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Measurement of transverse flow and longitudinal flow decorrelations in $\sqrt{s_{\mathrm{NN}}}$=5.44 TeV Xe+Xe collisions with ATLAS

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Measurement of flow harmonics v_n for $n = 2$, 3 and 4 and their longitudinal decorrelations in 3 μb^{-1} of Xe+Xe collisions at $\sqrt{s_{\mathrm{NN}}}$=5.44 TeV, performed with the ATLAS detector at the LHC, are presented. The results in Xe+Xe collisions are compared with the results from Pb+Pb collisions at $\sqrt{s_{\mathrm{NN}}}$=5.02 TeV. The v_n values in Xe+Xe collisions are larger than in Pb+Pb collisions in the most central events. With increasing centrality percentile the v_n values in Xe+Xe collisions become smaller than in Pb+Pb collisions. The decorrelation signal for v_3 and v_4 is found to be nearly independent of collision centrality, but for v_2 a strong centrality dependence is seen. Compared to Pb+Pb collisions, the longitudinal decorrelation signal in mid-central Xe+Xe collisions is found to be larger for v_2, but smaller for v_3. This opposite ordering between $n = 2$ and $n = 3$ is unique to the longitudinal decorrelations and is not present in the inclusive flow harmonics v_n. The results for v_n and v_n-decorrelations are compared with the theoretical calculations from hydrodynamic models. Current hydrodynamic models reproduce the ratios of the v_n between Xe+Xe collisions and Pb+Pb collisions but fail to describe the magnitudes and trends of the ratios of longitudinal v_n-decorrelations. The results on the system-size dependence provide new insights and an important lever-arm to separate effects of the longitudinal structure of the initial state from other early-time and late-time effects in heavy-ion collisions.

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1. Introduction

Heavy-ion collisions produce a novel state of matter known as a quark–gluon plasma (QGP) whose expansion with large anisotropic pressure gradients transforms the initial-state spatial anisotropies into momentum anisotropies of the final-state particles. The single-particle density in the azimuthal angle can be expanded as a Fourier series in ϕ, $dN/d\phi \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos n(\phi - \Phi_n)$, where v_n and Φ_n are the magnitude and phase of the $n^{\rm th}$-order flow vector $V_n = v_n e^{-in\Phi_n}$. The V_n reflects the hydrodynamic response of the QGP to the shape of the overlap region in the transverse plane, described by the eccentricity vector $\mathcal{E}_n = \varepsilon_n e^{-in\Psi_n}$ [1]. Extensive studies of V_n and their event-by-event fluctuations in a broad range of beam energy and collision systems [2] have provided strong constraints on $\mathcal{E}_n$ and the properties of the QGP [3].

Most previous measurements assumed boost-invariance of the dynamic evolution of QGP in the longitudinal direction. Recently, the first observation of longitudinal flow fluctuations along pseudorapidity (η) also termed as "flow decorrelations" was done in Pb+Pb collisions at the LHC [4, 5]. The comparison of flow decorrelation measurements in systems of different sizes can show the sensitivity of the observable to the fluctuations in the initial geometry arising from the asymmetry in eccentricities from forward and backward going nucleon participants [6].

In this proceedings the measurement of flow harmonics v_n [7] and their longitudinal decorrelations [8] for n = 2, 3 and 4 in Xe+Xe collisions at $\sqrt{s_{\rm NN}}$ = 5.44 TeV with the ATLAS detector [9] are presented. The results in Xe+Xe collisions are compared with previous measurements in Pb+Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV. These measurements show system-size dependence of v_n and v_n-decorrelations and can provide insight into the nature of the initial sources responsible for both the transverse harmonic flow and its longitudinal fluctuations.

2. Data Analysis

The analyses are done using 3 μb^{-1} of Xe+Xe collision data recorded by the ATLAS detector at $\sqrt{s_{\rm NN}}$=5.44 TeV in 2017. The flow harmonics v_n for n = 2, 3 and 4 are measured using the two-particle correlation method with template-fits. The details of the method can be found in Ref. [7]. The flow decorrelation is measured using the ratio of two-particle correlations from two different pseudorapidities η :

$$r_{n|n}(\eta) = \frac{\langle \boldsymbol{q}_n(-\eta)\boldsymbol{q}_n^*(\eta_{\rm ref})\rangle}{\langle \boldsymbol{q}_n(\eta)\boldsymbol{q}_n^*(\eta_{\rm ref})\rangle} = \frac{\langle v_n(-\eta)v_n(\eta_{\rm ref})\, \cos n[\Phi_n(-\eta) - \Phi_n(\eta_{\rm ref})]\rangle}{\langle v_n(\eta)v_n(\eta_{\rm ref})\, \cos n[\Phi_n(\eta) - \Phi_n(\eta_{\rm ref})]\rangle}, \tag{1}$$

where the average "$\langle\rangle$" is over events and $\boldsymbol{q}_n \equiv \Sigma_j w_j e^{in\phi_j}/(\Sigma_j w_j)$ are the flow vectors in an event calculated using the azimuthal angle ϕ_j and weight w_j of charged particles in the inner detector (ID) or the forward calorimeter (FCal), and $\eta_{\rm ref}$ is a reference pseudorapidity range in the FCal, common to both the numerator and the denominator. The $r_{n|n}$ correlator quantifies the decorrelation between η and $-\eta$ [4, 10]. Due to the factorization-breaking effect along η, $r_{n|n}(\eta) \neq 1$. The deviation of $r_{n|n}$ from unity can be parameterized with a linear function, $r_{n|n}(\eta) = 1 - 2F_n\eta$. The slope parameter F_n is obtained via a simple linear-regression [5] – $F_n = \left(\sum_i (1 - r_{n|n}(\eta_i))\eta_i\right) / \left(2\sum_i \eta_i^2\right)$.

3. Results

Figure 1 (left) shows the comparison of v_2 and v_3 between Xe+Xe and Pb+Pb collisions as a function of centrality. Figure 1 (right) shows the comparison of v_n ratios between Xe+Xe and

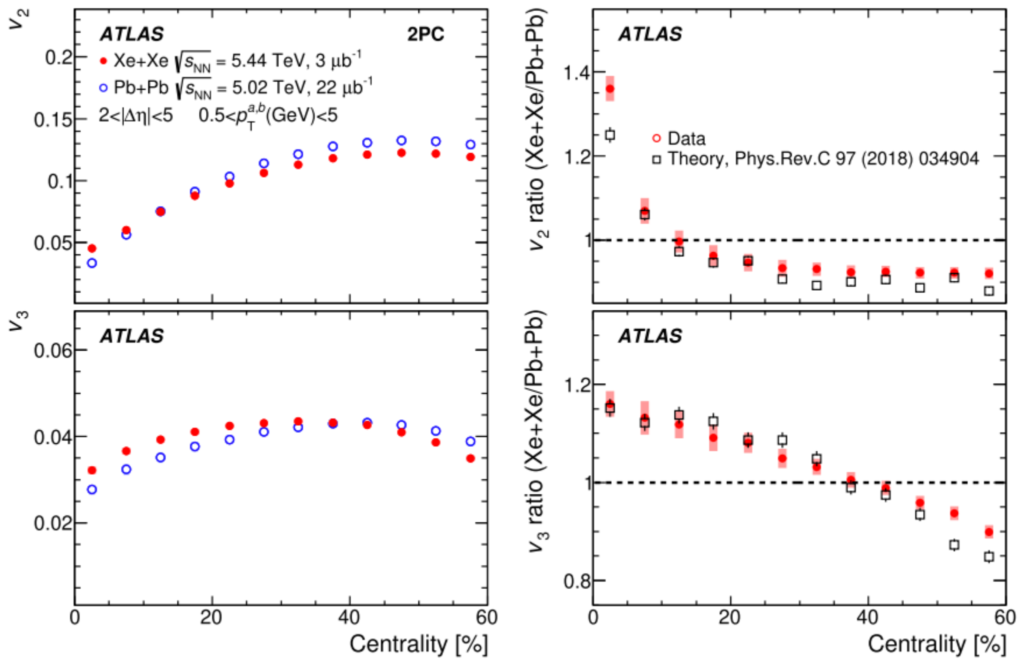

Figure 1: Comparison of v_n for $n = 2$ and 3 between Xe+Xe and Pb+Pb collisions (left). Comparison of v_n-ratios between the two systems for $n = 2$ and $n = 3$ with theory (right) from Ref. [7]

Pb+Pb collisions with the theoretical calculations [11]. In most central collisions v_2 is larger in Xe+Xe collisons and the v_2-ratio is greater than 1, due to the smaller size and larger fluctuations in Xe+Xe collisions. The presence of possible deformation in the Xe nucleus may also contribute to the rise of the ratio in the ultra-central region. Due to larger viscous effects in smaller Xe+Xe collisions, the ratio decreases with increasing centrality, crosses 1 at ∼15% centrality and then saturates in the peripheral collisions. Similarly, the v_3-ratio is also greater than 1 in central collisions and smaller than 1 above ∼35% centrality. The theoretical model can reproduce the v_n measurements quite well.

Figure 2 shows $r_{n|n}$ for $n = 2$, 3 and 4 in Xe+Xe collisions for different centrality ranges. A linear decrease with η is observed for $r_{2|2}$ with a smaller magnitude and stronger centrality dependence than $r_{3|3}$ and $r_{4|4}$. Figure 3 shows the comparison of the extracted slopes F_2 and F_3 in Xe+Xe and Pb+Pb collisions as a function of centrality (left) and $N_{\rm part}$ (right). A non-trivial reverse ordering is observed between $n = 2$ and $n = 3$ – $F_2^{\rm XeXe} > F_2^{\rm PbPb}$ and $F_3^{\rm XeXe} < F_3^{\rm PbPb}$ for most of the centralities and $N_{\rm part}$. The hydrodynamic model calculations [12, 13] can describe the F_2 values quantitatively in the central and mid-central collisions but fail to explain the magnitude as well as the ordering of F_3.

Figure 4 shows the direct comparison of v_n-ratios and F_n-ratios between Xe+Xe and Pb+Pb collisions along with the hydrodynamic model calculations for $n = 2$, 3 and 4 as a function of centrality. While the v_n-ratios all decrease with the centrality percentile, the F_n-ratios increase with the centrality percentile; this opposite trend implies that when the ratio of average flow is larger, the ratio of its relative fluctuations in the longitudinal direction is smaller and vice versa. An opposite ordering is seen in F_n-ratios – F_2-ratio > 1 but F_3-ratio < 1, which is not seen in v_n-ratios.

While the hydrodynamic model from Ref. [11] describes quantitatively the trend of the v_n-ratios, the agreement with the F_n-ratios is worse and in particular the model [12, 13] overestimates the F_2- and F_3-ratios for centrality percentiles beyond 20–30%. This failure is likely due to an inadequate description of the longitudinal structure of the initial state in these models.

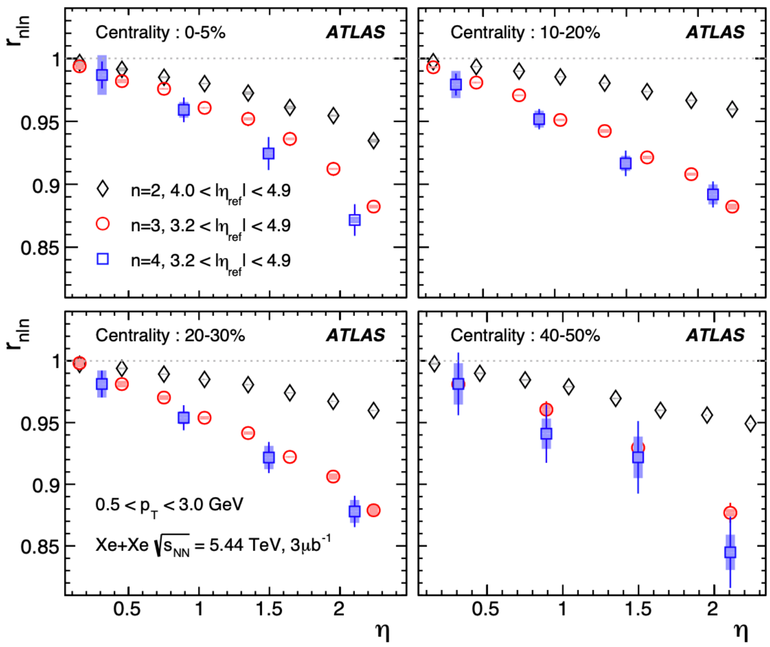

Figure 2: $r_{n|n}$ for n = 2, 3 and 4 in Xe+Xe collisions as a function of η from Ref. [8].

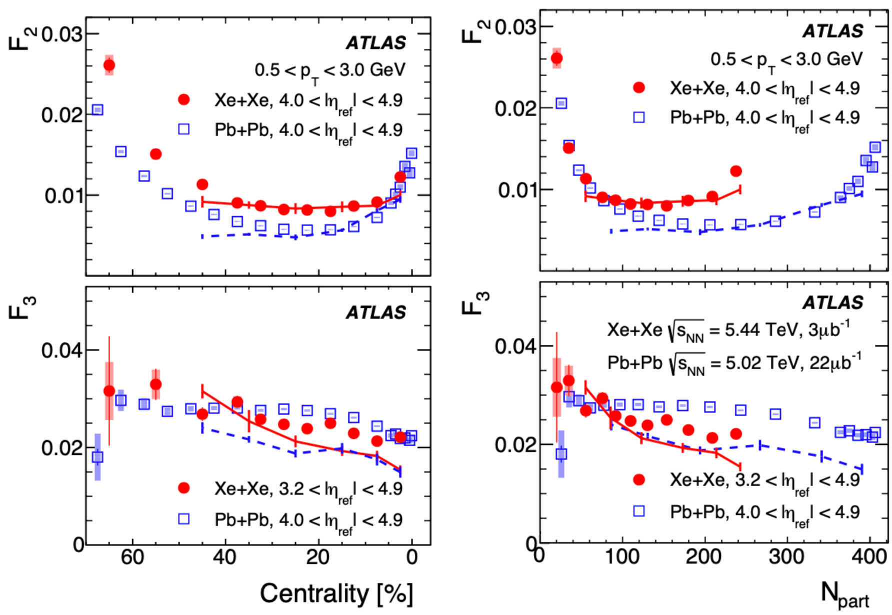

Figure 3: Comparison of F_n for n = 2 and n = 3 in Xe+Xe and Pb+Pb collisions with theory as a function of centrality (left) and N_{part} (right) from Ref. [8].

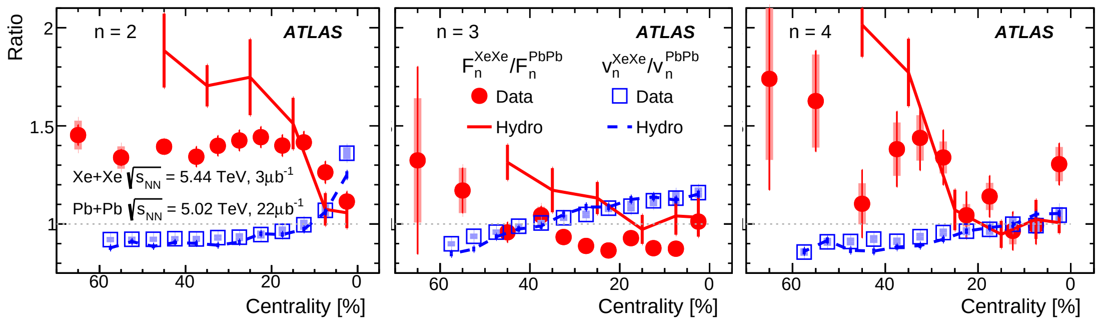

Figure 4: Comparison of v_n-ratios and F_n-ratios with theory as a function of centrality for $n = 2$, 3 and 4 from Ref. [8].

4. Summary

In this proceedings, ATLAS measurements of azimuthal flow harmonics v_n and their longitudinal decorrelations F_n for $n = 2$, 3, and 4 in Xe+Xe collisions at $\sqrt{s_{\mathrm{NN}}}$=5.44 TeV, and their comparisons with Pb+Pb collisions at $\sqrt{s_{\mathrm{NN}}}$=5.02 TeV are presented. Both v_n and F_n show strong dependence on the size of the system. The ratios of v_n and F_n between Xe+Xe and Pb+Pb collisions show opposite centrality dependence – v_n-ratios decrease while F_n-ratios increases with centrality. An opposite ordering is observed between F_2 and F_3 – F_2 is larger in Xe+Xe than in Pb+Pb collisions but F_3 is smaller in Xe+Xe than in Pb+Pb collisions. This behaviour is unique to F_n and not seen in v_n. Hydrodynamic models are found to describe the v_n-ratios very well but fail to describe most of the magnitudes and trends of the ratios of the v_n-decorrelations. These system-size dependence measurements of v_n and v_n-decorrelations provide new insights on the role of early-time and late-time effects on the transverse and longitudinal structure which can help in modeling of complete three-dimensional initial conditions in hydrodynamic models.

Acknowledgments

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