Sensitivity analysis of CME observables with AMPT model

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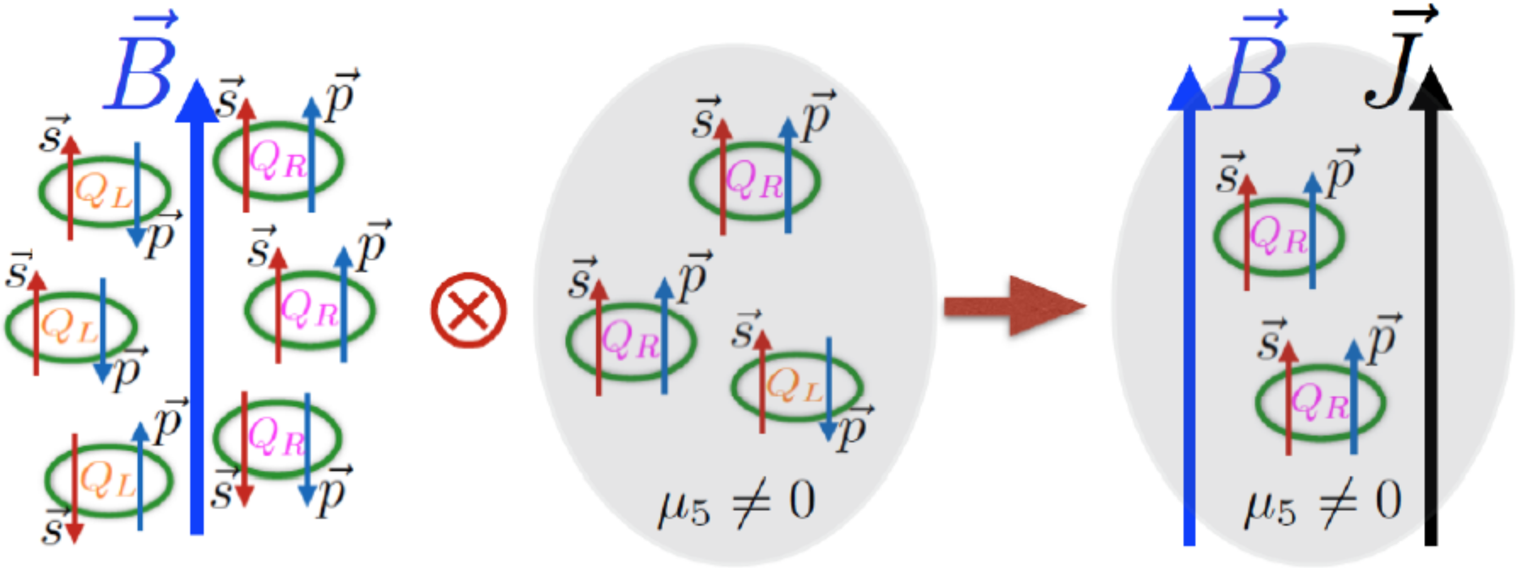
Based on arXiv: 1906.11631

Outline

- Motivation
- Model and Method
- Results
- Summary & outlook

Chiral magnetic effect (CME)

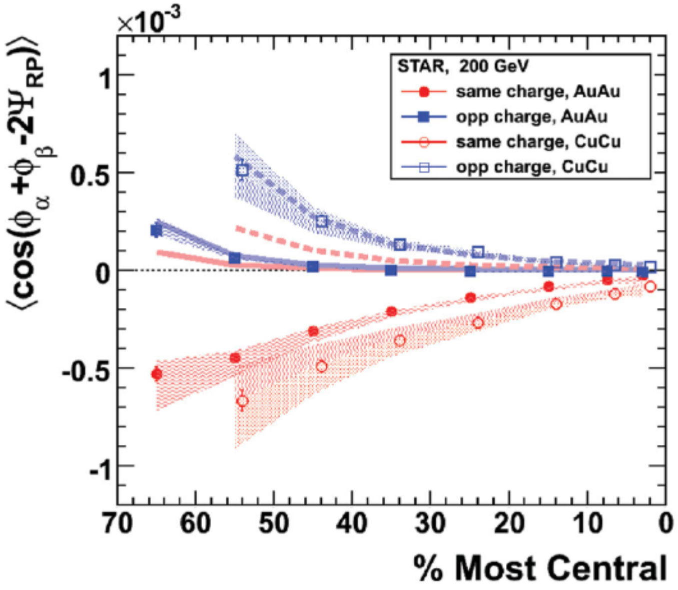
D. E. Kharzeev, J.Liao, S. A.Voloshin, et. al.
Prog. Part. Nucl. Phys. 88 (2016)



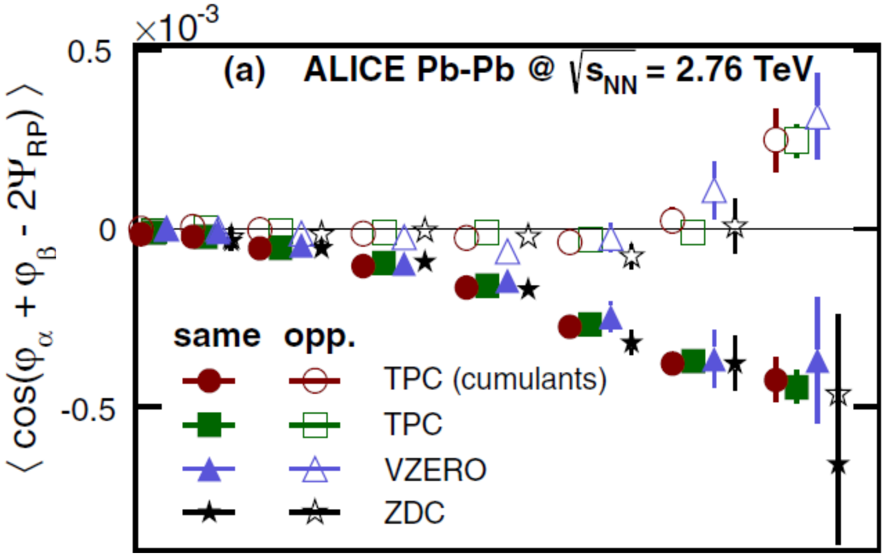
CME: (Extremely large magnetic field) && (nonzero chiral chemical potential) ➔ Charge current/separation in the direction of magnetic field

The observable γ

B. I. Abelev et al. [STAR Collaboration],
PRL. 103, 251601 (2009)



B. Abelev et al. [ALICE Collaboration],
PRL. 110. 012301 (2013)

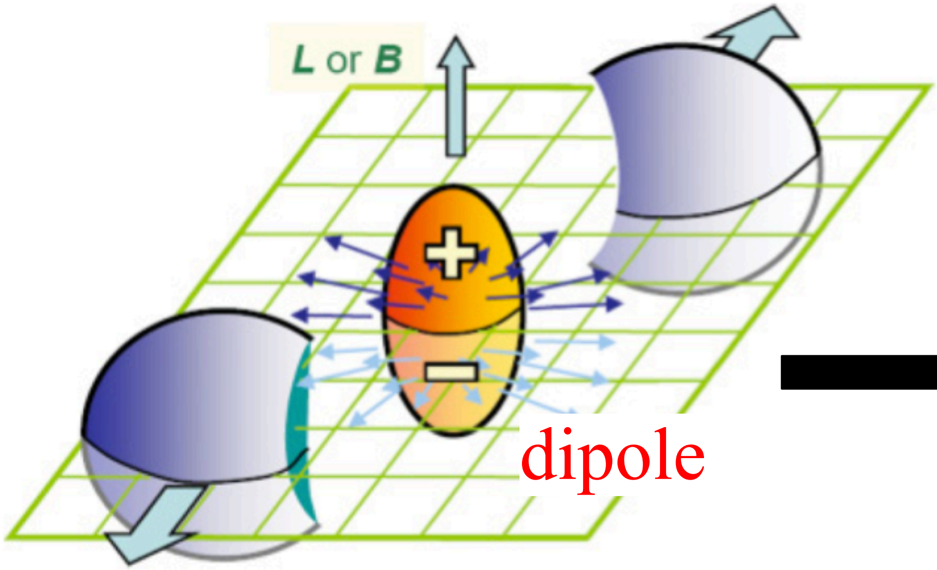


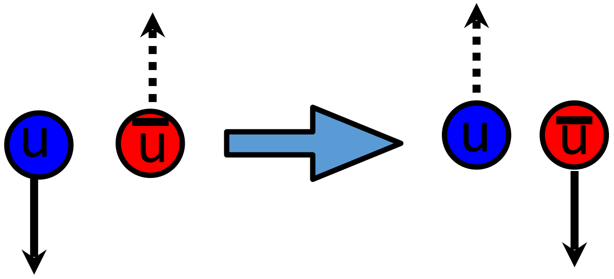
$$\gamma = \langle\cos(\phi_\alpha+\phi_\beta-2\psi_{RP})\rangle$$
$$=\langle\cos(\Delta\phi_\alpha)\cos(\Delta\phi_\beta)-\sin(\Delta\phi_\alpha)\sin(\Delta\phi_\beta)\rangle$$

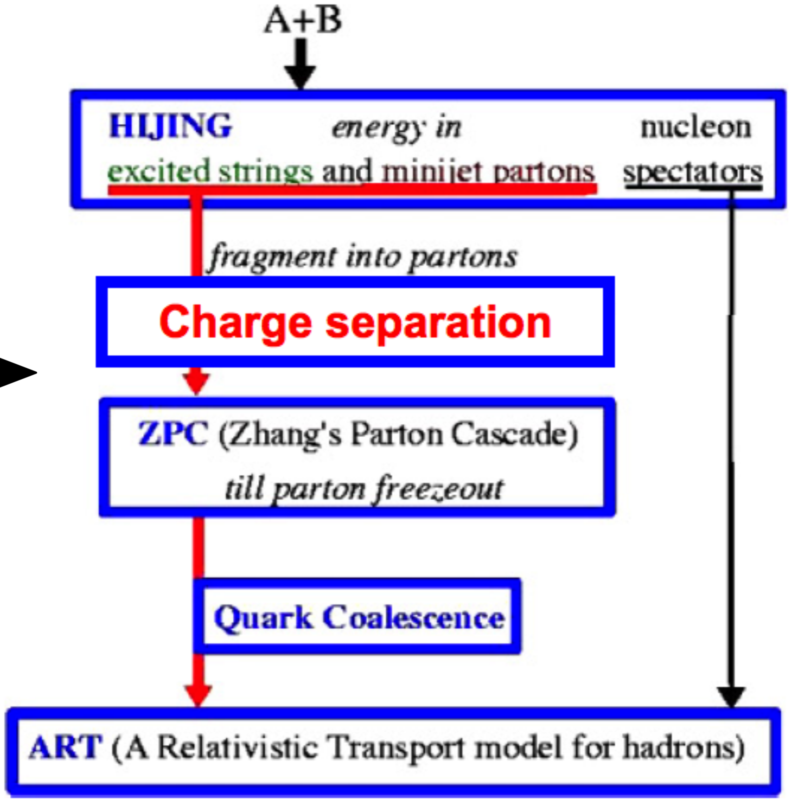
ϕ_α/ϕ_β: "+" or "−" particles
ψ_{RP}: reaction plane
$\Delta\phi = \phi - \psi_{RP}$

- The usual CME observable of is γ correlator measured at RHIC & LHC, consistent with CME expectation.

AMPT with CME-induced charge separation







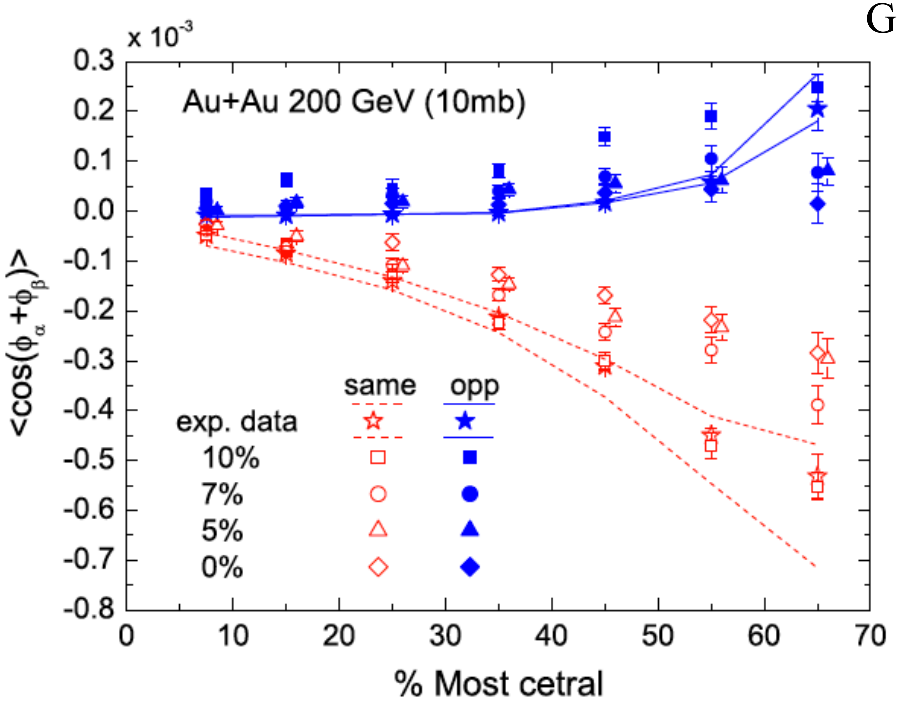
G. L. Ma, B. Zhang, Phys. Lett. B 700 (2011) 39

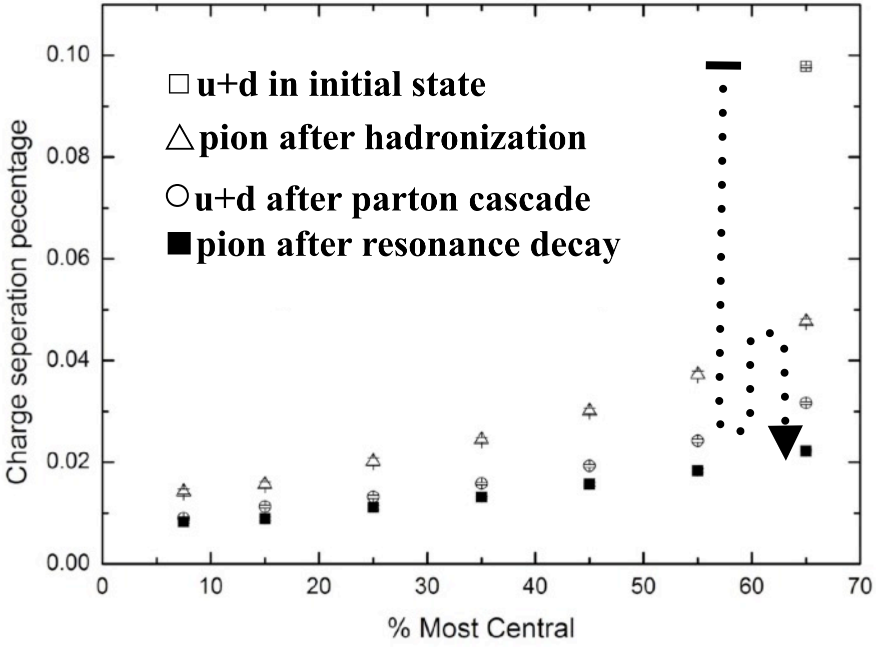
$$f\% = \frac{N^{+}_{\text{upward}} - N^{+}_{\text{downward}}}{N^{+}_{\text{upward}} + N^{+}_{\text{downward}}}$$

- To study CME, we introduce a strength of f% CME-induced charge separation into AMPT.

AMPT results on the observable γ

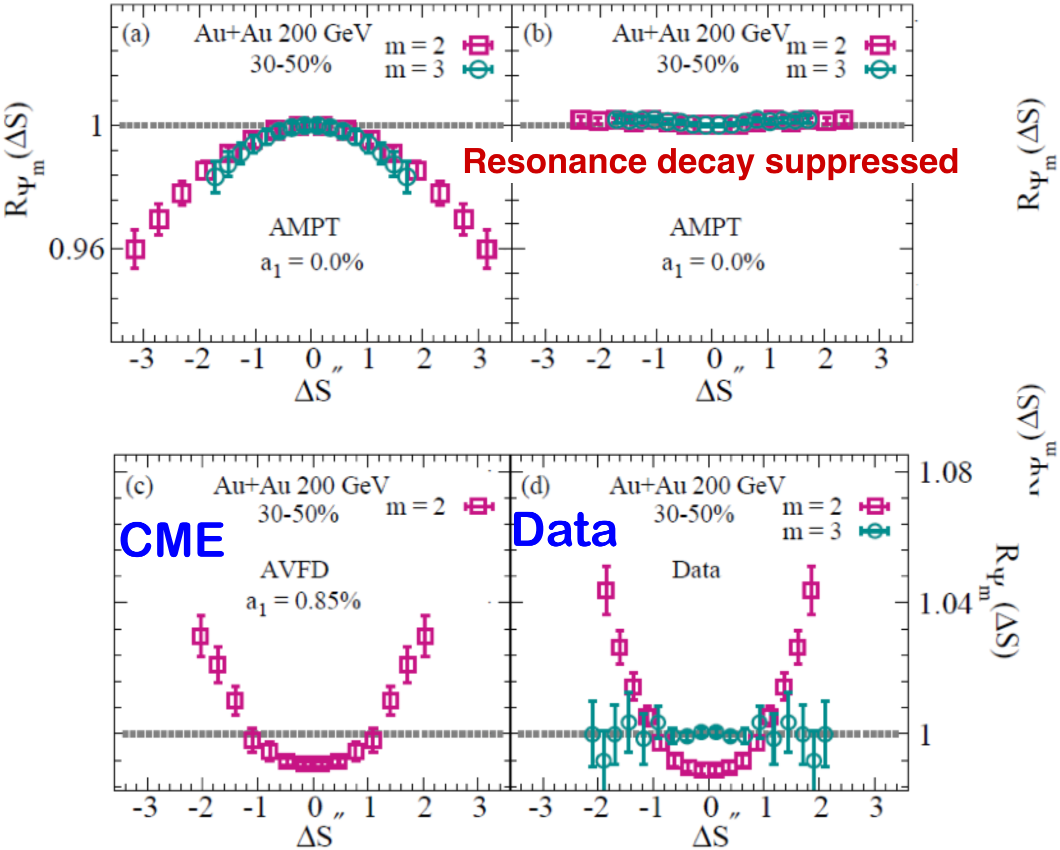
G.-L. Ma and B. Zhang, Phys. Lett. B 700 (2011) 39





- Original AMPT show comparable (60-70%) same-charge correlation (BG) with the data
- An initial charge separation ~10% is needed to describe the data
- **γ = BG + CME**
- **Final state interaction effect**: Only a small faction of CME can survive
- **Non-linear sensitivity**: γ can not response to a CME strength of f<=5%

The new observable R_{Ψ_m}



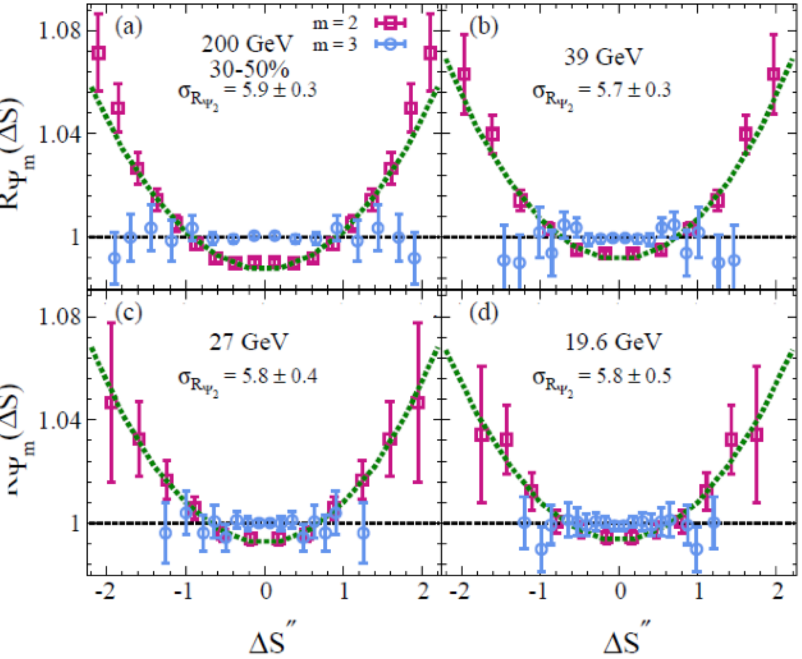
Background

Resonance decay suppressed

CME

Data

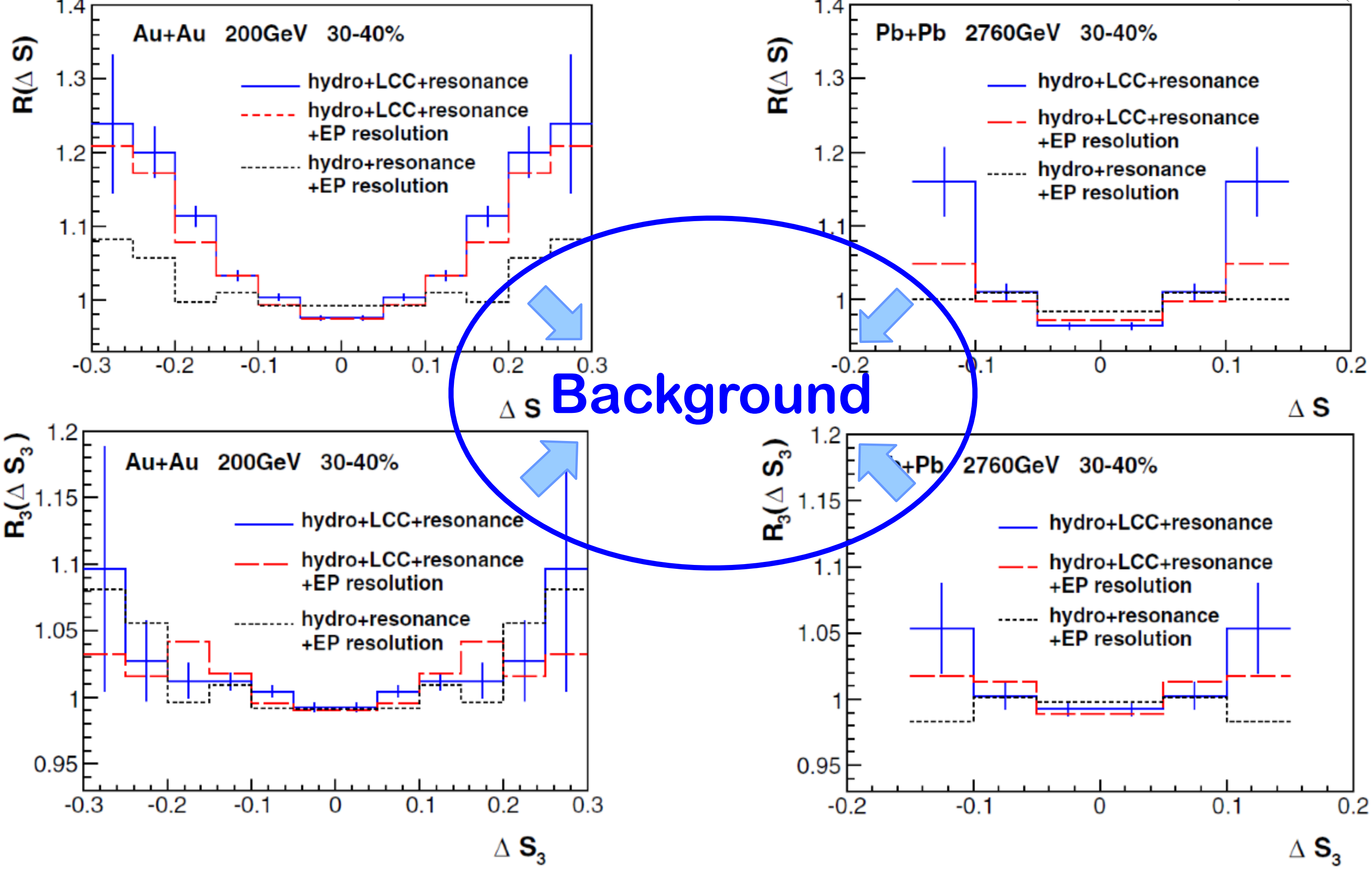
N. Magdy et. al. PRC 97,061901 (2018)



- The new CME observable of R_{Ψ_m}, m=2,3
- Sensitive to CME: R_{Ψ_2} is convex without CME, but concave with CME from original AMPT and AVFD

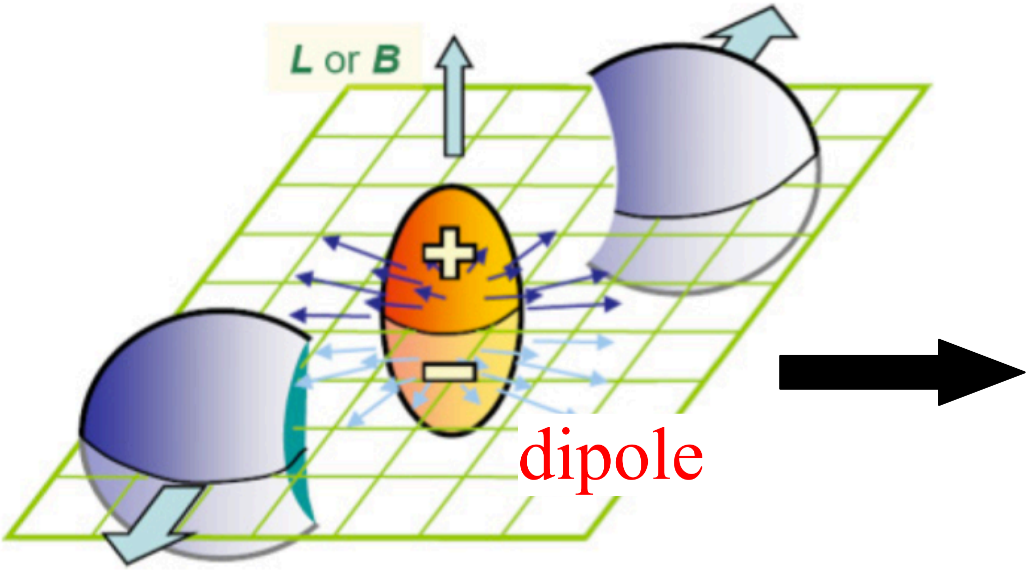
The new observable $R_{\Psi m}$

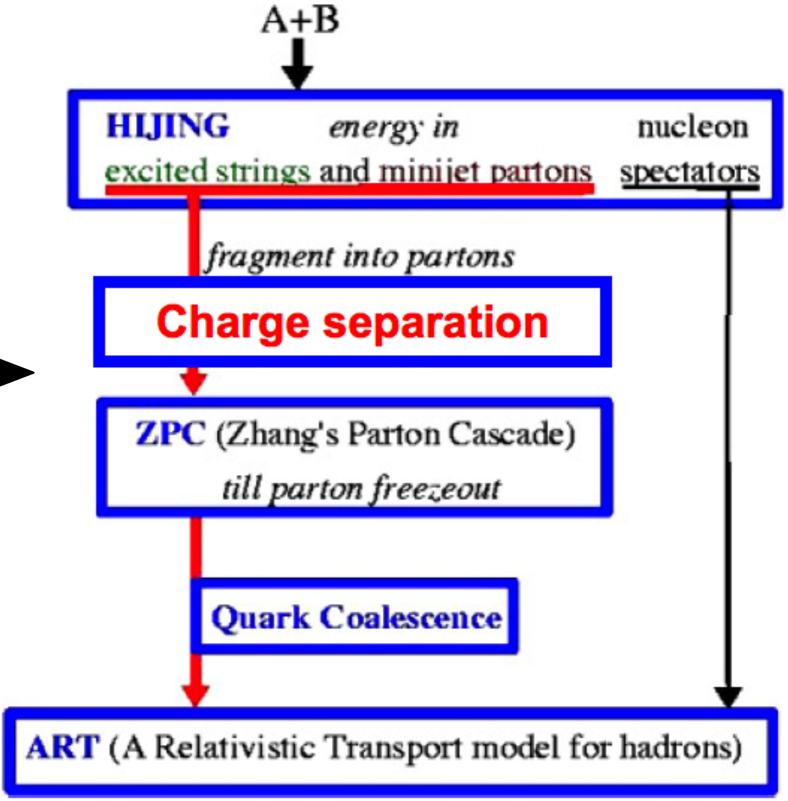
Piotr Bożek. PRC 97, 034907 (2018).



- Affected by BG: hydrodynamic results show $R_{\Psi 2}$ and $R_{\Psi 3}$ could be concave without CME

AMPT with CME-induced charge separation




A+B

HIJING *energy in* excited strings and minijet partons | nucleon spectators

fragment into partons

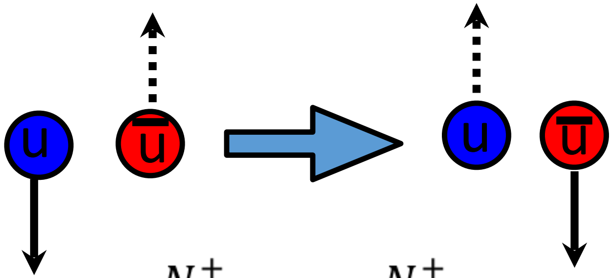
Charge separation

ZPC (Zhang's Parton Cascade) *till parton freezeout*

Quark Coalescence

ART (A Relativistic Transport model for hadrons)

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



$$f\% = \frac{N^{+}_{\mathrm{upward}} - N^{+}_{\mathrm{downward}}}{N^{+}_{\mathrm{upward}} + N^{+}_{\mathrm{downward}}}$$

- We introduce a strength of f% CME-induced charge separation into AMPT.
- We use the new charge-conserved version of AMPT
- Study R_{Ψ_2} and γ within same framework.

Method I: Mixing-particle method

$C_c(\Delta S)$ correlator:

$$C_c(\Delta S) = \frac{N\left(\Delta S_{\mathrm{csep}}\right)}{N\left(\Delta S_{\mathrm{csmix}}\right)}$$

randomly select particle
and ignore charges

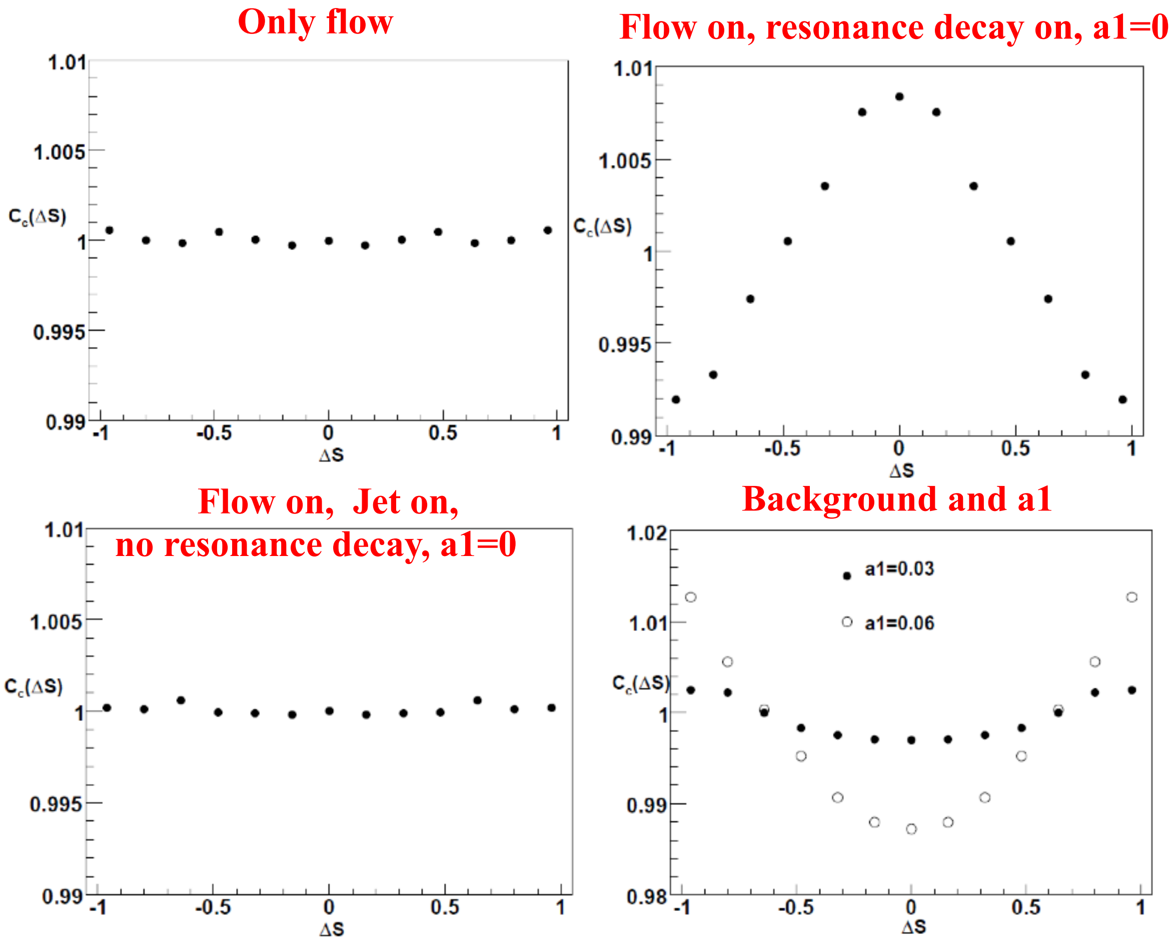
$$\Delta S_{csep} = \left\langle S_p^{h+} \right\rangle - \left\langle S_n^{h-} \right\rangle$$

$$\left\langle S_p^{h+} \right\rangle = \frac{\sum_1^p \sin\left(\Delta\varphi_+\right)}{p},$$

$$\left\langle S_n^{h-} \right\rangle = \frac{\sum_1^n \sin\left(\Delta\varphi_-\right)}{n}.$$

p/n: numbers of positive/
negative charged particles

$$\Delta\varphi_m = \phi - \Psi_m$$



N. N. Ajitanand. et. al, PRC 83, 011901 (2011)

- C(ΔS) is sensitive to CME, show a concave shape with CME

Method II: Shuffling-particle method

$R_{\Psi m}(\Delta S)$ correlator:

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

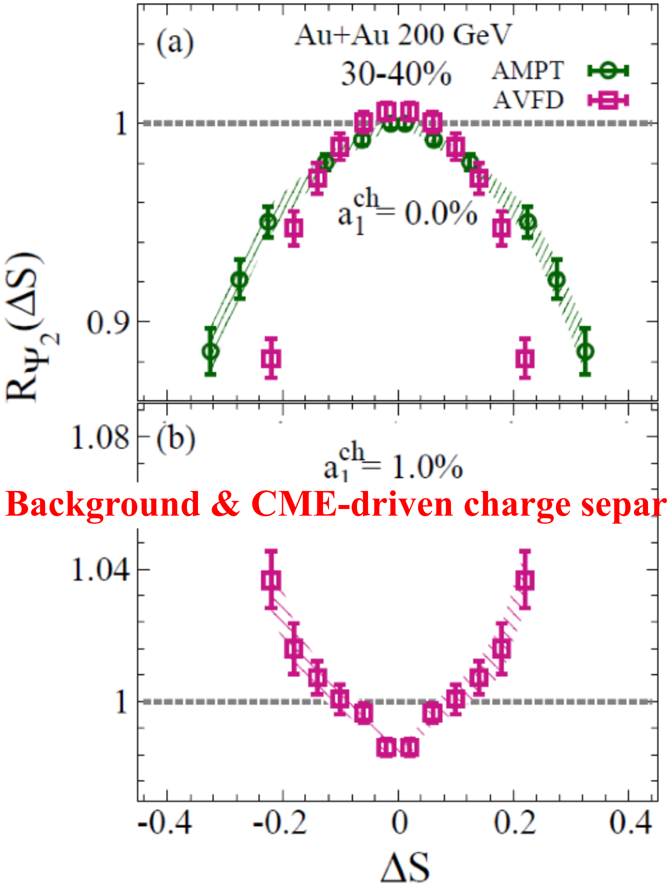
m=2,3

$$C_{\Psi_m}(\Delta S) = \frac{N_{\text{real}}(\Delta S)}{N_{\text{shuffled}}(\Delta S)}$$

Select charged particles, and resign their charges randomly

N. Magdy, et. al. PRC 97, 061901 (2018)

Background-driven charge separation



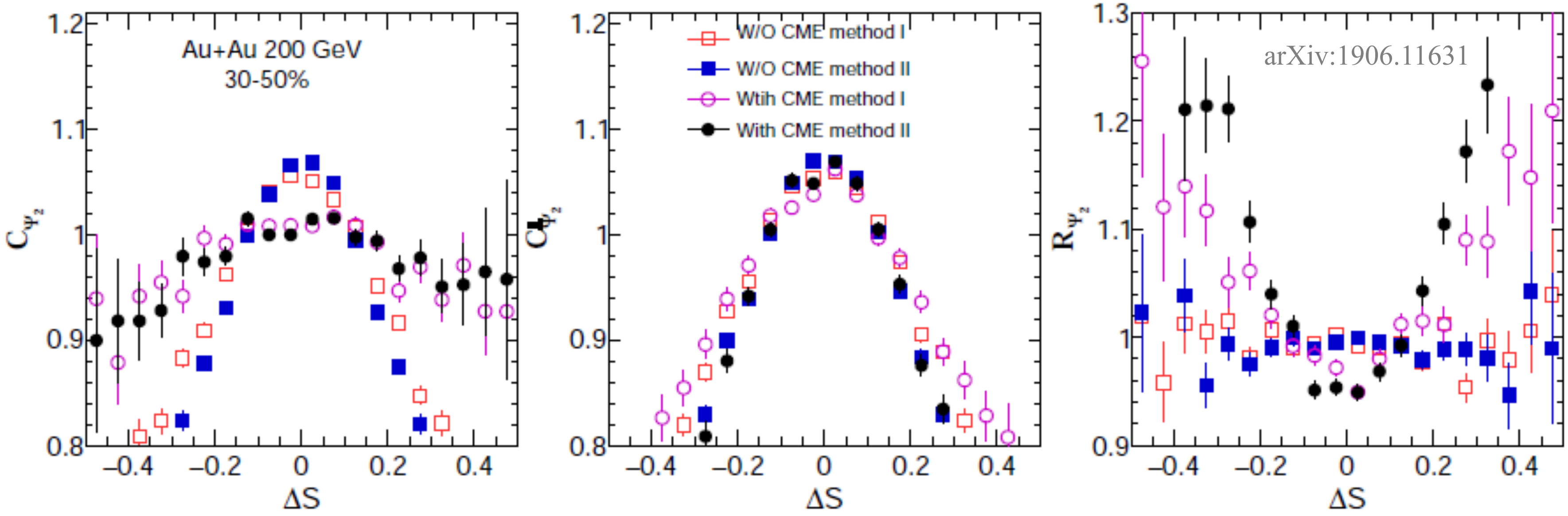
Background & CME-driven charge separation

- $R_{\Psi 2}(\Delta S)$ is sensitive to CME: convex for background only, but concave if CME happens

AMPT results on $R_{\Psi 2}$

Kinetic cut:0.35<pT<2GeV/c, |η|<1

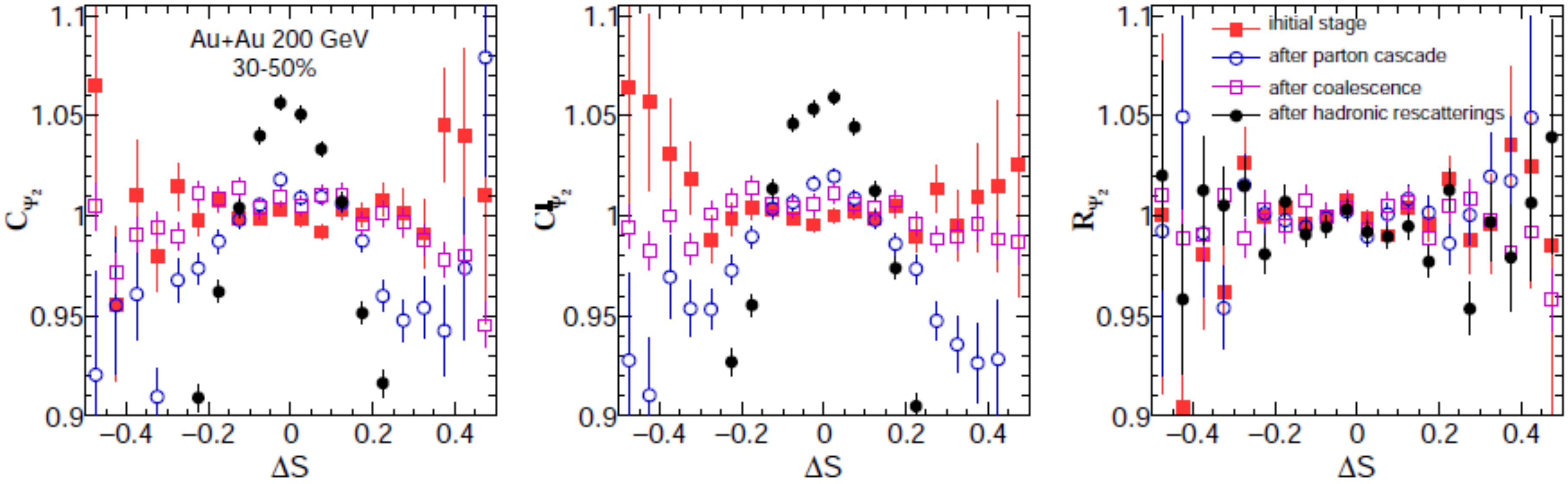
method I: Mixing-particle method
method II: Shuffling-particle method



- The results from two methods are consistent.
- Background (W/O CME): $C_{\Psi 2}$ is convex, and $R_{\Psi 2}$ is flat
- Signal (With CME(f=10%)): $C_{\Psi 2}$ is less convex, but $R_{\Psi 2}$ is concave
- **The shape of $R_{\Psi 2}$ is a good probe to search for CME. Why?**

Stage evolution of R_{Ψ_2} W/O CME

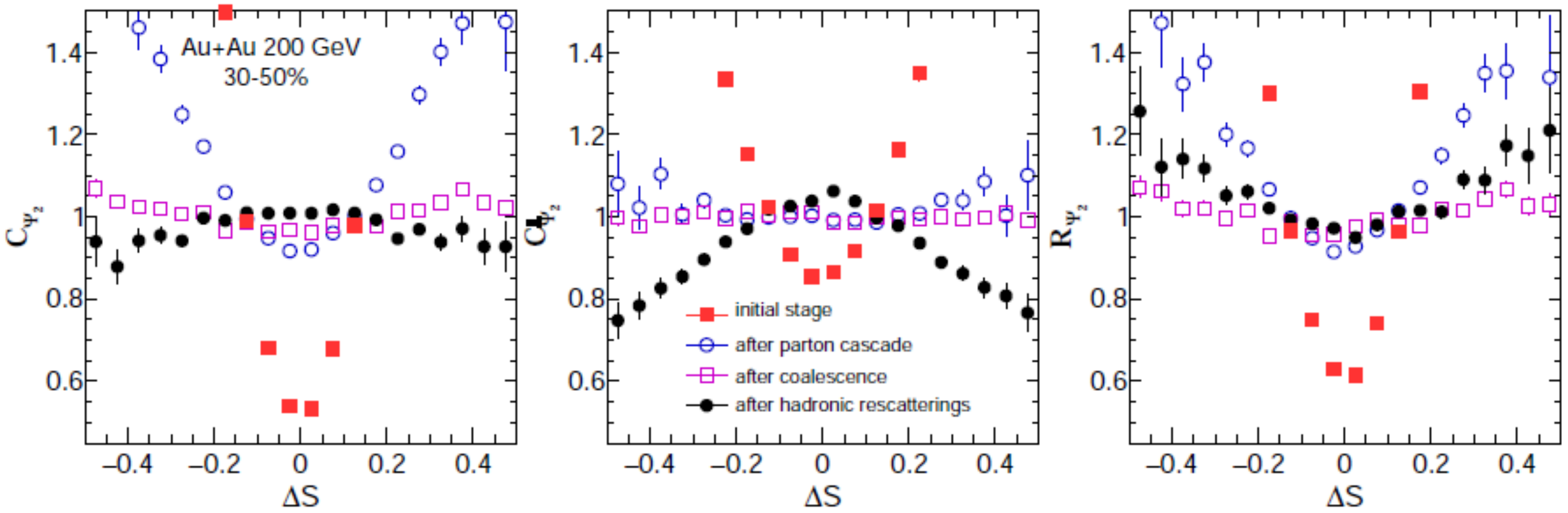
R_{ψ_2} from Background:



- Initial stage: C_{ψ_2} is and $C_{\psi_2}^{\perp}$ are flat
- After parton cascade: C_{ψ_2} and $C_{\psi_2}^{\perp}$ are convex
- After coalescence: C_{ψ_2} and $C_{\psi_2}^{\perp}$ are flat
- After hadronic rescatterings: C_{ψ_2} and $C_{\psi_2}^{\perp}$ are convex
- **But R_{ψ_2} is always flat for any stages**

Stage evolution of R_{Ψ_2} With CME

R_{Ψ_2} from Background+CME(f=10%):

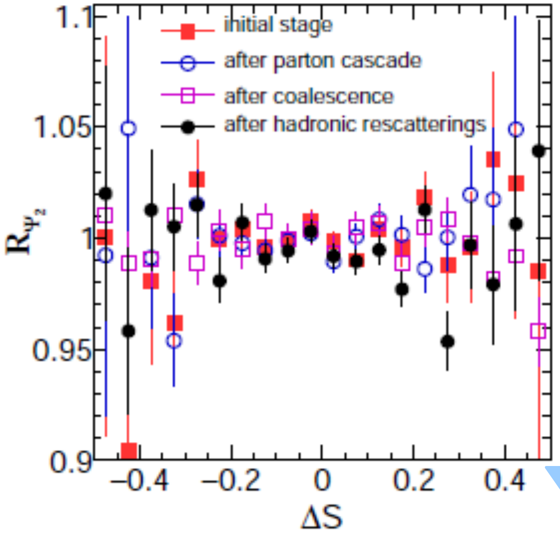


- Initial stage: C_{Ψ_2} is and $C_{\Psi_2}^{\perp}$ are concave
- After parton cascade: C_{Ψ_2} is concave, $C_{\Psi_2}^{\perp}$ is flat
- After coalescence: C_{Ψ_2} and $C_{\Psi_2}^{\perp}$ are flat
- After hadronic rescatterings: C_{Ψ_2} and $C_{\Psi_2}^{\perp}$ are convex
- **But R_{Ψ_2} is always concave for any stages**

Understanding the origin of R_{Ψ_2} shape

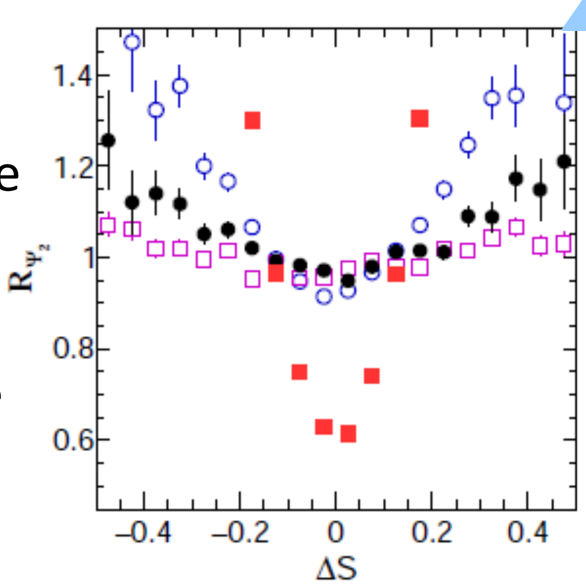
R_{Ψ_2} stage evolution:

If Background only,
R_{Ψ_2} is always flat

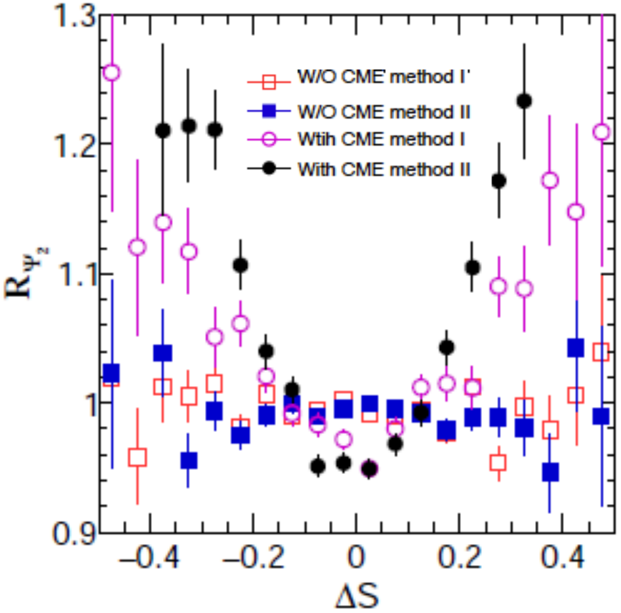


Keeping flat

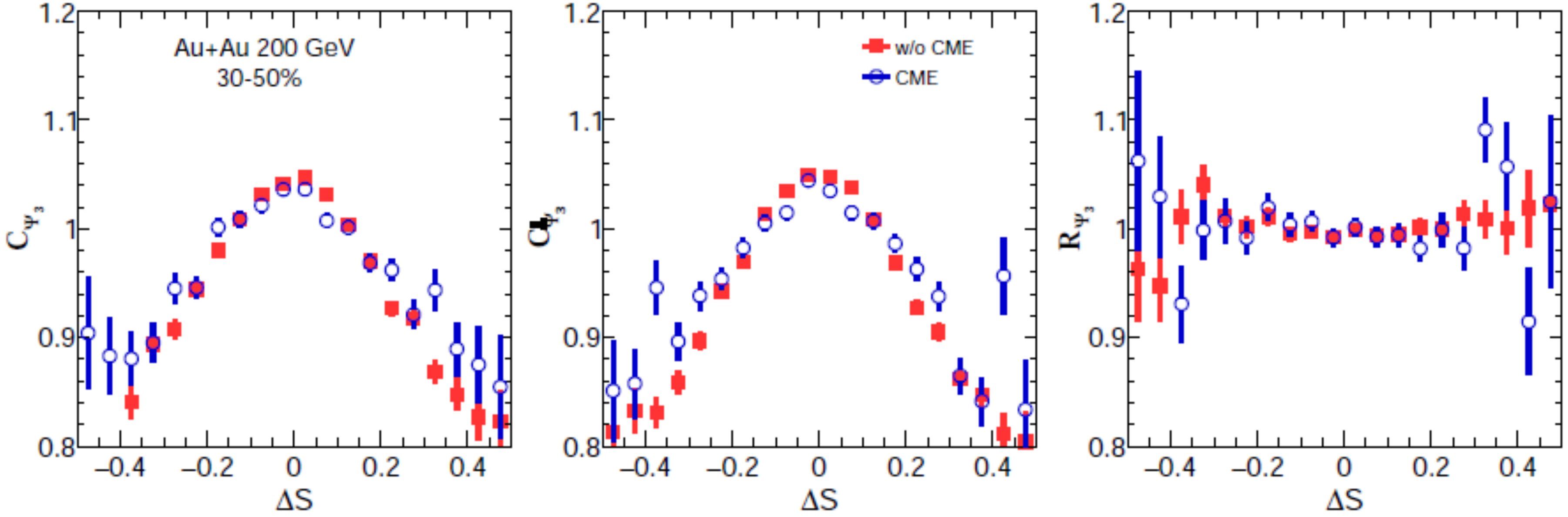
If BG +CME (10%),
R_{Ψ_2} is always concave



Concave shape survive

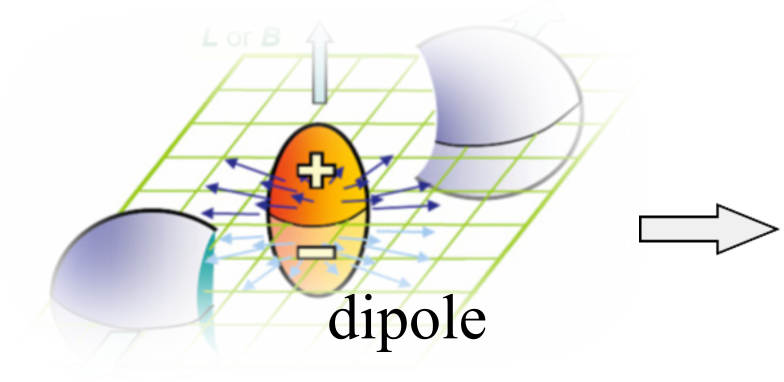


AMPT results on $R_{\Psi 3}$

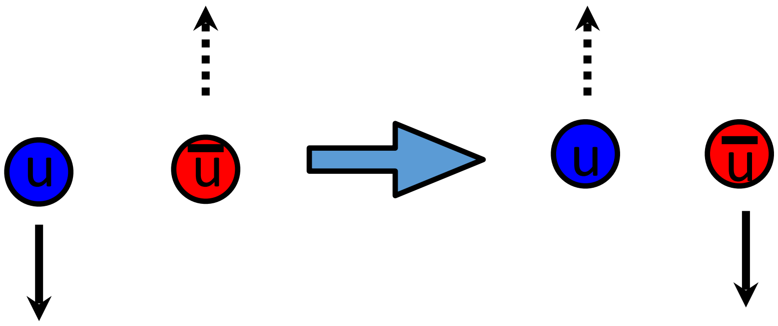


- $C_{\psi 3}$ is and $C_{\psi 3}^{\perp}$ are same between W/O CME and With CME
- $R_{\psi 3}$ is always flat in despite of CME
- $R_{\psi 3}$ is not sensitive to CME, since Ψ3 is not correlated to B

Sensitivity to the CME strength f%



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

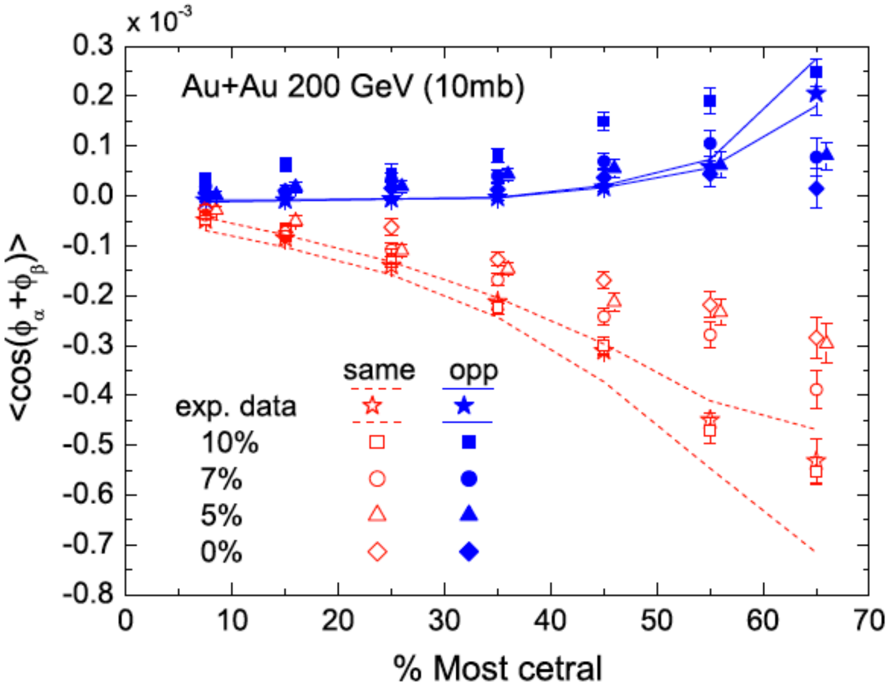


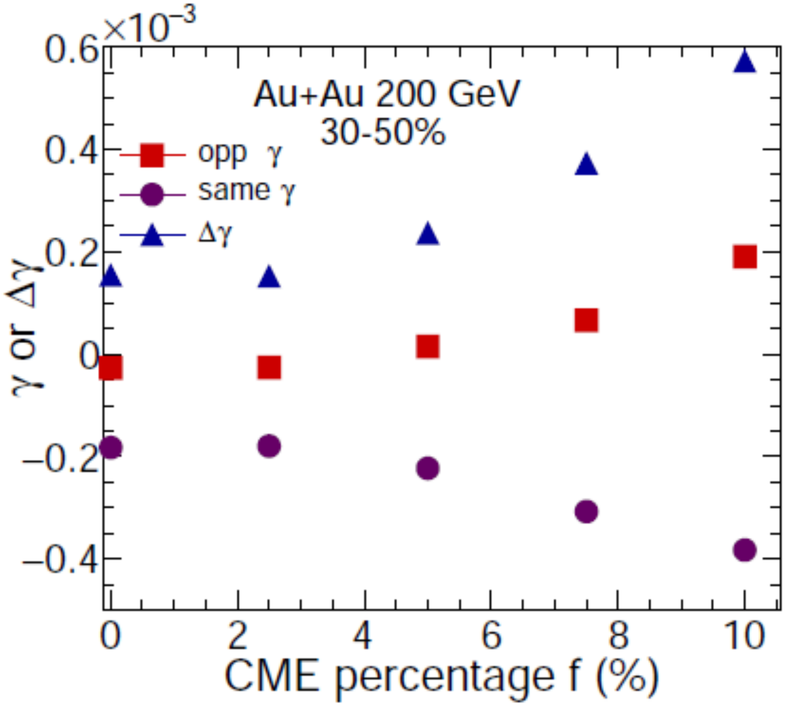
Initial charge seperation percentage:

$$f\% = \frac{N^{+}_{\text{upward}} - N^{+}_{\text{downward}}}{N^{+}_{\text{upward}} + N^{+}_{\text{downward}}}$$

Sensitivity to CME of the observable γ

AMPT results on γ for different initial CME percentages :

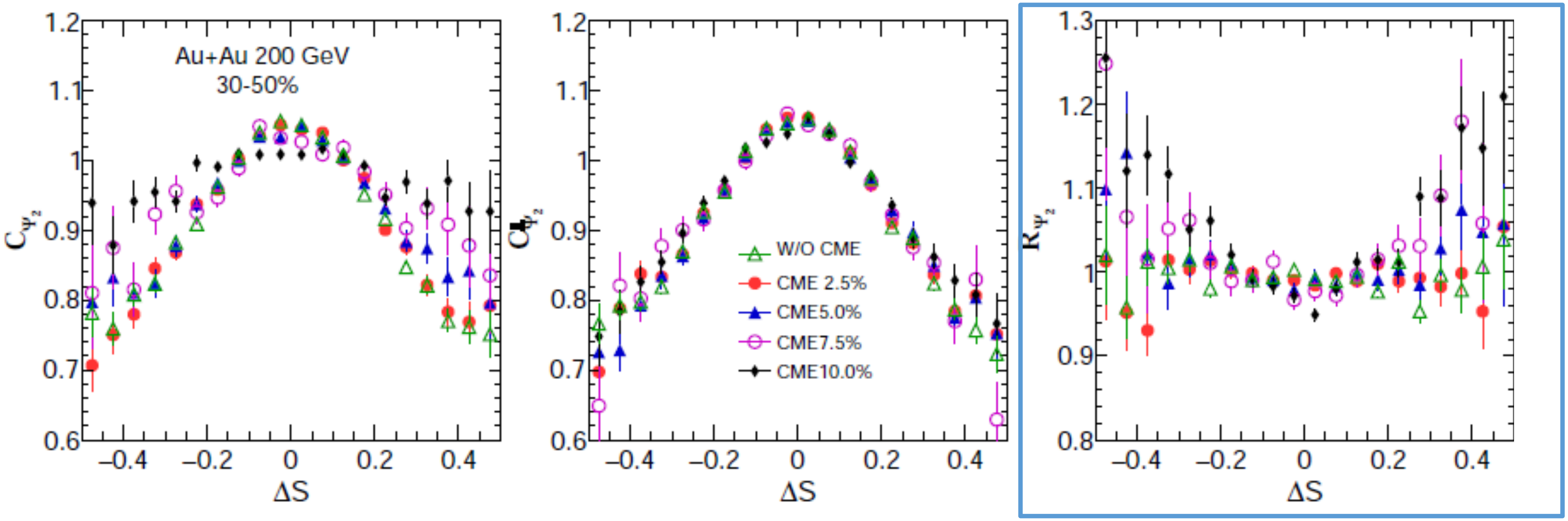




- $\Delta\gamma$ (f=2.5%) is similar to $\Delta\gamma$ (W/O CME) .
- $\Delta\gamma$ can not response to CME strength of f<=5%

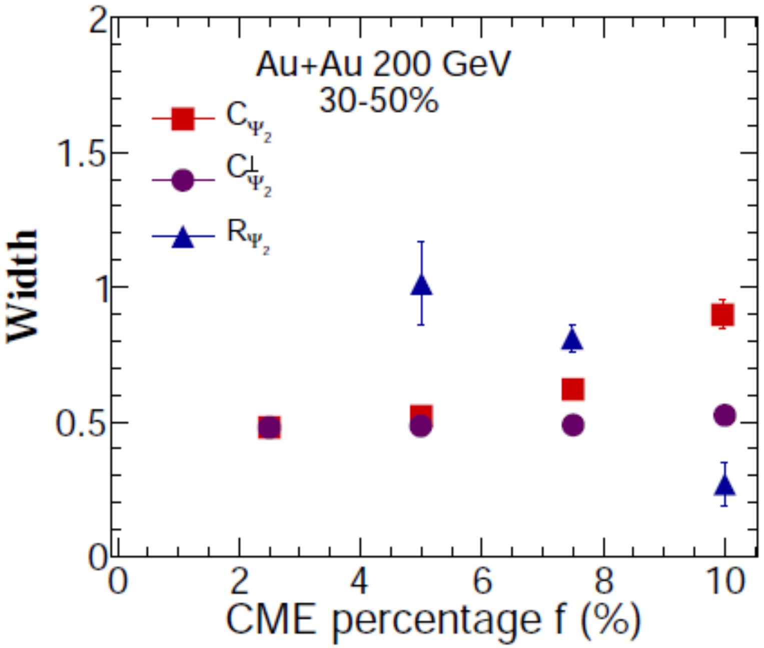
$C_{\Psi 2}$ & $R_{\Psi 2}$ for different CME percentages

AMPT results on $R_{\Psi 2}$ for different initial CME percentages :



- $R_{\psi 2}$ (f=2.5%) is similar to $R_{\psi 2}$(W/O CME), they look flat within current statistics.
- The shape of $R_{\psi 2}$ (f>=5%) is concave
- With increase of CME strength (f>=5%), the shape becomes more concave

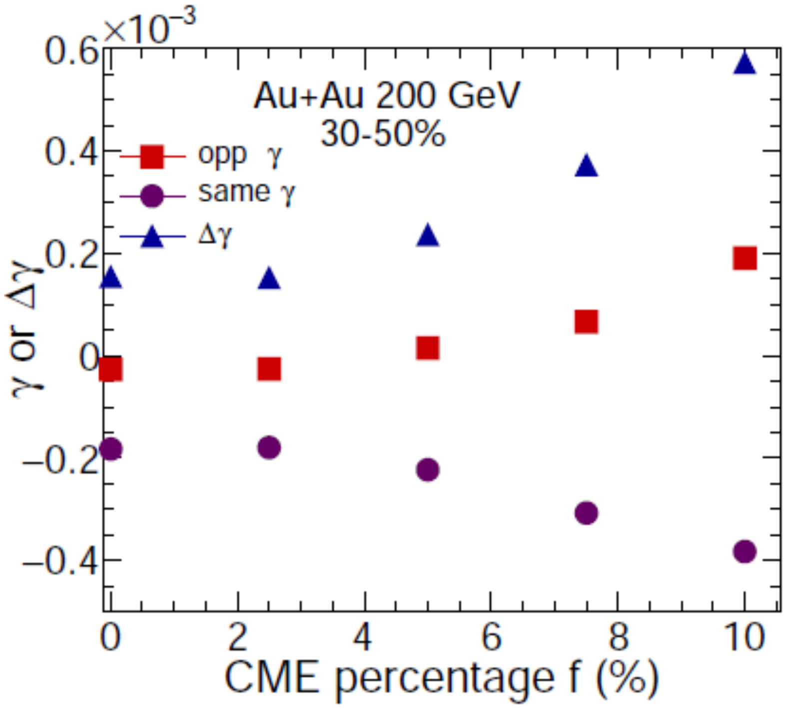
Sensitivity to CME of the observable $R_{\Psi 2}$

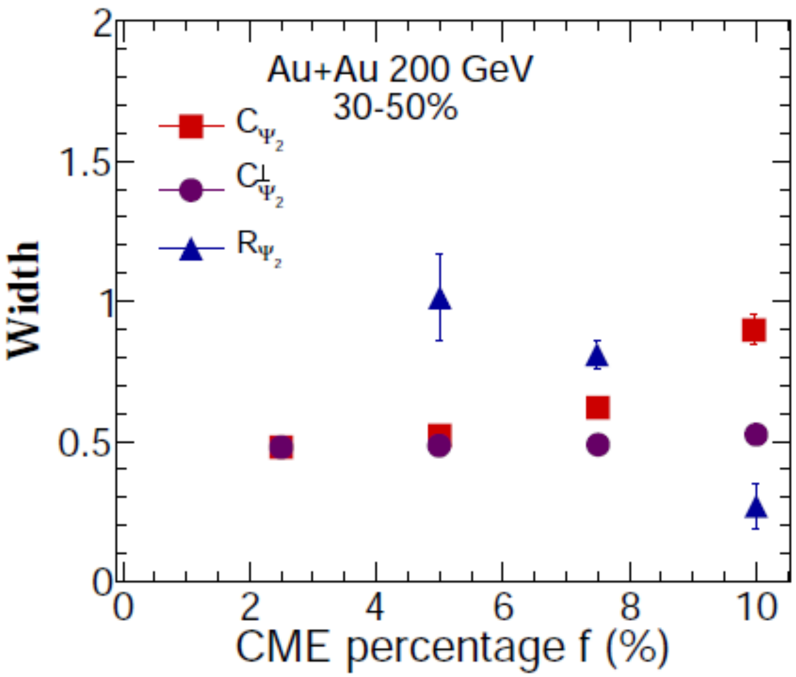


With increase of CME strength:

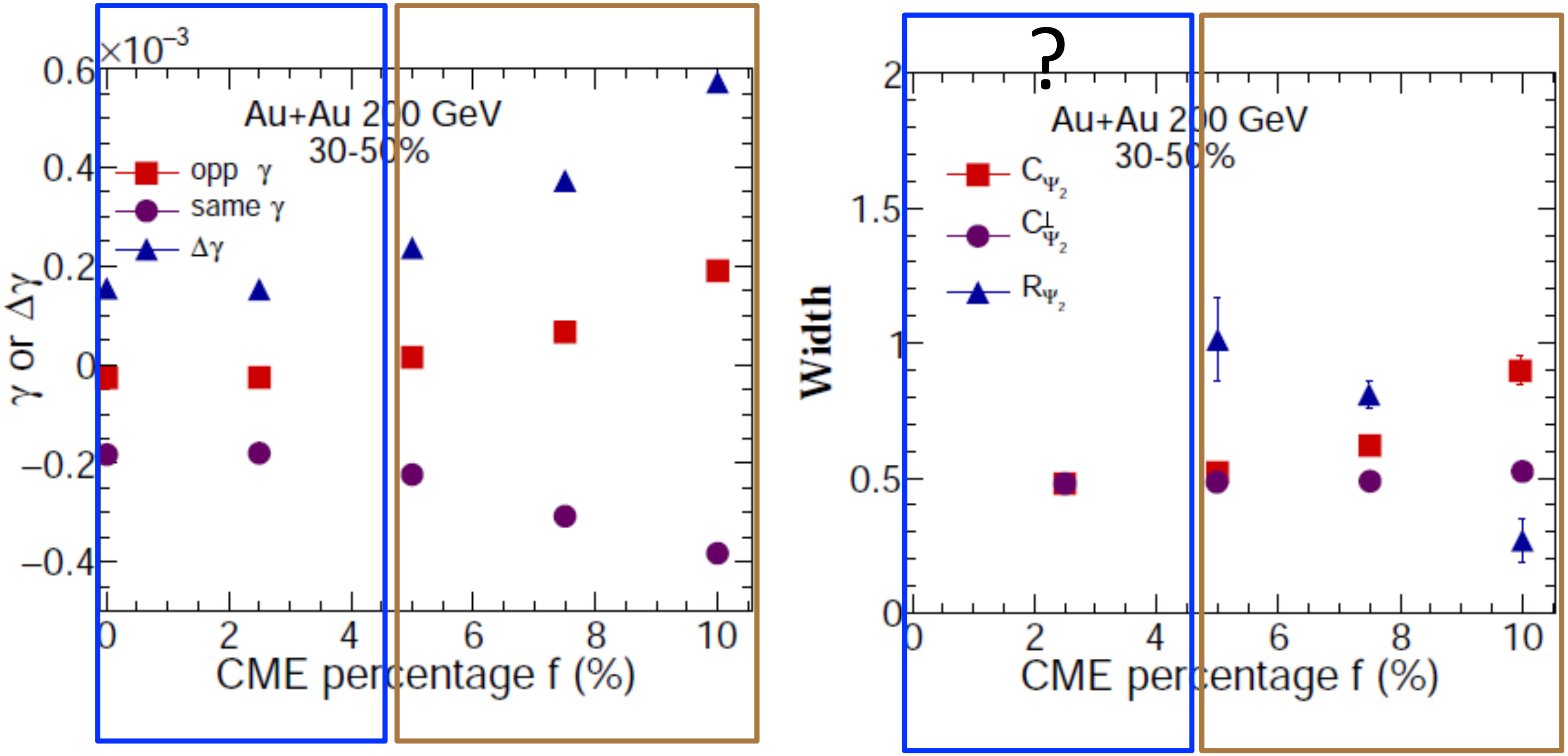
- the width of $C_{\psi 2}$ increases (less convex),
- the width of $C_{\psi 2}^{\perp}$ keeps unchanged
- the width of $R_{\psi 2}$ decreases (more concave)

Sensitivity comparison between γ and R_{Ψ_2}





Sensitivity comparison between γ and $R_{\Psi 2}$



- γ and $R_{\Psi 2}$ response to CME strength of f>5%
- γ and $R_{\Psi 2}$ (f<5%) look similar to those (W/O CME) .
- But $R_{\Psi 2}$ needs enough statistics to see if any tiny concave shape.

Summary & outlook

- CME-induced charge separation survives from final state interactions.
- The shape of $R_{\Psi 2}$ is sensitive to CME
- Nonlinear sensitivity:
  - γ and $R_{\Psi 2}$ can response to CME strength of f>5%;
  - when f<5%, $R_{\Psi 2}$ needs enough statistics to see if concave shape
- Sensitivity analysis of γ and $R_{\Psi 2}$ in isobaric collisions?

Thank you!