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Pseudorapidity dependence of the anisotropic flow of charged particles in Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV

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ABSTRACT

We present measurements of the elliptic (v_2), triangular (v_3) and quadrangular (v_4) anisotropic azimuthal flow over a wide range of pseudorapidities ($-3.5 < \eta < 5$). The measurements are performed with Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV using the ALICE detector at the Large Hadron Collider (LHC). The flow harmonics are obtained using two- and four-particle correlations from nine different centrality intervals covering central to peripheral collisions. We find that the shape of $v_n(\eta)$ is largely independent of centrality for the flow harmonics $n = 2$–4, however the higher harmonics fall off more steeply with increasing $|\eta|$. We assess the validity of extended longitudinal scaling of v_2 by comparing to lower energy measurements, and find that the higher harmonic flow coefficients are proportional to the charged particle densities at larger pseudorapidities. Finally, we compare our measurements to both hydrodynamical and transport models, and find they both have challenges when it comes to describing our data.

1. Introduction

The main goal of the heavy-ion physics program at the Large Hadron Collider (LHC) is to study the quark–gluon plasma (QGP), a deconfined state of matter existing at extreme temperatures and energy-densities. Experimental results from RHIC were the first to suggest that the QGP behaves as a nearly perfect fluid [1–4]. A particularly important observable when characterizing the QGP is anisotropic azimuthal flow. The anisotropic flow develops from pressure gradients originating from the initial spatial geometry of a collision and is observed as a momentum anisotropy in the final-state particles. It is usually described by flow harmonics, which are defined as the Fourier coefficients:

$$v_n = \langle \cos[n(\varphi - \Psi_n)] \rangle \,, \tag{1}$$

where n is the order of the flow harmonic, φ is the azimuthal angle and Ψ_n is the symmetry plane angle of harmonic n. The first three Fourier coefficients, v_1, v_2, and v_3 are known as directed, elliptic and triangular flow, respectively. The flow harmonics v_1 to v_6 have been studied extensively at RHIC [1–7] and the LHC [8–17]. The observed anisotropic flow is considered to be a strong indication of collectivity [18] and is described well by relativistic hydrodynamics [19].

Anisotropic flow studies at RHIC played a major role in establishing that the produced system is a strongly interacting quark–gluon plasma (sQGP) [1–4] with a shear viscosity to entropy density ratio (η/s) close to the conjectured lower limit of $1/(4\pi)$ predicted by the AdS/CFT correspondence [20]. The fact that higher order harmonics are increasingly suppressed by viscosity [21] makes it possible to use anisotropic flow measurements to estimate the η/s of the produced system [22,23].

The pseudorapidity (η) dependence of the flow harmonics can play a key role in understanding the temperature dependence of η/s, something that can be determined using Quantum Chromodynamics (QCD) [24–26]. At forward rapidities, the average temperature drops which implies η/s will also change. In addition, the lower temperatures at forward rapidities mean the system will spend less time in the QGP phase leading to the hadronic viscosity playing a greater role in affecting the flow harmonics [26,27]. Recently, it has been suggested that the symmetry plane angles may depend on η [28–30]. While this effect is not directly studied in this Letter, considering that the reference particles are taken from mid-rapidity, the measured values of anisotropy coefficients at forward rapidity will be suppressed if the symmetry-plane angles fluctuate with η.

At RHIC, the PHOBOS experiment reported the pseudorapidity dependence of elliptic flow over a wide range ($-5.0 < \eta < 5.3$) and variety of collision energies [31–33], and system sizes [34]. It was found that in the rest frame of one of the colliding nuclei ($\eta - y_{\rm beam}$), v_2 is energy independent. This feature was also ob-

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served in multiplicity density distributions [35,36] and for v_1 [37]. This suggests that at forward rapidity, in the fragmentation region, particle production is independent of the collision energy, an effect known as extended longitudinal scaling.

In this Letter, we present measurements of v_2, v_3, and v_4 over a wide pseudorapidity range ($-3.5 < \eta < 5.0$) in Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV using the ALICE detector. At the LHC, the pseudorapidity dependence of the flow harmonics has already been reported by ATLAS [12,38] and CMS [13,16] in a limited η-range ($|\eta| < 2.5$ and $|\eta| < 2.4$, respectively). The extended longitudinal scaling has been shown to hold for multiplicity densities [39] and directed flow [15], and appears to occur for elliptic flow [13,38]. Here, the η-range is extended considerably compared to the former results and we will investigate whether the extended longitudinal scaling of elliptic flow continues to hold. We will compare our data to hydrodynamical and transport models, and investigate the decrease of v_n in the forward regions relative to $dN_{\rm ch}/d\eta$.

2. Experimental setup

A detailed description of the ALICE detector is available elsewhere [40]. In this section, the sub-detectors used in this analysis are described: the V0 detector, the Time Projection Chamber (TPC), the Inner Tracking System (ITS) and the Forward Multiplicity Detector (FMD). The V0 detector consists of 2 arrays of scintillators located on opposite sides of the interaction point (IP) along the beam line. The detector has full azimuthal coverage in the ranges of $2.8 < \eta < 5.1$ (V0-A) and $-3.7 < \eta < -1.7$ (V0-C) [41]. The detector acts as an online trigger and, with its large coverage, as a centrality estimator.

Charged particle tracks are reconstructed using the TPC, a large Time Projection Chamber [42]. The detector can provide position and momentum information. Particles that traverse the TPC volume leave ionization trails that drift towards the endcaps, where they are detected. Full length tracks can be reconstructed in the range $|\eta| < 0.8$. For this analysis, a transverse momentum range of $0.2 < p_{\rm T} < 5.0$ GeV/c was used. To ensure good track quality, the tracks are required to have at least 70 reconstructed TPC space points (cluster) out of 159 possible and an average χ^2 per TPC cluster ≤ 4. In addition, to reduce contamination from secondary particles (weak decays or interactions with material), a cut on the distance of closest approach (DCA) between the track and the primary vertex is applied both in the transverse plane ($\mathrm{DCA}_{xy} < 2.4$ cm) and on the z-coordinate ($\mathrm{DCA}_z < 3.2$ cm).

The ITS is made up of six cylindrical concentric silicon layers divided into three sub-systems, the Silicon Pixel Detector (SPD), the Silicon Drift Detector (SDD) and the Silicon Strip Detector (SSD), each consisting of two layers [40]. ITS clusters can be combined with the TPC information to improve track resolution. The SPD has additional applications [40]. Firstly, it is used to estimate the primary vertex as it is located close to the beam pipe. Secondly, clusters from the SPD inner layer, which consists of 3.3×10^6 pixels of size 50×425 μm^2, are used to estimate the number of charged particles in the range $|\eta| < 2.0$.

The FMD consists of five silicon rings, providing a pseudorapidity coverage in the ranges $-3.5 < \eta < -1.7$ and $1.7 < \eta < 5.0$ [43]. The rings are single-layer detectors and only charged particle hits, not tracks, are measured. This means that primary and secondary particles cannot be distinguished. There are two types of FMD rings: inner ring and outer rings. Inner rings have 512 radial strips each covering 18° in azimuth and outer rings have 256 radial strips each covering 9° in azimuth. The charged particle estimation in the FMD is described in more detail elsewhere [39]. The inner layer of the SPD and the five FMD rings allow one to measure charged particle hits in the range $-3.5 < \eta < 5.0$.

3. Data sample and analysis details

We analysed 10 million minimum bias Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV. The sample was recorded during the first LHC heavy-ion data-taking period in 2010. A minimum-bias trigger requiring a coincidence between the signals from V0-A and V0-C was used. In addition, it is required that the primary vertex, determined by the SPD, be within $|v_z| < 10.0$ cm, where $v_z = 0$ cm is the location of the nominal interaction position. The measurements are grouped according to fractions of the inelastic cross section, and cover the 80% most central collisions. The V0 detector is used for the centrality estimate which is described in more detail elsewhere [44]. For the most central to the most peripheral events, the V0 has a centrality resolution of 0.5% to 2%, respectively.

The flow harmonics are estimated using the Q-cumulants method [45] for two- and four-particle correlations, denoted as $v_n\{2\}$ and $v_n\{4\}$ respectively. The two- and four-particle cumulants respond differently to flow fluctuations. The two-particle cumulants are enhanced, while four-particle cumulants are suppressed. At forward rapidities, the pseudorapidity density is relatively low. This means that it is not always possible to get statistically significant results using only particles from a small region in η. To circumvent this using the Q-cumulants method, the reference flow measurement is performed using the charged particle tracks from the TPC, where the correlations at mid-rapidity are measured. As a systematic check, the charged particle tracks using a combination of the TPC and ITS are also used. Then, for the $v_n(\eta)$ analysis, the correlations between charged particle hits (from the SPD or FMD) and the tracks are measured in η-bins 0.5 units of pseudorapidity wide. To avoid autocorrelations between the SPD clusters and tracks, the tracks for the reference particles are located in a different η-region than the SPD hits. Effectively, for SPD hits with $\eta < 0$, tracks are required to have $\eta > 0$ and vice versa. The same considerations apply for FMD hits. Due to the use of particle hits, only the $p_{\rm T}$-integrated flow is measured. The ϕ distribution for the SPD or FMD clusters is not uniform, therefore a non-uniform acceptance correction is applied based on relations derived elsewhere [46].

As the inner rings of the FMD have only 20 azimuthal segments, the flow harmonics are slightly suppressed. The effect of this was recently calculated [47] and found to be 1.6%, 3.7% and 6.5% for v_2, v_3 and v_4 respectively. This suppression is taken into account in the final results. When using charged particle hits it is not possible to distinguish secondary particles (from material interactions and decays) from primary particles. For the regions covered by the SPD, the contamination from secondary particles is small (< 10%), as the inner layer of the SPD is very close to the beam pipe. Away from mid-rapidity, in the FMD, dense material such as cooling tubes and read-out cables cause a very large production of secondary particles – up to twice the number of primary particles according to Monte Carlo (MC) studies. These secondary particles are deflected in φ with respect to the mother particle, which causes a reduction in the observed flow. The reduction of flow caused by the secondary particles is estimated using an event generator containing particle yields, ratios, momentum spectra and flow coefficients, which are then subject to a full detector simulation using GEANT3 [48]. To make sure that the correction is not model dependent, the AMPT MC event generator [49,50] is used as an independent input, with GEANT3 again used to model the detector response. Using these simulations, the reduction is found to be larger for higher harmonics, up to 41% for v_4. Finally, the correction also accounts for missing very low $p_{\rm T}$ particles, which increase the observed v_n as these particles have a very small v_n. However, as the correction is always less than 1, the dominant effect comes from the secondary particles, which reduce v_n.

Few-particle correlations, not originating from the initial geometry termed non-flow (decays, jets, etc.), enhance the two-particle cumulant measurements. The non-flow contribution to the four-particle cumulant is found to be negligible [45,51], however, it is necessary to apply a correction to the two-particle cumulant. In the FMD and SPD, there is also a non-flow contribution from secondary particles, as they are sometimes produced in pairs. For the differential flow measurement, there is a rapidity-gap between the charged particle hits and the charged particle tracks. For the SPD, it is between 0 and 2 units in pseudorapidity, while for the FMD it is between 0.9 and 4.2 units in pseudorapidity. The large rapidity gap suppresses the non-flow contribution at forward rapidity. However, at mid-rapidities, this contribution is non-negligible and needs appropriate corrections. For the reference flow measurement there is no rapidity gap, and non-flow removal is important. For this analysis, the non-flow contributions are estimated using the HIJING event generator [52] and GEANT3 for the detector simulation. The non-flow contribution is estimated and subtracted separately for the reference and differential flow, before the correction for the deflection of secondary particles is applied and the v_n estimates are derived.

4. Systematic uncertainties

Numerous sources of systematic uncertainty were investigated, including effects due to detector cuts, choice of reference particles and uncertainties related to the secondary particle correction. Four major contributors to the systematic uncertainty were identified: the choice of reference tracks, the model dependence of the secondary particle correction, the description of the detector used for the simulations, and finally the non-flow correction. As the non-flow contribution to the four-particle cumulant is negligible, only the first three systematic uncertainties are considered for $v_2\{4\}$. The systematic uncertainties assigned to each of the sources are shown in Table 1, and are described in more detail below.

The dependence of the differential flow on the reference tracks was tested by using tracks with combined information from the TPC and ITS, rather than tracks with only TPC information. The systematic uncertainty from the choice of reference tracks was found to vary slightly with centrality, with the most central events having the largest uncertainty. To test the model dependence of secondary particle production, the correction from the toy-model described above is compared to the one derived from AMPT tuned to LHC data. Both the secondary particle correction and the non-flow correction derived from HIJING are sensitive to inaccuracies in the description of the detector used for the simulation. To test this sensitivity, the output of two HIJING simulations with a flow afterburner, one with +7% material density and one with −7% material density, are compared to the output from having normal material density. In this case the systematic uncertainty has a small η-dependence, as there are significantly fewer secondary particles at mid-rapidity. The 3% uncertainty is applicable to the SPD, while the 4% uncertainty is applicable to the FMD.

We assessed the systematic uncertainty associated with the non-flow correction in two ways. Firstly, following another method proposed to subtract non-flow [53], the two-particle cumulants were obtained from minimum bias pp collisions, where it is assumed that there is negligible anisotropic flow. The pp reference and differential cumulants are then rescaled according to their multiplicity, M, using the ratio $M^{\mathrm{pp}}/M^{\mathrm{cent}}$, then subtracted from the corresponding A–A cumulants. Any differences found between this method and the default HIJING method are treated as systematic uncertainties. Secondly, by using only charged particle hits from the SPD and FMD, it is possible to construct a two-particle cumulant with a large rapidity-gap, $v_n\{2, |\Delta\eta| > 2.0\}$, which largely removes all non-flow contributions. Unfortunately, this observable is statistically stable only for v_2 and v_3, so it is used as a further cross check. In Table 1, the 2% uncertainties correspond to mid-central collisions where the ratio of flow to non-flow is largest, while the 10% uncertainties correspond to very central and very peripheral collisions where the ratio of flow to non-flow is smallest. Finally, we used the AMPT model [49,50] to investigate if there are differences between $v_n(\eta)$ and $v_n(y)$, as η is supposed to approximate y. We found there are 15% differences in the flow coefficients at mid-rapidity, which reduced to 0% for $\eta > 2$. We did not assign any systematic uncertainties due to these differences, as we are explicitly reporting measurements as a function of η (as in the case of $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ measurements).

Table 1
List of the systematic uncertainties for each observable.

Source	$v_2\{2\}$	$v_3\{2\}$	$v_4\{2\}$	$v_2\{4\}$
Reference particle tracks	2–4%	2–4%	2–6%	2–4%
Model dependence	5%	5%	7%	5%
Material budget	3–4%	3–4%	3–4%	3–4%
Non-flow correction	2–10%	2–10%	2–10%	-
Total	6–12%	6–13%	6–14%	6–8%

The systematic uncertainty assigned to the non-flow correction is the largest contributor to the total systematic uncertainty, except for $v_2\{4\}$ due to the four-particle cumulant's insensitivity to non-flow. The total systematic uncertainties are slightly dependent on centrality and pseudorapidity.

5. Results

An overview of the four observables in each centrality class is shown in Fig. 1. Due to the changing overlap geometry, a strong centrality dependence of the elliptic flow is observed over the entire pseudorapidity range. The weaker centrality dependence of the higher order coefficients v_3 and v_4 is an indication that initial-state fluctuations play a prominent role, as the centrality dependence of the corresponding eccentricities are more modest relative to $n = 2$ [21]. The different behaviour of $v_2\{2\}$ and $v_2\{4\}$ caused by flow fluctuations is also clearly seen. For the most peripheral events, there are not enough particles to get statistically stable results for $v_2\{4\}$ and similarly for $v_4\{2\}$ due to the relatively small quadrangular flow.

The p_{T}-integrated elliptic flow was also measured by CMS [13] and ATLAS [38] in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV and by PHOBOS in Au–Au collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV [32]. A comparison between those results and this analysis is shown for the 25–50% centrality class in Fig. 2. In the common region of pseudorapidity acceptance, the results of present analysis are consistent with the results obtained by CMS and ATLAS experiments within the systematic uncertainties. The present analyses extends the measurements to a wider range of pseudorapidity. The values of v_2 at all pseudorapidities measured at LHC energies are larger than the corresponding values at RHIC, as reported by PHOBOS. This increase in elliptic flow coincides with a larger p_{T} at the LHC energy [8].

The extended longitudinal scaling observed by PHOBOS in Au–Au collisions with centre-of-mass energies from 19.6 to 200 GeV [33] is found to hold up to the LHC energy (shown in Fig. 3). This is consistent with what was found by CMS [13] and ATLAS [38]. Here it is shown as an event average for the 0–40% most central events. The event average means that the analysis was performed in smaller centrality bins using multiplicity weights, and was then averaged over the centrality bins using the number of events as a weight [45]. To examine boost invariance, it would be preferable to

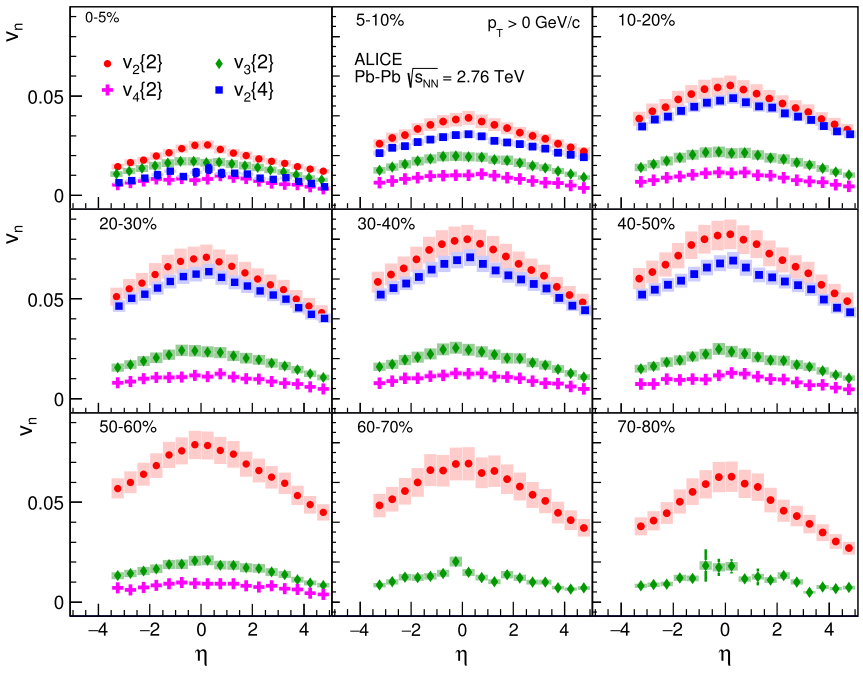

Fig. 1. Measurements of the pseudorapidity dependence of v_2, v_3 and v_4 in each centrality bin. The vertical lines represent the statistical uncertainties and the boxes represent the systematic uncertainties. The statistical uncertainties are usually smaller than the marker size.

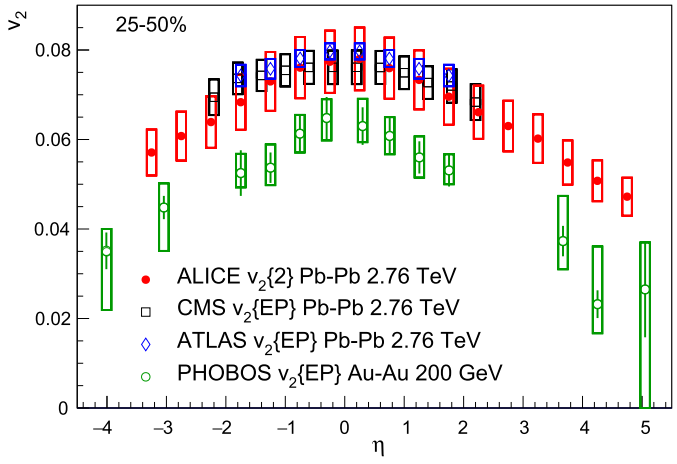

Fig. 2. Elliptic flow for the 25–50% centrality range. Boxes represent systematic uncertainties and errors bars represent statistical uncertainties. The results for $v_2\{2\}$ from this analysis are compared to measurements using the event plane method from CMS [13] and ATLAS [38] at the same energy and lower energy results from PHOBOS [32]. For the comparable LHC energy, the p_T range for ALICE is $p_T > 0$ GeV/c, for CMS is $0.3 < p_T < 3$ GeV/c, and for ATLAS is $p_T > 0.07$ GeV/c.

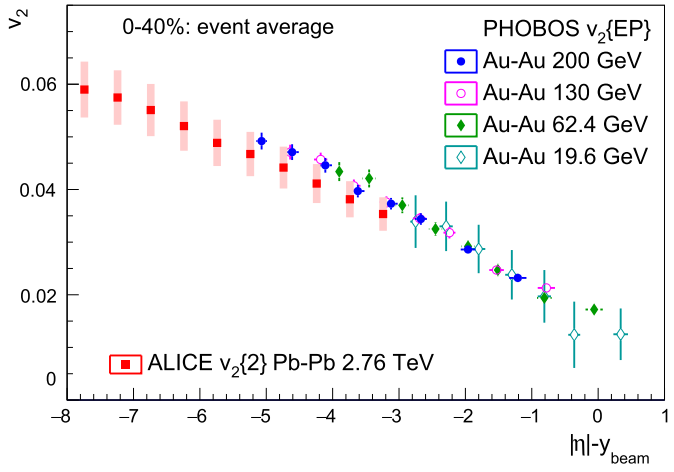

Fig. 3. The elliptic flow as observed in the rest frame of one of the projectiles by using the variable $|\eta| - y_{beam}$ ($y_{beam} = 7.99$) for the event averaged 0–40% centrality range. The results from $v_2\{2\}$ from this analysis are compared to lower energy results from PHOBOS [33]. The vertical lines represent the statistical uncertainties and the boxes represent the systematic uncertainties. For the PHOBOS results only statistical errors are shown.

use rapidity (y) instead of pseudorapidity, unfortunately that is not possible using the FMD as the momentum cannot be measured.

PHOBOS found the shape of $v_2(\eta)$ to be largely independent of centrality, with only the overall level changing between central and peripheral events [32]. The ratios of central to peripheral events for v_2, v_3 and v_4 using the two-particle cumulant are shown in Fig. 4. Here it is observed that none of the harmonics show a clear centrality dependence in the shape of $v_n(\eta)$ within uncertainties (albeit hints of such a dependence are present in the v_2 ratio), consistent with the results from PHOBOS at lower energy.

It is known that the suppression from viscous effects to the flow harmonics increases with n [21]. The hadronic phase is speculated to be more dominant at forward rapidity [26,27]. Therefore, the relative decrease of the flow harmonics may help to disentangle the viscous effects from the hadronic phase with those from the QGP phase. When the ratio v_m/v_n ($n \neq m$) is formed most of the common systematic uncertainties cancel, leaving the contribution from the non-flow correction. The ratios of v_3/v_2 and v_4/v_3 are shown for the 30–40% most central events in Fig. 5. A small decrease with η is observed for v_3/v_2, qualitatively consistent with the expectation from viscous effects suppressing higher harmonics. The v_4/v_3 ratio remains constant with $|\eta|$ within the uncertainties. The figure also shows v_4/v_2^2, which is commonly used to estimate the non-linear contribution to v_4 from the elliptic anisotropy [5]. Given the uncertainties, it is difficult to conclude whether v_4/v_2^2 changes with respect to η.

As mentioned previously, at forward rapidities the steepness of $v_n(\eta)$ has been linked to the hadronic contribution to the vis-

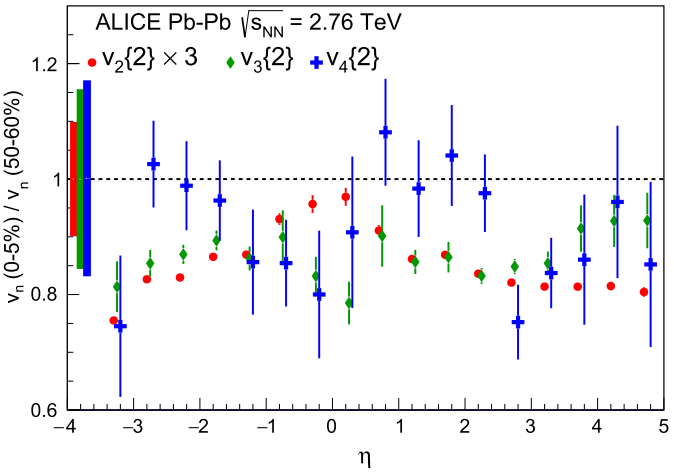

Fig. 4. Ratio of $v_n\{2\}$ between central (0–5%) and peripheral (50–60%) events for v_2, v_3 and v_4. The vertical lines represent the statistical uncertainties and the boxes represent the systematic uncertainties. The v_2 results are multiplied by 3 to fit on the same scale as v_3 and v_4.

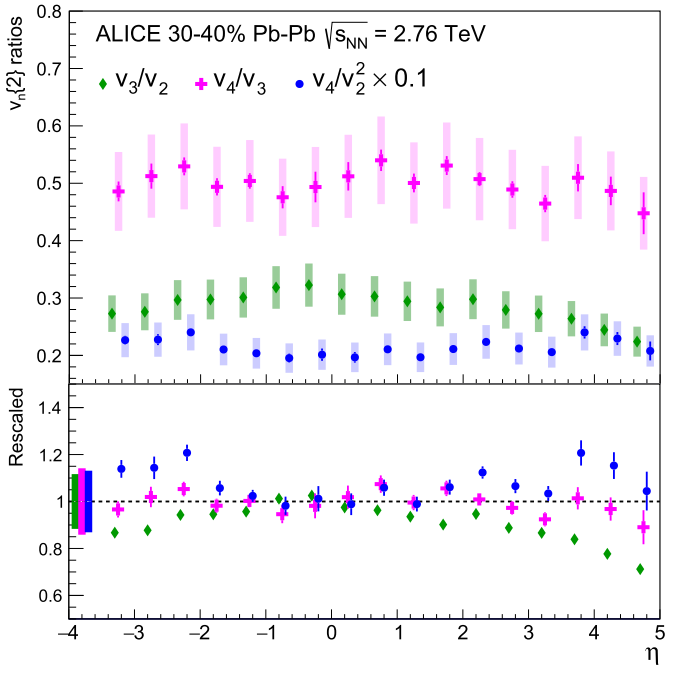

Fig. 5. Ratios between different harmonics for the 30–40% centrality range. The vertical lines represent the statistical uncertainties and the boxes represent the common systematic uncertainties. In the bottom panel the ratios are rescaled to 1 at mid-rapidity and the common systematic uncertainties are shown as the thick bars on the left.

cosity to entropy ratio [26,27]. The larger the hadronic η/s, the steeper the fall off. We also note that the pseudorapidity densities of charged particles decrease in this region. In order to investigate the correspondence of the latter, in Fig. 6 we show the ratio of various v_n coefficients to previous ALICE measurements of $dN_{ch}/d\eta$ [39]. In order to avoid any influence of the Jacobian translation from y to η, only the range $\eta > 2$ is shown. We find that this ratio is generally flat, with the exception of v_2 at the larger values of η. This indicates that within a fixed centrality interval, v_3 and v_4 are largely driven by the local particle density. Indeed, when comparing p–Pb and Pb–Pb collisions at LHC energies, it was found that values of $v_3\{2\}$ were similar for similar values of $dN_{ch}/d\eta$ [51]. The correlation found between both quantities may be simply attributed to the fact that both particle production and the development of anisotropic flow are driven by the number of interactions in the system.

In Fig. 7, we compare our data to hydrodynamic calculations tuned to RHIC data [26]. The tuning involves finding a parameterization of the temperature dependence of η/s, so that the hydrodynamical calculations describe PHOBOS measurements of $v_2(\eta)$ [32,33]. It is clear that the same parameterization does not describe the LHC data as well. For both centralities, the elliptic flow coefficient v_2 is generally underestimated, while the higher order coefficients v_3 and v_4 are generally overestimated. This points to the need for an either an alternative parameterization of η/s that describes both the RHIC and LHC data simultaneously, or further investigations into whether the initial state model used is applicable for the LHC energies.

In contrast to hydrodynamical models, AMPT is a non-equilibrium model that attempts to simulate parton production after the initial collision, and collective behaviour arises from parton and hadronic rescatterings. It has previously been tuned to agree with ALICE measurements of v_2 vs. p_T and multiplicity for the 40–50% most central events. It was found to reproduce $v_3(p_T)$ well using the same parameters. In Fig. 8 the results of this analysis are compared to the output of the AMPT model for two different centralities. For the centrality range of 40–50%, which AMPT is tuned to match, there is good agreement at mid-rapidity for all observables modulo $v_2\{4\}$ at larger $|\eta|$, where AMPT underestimates the data. The underestimation at forward rapidity is found to be independent of the choice of reference particles, suggesting that it is unrelated to symmetry plane angle fluctuations with η. For more central events AMPT tends to overestimate flow at forward rapidities, except for v_4 which it describes quite well over the entire range. At mid-rapidity AMPT agrees with the observed values of v_2, v_3 and v_4 within the systematic uncertainties. Further tuning may lead to an improvement at forward rapidities, and should be investigated in future studies.

6. Conclusions

The pseudorapidity dependence of the anisotropic flow harmonics v_2, v_3 and v_4 have been measured in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV using the ALICE detector. The measurement is performed over the widest η-range at the LHC, $-3.5 < \eta < 5.0$, in nine centrality bins covering 0 to 80% of the total inelastic cross section. It was found that the shape of $v_n(\eta)$ does not depend obviously on centrality. Comparing to lower energy measurements at RHIC, elliptic flow is larger at the LHC over the entire pseudorapidity range and extended longitudinal scaling of v_2 observed at lower collision energies is still valid up to the LHC energy. In the range $|\eta| < 2.5$ the results were found to be consistent with previous LHC measurements. At forward rapidities, the higher harmonic flow coefficients are proportional to the charged particle densities for a given centrality, while the ratio of v_2 to $dN_{ch}/d\eta$ rises with increasing η. A comparison to hydrodynamic calculations tuned to RHIC data has difficulties in describing our data in some η regions, and this suggests that the LHC data play a key role in constraining either the temperature dependence of η/s or the initial state. Finally, comparing our data to AMPT, the model describes the flow well at mid-rapidity, but fails for v_2 at forward rapidities.

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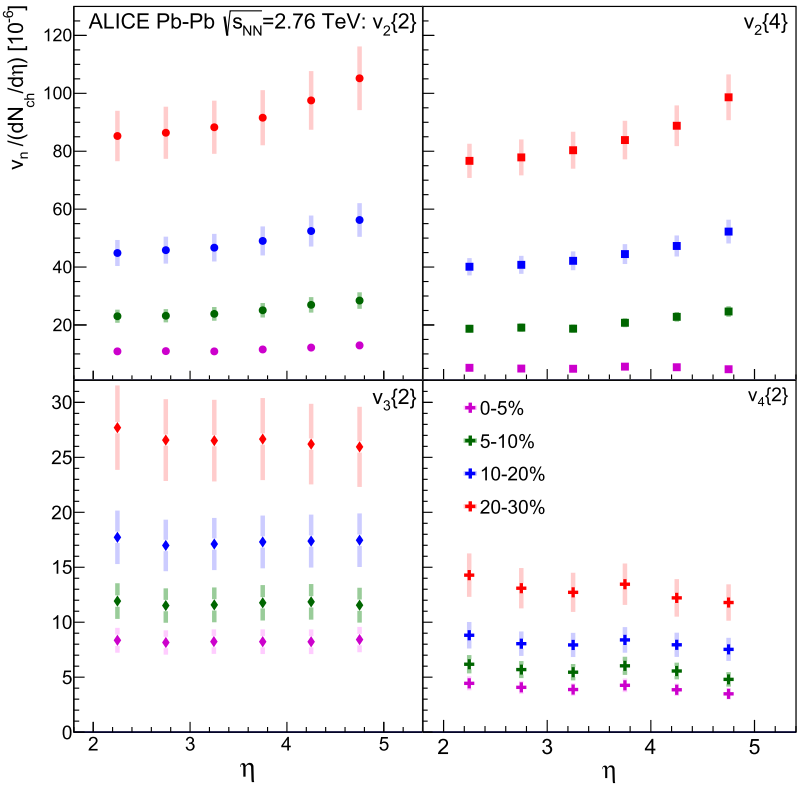

Fig. 6. Ratios between v_n coefficients and $dN_{ch}/d\eta$ values for different centralities. Measurements of $dN_{ch}/d\eta$ are taken from a previous ALICE publication [39]. Only systematic uncertainties are shown, as the statistical uncertainties are smaller than the symbols.

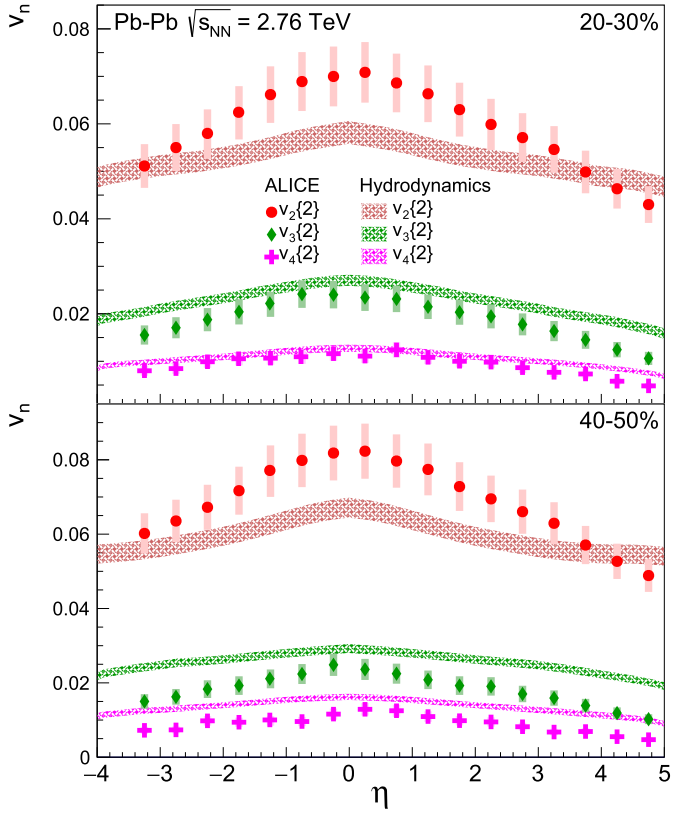

Fig. 7. Comparisons to hydrodynamics predictions [26], where input parameters (temperature dependence of η/s) have been tuned to RHIC data for the Pb–Pb 20–30% (top) and 40-50% (bottom) centralities. The predictions are for Pb–Pb $\sqrt{s_{NN}} = 2.76$ TeV collisions.

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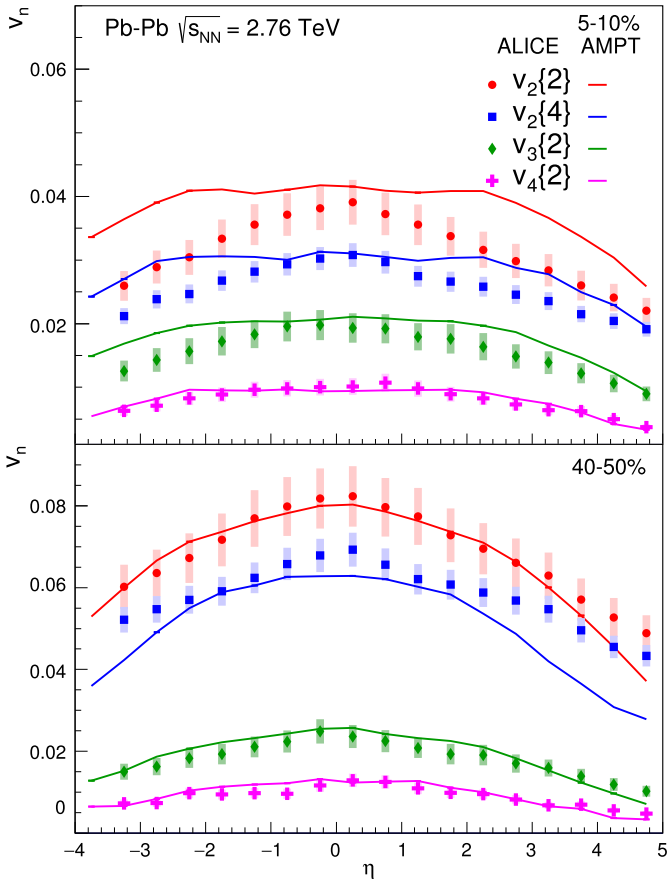

Fig. 8. Comparison to AMPT [49,50] for the centrality ranges 5–10% and (top) and 40–50% (bottom). The AMPT predictions are for Pb–Pb $\sqrt{s_{NN}} = 2.76$ TeV collisions.

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