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Measurement of the azimuthal anisotropy of charged particles in 5.02 TeV Pb+Pb and 5.44 TeV Xe+Xe collisions with ATLAS

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Abstract

The data collected by the ATLAS experiment during the 2015 Pb+Pb and 2017 Xe+Xe LHC runs offer new opportunities to study charged particle azimuthal anisotropy. The high-statistics Pb+Pb sample allows for a detailed study of the azimuthal anisotropy of produced particles. This should improve the understanding of initial conditions of nuclear collisions, hydrodynamical behavior of quark-gluon plasma and parton energy loss. New ATLAS measurements of differential and global Fourier harmonics of charged particles (v_n) in 5.02 TeV Pb+Pb and 5.44 TeV Xe+Xe collisions in a wide range of transverse momenta, pseudorapidity ($|\eta| < 2.5$) and collision centrality are presented. The higher order harmonics, sensitive to fluctuations in the initial state, are measured up to $n = 7$ using the two-particle correlation, cumulant and scalar product methods. The dynamic properties of QGP are studied using a recently-proposed modified Pearson's correlation coefficient, $\rho(v_n^2, p_{\mathrm{T}})$, between the event-wise mean transverse momentum and the magnitude of the flow vector in 5.02 TeV Pb+Pb and p+Pb collisions. Several important observations are made. The elliptic and triangular flow harmonics show an interesting universal p_{T}-scaling. A linear correlation between the v_2 and v_3 coefficients at low and high p_{T} ranges is observed and quantified. The correlation coefficient for v_2 is found to be negative in peripheral and positive in central Pb+Pb collisions. The value for v_3 is found to be much smaller than for v_2 and have similar centrality behavior as the v_2.

Keywords: heavy-ion, correlations, flow, collectivity, Pb+Pb, Xe+Xe

1. Introduction

In this proceedings a brief summary of the flow measurements performed by the ATLAS [1] experiment at the LHC on Xe+Xe collisions data at $\sqrt{s_{NN}} = 5.44$ TeV is given. Novel results on flow harmonics magnitude and event mean transverse momentum in Pb+Pb data at 5.02 TeV are also presented.

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2. Flow measurements in Pb+Pb and Xe+Xe

With the large dataset of Pb+Pb collisions at 5.02 TeV it is possible to measure the high order harmonics (up to $n = 7$) and up to charged particle $p_T = 25$ GeV [2]. The flow harmonics of charged particles are measured with Scalar-Product (SP) and 2-Particle Correlation (2PC), techniques. The v_n p_T dependence measured in Xe+Xe resembles that the dependence in Pb+Pb collisions, rise up to 3-4 GeV and fall at higher p_T values. The observed magnitude of the anisotropy depends strongly on the harmonics order while weakly on the collision centrality except for the v_2 which exhibits stronger centrality dependence as show in Fig. 1. This behaviour indicates the origin of the flow due to the initial geometry of collision region for v_2 and eccentricity fluctuations for v_n for $n > 2$. The flow harmonics in Xe+Xe collisions are studied using

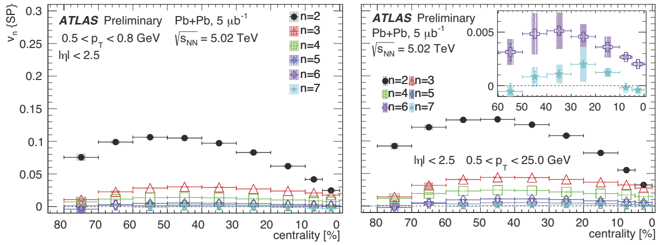

Fig. 1. The flow harmonics, v_n as a function of centrality measured with the SP method in Pb+Pb data at 5.02 TeV [2].

several techniques and compared to the Pb+Pb results. A typical v_n p_T trends were observed for charged hadrons in Xe+Xe. Also the magnitudes of v_n harmonics are comparable. The comparison of the v_n\{SP\} integrated over $p_T = 0.5 - 5$ GeV is shown in Fig. 2. A good agreement was found for v_2 when the

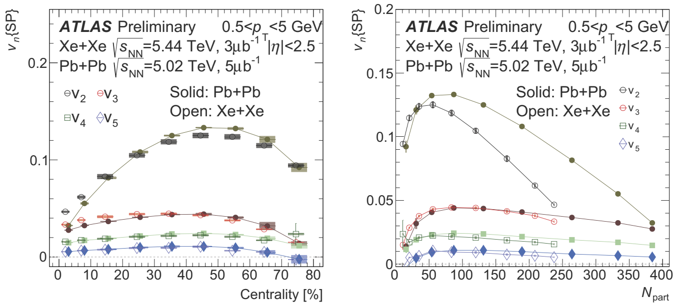

Fig. 2. The flow harmonics, v_n as a function of centrality and number of participants, N_{part}, measured with the SP method in Xe+Xe data at 5.44 TeV compared to Pb+Pb at 5.02 TeV [3].

comparison is made with the same collision centralities indicating that the v_2 is related to initial asymmetry of the collision zone. A small increase of the v_n value in the most central events are attributed to the Xe nuclei shape, while reduced values in peripheral events arise from the nuclear skin effect and hydrodynamic response in a smaler QGP volume [4].

When a similar values of N_{part} are used for comparisons an evident disagreement of v_2 is observed. This suggests that the magnitude of the fluctuations that is similar for similar N_{part} is not the dominant source of the observed v_2. For higher harmonics the comparison of the v_n magnitudes themselves are not sufficient to disentangle the v_n origin. Therefore the multi-particle cumulants, the c_4 in particular, are measured and compared as a function of centrality and N_{part}. This comparison is shown in Fig. 3. The agreement between the c_4 values is observed in similar N_{part} bins while the trends are different for centrality binning. This result indicates that the origin of the higher order flow harmonics is related to the fluctuations in the initial state, that are related to the nucleons participating in the collisions (N_{part}), acting as source of these fluctuations.

3. $v_n - p_T$ correlations

It is important to characterise the properties of QGP evolution by many independent variables. Among those of special interest are various correlations that were studied earlier [5, 6]. An additional correlation

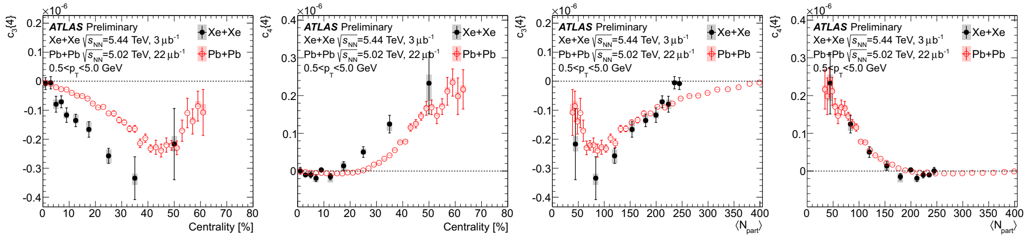

Fig. 3. The 4-particle cumulant, $c_n\{4\}$ as a function centrality (two left panels) and number of collision participants, N_{part}, (two right panels) in Xe+Xe data at 5.44 TeV compared to Pb+Pb at 5.02 TeV [3].

between the v_n and mean-p_{T}, $[p_{\text{T}}]$ in the event [7], is added to the set of measurements that can be used to validate initial stage and QGP evolution models. The correlation relates the magnitude of the v_n measured in one detetor region with the fluctuation of the event mean-p_{T} in another pseudorapidity range. The detector regions are chosen so that a pseudorapidity gap is assured and thus the short-range correlation suppressed. The correlation coefficient ρ is defined as:

$$\rho(v_n^2\{2\},[p_{\text{T}}]) = \frac{cov(v_n\{2\},[p_{\text{T}}])}{\sqrt{var(v_n^2)_{dyn}}\sqrt{c_k}}$$

where the cov is the covariance, the $var(v_n^2)_{dyn}$ is dynamical variance of $v_n\{2\}$ equal to $v_n\{2\}^4 - v_n\{4\}^4$ and c_k is a measure of $[p_{\text{T}}]$ fluctuation. Such redefined correlation coefficient estimates well the Pearson's correlation coefficient, irrespectively of the observed multiplicity and thus provides for an experiment independent measurement [7]. The event is split into 3 sub-events, sub-event of $|\eta| < 0.5$ in which the $[p_{\text{T}}]$ is estimated and sub-events of $|\eta| > 0.75$ from which the v_n is estimated by correlating charged particle tracks from opposite hemispheres, thus further reducing short range correlation impact on the measured flow harmonics. Four p_{T} ranges 0.5-2, 0.5-5, 1-2, 2-5 GeV are considered in order to study the ρ in the p_{T} region well described by QGP hydrodynamics as well as in the region with a significant jets contribution.

As an example figure 4 shows covariance, dynamical variance for the second harmonics and the c_k as a function of charged particle multiplicity. A significant variation of all quantities is observed and the covari-

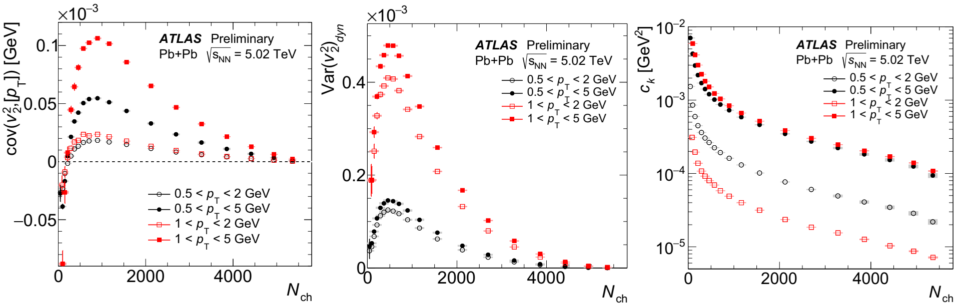

Fig. 4. The covariance, cov($v_2\{2\}$, $[p_{\text{T}}]$), dynamical variance Var$(v_2^2)_{dyn}$ and the c_k as a function of charged particle of $0.5 < p_{\text{T}} < 5$ GeV multiplicity [8].

ance becomes negative in peripheral collisions. A non-trivial p_{T} range dependence is also observed [8].

Figure 5 shows centrality dependence of the correlation coefficient for $n = 2-4$. A non-negligible values of correlation are observed for all harmonics and all centralities except for the v_2 in peripheral events where the dependence changes the sign. The most pronounced centrality dependence is observed for v_2 while for v_3 and v_4 the dependence is weaker. Figure 6 shows ρ comparison to the model predictions for v_2 [7]. A good agreement is observed for particles of $0.5 < p_{\text{T}} < 2$ GeV indicating applicability of the hydrodynamical system evolution modeling.

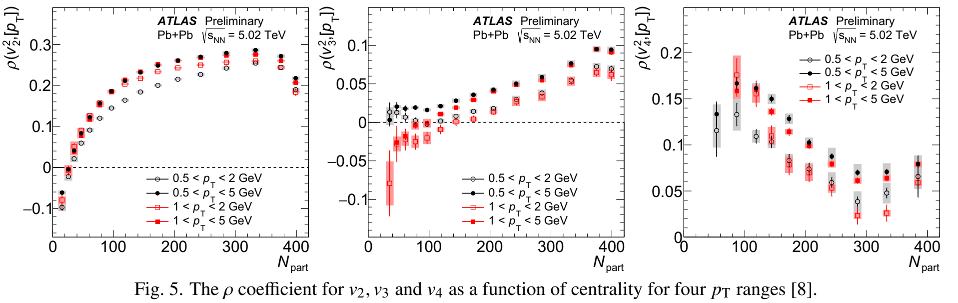

Fig. 5. The ρ coefficient for v_2, v_3 and v_4 as a function of centrality for four p_T ranges [8].

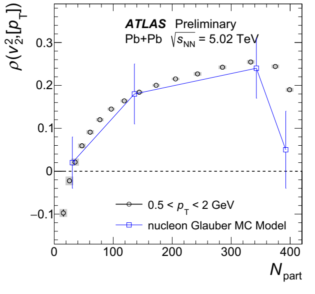

Fig. 6. The comparison of the $\rho(v_2^2, [p_T])$ coefficient measured using particles of $0.5 < p_T < 2$ GeV obtained from the hydrodynamical modeling [7] and the experimental results [8].

4. Summary

Using different collisions system data, the ATLAS experiment at the LHC advances studies of QGP by measuring the flow harmonics. Measurements in Xe+Xe collisions are compared to Pb+Pb results as function of centrality and number of collision participants which allows to relate observed harmonics to either initial geometry, v_2, or geometry fluctuations for higher order harmonics. The measurement of correlations of transverse momenta and flow harmonics adds an orthogonal quantity to the spectrum of rich ATLAS flow results. Strong correlations are observed for all studied harmonics. This new $v_n - p_T$ correlation can be used to test QGP evolution models. A comparison to the hydrodynamical predictions shows a good agreement.

5. Acknowledgements

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