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Charged particle anisotropic flow (v_2, v_3, v_4) in Pb-Pb collisions measured by ALICE

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The elliptic (v_2), triangular (v_3) and quadrangular (v_4) flow coefficients are measured in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV by the ALICE detector at the Large Hadron Collider. Results are reported in a wide pseudorapidity ($|\eta| < 5$) and transverse momentum ($0.2 < p_T < 20$ GeV/c) ranges for different collision centrality classes. The flow coefficients are estimated with the event plane, two- and four-particle cumulant methods. The measured v_2 is positive and depends weakly on transverse momentum for $p_T > 8$ GeV/c. The observed weak centrality dependence of v_3 suggests its origin in fluctuations of the initial energy density in the collision. The centrality dependence of v_4 is also observed to be weak. The results are compared to the measurements at RHIC and LHC and to hydrodynamic model calculations for LHC.

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1. Introduction

In relativistic heavy-ion collisions, the initial spatial anisotropy of the nuclei overlap zone is converted via interactions among contituents into the momentum anisotropy of the produced particles. This phenomenon is called anisotropic flow. It is sensitive to the early times in the collision evolution and its measurement provides information about the properties of the deconfined matter created in a heavy-ion collision [1]. The anisotropic flow is described by coefficients v_n in a Fourier expansion of azimuthal distribution of the produced particles [2]. Elliptic flow (v_2) is dominant in mid-central collisions. The event-by-event fluctuations in the initial energy density of the overlap zone in a heavy-ion collision can result in non-zero odd harmonics at midrapidity.

2. Analysis Details

This analysis is performed on the data sample recorded by the ALICE [3] experiment in the late fall of 2010. The charged particle tracks are reconstructed with the Inner Tracking System (ITS) and Time Projection Chamber (TPC) in the pseudorapidity range $|\eta| < 2.0$ and $|\eta| < 0.8$ respectively. Two Forward Multiplicity Detectors (FMD) with coverages -3.4 $< \eta <$ -1.7 and 1.7 $< \eta <$ 5.0 are used for flow measurements at forward rapidity. Two VZERO counters which cover the pseudorapidity ranges -3.7 $< \eta <$ -1.7 and 2.8 $< \eta <$ 5.1 and the Photon Multiplicity Detector (PMD) with pseudorapidity coverage 2.3 $< \eta <$ 3.9 are used for determination of the collision symmetry planes.

The flow coefficients v_n are estimated using the event plane [4], two- and four-particle cumulant methods [5] denoted as $v_n\{EP\}$, $v_n\{2\}$ and $v_n\{4\}$ respectively. The different methods have different sensitivity to flow fluctuations and correlations unrelated to the azimuthal asymmetry in the initial geometry ("non-flow"). The non-flow correlations in v_n measurement at midrapidity are suppressed by the large rapidity gap provided by the forward PMD and VZERO detectors used for determination of the collision symmetry planes.

3. Results and Discussion

The charged particle v_2, v_3 and v_4 as a function of transverse momentum in different centrality classes are shown in Fig.1. The flow coefficients are measured over a wide transverse momentum range, $0.2 < p_T < 20$ GeV/c for particles at midrapidity, $|\eta| < 0.8$. Results obtained with the event plane method using the PMD and VZERO detectors are in good agreement at all p_T. The difference between $v_2\{EP\}$ and $v_2\{4\}$ is predominantly due to flow fluctuations. v_2 is increasing with p_T up to $p_T \sim 3$ GeV/c and then slowly drops for $3 < p_T < 8$ GeV/c. For $p_T > 8$ GeV/c, the measured v_2 is non-zero, positive and approximately constant. The observed non-zero v_3 seems to orginate from the fluctuation in the initial energy density in the collision. The coefficient v_3 exhibits a weak centrality dependence with a magnitude significantly smaller than that of v_2, except for the most central collisions. The measured $v_{4/\Psi_4}\{EP\}$ does not depend strongly on the collision centrality which refers to a strong contribution from flow fluctuations. Figure 2 (left panel) shows the comparison of our $v_n\{EP\}$ results for 30-40% to the other LHC measurements by the ATLAS [6] and CMS [7] collaborations, and results obtained by STAR [8] at RHIC. Very good agreement

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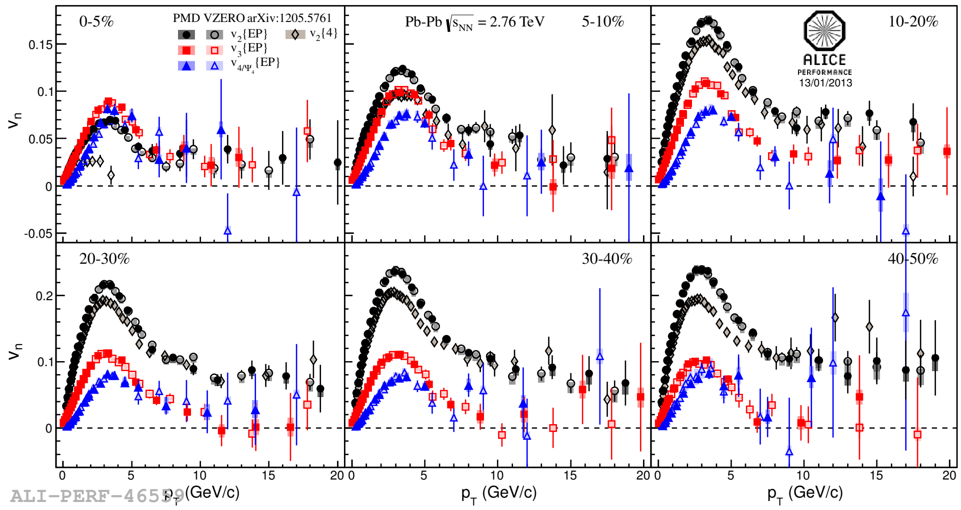

Figure 1: (color online) v_2, v_3, and v_4 of charged particles as a function of transverse momentum for various centrality classes.

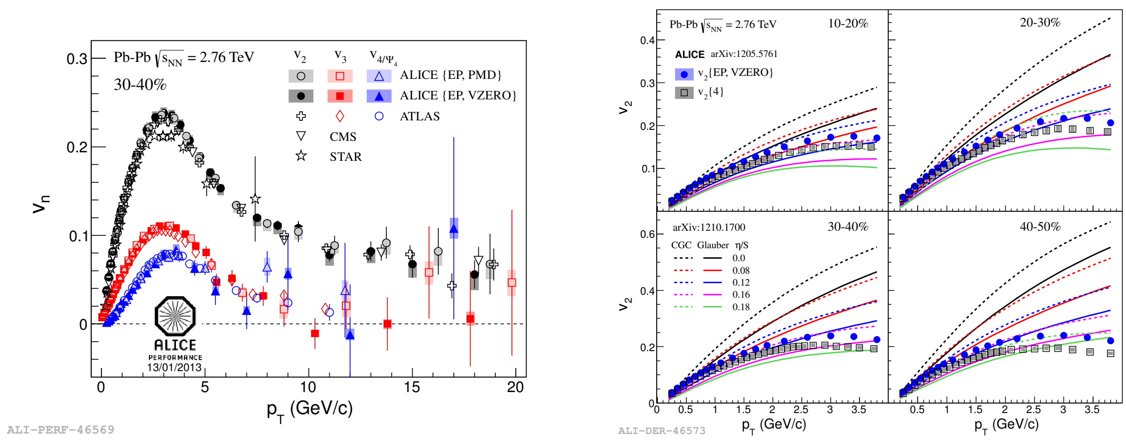

Figure 2: (color online) Left panel: Comparison of the ALICE results on $v_n(p_T)$ obtained with the event plane method to the measurements by ATLAS [6] and CMS [7] at the LHC and STAR [8] at RHIC for Au-Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. Right panel: Comparison of v_2 results to hydrodynamic model calculations [9] using MC Glauber and CGC initial conditions.

is found among the results from the three LHC experiments. $v_2(p_T)$ at RHIC has a similar shape but the peak value is about 10% lower than at LHC. Figure 2 (right panel) shows the comparison of data with hydrodynamic model calculations [9] in different centralities. The value of the shear viscosity to entropy density ratio (η/s) that describes the data is below 0.16 for MC Glauber and ranges between 0.08 to 0.18 for CGC based initial conditions. The pseudorapidity dependence of v_2 and v_3 in various centrality classes is shown in Fig.3. v_2 has a strong centrality dependence for all rapidities, while v_3 has a weak centrality dependence.

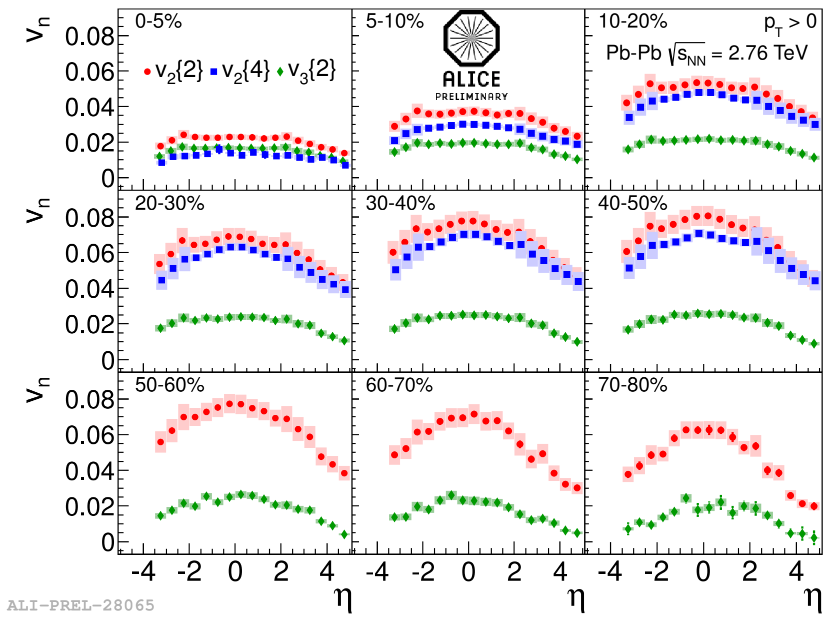

Figure 3: (color online) Pseudorapidity dependence of $v_2\{2\}$, $v_2\{4\}$ and $v_3\{2\}$ in various centrality classes.

4. Summary

We have reported on differential measurements of v_n coefficients over a broad range of pseudorapidity, $|\eta| < 5$ and transverse momentum, $0.2 < p_T < 20$ GeV/c. The $v_2(\eta)$ has a strong centrality dependence at all rapidities, while $v_3(\eta)$ shows a weak centrality dependence. $v_2(p_T)$ at LHC energies is comparable to that at RHIC energies. The measured $v_4(p_T)$ shows a weak centrality dependence. At low p_T, comparison to the hydro calculations suggests a low value of the shear viscosity to entropy density ratio (η/s).

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