The 16th Workshop on QCD Phase Transition and Relativistic Heavy-Ion Physics (QPT 2025)

Effects of QGP droplet evolution on initial charge separation in small collision systems

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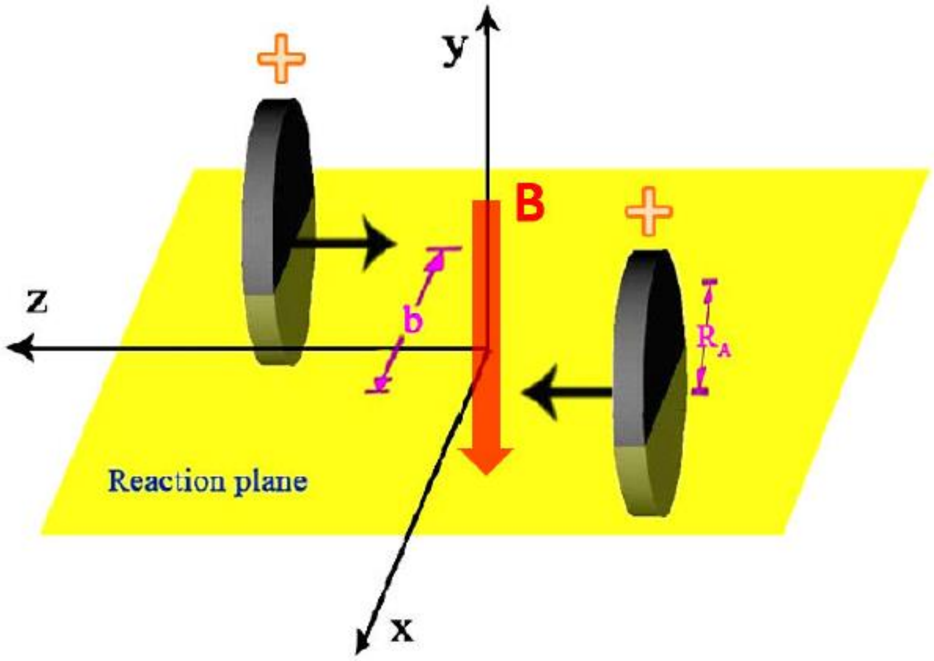
W-T Deng, C Gao, G-Z Wu, S-X Zhang, Z-W Zhang

Outline

- Introduction and motivation
- Azimuthal correlation between φ_B and φ_2 in small collisions system $p/p^{\uparrow} + A$
- Evolution of CME signal in small collision system.
- Summery and outlook

Motivation

Due to fast, oppositely directed motion of two colliding ions, off-central heavy-ion collisions can create strong transient magnetic fields.



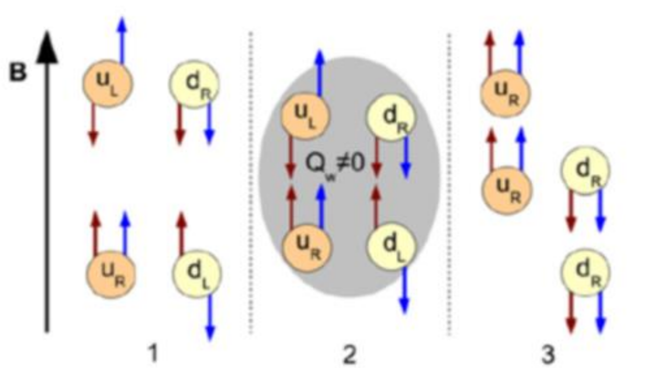
Such a strong B field may influence the dynamics of QGP

Chirality imbalance + magnetic field = chiral magnetic effect (CME)

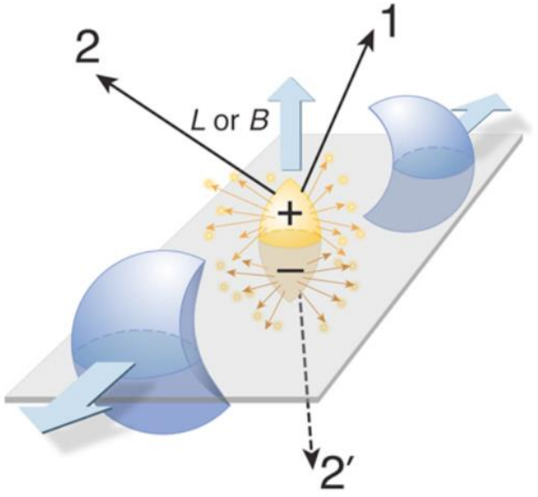
Kharzeev 2004, Kharzeev, Mclerran, Warringa, Fukushima 2007-2008

Charge separation $\vec{J} = \sigma_5 \vec{B}$

Chiral conductivity $\sigma_5 = N_c \sum_f \frac{q_f^2 \mu_5}{2\pi^2}$



Experiment searches of CME



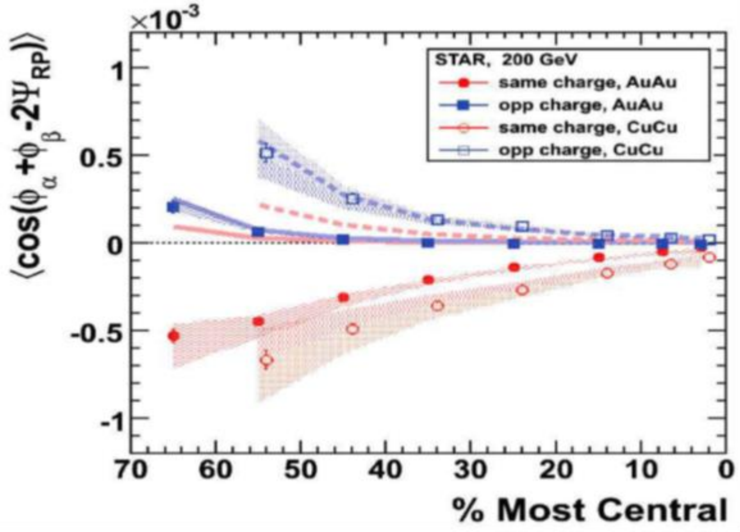
Two particle charge azimuthal correlation:

$$\gamma_{q_1,q_2} = \langle \cos(\phi_1 + \phi_2 - 2\psi_{RP}) \rangle$$

$$\gamma_{ss} = (\gamma_{++} + \gamma_{--})/2$$

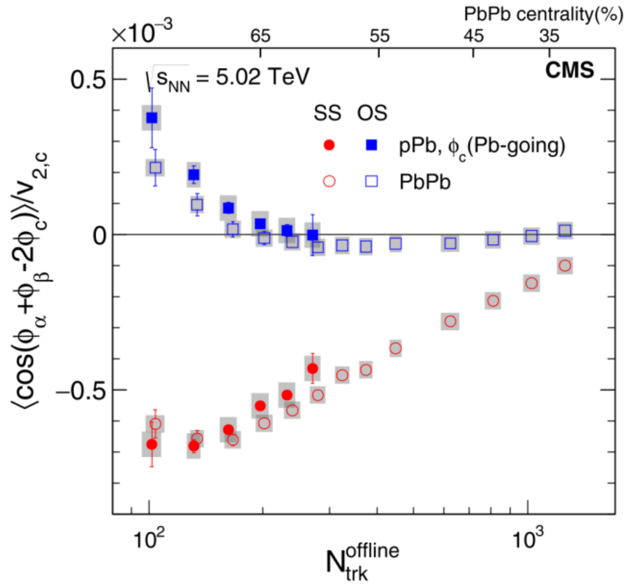
$$\gamma_{os} = \gamma_{+-}$$

charge correlator in Au+Au, Cu+Cu, and Pb+Pb are consistent with CME:



PRL 103, 251601 (2013)

CME signal in small collisions system (p+A)?



PRL 118, 122301 (2017)

Experiment signal include contri. from CME and background

$$\Delta\gamma_{\text{exp}} = \Delta\gamma_{\text{CME}} + \Delta\gamma_{\text{background}}$$

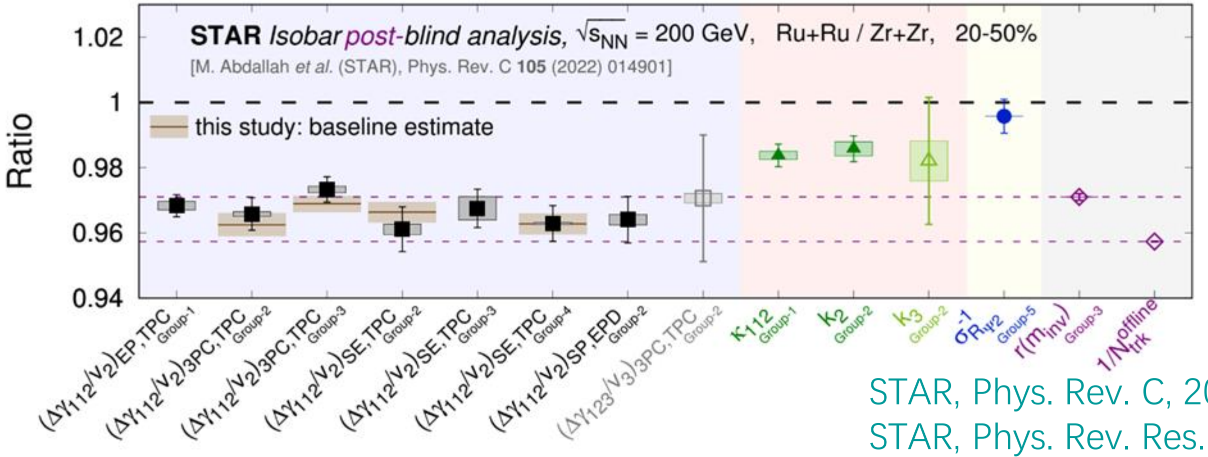
$$\Delta\gamma_{\text{CME}} \propto B^2 \cos 2(\varphi_B - \varphi_2) \qquad \Delta\gamma_{\text{background}} \propto v_2$$

How to distinguish them?

— $^{96}_{40}$Zirconium vs $^{96}_{44}$Ruthenium

Isobaric collision

Deng, Huang, Ma, Wang
Phys. Rev. C 94 (2016) 041901(R)



STAR, Phys. Rev. C, 2022, 105(1): 014901
STAR, Phys. Rev. Res., 2024, 6(3): L032005

- CME contribution is small.
- Nuclear deformation must be considered

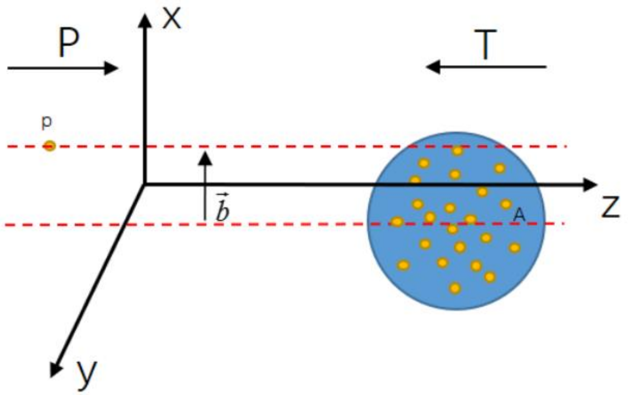
Experiment signal include contri. from CME and background

$$\Delta\gamma_{\text{exp}} = \Delta\gamma_{\text{CME}} + \Delta\gamma_{\text{background}}$$

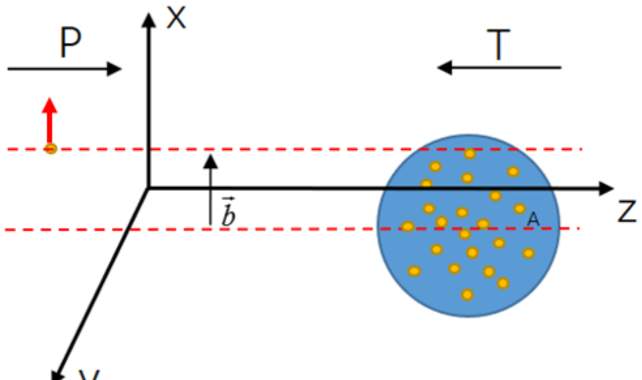
$$\Delta\gamma_{\text{CME}} \propto B^2 \cos\, 2(\varphi_B - \varphi_2) \qquad \Delta\gamma_{\text{background}} \propto v_2$$

CME in Small collisions system (p+A or p$^{\uparrow}$+A)

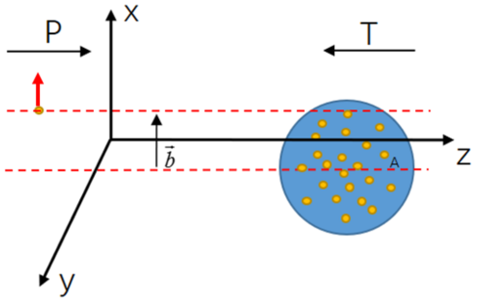
Zhang, Cen and Deng, Chin. Phys. C 46, 084103 (2022)
Wu, Zhang, Gao, **Yi Xu**, Deng, Phys. Rev. C 110 (2024) 6, L061901
Yi Xu, Gao, Zhang , Deng, Phys. Rev. C 112, 034904 (2025)

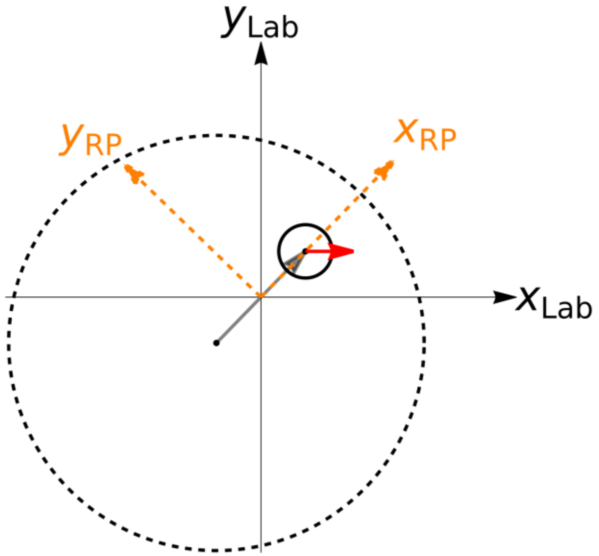


- Azimuthal correlation between φ_B and φ_2 ?
- Could CME signal remain to the final state ?



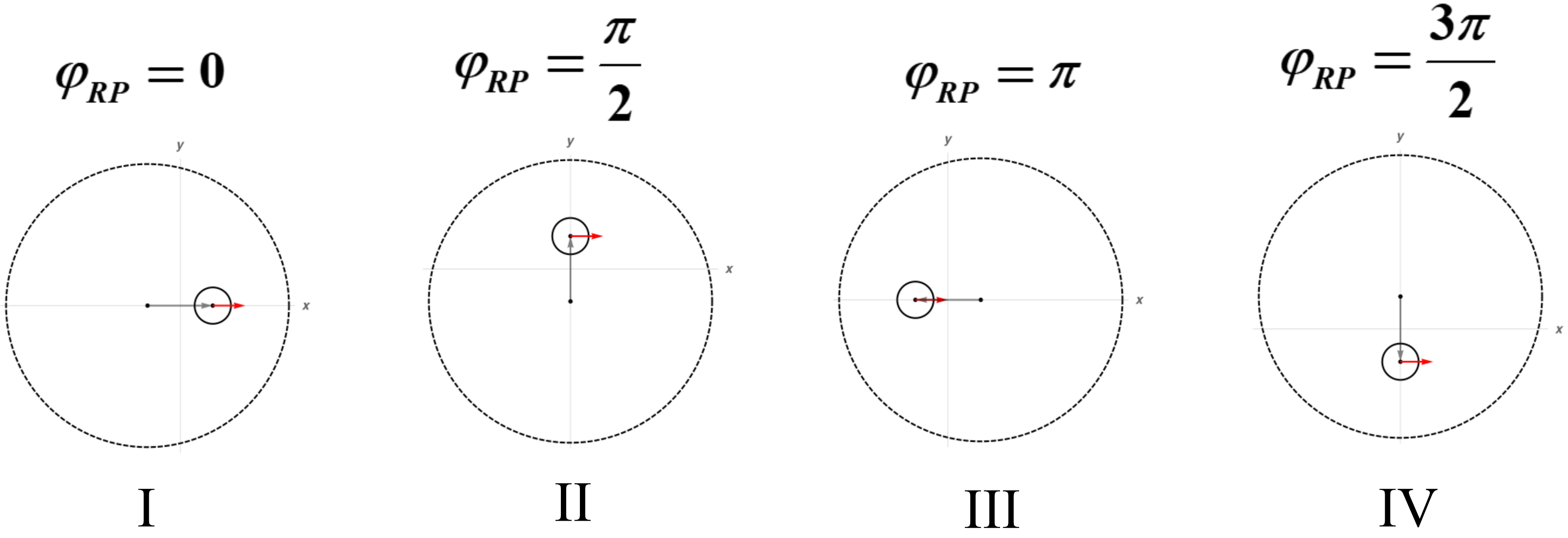
Small collision system p$^{\uparrow}$ +A





HIJING model is employed.

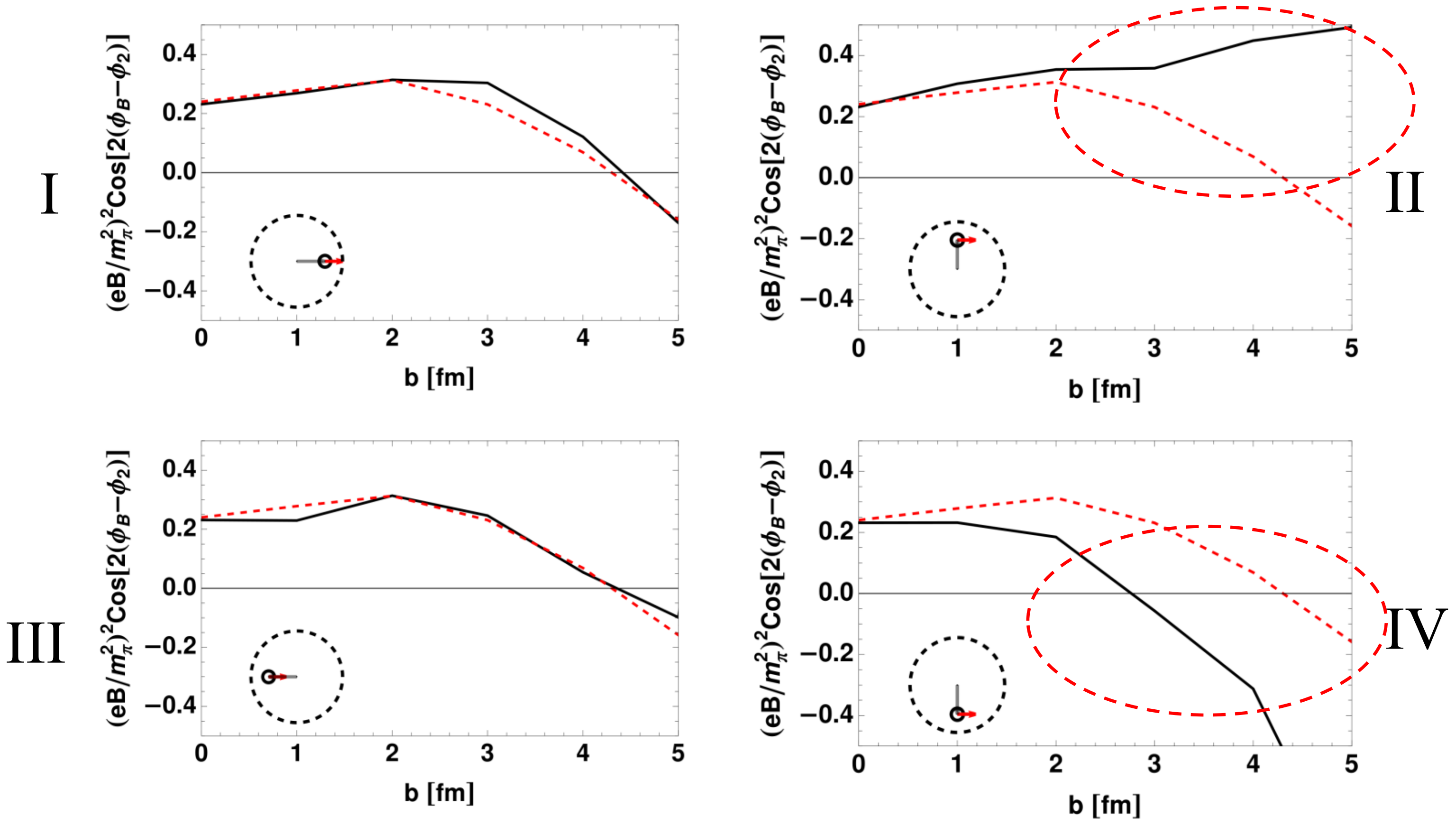
- Projectile p$^{\uparrow}$ moving along +z direction
- Polarization is fixed along +x direction
- φ_{RP} is random in each event,
  but detectable approximately.



CME correlator in p$^{\uparrow}$ +A

$$\Delta\gamma_{\rm CME} \propto B^2 \cos\ 2(\varphi_B - \varphi_2)$$

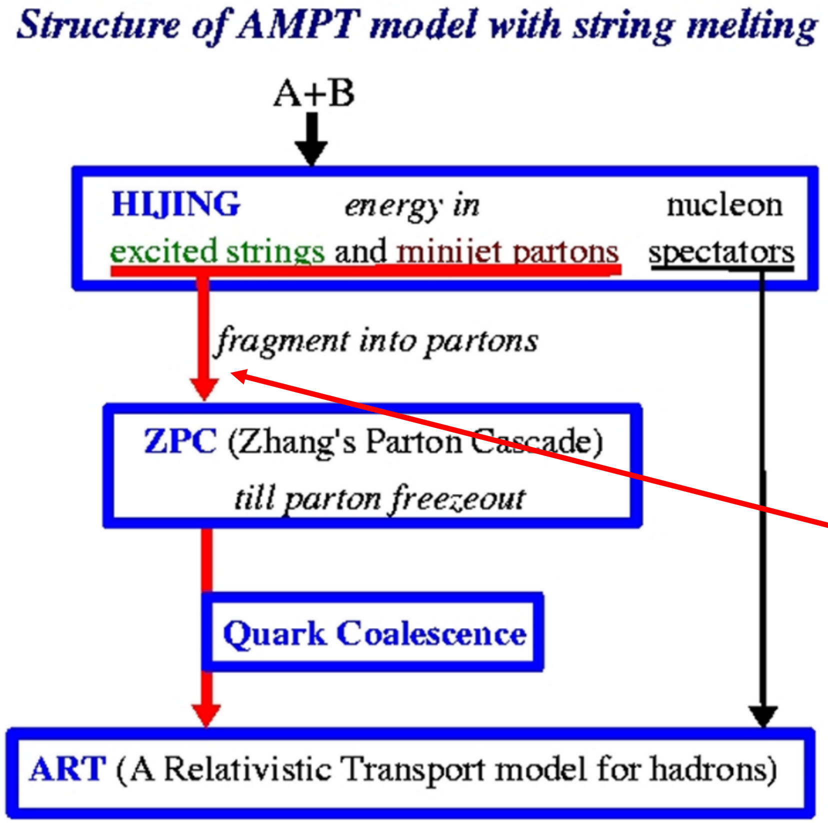
- In scheme II and IV, CME correlators are quite different

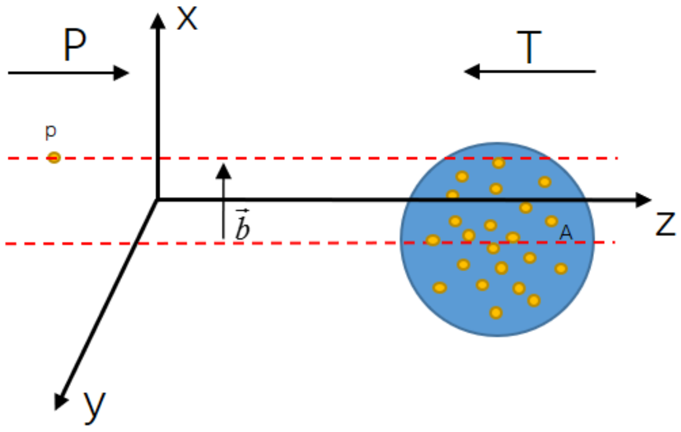


CME correlator in $p + A$, as a baseline

● Evolution of CME signal in small system

AMPT model (String melting version) is employed to simulate p+A collision with $\sqrt{s}$= 200 GeV .



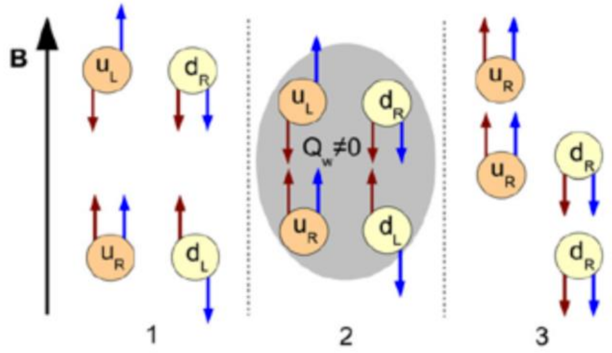


Initial CME signal is input before parton evolution.

Z.-W. Lin, C. M. Ko, B.-A. Li, B. Zhang, Phys. Rev. C, 2005, 72: 064901

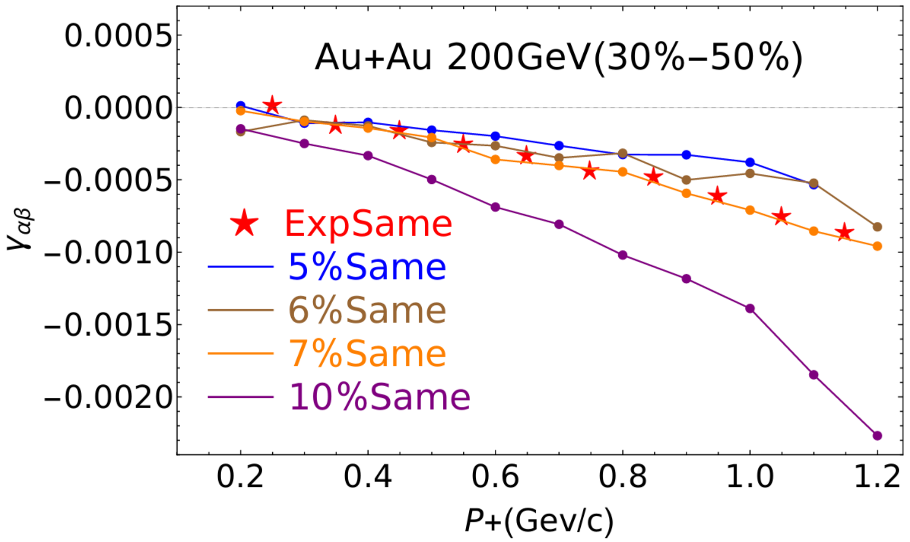
To set initial CME signal

Initial CME signal is input before parton evolution.

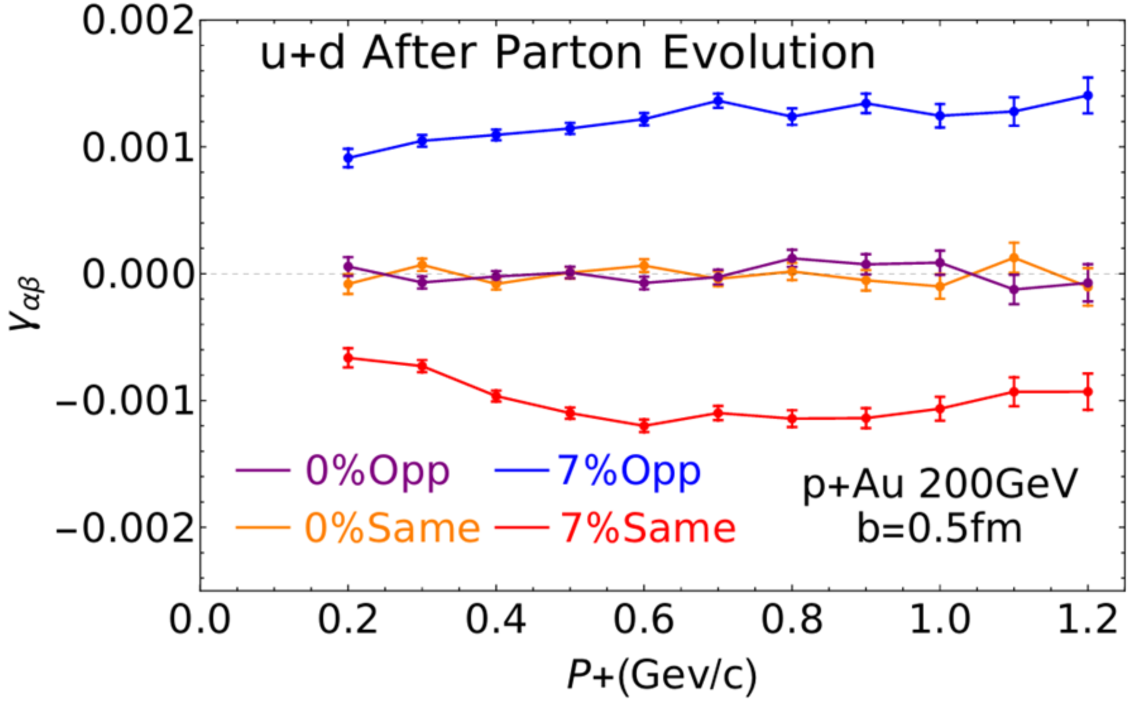


Interchange P_y of percentages of pos.-neg. parton pairs randomly.

G.-L. Ma and B. Zhang, Phys. Lett. B 700, 39 (2011)



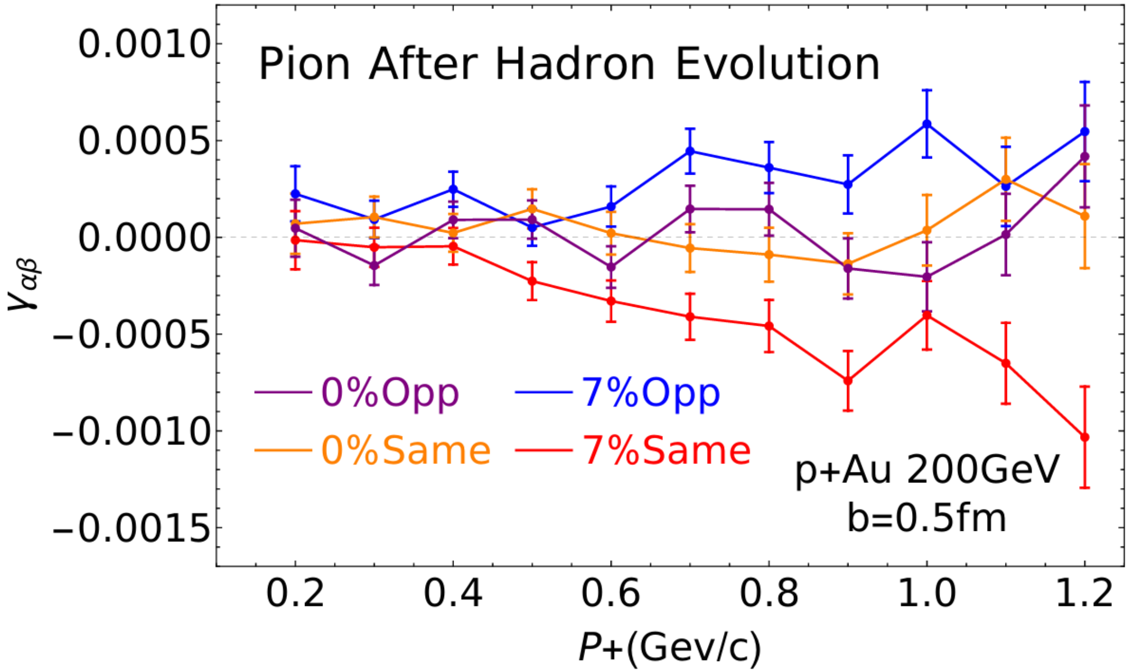
- 7% percentage can explain exp. data in $Au + Au$.
- The same percentage is set in $p + A$ as the upper limit of CME in our simulation.



$$P_+ = \frac{P_{T,\alpha} + P_{T,\beta}}{2}$$

- p_+ dependence is mild.
- The values of γ_{OS} and γ_{SS} are symmetric approximately in the whole range of P_+.

- 0% events : Background contribution is negligible in the evolution of QGP droplet.



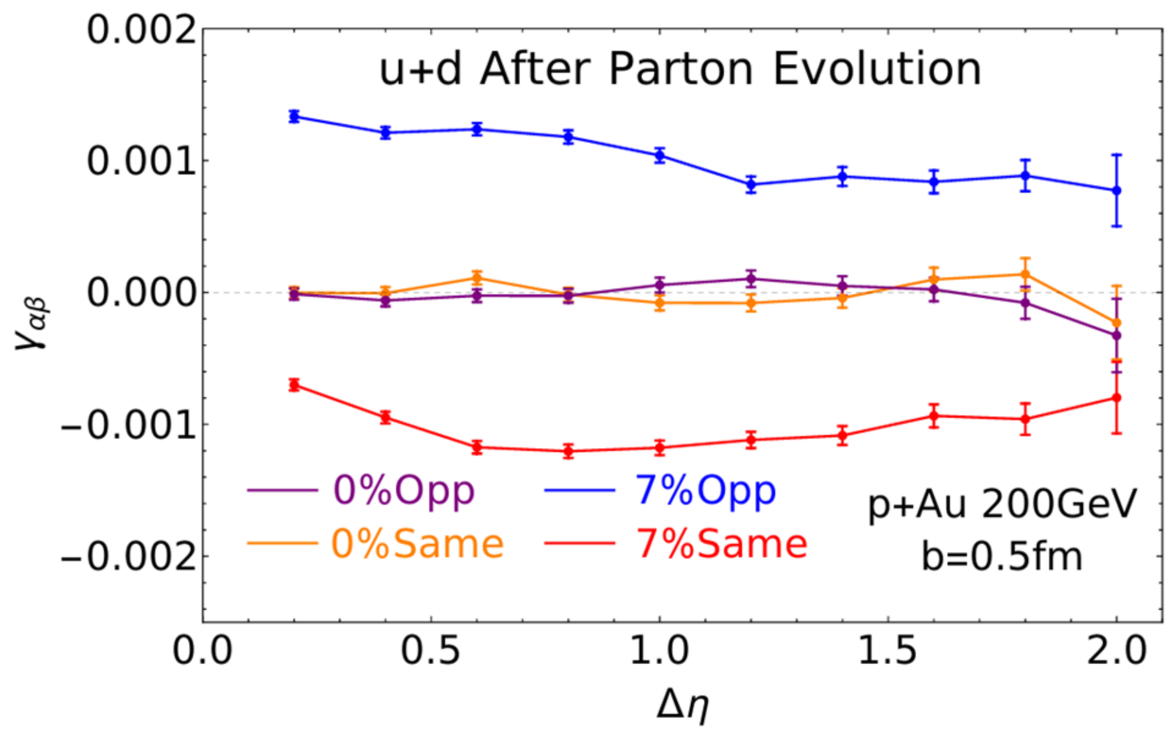
- p_+ dependence is strong.

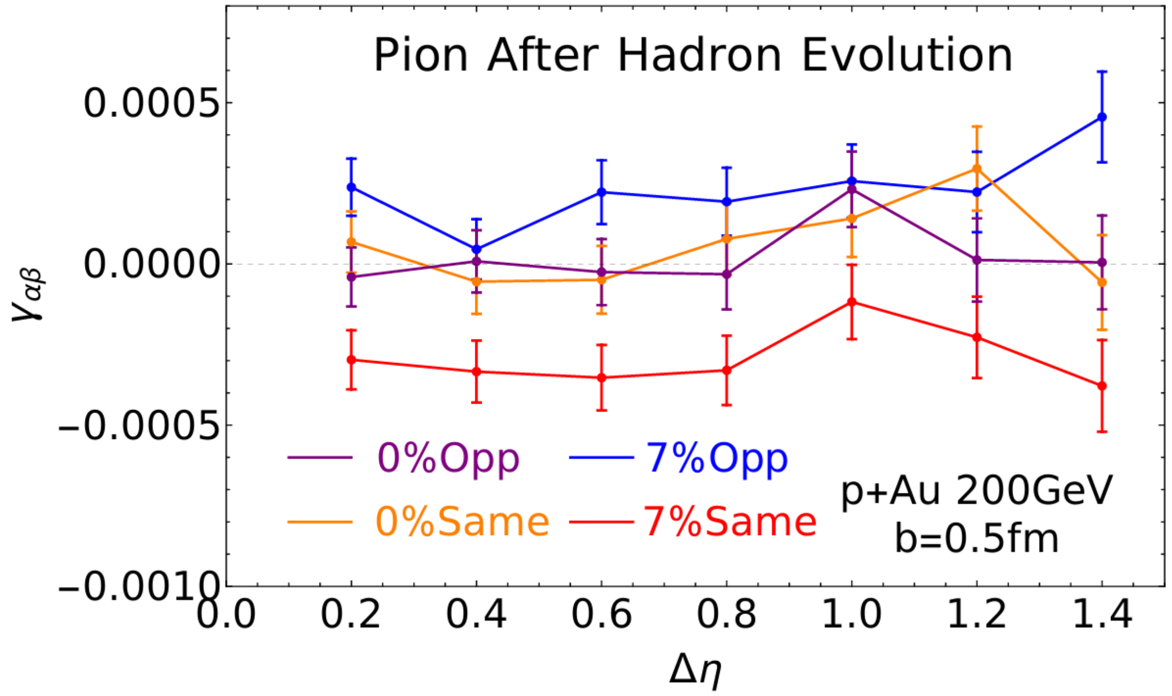
  More cascade collisions weaken signal effectively

- Hadron evolution break the symmetry of γ_{OS} and γ_{SS}

  Due to local momentum and charge conservation.

- 7% events: 50~90% signal can survive through hadron evolution.

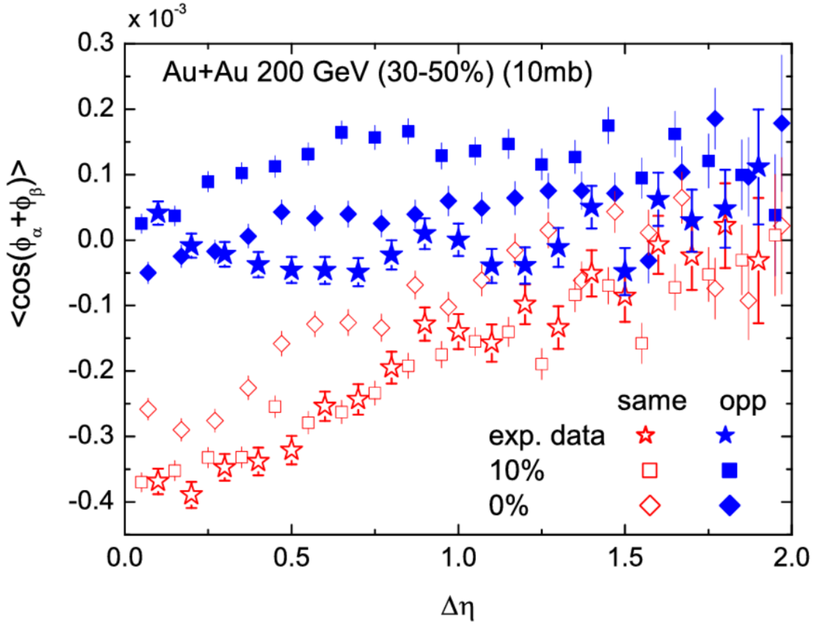


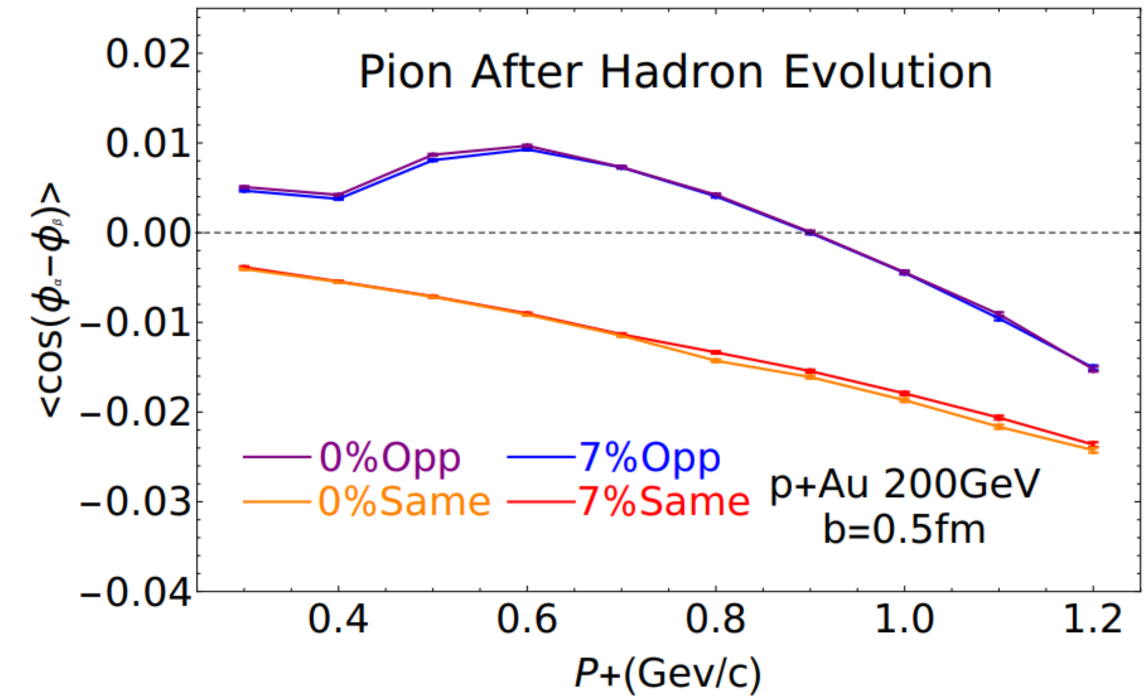


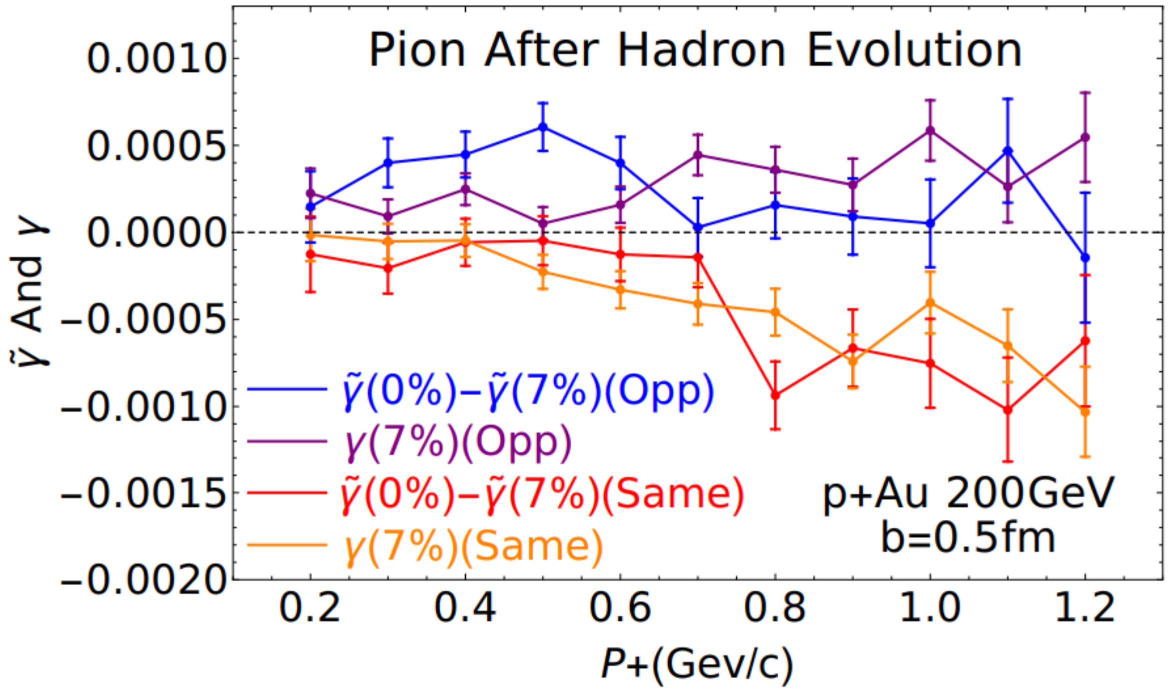
$$\eta = \frac{1}{2} log \frac{|P| + P_z}{|P| - P_z}$$

$$\Delta\eta = |\eta_A - \eta_B|$$

- $\Delta\eta$ dependence is mild.
- The dependency of $\Delta\eta$ is completely different from that of $Au + Au$.







$$\tilde{\gamma}_{\alpha\beta} = \langle \cos(\phi_\alpha - \phi_\beta) \rangle$$

- $\tilde{\gamma}_{\alpha\beta,0\%}$ and $\tilde{\gamma}_{\alpha\beta,7\%}$ are approximate

  Background independent of the reaction plane make a major contribution to $\tilde{\gamma}_{\alpha\beta}$.

$$\Delta\tilde{\gamma}_{0\%-7\%} = |\tilde{\gamma}_{\alpha\beta 0\%} - \tilde{\gamma}_{\alpha\beta 7\%}|$$

- $\Delta\tilde{\gamma}_{0\%-7\%}$ and $\gamma_{\alpha\beta,7\%}$ are approximate

  The CME signal is hardly affected by background effects in $p + Au$.

Summary and Outlook

- Calculating the azimuthal correlation between φ_B and φ_2
- CME signal can survive into final hadron system, and background contribution is negligible.
- Small system $p^{\uparrow}+A$ can provide us new experiment method to clarify CME contribution.

- E-by-E simulations of $p^{\uparrow}+A$ with more realistic model are processing.