MEASUREMENTS OF CHARGE-DEPENDENT CORRELATIONS WITH CMS*

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Received 1 August 2022, accepted 14 October 2022,
published online 14 December 2022

Charge-dependent azimuthal anisotropy Fourier coefficients are measured with two- and three-particle correlations in pPb and PbPb collisions. The difference between positively- and negatively-charged particles for the second-order two-particle, $v_2\{2\}$, and three-particle, $v_2\{3\}$, coefficients for both pPb and PbPb, and third-order two-particle coefficient, $v_3\{2\}$, for PbPb, are presented. The observed results are challenging the hypothesis that attributes the charge-dependent azimuthal correlations in heavy-ion collisions to the chiral magnetic effect. In addition, the two-particle electric charge balance function is used as a probe to study the charge creation mechanism in high-energy heavy-ion collisions, for the first time in CMS. The balance function is constructed using like and unlike charged-particle pairs. The width of the balance function, both in relative pseudo-rapidity and relative-azimuthal angle, increases from more central collisions to peripheral ones. Narrowing and widening of these widths indicate late and early hadronization, respectively.

DOI:10.5506/APhysPolBSupp.16.1-A41

1. Introduction

The ultra-relativistic nucleus–nucleus (AA) collisions can be used as a powerful tool to investigate the properties of the deconfined state of matter, known as quark–gluon plasma (QGP) [1, 2]. In quantum chromodynamics (QCD), the interactions of chiral quarks with the gluonic fields can produce a chiral imbalance due to the quantum anomaly by violating the local P and CP symmetries [3]. The strong magnetic field created from non-central heavy-ion collisions induces a current, and the electric charge separation is known as the chiral magnetic effect (CME) [4]. Also, a similar process due

* Presented at the 29$^{\text{th}}$ International Conference on Ultrarelativistic Nucleus–Nucleus Collisions: Quark Matter 2022, Kraków, Poland, 4–10 April, 2022.

to the chiral charge separation along the magnetic field is known as the chiral separation effect (CSE). The combined effect of CME and CSE leads to a long-wavelength collective excitation, known as a chiral magnetic wave (CMW) [5]. There will be a development of electric quadrupole moment due to the CMW, resulting in the positive (negative) charges accumulated away from (close to) the reaction plane. The charge-dependent variation of Fourier azimuthal anisotropy (v_2) is calculated for the positive and negative particles and a linear dependence on the observed event charge asymmetry, $A_{\mathrm{ch}} = (N_+ + N_-)/(N_+ - N_-)$. N_+ and N_- are the number of positively- and negatively-charged particles in each event. The elliptic azimuthal anisotropy as a function of charge asymmetry can be written as

$$v_{2,\pm} = v_{2,\pm}^{\mathrm{base}} \mp r A_{\mathrm{ch}} \,. \tag{1}$$

In Eq. (1), $v_{2,\pm}^{\mathrm{base}}$ represents the value in the absence of a charge quadrupole moment from the CMW, and r is the slope parameter. The A_{ch} value is also corrected due to the detector inefficiency and acceptance, called true event charge asymmetry ($A_{\mathrm{ch}}^{\mathrm{true}}$).

2. Results

This article presents the charge-dependent azimuthal anisotropy in pPb and PbPb collisions at $\sqrt{s}_{NN} = 5.02$ TeV using the CMS detector [6].

The v_2 of the positively- and negatively-charged hadrons are calculated using the two-particle cumulant method [7]. We observed a significant non-zero v_2, and the values are increasing (h^-) or decreasing (h^+) with A_{ch} [8]. Figure 1 (right plot) shows the $\langle p_{\mathrm{T}} \rangle$ as a function of charge asymmetry, we observed similar behaviour in average p_{T} as v_2.

The normalized slope parameter r^{norm} is calculated by fitting a linear function for the v_2 and average p_{T} as shown in figure 2. This behaviour is qualitatively consistent with the expectation of the local charge conservation (LCC) effect [9] from resonance decays. Since the v_n has a strong dependence on particle p_{T}, a correlation between the p_{T}-averaged v_n and A_{ch} can also be induced by the LCC mechanism.

The charge-dependent third-order harmonic coefficients were measured in PbPb collisions, and their magnitude was smaller than that of the second-order coefficient [8]. Figure 3 represents the normalized difference in v_n, for $n = 2$ and $n = 3$, as a function of true event charge asymmetry. The normalized slope parameter of v_3, r_3^{norm}, agrees well with r_2^{norm} within statistical uncertainties.

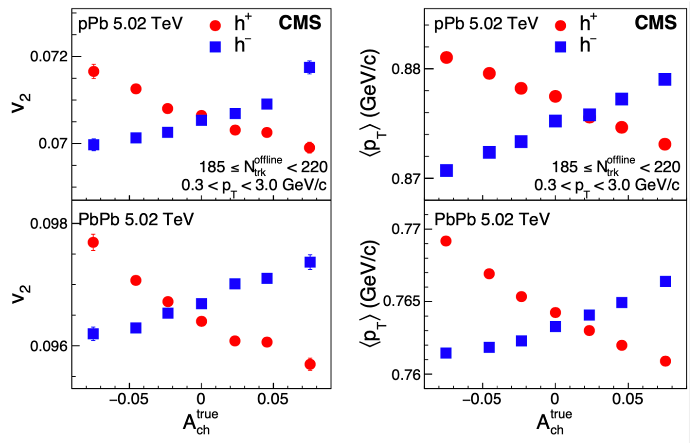

Fig. 1. The left plot shows the v_2 as a function of A_{ch} and the right plot shows the average p_{T} with charge asymmetry for the same and opposite charge pairs in pPb (top plot) and PbPb (bottom plot), respectively.

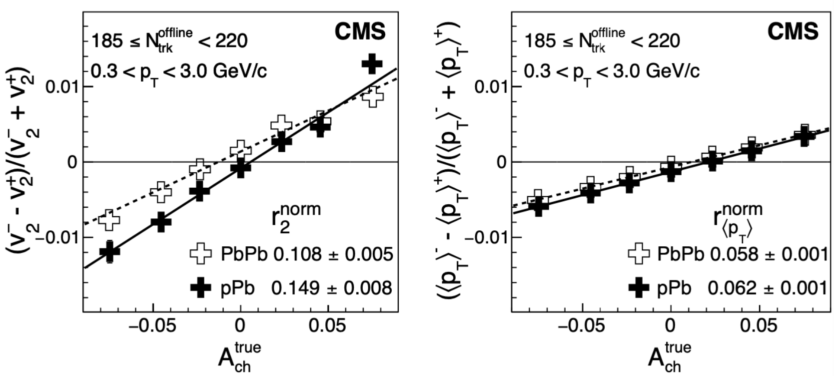

Fig. 2. The left plot shows the normalized v_2 as a function of A_{ch} and the right plot shows the normalized average p_{T} with charge asymmetry in pPb and PbPb collisions, respectively.

We measured the r_2^{norm} and r_3^{norm} as a function of centrality in PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. Over all the centrality ranges, the slope parameter is found consistent within the statistical uncertainties. The CMW effect is expected to be approximated by the second-order event plane with respect to the reaction plane in nucleus–nucleus collisions but highly suppressed for the third-order event plane [10]. The values for r_2^{norm} and r_3^{norm} are independent and similar, and this indicates that an underlying physics mechanism is unrelated to the CMW effect and, instead, can be qualitatively explained by the LCC effect.

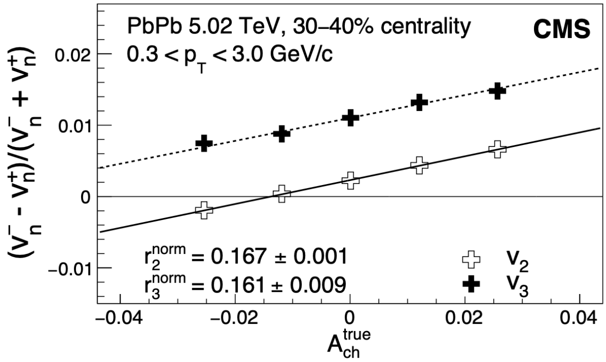

Fig. 3. The normalized difference of v_n for the same and opposite charge pairs, $(v_n^+ - v_n^-)/(v_n^+ + v_n^-)$ in PbPb collisions in 30–40% centrality.

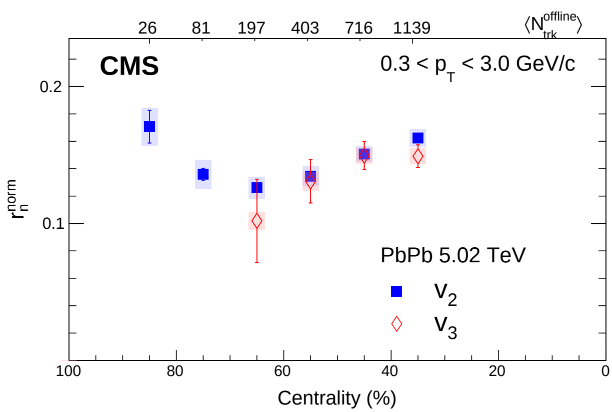

Fig. 4. The linear slope parameters, $r_2^{\rm norm}$ and $r_3^{\rm norm}$, as functions of the centrality class in PbPb collisions. Average $N_{\rm trk}^{\rm offline}$ values for each centrality class are indicated on the top axis. Statistical and systematic uncertainties are indicated by the error bars and shaded regions, respectively.

Figure 5 shows the normalized slope parameters for v_2 and $\langle p_{\rm T}\rangle$ in pPb and PbPb collisions, respectively. We observed that normalized slope parameter $r^{\rm norm}$ values, for the both v_2 and $\langle p_{\rm T}\rangle$ are found to have a weak dependence on the event multiplicity for both pPb and PbPb collisions, with values for $\langle p_{\rm T}\rangle$ approximately half of those for v_2. Normalized slope parameters are larger in pPb than PbPb collisions for the overlapping multiplicity region, which is not expected in the CMW context and may indicate a collision system dependence on the LCC.

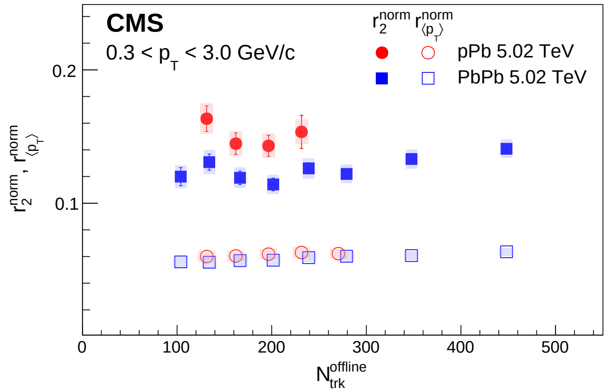

Fig. 5. The linear slope parameters, r_2^{norm} and $r_{\langle p_{\mathrm{T}}\rangle}^{\mathrm{norm}}$, as functions of event multiplicity in pPb and PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. Statistical uncertainties are indicated by the error bars and systematic uncertainties are indicated by shaded regions.

3. Summary

In this article, we discussed the charge-dependent Fourier coefficients of the azimuthal anisotropy as a function of the charge asymmetry in pPb and PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. A significant value of normalized slope parameters of v_2 coefficient is observed in pPb collisions, as well as in PbPb collisions over a wide range of charged particle multiplicities. A similar slope parameter for v_2 and v_3 coefficients are observed for the various centrality in PbPb collisions. A significant value of event-averaged transverse momenta of positively- and negatively-charged particles is observed in both pPb and PbPb collisions. The above-presented results using the CMS phase-space window for $\sqrt{s_{NN}} = 5.02$ TeV, are not expected from the chiral magnetic wave as the dominant physics mechanism. In addition, they are qualitatively consistent with predictions based on the LCC effect model. This indicates that the CMW is not the main source for the charge-dependent azimuthal anisotropies found in pPb and PbPb collisions.

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