PROCEEDINGS OF SCIENCE

Particle production as a function of charged-particle flattenicity in small collision systems

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Event classifiers based on charged-particle multiplicity have been extensively used in pp collisions at the LHC. However, a drawback of the multiplicity-based event classifiers is that selected samples at high charged-particle multiplicity are biased towards hard processes. These biases blur the effects of multi-parton interactions (MPI) and make it difficult to pinpoint the origins of fluid-like effects in small systems.

This proceedings contribution exploits a new event classifier, the charged-particle flattenicity, defined in ALICE using the charged-particle multiplicity estimated in the intervals $2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$. Final results on the production of identified and unidentified charged particles as a function of flattenicity in pp collisions at $\sqrt{s} = 13$ TeV are discussed. It is shown how flattenicity can be used to select events in a way that is more sensitive to MPI. All the results are compared with predictions from QCD-inspired Monte Carlo event generators.

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1. Introduction

Experimental results on collectivity in pp and p–Pb collisions (commonly referred to as small systems) are not conclusive on the origin of collective phenomena observed in these collisions. For a comprehensive review of results achieved by ALICE, see Ref. [1]. There are several approaches that aim at explaining collective effects in small systems. Notably, vacuum-QCD based models such as PYTHIA 8 [2] with the implementation of color reconnection (CR) and multi-parton interactions (MPI) work remarkably well in reproducing many of the experimental results.

Event classification based on charged-particle multiplicity measurements at forward pseudorapidity is shown to be sensitive to biases from local multiplicity fluctuations originating from jets that affect the high-p_{T} particle yield and, in turn, distort measurements aimed at searching for jet modification in small systems [3].

Several event activity classifiers have been constructed and measured so far, see e.g. Ref. [4]. In order to increase the sensitivity to the number of MPIs, a new event activity estimator, named flattenicity, was introduced [5]. This estimator can effectively select pp collisions with large number of MPIs. According to studies performed with PYTHIA 8, the flattenicity classifier leads to smaller selection bias towards large p_{T}, due to local multiplicity fluctuations at forward pseudorapidities, than the multiplicity-based estimator [6]. Preliminary results of the identified and unidentified charged-particle production as a function of flattenicity in pp collisions at $\sqrt{s} = 13$ TeV have been reported in Ref. [7]. In this contribution, the final ALICE results [6] are discussed.

2. Event classification using charged-particle flattenicity

Events are selected based on the following requirements: (i) a charged-particle signal in both V0 detectors, covering the pseudorapidity regions $2.8 < \eta < 5.1$ (V0A) and $-3.7 < \eta < -1.7$ (V0C), (ii) a primary vertex position along the beam axis within $|z| < 10$ cm, and (iii) at least one charged particle produced in the pseudorapidity interval $|\eta| < 1$ (commonly referred to as INEL>0). The present study uses about 1.64×10^9 selected minimum-bias (MB) pp collisions at $\sqrt{s} = 13$ TeV.

Both the V0A and V0C detectors contain four rings in the η direction and eight equidistant sectors in the azimuthal direction, resulting in a grid of 64 cells in their acceptance [8]. Charged-particle multiplicity is measured as the sum of signal amplitudes of the V0A and V0C detectors. The event classification based on this condition is denoted as V0M. Furthermore, events are classified using flattenicity defined as follows:

$$\rho = \frac{\sqrt{\sum_{i=1}^{64} (N_{\mathrm{ch}}^{\mathrm{cell},i} - \langle N_{\mathrm{ch}}^{\mathrm{cell}} \rangle)^2 / N_{\mathrm{cell}}^2}}{\langle N_{\mathrm{ch}}^{\mathrm{cell}} \rangle}, \qquad (1)$$

where $N_{\mathrm{ch}}^{\mathrm{cell},i}$ is the average multiplicity in the i-th cell, $\langle N_{\mathrm{ch}}^{\mathrm{cell}} \rangle$ is the average of $N_{\mathrm{ch}}^{\mathrm{cell},i}$ in the event. The flattenicity distribution measured in MB pp collisions and its division into percentiles is shown in Fig. 1. Events with large number of MPIs correspond to the 0–1% $1-\rho$ class, whereas those with a few MPIs correspond to the 50–100% $1-\rho$ class. The former class implicitly includes high-multiplicity (HM) pp events, and the latter one selects low-multiplicity pp ones. The multiplicity dependence can be factorized out by performing a double-differential analysis, i.e., the flattenicity selection is also performed for HM (0–1% V0M class) events.

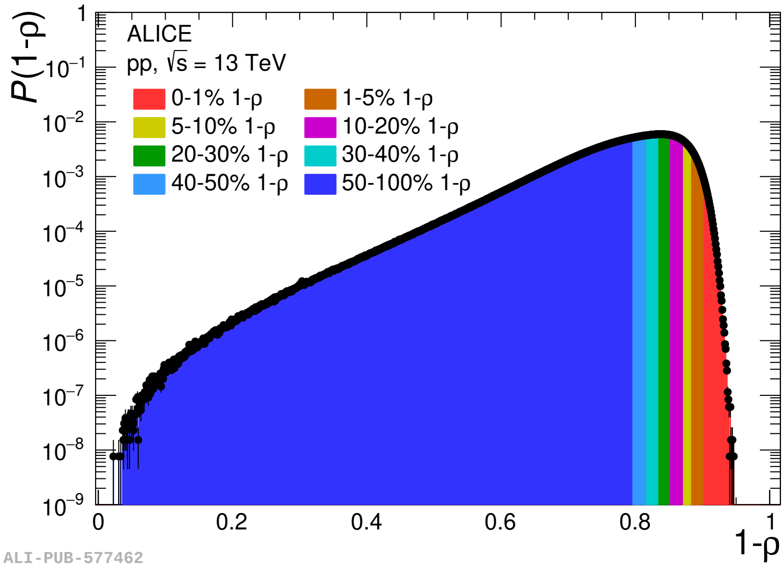

Figure 1: Flattenicity distribution measured in MB pp collisions at $\sqrt{s}$ = 13 TeV.

Tracking of charged particles is carried out using the silicon-based inner tracking system and the time projection chamber (TPC), whereas particle identification is performed with the TPC, based on specific energy loss, and the time-of-flight detector, using standard techniques [9]. The measurement of the production of primary charged particles ($h^{\pm}$) and charged pions ($\pi^{\pm}$), kaons ($K^{\pm}$), and (anti)protons ($\overline{p}$ and p) is performed in $|\eta| < 0.8$ and with transverse momentum, p_{T}, up to 20 GeV/c.

3. Results and Discussion

The evolution of the p_{T}-spectral shapes with flattenicity can be quantified by introducing a quantity Q_{pp}, which is is related to the ratio of the particle yield measured in a given $1-\rho$ class to the yield measured in MB pp collisions:

$$Q_{pp} = \frac{\langle dN_{ch}/d\eta\rangle_{MB}}{\langle dN_{ch}/d\eta\rangle_{1-\rho}} \times \frac{(d^2N/dydp_T)_{1-\rho}}{(d^2N/dydp_T)_{MB}} , \tag{2}$$

where $\langle dN_{ch}/d\eta\rangle$ is the average charged-particle pseudorapidity density measured in $|\eta| < 0.8$ for a given (flattenicity or MB) event class. The Q_{pp} quantity approaches unity if a pp collision in a given flattenicity class is a simple superposition of independent semi-hard parton-parton scatterings [6]. Figure 2 shows the measured Q_{pp} ratios of $\pi^{\pm}$, $K^{\pm}$, ($\overline{p}$)p, and $h^{\pm}$, where the data are compared with PYTHIA 8 (with and without CR) and EPOS LHC models [10]. The data deviate from unity, and depend on both the flattenicity event classes and p_{T}. A clear development of a peak structure for the 0–1% $1-\rho$ event class is observed in the interval $1 < p_{T} < 8$ GeV/c. Such a p_{T} evolution was not seen in previous measurements as a function of V0M multiplicity [9], where similar ratios to Q_{pp} show an increasing trend with p_{T} for HM events.

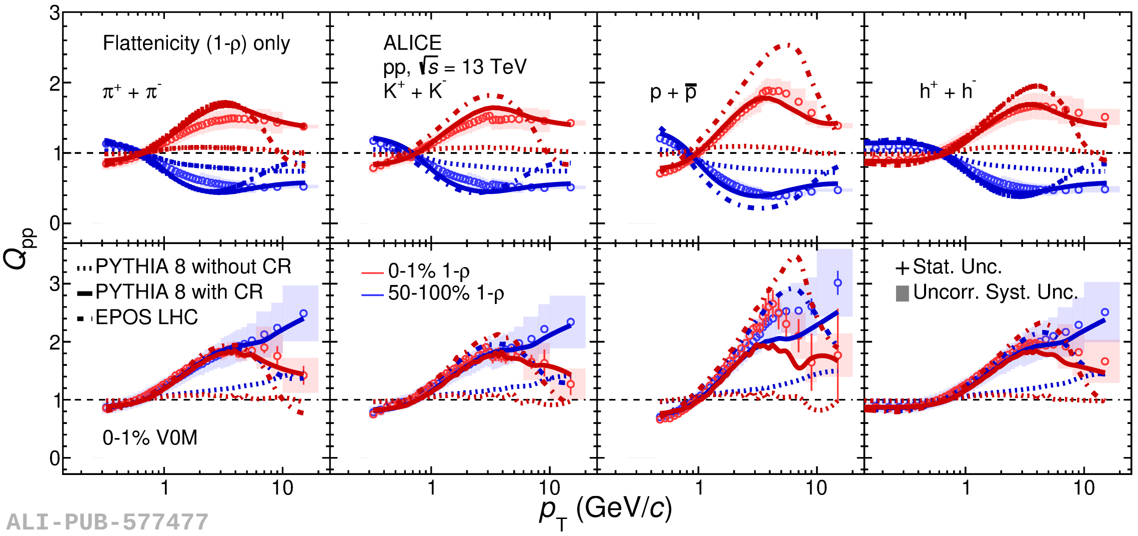

Figure 2: The $Q_{\rm pp}$ ratio of $\pi^{\pm}$, $\rm K^{\pm}$, $(\overline{\rm p})$p, and $\rm h^{\pm}$ for the 0–1% and 50–100% $1-\rho$ event classes (top row) and for the same $1-\rho$ classes in HM events (bottom row). The data are compared with PYTHIA 8 and EPOS LHC model predictions.

The PYTHIA 8 model describes the measurements of $\pi^{\pm}$, $\rm K^{\pm}$, $(\overline{\rm p})$p, and $\rm h^{\pm}$ well for the 0–1% and 50–100% $1-\rho$ event classes and for the same $1-\rho$ classes in HM events. The EPOS LHC model with parametrized collective hydrodynamics describes the data only partially from low to mid $p_{\rm T}$, while it underestimates $Q_{\rm pp}$ for $\pi^{\pm}$, $\rm K^{\pm}$, and $\rm h^{\pm}$ at high $p_{\rm T}$.

Figure 3 shows the $p_{\rm T}$-integrated $\rm K/\pi$ and $\rm p/\pi$ ratios as a function of the average charged-particle density with a flattenicity-based selection. These measurements are compared with the multiplicity-dependent results taken from Ref. [9]. The $\rm K/\pi$ and $\rm p/\pi$ ratios ratios increase from low (50–100% $1-\rho$) to high (0–1% $1-\rho$) charged-particle multiplicity. Such an increase is slightly steeper than that measured as a function of the V0M multiplicity due to different biases on the multiplicity estimators. The data are compared with model predictions. PYTHIA 8 shows no evolution with multiplicity for both particle ratios irrespective of CR. Oppositely, EPOS LHC describes the multiplicity dependence of the $\rm K/\pi$ particle ratio, although it underestimates the measurement.

Figure 4 shows the average transverse momenta of $\pi^{\pm}$, $\rm K^{\pm}$, and $(\overline{\rm p})$p as a function of the charged-particle density using the flattenicity and V0M multiplicity based estimators. For both estimators, the data show an increasing trend with multiplicity, and a mass ordering is also observed among the particle species. While the $\langle p_{\rm T}\rangle$ values of kaons and protons are similar within the reported systematic uncertainties for the two event selections, one can notice that the $\langle p_{\rm T}\rangle$ of pions using flattenicity selection is higher than the value observed in the V0M multiplicity-based selection at similar charged-particle densities. This effect might be due to an excess of low-$p_{\rm T}$ ($\lesssim$ 500 MeV/c) pions when using the V0M multiplicity estimator, which, in turn, produces a lower $\langle p_{\rm T}\rangle$ with respect to that measured as a function of flattenicity. The model prediction from PYTHIA 8 (with CR) and EPOS LHC provide a qualitative description of the data.

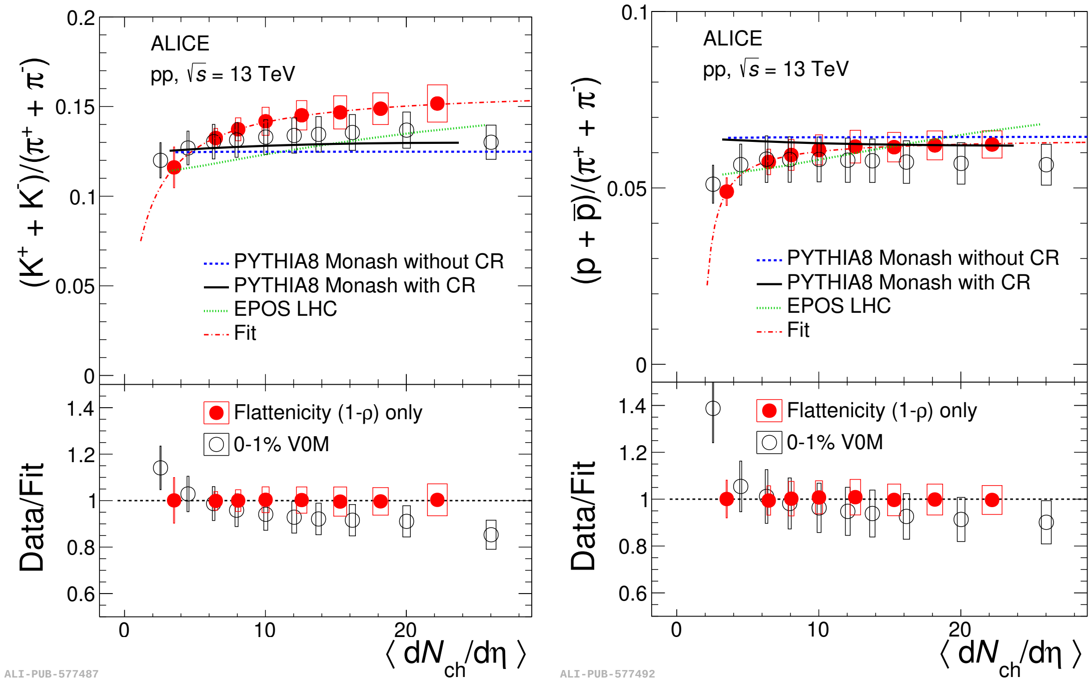

Figure 3: Transverse-momentum-integrated particle ratios as a function of the average charged-particle density, compared with PYTHIA 8 and EPOS LHC model predictions for flattenicity-dependent measurements.

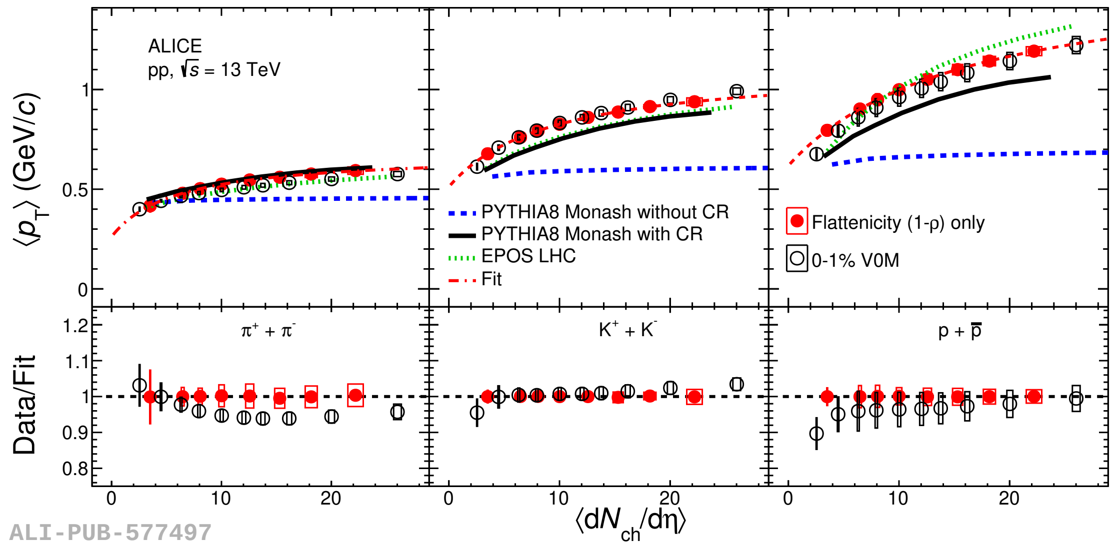

Figure 4: Average transverse momentum as a function of the average charged-particle density, compared with PYTHIA 8 and EPOS LHC model predictions for flattenicity-dependent measurements.

4. Summary

The ALICE Collaboration studied particle production in pp collisions at $\sqrt{s}$ = 13 TeV using a new event-shape observable, flattenicity, for the first time [6]. The ratio of event-class-dependent p_T spectra to that of MB (Q_{pp}) develops a peak with increasing multiplicity that has not been observed with the "standard" (V0M multiplicity-based) event classifier. The p_T-integrated particle ratios as a function of flattenicity also exhibits features that have not been reported before. Results are qualitatively described by the PYTHIA 8 model based on color strings and indicate that flattenicity-selected events are less affected by biases towards larger p_T due to local multiplicity fluctuations than multiplicity-selected ones.

Acknowledgments

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