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Search for CME in U+U and Au+Au collisions in STAR with different approaches of handling backgrounds

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Abstract

The chiral magnetic effect (CME) refers to charge separation along a strong magnetic field between left- and right-handed quarks, caused by interactions with topological gluon fields from QCD vacuum fluctuations. We present two approaches to handle the dominant elliptic flow (v_2) background in the three-particle correlator, $\Delta\gamma_{112}$, sensitive to CME.

In the first approach, we present the $\Delta\gamma_{112}$ and $\Delta\gamma_{123}$ measurements in U+U and Au+Au collisions. While hydrodynamic simulations including resonance decays and local charge conservation predict that $\Delta\gamma_{112}$ scaled by $N_{\rm part}/v_2$ will be similar in U+U and Au+Au collisions, the projected B-field exhibits a distinct difference between the two systems and with varying $N_{\rm part}$. Therefore, U+U and Au+Au collisions provide configurations with different expectations for both CME signal and background. Moreover, the three-particle observable $\Delta\gamma_{123}$ scaled by $N_{\rm part}/v_3$ provide baseline measurement for only the background.

In the second approach, we handle the v_2 background by measuring $\Delta\gamma_{112}$ with respect to the planes of spectators measured by Zero Degree Calorimeters and participants measured by Time Projection Chamber. These measurements contain different amounts of contributions from CME signal (along B-field, due to spectators) and v_2 background (determined by the participant geometry). With the two $\Delta\gamma_{112}$ measurements, the possible CME signal and the background contribution can be determined. We report such a measurement at Au+Au 27 GeV with the newly installed event plane detector, and report the new findings in U+U system where the spectator-participant plane correlations are expected to differ from those in Au+Au collisions.

Keywords: QCD, heavy-ion collisions, chiral magnetic effect, spectators plane, participant plane

1. Introduction

Quark interactions with fluctuating topological gluon field can induce chirality imbalance and local parity violation in quantum chromodynamics (QCD) [1, 2, 3]. This can lead to electric charge separation in the presence of a strong magnetic field (B), a phenomenon known as the chiral magnetic effect (CME) [4, 5]. Such a strong B may be present in non-central heavy-ion collisions, generated by the spectator protons at early times [6, 7]. Extensive theoretical and experimental efforts have been devoted to the search for the CME-induced charge separation along B in heavy-ion collisions [8, 9, 10, 11].

2. Results

We present two approaches to handle the dominant elliptic flow (v_2) background in the observable, $\Delta\gamma_{112}$ (charge separation across second-order event plane), sensitive to CME.

In the first approach, we present the $\Delta\gamma_{112}$, $\Delta\gamma_{123}$ and $\Delta\gamma_{132}$ measurements in U+U and Au+Au collisions. The systematic studies of the $\Delta\gamma_{112}$, $\Delta\gamma_{123}$ and $\Delta\gamma_{132}$ in those two systems can provide insights on the CME signal and background behaviors. Figure 1 left upper panel show the expected B-field from MC-Glauber calculations [12], which indicate that U+U and Au+Au have large B-field difference at large N_{part}. Charge separation driven by CME should be sensitive to such difference. On the other hand, background model studies using hydrodynamic simulations [13] indicate background to be similar between U+U and Au+Au as seen in Fig. 1 left lower panel. Furthermore, the third harmonic event-plane (ψ_3) is not expected to be correlated with the magnetic field. One thus does not expect CME contribute to $\Delta\gamma_{123}$.

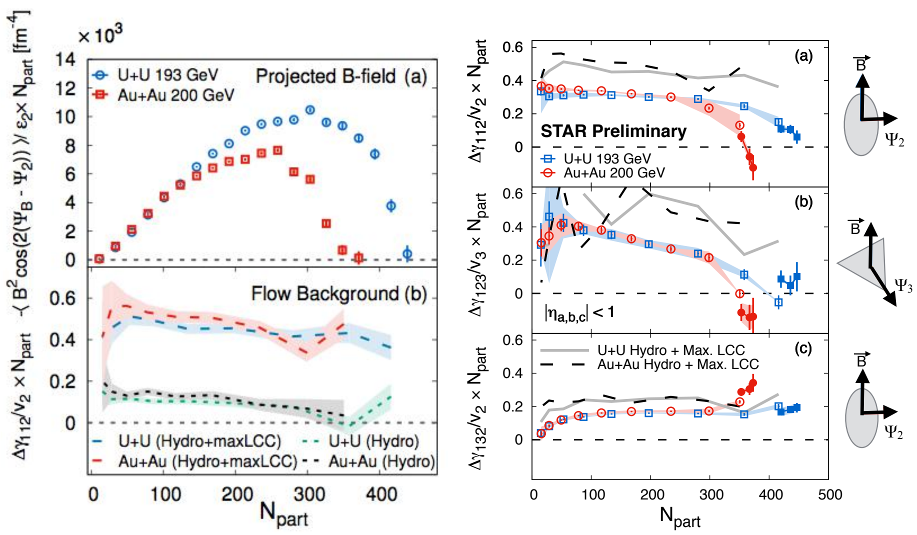

Fig. 1. (Left upper) Predictions from MC-Glauber model [12] for projected magnetic field in Au+Au and U+U collisions. (Left bottom) Predictions for flow driven background using hydrodynamic simulations [13]. (Right) The $\Delta\gamma_{112}$, $\Delta\gamma_{123}$ and $\Delta\gamma_{132}$ measurements in U+U and Au+Au collisions.

Figure 1 right panels show the $\Delta\gamma_{112}$, $\Delta\gamma_{123}$ and $\Delta\gamma_{132}$ measurements in U+U and Au+Au collisions. Background contribution based on hydrodynamic simulations with local charge conservation and global momentum conservation are included for comparison. The mixed-harmonic correlations do not follow signal-only or background-only expectations. Interesting features in ultra-central collisions are observed, which need further investigations.

In the second approach, we study the $\Delta\gamma$ measurements with respect to participant plane (ψ_{PP}) and spectator plane (ψ_{SP}). The CME refers to charge separation along a strong magnetic field. The magnetic field is mainly produced by spectator protons in heavy ion collisions, strongest perpendicular to the ψ_{SP}. On the other hand, the major elliptic flow background is determined by the participant geometry, largest in the ψ_{PP}. The ψ_{SP} and the ψ_{PP} can be assessed, experimentally in STAR, by the spectator neutrons in zero degree calorimeters, ψ_{ZDC}, and by mid-rapidity particles in the time projection chamber, ψ_{TPC}, respectively. The $\Delta\gamma$ measurements with respect to ψ_{ZDC} and ψ_{TPC} can therefore resolve the possible CME signal (and the background). Consider the measured $\Delta\gamma$ to be composed of the v_2 background and the CME signal:

$$\Delta\gamma\{\psi_{TPC}\} = \Delta\gamma_{CME}\{\psi_{TPC}\} + \Delta\gamma_{Bkg}\{\psi_{TPC}\},\ \Delta\gamma\{\psi_{ZDC}\} = \Delta\gamma_{CME}\{\psi_{ZDC}\} + \Delta\gamma_{Bkg}\{\psi_{ZDC}\}. \quad (1)$$

Assuming the CME is proportional to the magnetic field squared and background is proportional to v_2 [14], both projected onto the ψ direction, we have

$$\Delta\gamma_{CME}\{\psi_{TPC}\} = a\Delta\gamma_{CME}\{\psi_{ZDC}\},\ \Delta\gamma_{Bkg}\{\psi_{ZDC}\} = a\Delta\gamma_{Bkg}\{\psi_{TPC}\}, \quad (2)$$

where $a = \langle\cos 2(\psi_{\rm ZDC} - \psi_{\rm TPC})\rangle$. The parameter a can be readily obtained from the v_2 measurements:

$$a = v_2\{\psi_{\rm ZDC}\}/v_2\{\psi_{\rm TPC}\}. \tag{3}$$

The CME signal relative to the inclusive $\Delta\gamma\{\psi_{\rm TPC}\}$ measurement is then given by

$$f^{\rm EP}_{\rm CME} = \Delta\gamma_{\rm CME}\{\psi_{\rm TPC}\}/\Delta\gamma\{\psi_{\rm TPC}\} = (A/a - 1)(1/a^2 - 1), \tag{4}$$

where

$$A = \Delta\gamma\{\psi_{\rm ZDC}\}/\Delta\gamma\{\psi_{\rm TPC}\}. \tag{5}$$

Note the only two free parameters a and A can be measured experimentally.

Applying this method, we have previously reported the measurements of possible CME signal fraction in 200 GeV Au+Au collisions, revealing dominant background contribution [15]. Here, we report our findings in U+U collisions where the spectator-participant plane correlations are expected to differ from those in Au+Au collisions. Figure 2 upper panels show the measured v_2 (left) and $\Delta\gamma$ (right) with respect to the $\psi_{\rm ZDC}$ and $\psi_{\rm TPC}$, as functions of the collision centrality. Figure 2 bottom panels show the ratio of v_2 (left) measured with respect to the $\psi_{\rm ZDC}$ and that with respect to $\psi_{\rm TPC}$, the a in Eq. 3, and the ratio of $\Delta\gamma$ (right), the A in Eq. 5, as functions of the collision centrality in Au+Au 200 GeV and U+U 193 GeV. Data indicate difference in v_2 between central U+U and Au+Au. And the "a" and "A" are similar both in trend and magnitude, which indicate background contribution dominants in the $\Delta\gamma_{112}$ measurements.

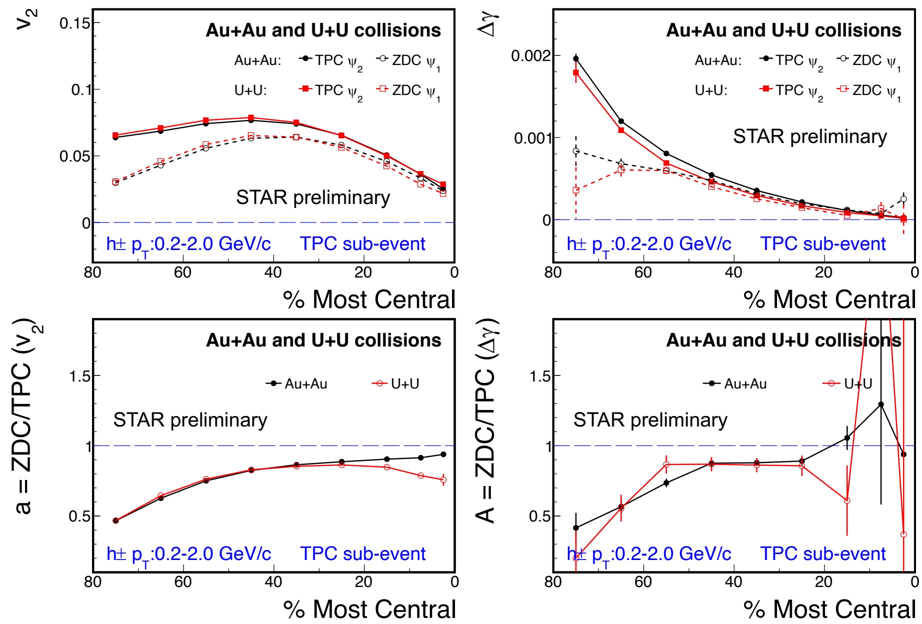

Fig. 2. The centrality dependences of the v_2 (Upper left) and $\Delta\gamma$ (Upper right) measured with respect to the ZDC and TPC event planes. The corresponding ratios of the v_2 (Bottom left) and $\Delta\gamma$ (Bottom right) measured with respect to that two planes.

Figure 3 show the extracted CME fractions ($f_{\rm CME}$) at Au+Au 200 GeV and U+U 193 GeV. The combined results is $f_{\rm CME} = 8 \pm 4 \pm 8\%$.

At Au+Au 27 GeV, the differential $\Delta\gamma$ measurements can be achieved by the newly installed Event Plane Detector (EPD) ($2.1 < |\eta| < 5.1$) [16]. At this energy, the rapidity of the colliding beam (y_{beam}=3.4) falls in the middle of acceptance of EPD. Therefore the EPD can provide an unique way to search for CME using both $\psi_{\rm PP}$, by outer EPD, and $\psi_{\rm SP}$, by inner EPD. Figure 4 upper panel shows the multiplicity and v_2 scaled $\Delta\gamma$ measurements with respect to $\psi_{\rm PP}$ and $\psi_{\rm SP}$ from EPD [17]. The bottom panel show that the corresponding ratio of v_2 or $\Delta\gamma$ measurements with $\psi_{\rm SP}$ over the one with $\psi_{\rm PP}$ is consistent with unity with large uncertainty, indicating CME fraction is consistent with zero. More quantitative studies are in progress.

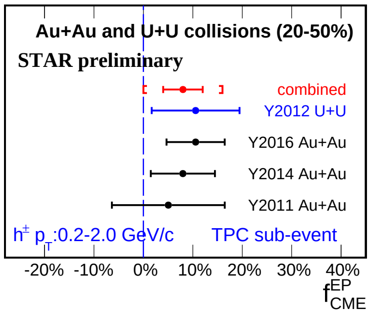

Fig. 3. The extracted CME fractions (f_{CME}) from Au+Au 200 GeV and U+U 193 GeV.

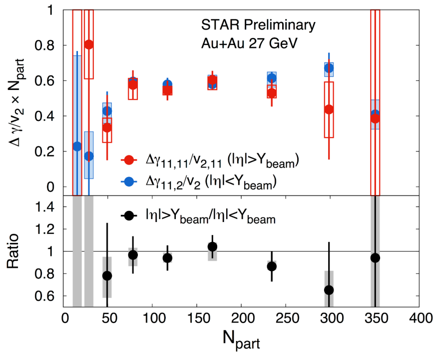

Fig. 4. (Upper) The multiplicity and v_2 scaled $\Delta\gamma$ measured with respect to participant and spectator planes from EPD, (Bottom) the corresponding ratio between participant and spectator planes.

3. Summary

In summary, we report mixed-harmonic three-particle correlations studies in Au+Au 200 GeV and U+U 193 GeV collisions. The results indicate that background models capture most of the observed trends. Meanwhile interesting features are observed in ultra-central Au+Au and U+U collisions, which need further investigations. We also report v_2 and $\Delta\gamma$ measurements with respect to ψ_{ZDC} and ψ_{TPC}, and extract the possible CME signal fraction assuming the proportionality of the CME and background to the projection onto the corresponding plane. The extracted possible CME fraction is $(8 \pm 4 \pm 8)\%$ averaged over 20-50% centrality in Au+Au 200 GeV and U+U 193 GeV collisions. We further explore the Au+Au 27 GeV data, where the newly installed EPD can be sensitive to both spectator and participant planes.

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