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Measurement of anisotropic flow in XeXe collisions at 5.44 TeV with the CMS experiment

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Abstract

New measurements of anisotropic flow in XeXe collisions at a center-of-mass energy of 5.44 TeV per nucleon pair, collected by the CMS experiment at the LHC, are presented. The v_2, v_3 and v_4 Fourier coefficients of the anisotropic azimuthal distribution are obtained employing three different analysis techniques: two-particle correlations, the scalar product method, and multiparticle cumulants, which have different sensitivities to non-flow and flow fluctuation effects. The results are shown as a function of transverse momentum (p_T) for various centrality selections, and compared with corresponding results from PbPb collisions. These new measurements in a smaller nucleus-nucleus system than PbPb provide additional insights into the system-size dependence of the collective flow induced by the dominant collision geometry and its fluctuations. In particular, these results, compared to theoretical predictions and Monte Carlo generators, will provide important details on the system size dependence of the medium response in heavy ion collisions. They also offer a unique opportunity to study the onset of flow from small to large systems.

Keywords: flow, collectivity, system size, correlations

1. Introduction

The initial geometry of the overlapping region in ultra-relativistic heavy ion collisions creates different pressure gradients in different directions, which leads to preferential particle-emission directions. This phenomenon is usually called collective anisotropic flow and measurements of this anisotropy provide information on features of the strongly-coupled quark gluon plasma (QGP).

The particle distribution over azimuthal angle can be described by Fourier decomposition [1]:

$$\frac{2\pi}{N}\frac{dN}{d\phi} = 1 + \sum_{n=1}^{\infty} 2v_n \cos[n(\phi - \Psi_n)], \tag{1}$$

where v_n harmonics represent the magnitude of the n-th order azimuthal anisotropy. In large collision systems, this phenomena is rather well understood with viscous hydro models [2]. However, because of the complexity of the system and fluctuations of the initial states, the properties of the medium, like shear viscosity over entropy ratio (η/s), are not fully constrained. Furthermore, v_n coefficients are found to be

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larger than zero in small collision (pp and pPb) systems [3] where one does not expect the creation of the QGP.

In the fall of 2017, the LHC provided collisions with the Xe nuclei. The change in size with respect to Pb case was expected to increase initial state fluctuations [4] as well as viscous effects [5], while the non-spherical shape of the Xe nuclei was expected to increase v_2 in very central collisions [6]. Hence studying XeXe collisions was considered a good chance to improve the understanding of these effects, and to explore the limits of hydrodynamics applicability.

The presented analysis had measured v_2, v_3 and v_4 coefficients of the charged particles from XeXe collisions at $\sqrt{s_{NN}} = 5.44$ TeV. A comparison with the corresponding coefficients from PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV was made.

2. Datasets and analysis details

The XeXe analysis uses data with a total integrated luminosity of 3 μb^{-1}. In addition, around 100 million PbPb events, from the 2015 dataset, have been analysed, for comparison. All data are collected by the CMS detector [7].

Three different techniques are applied to measure azimuthal anisotropy, with different sensitivity to non-flow effects and event-by-event fluctuations.

The Scalar Product technique [8] correlates particles detected in the tracker detector with ones from the hadron forward calorimeter. Coming from two different sub-detectors, correlated particles have a minimal pseudorapidity difference of 3 units ($|\Delta\eta| > 3$), hence short-range correlations are highly suppressed.

The two-particle correlations technique [9, 10] builds correlations from particle pairs in pseudorapidity and azimuthal angle difference ($\Delta\eta$, $\Delta\phi$) with condition that pseudorapidity difference has to be at least two units ($|\Delta\eta| > 2$). The eta gap condition ensures that short-range correlations are avoided. The event-by-event fluctuations make the results averaged over many events, from both scalar product and two-particles correlations, to have lower values if the fluctuations are larger [11].

Unlike previous two methods, for the 4-, 6- and 8-particle cumulants [8] flow fluctuations tend to decrease the measured v_n coefficients [11]. So comparison of results with different techniques can probe the amount of fluctuations. Multi-particle correlations avoid non-flow effects by combining many particles at the same time. Hence if the measured anisotropy is consequence of collectivity one expects $v_n\{4\} \approx v_n\{6\} \approx v_n\{8\}$. A very small deviation from this equality can come from a non-gaussian shape of the flow fluctuations.

The scalar product results correspond to the pseudorapidity range of $|\eta| < 0.8$, while for two- and multi-particle correlations the corresponding range is $|\eta| < 2.4$.

3. Results

Figure 1 shows the v_2 harmonic measured with three different methods as a function of transverse momentum (p_T) in eleven centrality ranges. There is no significant difference between the results from different cumulant order, which suggests that collectivity still holds on this scale. Furthermore, all cumulant results are below two-particle correlation results. This difference is the measure of the event-by-event flow fluctuations. The difference between scalar product and two-particles results can be attributed to the different pseudorapidity range that two techniques use.

The v_2, v_3 and v_4 coefficients from two-particle correlations in XeXe and PbPb collisions, in a form of ratio, as a function of p_T in eleven centrality ranges, are shown in Fig. 2. In most central collisions, all flow harmonics are higher in XeXe than in PbPb collisions. This is the most pronounced for elliptic flow because it is affected by the Xe nuclei shape, unlike higher harmonics. The ratio for v_2 reaches a value of 1.4 for 0-5% centrality range, but then suddenly drops, and for 5-10% centrality is close to one. A similar behaviour is reported from the ALICE experiments [12]. The v_3 and v_4 ratios show a smooth decrease going towards more peripheral events, the ratios of all harmonics eventually falling below unity. This suggests that fluctuations are the main effect in central events, while going to more peripheral events, viscous effects become dominant.

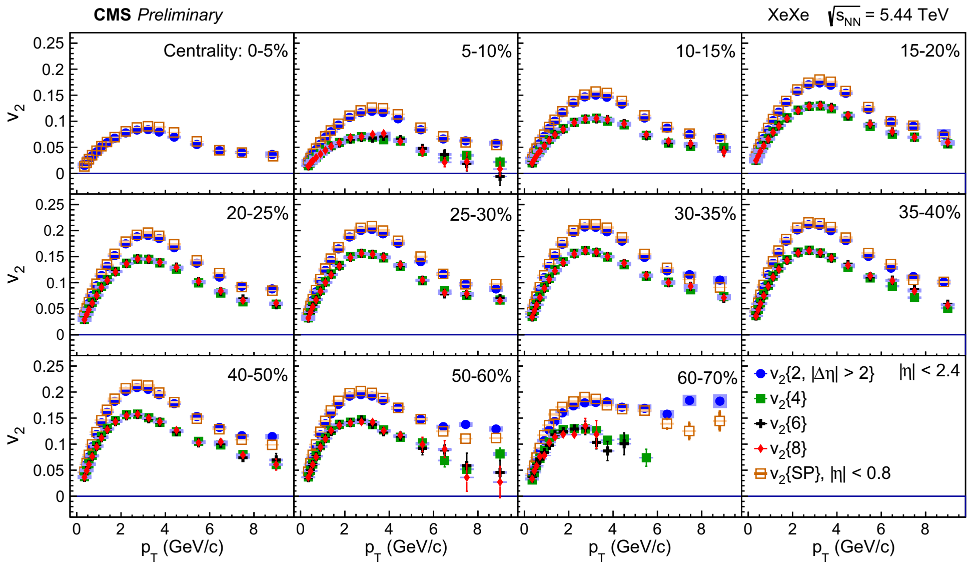

Fig. 1. The v_2 coefficients measured with different analysis techniques as a function of transverse momentum in different centrality ranges [13].

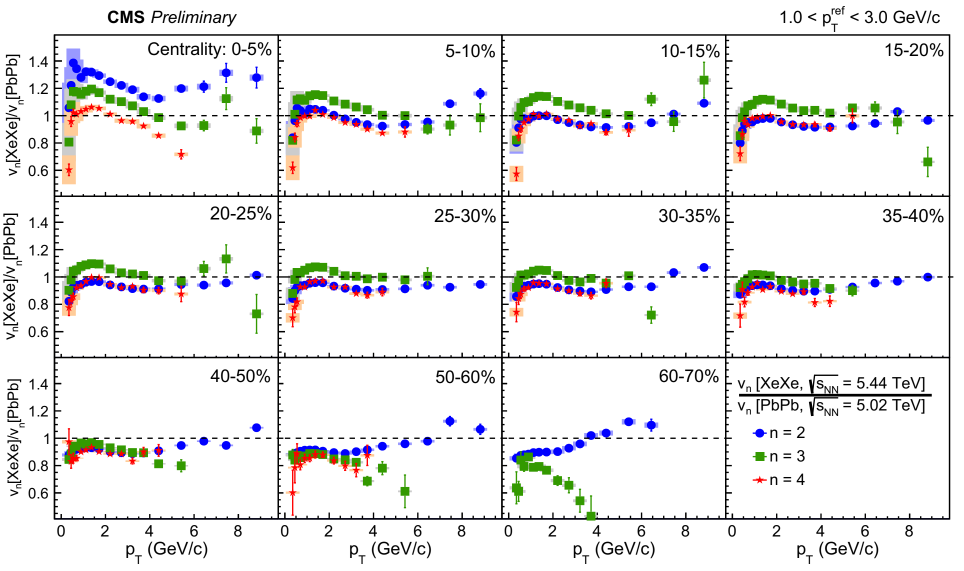

Fig. 2. The ratio of the v_2, v_3 and v_4 flow harmonic from two-particle correlations in XeXe and PbPb as a function of p_T in different centrality range [13].

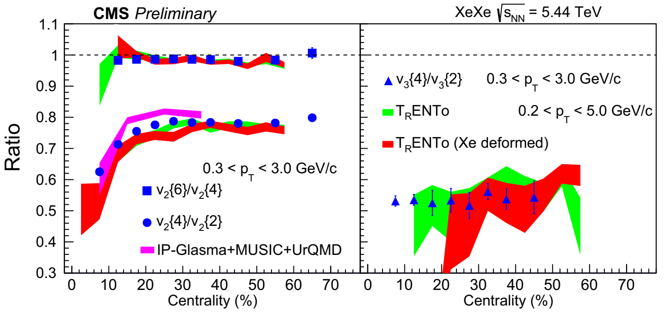

Fig. 3. The ratios $v_2\{6\}/v_2\{4\}$, $v_2\{4\}/v_2\{2\}$ (left panel) and $v_3\{4\}/v_3\{2\}$ (right panel) as a function of centrality [13]. In addition, comparison with IP-Glasma+Music+UrQMD and hydrodynamic model from [6] are shown.

Figure 3 shows the ratio between flow harmonics measured with different techniques, $v_2\{6\}/v_2\{4\}$, $v_2\{4\}/v_2\{2\}$ and $v_3\{4\}/v_3\{2\}$, as a function of centrality, averaged in $0.3 < p_T < 3.0$ GeV/c range. The $v_2\{4\}/v_2\{2\}$ ratio shows strong centrality dependence with a greater influence of fluctuations being in central collisions. On the other hand, $v_2\{6\}/v_2\{4\}$ and $v_3\{4\}/v_3\{2\}$ have a very weak centrality dependence. The $v_2\{6\}/v_2\{4\}$ ratio is slightly below unity, and this suggests non-gaussian corrections to the event-by-event v_2 fluctuations. The data are in good agreement with predictions from IP-Glasma+Music+UrQMD and the hydrodynamic model from [6]. The model shows very similar predictions with and without taking Xe nuclei shape into account, which is expected since this observable measures only flow fluctuations, not flow itself.

4. Summary

The first measurements of collective anisotropic flow in the medium size XeXe system is presented from the CMS collaboration. The results are consistent with the ones observed in large, PbPb collisions, including small non-gaussian corrections to the event-by-event flow fluctuations. The results also show that the value of the v_n coefficients in central collisions is mainly driven by fluctuations of the initial geometry, while in more peripheral events viscous effects take the leading role. Rather good agreement between theoretical models and data shows that hydrodynamical description of the ultra-relativistic heavy nuclear collision is also applicable for the lighter nuclei.

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