

Pinning down the origin of collective flow in small systems with ALICE

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Abstract. In this proceeding, the new preliminary results of anisotropic flow in pp, p–Pb, and Pb–Pb collisions measured with ALICE are presented. The highlights include the flow of charged particles, correlations and fluctuations of flow vectors, and correlations between the mean transverse momentum and flow coefficients, $\rho(v_n^2, [p_T])$. We compare our results to state-of-the-art theoretical models, allowing us to study contributions from initial momentum anisotropies to final anisotropic flow and understand how anisotropic flow is developed from the initial geometry through the system’s dynamic evolution in hadron collisions of different sizes.

1 Introduction

In heavy ion collisions, the initial geometrical anisotropy is transferred via interactions in the collectively expanding medium, the quark-gluon plasma, into the anisotropic distribution of final-state particles. Collective effects, usually attributed to the presence of the QGP in heavy-ion collisions, are also observed in small systems, such as pp and p–Pb collisions [1, 2], which were considered not able to acquire the requirements of forming a quark-gluon plasma. It is still unclear whether these observations in small systems originate from final state interactions on a similar principle as in heavy-ion collisions, possibly described via hydrodynamics. Another potential source of anisotropy can originate from initial gluon momentum correlations within the Color Glass Condensate (CGC) framework, but its relative contribution to the final measurements, if any, is unknown.

The anisotropic flow [3] characterizes the anisotropy of azimuthal distribution of final-state particles, which is expanded into Fourier series,

$$\frac{dN}{d\phi} = \frac{N}{2\pi} \left(1 + \sum_{n=1}^{\infty} 2v_n \cos n(\phi - \Psi_n) \right), \quad (1)$$

where v_n is the n -th order flow coefficient, and Ψ_n is the n -th order symmetry plane angle. The flow coefficient and the symmetry plane angle together form the flow vector ($V_n \equiv v_n \exp(in\Psi_n)$). Event-by-event fluctuations in the initial conditions cause flow vector fluctuations in both p_T and η , resulting in measurable decorrelation effects [4].

The quantitative study on η -decorrelation provides a constraint on the η -dependent initial geometry profile, which is measured as $r_2(\eta^a, \eta^b) = \langle V_2^*(-\eta^a)V_2(\eta^b) \rangle / \langle V_2^*(\eta^a)V_2(\eta^b) \rangle$, where

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η^a, η^b are two different pseudo-rapidity. It is expected to be $r_2(\eta^a, \eta^b) < 1$ in case of decorrelation.

In heavy ion collisions, the lower order flow coefficients are expected to be proportional to the initial spatial anisotropy coefficients, i.e., $v_n \propto \varepsilon_n$ for $n = 2, 3$ [5], while the mean transverse momentum is proportional to the energy density, thus inversely proportional to the size of the fireball. The Pearson correlation coefficient, $\rho(v_2^2, [p_T]) = \text{cov}(v_2^2, [p_T]) / (\sqrt{\text{var}(v_2^2)} \sqrt{\text{var}([p_T])})$ characterizes the correlation between the shape and the size of the created matter in heavy-ion collisions. This observable was shown to have a particular sensitivity to the initial momentum anisotropy within the CGC picture [6].

2 Analysis details

The results presented in this proceeding are obtained using the ALICE detector [7]. Charged particles with a transverse momentum $0.2 < p_T < 3.0$ GeV/c and full azimuthal coverage within $|\eta| < 0.8$, reconstructed using the Inner Tracking System (ITS) and Time Projection Chamber (TPC) detectors, were used to calculate flow coefficients and $\rho(v_2^2, [p_T])$, employing the cumulant method with subevents [9]. In addition, η -dependent flow vector decorrelations were obtained by using a signal in the Forward Multiplicity Detector (FMD) [8] which provides a unique pseudorapidity coverage of $-3.7 < \eta < -1.7$ and $2.8 < \eta < 5.1$. This enables us to measure correlations with very large η separation, ensuring a large suppression of non-flow contamination in the measurements.

3 Results

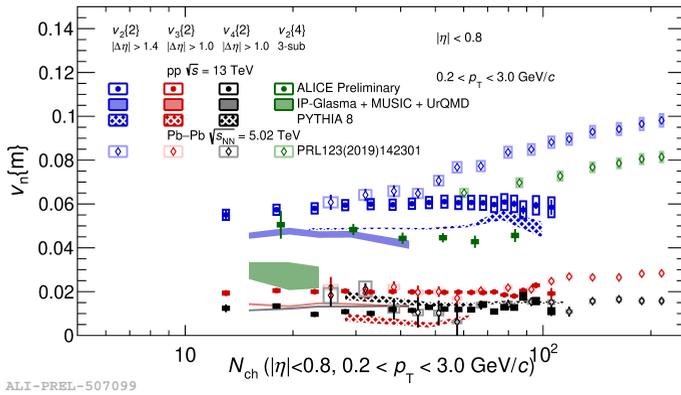


Figure 1. The anisotropic flow coefficients $v_n\{2\}$ and $v_n\{4\}$ as a function of charged particle multiplicity measured in pp and Pb–Pb collisions.

Figure 1 shows the anisotropic flow coefficients $v_n\{2\}$ and $v_n\{4\}$ measured using the two- and four-particle cumulant method [9], respectively, as a function of charged particle multiplicity (N_{ch}) in pp and Pb–Pb collisions. At low N_{ch} , the results in pp collisions are of similar magnitude as those from Pb–Pb collisions. Furthermore, measurements in small systems depend weakly on multiplicity for all three presented v_n coefficients. On the other hand, in Pb–Pb collisions this is valid only for v_3 and v_4 , while v_2 exhibits a rising trend with multiplicity, starting from $N_{\text{ch}} \sim 50$. This suggests that flow in small systems arises as a response to

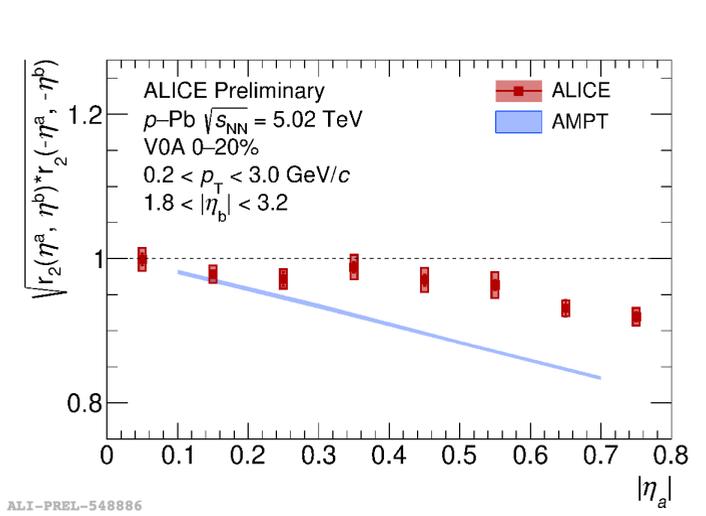


Figure 2. Measurements of flow vector decorrelations as a function of pseudorapidity measured in p–Pb collisions.

the initial geometry, which is dominated by the fluctuations, while the overall nucleon elliptic geometry becomes increasingly important in case of Pb–Pb collisions at $N_{ch} > 50$.

The pseudorapidity dependence of flow vector decorrelation measured in p–Pb collisions is shown in Fig. 2. The particles with η^a ($-\eta^a$) are taken from the midrapidity, while the particles with η^b ($-\eta^b$) are taken from forward rapidity, ensuring ultra-long-range correlations. As p–Pb collisions are not symmetric in the forward and backward direction, the $\sqrt{r_2(\eta^a, \eta^b)r_2(-\eta^a, -\eta^b)}$ is measured instead of r_2 . A deviation from unity is observed at large $|\eta_a|$ region, which implies the presence of η dependent flow vector fluctuations in p–Pb collisions. These measurements provide constraints on the three-dimensional initial geometry fluctuations in p–Pb collisions. The AMPT model [10] overestimates the decorrelation in η , while it is able to reproduce the p_T dependent flow vector fluctuations (not shown here).

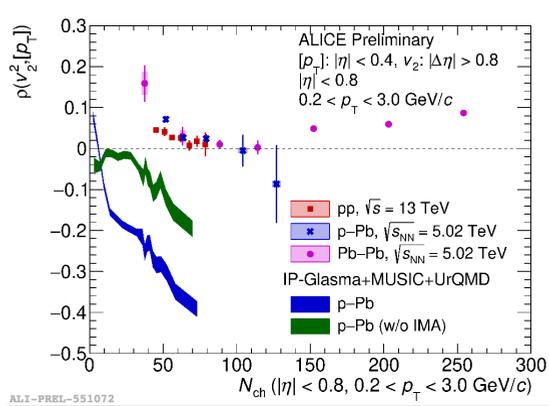


Figure 3. The Pearson correlation coefficient $\rho(v_n^2, [p_T])$ as a function of charged particle multiplicity measured in pp, p–Pb, and Pb–Pb collisions.

The $\rho(v_2^2, [p_T])$ is measured in pp, p–Pb, and Pb–Pb collisions, shown in Fig. 3. The measurements show that for $N_{\text{ch}} < 130$, $\rho(v_2^2, [p_T])$ decreases with increasing multiplicity for all collision systems. In heavy-ion collisions, the ρ observable is sensitive to both the hydrodynamical response of shape-size correlation and the contributions from initial momentum anisotropy [6]. The observed similar magnitude of $\rho(v_2^2, [p_T])$ in different collision systems indicates that the relative contributions of the different mechanisms could be comparable. The state-of-the-art model IP-Glasma + MUSIC + UrQMD for p–Pb collisions performed in two scenarios with and without the contribution from initial momentum anisotropy [6], is compared to the measurements, to determine the effects of these correlations on the measurements. Neither of the two scenarios of the presented calculations are able to reproduce the measurements. This suggests that the CGC effect is likely not well modeled, but the deviation may be partially caused by remnants of non-flow contamination in the measurements, which is not present in the hydrodynamic model.

4 Summary

In this proceeding, we presented the ALICE measurements on flow coefficients, decorrelation of flow vectors, and correlation between flow and transverse momentum in large and small collision systems. The results provide further insight into the understanding of where collective effects in small systems originate. In particular, measurements of v_n indicate that anisotropic flow is created as a response to fluctuations of the initial-state geometry, results of flow vector decorrelations provide new constraints on the modeling of the three-dimensional structure of the initial geometry and subsequent system evolution, and finally the $\rho(v_2^2, [p_T])$ observable proved to be beneficial in constraining the contribution from initial state correlations in the state-of-the-art models of small and large collision systems.

Acknowledgments

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