Anomalous chiral effects in heavy ion collisions[†]

J. Liao[*1,*2]

Anomalous chiral effects, notably the Chiral Magnetic Effect (CME), are remarkable phenomena that stem from highly nontrivial interplay of QCD chiral symmetry, axial anomaly, and gluonic topology. It is of fundamental importance to search for these effects in experiments. The heavy ion collisions provide a unique environment where a hot chiral-symmetric quark-gluon plasma is created, gluonic topological fluctuations generate chirality imbalance, and very strong magnetic fields $|\vec{\mathbf{B}}| \sim m_\pi^2$ are present during the early stage of such collisions. For recent reviews, see[1–3].

The CME predicts the generation of charge current $\vec{\mathbf{J}}$ along magnetic field $\vec{\mathbf{B}}$ for a chiral medium in the presence of axial charge imbalance: $\vec{\mathbf{J}} = C_A \mu_A \vec{\mathbf{B}}$ where μ_A characterizes chirality imbalance. In non-central heavy ion collisions, the CME may lead to an out-of-plane charge separation effect, contributing to the reaction-plane dependent azimuthal correlation observable: $\gamma_{H_\alpha H_\beta} =< \cos(\phi_i + \phi_j - 2\Psi_{\mathrm{RP}}) >_{\alpha\beta}$ with H_α, H_β labeling the hadron species and $\phi_{i,j}$ the azimuthal angles of the two final state charged hadrons. The Ψ_{RP} denotes reaction plane angle. However, the measured correlation suffers from elliptic flow driven background contributions and can not be entirely attributed to CME. The separation of flow-driven background and possible CME signal is the most pressing issue in current CME search.

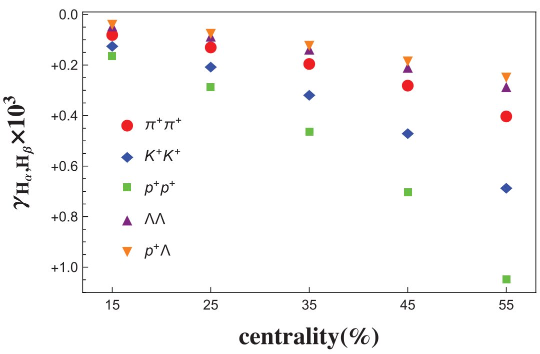

Fig. 1. Correlations $\gamma_{H_\alpha,H_\beta}$ vs centrality for 3-flavor case.

To draw a definitive conclusion, it is vital to develop anomalous hydrodynamic simulations that quantify the CME signals with realistic initial conditions as well as account for background contributions. Recently a first attempt has been made in[4] to consistently quantify contributions to observed charge correlations from both the CME signal and background contributions in one and same framework that integrates anomalous hydro with data-validated bulk viscous hydro simulations. The anomalous hydrodynamic equations for pertinent currents are solved in a linearized way on top of the bulk evolution. The results from this computation have demonstrated that the same-charge correlation data by STAR can be described quantitatively with CME and TMC together, computed with modest magnetic field lifetime ($\sim$ 1fm/c) and realistic initial axial charge density. To further test this interpretation, predictions have been made for the azimuthal correlations of various identified hadron paris (see Fig. 1), to be compared with future data.

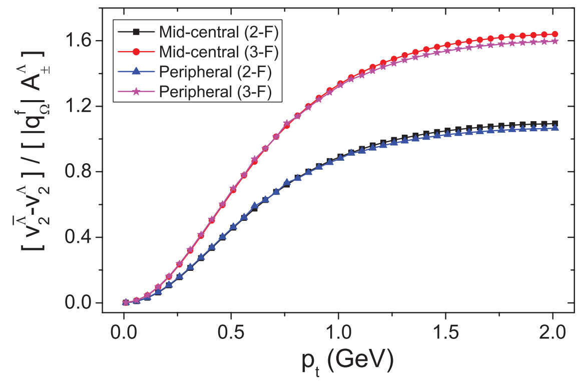

Fig. 2. Normalized $\bar{\Lambda}$ and Λ elliptic flow splitting, $[v_2^{\bar{\Lambda}} - v_2^{\Lambda}]/[|q_\Omega^f|A_\pm^\Lambda]$, for symmetric 2-flavor(2-F) and 3-flavor(3-F) cases (for $15-30\%$ and $60-92\%$ centrality).

Studying CME-related anomalous transport phenomena provides an independent avenue for the search of CME. Global fluid rotation (quantified by nonzero vorticity $\vec{\omega}$) bears close similarity to a magnetic field $\vec{\mathbf{B}}$ and can induce Chiral Vortical Effects (CVE). In the presence of fluid rotation, a new gapless collective mode called Chiral Vortical Wave (CVW) has recently been found in[5]. The CVW arises from interplay between vector and axial charge fluctuations induced by CVE. For the rotating quark-gluon plasma in non-central collisions, the CVW-induced charge transport leads to the formation of flavor-wise quadrupole in the fireball. Such phenomenon could be manifested through the elliptic flow splitting of Λ and $\bar{\Lambda}$ baryons (with predictions shown in Fig. 2) that may be experimentally measured.

References
1) D. E. Kharzeev, J. Liao, S. A. Voloshin and G. Wang, Prog. Part. Nucl. Phys. **88**, 1 (2016).
2) J. Liao, Pramana **84**, no. 5, 901 (2015).
3) J. Liao, arXiv:1601.00381 [nucl-th].
4) Y. Yin and J. Liao, Phys. Lett. B **756**, 42 (2016).
5) Y. Jiang, X. G. Huang and J. Liao, Phys. Rev. D **92**, no. 7, 071501 (2015).

† Condensed from the articles in Phys. Rev. D. **92**, 071501(R) (2015) and in Phys. Lett. B **756**, 42 (2016).

*1 RIKEN Nishina Center
*2 Department of Physics, Indiana University