Systematical searches for chiral magnetic effect and chiral vortical effect using identified particles at RHIC/STAR

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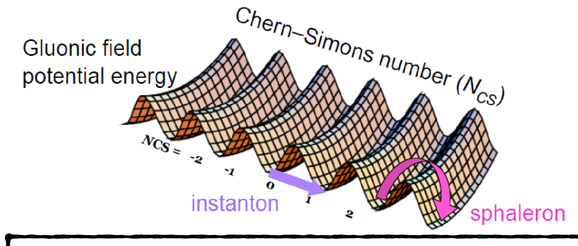
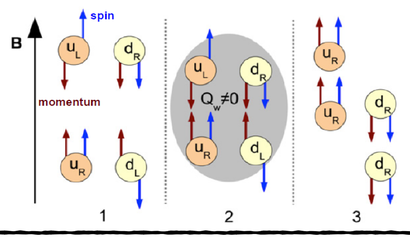
Abstract

QCD allows chirality imbalance as a consequence of vacuum transition. When coupled with a strong magnetic field produced in heavy-ion collisions, the chirality imbalance in local domains can lead to an electric charge separation along the magnetic field direction, manifested as chiral magnetic effect (CME). Recently, an analogous effect, the chiral vortical effect(CVE) was also proposed, in which the vorticity of the collision system replaces the magnetic field, and a baryonic charge separation appears. In order to shed light on the magnitude of the CME and CVE, we use identified-particle correlation measurements from Au+Au at 200 GeV with the STAR detector to explore possible hierarchal structure in the particle dependent correlations. Four case studies will be reported: p-K_s^0 (no CME/CVE), p-$\pi^{\pm}$ (CME only), p-Λ (CVE only), and p-p (both CME and CVE). These measurements can potentially help to learn about the magnitudes of CME and CVE and the level of background.

Introduction





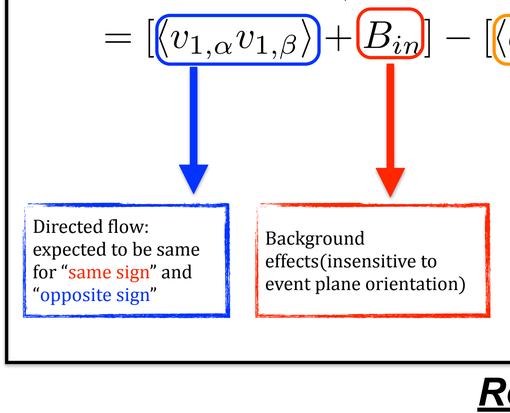
Theory:

When energy density is high enough(e.g. in heavy ion collision), vacuum may transit between different states which can be characterized by Chern-Simons Number. Such a kind of QCD vacuum state transition will induce:

- ☑ Non-zero topological charge;
- ☑ Chirality imbalance;

Chiral Magnetic Effect(CME): Coupled with strong magnetic field, finite chiral charge density induces electric current that finally leads to electric charge separation along B field.

Chiral Vortical Effect(CVE): Recently a similar effect -"Chiral Vortical Effect", which is due to the coupling of created nuclear matter's fluid vorticity and chirality imbalance, is also proposed. CVE predicts baryonic charge separation across event plane in heavy ion collisions.



Experiment:

Data of Au+Au at 200GeV were collected by STAR detector in RHIC run 2011.

☑Particle Identification:

TPC(Time Projection Chamber) dE/dx is used for proton/pion/kaon identification;

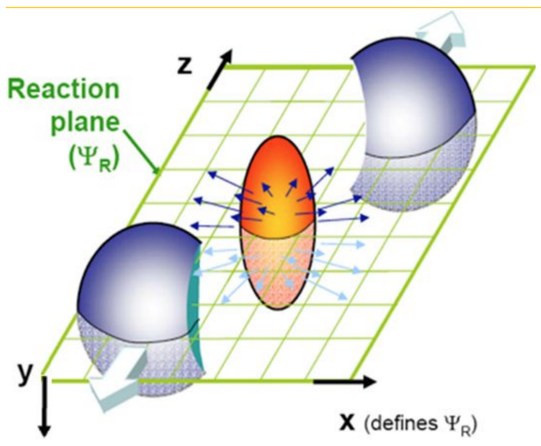
Other hadrons(Λ , K_s^0) are reconstructed by topological reconstruction of daughters.

☑Event Plane Reconstruction:

Large elliptic flow is used to determine event-plane orientation.

Observable

We investigate the charge dependent two-particle correlations with respect to the reaction plane:



$$\frac{dN_{\pm}}{d\phi} \propto 1 + 2a_{\pm}sin(\phi^{\pm} - \Psi_{RP})$$

Direct measurement of "a" would yield zero value. So we need "three-point-correlation"—observable "gamma"!

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

Background effects(insensitive to event plane orientation)

Directed flow: expected to be same for "same sign" and "opposite sign"

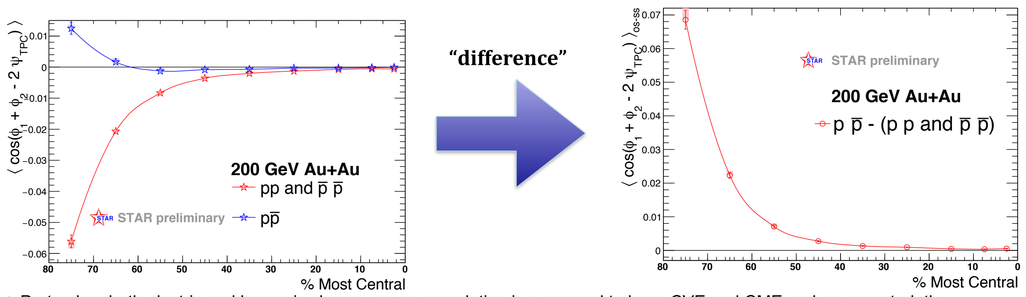
Background effects(insensitive to event plane orientation)

P-even quantity: still sensitive to separation effect, i.e., different for "same sign" and "oppo sign"

Same & opposite sign : correlated particles (α, β)have same (opposite)electric/baryonic charge.

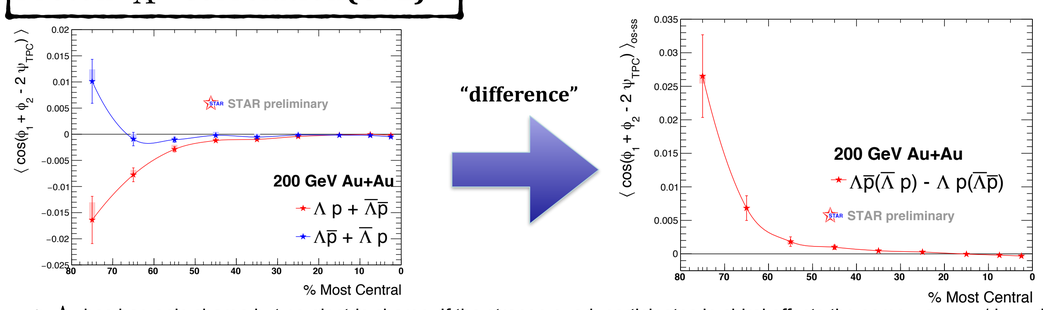
Results

Proton-Proton Correlation(CVE+CME)



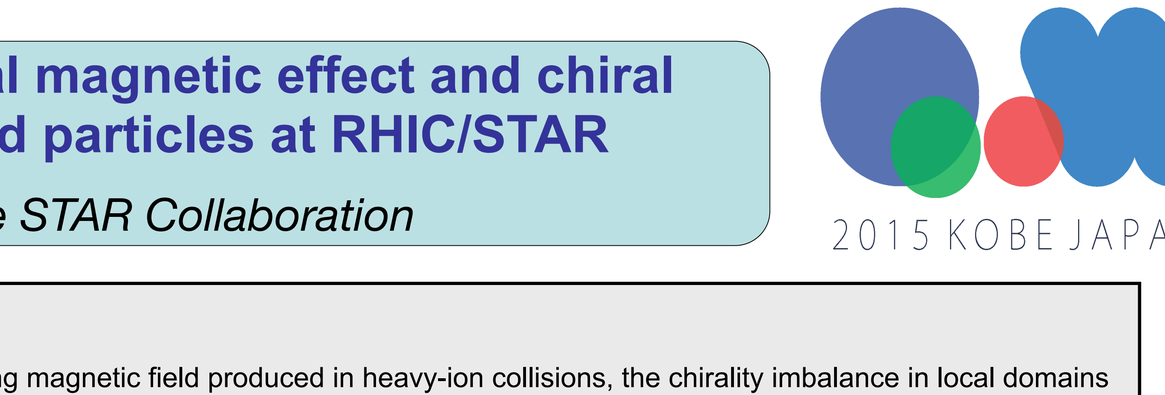
▶ Proton has both electric and baryonic charge, so p-p correlation is supposed to have CVE and CME and as expected, the measurement shows large difference between "same sign"(pp and antip-antip) and "oppo sign"(p-antip).

Proton- Λ^0 Correlation(CVE)



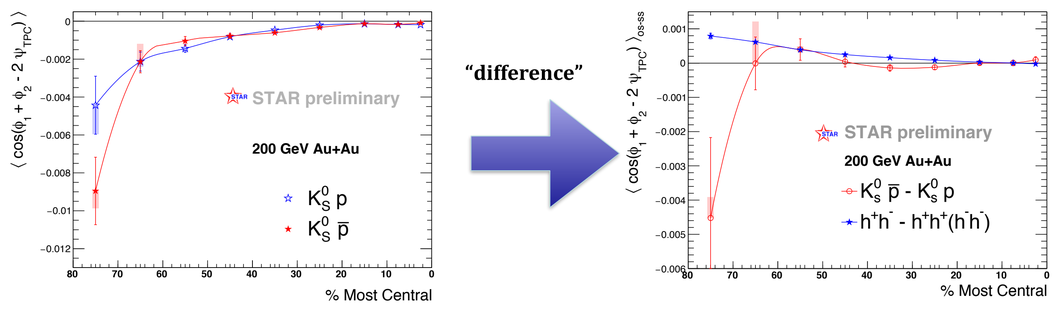
▶ Λ has baryonic charge but no electric charge. If the strange quark participates in chiral effects the same way as u/d quark, proton-Λ correlation is supposed to have CVE only. The result shows significant baryonic charge separation signal.

Proton- $\pi^{\pm}$ Correlation(CME)



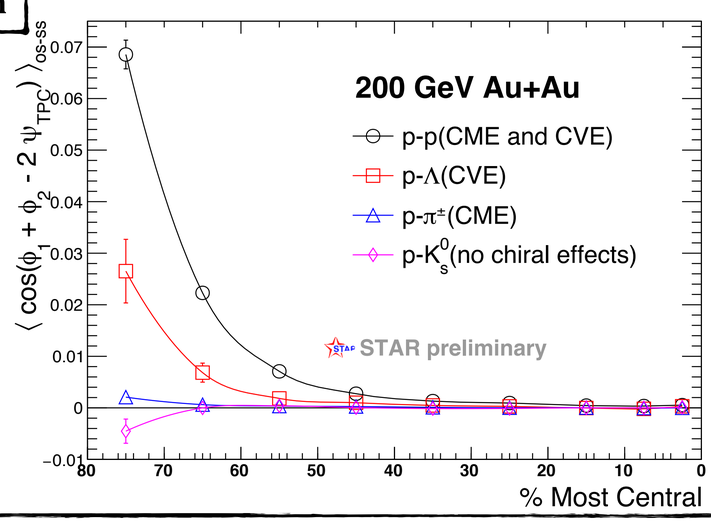
▶ Since pion has electric charge only, we are expecting to see CME induced charge separation effect in Proton-Pion correlation measurement. Results show the charge separation signal magnitude is close to hadron-hadron's signal, which may indicates the similar underlying physics.

Proton- K_s^0 Correlation(No Chiral Effects)



▶ K_s^0 particle has no baryonic or electric charge, so no charge separation effect will be seen based on theoretical prediction. And we indeed observe no significant charge separation signal in Proton-K_s^0 correlation measurement, but more statistics is still needed to make a strong conclusion.

Comparison



Put together, these four case studies show a hierarchical structure in identified particles correlation due to Chiral Magnetic Effect and Chiral Vortical Effect: Proton-Proton correlation which in theory has both CVE and CME shows the biggest charge separation signal magnitude; Proton-Λ correlation signal, which has CVE only(if the strange quark participates in chiral effects the same way as u/d quark), is on the second highest level; Proton-Pion correlation has only CME, whose signal is much smaller than CVE; Proton-K_s^0 almost has no separation signal as expected. As flow-related background check, H correlators for Proton-Proton and Proton-Pion were tested and show robust signals(not shown here).

Summary and Future Work

- ☑ A particle-dependent hierarchical structure in the values of the three-point correlator has been observed.
- ☑ Other identified-particle correlation studies(π-π, Λ-π, Λ-Λ…) will be done for systematic check.
- ☑ Flow contributions will be further investigated in the future study.

Reference

1. D. E. Kharzeev, L. D. McLerran and H. J. Warringa, Nuclear Physics A 803 (2008) 227
2. S. Voloshin, Physical Review C. 70 (2004) 057901
3. D. E. Kharzeev, D. T. Son, Physical Review Letters 106 (2011) 062301
4. A.Bzdak, V.Koch and J.Liao Lect. Notes Phys. 871(2013)503

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