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Measurements of the chiral magnetic effect in Pb–Pb collisions with ALICE

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Abstract

We present the measurement of the charge-dependent 3-particle azimuthal correlation for unidentified charged particles in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV in ALICE. The results are compared with corresponding results from Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 2.76 TeV. We observe no significant difference in the charge-sensitive 3-particle correlator (γ_{112}) between the two collision energies. Charged-dependent mixed-harmonic correlator (γ_{132}) is also presented and compared with the predictions from a blast-wave model incorporating local charge conservation.

Keywords: 3-particle correlator, charge separation, CME, ALICE.

1. Introduction

It has been speculated that a heavy-ion collision can give rise to a very strong magnetic field $\vec{B}$ ($\sim$m$_\pi^2$ GeV$^2/c^4$) due to the relativistic motion of charged nuclei [1]. This magnetic field can interact with the non-trivial topological charge present in the hot and dense medium of quarks and gluons (known as QGP), and create a non-zero current along $\vec{B}$. The end result of this interaction is a charge asymmetry along the direction of $\vec{B}$. This phenomenon is called the Chiral Magnetic Effect or CME [2]. On average, $\vec{B}$ is perpendicular to the reaction plane angle, Ψ_{RP}, which is defined as the angle between the impact parameter and the laboratory x-axis. Since we cannot measure the impact parameter, we use the symmetry plane angle (Ψ_{n}) for each harmonic n. On average, the 2^{nd} order symmetry plane (Ψ_2) measures the direction of Ψ_{RP}. Therefore, any charge difference along $\vec{B}$ can be measured with respect to Ψ_2. The 3-particle correlator to study the CME effect was first suggested in [3], it can be generalized as,

$$\gamma_{\mathrm{nmp}} = \cos[\mathrm{n}\phi_\alpha + \mathrm{m}\phi_\beta - (\mathrm{n}+\mathrm{m})\Psi_{\mathrm{k}}], \tag{1}$$

where ϕ_α and ϕ_β are the azimuthal angles of two particles from the same event with either opposite or the same charge and Ψ_{k} is the k$^{\mathrm{th}}$ order symmetry plane. The symmetry plane Ψ_{k} is defined as,

$$\Psi_{\mathrm{k}} = \frac{1}{\mathrm{k}} \tan^{-1} \frac{Q_{\mathrm{k,y}}}{Q_{\mathrm{k,x}}}, \tag{2}$$

where $Q_{\mathrm{k,y}} = \sum_{i=1}^{M} \sin(\mathrm{k}\phi_{\mathrm{i}})$ and $Q_{\mathrm{k,y}} = \sum_{i=1}^{M} \cos(\mathrm{k}\phi_{\mathrm{i}})$ are the components of the flow vector $\vec{Q}_{\mathrm{k}}$ for an event with multiplicity M. The first harmonic γ_{112} is sensitive to charge separation due to CME as Ψ_2, on

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average, is correlated (perpendicular) to $\vec{B}$. The leading backgrounds to this correlator are collective flow (v_2), weak-decay pairs (of opposite sign) and local charge conservation (which can be studied in balance function measurements). Previous measurements done at RHIC and at the LHC have shown that the first harmonic γ_{112} has the same strength in both Au–Au and Pb–Pb collisions despite the ten fold difference in the collision energy [4, 5]. CMS collaboration measured charge dependent 3-particle correlation in smaller system which showed that the correlation strength is same in p–Pb and Pb–Pb [6]. A recent measurement by ALICE used the event-shape-engineering (ESE) technique to classify events according to the 2^{nd} order flow vector and put a constrain over the strength of the CME signal to be in the range 26% to 33% at a 95% confidence level [7]. However, more recent study by CMS collaboration also used ESE technique and mixed harmonic correlator γ_{123} to put a stringent constrain of CME fraction of 7% (with 95% confidence) for Pb–Pb collisions [8]. In this analysis we follow an approach to disentangle the background by measuring mixed and higher harmonics such as γ_{224}, γ_{132} and γ_{123}. These mixed and higher harmonic correlators are not sensitive to CME due to the inclusion of higher order symmetry planes (k > 2), which do not have any correlation with $\vec{B}$ [8]. Therefore, mixed and higher harmonics would contain mostly background, which is also present in γ_{112} along with the CME signal. A theoretical model, *e.g.*, blast-wave model incorporating local charge conservation [7] could be tuned to reproduce the background as measured by γ_{132}, γ_{123} and γ_{224}. Then, this model can predict the background contribution to γ_{112} and enable us to quantify the CME signal measured in data. The study of γ_{112} with identified particles will allow us to investigate the particle-type dependence of the CME.

2. The ALICE detector

The ALICE detector consists of many sub-detector systems [9, 10]. For the analysis with unidentified charged particles we have used the TPC and the ITS for the tracking and the V0 detectors (V0A and V0C) for the symmetry-plane calculation and the centrality estimation. A total of 34 million minimum-bias Pb–Pb events at $\sqrt{s_{\rm NN}}$ = 5.02 TeV were analyzed. Events with the z-component of the collision vertex lying between ±10 cm from the nominal position (center of the ALICE tracking detectors) and at least two charged particles have been used for the analysis. A strict selection criteria on the distance of closest approach (DCA) is applied for each charged particle with respect to the event vertex to minimize the secondary particles (such as those from weak decays, particles originating from beam−material or beam−gas events). Charged particles are selected if they have at least one tracking point originating in the ITS which also helps to remove secondaries. The correlation on the number of tracks from ITS and from TPC has been used to remove pile-up events. To take into account the detector inefficiency the charge particles are weighted accordingly. These weights are evaluated using simulated tracks from Monte-Carlo event generators convoluted with a detector response. Finally, the inverse of the azimuthal distribution of the charged particles (averaged over all events of a particular class) are used as weights to account for non-uniform azimuthal acceptance (such as dead/inactive sectors of TPC). The variation of all these selection criteria is used to determine the systematic uncertainties in the analysis.

3. Results and Discussion

Figure 1 shows the γ_{112} correlator as a function of centrality measured in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV. The measurements are also compared with results from Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV [5]. Despite the two fold increase in the center-of-mass energy we do not see any significant change in the magnitude of the correlator for the same-sign and opposite-sign pairs. We can observe from other measurements that the background to the γ_{112} correlator (such as elliptic flow v_2, and width of the balance function) does not change much for these two colliding energies [11, 12]. Therefore, the agreement of γ_{112} in these two colliding energies suggests that there is no apparent enhancement of the CME signal. Figure 2 shows the mixed harmonic γ_{132} correlator as function of centrality measured in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV. The data dave been compared with a Blast-wave + LCC model and shown as the continuous thick lines. The model clearly under predicts the opposite sign results, which is to be expected as the model does

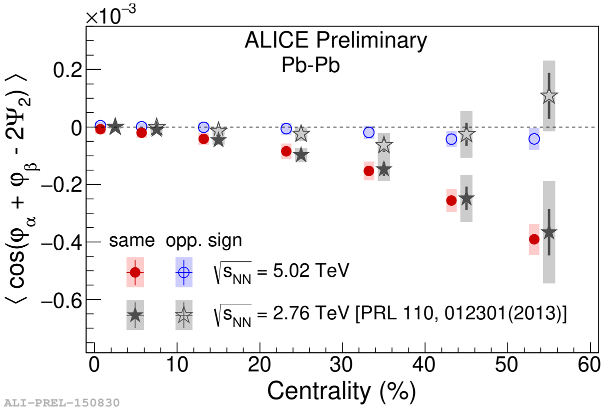

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Fig. 1. Opposite-sign (red) and same-sign (blue) γ_{112} vs. centrality. The error bars and bands on each marker corresponds to statistical and systematic uncertainty, respectively.

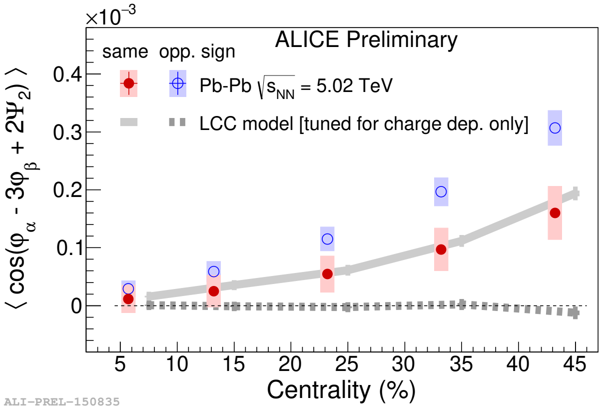

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Fig. 2. Opposite-sign (red) and same-sign (blue) γ_{132} vs. centrality. The error bars and bands on each marker corresponds to statistical and systematic uncertainty, respectively. The solid lines corresponds to the model predictions (see text for details).

not include all possible background sources (*e.g.* the model does not include weak decays, resonances). Further improvement to the model could give a better agreement to reproduce the measured mixed and higher harmonic correlators. The development of the model and comparison of the model predictions with other mixed and higher harmonics (*e.g.* γ_{123} and γ_{224}) will be investigated in the future.

Fig. 3 shows the single identified γ_{112} as a function of the average transverse momentum for the 30–50% central events in Pb–Pb at $\sqrt{s_{\rm NN}}$ = 2.76 TeV. The γ_{112} with one identified pion which is found to be similar to that for inclusive charge particles (shown by solid horizontal bands). The results for protons indicate a particle type dependence although the large systematic uncertainty prevents a conclusion. With the new data expected for Run 3 and Run 4 at the LHC, we can significantly reduce the statistical/systematic uncertainty for γ_{112} correlations with one and two identified hardons.

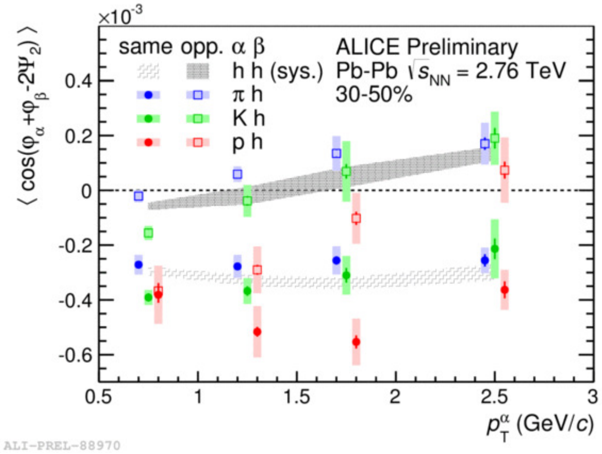

Fig. 3. Single identified opposite-sign (open) and same-sign (filled) γ_{112} vs. average transverse momentum. The error bars and bands corresponds to statistical and systematic uncertainty respectively

4. Summary

We have presented the γ_{112} and γ_{132} correlator as a function of centrality in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV. A comparison of γ_{112} with earlier results (Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV) shows no significant increase in the signal or the background. The γ_{132} correlator from data has been compared with a prediction from a Blast-wave + LCC model (which is tuned to reproduce the measured elliptic flow in data) as an attempt to estimate the background to γ_{112}. Further improvement of the Blast-wave + LCC model is ongoing to describe other mixed and higher harmonic correlators (*e.g.* γ_{123} and γ_{224}) and estimate the CME contribution to γ_{112}. A single identified γ_{112} correlator is presented for mid central (30–50%) events in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV. A slight hint of particle type dependence is observed albeit with a large systematic uncertainty. The larger data sample from ALICE in the Run 3 and Run 4 period would allow us to draw more definitive conclusions about particle-type dependence of γ_{112}.

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