The Compact Muon Solenoid Experiment

Conference Report

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Principle Component Analysis of two-particle correlations in PbPb and pPb collisions at CMS

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Abstract

A Principle Component Analysis (PCA) of two-particle azimuthal correlations as a function of transverse momentum (p_T) is presented in PbPb collisions at 2.76 TeV and high-multiplicity pPb collisions at 5.02 TeV. The data were recorded using the CMS detector at the LHC. It was shown that factorization breaking of two-particle azimuthal correlations can be attributed to the effect of initial-state fluctuations. Using a PCA approach, Fourier coefficients of observed two-particle azimuthal correlations as a function of both particles p_T are characterized into leading and sub-leading mode terms. The leading modes are essentially equivalent to anisotropy harmonics (v_n) previously extracted from two-particle correlation methods as a function of p_T . The sub-leading modes represent the largest sources of factorization breaking. In the context of hydrodynamic models, they are a direct consequence of initial-state fluctuations. The results are presented over a wide range of centrality and event multiplicity. The results are connected to the measurement of p_T -dependent flow factorization breaking.

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A Principle Component Analysis (PCA) of two-particle azimuthal correlations as a function of transverse momentum (p_T) is presented in PbPb collisions at 2.76 TeV and high-multiplicity pPb collisions at 5.02 TeV. The data were recorded using the CMS detector at the LHC. It was shown that factorization breaking of two-particle azimuthal correlations can be attributed to the effect of initial-state fluctuations. Using a PCA approach, Fourier coefficients of observed two-particle azimuthal correlations as a function of both particles' p_T are characterized into leading and sub-leading mode terms. The leading modes are essentially equivalent to anisotropy harmonics (v_n) previously extracted from two-particle correlation methods as a function of p_T . The sub-leading modes represent the largest sources of factorization breaking. In the context of hydrodynamic models, they are a direct consequence of initial-state fluctuations. The results are presented over a wide range of centrality and event multiplicity. The results are connected to the measurement of p_T -dependent flow factorization breaking.

Keywords: relativistic collisions, collective flow

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1. Introduction

Quantum Chromodynamics predicts that at sufficiently high energy density achieved in ultra-relativistic heavy-ion collisions a new state of matter, Quark-Gluon-Plasma (QGP), is created. The QGP exhibits a collective expansion which could be described by hydrodynamic flows. The spatial anisotropy of the initial state in a collision converts, via interactions, into a momentum anisotropy in the final state. This phenomenon, called anisotropic flow, quantitatively is described by Fourier decomposition and corresponding Fourier coefficients, v_n , are used to quantify the strength of the single-particle azimuthal anisotropy. The correlation structure of emitted particle pairs as a function of azimuthal angles difference, $\Delta\phi$, could be also Fourier decomposed. Usually, it is assumed that two-particle Fourier coefficients, $V_{n\Delta}$, factorize into a product of single-particle azimuthal anisotropies. In [1, 2] is shown that even if the hydrodynamic flow is the only source of these correlations, initial-state fluctuations makes that the event plane is not a global quantity, but dependent on both, p_T and η . This leads to factorization breaking of the two-particle azimuthal anisotropy into a product of single-particle anisotropies. Lumpy hot-spots raised from the initial-state fluctuations can generate a local pressure gradient that the corresponding local event plane may be different although still correlated with the global participant plane. These effects are studied in PbPb collisions at 2.76 TeV [3, 4]

and in pPb at $\sqrt{s_{NN}} = 5.02$ TeV [4]. Recently, a new approach which employs the Principal Component Analysis (PCA) to study the flow phenomena is introduced [5, 6]. The results are presented in leading and sub-leading mode terms. The first is essentially equivalent to anisotropy harmonics (v_n) extracted from two-particle correlation methods, while the second represents the largest sources of factorization breaking. In this contribution is presented the first experimental measurement of the elliptic and triangular sub-leading flow.

2. Experimental setup and data used

A super-conducting solenoid with 3.8 T magnetic field surrounds the CMS tracker detector [7] enabling precise p_T measurements above 0.3 GeV/c. The PbPb and pPb collisions at the LHC energies of $\sqrt{s_{NN}} = 2.76$ TeV and 5.02 TeV with integrated luminosities of $160 \mu\text{b}^{-1}$ and 35 nb^{-1} , respectively, were collected. A wide pseudorapidity coverage ($|\eta| < 2.5$) excellently suites for studying the long-range flow correlations.

3. Results

In the left panel of Fig. 1 are shown PCA leading ($\alpha = 1$) and sub-leading ($\alpha = 2$) flow modes of the elliptic harmonic ($n = 2$) in high-multiplicity pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV in four multiplicity bins. A symmetric, 6×6 in size, covariance $V_{n\Delta}(p_{T1}, p_{T2})$ matrix is used to extract the first two modes. The obtained first flow mode, $v_2^{(1)}$, is essentially equal to the v_2 values measured in [8]. The second flow mode values are close to zero at low p_T with a moderate increase towards high p_T . At high- p_T region, $1.7 < p_T < 2.7$ GeV/c, the $v_2^{(2)}$ has a significant non-zero magnitude. Such behaviour is seen also in the r_2 results from [4] where the biggest factorization breaking effect has been seen in the same p_T region in high-multiplicity pPb collisions. Due to the presence of non-flow effects, with further increase of the p_T above 3 GeV/c, the sub-leading mode continue to increase.

Fig. 1. First ($\alpha = 1$) and second ($\alpha = 2$) mode for $n=2$ (left panel) and $n=3$ (right panel) harmonic as a function of p_T measured in high-multiplicity pPb collisions at $\sqrt{s_{NN}}=5.02$ TeV. The first mode results are compared to the v_2 (left panel) and v_3 (right panel) taken from [8]. The error bars correspond to statistical while shaded areas to systematic uncertainties.

In the right panel of Figure 1 are shown the leading and sub-leading flow modes corresponding to the triangular flow ($n = 3$) in four multiplicity intervals from high-multiplicity pPb collisions. Again, the leading flow mode, $v_3^{(1)}$, and the triangular flow measurements, v_3 , taken from [8] are essentially equal. As in the case of the v_2 , in these four analyzed multiplicity bins, practically there is no multiplicity dependence

Fig. 2. First ($\alpha = 1$) and second ($\alpha = 2$) mode for $n=2$ (upper row) and $n=3$ (bottom row) harmonic as a function of p_T measured in a wide centrality range of PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The first mode results are compared to the v_2 (upper row) and v_3 (bottom row) measured by the ALICE collaboration using the two-particle correlation method taken from [9]. The error bars correspond to statistical while shaded areas to systematic uncertainties.

of the v_3 . In the figure one can also see that the $v_3^{(2)}$ is equal to zero up to 2 GeV/c. For highest p_T value it seems that the $v_3^{(2)}$ slightly increases and shows a tendency to become positive.

Upper row of Fig. 2 shows leading and sub-leading flow mode of the elliptic harmonic for 8 centrality regions ranged from ultra-central (0-0.2%) to peripheral (50-60%) PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. Similarly as in the case of pPb collisions, the leading flow mode, $v_2^{(1)}$, is dominant and essentially equal to the v_2 measured from two-particle correlations in [9]. In difference with respect to the pPb case, where the magnitude of the both flow modes are independent from multiplicity, in the case of PbPb collisions the $v_2^{(1)}$ has expected centrality behavior. It has a small magnitude at ultra-central collisions and then gradually increases going to peripheral collisions. At high- p_T region, the sub-leading flow mode, $v_2^{(2)}$, becomes positive and slightly increases going from semi-central to peripheral PbPb collisions. Additionally, at ultra-central collisions it has a non-zero value. Qualitatively, such behavior is in an agreement with the r_2 multiplicity dependence presented in [4]. As in the case of pPb collisions, the $v_2^{(2)}$ has a non-zero value at high- p_T region, while further increase of the $v_2^{(2)}$ could be, again, explained by strong non-flow presence in the high- p_T (above 3 GeV/c) region.

In the bottom row of Fig. 2 are shown the leading and sub-leading mode for the third harmonic for 8 centralities in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The $v_3^{(1)}$ is in a very good agreement with the v_3 results calculated using two-particle correlations in [9]. The sub-leading mode is, up to 3 GeV/c, practically equal to zero. This support finding from [4] that the third harmonic factorizes better than the second one.

4. Summary

As the PCA method uses all the information encoded in the covariance matrix it provides high sensitivity to the influence of the initial-state fluctuations to the hydrodynamic flow. The detailed information depends on the momenta of both particles as opposed to the previously used two-particle correlation methods where the information was obtained by integrating over momentum of one of particles from the pair. The leading flow mode is the hydrodynamic response to the average geometry and they are essentially equal to the single-particle anisotropy measured using the two-particle correlations method. The sub-leading mode is the response to the event-by-event initial-state fluctuations which represent the main source of the factorization-breaking effect.

References

- [1] G. F. Gardim, F. Grassi, M. Luzum and J.-Y. Ollitrault, Phys. Rev. C **87**, 031901 (2013).
- [2] U. Heinz, Z. Qiu and C. Shen, Phys. Rev. C **87**, 034913 (2013).
- [3] CMS Collaboration, JHEP **02**, 088 (2014).
- [4] CMS Collaboration, Phys. Rev. C **92**, 034911 (2015).
- [5] R. Bhalerao, J.-I. Ollitrault, S. Pal, and D. Teaney, Phys. Rev. Lett. **114**, 152301 (2015).
- [6] A. Mazeliauskas and D. Teaney, Phys. Rev. C **91**, 044902 (2015).
- [7] CMS Collaboration, JINST **3**, S08004 (2008).
- [8] CMS Collaboration, Phys. Lett. B **724**, 213 (2013).
- [9] ALICE Collaboration, Phys. Lett. B **708**, 249 (2012).