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The Compact Muon Solenoid Experiment

Conference Report

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Elliptic azimuthal anisotropy of charged hadrons and neutral pions in PbPb collisions at 2.76 TeV with CMS

Eric Andrew Appelt for the CMS Collaboration

Abstract

The elliptic flow anisotropies of charged particles and neutral pions (π^0s) have been measured by the CMS collaboration for PbPb collisions at a nucleon-nucleon center-of-mass energy of 2.76 TeV. The second Fourier components of the anisotropic azimuthal distribution are obtained using an event-plane technique for π^0s and four different analysis techniques for charged particles: event plane, two- and four-particle cumulants, and Lee-Yang Zeros. These techniques have different sensitivities to non-flow and flow fluctuation effects and their comparison helps disentangle hydrodynamic flow, initial state fluctuations and non-flow correlations. A comparison of the CMS measurements of $v_2(p_T)$ from π^0 mesons and inclusive charged particles indicates a particle-species dependence in the azimuthal anisotropy at the LHC.

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Elliptic azimuthal anisotropy of charged hadrons and neutral pions in PbPb collisions at 2.76 TeV with CMS

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Abstract

The elliptic flow anisotropies of charged particles and neutral pions (π^0s) have been measured by the CMS collaboration for PbPb collisions at a nucleon-nucleon center-of-mass energy of 2.76 TeV. The second Fourier components of the anisotropic azimuthal distribution are obtained using an event-plane technique for π^0s and four different analysis techniques for charged particles: event plane, two- and four-particle cumulants, and Lee-Yang Zeros. These techniques have different sensitivities to non-flow and flow fluctuation effects and their comparison helps disentangle hydrodynamic flow, initial state fluctuations and non-flow correlations. A comparison of the CMS measurements of $v_2(p_T)$ from π^0 mesons and inclusive charged particles indicates a particle-species dependence in the azimuthal anisotropy at the LHC.

The azimuthal anisotropy of charged hadrons and identified particles produced in PbPb collisions are typically characterized by the coefficients (v_n) of Fourier harmonics in an azimuthal distribution (ϕ) of the charged particle yield, $dN/d\phi \propto 1 + \sum_{n=1}^{\infty} 2v_n \cos(n(\phi - \Psi_R))$, where Ψ_R is a reference angle determined event-by-event that corresponds to a "participant plane" defined by the minor axis of the overlap region and the beam direction. The coefficient v_2, or elliptic flow coefficient, is dominant in non-central events due to the typically lenticular shape of the overlap region of the colliding nuclei. The results presented here include detailed measurements of the elliptic flow of charged particles produced in PbPb collisions at $\sqrt{s_{_{NN}}} = 2.76$ TeV in a broad kinematic range of $|\eta| < 2.4$, and $0.3 < p_T < 20$, in the centrality range of 0-80% of the total inelastic PbPb cross-section. Additionally, first measurements of the elliptic flow of neutral pions in the same collisions are presented in the centrality range of 20-80%, and the kinematic range of $|\eta| < 0.8$ and $1.6 < p_T < 8.0$. The low-p_T measurements ($p_T \lesssim 3$ GeV/c) are of interest as they carry information about the collective expansion of the system and the viscosity of the produced medium. The measurements at intermediate and high p_T ($p_T > 3$ GeV/c) are sensitive to the hadronization mechanism and the parton energy loss in the medium.

The CMS detector is described elsewhere [1]. These analyses use the standard CMS minimum bias trigger and heavy-ion event selection [2]. Charged particles are reconstructed using a two-iteration tracking algorithm, with the first iteration employing signals from the silicon strip and pixel detectors, and the second iteration recostructing low-p_T charged particles using only the silicon pixel detectors [3]. For the event plane method, the event plane is determined from the azimuthal energy distribution in the forward hadronic calorimeters. Neutral pions are measured by reconstructing their decay photons ($\pi^0 \to \gamma\gamma$) in the barrel electromagnetic calorimeter

[1] A list of members of the CMS Collaboration and acknowledgements can be found at the end of this issue.

(ECAL). Photons are reconstructed in 3x3 arrays of ECAL crystals, which contain on average 93% of the photon energy [4].

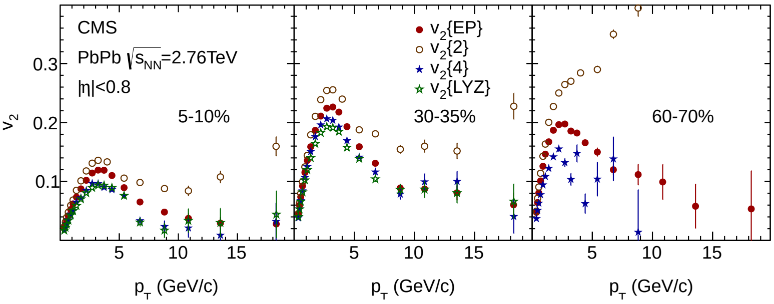

Figure 1: Comparison of the four different methods for measuring v_2 as a function of p_T at mid-rapidity ($|\eta| < 0.8$) for three representative centrality classes given in the figures [3]. The error bars show the statistical uncertainties only.

In Fig. 1, the v_2 of charged particles as a function of p_T is given at midrapidity ($|\eta| < 0.8$) for the event-plane, two-particle cumulant, four-particle cumulant, and Lee–Yang zeros methods, denoted as $v_2\{EP\}$, $v_2\{2\}$, $v_2\{4\}$, and $v_2\{LYZ\}$, respectively [3]. Excepting the $v_2\{2\}$ results in peripheral events which are dominated by non-flow effects at high-p_T, the transverse momentum dependence shows a rise of v_2 up to $p_T \approx 3$ GeV/c and then a decrease.

In Fig 2, the π^0 meson v_2 results using the event-plane method are shown in six centrality classes from 20-30% to 70-80% [4] and compared to inclusive charged particle v_2 measured using the event-plane method. The π^0 meson v_2 is systematically lower than that for inclusive charged particles v_2 between $2.5 < p_T < 5.0$ GeV/c for all six collision centrality intervals. The differences observed between the inclusive charged particle and π^0 meson results may be due to the contribution from baryons which would increase the overall v_2 of the inclusive charged particles, compared to that for neutral pions, assuming a baryon-meson v_2 splitting comparable to that seen at RHIC [5, 6].

In the left panel of Fig. 3, the v_2 obtained from the event-plane and cumulant methods at midrapidity is integrated over the range $0.3 < p_T < 3.0$ GeV/c, scaled by the participant eccentricity, denoted by ϵ or ϵ_{part}, as determined from a Monte Carlo Glauber-model simulation, and plotted as a function of centrality. These data show a near-linear decrease in the eccentricity scaled v_2 from central to peripheral collisions. The values of v_2 from the cumulant methods were scaled with their respective cumulant moments of the participant eccentricity, defined as $\epsilon\{2\}^2 \equiv \langle\epsilon^2_{\text{part}}\rangle$ and $\epsilon\{4\}^4 \equiv 2\langle\epsilon^2_{\text{part}}\rangle^2 - \langle\epsilon^4_{\text{part}}\rangle$. If the hydrodynamic response to the participant eccentricity is linear, i.e. $v_2 \sim \epsilon$, and nonflow effects are negligible, then the identity $v_2\{2\}/\epsilon\{2\} = v_2\{4\}/\epsilon\{4\}$ should hold [7]. In the right panel of Fig. 3, $v_2\{2\}/\epsilon\{2\}$ and $v_2\{4\}/\epsilon\{4\}$ are plotted and agree in the centrality range of 15-40%, suggesting that the difference between these methods can be attributed to their respective sensitivities to event-by-event flow fluctuations.

The PHOBOS experiment at the Relativistic Heavy Ion Collider (RHIC) has observed that the v_2 over a large range of collision energies ranging from $\sqrt{s_{NN}} = 19.6$ GeV to 200 GeV exhibited extended longitudinal scaling when viewed from the rest frame of one of the colliding nuclei [8]. As the measured particles are unidentified in both the CMS and PHOBOS measure-

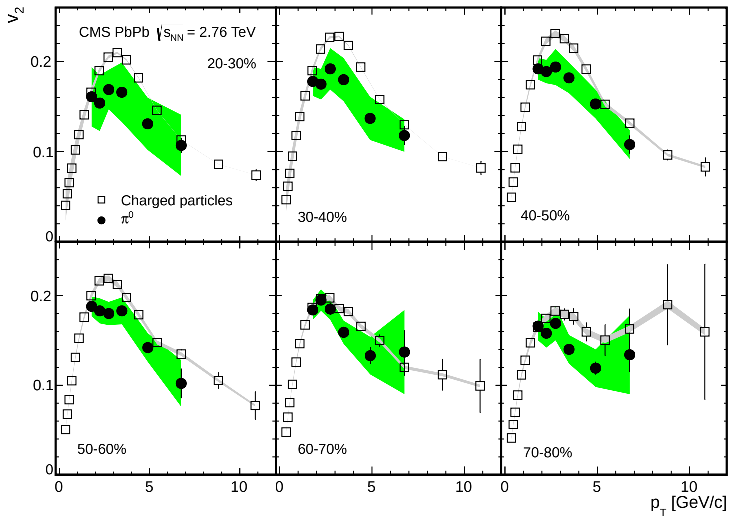

Figure 2: π^0 meson v_2 (solid circles) [4] compared to charged particle v_2 (open squares) [3] for mid-rapidity ($|\eta| < 0.8$). Results are presented as a function of p_T for six centrality intervals (20-30% to 70-80%). Green (gray) shaded bands represent systematic uncertainties associated with π^0 meson (charged particle) v_2 measurements.

ments, the pseudorapidity η^+ (η^-) of the particles in the rest frame of the nucleus moving in the positive (negative) direction is given by $\eta^\pm = \eta \pm y_{\text{beam}}$ where η is the pseudorapidity of the particles in the laboratory or center-of-mass frame, and $y_{\text{beam}} \approx \ln \sqrt{s_{NN}}$[GeV]. In Fig. 4, the left (right) half of each plot shows v_2 in the rest frame of the beam moving in the positive (negative) direction. The CMS results plotted here are obtained from the event-plane method integrated over the range $0 < p_T < 3.0$ GeV/c, where values of $v_2(p_T)$ below $p_T = 0.3$ GeV/c are estimated by extrapolating the charged particle spectrum and $v_2(p_T)$ distribution to $p_T = 0$ by assuming that $v_2(p_T = 0) = 0$. Although the CMS data cover 4.8 units of pseudorapidity, they do not overlap the PHOBOS data when plotted in the rest frames of the colliding nuclei due to the extreme difference in beam energies. The CMS data show a weaker pseudorapidity dependence than the PHOBOS data, and suggest a nearly boost-invariant region which is wider in η for more central events.

The elliptic flow for charged particles has been measured over a broad kinematic range using several experimental techniques. In the centrality range 15-40%, the differences between the methods are consistent with expectations of initial-state eccentricity fluctuations as described by the Glauber model. The strength of the elliptic flow signal at LHC is similar to that observed at lower energies and suggest a longitudinal scaling. At intermediate p_T , particle-species-dependent v_2 is observed similar to previous findings at RHIC.

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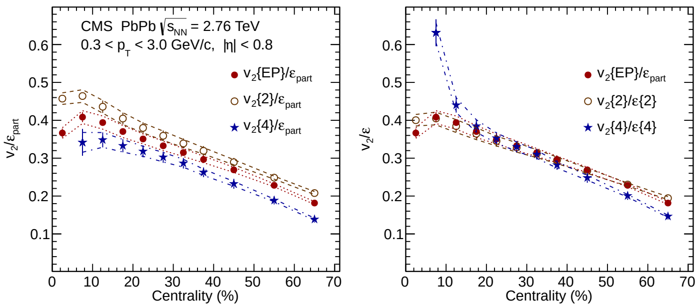

Figure 3: Left panel: Centrality dependence of the p_T-integrated v_2 divided by the participant eccentricity, ε_{part}, measured at mid-rapidity ($|\eta| < 0.8$) for the event-plane, two-particle cumulant, and four-particle cumulant methods [3]. Right panel: The same measurements as in the left panel, but here the two-particle and four-particle cumulant results are divided by their corresponding moments of the participant eccentricity, $\varepsilon\{2\}$ and $\varepsilon\{4\}$. In both panels the error bars show the sum in quadrature of the statistical and systematic uncertainties in the measurement of v_2, and the lines show the systematic uncertainties in the eccentricity determination.

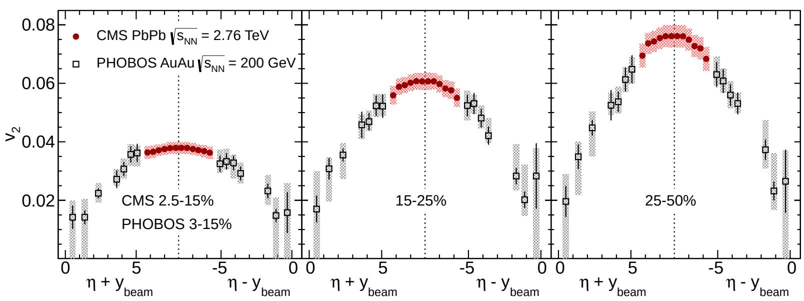

Figure 4: Measured $v_2(\eta)$ from CMS [3] (closed symbols) and PHOBOS [9] (open symbols) in three centrality intervals. The left (right) half of each plot shows v_2 in the rest frame of the beam moving in the positive (negative) direction. The error bars show the statistical uncertainties, and the boxes show the systematic ones.

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