Vol. 12 (2019) *Acta Physica Polonica B Proceedings Supplement* No 2

THE TWO PARTICLE CORRELATION IN Z-BOSON TAGGED EVENTS*

Alexander Milov

on behalf of the ATLAS Collaboration

Weizmann Institute of Science, 234 Herzl, Rehovot 76100, Israel

(Received January 17, 2019)

These proceedings present the result of the first study of the long-range hadron correlations in pp collisions with a constraint on collision geometry. The constraint is implemented by requiring events in which a Z boson is produced. Selecting collisions with hard scattering causes the impact parameter distribution to be different from the inclusive pp collision. The analysis uses 19.4 fb^{-1} of $\sqrt{s} = 8$ TeV pp data obtained by the ATLAS experiment at the LHC. The correlations between the charged-particle pairs in relative azimuthal angle over the transverse momentum range from 0.5 GeV to 5 GeV are studied as a function of the charged particle multiplicity of the event. The number of charged particle tracks and the correlation functions are corrected to account for the significant pileup contribution present in the events. The correlation in the Z-tagged events is found to be independent of multiplicity, and its magnitude is $8 \pm 6\%$ larger than that in inclusive pp events.

DOI:10.5506/APhysPolBSupp.12.387

1. Introduction

Measurements of two particle correlations (2PC) in small systems show the presence of azimuthal correlations of two hadrons separated in pseudorapidity [1–3]. Recent studies demonstrated that these long-range correlations are consistent with the modulation of the single particle azimuthal angle distributions [1, 2], similar to that seen in larger systems [4–6] and with the modulation magnitudes v_n that are comparable to the large systems.

In nuclei–nuclei ($A+A$) and proton–nuclei ($p+A$) collisions, the v_n result from anisotropies of the initial collision geometry which are transferred to the azimuthal distributions of the produced particles by the collective

* Presented at the XIII Workshop on Particle Correlations and Femtoscopy, Kraków, Poland, May 22–26, 2018.

evolution of the medium, well described by relativistic hydrodynamics models [7–9]. The striking similarities between the $p_{\rm T}$ and $\sqrt{s}$ dependence of the v_2 in pp collisions to large collision systems indicate the possibility of collective behaviour developing in pp collisions, though alternate models that qualitatively reproduce the features observed in the pp 2PC exist [10–15].

One feature in which the v_2 in pp and in larger systems differ is that the v_2 in pp is independent of the event multiplicity, while in larger systems, it exhibits multiplicity dependence. This is due to a correlation between the initial collision geometry, generating the final-state azimuthal anisotropy and the size of the system. A recent study that models the proton substructure and fluctuations in the multiplicity of the final particles in pp collisions showed that the initial entropy-density distributions have no correlation with the final particle multiplicity [16].

This paper presents the 2PC of charged hadrons measured in pp interactions that have a Z boson. The presence of a Z boson selects hard scattering events with large momentum transfer, which may lower the partonic impact parameter [17] which, in turn, may cause the v_2 to be different from the inclusive collisions.

The pp data used in the analysis was recorded by the ATLAS detector [18] in high luminosity runs of the LHC, with equivalent number of simultaneous interactions, $\mu \approx 20$. This poses significant complications to the correlation analysis due to a large number of tracks coming from simultaneous interactions (pileup). A procedure is developed to solve the problem that removes the contribution of such tracks on a statistical basis.

2. Datasets, event and track selection

The analysis is based on pp collisions at $\sqrt{s} = 8$ TeV with the total integrated luminosity of 19.4 fb^{-1}. Z bosons are reconstructed via the di-muon channel. Events are recorded based on a di-muon or high-$p_{\rm T}$ single muon trigger. Pairs of muons with $p_{\rm T} > 20$ GeV and $|\eta| < 2.4$ one of which is matched to the trigger are required to form an invariant mass between 80 GeV and 100 GeV. Approximately 6.2×10^6 events satisfy these criteria.

The event activity is quantified by the total number of reconstructed tracks passing quality requirements, and with $p_{\rm T} > 0.4$ GeV [1, 2, 6, 19]. Tracks are also selected based on the track impact parameters, the distance from the event vertex to the closest point on the track trajectory. In the transverse plane, the impact parameter is restricted to 1.5 mm, rejecting secondary tracks. Along the beam axis, the longitudinal impact parameter times the sinus of the track polar angle is required to be $|\omega| < \omega_0 = 0.75$ mm, rejecting the tracks coming from the pileup interactions. Tracks associated with the muons coming from the Z-boson decay are excluded.

3. Pileup subtraction

Selected tracks still contain a significant contribution from pileup. To correct for it, a special strategy has been adopted. It consists in constructing a sample of (mixed) events that are on average equivalent to the pileup contribution in the Z-tagged (direct) events. Each mixed event is obtained by selecting tracks within the longitudinal impact parameter of 0.75 mm from the point of the Z-boson production in another event taken at the same instantaneous luminosity. The points of the Z-boson origin in the two events are required to be sufficiently separated in the longitudinal direction. Mixing is repeated 20 times per each direct event to increase statistics.

Studies based on data and on simulations demonstrate that the mixed events are equivalent to the pileup in direct events. All mixed event distributions depend on one parameter that is the average number of the pileup tracks in an event. This parameter (ν) is given by Eq. (1)

$$\nu = 2\omega_0 \left.\frac{\mathrm{d}^2 n_{\mathrm{trk}}}{\mathrm{d}\omega\,\mathrm{d}\bar{\mu}}\right|_{\bar{z}_{\mathrm{vtx}}=0} \mathrm{Gauss}(\bar{z}_{\mathrm{vtx}})\bar{\mu}\,, \tag{1}$$

where z_{vtx} is the longitudinal vertex location which has a Gaussian profile $\mathrm{Gauss}(\bar{z}_{\mathrm{vtx}})$ and μ is the instantaneous luminosity. To account for run-by-run variations, the variables are used in a reduced form ($\bar{z}_{\mathrm{vtx}}$, $\bar{\mu}$), explained in Ref. [20]. Coefficient $2\omega_0\, \mathrm{d}^2 n_{\mathrm{trk}}/(\mathrm{d}\omega\,\mathrm{d}\bar{\mu})|_{\bar{z}_{\mathrm{vtx}}=0}$ is the average number of tracks emitted in an interaction defined by particle production in inclusive pp collisions and by the detector acceptance and efficiency.

Equation (1) reflects the fact that the properties of the pileup tracks depend entirely on the pp-interaction density which, in turn, is fully defined by the instantaneous luminosity and vertex position. Thus, the number of pileup tracks in direct event can be derived from μ and z_{vtx} and events in the sample can be categorised based on the value of the parameter ν, defined above. Distributions of n_{trk} found in direct and mixed events are shown in Fig. 1.

Using distributions in Fig. 1, one can find the probability that the track is coming from the Z-boson interaction (signal). The shapes of these distributions depend on the total n_{trk} in the direct event and on ν. Examples are shown in Fig. 2.

To derive the 2PC for the signal, the contribution of the pileup has to be removed. This is done with mixed events having the 2PC equivalent to the pileup and using the distributions shown in Fig. 2 as weighting factors. The 2PC of signal tracks are

$$\begin{aligned}(\mathrm{signal}\times\mathrm{signal}) &= (\mathrm{direct}\times\mathrm{direct}) - (\mathrm{mixed}\times\mathrm{mixed}) \\ &\quad -2((\mathrm{direct})\times(\mathrm{mixed}) - (\mathrm{mixed})\times(\mathrm{mixed}))\,,\end{aligned} \tag{2}$$

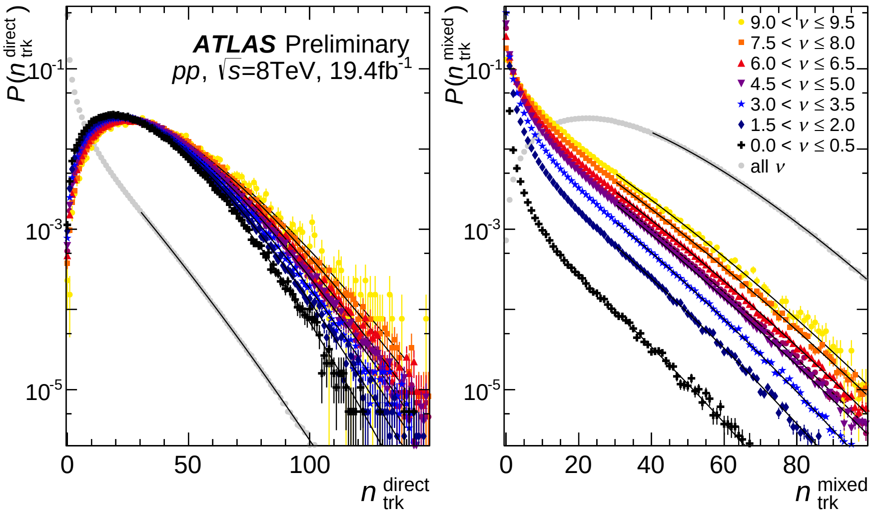

Fig. 1. Distributions of the n_{trk} in direct events (left) and mixed events (right) for different values of ν from [20]. Lines are fits to data points.

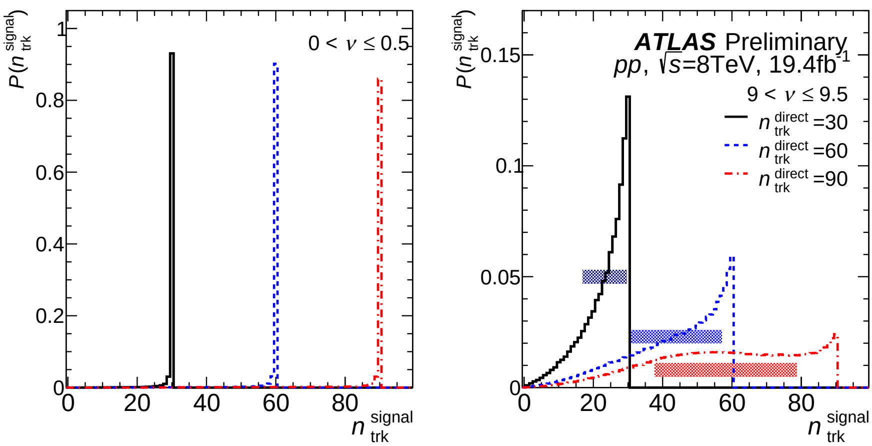

Fig. 2. Probability to find a number of signal tracks in an event with 30, 60 and 90 direct tracks [20]. Boxes indicate mean ± RMS value of a corresponding histogram.

where brackets $(\times)$ denote whether the correlation function is constructed between the tracks in the same event and $(\ )\times(\ )$ between two different events. Naturally, in the latter case, the tracks are uncorrelated, therefore, $(\ )\times(\ )$ terms are constant factors of $\Delta\phi$. The 2PC are calculated using Eq. (2) independently in narrow intervals of ν for all combinations of direct–mixed tracks. Then the results of ν-intervals are added together.

4. Measurements of the 2PC and systematics

Figure 3 shows corrected 2PC for two different n_{trk} intervals. Correlations are approximated by template fit method [2] with the interval of [20,30] used as the peripheral reference. The data are well-described by the template fits, with long-range correlations observed in both cases.

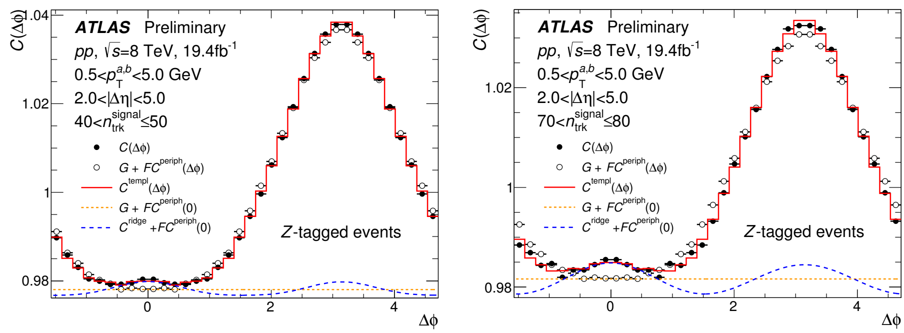

Fig. 3. Template fits [20] to the pileup corrected $C(\Delta\phi)$ for two different track multiplicity intervals. The [20,30] track interval is used to determine the $C^{\mathrm{periph}}(\Delta\phi)$.

The systematic uncertainties of this analysis fall into two categories: related to the pileup subtraction, listed in the left column of Table I, and related to the measurement of the 2PC, listed in the right column.

TABLE I

Systematic uncertainties [20] for pileup subtraction (left) and 2PC (right).

Source	Unc.	Source	Unc.
Mixed and pileup equivalence	2%	Peripheral bin	8–3%
Accuracy of ν estimation	1%	Tracking efficiency	0.5%
Uncertainties in corrections	2%	Pair acceptance	1%
ν dependence	3.5%		

5. Results

The left panel of Fig. 4 shows the final v_2 values obtained from the template fit in the 8 TeV Z-tagged sample, together with the systematic uncertainties. For comparison, the v_2 values obtained in 13 TeV and 5 TeV inclusive pp collisions from Ref. [1] are also shown. The right panel shows the ratio of the 8 TeV v_2 to the 13 TeV v_2 values. The Z-tagged 8 TeV v_2 values show at most a weak dependence on the multiplicity, similar to the results obtained with the inclusive samples. However, the Z-tagged v_2 values are $8 \pm 6\%$ larger than the inclusive v_2 results.

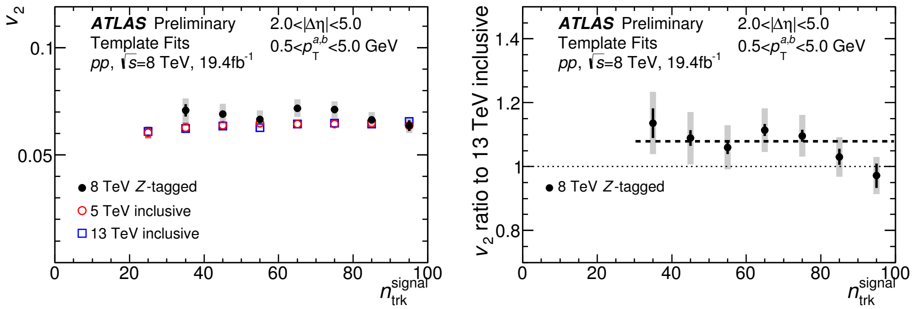

Fig. 4. Left panel: fully corrected v_2 values obtained from the template fits, plotted as a function of the $n_{\rm trk}$. Right panel: the ratio of the v_2 measured in the Z-tagged 8 TeV to the v_2 measured in the inclusive 13 TeV events from [20].

This research of the author is supported by the Israel Science Foundation (grant 1065/15), by the Israel Academy of Sciences and Humanities grant number IASAH-ATLAS 712760, and by the MINERVA Stiftung with the funds from the BMBF of the Federal Republic of Germany.

REFERENCES

[1] ATLAS Collaboration, *Phys. Rev. C* **96**, 024908 (2017).
[2] ATLAS Collaboration, *Phys. Rev. Lett.* **116**, 172301 (2016).
[3] CMS Collaboration, *J. High Energy Phys.* **1009**, 091 (2010).
[4] CMS Collaboration, *Phys. Lett. B* **718**, 795 (2013).
[5] ALICE Collaboration, *Phys. Lett. B* **719**, 29 (2013).
[6] ATLAS Collaboration, *Phys. Rev. Lett.* **110**, 182302 (2013).
[7] H. Sorge, *Phys. Rev. Lett.* **78**, 2309 (1997).
[8] P. Huovinen *et al.*, *Phys. Lett. B* **503**, 58 (2001).
[9] P.F. Kolb *et al.*, *Nucl. Phys. A* **696**, 197 (2001).
[10] A. Dumitru *et al.*, *Phys. Lett. B* **697**, 21 (2011).
[11] A. Kovner, M. Lublinsky, *Phys. Rev. D* **83**, 034017 (2011).
[12] T. Altinoluk, A. Kovner, *Phys. Rev. D* **83**, 105004 (2011).
[13] K. Dusling, R. Venugopalan, *Phys. Rev. Lett.* **108**, 262001 (2012).
[14] E. Levin, A.H. Rezaeian, *Phys. Rev. D* **84**, 034031 (2011).
[15] M. Strikman, *Acta Phys. Pol. B* **42**, 2607 (2011).
[16] K. Welsh, J. Singer, U.W. Heinz, *Phys. Rev. C* **94**, 024919 (2016).
[17] L. Frankfurt, M. Strikman, C. Weiss, *Phys. Rev. D* **69**, 114010 (2004).
[18] ATLAS Collaboration, *JINST* **3**, S08003 (2008).
[19] ATLAS Collaboration, *Phys. Rev. C* **90**, 044906 (2014).
[20] ATLAS Collaboration, ATLAS-CONF-2017-068, `http://cdsweb.cern.ch/record/2285806`