SEARCH FOR CHIRAL MAGNETIC EFFECTS IN AU+AU COLLISIONS AT STAR

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We report the STAR's measurements of the electric charge separation with respect to the reaction plane in Au + Au collisions at $\sqrt{s_{NN}} = 200, 62.4, 39, 27, 19.6, 11.5$ and 7.7 GeV. It is believed to be a probe to the possible Local Parity Violation in heavy ion collisions. We also report the measurements of azimuthal anisotropy, v_2, of charged pions as a function of event-by-event charge asymmetry, $A_{\rm ch}$. We found that the v_2 of $\pi^-(\pi^+)$ linearly increases (decreases) with the increasing charge asymmetry. The slope parameter (r) of the $v_2(A_{\rm ch})$ between π^- and π^+ shows similar centrality dependency to calculations based on the Chiral Magnetic Wave and it only shows weak energy dependency at $\sqrt{s_{NN}} = 200, 62.4, 39, 27, 19.6$ GeV.

1 Introduction

In relativistic heavy ion collisions a hot and dense quark-gluon matter may be created in the collision region, where the chiral symmetry may be restored. On the other hand, the spectators in mid-central collisions can create extremely strong magnetic field in the center of the collision region. The peak intensity can reach up to $eB_y \approx m_\pi^2$ [1]. Two phenomena Chiral Magnetic Effect (CME) [1] and Chiral Separation Effect (CSE) [2,3] characterize the interplay between the quark-gluon matter and the magnetic field.

The CME is the interplay between a non-zero axial chemical potential and the magnetic filed, which separates electric charge along the magnetic field. Since the magnetic field generated in heavy ion collisions is perpendicular to the reaction plane, electric charge separation with respect to the reaction plane beyond the statistical fluctuation is expected to be observed due to CME. STAR and PHENIX experiments at RHIC and ALICE experiment at LHC have measured the charge separation in Au + Au [4,5,6,7] and Pb + Pb [8] collisions and provide possible evidences for the possible CME. The CSE refers to the chiral charge separation alone the magnetic field due to the interplay between a non-zero vector chemical potential and the magnetic field.

The CME and CSE can actually induce each other and make a collective excitation called Chiral Magnetic Wave (CMW) [9], which is a density wave of electric charge and topological charge . The CMW in heavy ion collisions induces an electric quadrupole moment in the fireball created, which acquires more negative charge near the equator of the fireball and more positive charge near the two poles. This configuration can be reflected in the azimuthal anisotropy, v_2, of final state charged particles, in particular by charged pions as argued by theorists [10]. Based on the idea of CMW, there is another charge asymmetry dependent part of the v_2 on top of the baseline $v_2(\pi^{\pm})$.

$$v_2(\pi^{\pm}) = v_2^{\text{base}}(\pi^{\pm}) \mp \left(\frac{q_e}{\bar{\rho}_e}\right) A_{\text{ch}}, \tag{1}$$

where $A_{\text{ch}} = (N_+ - N_-)/(N_+ + N_-)$ is the event-by-event charge asymmetry, q_e reflects the electric quadrupole and $\bar{\rho}_e$ is the charge density. The v_2 difference between π^+ and π^- caused by the CMW can be written as

$$\Delta v_2^{\text{CMW}} = v_2(\pi^-) - v_2(\pi^+) \approx r A_{\text{ch}}. \tag{2}$$

The slope parameter $r = 2(q_e/\bar{\rho}_e)$ will be our interested observable, which represents the electric quadrupole momentum induced by CMW.

In these proceedings, we will present the charge separation with respect to the reaction plane measured by STAR in Sec. 2. Charge asymmetry dependency of charged pions' v_2 will be presented in Sec. 3.

2 Charge Separation with respect to the Reaction Plane

If there are small bubbles, where the parity is locally violated (LPV), created in heavy ion collisions, the Chiral Magnetic Effect will cause electric charge separation alone the magnetic field. This will lead the same charge emission tend to stay in the same side of the reaction plane. A three-particle correlator is proposed to measure such asymmetry [11],

$$\gamma = \langle \cos(\phi_\alpha + \phi_\beta - 2\psi_{\text{RP}}) \rangle \tag{3}$$

where $\alpha, \beta = +, -$ represent the charge sign of two particles involve in the correlation and ψ_{RP} is the azimuthal angle of the reaction plane. In STAR, both of the same sign correlator $\gamma_{\text{SS}}(\alpha = \beta)$ and

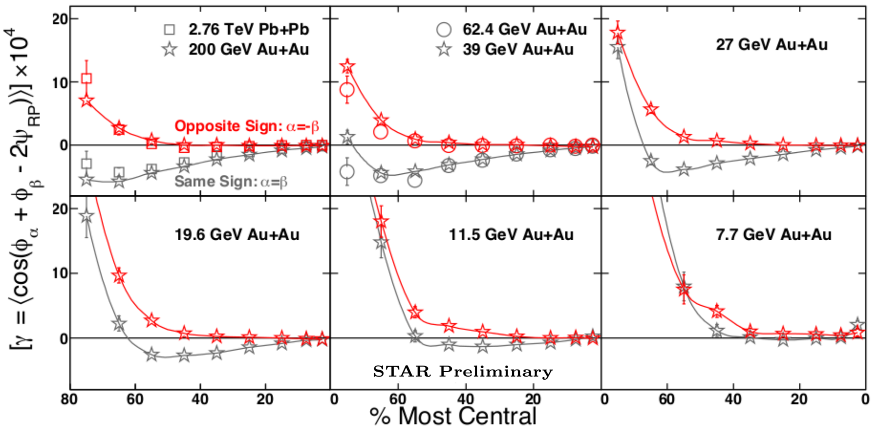

Figure 1: The centrality dependency of three-particle correlators, γ_{SS} and γ_{OS}, measured by STAR in Au + Au collisions from $\sqrt{s_{NN}}$ = 200 GeV to 7.7 GeV. The ALICE measurement is showing for comparison [8].

the opposite sign correlator $\gamma_{\text{OS}}(\alpha = -\beta)$ have been measured in minimum bias triggered Au + Au collisions at all STAR energies. The data samples used include 57 M events at $\sqrt{s_{NN}}$ = 200 GeV taken in year 2007, 7 M at 62.4 GeV (2005), 100 M at 39 GeV (2010), 40 M at 27 GeV (2011), 20 M at 19.6 GeV (2011), 10 M at 11.5 GeV (2010) and 4 M at 7.7 GeV (2010) [12]. The results are shown in Fig. 1. The ALICE measurement in Pb + Pb collisions at 2.76 TeV is also shown in the same figure for comparison [8].

The main background for such measurements include the radial flow, the charge conservation and the influence of the statistical fluctuations. Those sources of background are believed to be same for γ_{SS} and γ_{OS} [12]. Therefore, the difference between the two correlator $\gamma_{\text{OS}} - \gamma_{\text{SS}}$ should be a better signal, which is showing in Fig. 2. The signal does not show strong energy dependency from 2.76 TeV to 11.5 GeV and it seems to disappear at 7.7 GeV [12].

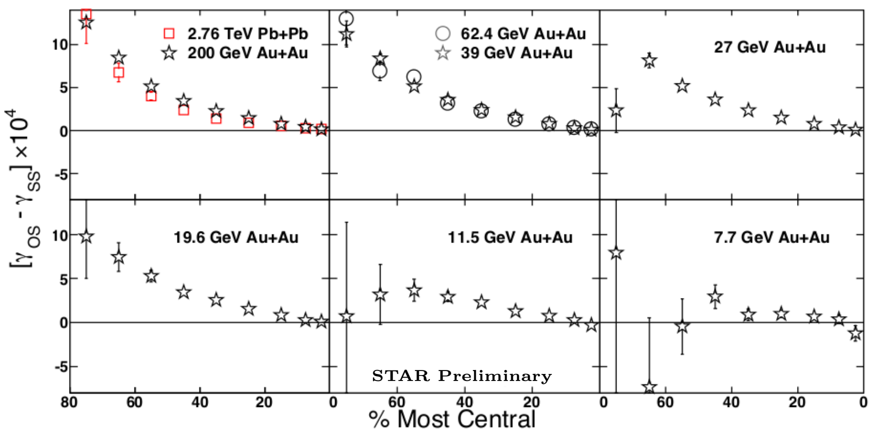

Figure 2: The centrality dependency of the difference between the two correlators $\gamma_{\rm OS} - \gamma_{\rm SS}$ in Au + Au collisions from $\sqrt{s_{NN}}$ = 200 GeV to 7.7 GeV. The ALICE measurement is showing for comparison [8].

3 Charge Asymmetry Dependency of Pion Azimuthal Anisotropy

To study the charge asymmetry dependency of the v_2 of charged pions, more than 200 M Au + Au minimum bias events taken in year 2010 are used. Other data samples include 60 M at 62.4 GeV (2010), 100 M at 39 M (2010), 40 M at 27 GeV (2011) and 20 M at 19.6 GeV (2011). To select charged pions, charged particles are chosen if its ionization energy loss in STAR TPC stays within 2σ from the expected value of pions. Meanwhile, the selected pions are also required to have a distance of the closest approach (DCA) to primary vertex less than 1 cm and stays in low transverse momentum range, $0.15 < p_T < 0.5$ GeV/c. To measure the event-by-event charge asymmetry $A_{\rm ch}$, all charged particles within DCA $<$ 1 cm are used except the protons and anti-protons with $p_T < 0.4$ GeV/c. Low p_T (anti-)protons are excluded to avoid the influence of beam pipe protons. The measured $A_{\rm ch}$ are corrected subject to the limited tracking efficiency via HIJING model and GEANT simulation. The left panel of Fig. 3 shows the v_2 measurements for π^+ and

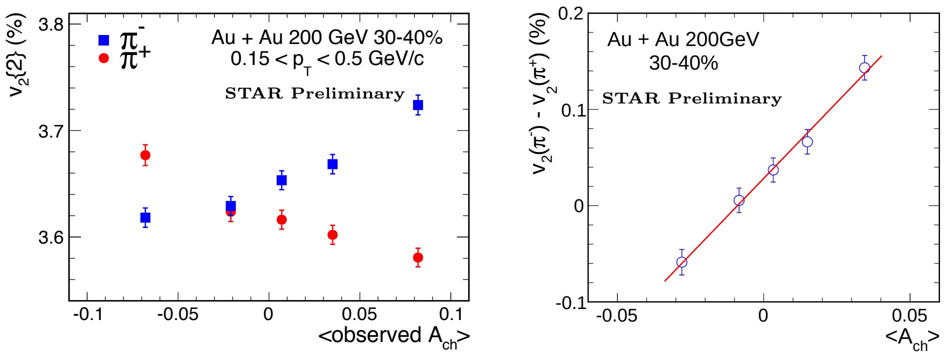

Figure 3: Left: Integrated v_2 measurement over $0.15 < p_T < 0.5$ GeV/c for π^+ and π^- as a function of measured charge asymmetry in Au + Au collisions at $\sqrt{s_{NN}}$ = 200 GeV, 30-40% centrality. Right: the v_2 difference in the same centrality as a function of corrected charge asymmetry.

π^- as a function of measured charge asymmetry in Au + Au collisions at $\sqrt{s_{NN}}$ = 200 GeV, 30-40% centrality [13]. The right panel shows the v_2 difference between π^+ and π^- as a function of corrected charge asymmetry. We observed that the v_2 of $\pi^+(\pi^-)$ linearly decreases (increases) with the increasing charge asymmetry in 30-40% centrality. The slope parameter of $\Delta v_2(A_{\rm ch})$ is extracted in all centralities and all energies under study [12]. The results are showing in Fig. 4. The behavior of $v_2^{\pi^{\pm}}(A_{\rm ch})$ and the rise and fall feature of the slope parameter as a function of centrality are qualitatively consistent with calculation based on CMW. However, it is not clear why the slope parameter as a function of centrality only shows weak energy dependency from $\sqrt{s_{NN}} = 200$ GeV to 27 GeV.

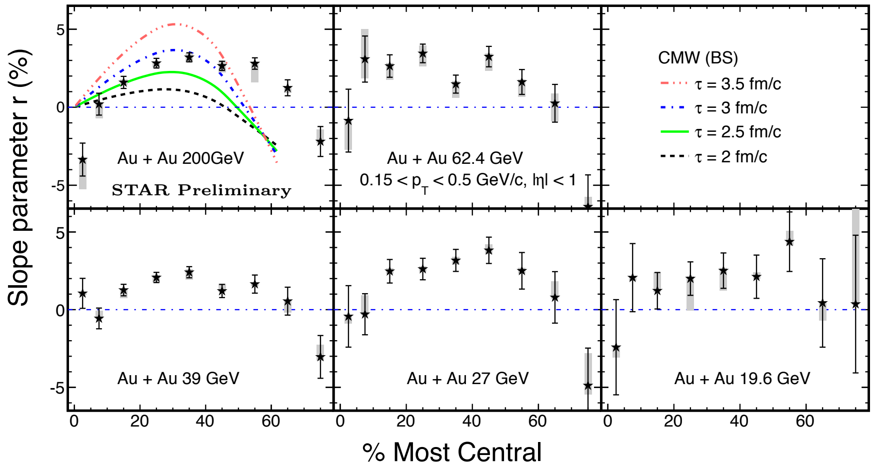

Figure 4: Centrality dependency of the slope parameter r measured in Au + Au collisions from $\sqrt{s_{NN}} = 200$ GeV to 19.6 GeV. A set of theoretical calculation based on CMW is showing for comparison.

4 Summary

The three-particle correlation have been measured in STAR, which may provide the evidence for the Local Parity Violation and Chiral Magnetic Effect. It turns out that the signal almost unchanged from 2.76 TeV to 11.5 GeV and seems to disappear in 7.7 GeV.

We also measured the charge asymmetry dependency of the charged pion v_2 from 200 GeV to 19.6 GeV. The observed $v_2^{\pi^\pm}(A_{\rm ch})$ and its difference between π^+ and π^- qualitatively consistent with the expectation of Chiral Magnetic Wave model. But the reason for the weak energy dependency of the slope parameter as a function of centrality is not quite clear yet.

References

1. D. E. Kharzeev, L. D. McLerran, and H. J. Warringa, *Nuclear Physics* A **803**, 227 (2008).
2. D. T. Son and A. R. Zhitnitsky, *Phys. Rev. D* **70**, 074018 (2004).
3. M. A. Metlitski and A. R. Zhitnitsky, *Phys. Rev. D* **72**, 045011 (2005).
4. STAR Collaboration, B. I. Abelev *et al.*, *Phys. Rev. Lett.* **103**, 251601 (2009).
5. STAR Collaboration, B. I. Abelev *et al.*, *Phys. Rev. C* **81**, 054908 (2010).
6. N. N. Ajitanand, S. Esumi, R. A. Lacey [PHENIX Collaboration], in Proc. of the RBRC Workshops, vol.96, 2010: "P- and CP-odd effects in hot and dense matter"
7. N. N. Ajitanand, R. A. Lacey, A. Taranenko, and J. M. Alexander, *Phys. Rev. C* **83**, 011901 (2011).
8. ALICE Collaboration, B. Abelev *et al.*, *Phys. Rev. Lett.* **110**, 012301 (2013).
9. D. Kharzeev and H.-U. Yee, *Physical Review D* **83**, 085007 (2011).
10. Y. Burnier, D. E. Kharzeev, J. Liao, and H.-U. Yee, *Phys. Rev. Lett.* **107**, 052303 (2011).
11. S. A. Voloshin, *Phys. Rev. C* **70**, 057901 (2004).
12. G. Wang for the STAR Collaboration, arXiv:1210.5498v2 [nucl-ex]
13. H. W. Ke for the STAR Collaboration, *Journal of Physics: Conference Series* **389**, 012035 (2012).