

Recent flow and correlation measurements from ATLAS in Pb+Pb collisions

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Abstract. This proceeding reports on the ATLAS measurement of v_2 and v_3 flow coefficients for charged particles produced in Pb+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV collected with the ATLAS detector at the LHC. The v_2 and v_3 are obtained for high p_T , 1–400 GeV/c and in the centrality range 0–60%. Two methods, the scalar product and multi-particle cumulants, were used to probe the sensitivity to event-by-event fluctuations and non-flow effects. Positive values of v_2 and v_3 are observed up to a $p_T \approx 100$ GeV/c and 25 GeV/c respectively. As jets are the primary source of high p_T particles, the measurement is sensitive to jets' interaction with QGP and in particular to the jets' QGP path-dependent energy loss.

1 Introduction

High- p_T particles in Pb+Pb collisions mainly result from the hadronisation of hard-scattered partons, that is jets. As these jets traverse the quark-gluon plasma (QGP), they lose energy through interactions with the medium. This energy loss is dependent on the path length that the jet travels within the plasma and is expected to introduce a direction-dependent suppression of jet yields. Therefore, the anisotropies observed in the distribution of high- p_T charged particles carry information about the path-length dependence of this energy loss and thus provide valuable insight into the microscopic structure and behavior of the QGP. The analysis reported here and detailed in Ref. [1] uses two main techniques to extract the anisotropy coefficients: the scalar product (SP) method [2] and the multi-particle cumulants (MPC) method [3]. Both techniques are designed to reduce contamination from non-flow effects, such as resonance decays or back-to-back jets, which are not related to the collective behavior of the medium.

2 Experimental setup and data

The analysis is based on Pb+Pb collision data collected in 2018 by the ATLAS detector [4]. The centrality of each event, which corresponds to the degree of overlap between the colliding nuclei, is determined using the total transverse energy measured in the forward calorimeters. Events are grouped into centrality intervals ranging from the most central (0–5%) to more peripheral (up to 50–60%). Charged-particle tracks are reconstructed using hits in the inner detector. Several criteria are applied to ensure track quality, including requirements on the

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number of hits and the proximity of the track to the primary vertex. These tracks are corrected for detector inefficiencies and acceptance variations using Monte Carlo simulations, which simulate Pb+Pb events and the detector response. The reconstruction efficiency is dependent on centrality, η , and p_T , and reaches a plateau of about 80% for p_T greater than 20 GeV/c. Fake tracks, i.e., tracks not matched to a true generated particle, are found to be negligible after the selection cuts.

The SP method correlates individual particle flow vectors with reference flow vectors obtained from the forward calorimeters. A large pseudorapidity gap between the two helps suppress non-flow correlations.

On the other hand, the MPC method uses genuine multi-particle correlations to isolate collective flow effects. In particular, a three-subevent version of the MPC method is employed, which divides the detector into three separate η regions and only forms correlations among particles from different sub-events. This method is especially effective at minimizing contributions from short-range non-flow effects, which are more likely to occur among particles that are close in η . Both reference and p_T -differential flow coefficients are calculated using these methods, and an impact of various centrality binning procedures on the results tested.

3 Results

The measurements of second (v_2) and third (v_3) order flow harmonics using SP method as functions of transverse momentum and centrality shown in Figure 1 reveal several important patterns. The v_2 rises quickly to a peak around 3–4 GeV/c and then gradually decreases with increasing p_T , but remains non-zero even at very high $p_T \simeq 100$ GeV/c. This trend is consistent with the expectation that a path-length-dependent energy loss in the QGP introduces an azimuthal anisotropy in the distribution of high- p_T particles. The persistence of v_2 at high p_T supports the interpretation that jets lose more energy when traveling in the long axis of the medium. The triangular flow coefficient v_3 , while smaller than v_2 , is also found to be positive up to p_T values around 25 GeV/c in most centrality intervals. However, in the most peripheral collisions, v_3 tends to become negative or statistically consistent with zero at high p_T . The v_3 signal is more sensitive to initial-state fluctuations and is thus more affected by statistical noise and non-flow effects, particularly in peripheral collisions where the QGP volume is smaller. The use of the three-subevent cumulant technique shows that v_3 is notably reduced at high p_T when compared to standard two-particle methods, indicating that non-flow effects contribute significantly to the observed signal in that regime.

The analysis also investigates the dependence of the results on the pseudorapidity range used for the charged particles. Figure 2 shows a comparison of v_n {SP} for different η ranges. The measurements using a larger η gap between the particles and the reference region yield slightly smaller v_n values, particularly at low p_T . This is attributed to the suppression of non-flow effects and the increased influence of longitudinal decorrelation—an effect where the flow vector orientation varies with η . The v_n values measured in this study are found to be in good agreement with previous ATLAS [5] and CMS results [6] from earlier LHC runs. Furthermore, comparisons with v_n measurements from fully reconstructed jets show similar trends, strengthening the interpretation that high- p_T charged particles reflect the same underlying path-length-dependent energy loss mechanisms as jets. Such a comparison is shown in Figure 3.

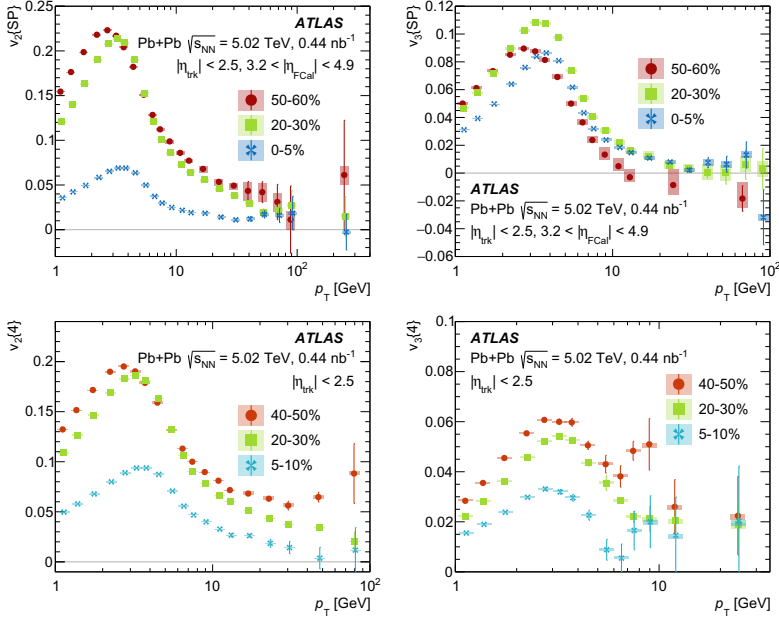


Figure 1. The v_2 and v_3 obtained with SP (top row) and 4-particle cumulants (bottom) methods as a function of charged-particle p_T for three centrality intervals [1].

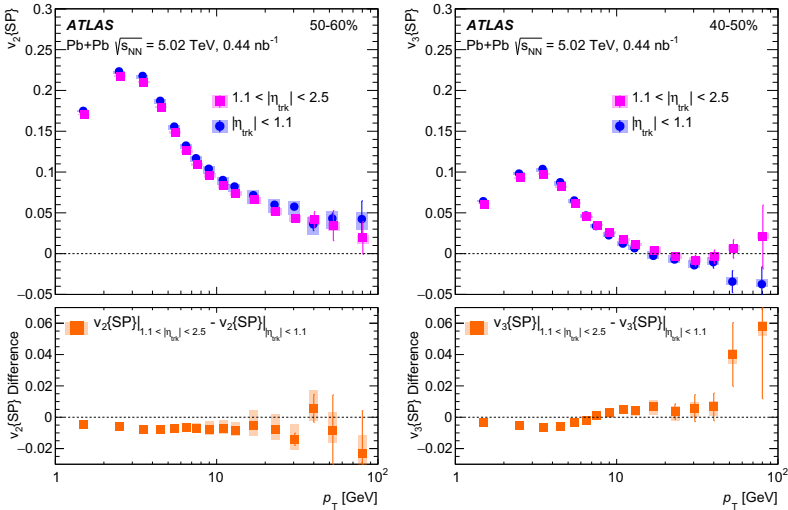


Figure 2. The comparison of v_2 (left panel) and v_3 (right panel) obtained with the SP and different pseudorapidity gaps as a function of charged-particle p_T [1].

4 Conclusions

The results presented in this proceedings are the most detailed measurements of azimuthal anisotropies of charged particles at highest p_T in Pb+Pb collisions. The observation that

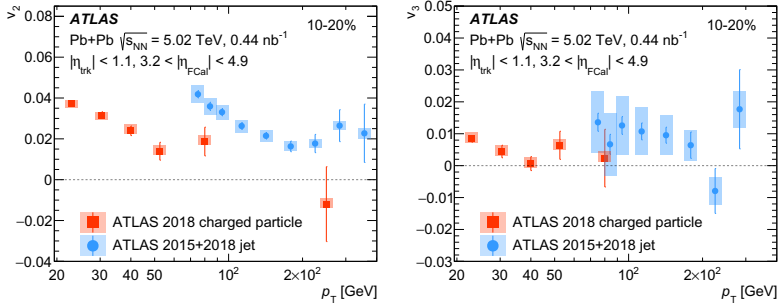


Figure 3. The comparison of v_2 (left panel) and v_3 (right panel) obtained with the SP method using charged particles and inclusive jets as a function of charged-particle or jet p_T for semi central collisions [1].

v_2 remains positive up to p_T at least 100 GeV/c across all centrality intervals provides strong evidence for the path-length dependence of parton energy loss in the QGP. This effect persists even in the high- p_T regime where particle production is dominated by jet fragmentation, indicating that even energetic partons are sensitive to the geometry of the medium. The measurements of v_3 confirm the presence of collective triangular flow up to intermediate p_T and highlight the importance of advanced techniques such as the three-subevent cumulants to suppress non-flow contributions.

The comparison between different analysis methods and η ranges helps to validate the robustness of the results and provides insight into the role of non-flow and decorrelation effects. These results also offer critical benchmarks for theoretical models of jet quenching and hydrodynamic evolution, which must now reproduce not only the magnitude but also the p_T and centrality dependence of the observed anisotropies.

Looking ahead, future studies may extend these methods to smaller collision systems such as p+Pb or O+O collisions, where signs of collectivity have also been observed or are anticipated. The techniques developed here can also be used to explore correlations between different flow harmonics, study event-by-event fluctuations, and further characterize the jet-medium interaction. Together, these measurements deepen our understanding of the QGP and the fundamental dynamics of strong interactions at high energy.

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