Measurements of Elliptic Flow with the ATLAS Detector

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Abstract

The measurement of the azimuthal anisotropy of charged particles obtained with the multi-particle correlations method is presented and compared to the results obtained with the event plane method for Pb+Pb collisions at 2.76 TeV from the ATLAS experiment. Results on flow harmonics, determined from the cumulants of particle correlations, over wide transverse momenta ($0.5<p_T<20$ GeV), pseudorapidity ($|\eta|<2.5$) and centrality ranges are shown. The applied cumulant approach provides a unique handle on non-flow effects and allows for the evaluation of the genuine flow fluctuations. Derived estimates of the non-flow correlations and the magnitude of flow fluctuations are discussed. Centrality and pseudorapidity dependence of the elliptic flow measured with the event-plane method and integrated down to very low p_T is also shown and compared to the results obtained by the other LHC experiments.

1. Introduction

The collective flow of particles produced in heavy-ion collisions, which manifests itself in a significant anisotropy in the plane perpendicular to the beam direction, has been extensively studied due to its sensitivity to the early system properties and its subsequent dynamical evolution [1]. The final-state anisotropy arises due to the initial spatial asymmetry of the overlap zone in the collision of two nuclei with a non-zero impact parameter. The initial spatial asymmetry is converted into a final state momentum anisotropy via multiple rescattering processes. The final-state anisotropy is customarily characterized by coefficients, v_n, of the Fourier decomposition of the azimuthal angle distribution of produced particles [2, 3]. The second Fourier coefficient, v_2, is called elliptic flow and is related to the elliptical shape of the overlap region in non-central heavy-ion collisions while the higher flow harmonics reflect fluctuations in the initial collision geometry and, in addition, may provide information on the ratio of shear viscosity to the entropy density [4].

2. Integrated flow measurement using the event-plane method

The application of the event-plane method [5] in the ATLAS experiment [6] begins from the measurement of the event-plane angles using Forward Calorimeters ($3.2< |\eta| <4.8$). To estimate v_n, the azimuthal angles of tracks measured in the inner detector ($|\eta| <2.5$), are correlated with

[1] A list of members of the ATLAS Collaboration and acknowledgements can be found at the end of this issue.

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the event-plane angle of the opposite hemisphere (3.2 units of pseudorapidity gap) to reduce non-flow contributions [7]. The integrated flow signal is obtained by summing v_n weighted by a number of charged particles in narrow bins of p_T and η. The charged particle multiplicities are corrected for track reconstruction inefficiencies and background track rates.

At very high p_T (above 5 GeV) and very low p_T (below 100 MeV) the charged particle multiplicity is very low and these regions do not contribute significantly to the integral. Moreover v_2 at very low p_T linearly approaches zero. The high p_T region poses no experimental difficulty,

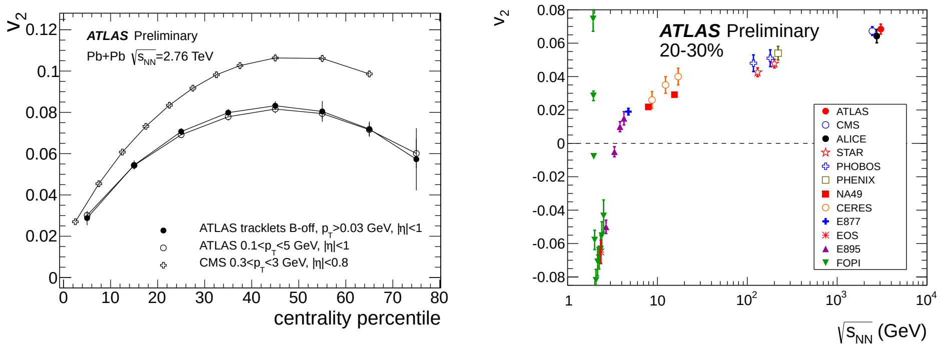

Figure 1: (color online) On the left, centrality dependence of v_2 measured for $|\eta| < 1$ and integrated over transverse momenta $p_T > 0.03$ GeV for the tracklet method (full circles) and over $0.1 < p_T < 5$ GeV for the pixel track method [8] (open circles). Also shown are results of CMS v_2 measurements using the event plane method and integrated over $0.3 < p_T < 5$ GeV [9] (open crosses). Error bars show statistical and systematic uncertainties added in quadrature. On the right, elliptic flow dependence on $\sqrt{s_{NN}}$, for 20-30% centrality bin, including ATLAS, ALICE and CMS as well as experiments at lower center-of-mass energy as denoted in the figure. The LHC points are slightly shifted in $\sqrt{s_{NN}}$ for clarity.

however, to reach reliably very low track p_T three track reconstruction techniques are used. In the short period of 2010 Pb+Pb run the solenoidal magnetic field was disabled during data taking which allowed to detect tracks down to 30 MeV. In this data sample the simplified model of straight tracks, the so called Pixel tracklets is used [10]. The cross-check measurement is performed using data with the solenoidal field on and tracks reconstructed using only Pixels, the innermost ATLAS tracking detector. With this method tracks of p_T as low as 100 MeV can be reconstructed with a good efficiency. Due to the aforementioned drop of charged particles spectra at low p_T the two methods are expected to give comparable results and Figure 1 shows that this is indeed observed. A further cross-check is performed with the tracks built from hits from all three ATLAS tracking detectors (ID tracks). The results are found to agree within uncertainties.

The results of the ATLAS measurement [8] are shown in Figure 1 together with the comparison to the results from CMS [9] clearly pointing out sensitivity of the integrated v_2 to the low-p_T part of the spectra. The Figure 1 (right) also shows the evolution of the integrated v_2 as a function of center-of-mass energy, over a broad range of energies. Measurements from all three LHC experiments agree within uncertainties.

3. Elliptic flow measurements with cumulants

The multiparticle correlation method to measure flow harmonics provides a possibility to study elliptic flow fluctuations which can be related to the fluctuations in the initial geometry of the interaction region [11, 12, 13]. In order to get a handle on the non-flow contributions or flow fluctuations the cumulants method was introduced [14, 15].

The commonly used notation $v_n\{2k\}$ denotes the n-th harmonic derived using $2k$-particle correlations. It has to be noticed that in the cumulant expansion of the $2k$-particle, correlations between fewer than $2k$ particles are eliminated thus reducing the non-flow contributions usually involving a small number of particles. For instance, assuming the non-flow contribution is only due to the two-particle correlations, they are eliminated in 4-particle cumulants and $v_n\{4\}$ directly measures flow harmonics. The computational difficulty of calculating many-particle correlation functions in events with thousands of particles produced in central heavy-ion collisions, is overcome by the application of the generating functions [16].

The elliptic flow, $v_2\{2\}$ and $v_2\{4\}$, has been measured by the ATLAS experiment [17] using ID tracks with $p_T > 500$ MeV and $|\eta| < 2.5$. Figure 2 shows $v_2\{2\}$ and $v_2\{4\}$ in one centrality bin together with a comparison to the ALICE [18] and CMS [9] results. An agreement between the three experiments is found for $v_2\{2\}$ and $v_2\{4\}$ (left and right plot respectively), while v_2 coefficients obtained from 2- and 4-particle cumulants and event-plane methods are discrepant due to non-flow contributions and flow fluctuations (middle plot). Measurements of

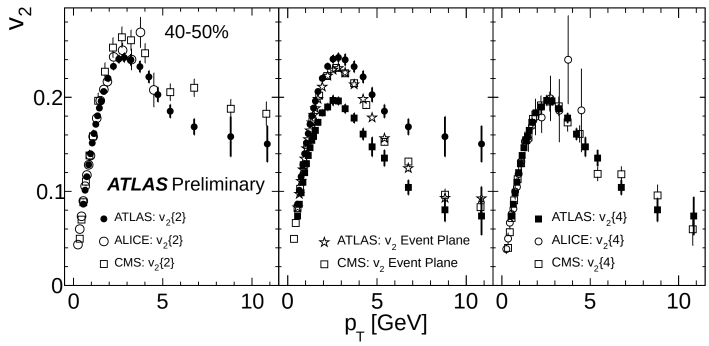

Figure 2: The comparison of the ATLAS [17], CMS [9] and ALICE [18] measurements of v_2 with different methods for the centrality bin 40–50% at mid-rapidity. The $v_2\{2\}$ ($v_2\{4\}$) results are shown in the left (right) panel. The middle plot shows the comparison of the CMS and ATLAS measurements of v_2 of the event plane method with the ATLAS $v_2\{2\}$ and $v_2\{4\}$. Error bars denote statistical and systematic errors added in quadrature.

the elliptic flow dynamic fluctuations have attracted a lot of interest, since flow fluctuations can be traced back to fluctuations of the initial collision zone. Experimentally, flow fluctuations are difficult to measure due to unavoidable contaminations by non-flow effects. The reported elliptic flow fluctuation measurements from RHIC [11, 12, 13] are affected by non-flow correlations, despite the attempts made to estimate their contribution. Using the formula $\sigma_{v_2}/{<}v_2{>} \;=\; \sqrt{(v_2\{2\}^2 - v_2\{4\}^2)\,/\,(v_2\{2\}^2 + v_2\{4\}^2)}$, one can estimate the relative elliptic flow fluctuations with measurements of multi-particle cumulants [19]. This estimate should be considered as an upper limit on the flow fluctuations since the above equation is only valid under the assumption that non-flow correlations and flow fluctuations are small compared to v_2. It should be noted that this estimate includes $v_2\{2\}$, which as shown before, has a sizable contribution from non-flow correlations. Figure 3 shows the relative v_2 fluctuations as a function of transverse momentum in different centrality bins. Interestingly, for the most central collisions, $\sigma_{v_2}/{<}v_2{>}$ does not depend on p_T. The comparison to the theory predictions [20] (right plot in Figure 3), shows a good agreement with the data over broad range in centrality.

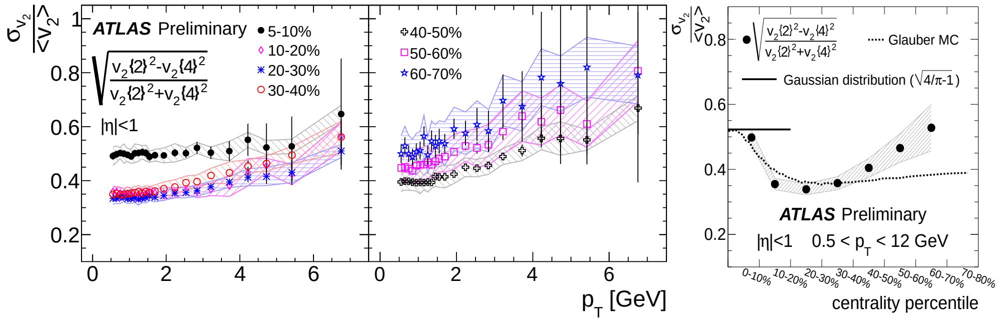

Figure 3: (color online) On the left, the transverse momentum dependence of the relative elliptic flow fluctuations for central collisions (left panel) and peripheral collisions (right panel) [17]. The systematic uncertainties are shown as hatched bands. On the right, the centrality dependence of $\sigma_{v_2}/\langle v_2 \rangle$ for the p_T-integrated elliptic flow compared to the predictions from [20] (dotted line). The solid line represents the relative fluctuations for the Gaussian distribution.

4. Summary

The ATLAS collaboration has applied the event-plane method to measure elliptic flow integrated over the p_T range covering the entire spectra and indicating sensitivity to the low p_T part of the charged particle spectrum. Elliptic flow has been also measured with the cumulant method and the agreement is found with the other LHC experiments. The upper limit on the v_2 fluctuations is assessed and found to be p_T-independent in the most central collisions and to scale with p_T in less central collisions.

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