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

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ALICE (A Large Ion Collider 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 characterize the properties of the QGP is the azimuthal anisotropy in particle production. This so-called anisotropic flow is sensitive to the transport properties and equation of state of the QGP. In this presentation, we report the first measurements of anisotropic flow in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV with ALICE and compare them with both theoretical predictions and experimental measurements at lower energies and other collision systems. This provides a unique opportunity to test the validity of the hydrodynamic paradigm and to further constraint the key transport parameters of the QGP.

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1. Introduction

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, have been a key observable in the study of heavy–ion collisions. This phenomenon goes under the name of anisotropic flow and has been most commonly interpreted at higher energies as the result of the hydrodynamic behaviour of the QGP. It stands as one of the most solid evidences of the non–trivial collective dynamics of such system. Anisotropic flow is sensitive to the transport parameters (e.g. viscosities) and equation of state of the system, both in its QGP phase and after hadronisation. By using a general Fourier series decomposition of the azimuthal distribution of produced particles:

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

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

2. Analysis

We use data recorded with the ALICE detector in November 2015, during the Run 2 of the LHC. Of the full period, 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, which corresponds to a sample of 140 k minimum bias Pb–Pb collisions. We use charged tracks in the p_{T} range $0.2 < p_{\mathrm{T}} < 5$ GeV/c and pseudorapidity $|\eta| < 0.8$, reconstructed using combined information from the Inner Tracking System (ITS) and the TPC. Non-uniformities in the azmuthal distribution of reconstructed tracks, which influence flow observables, are found to be at the level of 1%. The systematic uncertanty associated to track selection criteria is estimated varying such criteria and is found to be 0.5% at most. As an additional systematic check, we compare the flow coefficients from tracks that are reconstructed from TPC space points alone and from both TPC clusters and ITS hits and we find them to agree within 2%. This difference is included in the total systematic uncertainty. The centrality determination, the polarity of the magnetic field of the ALICE detector and the position of the reconstructed primary vertex are also studied and do not result in a significant variation of the results. The total systematic uncertanty is evaluated adding in quadrature the aforementioned contributions.

3. Results

In fig.1 (a) we show 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. We observe that v_2 increases from central to peripheral collisions, reaching a maximum in the 40-50% centrality class and then decreasing. v_3 and v_4, on the contrary, show a milder centrality dependence, which is consistent with initial state fluctuations depending weakly on centrality. These features are consistent across collision energies. The difference between two- and multi–particle cumulants is most commonly attributed to the opposite contribution of flow fluctuations to these observables. Concerning the differences between 2.76 and 5.02 TeV, the flow coefficients are all found to increase, as shown in fig.1 (b) and (c), and such increase shows no significant centrality dependence, at least in the centrality range 0-50%. These measurements are found to be compatible with theoretical predictions [4, 5]. Compared to the set of predictions from [4], the results seem to indicate that the shear viscosity over entropy ratio (η/s) does not vary significantly between 2.76 and 5.02 TeV. The two parametrisations of $\eta/s(T)$ that are compatible with the data, shown in fig.1 (b) and (c), point to small or non existent temperature dependence of η/s in the QGP phase:

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

We note that this is consistent with other recent findings [6].

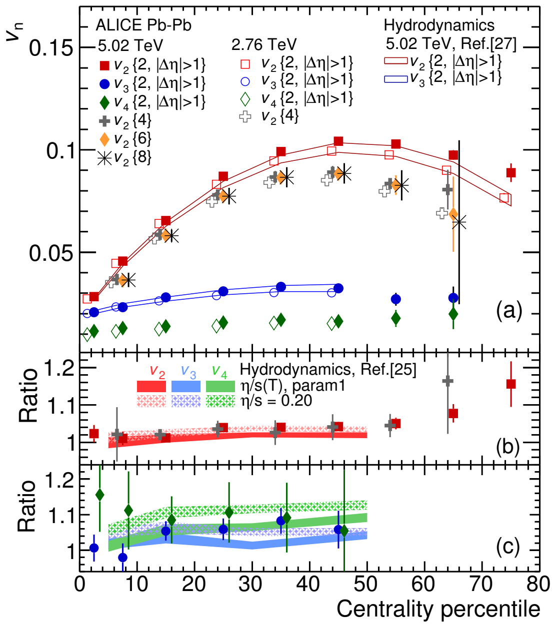

Figure 1: (a) p_T-integrated anisotropic flow coefficients v_n as a function of event centrality, for 2.76 and 5.02 TeV Pb–Pb collisions. (b), (c) Ratios of v_n for these two energies. Various predictions from hydrodynamical models are also presented [4, 5].

In fig.2 we show 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 2.76 and 5.02 TeV, we find the p_T-differential flow coefficients to be compatible and therefore we attribute the increase in the p_T-integrated ones to an increase of mean transverse momentum $\langle p_T \rangle$. This is qualitatively consistent with the expected increase in radial flow at higher energies.

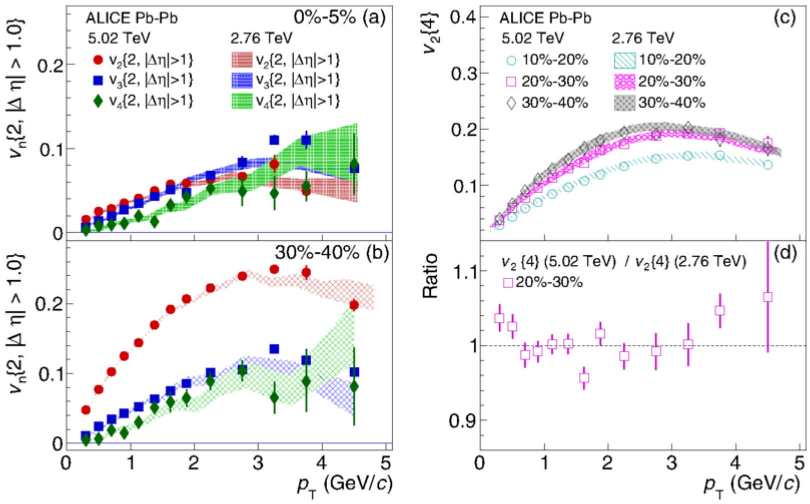

Figure 2: Anisotropic flow coefficients v_n as a function of p_{T} in the centrality classes 0-5% (a) and 30-40% (b) from two–particle cumulants. $v_2\{4\}(p_{\mathrm{T}})$ is shown in panel (c) and the ratio between the measurements at 2.76 and 5.02 TeV in (d).

In fig.3 we show the 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 is performed combining two methods, one based on the fit of the p_{T} spectra and $v_2\{4\}(p_{\mathrm{T}})$, the other on the direct calculation of $v_2\{4\}$ from tracklets in the ITS, which has an acceptance of $p_{\mathrm{T}} > 50$ MeV/c. We find the fully p_{T} integrated v_2 to increase by $4.89 \pm 2.27\%$ between 2.76 and 5.02 TeV.

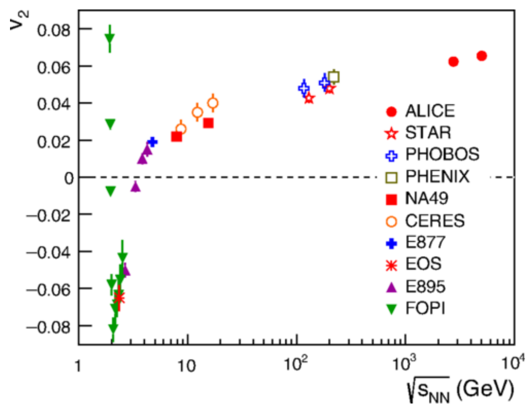

Figure 3: Fully p_{T}-integrated elliptic flow $v_2\{4\}$ in the 20–30% centrality range at 5.02âĂĹâĂĹTeV compared with v_2 measurements at lower energies with similar centralities.

4. Summary

In these proceedings we present the first measurements of anisotropic flow coefficients in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV. Compared to 2.76 TeV, we observe an increase in the p_{T}–integrated flow, while the p_{T}–differential ones are found to be compatible. Therefore, we attribute the increase observed in p_{T}–integrated flow to an increase in average p_{T}. Compared to theoretical predictions, the data are found to be compatible, which constitutes an important test for the hydrodynamical models with which we most commonly describe ultra–relativistic heavy–ion collisions. We also derive an indication that the temperature dependence of the shear viscosity over entropy ratio is relatively small ($0 < d(\eta/s)/dT < 0.15$ [$100\,\mathrm{MeV}^{-1}$] for $T > 150\,\mathrm{MeV}$), which is consistent with other recent findings.

References

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