Characterization of flavor dependence of Chiral Magnetic Effect with multiple correlators

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Chiral Magnetic Effect

- Chiral Magnetic Effect (CME) is a transport phenomenon arising from the interaction between quantum anomalies and strong magnetic fields in the relativistic nuclear collisions.
- CME in Quantum Chromodynamics a generation of electric current along an extremly strong magnetic field that is induced by the chirality imbalance of the quarks.

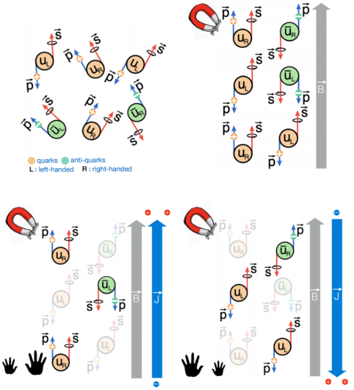


Figure: Chiral Magnetic Effect

- Chirality imbalance + Magnetic Field → Current

Why flavor dependency?

- The current induced along the magnetic field is given by,

$$J_{CME} = N_C(\sum_f Q_f{}^2)\frac{e^2}{2\pi^2}\mu_5\vec{B} \qquad (1)$$

$N_C \longrightarrow$ 3(color number), $Q_f \longrightarrow$ Charge of quark flavors

$\vec{B} \longrightarrow$ Magnetic field, $\mu_5 \longrightarrow$ Chiral chemical potential

- CME carries information about the quark number(N_f). Since CME current is depend on the charge of quark flavors.

$$J_{CME} \approx \frac{2}{3}K(N_f = 3)$$

$$J_{CME} \approx \frac{5}{9}K(N_f = 2) \qquad (2)$$

where, $K = \frac{N_c\mu_5\vec{B}}{2\pi^2}e^2$.

Gamma Correlator

- Any observable designed to detect the CME will invlove measuring the angles of the emitted particles. This could be measured by two particle azimuthal correlations.
- The observable Gamma correlator (γ) referes to the correlation between the azimuthal angles of two charge particles produced in RHIC.

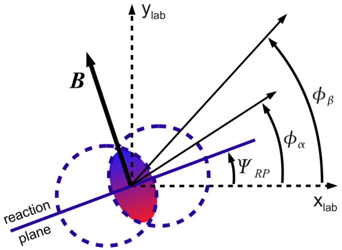


Figure: schematic diagram of HIC

$$\gamma =< \cos\left(\phi_\alpha + \phi_\beta - 2\psi_{RP}\right) > \quad (3)$$

$\phi \longrightarrow$ azimuthal angle of charge particles
$\psi_{RP} \longrightarrow$ reaction plane angle
α and β are the combination of charges(+ +,- +,- +,- -)

$R_{\psi_2}(\Delta S)$ Correlator

$R_{\psi_2}(\Delta S)$ Correlator designed to supress or separate back-ground contribution from genuine CME-driven charge separation.

$$R_{\psi_2}(\Delta S) = \frac{C_{\psi_2}(\Delta S)}{C^{\perp}_{\psi_2}(\Delta S)} \quad (4)$$

Where, $C_{\psi_2}(\Delta S)$ and $C^{\perp}_{\psi_2}(\Delta S)$ are the correlation functions designed to quantify charge-separation ΔS.

$$C_{\psi_2}(\Delta S) = \frac{N(\Delta S)}{N(\Delta S_{mix})} \quad (5)$$

$$\Delta S = < S_p > - < S_n > \quad (6)$$

$$\Delta S_{mix} = < S_{p_{mix}} > - < S_{n_{mix}} > \quad (7)$$

$$< S_p > = \frac{1}{p}\sum_p \sin(\phi_p - \psi_2)$$

$$< S_n > = \frac{1}{n}\sum_n \sin(\phi_n - \psi_2)$$

$$C^{\perp}_{\psi_2}(\Delta S) = \frac{N(\Delta S^{\perp})}{N(\Delta S^{\perp}_{mix})} \quad (8)$$

$$\Delta S^{\perp} = < S^{\perp}_p > - < S^{\perp}_n > \quad (9)$$

$$\Delta S^{\perp}_{mix} = < S^{\perp}_{p_{mix}} > - < S^{\perp}_{n_{mix}} > \quad (10)$$

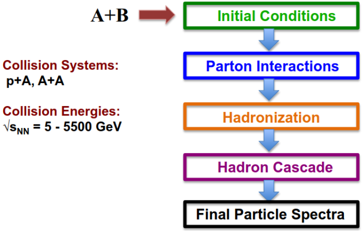
$$< S^{\perp}_p > = \frac{1}{p}\sum_p \sin(\phi_p - \psi_2 - \frac{\pi}{2})$$

$$< S^{\perp}_n > = \frac{1}{n}\sum_n \sin(\phi_n - \psi_2 - \frac{\pi}{2})$$

- $C_{\psi_2}(\Delta S)$ measures both CME and back-ground driven charge separation. $C^{\perp}_{\psi_2}(\Delta S)$ measures only background driven charge separation.
- $N(\Delta S) \longrightarrow$ distribution of ΔS over events relative to ψ_2.
- p and n are number of positive and negative charge particles respectively, $\phi \rightarrow$ azimuthal angle of charged particles;$\psi_2 \rightarrow$ second order event plane angle.
- For $C^{\perp}_{\psi_2}(\Delta S)$ calculation $\psi_2 \rightarrow \psi_2 + \frac{\pi}{2}$.
- we have used Particle Mixing Method to calculate ΔS_{mix} and select same number of particles irrespective of their charges.
- The correlator $R_{\psi_2}(\Delta S)$ gives a measure of charge separation $\parallel$ to the $\vec{B}(\perp \psi_2)$ relative to the charge separation $\perp$ to $\vec{B}(\parallel \psi_2)$.
- $R_{\psi_2}(\Delta S)$ is dominated by CME-driven charge separation result in **concave-shaped distributions** having width that reflects the magnitude of charge separation.
- **The stronger the CME driven charge separation narrower the $R_{\psi_2}(\Delta S)$ distribution.**

Introducing CME in AMPT

- A MultiPhase Transport Model (AMPT) has been extensively used to study RHIC, which provides individual particle information including position, momentum, energy etc.



- We have introduced CME in the AMPT model by switch p_y values for a fraction(f) of the downward $u(\bar{d})$ moving quarks with those of the upward moving $\bar{u}(d)$ quarks and introduce into the initial partonic states.

  where, $f = \frac{N_{\uparrow(\downarrow)}{}^{+(-)} - N_{\downarrow(\uparrow)}{}^{+(-)}}{N_{\uparrow(\downarrow)}{}^{+(-)} + N_{\downarrow(\uparrow)}{}^{+(-)}}$

  N$\rightarrow$number of a given of quarks; + and - $\rightarrow$ positive and negative charges; $\uparrow$ and $\downarrow$ are the moving directions of quarks along the y axis respectively.

Effect of flavor dependence of CME for γ and $R_{\psi_2}(\Delta S)$ Correlators

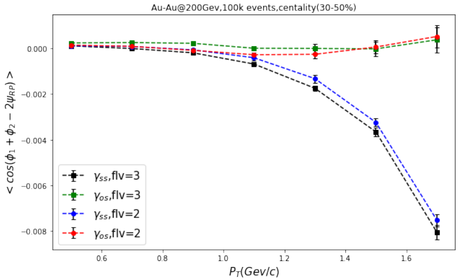


Figure: Gamma correlation vs P_T plot for Au-Au collision at 200 Gev for $(30 - 50)\%$ centrality

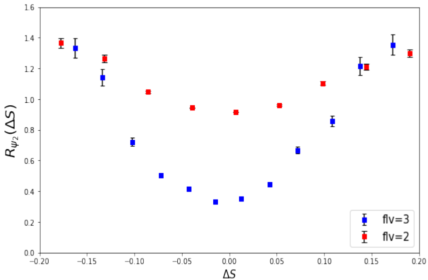


Figure: R_{ψ_2} vs ΔS plot for Au-Au collsion at 200 Gev for $(30 - 50)\%$ centrality

Classification Model with ML Algorithm

- A classification model in machine learning is a predictive modeling approach used to categorize data into predefined classes or labels by learning patterns from labeled training data.

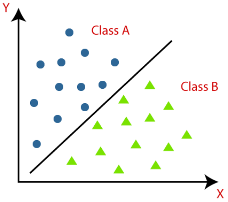
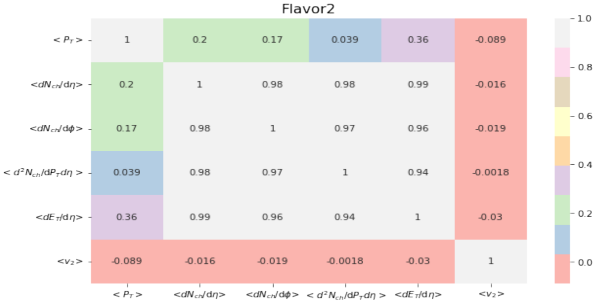
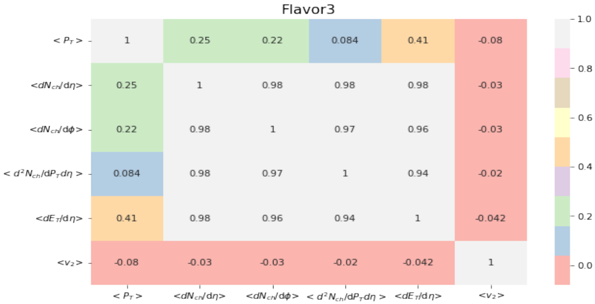


Figure: An example of classification

- Here we want to classify 2 flavor and 3 flavor CME.
- To train our model we need to find out best suited distributions.
- For that we have calculated correlation matrix for both flavors and distinguish them by observing their coefficients.

- we choose different observales like P_T, $dN_{ch}/d\eta$, $dN_{ch}/d\phi$, $d^2N_{ch}/dP_T d\eta$, $dE_T/d\eta$, V_2 as variables to construct correlation matrix.


Flavor2
$< P_T >$
$<dN_{ch}/d\eta>$
$<dN_{ch}/d\phi>$
$< d^2N_{ch}/dP_T d\eta >$
$<dE_T/d\eta>$
$<v_2>$
1 0.2 0.17 0.039 0.36 -0.089
0.2 1 0.98 0.98 0.99 -0.016
0.17 0.98 1 0.97 0.96 -0.019
0.039 0.98 0.97 1 0.94 -0.0018
0.36 0.99 0.96 0.94 1 -0.03
-0.089 -0.016 -0.019 -0.0018 -0.03 1
1.0
0.8
0.6
0.4
0.2
0.0


Flavor3
$< P_T >$
$<dN_{ch}/d\eta>$
$<dN_{ch}/d\phi>$
$< d^2N_{ch}/dP_T d\eta >$
$<dE_T/d\eta>$
$<v_2>$
1 0.25 0.22 0.084 0.41 -0.08
0.25 1 0.98 0.98 0.98 -0.03
0.22 0.98 1 0.97 0.96 -0.03
0.084 0.98 0.97 1 0.94 -0.02
0.41 0.98 0.96 0.94 1 -0.042
-0.08 -0.03 -0.03 -0.02 -0.042 1
1.0
0.8
0.6
0.4
0.2
0.0

Result:

- From Correlation Matrix we have figured out $dN_{ch}/d\eta$ vs P_T, $dN_{ch}/d\phi$ vs P_T,$dE_T/d\eta$ vs P_T, these three distributions are showing some differences and chosen as input to train our model.

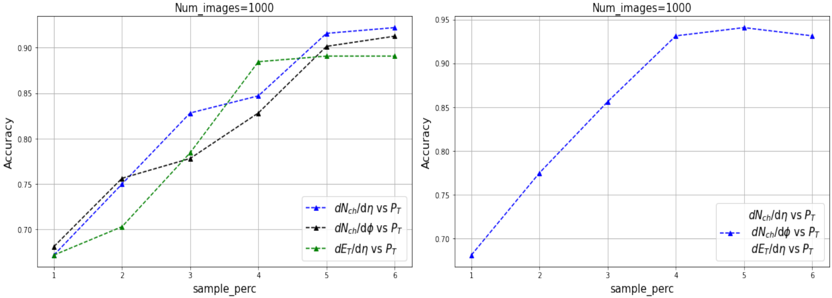


Fig: Accuracy Prediction with individual and all distribution

Summary

- At first we have introduced CME in AMPT.
- After that we have studied how γ and $R_{\psi_2}(\Delta S)$ correlators characterizes 2 flavor and 3 flavor CME.
- Then we have calculated correlation matrix with differnt observables to figure out best suited distributions to distinguish 2 flavor and 3 flavor CME.
- We have used those distributions as an input to train our neural network model(CNN) and make a prediction how accurately it can classify 2 flavor and 3 flavor CME.

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THANK YOU!