# Investigating the Chiral Magnetic Wave at RHIC-STAR

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**Abstract**

In heavy-ion collisions, the Chiral Magnetic Wave (CMW) is theorized to produce an electric quadrupole moment, leading to differences in elliptic flow between positively and negatively charged particles. This CMW signal can be detected by examining the correlation between charge-dependent elliptic flow and event charge asymmetry. This study focuses on the difference in covariance of elliptic flow ($v_2$) and charge asymmetry ($A_{\rm ch}$) for positively and negatively charged particles across various collision centralities. A comparison between the two isobar systems ($^{96}_{44}$Ru + $^{96}_{44}$Ru and $^{96}_{40}$Zr + $^{96}_{40}$Zr) is conducted to investigate any potential enhancement of the CMW signal in Ru+Ru collisions, which may be attributed to the stronger magnetic field generated in Ru. Additionally, correlations between triangular flow ($v_3$) and $A_{\rm ch}$ will be presented to assess background contributions.

*Keywords:*
Heavy-ion collisions, Quark Gluon Plasma, Chiral Magnetic Wave

## 1. Introduction

In non-central relativistic heavy-ion collisions, interaction of produced quarks with topologically non-trivial gluon fields and the strong magnetic field generated by spectator protons can give rise to novel phenomena such as the Chiral Magnetic Effect (CME) and the Chiral Separation Effect (CSE). The CME refers to the separation of electric charge along the magnetic field due to a nonzero axial charge density, while the CSE is described as the separation of chiral charges along the magnetic field in the presence of a finite vector charge density. The interplay between these two effects induces an oscillatory propagation of electric and chiral charge densities, leading to a long-wavelength collective excitation known as the Chiral Magnetic Wave (CMW) [1]. The CMW results in the formation of an electric quadrupole moment where the ”poles” (”equator”) of the produced fireball acquire additional positive (negative) charge, which leads to charge-dependent elliptic flow ($v_2$). The isobar (Ru+Ru and Zr+Zr) collision systems, offers a unique opportunity to study the CMW signal. The stronger magnetic fields in Ru+Ru is expected to yield a larger signal, while both isobars have similar backgrounds.

## 2. Data selection and analysis method

The present analysis is based on $\sim$1.6 billion minimum-bias events from each Ru+Ru and Zr+Zr collisions at $\sqrt{s_{NN}}$ =200 GeV, recorded by STAR detector at RHIC. Events are selected with primary vertex within $-35 < V_z < 25$ cm and within 2 cm in the transverse plane. Tracks must have pseudorapidity range of $|\eta|$ $< 1$ and distance of closest approach (DCA) to the primary vertex less than 3 cm.

The CMW induced quadrupole leads to the difference in $v_2$ of negatively and positively charged particles, $\Delta v_2$, which is expected to be proportional to the charge asymmetry ($A_{\mathrm{ch}}$), i.e., $\Delta v_2 = v_2^- - v_2^+ \approx r_2 A_{\mathrm{ch}}$. Here $r_2$ denotes the slope parameter of $\Delta v_2$ versus $A_{\mathrm{ch}}$ and $A_{\mathrm{ch}} = (\mathrm{N}_+ - \mathrm{N}_-)/(\mathrm{N}_+ + \mathrm{N}_-)$ with $\mathrm{N}_+$ ($\mathrm{N}_-$) denoting the number of positive (negative) particles in a given event. In addition to measuring $v_{\mathrm{n}}^{\pm}$ as a function of $A_{\mathrm{ch}}$, the covariance of $v_n^{\pm}$ and $A_{\mathrm{ch}}$, i.e., $\langle v_n^{\pm} A_{\mathrm{ch}}\rangle - \langle v_n^{\pm}\rangle\langle A_{\mathrm{ch}}\rangle$ also known as three particle integral correlator can also be measured to quantify strength of CMW signal [2] . It is more robust against detector efficiency correction and statistically reduce fluctuations as sample need not be divided into further $A_{\mathrm{ch}}$ bins to calculate slope of $\Delta v_2$ versus $A_{\mathrm{ch}}$. To study CMW signal equivalently to $r_2$ parameter, an alternative observable, the delta integral covariance can be used, defined as $\Delta\mathrm{IC} = (\langle v_n^- A_{\mathrm{ch}}\rangle - \langle v_n^-\rangle\langle A_{\mathrm{ch}}\rangle) - (\langle v_n^+ A_{\mathrm{ch}}\rangle - \langle v_n^+\rangle\langle A_{\mathrm{ch}}\rangle)$, where the angular bracket denotes the average over the events. The Q-cumulant method [3] with $\eta$ gap of 0.3 between particle of interest and reference particles is used to calculate anisotropic flow coefficients ($v_{\mathrm{n}}$).

## 3. Results

Fig. 1 (left) shows covariance of $v_2$ and $A_{\mathrm{ch}}$ for positive and negative charges in Ru+Ru and Zr+Zr collisions versus centrality. Both systems exhibit similar trends, covariance increases from central to peripheral collisions for both positive and negative particles. $\Delta$IC also increases from central to peripheral collisions. Fig. 1 (right) presents $\Delta\mathrm{IC}/\sigma^2_{A_{\mathrm{ch}}}$ (for $v_2$), the values from both the systems agree within errors, no enhanced CMW signal is seen in Ru+Ru over Zr+Zr despite Ru having four more protons compared to Zr. The covariance of $v_3$ and $A_{\mathrm{ch}}$ for positive and negative charges (Fig. 2 left) and $\Delta\mathrm{IC}/\sigma^2_{A_{\mathrm{ch}}}$ (Fig. 2 right) are independent of collision centrality.

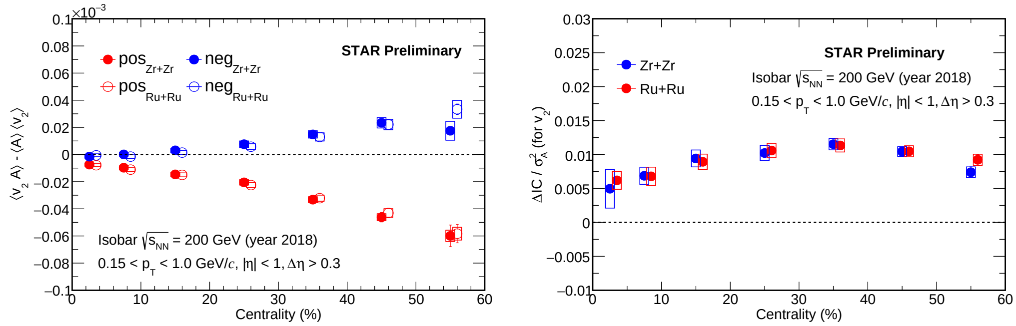


Figure 1: Comparison of covariance (Left) between $v_2$ and $A_{\rm ch}$, and (Right) $\Delta\mathrm{IC}/\sigma^2_{A_{\rm ch}}$ for $v_2$ in Ru+Ru and Zr+Zr collisions. Points are horizontally shifted for clarity.

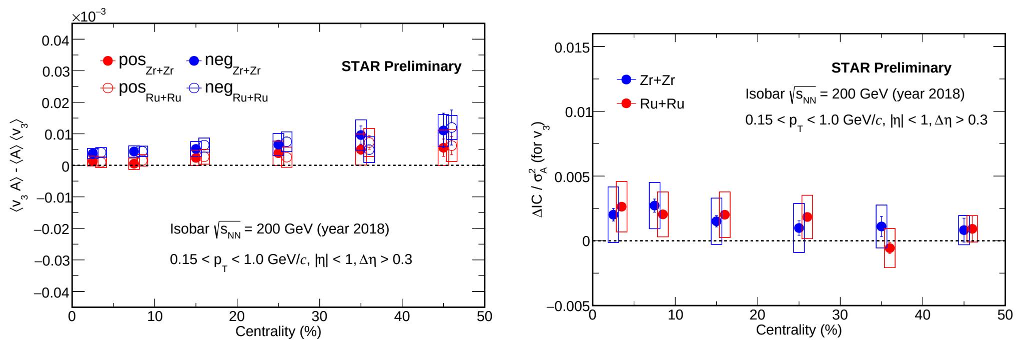


Figure 2: Comparison of covariance (Left) between $v_3$ and $A_{\rm ch}$, and (Right) $\Delta\mathrm{IC}/\sigma^2_{A_{\rm ch}}$ for $v_3$ in Ru+Ru and Zr+Zr collisions. Points are horizontally shifted for clarity.

## 4. Summary

The charge-dependent correlation between elliptic flow and $A_{\rm ch}$ is investigated in Ru+Ru and Zr+Zr collisions at $\sqrt{s_{NN}}$ =200 GeV. The covariance of $v_2$ and $A_{\rm ch}$ increases from central to peripheral collisions for both positive and negative particles. However, no charge-dependent effects are observed in the third-harmonic. No enhancement of the CMW signal is found in Ru+Ru collisions, despite the stronger magnetic field in Ru+Ru collisions . To further explore the CMW contribution, techniques such as Event Shape Engineering will be used to estimate CMW signal.

## References

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