

Measurements of multi-particle correlations and collective flow with the ATLAS detector

Tomasz Bold*†

AGH University of Science and Technology, Krakow, Poland

E-mail: tomasz.bold@fis.agh.edu.pl

The measurement of flow harmonics of charged particles from v_2 to v_7 in Pb+Pb collisions in the wide range of transverse momentum and pseudorapidity provides not only a way to study the initial state of the nuclear collisions and soft particle collective dynamics, but also provides insight into jet quenching via the measurement of flow harmonics at high transverse momenta. The longitudinal fluctuations of v_n and event-plane angles Ψ_n are also presented. The longitudinal flow decorrelations have contributions from v_n -magnitude fluctuations and event-plane twist. A four-particle correlator is used to separate these two effects. Results show that both effects have a linear dependence on pseudorapidity separation from v_2 to v_5 , and show a small but measurable variation with collision energy. While collectivity is well established in collisions involving heavy nuclei, its evidence in pp collisions is less clear. In order to assess the collective nature of multi-particle production, the correlation measurements are extended to include azimuthal correlations measured using multi-particle cumulants. The measurements of multi-particle cumulants $c_2\{2-8\}$ confirm the evidence for collective phenomena in p +Pb and low-multiplicity Pb+Pb collisions. For pp collisions, the measurements of cumulants do not yet provide clear evidence for collectivity as they are susceptible to event-by-event multiplicity fluctuations. A new modified cumulant method, which suppresses both the contribution of multiplicity fluctuations and non-flow effects, is used to address this issue.

The European Physical Society Conference on High Energy Physics

5-12 July, 2017

Venice

*Speaker.

†On behalf of the ATLAS Collaboration

1. Introduction

The correlation studies in ATLAS [1] concentrate on detailed analysis of the QGP dynamics in Pb+Pb collisions. Smaller systems of p +Pb or pp collisions are also in the area of interest where an unquestioned QGP signature has still to be found.

2. Correlation studies in Pb+Pb

The charged-hadrons azimuthal flow coefficients of up to v_7 are measured in Pb+Pb data using the scalar product (SP) and two-particle correlations (2PC) methods [2]. The measurement is performed in a wide range of transverse momenta, p_T for 0-80% most central events with the emphasis on the most central collisions. Non-zero values are found for up to v_7 in the intermediate p_T range as shown in Figure 1. Results obtained with 2PC and SP methods are consistent. The integrated v_n harmonics vary little with centrality except for the v_2 which maximises at mid-centralities due to the sensitivity to the initial-state eccentricities.

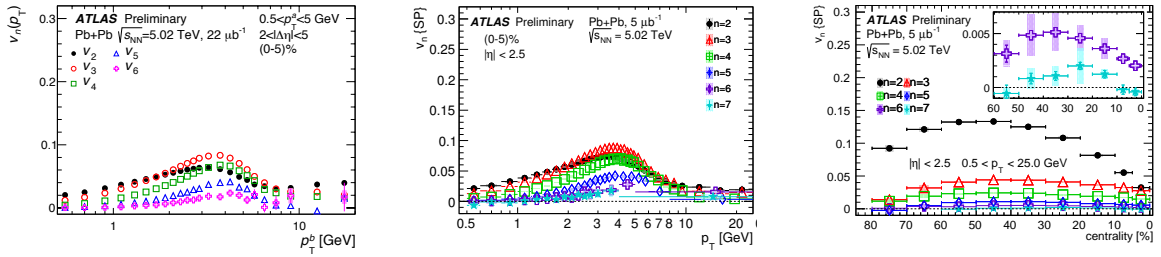


Figure 1: The v_n as a function of p_T measured with 2PC (left), SP methods (center) and integrated over the p_T range of 0.5-25 GeV and pseudorapidity $|\eta| < 2.5$ (left) as a function of collision centrality in Pb+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV [2].

In the Pb+Pb collisions the flow longitudinal decorrelation is studied [3]. The correlators sensitive the flow v_n magnitude $r_{n|n;k}$ and event-plane twist $R_{n|n;2}$ are measured as a function of pseudorapidity, η . The decorrelation of the magnitude shown in Figure 2 for v_2 and v_3 increases with η indicating breaking of 2PC factorisation to 1-particle correlation with η . The effect has different dynamics as a function of centrality for v_2 and v_3 . The $r_{n|n;k}$ remains centrality independent for the latter. The effect is weaker at higher center-of-mass energies. The $R_{n|n;2}$ correlators, shown in Figure 3, show a similar magnitude and behaviour with η and energy indicating that the event-plane twist has an equally significant contribution to the longitudinal v_n dynamics.

3. Small system measurements

3.1 Sub-event cumulants

The observation of the ridge structure in pp collisions at the LHC [4] opened the discussion on the presence of collectivity in small collision systems or a different origin of the observed phenomena. It was found that a method robust against local correlations due to jets or resonances has to be established to resolve the puzzle. For instance in the cumulants measurement not only

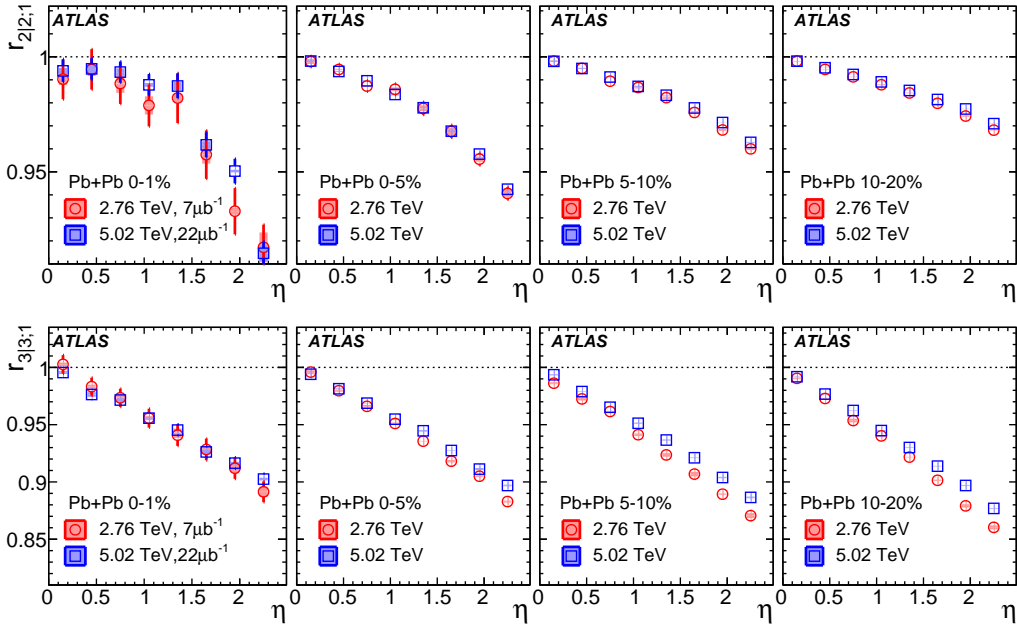


Figure 2: The $r_{n|n;k}$ correlator as a function of η at two energies for $n = 2$ (top) and $n = 3$ (bottom) in bins of centrality [3].

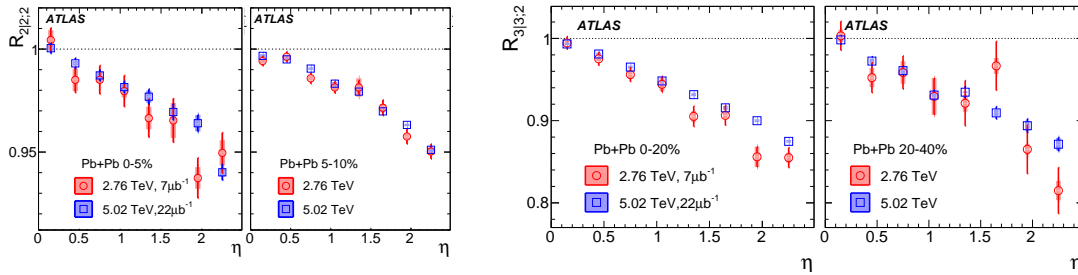


Figure 3: The $R_{n|n;2}$ correlator as a function of η at two energies for $n = 2$ (left) and $n = 3$ (right) in bins of centrality [3].

the quantitative but also qualitative results may depend on an arbitrary choice of kinematics of reference particles [5]. A novel method of sub-event cumulants is devised to reduce the non-flow background on measured correlations [6]. In this method the event is partitioned into sub-events (two or three in case of pp measurements) and particles from disparate sub-events are used. In practice, the formulation of traditional cumulants is modified as follows:

$$\langle\langle\{2\}_n\rangle\rangle = e^{in(\phi_1 - \phi_2)} \rightarrow \langle\langle\{2\}_n\rangle\rangle_{a|b} = e^{in(\phi_1^a - \phi_2^b)} \quad (3.1)$$

$$\langle\langle\{4\}_n\rangle\rangle = e^{in(\phi_1 + \phi_2 - \phi_3 - \phi_4)} \rightarrow \langle\langle\{4\}_n\rangle\rangle_{2a|b,c} = e^{in(\phi_1^a + \phi_2^a - \phi_3^b - \phi_4^c)} \quad (3.2)$$

$$c_n\{4\} = \langle\langle\{4\}_n\rangle\rangle - 2\langle\langle\{2\}_n\rangle\rangle^2 \rightarrow c_n^{2a|b,c}\{4\} = \langle\langle\{4\}_n\rangle\rangle_{2a|b,c} - 2\langle\langle\{2\}_n\rangle\rangle_{a|b}\langle\langle\{2\}_n\rangle\rangle_{a|c} \quad (3.3)$$

where the particles are taken from three ranges of pseudorapidity into which the full detector cover-

age $|\eta| < 2.5$ is split. The angle brackets denote an event average while double angle brackets denote averaging over the event and then over many events. The flow coefficient, $v_n\{4\} = \sqrt[4]{-c_n\{4\}}$, is then only defined when the cumulant $c_n\{4\}$ assumes positive values while positive cumulant is an indicator of lack of collectivity.

In the ATLAS measurement [7], a cross-check of this method on the p +Pb collision system is performed as shown in the left panel of Figure 4 where the results obtained from the standard cumulant, two sub-events or three sub-events methods are consistent except for very peripheral collisions where only three sub-events method indicates collectivity ($c_2\{4\} < 0$). The results of the method application to the pp system is shown in the right panel of Figure 4 where the three sub-events method indicates presence of non-local correlation. The comparison of the v_n measurements obtained with the 2PC method and three sub-event is shown in Figure 5 for the pp collisions at two energies as well as for p +Pb. Flow at the level of 4% independent of the multiplicity is observed in all conditions. In comparison to the 2PC measurements deploying various techniques of subtracting non-flow contributions estimated from peripheral collisions the three sub-events results yield smaller v_2 . The v_3 in pp system is found to be consistent with zero.

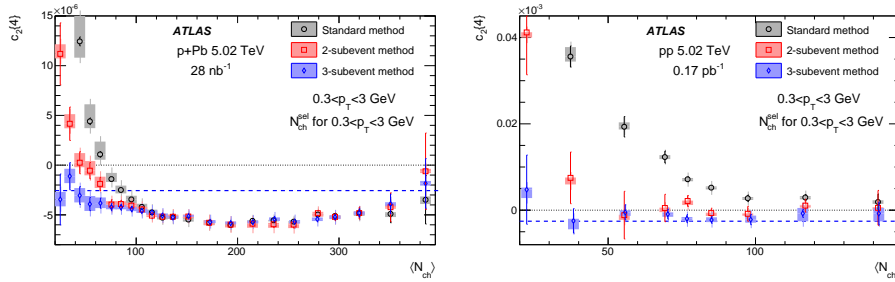


Figure 4: The $c_2\{4\}$ measured with the standard, two sub-events and three sub-event methods in p +Pb collisions (left) and pp collisions (right) [7].

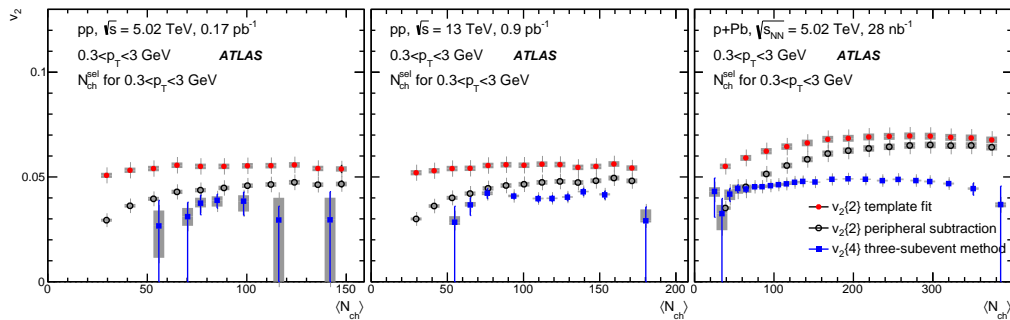


Figure 5: The v_2 measured in pp at $\sqrt{s} = 5.02$ TeV (left), at 13 TeV (centre) and p +Pb at $\sqrt{s_{NN}} = 5.02$ TeV (right) with a sub-event cumulant method as well as with 2PC methods with two non-flow removal procedures based on peripheral collisions [7].

4. Summary

In these proceedings ATLAS correlation measurements in Pb+Pb, p +Pb and pp collision systems are presented. ATLAS measures flow harmonics up to v_7 in a broad range of p_T . The lon-

itudinal decorrelations are studied in Pb+Pb at 2.76 and 5.02 TeV. It is found that the slope of this decorrelation is slightly bigger at lower energies. Both, the flow magnitude change and the event-plane twist influence the decorrelation at a similar level. For small collision systems a novel method of sub-event cumulants is proposed in order to robustly eliminate non-flow effects. The v_2 coefficient is found to be about 4% in a wide range of event activity quantified by charged particle multiplicity in pp as well as in p +Pb collisions.

Acknowledgements

This work was supported in part by the National Science Center grant UMO-2015/19/B/ST2/00906 and by PL-Grid Infrastructure.

References

- [1] ATLAS Collaboration, JINST **3** (2008) S08003.
- [2] ATLAS Collaboration, ATLAS-CONF-2016-105, <https://cds.cern.ch/record/2220372>
- [3] ATLAS Collaboration, arXiv:1709.02301 [nucl-ex].
- [4] CMS Collaboration, JHEP **1009** (2010) 091 [arXiv:1009.4122 [hep-ex]].
- [5] ATLAS Collaboration, Eur. Phys. J. C **77** (2017) no.6, 428 [arXiv:1705.04176 [hep-ex]].
- [6] J. Jia, M. Zhou and A. Trzupek, arXiv:1701.03830 [nucl-th].
- [7] ATLAS Collaboration, arXiv:1708.03559 [hep-ex].