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Anisotropic flow and related phenomena in Pb-Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV with ALICE

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Abstract. The ALICE experiment is designed and optimised to study the properties of the Quark-Gluon Plasma (QGP), a new state of matter, which is expected to be created at the high energy densities reached at the LHC. One of the key observables used to characterise the transport properties and the equation of state of the QGP is the azimuthal anisotropy in particle production, which is usually called anisotropic flow. In this presentation, we report the first measurements of anisotropic flow in Pb-Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV, the highest energy ever achieved in heavy-ion collisions, and compare them with both theoretical predictions and experimental measurements at lower energies. This provides a unique opportunity to test the validity of the hydrodynamic paradigm at new energies and to further constrain key transport parameters of the QGP, such as the shear viscosity over entropy ratio.

1. Introduction

One key observable in the study of heavy-ion collisions has been the azimuthal anisotropies of particle production in momentum space with respect to the reaction plane, i.e. the plane spanned by the impact parameter and the beam axis. This phenomenon, usually referred to as anisotropic flow, has been most commonly interpreted at higher energies as the result of the hydrodynamic behaviour of the QGP, thus providing one of the most solid evidences of the non-trivial collective dynamics of such system. Anisotropic flow is also sensitive to the transport parameters (e.g. viscosities) and equation of state of the system, both in its QGP phase and after hadronisation, which then makes it a suitable probe of such properties. By using a general Fourier series decomposition of the azimuthal distribution of produced particles:

$$\frac{dN}{d\varphi} \propto 1 + \sum_{n=1}^{+\infty} v_n \cos [n(\varphi - \Psi_n)],$$

anisotropic flow is quantified with the Fourier coefficients v_n and corresponding symmetry planes Ψ_n [1]. While the 2nd harmonic (v_2), usually referred to as elliptic flow, is mostly determined by the approximately ellipsoidal shape of the overlap region in a non-central heavy-ion collision, the higher ones ($v_3, v_4, v_5 \dots$) come from fluctuations in such shape. In these proceedings, we report the first measurements of anisotropic flow of charged particles in Pb-Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV [3], obtained from two- and multi-particle cumulants, using the approach proposed in [2].



2. Analysis

The data used for this measurement have been recorded with the ALICE detector in November 2015, during the Run 2 of the LHC. Only one low luminosity run (with trigger rate of 27 Hz), being least affected by pile-up and distortions from space charge in the main tracking detector, the Time Projection Chamber (TPC), is used for this analysis. A sample of 140 k minimum bias Pb–Pb collisions passed the selection criteria. All charged tracks in the p_T range $0.2 < p_T < 5$ GeV/ c and pseudorapidity $|\eta| < 0.8$ are used in this analysis. These tracks are reconstructed using combined information from the Inner Tracking System (ITS) and the TPC. The systematic uncertainty related to the non-uniform reconstruction efficiency is found to be at the level of 1%. A variation of the track selection criteria is used to estimate the corresponding systematic uncertainty, which is found to be 0.5% at most. The flow coefficients from tracks that are reconstructed from TPC space points alone are compared to coefficients extracted from particles that used both TPC clusters and ITS hits and are found to agree within 2%. This difference is included in the total systematic uncertainty. Other systematic uncertainties that are studied relate to the centrality determination, the polarity of the magnetic field of the ALICE detector and the position of the reconstructed primary vertex, which are found to be negligible. The total systematic uncertainty is evaluated adding in quadrature the aforementioned contributions.

3. Results

Fig. 1 (a) shows the centrality dependence of the anisotropic flow coefficients v_2 , v_3 and v_4 from two- and multi-particle cumulants, for 2.76 and 5.02 TeV Pb–Pb collisions, integrated in the p_T range $0.2 < p_T < 5$ GeV/ c . v_2 increases from central to peripheral collisions, reaches a maximum in the 40-50% centrality class and then decreases. v_3 and v_4 , on the contrary show a much milder centrality dependence. These features do not vary with collision energy. The difference between two- and multi-particle cumulants are attributed to the opposite contribution (positive and negative, respectively) of flow fluctuations to these observables. Concerning the energy dependence, the flow coefficients are all found to increase going from 2.76 to 5.02 TeV, as shown in fig. 1 (b) and (c), without significant differences across centralities, at least in the centrality range 0-50%. The measurements are found to be compatible with theoretical predictions [4, 5]. In particular, compared to the different predictions from [4], the measurements seem to indicate that the shear viscosity over entropy ratio (η/s) does not vary significantly between collision energies. The two parametrisations of $\eta/s(T)$ that are found to be compatible with the data point to small or non existent temperature dependence of η/s in the QGP phase:

$$0 < \frac{d\eta/s}{dT} < 0.15 [100 \text{ MeV}^{-1}] \quad \text{for } T > 150 \text{ MeV}.$$

This is consistent with other recent findings [6].

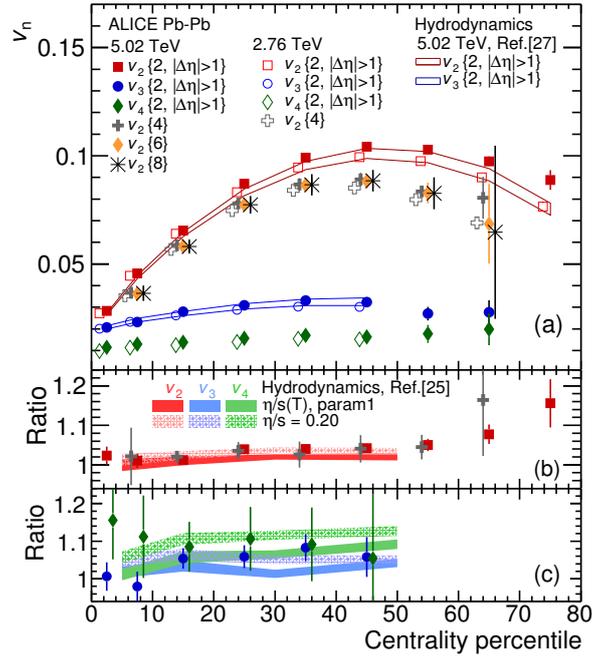


Figure 1. (a) p_T -integrated anisotropic flow coefficients v_n as a function of event centrality, for 2.76 and 5.02 TeV Pb–Pb collisions. (b), (c) Ratios of v_n for these two energies. Various predictions from hydrodynamical models are also presented [4, 5].

In fig. 2 we report v_2 , v_3 and v_4 as a function of p_T , for 2.76 and 5.02 TeV Pb–Pb collisions, in the centrality classes 0–5% and 30–40%. Comparing measurements at different collision energies, the p_T -differential flow coefficients are found to be compatible, indicating that the increase observed in the p_T -integrated ones can be attributed to an increase of mean transverse momentum $\langle p_T \rangle$, due to an increase in radial flow.

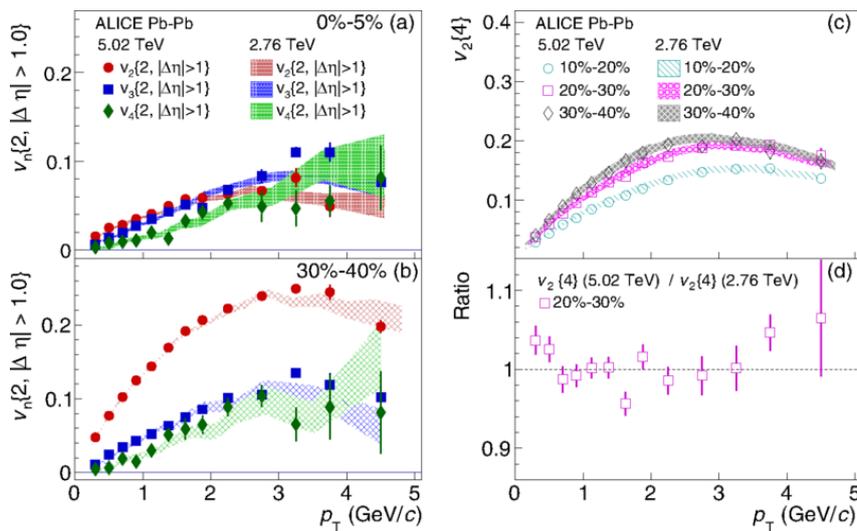


Figure 2. Anisotropic flow coefficients v_n as a function of p_T in the centrality classes 0–5% (a) and 30–40% (b) from two–particle cumulants. $v_2\{4\}(p_T)$ is shown in panel (c) and the ratio between the measurements at 2.76 and 5.02 TeV in (d).

Finally, in fig. 3 we show the fully p_T integrated v_2 measured in the 20–30% centrality range and compare it with results at lower energies and similar centralities. This measurements was performed combining two methods, one based on the fit of the p_T spectra and $v_2\{4\}(p_T)$, the other on the direct calculation of $v_2\{4\}$ from tracklets in the ITS, which has an acceptance of $p_T > 50$ MeV/c. The fully p_T integrated v_2 is observed to increase by $4.89 \pm 2.27\%$ between 2.76 and 5.02 TeV.

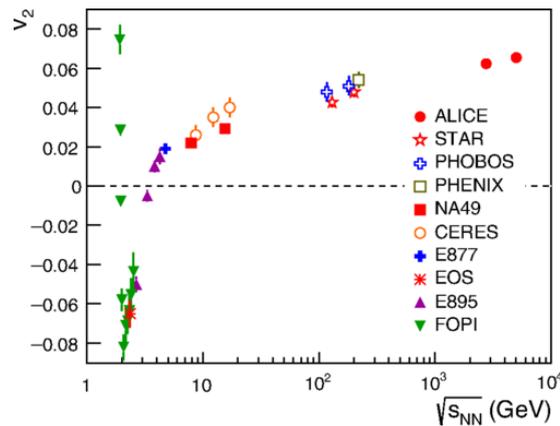


Figure 3. Fully p_T -integrated elliptic flow $v_2\{4\}$ in the 20–30% centrality range at 5.02TeV compared with v_2 measurements at lower energies with similar centralities.

4. Summary

In these proceedings we present the first measurements of anisotropic flow in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. Compared to measurements at 2.76 TeV, an increase is observed in the p_T -integrated flow coefficients, while no significant differences are observed in the p_T -differential ones. Therefore, the increase observed in p_T -integrated flow is attributed to an increase in average p_T . The data are found to be compatible with theoretical predictions. This constitutes an important test for the hydrodynamical models with which we most commonly describe ultra-relativistic heavy-ion collisions. We also have indications that the temperature dependence of the shear viscosity over entropy ratio is relatively small ($0 < d(\eta/s)/dT < 0.15$ [100 MeV $^{-1}$] for $T > 150$ MeV.).

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