Search for the Chiral Magnetic Effect in Heavy-Ion Collisions and Quantification of the Background with the AMPT Model

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Abstract

The chiral magnetic effect (CME) arises from the chirality imbalance of quarks and its interaction to the strong magnetic field generated in non central heavy-ion collisions. Possible formation of domains of quarks with chirality imbalances is an intrinsic property of the Quantum ChromoDynamics (QCD), which describes the fundamental strong interactions among quarks and gluons. Azimuthal-angle correlations have been used to measure the magnitude of charge-separation across the reaction plane, which was predicted to arise from the CME [1]. However, backgrounds from collective motion (flow) of the collision system can also contribute to the correlation observable. In this poster, we investigate the magnitude of the background utilizing the AMPT model [2], which contains no CME signals. We demonstrate, for Au+Au collisions at 200 and 39 GeV, a scheme to remove the flow background via the event-shape engineering with the vanishing magnitude of the flow vector. We also calculate the ensemble average of the charge-separation observable, and provide a background baseline for the experimental data.

Introduction

The thermodynamic states of the hot, dense, and de-confined nuclear medium created in high-energy heavy-ion collisions can be specified by the axial chemical potential μ_5. as well as the temperature T and the vector chemical potential μ. The quantity μ_5 characterizes the imbalance of right-handed and left-handed fermions in a system, and a chiral system bears a nonzero μ_5. In a non-central collision, a strong magnetic field (B ~ 10^{15} T) can be produced (mostly by energetic spectator protons) and will induce an electric current (J_B) along B in chiral domains, $J_B \propto \mu_5 B$, which is called the chiral magnetic effect (CME).

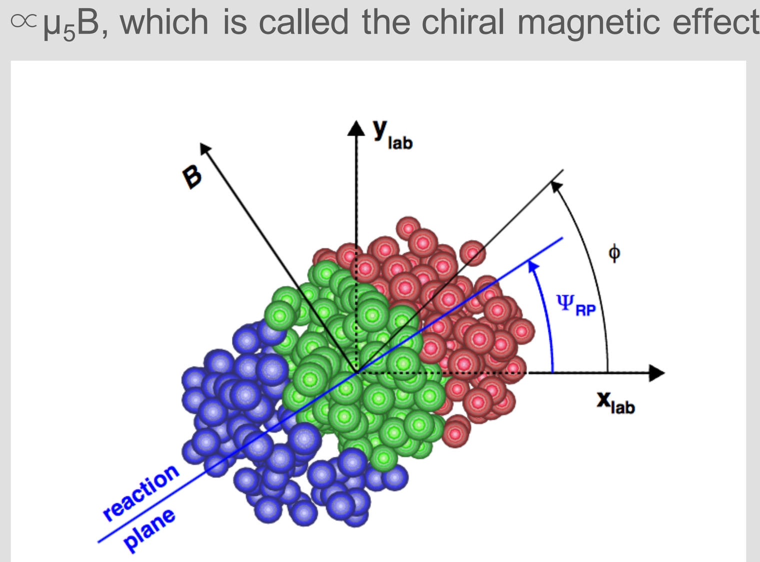

Figure 1: Schematic of Ion Collision [3]

$$\frac{dN}{d\phi} \propto 1 + 2v_{1,\alpha}cos(\delta\phi) + 2v_{2,\alpha}cos(2\delta\phi) + 2a_{1,\alpha}sin(\delta\phi) + ...$$

where $\delta\phi = \phi - \Psi_{RP}$

$alpha(+or-)$: denotes the charge sign of the particle

v_1 : directed flow, v_2 : elliptic flow

a_1 quantifies the charge separation due to CME

$$\gamma = \langle\langle cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP})\rangle_P\rangle_E$$
$$= [\langle v_{1,\alpha}v_{1,\beta}\rangle + B_{in}] - [\langle \alpha_{1,\alpha}\alpha_{1,\beta}\rangle + B_{out}]$$

where $(B_{in} - B_{out})$: flow-related background

$$v_2 = \langle\langle cos(2\phi - 2\Psi_{RP})\rangle_P\rangle_E$$
$$v_2^{obs} = \langle\langle cos(2\phi - 2\Psi_{EP})\rangle_P\rangle_E$$

Resolution: $R^B = \langle cos(2\Psi_{EP}^B - 2\Psi_{RP})\rangle_E$

Ensemble Average: $v_2^A = v_2^{obs}/R^B$

AMPT Simulation (Au+Au Collisions)

It contains only background contribution, and each event has been divided into 3 sub-events.

A: |η| < 1.5 contains particles of interest.

B_1: 1.5 < η < 4

B_2: -4 < η < -1.5

Both B_1 and B_2 serve as reconstructed sub-event planes.

Disappearance of background

- Flow Background is removed by selecting "spherical" events that have vanishing flow

- A good handle for event shape is the vector q.

$$\vec{q} = \left(\frac{1}{\sqrt{N}}\sum_i^N cos(2\phi_i^A), \frac{1}{\sqrt{N}}\sum_i^N sin(2\phi_i^A)\right)$$

200 GeV

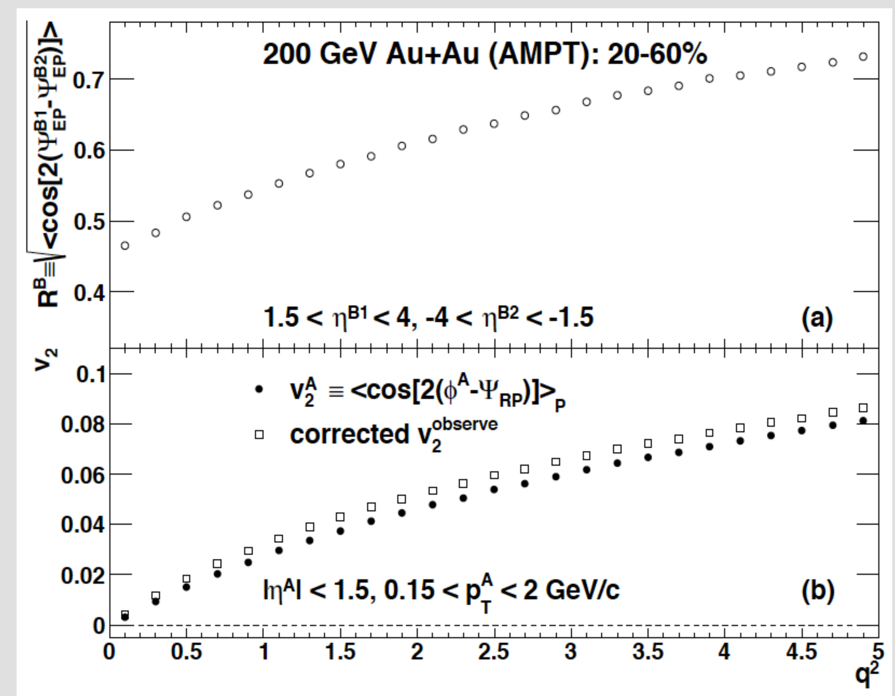

Figure 2: The sub-event plane resolution (R^B), and elliptic flow true (v_2^A) and observed (v_2^{obs}) as functions of q^2, from AMPT simulation for 200 GeV.

39 GeV

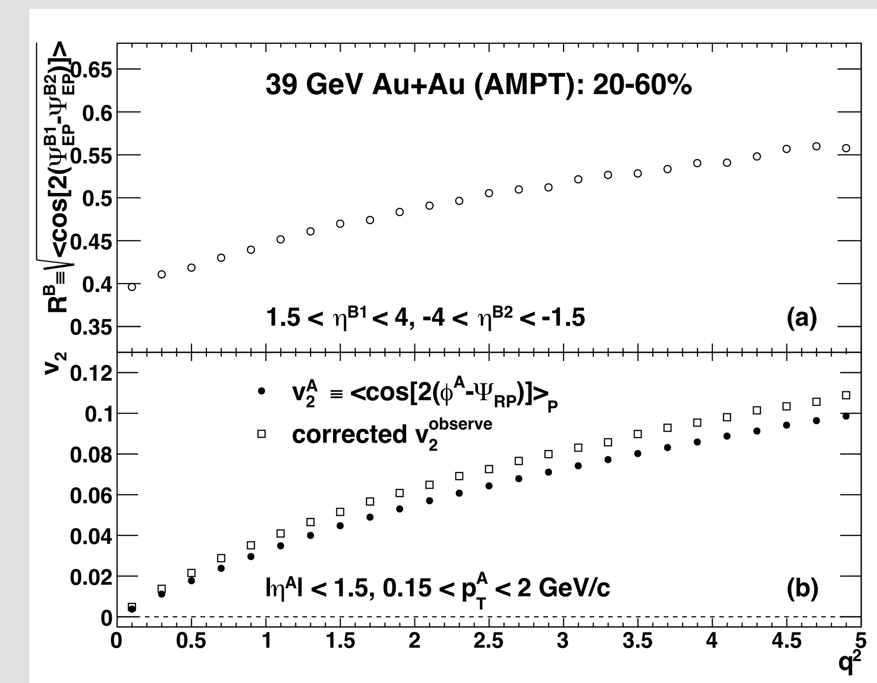

Figure 4: The sub-event plane resolution (R^B), and elliptic flow true (v_2^A) and observed (v_2^{obs}) as functions of q^2, from AMPT simulation for 39 GeV.

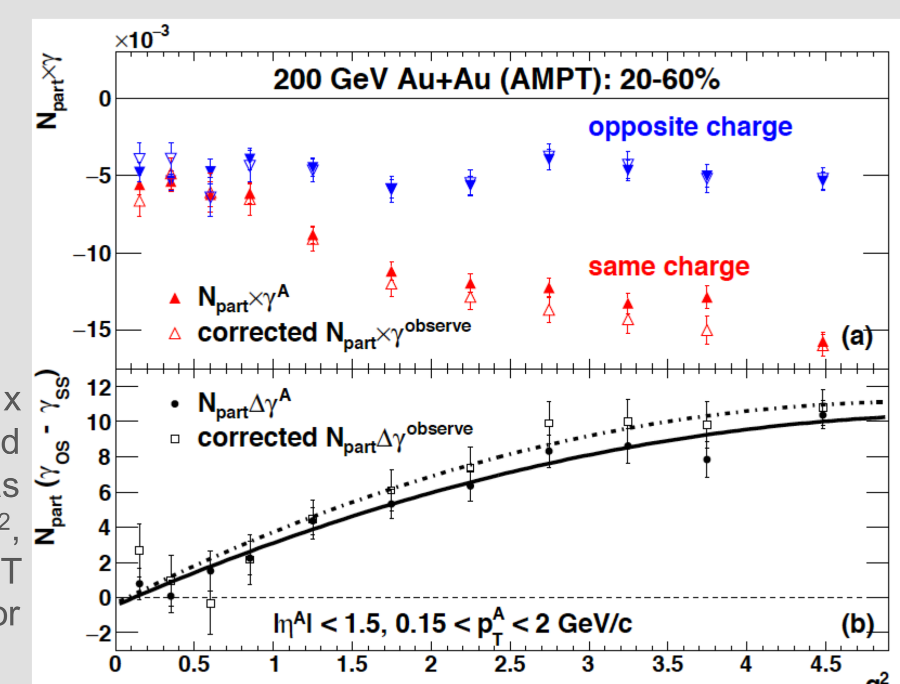

Figure 3: $N_{part} \times \gamma$(upper) and $N_{part}\,\Delta\gamma$(lower) as functions of q^2, from AMPT simulation for 200 GeV with fit

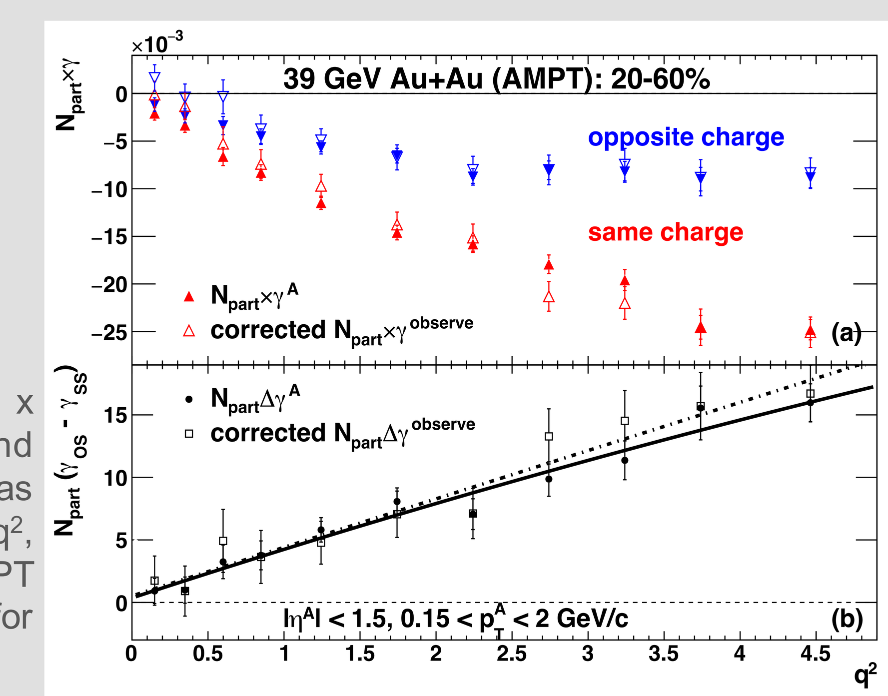

Figure 5: $N_{part} \times \gamma$(upper) and $N_{part}\,\Delta\gamma$(lower) as functions of q^2, from AMPT simulation for 39GeV with fit

- Discrepancy between v_2^A and corrected v_2^{obs} comes from non-flow and flow fluctuation
- Both v_2 for 39 and 200 GeV drop to 0 at vanishing q^2

- γ is less sensitive to non-flow and flow fluctuation
- Intercepts are consistent with zero, so disappearance of background at zero q^2 is demonstrated

Ensemble average method

When the q reconstruction is not applicable or reliable, we resort to the ensemble average of several observables.

$$\gamma \equiv \langle cos(\phi_\alpha + \phi_\beta - 2\psi)\rangle = \kappa_B v_2 B - H$$
$$\delta \equiv \langle cos(\phi_\alpha - \phi_\beta)\rangle = B + H$$
$$\kappa_B = \frac{\Delta\gamma}{v_2\delta}$$

H: CME signal contribution.

B: Flow background contributions, include the decays of the clusters, transverse momentum conservation (TMC) and local charge conservation (LCC).

200 GeV

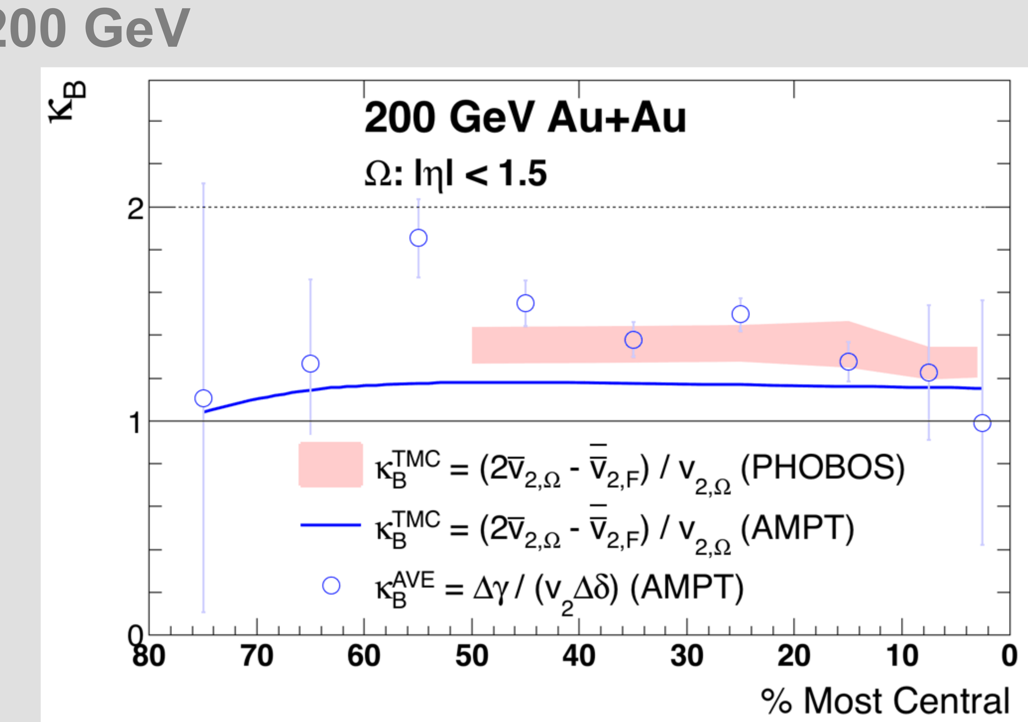

Figure 6: Estimation of κ_B with three approaches for 200 GeV Au+Au collision

- For both 39 and 200 GeV Au+Au collision, the estimated κ_B is roughly contained in [1, 2]

39 GeV

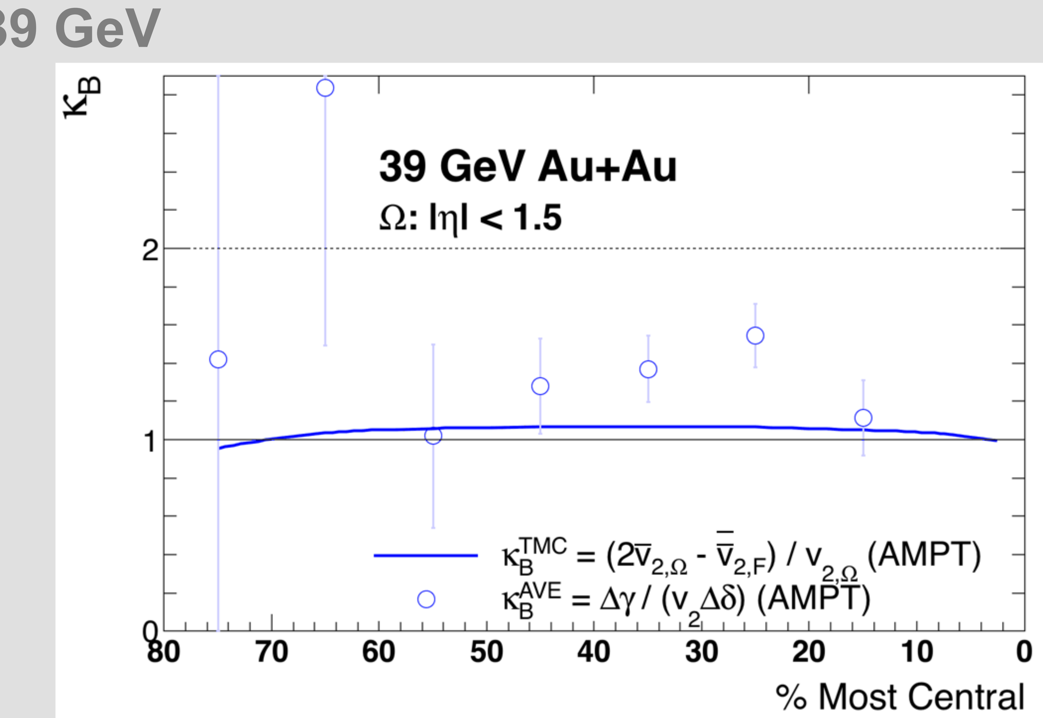

Figure 7: Estimation of κ_B with two approaches for 39 GeV Au+Au collision

- If κ_B obtained from real data is significantly above 2, it evidences a real charge separation due to CME.

Restore ensemble average of signal

$$\gamma_{ebye} \equiv \langle cos(\phi_\alpha + \phi_\beta - 2\psi)\rangle \approx 2\delta v_{2,ebye} - a_{1,\alpha}a_{1,\beta} - 2\delta v_2$$

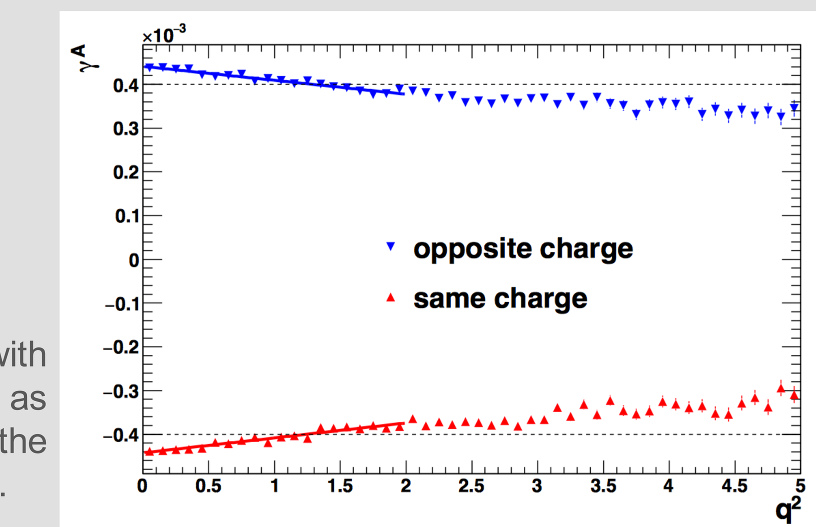

Figure 8: γ obtained with the true reaction plane as a function of q^2, from the Monte Carlo simulation.

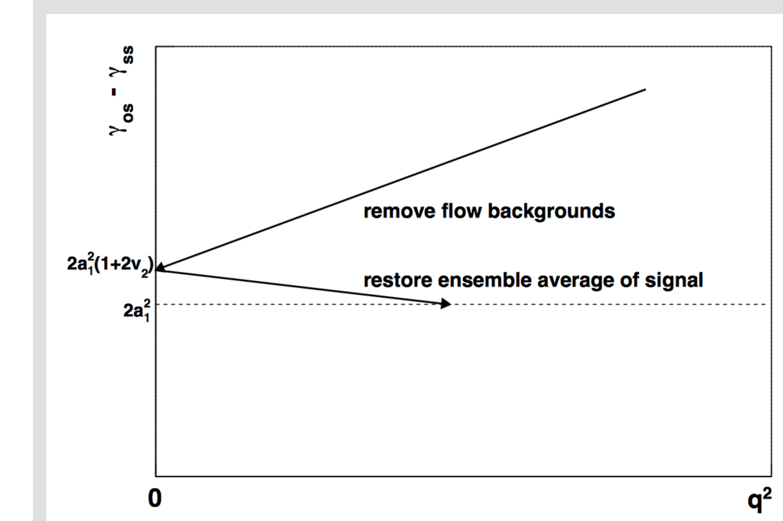

Figure 9: A schematic diagram of how to reveal the ensemble-averaged CME signal via the ESE.

- The apparent value at zero q^2 exaggerates the charge separation: $\Delta\gamma = \frac{\Delta\gamma(q^2=0)}{1+2v_2}$

Summary

- q^2 is a valid basis to select spherical sub-event.
- First projection is applied to remove the flow background, and second projection is applied to remove artificial background.
- Real CME signal can be obtained from: $\Delta\gamma = \frac{\Delta\gamma(q^2=0)}{1+2v_2}$

References

[1] D. E. Kharzeev, L. D. McLerran and H. J. Warringa, Nucl. Phys. A 803, 227 (2008).

[2] Z.W. Lin and C.M. Ko, Phys. Rev. C 65, 034904 (2002).

[3] F. Wen, L. Wen, and G. Wang, (2016), 1608.03205

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