Searching for the chiral magnetic effect in heavy-ion collisions with the sliding dumbbell method

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Motivation
Investigation of the Chiral Magnetic Effect (CME) which causes the charge separation in deconfined matter along the axis of magnetic field in the presence of the strong magnetic field.

Sliding Dumbbell Method (SDM)
The azimuthal plane displaying hits of positive/negative particles in an event is scanned by sliding the dumbbell of $90^\circ$ in steps of $1^\circ$ searching for maximum of the sum $(D_b^{\text{max}})$ of positive charge fraction on one side (a) and negative charge fraction on other side (b) of the dumbbell to search back-to-back charge separation on an event-by-event basis for the first time.
Following condition is imposed on the charge asymmetry ($D_{\text{asy}}$) of positive charge excess ($\text{Pos}_{\text{ex}}$) on (a) side of dumbbell and negative charge excess ($\text{Neg}_{\text{ex}}$) on (b) side of dumbbell:

$$|D_{\text{asy}}| = |(\text{Pos}_{\text{ex}} - \text{Neg}_{\text{ex}})/(\text{Pos}_{\text{ex}} + \text{Neg}_{\text{ex}})| < 0.25$$

, to get CME-like events.

Fractional charge separation across the dumbbell ($f_{\text{DbCS}}$) = $$D_{b}^{\text{max}} - 1$$

Positive charge asymmetry across the dumbbell ($A^{+}$) = $$(N_{a}^{+} - N_{b}^{+})/(N_{a}^{+} + N_{b}^{+})$$

$f_{\text{DbCS}}$ distribution is sliced into 10 percentile bins to get CME-like events.

The CME sensitive 3-particle $\gamma$ correlator defined as (Voloshin PRC 70, 057901(2004)):

$$\gamma = \langle \cos(\phi_{a} + \phi_{b} - 2\psi_{\text{RP}}) \rangle \approx (v_{1,a} v_{1,b} - a_{a} a_{b}) = \langle \cos(\phi_{a} + \phi_{b} - 2\phi_{c}) \rangle / v_{2,c}$$

here, $\phi_{a}$, $\phi_{b}$ and $\phi_{c}$ are azimuthal angles of particle a, b and c ; $\psi_{\text{RP}}$ is reaction plane angle, $v_{1,a(b)}$ is direct flow and $v_{2,c}$ is elliptic flow of third particle “c”.

For symmetric rapidity direct flow, $v_{1,a} = v_{1,b} \sim 0$, so $\gamma \approx |a_{a} \cdot a_{b}|$

**Background estimation:**

$$\gamma_{\text{bkg}} = \gamma_{\text{ch.re}} + \gamma_{\text{correlated}}$$

$\gamma_{\text{ch.re}}$ is obtained by reshuffling the charges of particles in an event and $\gamma_{\text{correlated}}$ from the AMPT events for a given collision centrality.
Following data of AMPT generated 16M Au + Au collisions at $\sqrt{s_{\text{NN}}}=200$ GeV are analyzed.

- AMPT with string melting ON.
- Externally injected CME-like signal in AMPT i.e., flipping one positive/negative particle to negative/positive particle perpendicular to the reaction plane denoted as Fix 1 sample.
- Fix 2 same as Fix 1 but two particles are flipped instead of one particle.

Collision centrality: Determined from the number of participant nucleons.

Track cuts: $0.15 \text{ GeV}/c < p_T < 2.0 \text{ GeV}/c$ and $-1.0 < \eta < 1.0$.

### Results and Discussion

3-particle $\gamma$ correlator dependences on collision centrality for same and opposite signed charged pairs and $\Delta \gamma$ (opposite sign- same sign) are shown below:

Same sign charged particles are strongly correlated and correlation increases with increasing injected CME-like signal. It decreases with increasing collision centrality. $\Delta \gamma$ increases with increasing externally injected CME-like signal and decreasing collision centrality.
Analyzing with Sliding Dumbbell Method

$f_{\text{DbCS}}$ distributions for different collision centralities for AMPT, charge reshuffle, Fix 1 and Fix 2

Distributions move towards $f_{\text{DbCS}} = 1$ (i.e., 100% charge separation) with increasing externally injected signal and decreasing collision centrality.
$\gamma$ for opposite and same signed charged pairs and $\Delta \gamma$ (opposite sign–same sign) dependences on collision centrality for different $f_{\text{DbCS}}$ bins are shown below:

Strong correlations are seen for the top 0-20% $f_{\text{DbCS}}$ which increase with increasing externally injected signal and decreases with increasing collision centrality as the signal injected was kept constant. Also it is observed that $|\gamma_{\text{opp-sign}}| \sim |\gamma_{\text{same-sign}}|$
Centrality (%)

| AMPT | Fix 1 | Fix 2 |

CME

Summation runs over 10 $f_{\text{DbCS}}$ bins and $N_{\text{Total}}$ is total number of events.

$f_{\text{CME}}$ decreases with increasing collision centrality and increases with increasing externally injected signal. $f_{\text{CME}}$ is zero for AMPT.
Summary

- It became possible with SDM for the first time to extract CME-like events corresponding to the top $\sim 0$-$20\% f_{\text{D}}$.
- For the top $\sim 0$-$20\% f_{\text{D}}$, $|\gamma_{\text{opp-sign}}| \sim |\gamma_{\text{same-sign}}|$.
- $|\gamma_{\text{same-sign}}|$ varies approximately linearly with $<A^+A^+>$ for higher values of $<A^+A^+>$.
- $f_{\text{CME}}$ decreases with increasing collision centrality as the signal injected was kept constant.
- $f_{\text{CME}}$ increases with increasing injected signal and is approximately zero for the AMPT.

Thank you!