



Signatures of Chiral Magnetic Effect in Isobaric Collisions

Hui Zhang^{*1}, Shuzhe Shi², Anping Huang³, Defu Hou⁴, Jinfeng Liao³

¹South China Normal University, ²McGill University, ³Indiana University, ⁴Central China Normal University

Abstract

With the recently developed quantitative simulation tool for computing CME signal, the Anomalous-Viscous Fluid Dynamics (AVFD), we demonstrate that a joint (multiplicity + elliptic-flow) event selection is crucial for contrasting the correlation observables of the two colliding systems that supposedly have identical flow-driven background contributions while quite different CME signal contributions. We further propose to use the absolute difference between RuRu and ZrZr events (after using identical event selection) for detecting CME signal and make predictions for the correlation observables.

AVFD: Anomalous-Viscous Fluid Dynamics

$$\hat{D}_\mu J_R^\mu = +\frac{N_c Q^2}{4\pi^2} E_\mu B^\mu, \quad \hat{D}_\mu J_L^\mu = -\frac{N_c Q^2}{4\pi^2} E_\mu B^\mu$$

$$J_R^\mu = n_R u^\mu + \nu_R^\mu + \frac{N_c Q}{4\pi^2} \mu_R B^\mu$$

$$J_L^\mu = n_L u^\mu + \nu_L^\mu - \frac{N_c Q}{4\pi^2} \mu_L B^\mu$$

CME

Viscous Effect

$$\Delta_\nu^\mu \hat{d}(\nu_\chi^\nu) = -\frac{1}{\tau_r} [(\nu_\chi^\mu) - (\nu_\chi^\mu)_{NS}]$$

$$(\nu_\chi^\mu)_{NS} = \frac{\sigma T}{2} \Delta^{\mu\nu} \partial_\nu \left(\frac{\mu_\chi^f}{T} \right) + \frac{\sigma}{2} Q E^\mu$$

on top of VISH2+1D — OSU Group

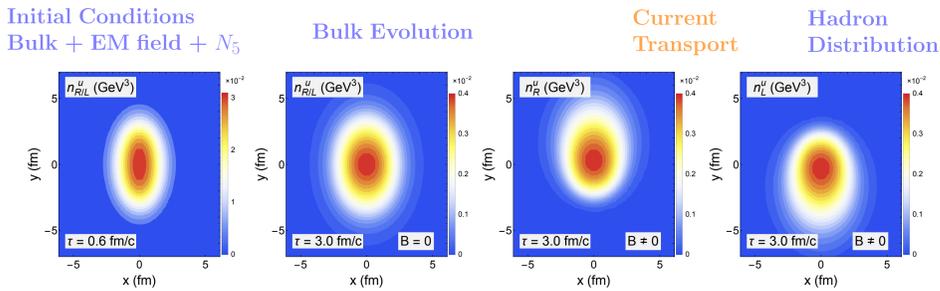
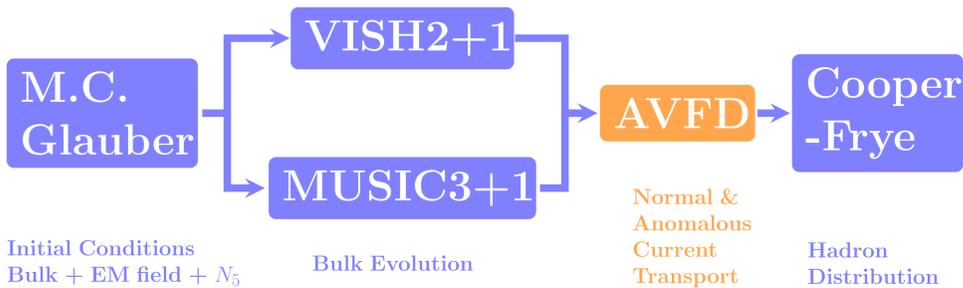


Figure 1: The evolution of u -flavor densities via solving AVFD equations from the same initial charge density distribution (for either RH or LH) at $\tau = 0.60\text{fm}/c$ (left most panel) in three cases: (a) (second left panel) for either RH or LH density at $\tau = 3.00\text{fm}/c$ with magnetic field $B \rightarrow 0$ i.e. no anomalous transport; (b) (second right panel) for RH density and (c) (most right panel) for LH density, both at $\tau = 3.00\text{fm}/c$ with nonzero B field along positive y -axis.

Isobaric Collisions: $^{96}_{44}\text{Ru}$ vs. $^{96}_{40}\text{Zr}$

Same Nucleons \Rightarrow Similar Bulk Background
Different Protons \Rightarrow Different CME!

• $B \otimes \mu_A \Rightarrow$ current \Rightarrow dipole (charge separation)

$$\frac{dN^\pm}{d\phi} \propto 1 + 2a_1^\pm \sin(\phi - \Psi_{RP}) + 2v_2 \cos(2\phi - 2\Psi_{RP}) + \dots$$

• charge separation \Rightarrow two particle correlation

$$\gamma = \langle \cos\Delta\phi_i \cos\Delta\phi_j \rangle - \langle \sin\Delta\phi_i \sin\Delta\phi_j \rangle = \kappa v_2 F - H$$

$$\beta = \langle \cos\Delta\phi_i \cos\Delta\phi_j \rangle + \langle \sin\Delta\phi_i \sin\Delta\phi_j \rangle = F + H$$

F: Bulk Background H: Possible CME Signal

Event Selection for the Isobaric Collisions: Insights from Initial Conditions

Key idea: contrasting two systems with identical bulk, varied magnetic fields.

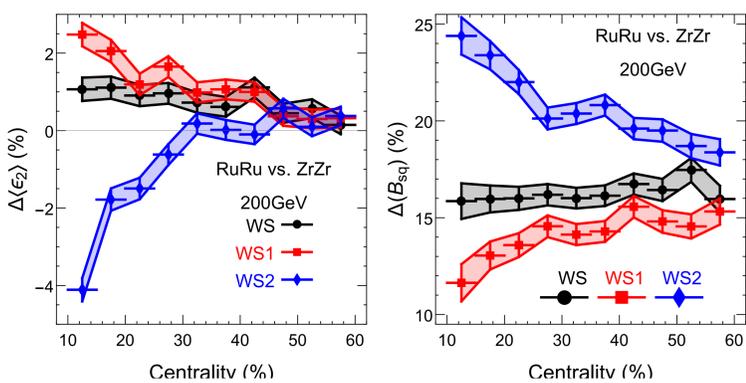


Figure 2: The relative difference in eccentricity $\Delta(\epsilon_2)$ (left) and projected magnetic-field-strength-squared $\Delta(B_{sq})$ (right) between RuRu and ZrZr, with conventional centrality event selection.

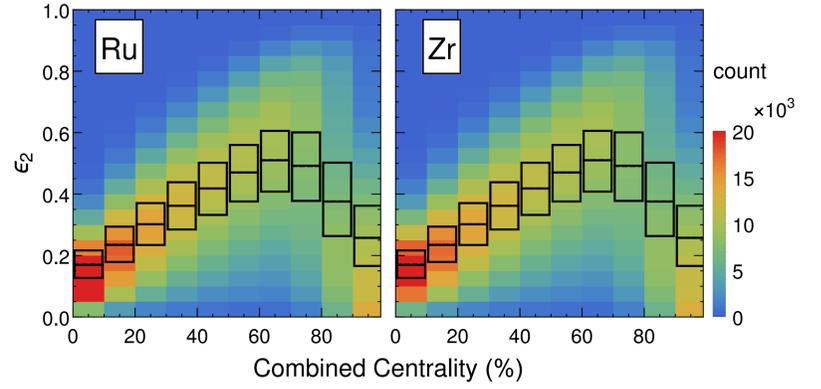


Figure 3: joint (multiplicity + elliptic-flow) identical event selection

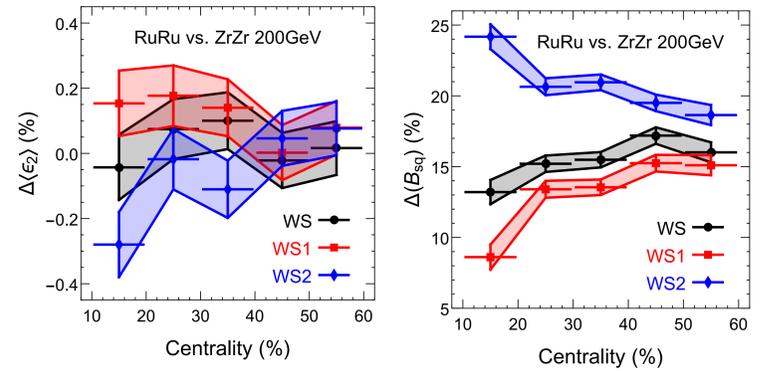


Figure 4: The relative difference in eccentricity $\Delta(\epsilon_2)$ (left) and projected magnetic-field-strength-squared $\Delta(B_{sq})$ (right) between RuRu and ZrZr, with the proposed joint (multiplicity + elliptic-flow) event selection.

Predictions for CME Signals in Isobaric Collisions with EBE-AVFD

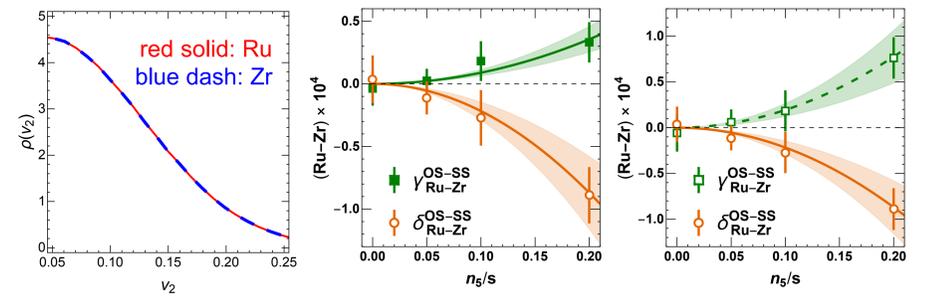


Figure 5: (left) The measured v_2 distributions of the post-selection simulation events for RuRu and ZrZr collisions. (right two) The absolute difference in correlation observables ($\gamma_{Ru}^{OS-SS} - \gamma_{Zr}^{OS-SS}$) and ($\delta_{Ru}^{OS-SS} - \delta_{Zr}^{OS-SS}$) with respect to event-plane (EP: center panel) and reaction plane (RP: right panel) geometry, measured with post-selection events, for varied signal strength as controlled by initial axial charge density n_5/s .

$$\gamma_{Ru-Zr}^{OS-SS}|_{EP} \simeq (0.89 \pm 0.51) \times 10^{-3} \times \left(\frac{n_5}{s}\right)^2$$

$$\delta_{Ru-Zr}^{OS-SS}|_{EP} \simeq -(2.17 \pm 0.72) \times 10^{-3} \times \left(\frac{n_5}{s}\right)^2$$

$$\xi_{isobar}^{EP} \equiv \frac{\gamma_{Ru-Zr}^{OS-SS}|_{EP}}{\delta_{Ru-Zr}^{OS-SS}|_{EP}} \simeq -(0.41 \pm 0.27)$$

$$\gamma_{Ru-Zr}^{OS-SS}|_{RP} \simeq (1.94 \pm 0.72) \times 10^{-3} \times \left(\frac{n_5}{s}\right)^2$$

$$\delta_{Ru-Zr}^{OS-SS}|_{RP} \simeq -(2.17 \pm 0.72) \times 10^{-3} \times \left(\frac{n_5}{s}\right)^2$$

$$\xi_{isobar}^{RP} \equiv \frac{\gamma_{Ru-Zr}^{OS-SS}|_{RP}}{\delta_{Ru-Zr}^{OS-SS}|_{RP}} \simeq -(0.90 \pm 0.45)$$

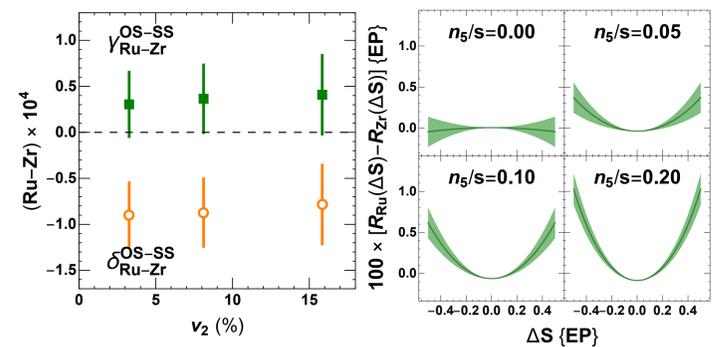


Figure 6: (left) Predictions from EBE-AVFD simulations for observables ($\gamma_{Ru}^{OS-SS} - \gamma_{Zr}^{OS-SS}$) and ($\delta_{Ru}^{OS-SS} - \delta_{Zr}^{OS-SS}$) as a function of bin-wise elliptic flow v_2 from event-shape analysis with three identical bins for RuRu and ZrZr systems. The simulation results are obtained with $n_5/s = 20\%$. (right) Predictions from EBE-AVFD simulations for the R-correlator distributions for $n_5/s = 0\%$, 5% , 10% and 20% respectively.

Reference

- S. Shi, Y. Jiang, E. Lilleskov and J. Liao, Annals Phys. **394**, 50 (2018) [arXiv:1711.02496 [nucl-th]].
Y. Jiang, S. Shi, Y. Yin and J. Liao, Chin. Phys. C **42**, no. 1, 011001 (2018) [arXiv:1611.04586 [nucl-th]].
S. Shi, H. Zhang, D. Hou and J. Liao, Nucl. Phys. A **982**, 539 (2019) [arXiv:1807.05604 [hep-ph]].
S. Shi, H. Zhang, D. Hou and J. Liao, [arXiv:1910.14010 [nucl-th]].