PROCEEDINGS OF SCIENCE

Anisotropic flow of identified particles in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV with ALICE

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Anisotropic flow plays a critical role in understanding the properties of the quark-gluon plasma. The elliptic and triangular flow at mid-rapidity of identified particles, including $\pi^{\pm}$, $\mathrm{K}^{\pm}$, $\mathrm{p}+\bar{\mathrm{p}}$, ϕ, $\mathrm{K}^0_{\mathrm{S}}$, $\Lambda+\bar{\Lambda}$, $\Xi^-+\bar{\Xi}^+$ and $\Omega^-+\bar{\Omega}^+$ were measured by ALICE for Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV. The measurements are presented for a wide range of particle transverse momenta. The results are compared to those for elliptic and triangular flow in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV.

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1. Anisitropic flow

Ultrarelativistic heavy-ion collisions enable the study of matter at high temperature and pressure where quantum chromodynamics predicts the existence of the quark-gluon plasma (QGP). Anisotropic flow, which is caused by the initial asymmetries in the geometry of the system produced in a non-central collision, provides experimental information about the equation of state and the transport properties of the created QGP. Interactions among medium constituents in heavy-ion collisions transform the initial spatial anisotropy into momentum anisotropy of observed particles. The momentum anisotropy can be quantified via the coefficients v_n of the Fourier expansion of the particle azimuthal distribution relative to the collision symmetry axes.

2. Analysis method

This analysis is based on a sample of about 60 million minimum–bias Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV with the ALICE experiment[1]. Tracks are reconstructed using the Inner Tracking System (ITS) and Time Projection Chamber (TPC) within $|\eta| < 0.8$ and $0.5 < p_{\rm T} < 16.0$ GeV/c. Before proceeding further, we defined one of the central objects in anisotropic flow analysis, the so-called Qn-vector. It is defined as $\mathbf{Q}_n = \sum w_i e^{in\phi_i}$, where ϕ_i is the azimuthal angle of the i-th reference flow particle, n is the order of the harmonic and w_i is a weight applied for every reference flow particle. We define the $\mathbf{Q}_n$ vector, which is an event-by-event complex number, with one defined for each harmonic index n. The v_n is measured using the scalar product method [2], written as

$$v_n = \frac{\langle\langle \mathbf{u}_n \mathbf{Q}_n^{V0A*} \rangle\rangle}{\sqrt{\frac{\langle \mathbf{Q}_n^{V0A} \mathbf{Q}_n^{V0C*}\rangle \langle \mathbf{Q}_n^{V0A} \mathbf{Q}_n^{TPC*}\rangle}{\langle \mathbf{Q}_n^{V0C} \mathbf{Q}_n^{TPC*}\rangle}}} \tag{1}$$

where $\mathbf{u}_n = e^{in\phi_i}$, is the unit vector of the particle of interest with azimuthal angle ϕ_i. The vector $\mathbf{Q}_n^{V0A}$ and $\mathbf{Q}_n^{V0C}$ are calculated from the azimuthal distribution of the energy deposition measured in the V0A ($2.8 < \eta < 5.1$) detector and V0C ($-3.7 < \eta < -1.7$) detector, respectively. $\mathbf{Q}_n^{TPC}$ are calculated from the azimuthal distribution of the tracks reconstructed in the Time Projection Chamber (TPC). Brackets $\langle \cdots \rangle$ denote an average over all events, the double brackets $\langle\langle \cdots \rangle\rangle$ an average over all particles in all events, and $*$ the complex conjugate. The v_n of $\pi^{\pm}$, $K^{\pm}$, p is directly measured using scalar product method. Identification of $\pi^{\pm}$, $K^{\pm}$, p is performed using the combined information from Time Project Chamber and Time-Of-Flight detectors. The v_n of ϕ, $\mathrm{K}^0_{\mathrm{s}}$, Λ, Ξ, Ω is obtained using the v_n vs invariant mass method [3]:

$$v_n^{Tot}(m_{inv}) = v_n^{Sig} \frac{N_{Sig}(m_{inv})}{N_{Tot}(m_{inv})} + v_n^{Bg}(m_{inv}) \frac{N_{Bg}(m_{inv})}{N_{Tot}(m_{inv})} \tag{2}$$

Yields N_{Sig} and N_{Bg} are extracted from fitting the invariant mass distributions with a sum of a Gaussian function and a third-order polynomial. v_n^{Sig} is extracted from fitting the v_n vs invariant mass distribution. The candidates are reconstructed in bins of $p_{\rm T}$ and invariant mass. Azimuthal correlations are calculated for candidates in each bin of $p_{\rm T}$ and invariant mass.

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3. Results

Figure 1 and Figure 2 show v_2 and v_3 of identified particles measured for 10–20% and 30–40% centrality classes, respectively. Clear mass ordering is observed for $p_T < 2$-3 GeV/c. The v_2 and v_3 of heavier hadrons are smaller than that of light particles at the same p_T. It is caused by the interplay between the isotropic expansion and anisotropic flow [4]. Particle type scaling and mass ordering are most directly tested by the v_2 and v_3 of ϕ-meson, as its mass is close to the proton mass. At low p_T, the v_2 and v_3 of ϕ-meson

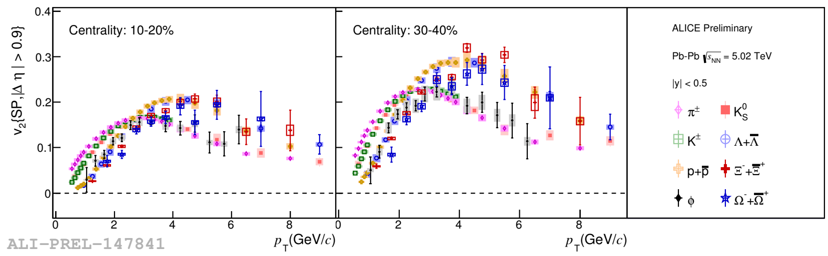

Figure 1: The p_T-differential v_2 of $\pi^{\pm}$, $K^{\pm}$, $p+\bar{p}$, ϕ, K^0_S, $\Lambda+\bar{\Lambda}$, $\Xi^-+\bar{\Xi}^+$ and $\Omega^-+\bar{\Omega}^+$ measured for 10–20% (left) and 30–40% (right) centrality classes.

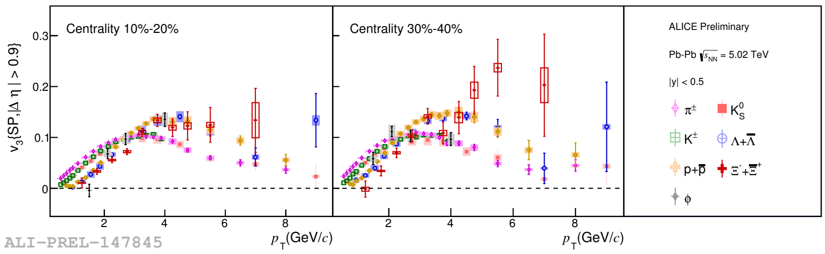

Figure 2: The p_T-differential v_3 of $\pi^{\pm}$, $K^{\pm}$, $p+\bar{p}$, ϕ, K^0_S, $\Lambda+\bar{\Lambda}$ and $\Xi^-+\bar{\Xi}^+$ measured for 10–20% (left) and 30–40% (right) centrality classes.

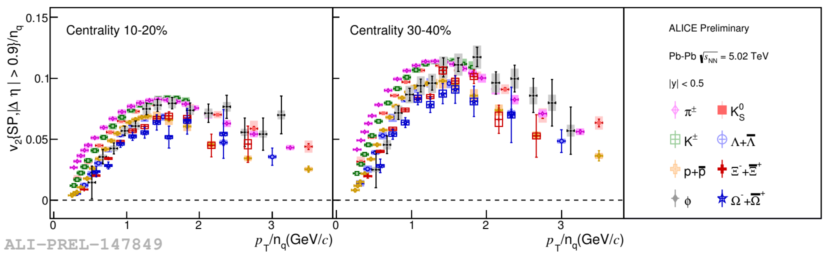

Figure 3: The p_T/n_q dependence of v_2/n_q of $\pi^{\pm}$, $K^{\pm}$, $p+\bar{p}$, ϕ, K^0_S, $\Lambda+\bar{\Lambda}$, $\Xi^-+\bar{\Xi}^+$ and $\Omega^-+\bar{\Omega}^+$ for 10–20% (left) and 30–40% (right) centrality classes.

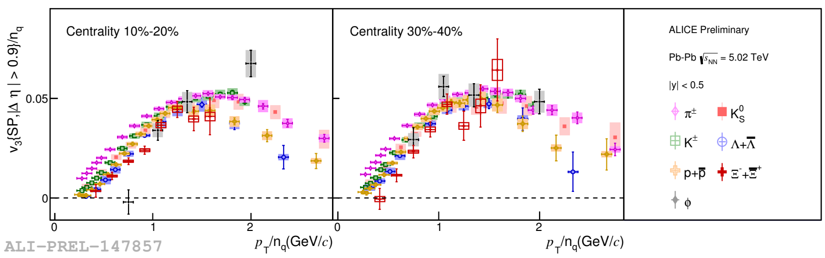

Figure 4: The p_T/n_q dependence of v_3/n_q of $\pi^{\pm}$, $K^{\pm}$, $p+\bar{p}$, ϕ, K^0_S, $\Lambda+\bar{\Lambda}$ and $\Xi^-+\bar{\Xi}^+$ for 10–20% (left) and 30–40% (right) centrality classes.

are similar to that of (anti-)proton, indicating a similar radial flow effect on particles of similar mass. For $3 < p_T < 8$-10 GeV/c, particles are grouped into mesons and baryons, v_2 and v_3 of baryons are larger than that of mesons, supporting the hypothesis of hadronization through quark coalescence [5]. The crossing between meson and baryon v_2 and v_3 exhibits a centrality and particle mass dependence.

In the intermediate p_T region, both v_n and p_T were divided by the number of constituent quarks (n_q) independently for each particle species. v_2/n_q versus p_T/n_q scaling was initially proposed to service as a test of the hadron production via quark coalescence. The number of constituent quark (NCQ) scaling of v_2 and v_3 might suggest that quark degrees of freedom dominate in the early stages of heavy-ion collisions when collective flow develops. Figure 3 and Figure 4 show the p_T/n_q dependence of v_2/n_q and v_3/n_q of identified particles for 10–20% and 30–40% centrality classes, respectively. The number of constituent quark (NCQ) scaling of v_2 and v_3 has not been accurately observed at the LHC. The magnitude of the observed deviations seems to be similar for all centrality intervals.

The p_T-differential v_2 and v_3 of identified particles have been compared to ALICE measurements performed in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV [6]. With the increase of collision energy, the increase of radial flow is expected to lead to the inhibition of v_n at low p_T. It has the most obvious effect on heavier particles. The precision of the results does not allow for conclusions to be drawn as the measurements at different collision energies are compatible within uncertainties.

4. Summary

Anisotropic flow coefficients of $\pi^{\pm}$, $K^{\pm}$, $p+\bar{p}$, ϕ, K^0_S, $\Lambda+\bar{\Lambda}$, $\Xi^-+\bar{\Xi}^+$ and $\Omega^-+\bar{\Omega}^+$ have been measured in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV. Mass ordering is observed for p_T <2-3 GeV/c. For $3 < p_T < 8$-10 GeV/c, particles are grouped into mesons and baryons, v_2 and v_3 of baryons are larger than that of mesons. The number of constituent quark (NCQ) scaling of v_2 and v_3 has not been accurately observed at the LHC. No significant collision energy dependence is observed for the p_T differential v_n.

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