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Measurements of v_n at high p_T and correlation between v_n and mean p_T in p+Pb collisions with the ATLAS detector

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This report presents ATLAS measurements of the azimuthal anisotropy for charged particles in 8.16 TeV p+Pb collisions up to a p_T of 50 GeV. The measurements are performed via the two-particle correlation method and the statistics are enhanced at high p_T by selecting events triggered by a high p_T jet. Restrictions on other particles are imposed to suppress the contribution from jets. Measurements of the resulting second- and third-order flow coefficients are presented in intervals of p+Pb event activity classes. The results from jet-triggered events are compared to those from minimum-bias p+Pb events, and the differences between the two event samples are analysed in terms of the different origin of particles in these events, such as the different fraction of particles that arise from the jet fragmentation process. In Pb+Pb collisions non-zero flow coefficients at high p_T are understood to arise from the path-length dependent energy loss of jets. Thus, these measurements in p+Pb collisions can provide information on the origin of these collective phenomena. To further assess properties of the azimuthal anisotropy in p+Pb collisions, the correlation between the mean transverse momentum and the magnitudes of the flow harmonics is also measured. The measurements are performed in 5.02 TeV p+Pb collisions for several intervals of the charged particle transverse momentum and as a function of the event multiplicity. The measured correlations are compared to similar measurements in Pb+Pb collisions.

HardProbes2020
1-6 June 2020
Austin, Texas

[1]On behalf of the ATLAS Collaboration
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PoS(HardProbes2020)103

1. Azimuthal correlations at high p_T in p+Pb collisions

The low-p_T behaviour of the flow signal in p+Pb collisions is confirmed to be produced by hydrodynamical evolution of the Quark Gluon Plasma (QGP). The medium impact on charged particle of higher p_T is not yet understood or precisely measured. In collisions of large ions such as Pb+Pb the modification is due to the jet energy loss that is sensitive to an average path in the QGP. The same is therefore expected in p+Pb. However no spectra modification at high charged particle p_T nor jet-quenching have been observed yet. For that reason the ATLAS experiment [1] embarked on the precise measurement of v_2 and v_3 at high p_T [2] in p+Pb collisions at $\sqrt{s_{NN}} = 8.16$ TeV. The events were triggered with either the minimum-bias trigger requiring only the presence of charged particles or at high charged particle p_T the trigger selection was enhanced with events with 75 or 100 GeV jets. The two-particle correlations method with the non-flow subtraction using peripheral collisions [3] is further used to extract flow harmonics as a function of p_T and collision centrality. In the inclusive analysis in order to suppress the non-flow effect, the trigger and associated particles forming the correlation function are required to be separated by the rapidity gap of $\Delta\eta > 2$. In the analysis of events triggered with a jet, the associated particles are required to be away by $\Delta\eta > 1$ from any jet of $p_T > 15$ GeV. This approach results in reduced statistics however it improves signal extraction due to better convergence of the harmonic fits. The evolution of v_n with the charged particle momenta is shown in Figure 1. At low p_T the evolution resembles the raise symptomatic for the hydrodynamic evolution. At high p_T the values of v_n decrease, however they never become zero as in Pb+Pb collisions. Predictions involving jet energy loss are able to describe the data qualitatively [4]. The splitting in the mid-p_T range is a result of a different admixture of the particles from hard and soft sources. The extraction of v_3 is not yet possible at high p_T due to insufficient statistics.

Figure 2 shows the evolution of v_n with collision centrality in three p_T intervals. At low and high p_T the observed v_2 is nearly independent of centrality and method of the event selection (inclusive or jet triggered). For $2 < p_T < 9$ GeV a more significant trend is observed as well as dependence on the event selection. The effect is found to arise from the change in the admixture of particles from the hard scatter and soft underlying event. It happens that at low p_T the particles from the underlying event are mostly used in the correlation function, while in a smooth transition the particles from the hard scatter and soft underlying event dominate the correlation at high p_T.

2. Correlation of v_n and mean p_T

The ATLAS experiment measured correlation between the average momentum of charged particles $[p_T]$ and the magnitude of flow harmonics, v_n [5] quantified by the modified Pearsons coefficient. The measurement is performed in Pb+Pb and p+Pb collisions at centre-of-mass energy per nucleon pair of 5.02 TeV. For comparison between Pb+Pb and p+Pb the measurement is performed in event activity classes that are defined by charged particle multiplicity, N_{ch}, with $0.5 < p_T < 5$ GeV and $|\eta| < 2.5$. The Pearsons coefficient depends on the event multiplicity that in turn is a function of detector performance and selection of the kinematic region. A modified variant of it, ρ, that is independent on the particle multiplicity [6], is used thus allowing for comparisons

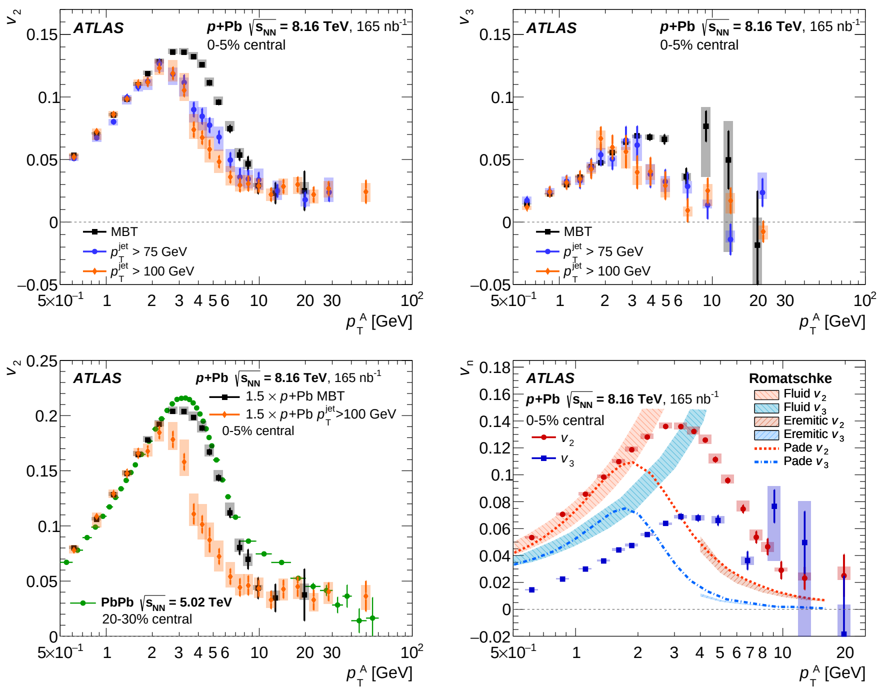

Figure 1: The evolution of v_2 (top left) and v_3 (top right) with the trigger particle $p_{\mathrm{T}}^{\mathrm{A}}$ in p+Pb collisions [2]. (bottom left) Comparison of scaled v_2 obtained in Pb+Pb collisions. (bottom right) Comparison of measured v_n with models featuring the hydrodynamical evolution at low values of charged particle $p_{\mathrm{T}}^{\mathrm{A}}$ and 'eremitic' model [4] at high $p_{\mathrm{T}}^{\mathrm{A}}$. Lines are Pade fits to these models [2].

across experiments and to the theory predictions. It is defined as:

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

where the covariance, dynamical variance $var(v_n\{2\}^2)_{dyn}$ and c_k are averages over events as denoted by $\langle\rangle$, and are defined as:

$$cov(v_n\{2\}^2, [p_{\mathrm{T}}]) = \left\langle \frac{1}{N_{\mathrm{pairs}}} \sum_{k,j} \mathrm{e}^{in\phi_k - in\phi_j} ([p_{\mathrm{T}}] - \langle [p_{\mathrm{T}}] \rangle) \right\rangle$$

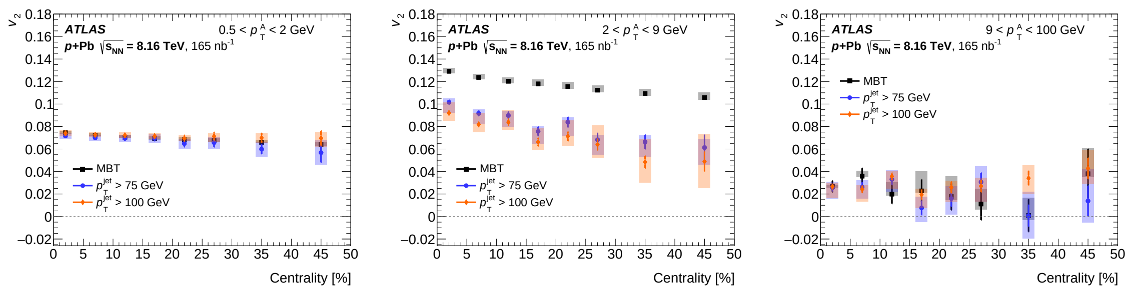

Figure 2: The evolution of v_2 with the collision centrality in p_{T} intervals [2].

$$var(v_n\{2\}^2)_{dyn} = v_n\{2\}^4 - v_n\{4\}^4 = \langle \mathrm{corr}_n\{4\}\rangle - \langle \mathrm{corr}_n\{2\}\rangle^2$$
$$c_k = 1/N_{\mathrm{pairs}}\left\langle \sum_i \sum_{j\neq i} (p_{\mathrm{T},i} - \langle[p_{\mathrm{T}}]\rangle)(p_{\mathrm{T},j} - \langle[p_{\mathrm{T}}]\rangle)\right\rangle$$

where N_{pairs} is the number of particle pairs and ϕ is the particle azimuthal angle. In the calculation of $var(v_n\{2\}^2)_{dyn}$, particles from opposite forward ($\eta > 0.75$) and backward ($\eta < -0.75$) sides of the detector are used to remove the non-flow effects. The $[p_{\mathrm{T}}]$ is obtained using particles within $|\eta| < 0.5$. In the calculation of the covariance the central and forward regions are combined to ensure suppression of short-range correlations. The measurements are performed for three intervals of p_{T} to probe different regions of spectra: $0.3 < p_{\mathrm{T}} < 2$ GeV which is well described by hydrodynamics, $0.3 < p_{\mathrm{T}} < 5$ GeV to observe an impact of the energy loss on ρ and the region with the increased lower threshold from 0.3 to 0.5 GeV to test sensitivity to significant change in multiplicity. The $0.5 < p_{\mathrm{T}} < 2$ GeV is also used in the Pb+Pb measurement to facilitate the direct comparison.

The covariance, dynamical variance for v_2 and c_k for p+Pb collisions are shown in Figure 3. Except for c_k a weak multiplicity dependence is observed for the ingredients of ρ. A nontrivial

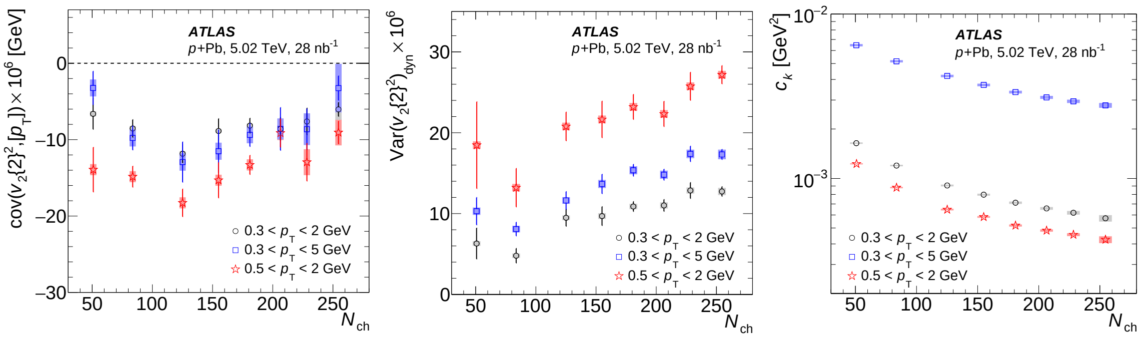

Figure 3: The covariance, $cov(v_2\{2\}^2, [p_{\mathrm{T}}])$ (left), dynamical variance, $var(v_2\{2\}^2)_{dyn}$ (centre), and c_k (right) in p+Pb collisions as a function of the charged particles multiplicity N_{ch} [5].

ordering for various p_{T} intervals can be observed. The coefficient ρ is shown in the left panel of Figure 4 for the p+Pb system. A negative correlation, independently of the p_{T} interval, roughly independent of the N_{ch} is observed. Overall the correlation is similar to those in Pb+Pb collisions shown in the right panel of the same figure. However with growing N_{ch} a strong geometric component induces a positive correlation in case of the Pb+Pb collisions. It was thought that the ρ would reveal the interplay between the initial stage and the medium evolution in the heavy-ion collisions. However recently it has been found through detailed simulations that it is mostly sensitive to the initial conditions, and hydrodynamic evolution parameters play a marginal role in the observed values [7, 8]. It is expected that the same is the case for p+Pb collisions and strong dependence of ρ on the system size would make this quantity a useful tool to constrain the initial conditions in the small systems.

3. Summary

The phenomena in the small collision systems are a field of active studies in relativistic heavy-ion collisions. The picture inherited from the collision of large ions with a well established role

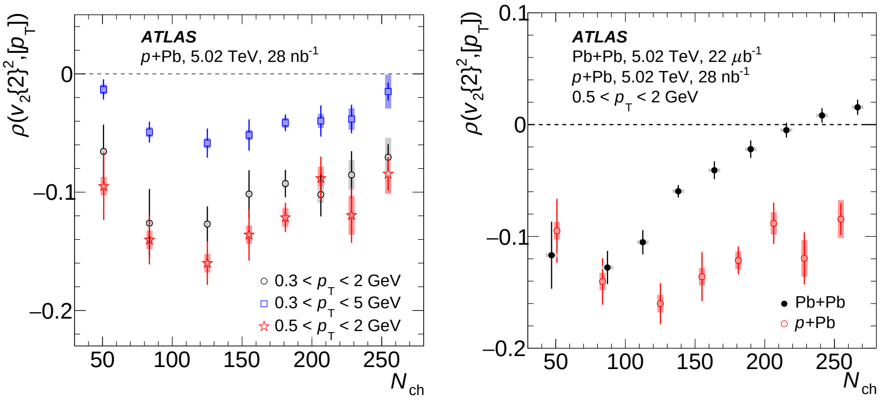

Figure 4: The $\rho(v_3\{2\}^2, [p_\mathrm{T}])$ coefficient in p+Pb collisions as a function of multiplicity for three p_T intervals (left), the comparison to the correlation in Pb+Pb in the same multiplicity range (centre) and the comparison of c_k for the collision systems (right) [5].

of the QGP is used to explain observed data in p+Pb or even pp collisions with success. The presence of long range azimuthal correlations is well established experimentally. The reported ATLAS measurement confirms a similarity in a more sophisticated probe that is the correlation of the radial ($[p_\mathrm{T}]$) and elliptic (v_2) flow. On the other hand the landmark QGP effects like jet quenching or spectra modification at high p_T are not observed in p+Pb collisions. However, ATLAS measurements presented here of non-zero elliptic flow at high p_T that is linked with jet quenching may contribute to the solution of this puzzle.

This work was partly supported by the National Science Centre of Poland under grant number UMO-2016/23/B/ST2/01409, by the AGH UST statutory task No. 11.11.220.01/4 within subsidy of the Ministry of Science and Higher Education and by PL-GRID infrastructure.

References

[1] ATLAS Collaboration, JINST 3 (2008) S08003
[2] ATLAS Collaboration, Eur. Phys. J. C 80 (2020), 73 arXiv:1910.13978[nucl-ex]
[3] ATLAS Collaboration, Phys. Rev. C 96 (2017), 024908 arXiv:1609.06213[nucl-ex]
[4] P. Romatschke and U. Romatschke, arXiv:1712.05815[nucl-th]
[5] ATLAS Collaboration, Eur. Phys. J. C 79 (2019) 985 arXiv:1907.05176 [nucl-ex]
[6] P. Bozek, Phys. Rev. C 93 (2016) 044908. arXiv:1601.04513 [nucl-th]
[7] B. Schenke, C. Shen and D. Teaney, arXiv:2004.00690 [nucl-th]
[8] G. Giacalone, F. G. Gardim, J. Noronha-Hostler and J.-Y. Ollitrault, arXiv:2004.01765 [nucl-th]