Vol. 6 (2013) *Acta Physica Polonica B Proceedings Supplement* No 3

LATEST QCD RESULTS ON Pb–Pb COLLISIONS FROM CMS*

Jovan Milošević

for the CMS Collaboration

University of Belgrade and Vinča Institute of Nuclear Sciences
Belgrade, Serbia

(Received July 11, 2013)

Although the CMS is an LHC experiment designed to study *pp* collisions it is well suited to study heavy-ion collisions too. In this paper, we present the results of anisotropic particle emission and jet production in PbPb collisions at the CMS. The anisotropy is measured using four methods each of which has different sensitivities to the non-flow correlations and initial geometrical fluctuations. Additionally, the two-dimensional two-particle correlations are also used to extract Fourier coefficients which quantify the magnitude of the anisotropy. The strong CMS magnet allowed to measure accurately particle anisotropy up to 60 GeV/c. Besides transverse momentum dependence, the results are presented *versus* centrality too.

DOI:10.5506/APhysPolBSupp.6.827
PACS numbers: 25.75.Ld, 25.75.Gz, 25.75.Ag

1. Introduction

The magnitude of the azimuthal anisotropy is characterized by coefficients, v_n, in Fourier decomposition of the azimuthal particle distribution constructed with respect to the event plane [1, 2]. The observations could give an insight into the strong interactions among constituents of the expanding, hot and dense medium, formed in the heavy-ion collision, by which the spatial anisotropy of the almond shaped overlap zone converts into the momentum anisotropy that is measured. Different methods were developed to measure v_n coefficients. Beside the event plane (EP) method, there are others which do not require the knowledge about the EP as two- and four-particle cumulants [3] and Lee–Yang Zero method (LYZ) [4, 5]. These methods have different sensitivities to the influence from correlations not connected to the event plane (non-flow) and to the initial-state eccentricity fluctuations.

* Presented at the Workshop "Excited QCD 2013", Bjelašnica Mountain, Sarajevo, Bosnia–Herzegovina, February 3–9, 2013.

2. Experiment

The CMS detector is axially symmetric around the beam direction and consists of a silicon tracker, an electromagnetic calorimeter, and a hadron calorimeter. They are surrounded with a superconducting solenoid which provide a 3.8 T magnetic field in the center of the detector. Outside the solenoid, the muon chambers are placed. The detector covers full azimuthal angle, ϕ, at pseudo-rapidity range $|\eta| < 2.5$. A more detailed description of the CMS detector can be found in Ref. [6].

3. Results

The study is performed in 12 centrality bins ranging from 0% to 80% of the total inelastic PbPb cross section. The most central collisions with impact parameter $b = 0$ correspond to 0%, while the most peripheral to 100%. The corresponding p_{T} dependent results are shown in Fig. 1 [7]. As expected, results from two-particle cumulant method ($v_2\{2\}$) gives the biggest v_2 values due to the short-range non-flow correlations from jet fragmentation. The $v_2\{\mathrm{EP}\}$ is less affected by non-flow correlations as it is derived with respect to the EP reconstructed using forward hadronic calorimeter (HF) covering

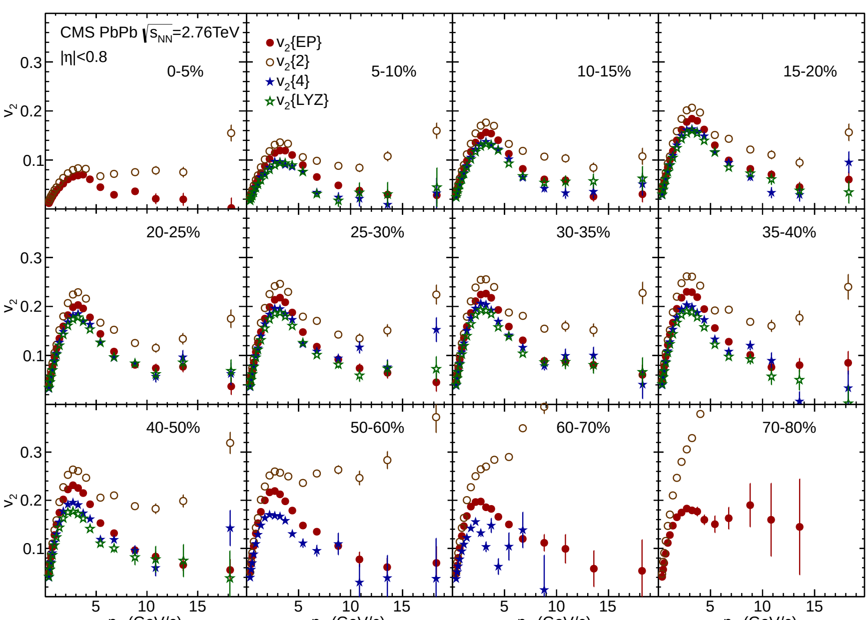

Fig. 1. Measurements of v_2 *versus* transverse momentum (p_{T}), obtained using 4 different methods, in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV at mid-rapidity ($|\eta| < 0.8$) for the 12 centrality classes.

$3 < |\eta| < 5$. The fourth-order cumulant, $v_2\{4\}$, and the Lee–Yang Zero, $v_2\{\mathrm{LYZ}\}$, are expected to be much less affected by the non-flow contributions than the $v_2\{2\}$ and $v_2\{\mathrm{EP}\}$ by utilizing multiparticle technique. This trend is seen in our data.

The centrality dependence of the v_2 values integrated over p_{T} at mid-rapidity $|\eta| < 0.8$ is shown in Fig. 2 [7]. The integration range, $0.3 < p_{\mathrm{T}} < 3$ GeV$/c$, is limited to low p_{T} to maximize the contribution from soft processes. The systematic uncertainties are represented with the boxes. The v_2 increases going from central to peripheral collisions with a maximum around 40% centrality. The ordering in the v_2 is the same as in Fig. 1. The ratio shown at the bottom panel of Fig. 2 is roughly constant (10% up for the $v_2\{2\}$ and 10% down for the $v_2\{4\}$) for semi-central collisions. They are understood in terms of their sensitivity to the initial-state eccentricity fluctuations. Larger effect is seen in most central and most peripheral collisions that could be due to non-flow correlations.

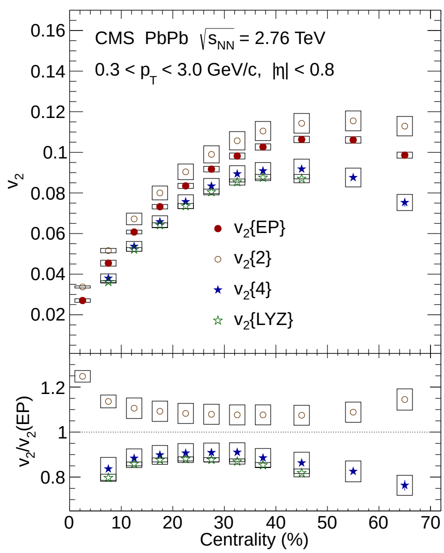

Fig. 2. The v_2 values shown in Fig. 1 integrated over $0.3 < p_{\mathrm{T}} < 3.0$ GeV$/c$ *versus* centrality. At the bottom panel, there is shown the ratio between the values from three of the methods and the EP method.

The strong CMS magnet allowed to measure accurately particle anisotropy up to 60 GeV$/c$. In Fig. 3, there are shown corresponding data taken during 2011, for six centrality intervals and covering mid-rapidity ($|\eta| < 1$), in comparison with the data taken during 2010 as well as with those from the ATLAS experiment [8]. The results are based on the EP analysis. The mutual agreement is very good. The v_2 values rapidly rise and reach the maximum at $p_{\mathrm{T}} \approx 3$ GeV/c. Then they quickly decrease. For p_{T} above 10 GeV/c, v_2 decreases much slower. The data show the expected centrality dependence too.

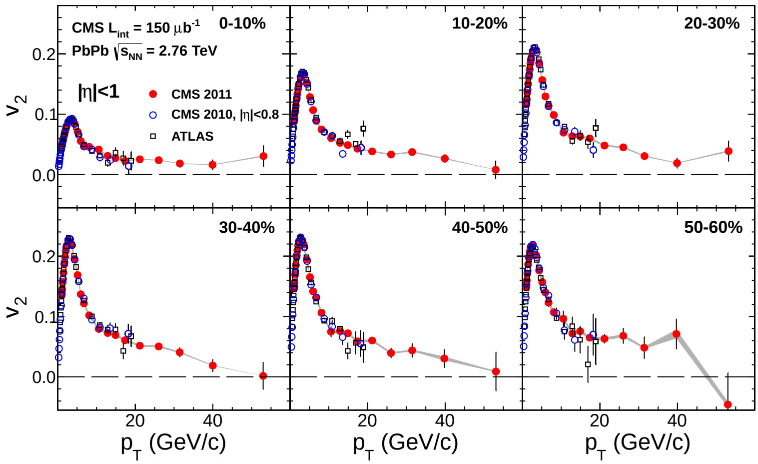

Fig. 3. Comparison between the $v_2(p_{\mathrm{T}})$ measurements performed, within 6 centrality bins, on the CMS 2010 and 2011 data as well as on the ATLAS data.

In heavy ion collisions, jet could emerge in fragmentation of colliding partons. Correlating in $\Delta\phi = \phi_{\mathrm{trig}} - \phi_{\mathrm{assoc}}$ the leading (trigger) hadron within a certain p_{T} range with associated hadrons within lower p_{T}, one can get jet signal in a form of dihadron correlation function. Within the same signal, azimuthal anisotropy is also present as a cosine-like contribution. As an example, in Fig. 4, there are shown 2-dimensional, $\Delta\phi$–$\Delta\eta$, dihadron correlations in 12 centrality bins [9]. They are obtained demanding that transverse momentum of trigger (associated) particle is between 3.0 and 3.5 GeV/c (1.0 and 1.5 GeV/c). These correlations are rich in structure, and evolve with centrality. From the shape of these correlations, one could see the presence of both azimuthal anisotropy and jet signal. The first one appears as elongated structures in $\Delta\eta$ positioned at $\Delta\phi = 0$ and at $\Delta\phi = \pi$[1]. Additionally, at $\Delta\phi = 0$ and $\Delta\eta = 0$, one can see a pronounced peak structure as a jet signal[2].

The shape of 2D correlations suggest that cutting on $\Delta\eta$, jet contribution on the near side could be largely suppressed. In the long-range region ($2 < |\Delta\eta| < 4$) largely dominates azimuthal anisotropy, while in the short-range region ($|\Delta\eta| < 1$) exists huge jet contribution. In order to quantitatively examine the features of short- and long-range azimuthal correlations, one

[1] Azimuthal anisotropy is a long-range correlation.

[2] Jet, as a spray of particles, is a short-range correlation, both in $\Delta\phi$ and in $\Delta\eta$.

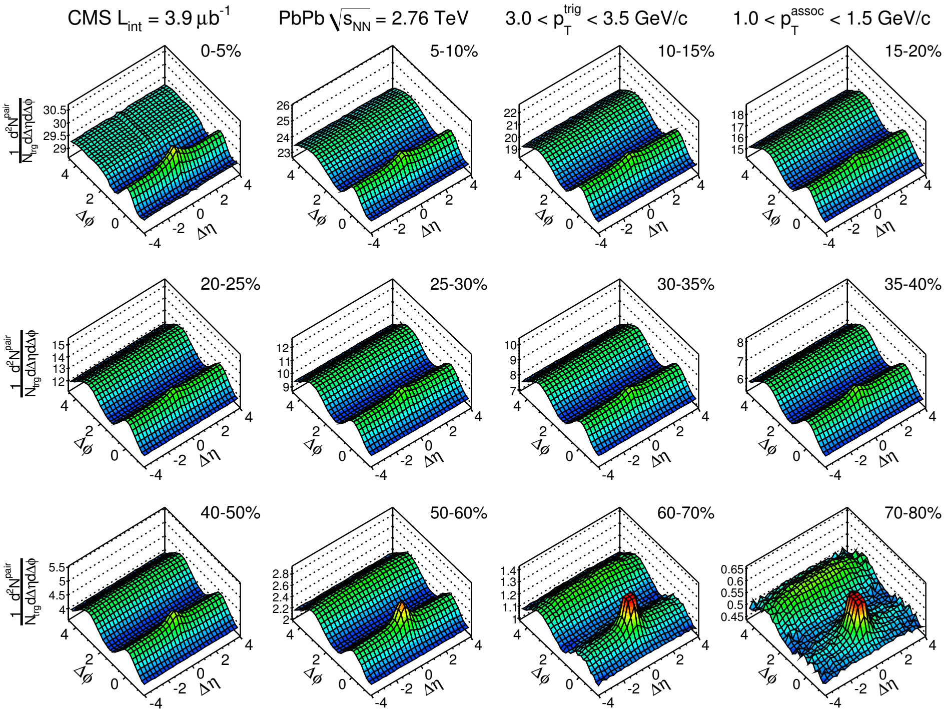

Fig. 4. Two dimensional $\Delta\eta$–$\Delta\phi$ correlation function for 12 centrality classes in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV using CMS detector.

could project 2D correlations onto $\Delta\phi$ and average it over certain $\Delta\eta$ range. In that way, the 1D ($\Delta\phi$) correlation function is obtained. In the case where short-range region is examined in more details could be found in [9].

The 1D correlation function, in the long-range region case, is fitted with a Fourier series. This fit includes the first five Fourier coefficients $V_{n\Delta}$ (see Eq. (6) in [9]). Supposing that the correlations from large $\Delta\eta$ results from azimuthal anisotropy only, one could factorise $V_{n\Delta}$ into a product of the single-particle azimuthal anisotropy harmonics, v_n, as $V_{n\Delta}(p_{\mathrm{T}}^{\mathrm{trig}}, p_{\mathrm{T}}^{\mathrm{assoc}}) = v_n(p_{\mathrm{T}}^{\mathrm{trig}})v_n(p_{\mathrm{T}}^{\mathrm{assoc}})$. Finally, the single-particle azimuthal anisotropy coefficients are obtained as $v_n(p_{\mathrm{T}}^{\mathrm{trig}}) = V_{n\Delta}(p_{\mathrm{T}}^{\mathrm{trig}}, p_{\mathrm{T}}^{\mathrm{assoc}})/\sqrt{V_{n\Delta}(p_{\mathrm{T}}^{\mathrm{assoc}}, p_{\mathrm{T}}^{\mathrm{assoc}})}$. These coefficients, as a function of $p_{\mathrm{T}}^{\mathrm{trig}}$, are shown in Fig. 5. The range chosen for $p_{\mathrm{T}}^{\mathrm{assoc}}$ is 1–3 GeV/c. As expected, the results for v_2 are similar to the $v_2\{2\}$ and $v_2\{\mathrm{EP}\}$ results shown in Fig. 1. Besides the v_2, results for higher order harmonics, up to the 5$^{\mathrm{th}}$ order, are also extracted in the same way. The magnitude of the harmonics decreases with increase of its order, n, showing an expected ordering. A proper centrality dependence is found too.

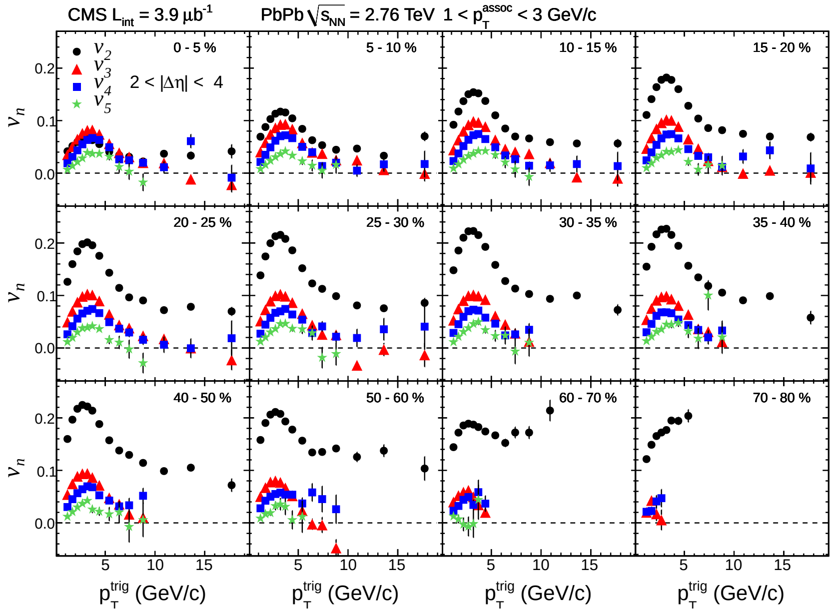

Fig. 5. Fourier harmonics as a function of p_{T} extracted from the long-range part of the dihadron correlation function in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.

4. Conclusions

Several methods have been applied to study angular correlations in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV over wide centrality range. They show different sensitivities to the non-flow correlations and initial geometrical fluctuations which could be used to explore further these influences in the azimuthal anisotropy measurements.

REFERENCES

[1] J.-Y. Ollitrault, *Phys. Rev.* **D46**, 229 (1992).

[2] A.M. Poskanzer, S.A. Voloshin, *Phys. Rev.* **C58**, 1671 (1998).

[3] N. Borghini, P.M. Dinh, J.-Y. Ollitrault, *Phys. Rev.* **C64**, 054901 (2001).

[4] R.S. Bhalerao, N. Borghini, J.-Y. Ollitrault, *Nucl. Phys.* **A727**, 373 (2003).

[5] N. Borghini, R.S. Bhalerao, J.-Y. Ollitrault, *J. Phys. G* **30**, S1213 (2004).

[6] S. Chatrchyan *et al.* [CMS Collaboration], *JINST* **03**, S08004 (2008).

[7] S. Chatrchyan *et al.* [CMS Collaboration], *Phys. Rev.* **C87**, 014902 (2013).

[8] S. Chatrchyan *et al.* [CMS Collaboration], *Phys. Rev. Lett.* **109**, 022301 (2012).

[9] S. Chatrchyan *et al.* [CMS Collaboration], *Eur. Phys. J.* **C72**, 2202 (2012).