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Elliptic flow of identified hadrons in small collisional systems measured with ALICE

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Abstract

Recent observations of long-range multi-particle azimuthal correlations in p–Pb and high multiplicity pp collisions provided new insights into collision dynamics and opened a possibility to study collective effects in these small systems. New measurements of p_{T}-differential elliptic flow (v_2) coefficient for inclusive charged hadrons as well as a variety of identified particle species in p–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV are presented. The data was collected by ALICE during the LHC Run 2 data taking. Besides high precision measurements of $v_2(p_{\mathrm{T}})$ for $\pi^{\pm}$, $\mathrm{K}^{\pm}$ and $\mathrm{p}(\bar{\mathrm{p}})$, the first results for $\mathrm{K}^0_{\mathrm{S}}$, $\Lambda(\bar{\Lambda})$ and ϕ are shown. In order to eliminate non-flow contamination, a pseudorapidity separation between correlated particles is applied as well as subtraction of remaining non-flow estimate based on a measurement of minimum-bias pp collisions at $\sqrt{s} = 13$ TeV. Moreover, the reported characteristic mass ordering and approximate number of constituent quarks (NCQ) and transverse kinetic energy ($\mathrm{KE_T}$) scaling of v_2 allow to test various theoretical models, constrain the initial conditions, and probe the origin of collective behavior in small collision systems.

Keywords:
anisotropic azimuthal correlations, elliptic flow, p_{T}-differential, identified particles, small systems, p–Pb, ALICE, LHC

1. Introduction

Formation of Quark-Gluon plasma (QGP), strongly-interacting nuclear matter created under extreme conditions such as collisions of heavy ions at the Large Hadron Collider (LHC) and Relativistic Heavy Ion Collider (RHIC), is well established and supported by plethora of measurements. In such collisions, initial spacial anisotropy evolves into momentum anisotropy by hydrodynamical expansion of the created medium. The azimuthal momentum distribution of emitted particles can be decomposed into a Fourier expansion (1) with anisotropic flow coefficients $v_n = \langle \cos n(\varphi - \Psi_n) \rangle$, where φ is azimuthal angle and Ψ_n is symmetry plane of n-th harmonic [1].

$$E\frac{\mathrm{d}N}{\mathrm{d}\vec{p}} = \frac{1}{2\pi}\frac{\mathrm{d}^2N}{p_{\mathrm{T}}\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}\left[1 + 2\sum_{n=1}^{\infty} v_n \cos\left[n(\varphi - \Psi_n)\right]\right] \tag{1}$$

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Specifically, results of second order coefficient v_2, referred to as elliptic flow, are presented in this contribution.

Recent measurements of anisotropic flow coefficients in high multiplicity p–Pb and pp collisions at the LHC exhibit similar features as observed in heavy-ion collisions. Observation of non-zero values of v_n indicates the presence of collective behavior in small collision systems, even though QGP creation was not expected in such a limited volume. Measurements of p_T-differential v_n coefficients are used to investigate the origin of the collectivity, which remains an open question. Moreover, study of this observable for various particle species provides a unique tool to study the effect of collective phenomena in the context of particle production mechanisms.

2. Analysis details

The data sample used for this analysis contains 600 million minimum-bias p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV and 166 million minimum-bias pp collisions at $\sqrt{s}$ = 13 TeV recorded by the ALICE detector [2] in 2016 during Run 2 phase of the LHC operation. The sample is divided into multiple event classes based on the multiplicity distribution measured by the V0A detector with a pseudorapidity coverage of $2.8 < \eta < 5.1$ (Pb-going direction).

Charged particles are reconstructed using tracking information from Inner Tracking System (ITS) and Time-Projection Chamber (TPC) with a coverage of pseudorapidity $|\eta| < 0.8$ and full azimuthal angle. Particle identification (PID) of $\pi^{\pm}$, $K^{\pm}$ and $p(\bar{p})$ is performed based on signal from TPC and Time-of-Flight (TOF) detectors using Bayesian approach described in [3]. The purity of the selected particles is above 95% over the whole reported momentum range (80% for $K^{\pm}$ at $p_T > 3.5$ GeV/c). Due to their neutral charge and relatively short life-time, K^0_S, $\Lambda(\bar{\Lambda})$ and ϕ cannot be detected directly. Instead, selection is performed on candidates reconstructed via their decay products on a statistical basis. Specifically, the following hadronic decays are considered: $K^0_S \to \pi^+ + \pi^-$, $\phi \to K^+ + K^-$ and $\Lambda \to \pi^- + p$ ($\bar{\Lambda} \to \pi^+ + \bar{p}$). In order to suppress combinatorial background, PID of decay products and selection criteria on characteristic decay topology of K^0_S and $\Lambda(\bar{\Lambda})$ are applied.

The p_T-differential v_2 coefficient is obtained from measurement of 2-particle Q-cumulants [4] using the generic framework implementation including the non-uniform acceptance correction introduced in [5]. Inclusive charged particles within $0.2 < p_T < 3$ GeV/c are selected as reference flow particles.

Measurements of two-particle correlations in small collision systems are very sensitive to short-range contributions which are not related to the common symmetry plane, such as jets and resonance decays, commonly referred to as non-flow. To suppress such bias, the sub-event method, where pseudorapidity separation ($\Delta\eta$ gap) is introduced between the correlated particles, is used. Additionally, in order to remove remaining short-range contamination, subtraction is performed on cumulant level using data of minimum-bias pp collisions. The subtraction is done according to

$$v_2^{\mathrm{pPb,sub}}(p_T) = \frac{d_2^{\mathrm{pPb}}(p_T) - k \cdot d_2^{\mathrm{pp}}(p_T)}{\sqrt{c_2^{\mathrm{pPb}} - k \cdot c_2^{\mathrm{pp}}}}, \quad (2)$$

where c_2 and d_2 denote integrated (reference flow) and differential cumulants, respectively [4]. Prior to subtraction, non-flow estimation is scaled by a ratio of mean event multiplicities $k = \langle M \rangle^{\mathrm{pp}} / \langle M \rangle^{\mathrm{pPb}}$ based on its scaling properties [6] to account for different system size of p–Pb and pp collision.

3. Results

The results of non-flow-subtracted p_T-differential elliptic flow coefficients of inclusive charged hadrons $h^{\pm}$ and identified $\pi^{\pm}$, $K^{\pm}$, K^0_S, $p(\bar{p})$, ϕ and $\Lambda(\bar{\Lambda})$ with pseudorapidity separation of $|\Delta\eta| > 0.4$ in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV are presented.

The results for two event classes based on forward multiplicity measured with V0A detector are shown in Fig. 1: 0-20% events with highest multiplicity (left) and 20-40% (right). For $p_T \leq 2.5$ GeV/c, a clear

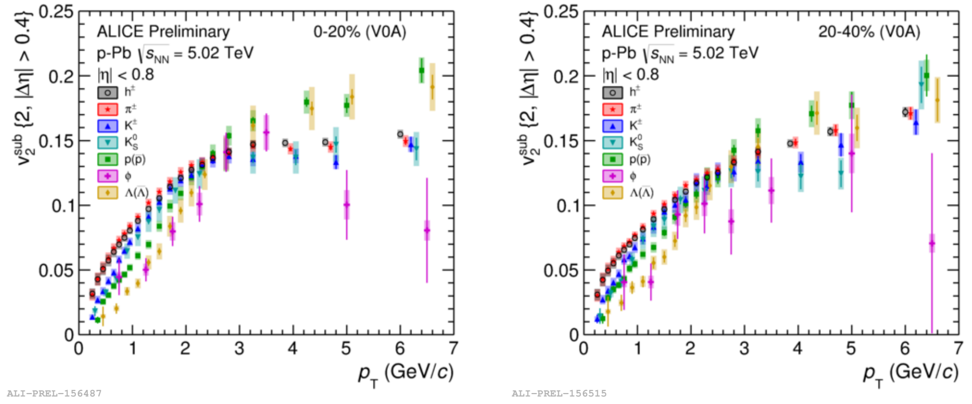

Fig. 1. Results of p_T-differential $v_2^{sub}\{2, |\Delta\eta| > 0.4\}$ of $h^{\pm}$, $\pi^{\pm}$, $K^{\pm}$, K_S^0, $p(\bar{p})$, ϕ and $\Lambda(\bar{\Lambda})$ in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV with non-flow subtraction performed using measurements of minimum-bias pp collisions at $\sqrt{s}$ = 13 TeV for V0A multiplicity classes: 0-20% (left) and 20-40% (right).

mass ordering of $v_2(p_T)$ is observed, which is an indication of strong radial expansion with common velocity pushing heavier particles towards higher momentum. This trend is qualitatively consistent with the results of hydrodynamic models [7, 8]. In the region of $2.5 < p_T \lesssim 6$ GeV/c, particles are grouped based on their constituent quark content with a clear separation between the higher $v_2(p_T)$ values for baryons and the lower values for mesons. In the picture of heavy-ion collision, such splitting effect is usually attributed to parton coalescence [9] or recombination mechanism of particle production [10].

To test the extent of scaling properties of the elliptic flow coefficient originally reported by RHIC experiments [11], both v_2 and p_T were divided by the number of constituent quarks n_q (NCQ scaling). The result of such scaling is shown in the upper row of Fig. 2. Moreover, to extend the scaling to low p_T region and to account for the observed mass hierarchy of v_2, transverse kinetic energy

$$\mathrm{KE_T} = m_T - m_0 = \sqrt{p_T^2 + m_0^2} - m_0 \tag{3}$$

is used instead of p_T ($\mathrm{KE_T}$ scaling) and the results are reported in the bottom row of Fig. 2. In both cases, all particle species show a universal trend indicating a presence of collective behavior on the partonic level in p–Pb collisions, even though the observed scaling is only approximate.

4. Conclusion

New measurements of $v_2(p_T)$ using 2-particle cumulants of inclusive and identified charged hadrons in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV using the LHC Run 2 data are presented.

The reported measurements of elliptic flow coefficients in p–Pb collisions exhibit similar features as previously observed in Pb–Pb collisions [12, 13]. Specifically, they confirm the mass ordering in the low p_T region followed by the baryon/meson grouping at intermediate $2.5 < p_T \lesssim 6$ GeV/c together with only approximate NCQ and $\mathrm{KE_T}$ scaling. These results support that collective phenomena are present in high multiplicity collisions of small systems. However, whether they are manifestations of initial or final state effects is not yet fully understood. The unprecedented precision of the reported $v_2(p_T)$ results presents an invaluable tool to further constrain theoretical models, test their validity and penultimately will help to disentangle the origin of the collectivity.

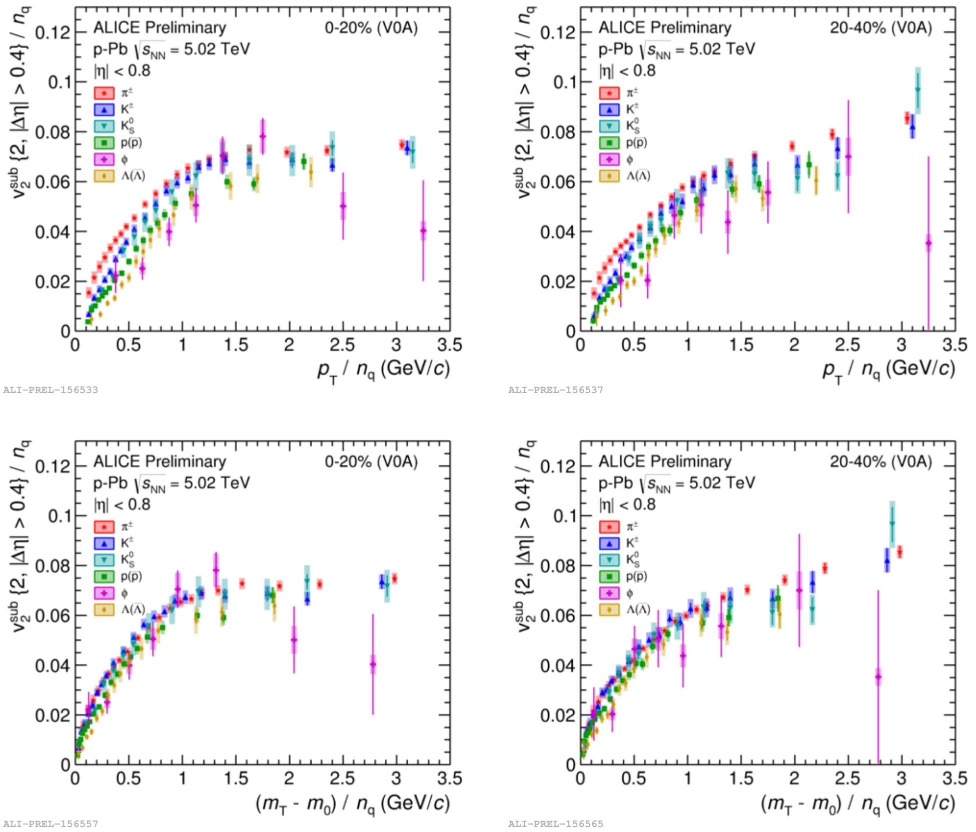

Fig. 2. Test of scaling properties of v_2 coefficients. Upper: both $v_2^{\rm sub}$ and $p_{\rm T}$ are scaled by number of constituent quarks $n_{\rm q}$ (NCQ scaling). Lower: transverse kinetic energy ($\rm KE_T$) scaling, where rest mass m_0 of individual species is subtracted from $m_{\rm T}$.

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