for primary charged particles for $|\eta| < 1$ are shown in Fig. 2. The analysis of particle p_T spectra has been conducted within both the jetty and isotropic regimes of transverse spherocity intervals in the centrality bin 0-10% bin.

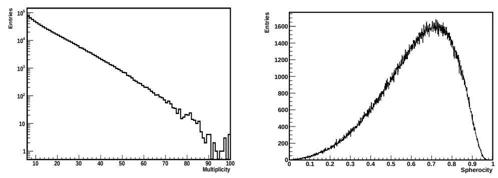

FIG. 2: Left: The multiplicity distribution of primary charged-particles. Right: The spherocity distributions for primary charged-particles.

Fig. 3 and Fig. 4 present the p_T spectra of $\pi^{\pm}$, $K^{\pm}$, and $p^{\pm}$ for centrality bins of 0-10% and 80-100%, focusing on most central and peripheral region respectively, within the mid-rapidity region $|\eta| < 0.8$. The cen-

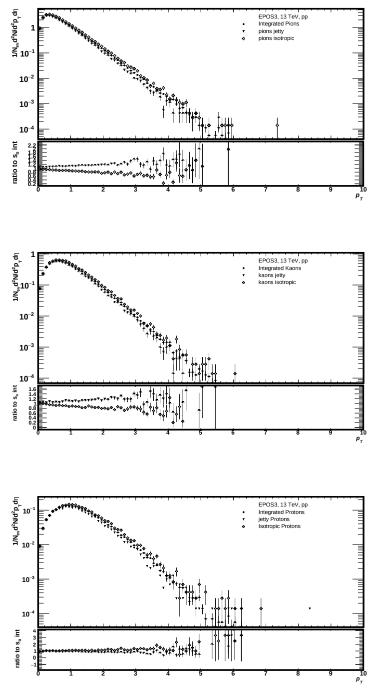

FIG. 3: p_T spectra of $\pi^{\pm}$(top), $K^{\pm}$(middle), and $p^{\pm}$(bottom) in the centrality bin 0-10% bin. The lower panel of the respective figures show the ratio of p_T-spectra for isotropic and jetty events w.r.t S_o integrated events.

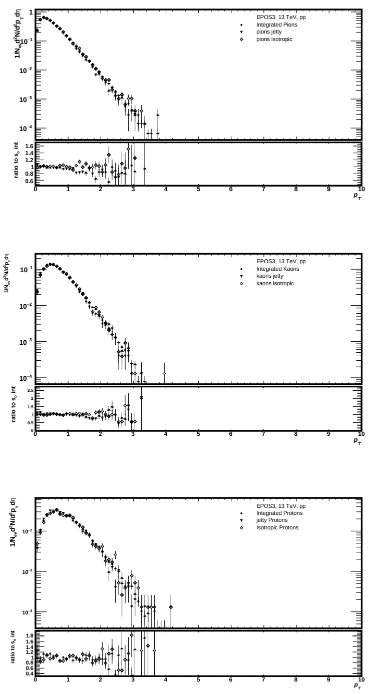

FIG. 4: p_T spectra of $\pi^{\pm}$(top), $K^{\pm}$(middle), and $p^{\pm}$(bottom) in the centrality bin 80-100% bin. The lower panel of the respective figures show the ratio of p_T-spectra for isotropic and jetty events w.r.t S_o integrated events.

trality classes include jetty (representing the lower 10% of events in the spherocity distribution), isotropic (representing the upper 10% of events in the spherocity distribution), and integrated (0-1 transverse spherocity). The ratios of pT spectra for isotropic and jetty events with respect to the spherocity-integrated events ($0 < So < 1$) are depicted in the lower panels. The figures reveal that low pT regions are predominantly characterized by isotropic events, whereas jetty events become dominant at higher pT. At certain points referred to as crossing points [4–6], the dominance shifts from isotropic to jetty events. In our study, similar analyses of identified particles ($\pi^{\pm}$, $K^{\pm}$, and $p_{\pm}$) within the central pseudorapidity region $|\eta| < 0.8$ in the pp collision system demonstrate that isotropic events prevail at low centralities (high multiplicities), while the opposite is observed at higher centralities (low multiplicities).

Summary

In conclusion, we introduce the novel application of the Transverse Spherocity Analysis to pp collisions at $\sqrt{s} = 13$ TeV using EPOS3 event generator. Our findings reveal that this analysis effectively distinguishes between high-S_o and low-S_o event topologies in pp collisions.

From our results, it becomes evident that the crossover points occur at relatively lower transverse momentum (p_T) values as we transition from low centrality to high centrality events. This suggests that in low centrality events, jettiness prevails over isotropy, whereas in high centrality events, isotropy dominates.

Acknowledgments

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References

[1] S. Acharya et al. [ALICE], "Charged-particle production as a function of multiplicity and transverse spherocity in pp collisions at $\sqrt{s} = 5.02$ and 13 TeV," Eur. Phys. J. C 79 (2019) no.10, 857

[2] 1] ALICE Collaboration, A. Morsch, "Multiple Parton Interactions with ALICE: from pp to p-Pb," arXiv:1407.3628 [nucl-ex]. [J. Phys. Conf. Ser.535,012012(2014)]

[3] CMS Collaboration, S. Chatrchyan et al., "Jet and underlying event properties as a function of charged-particle multiplicity in proton?proton collisions at sqrts = 7 TeV," Eur. Phys. J. C73 no. 12, (2013) 2674, arXiv:1310.4554 [hep-ex].

[4] S. Prasad, N. Mallick, D. Behera, R. Sahoo and S. Tripathy, "Event topology and global observables in heavy-ion collisions at the Large Hadron Collider," Sci. Rep. 12 (2022) no.1, 3917

[5] S. Prasad, N. Mallick, S. Tripathy and R. Sahoo, "Probing initial geometrical anisotropy and final azimuthal anisotropy in heavy-ion collisions at Large Hadron Collider energies through event-shape engineering," [arXiv:2207.12133 [hep-ph]].

[6] J. Adam et al. [ALICE], "Centrality dependence of the nuclear modification factor of charged pions, kaons, and protons in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV," Phys. Rev. C 93 (2016) no.3, 034913