Vol. 5 (2012) *Acta Physica Polonica B Proceedings Supplement* No 2

# RESULTS ON ELLIPTIC FLOW AND HIGHER-ORDER FLOW HARMONICS IN Pb + Pb COLLISIONS FROM THE ATLAS DETECTOR AT THE LHC*

Dominik Derendarz

on behalf of the ATLAS Collaboration

The Henryk Niewodniczański Institute of Nuclear Physics PAN
Radzikowskiego 152, 31-342 Kraków, Poland

*(Received December 8, 2011)*

The measurement of elliptic flow and higher-order flow harmonics of charged particles in $\sqrt{s_{NN}} = 2.76$ TeV Pb + Pb collisions with the ATLAS detector is presented. Fourier harmonics $v_2$–$v_6$ were extracted with the event plane and two-particle correlation methods in a broad range of transverse momentum (0.5 GeV $< p_{\mathrm{T}} <$ 20 GeV), pseudorapidity ($|\eta| < 2.5$) and collision centrality (0–80%). Results obtained with the two methods were found to be consistent. Elliptic flow shows rapid rise with $p_{\mathrm{T}}$ up to about 3 GeV followed by a decrease within range 3–8 GeV and then becomes weakly dependent at the highest $p_{\mathrm{T}}$. Similar trend is observed for higher-order harmonics. As a function of pseudorapidity a very weak dependence of all flow harmonics is measured.

DOI:10.5506/APhysPolBSupp.5.401
PACS numbers: 25.75.–q, 25.75.Gz, 25.75.Ld

## 1. Introduction

A rich program of measurements using Pb + Pb collisions is underway with the ATLAS detector [1]. Its main goal is to understand the properties of QCD matter at high temperatures and densities available at the LHC energies. One of the manifestations of the new state of matter formed in relativistic heavy ion collisions is large azimuthal anisotropy of produced particles [2]. At the beginning of the collision, asymmetric shape of interaction region induces pressure gradients in the droplet of the hot medium with the largest pressure within the reaction plane (defined by the impact parameter

* Presented at the Conference "Strangeness in Quark Matter 2011", Kraków, Poland, September 18–24, 2011.

and the beam axis). The initial state asymmetry transforms into the final state anisotropy of produced particle transverse momenta. This anisotropic flow is characterized by $v_n$ coefficients of the Fourier expansion of particles azimuthal angle distribution [3]. The second coefficient, $v_2$, usually called elliptic flow, is related to the approximate elliptical shape of initial state while higher order harmonics are expected to be induced by fluctuations in the initial shape of the interaction region [4]. The ATLAS detector with full acceptance in the azimuthal angle and wide pseudorapidity coverage is a perfect device for azimuthal anisotropies studies.

## 2. Analysis methods

Analysis presented in this paper is based on 8 $\mu\mathrm{b}^{-1}$ of Pb + Pb data collected during the 2010 LHC heavy ion run. The analyzed dataset consists of about $4\times10^7$ minimum bias Pb + Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV selected after rejection of non-collision backgrounds and Coulomb interactions. The coincidence and time correlation between two-arm Minimum Bias Trigger System ($2.1 < |\eta| < 3.9$) and Zero Degree Calorimeter ($|\eta| > 8.3$) were used to obtain clean sample of minimum bias events. Centrality percentiles were determined based on total transverse energy deposited in forward calorimeters (FCal) covering $3.2 < |\eta| < 4.9$.

Flow harmonics were extracted with two independent methods. In the event plane method charged particle tracks, measured in the inner detector ($|\eta| < 2.5$), were correlated with the event plane angle ($\Psi_n$) measured in the first sampling layer of forward calorimeters [5]. In order to maximize the separation between detectors measuring event plane and charged particle tracks, two hemispheres in detector acceptance were defined: positive for $\eta > 0$ and negative for $\eta < 0$. Flow harmonics $v_n = \langle\cos(n[\phi - \Psi_n])\rangle$ were then reconstructed by correlating tracks with event plane from opposite side hemispheres. The sub-events technique provides large $\eta$ gap (at least 3.2 $\eta$ units) which suppresses short range non-flow correlations interfering with flow originating from initial geometry. The final $v_n$ needs to be corrected by resolution correction factor $R = \sqrt{\langle\cos[n(\Psi_n^P - \Psi_n^N)]\rangle}$ which accounts for the experimental event plane resolution. Two-particle azimuthal correlation were used as a second method of $v_n$ measurement [6]. The correlation functions $C(\Delta\phi, \Delta\eta)$ are built from the ratio of the numbers of the same, $N_{\mathrm{s}}(\Delta\phi, \Delta\eta)$, and mixed, $N_{\mathrm{m}}(\Delta\phi, \Delta\eta)$, events particle pairs, where $\Delta\phi$ and $\Delta\eta$ are relative azimuthal angle and pseudorapidity of two particles [7]. Flow harmonics of two-particle correlations, $v_{n,n}$, are extracted from 1-D projection of correlation function in $\Delta\eta$ slices (in the range $2< |\Delta\eta| <5$) via Fourier transform. For the correlation arising only from collective flow it is expected that two-particle harmonics $v_{n,n} = \langle\cos(n\Delta\phi)\rangle$ factorize into product of two single-particle harmonics $v_n = \sqrt{v_{n,n}}$ [8]. This method does not require determination of reaction plane and by taking a ratio the effects from particle reconstruction efficiency and detector acceptance non-uniformities are minimized.

## 3. Results

The transverse momentum and centrality dependence of $v_2$ for charged particle tracks of $|\eta| < 1$ is shown in Fig. 1 [9]. Elliptic flow rises quickly in low $p_{\mathrm{T}}$ region to reach maximum at about 3 GeV then decreases up to 8 GeV and varies weakly beyond. Similar shape of the distribution is observed in all considered centrality bins. Higher order flow harmonics follow the same trend as it is shown in Fig. 2 [7], where $v_2$–$v_6$ are compared in six centrality bins. In general, $v_n$ coefficients are ordered in magnitude with $v_2$ being dominant. The exception is the most central bin (0–5%), where the magnitude of $v_2$ is dropping below $v_3$ and even $v_4$ in the narrow $p_{\mathrm{T}}$ range (2–4 GeV). The elliptic flow signal is strongest in semi-central Pb + Pb collisions (30–50%) and decreases in more central and peripheral interactions while $v_3$–$v_6$ remain approximately constant in all centrality classes. The pseudorapidity dependence of $v_2$ covering 5 $\eta$ units is shown in Fig. 3. Weak pseudorapidity dependence of elliptic flow as well as $v_3$–$v_6$ (shown in [7]) is observed. Interestingly, the elliptic flow $p_{\mathrm{T}}$ dependence at the LHC energy is similar to PHENIX and STAR measurements [9] at the RHIC center-of-mass energy about 14 times lower while $\eta$ dependence is much different from PHOBOS result [10] which shows 30% drop of $v_2$ in the same pseudorapidity range.

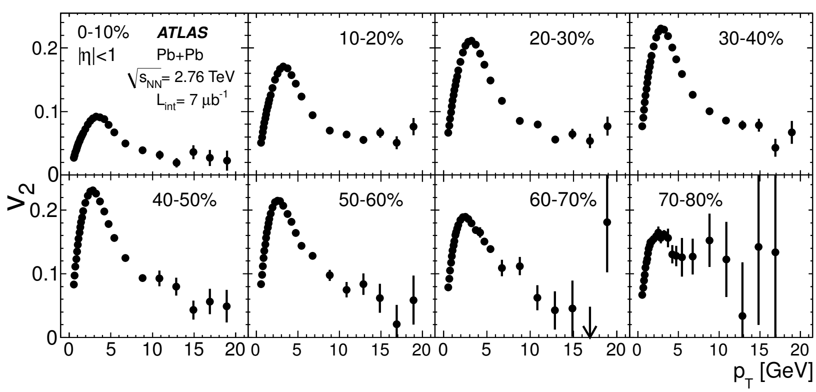


Fig. 1. $v_2(p_{\mathrm{T}})$ for eight centrality bins and $|\eta| < 1$. Error bars indicates statistical and systematic uncertainties added in quadrature [9].

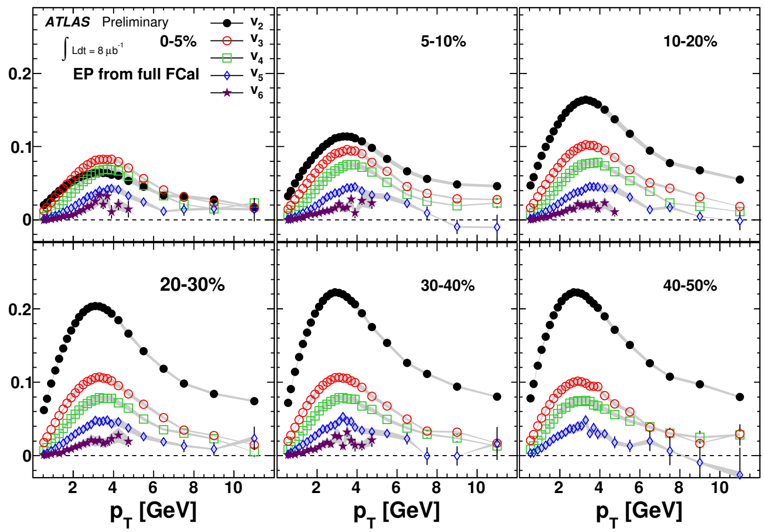


Fig. 2. $v_n(p_\mathrm{T})$ for six centrality bins. Shaded bands denote systematic uncertainties. To improve resolution for higher order flow harmonics event plane from full FCal was used [7].

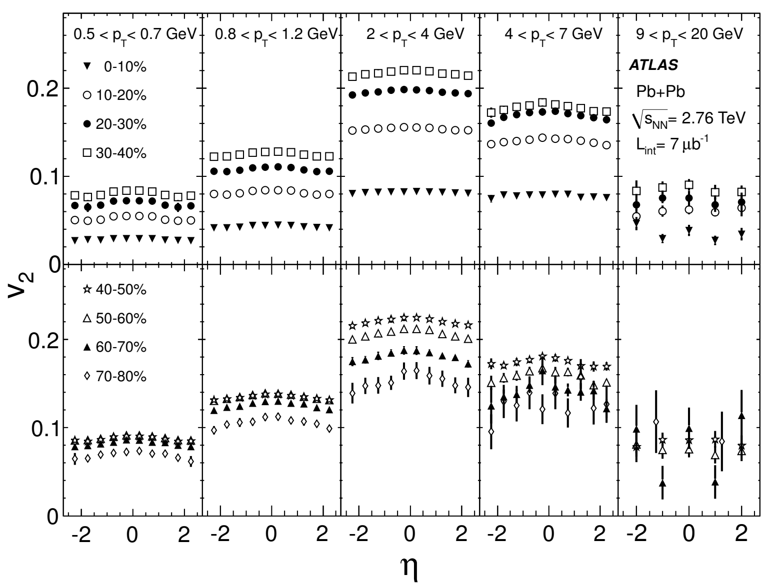


Fig. 3. $v_2(\eta)$ in five $p_\mathrm{T}$ slices and eight centrality bins. Error bars indicates statistical and systematic uncertainties added in quadrature [9].

Comparison of results obtained with the event plane and two-particle correlation methods is shown in Fig. 4 as a function of centrality within 1–2 GeV and 2–3 GeV $p_{\rm T}$ intervals. The centrality dependence of $v_n$ for the two $p_{\rm T}$ ranges were found consistent within systematic uncertainties. The agreement at the level of 5% is observed for harmonics $v_2$–$v_4$, but it worsens to 10% and 15% for $v_5$ and $v_6$ respectively.

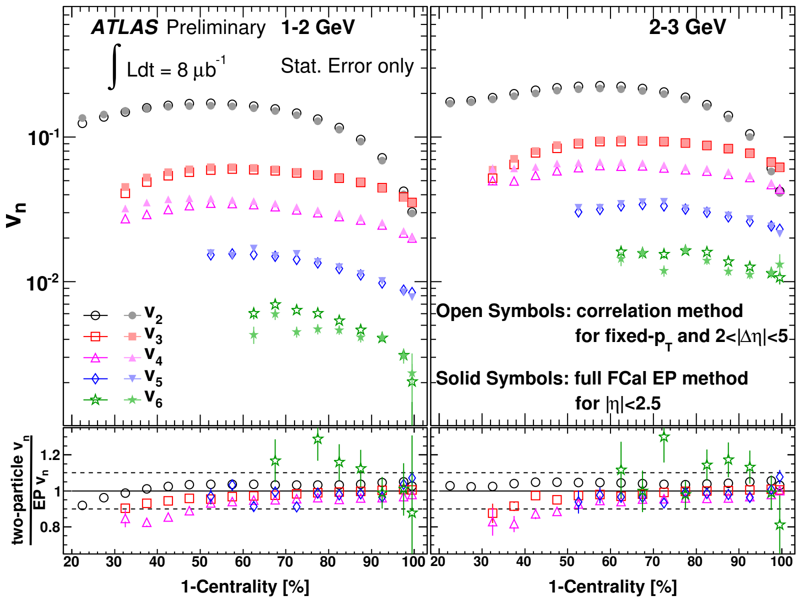


Fig. 4. $v_n$ for charged particles as a function of centrality in two $p_{\rm T}$ bins. Results obtained with two-particle correlation method (open symbols) and event plane method (solid symbols) are compared [7].

## 4. Summary

In summary, $v_2$–$v_6$ harmonics have been measured in Pb + Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV over a broad pseudorapidity, transverse momentum, and centrality range. All harmonics show similar $p_{\rm T}$ dependence, they increase up to $p_{\rm T}$ about 3–4 GeV and decrease for higher $p_{\rm T}$. Weak pseudorapidity dependence of $v_2$–$v_6$ harmonics is observed in the region covering $|\eta| < 2.5$. Results obtained with event plane and two-particle correlation method are consistent within 1–3 GeV $p_{\rm T}$ range.

## REFERENCES

[1] G. Aad *et al.* [ATLAS Collaboration], *JINST* **3**, S08003 (2008).

[2] RHIC White Papers, *Nucl. Phys.* **A757**, 1–283 (2005).

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

[4] B. Alver, G. Roland, *Phys. Rev.* **C81**, 054905 (2010); [*Erratum ibid.* **C82**, 039903 (2010)].

[5] A. Trzupek [ATLAS Collaboration], *J. Phys. G: Nucl. Part. Phys.* **38**, 124163 (2011).

[6] S. Wang *et al.*, *Phys. Rev.* **C44**, 1091 (1991).

[7] The ATLAS Collaboration, ATLAS-CONF-2011-074, `https://cdsweb.cern.ch/record/1352458`

[8] Jiangyong Jia [ATLAS Collaboration], *J. Phys. G: Nucl. Part. Phys.* **38**, 124012 (2011).

[9] The ATLAS Collaboration, submitted to *Phys. Lett.* **B**, `arXiv:1108.6018 [hep-ex]`.

[10] B.B. Back *et al.* [PHOBOS Collaboration], *Phys. Rev.* **C72**, 051901 (2005).