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on Ultrarelativistic
Nucleus-Nucleus Collisions

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Palazzo del Cinema

Lido di Venezia, Italy

A novel invariant mass method to isolate resonance backgrounds from the chiral magnetic effect

Fuqiang Wang

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Based on

Jie Zhao, Hanlin Li, FW, *Isolating backgrounds from the chiral magnetic effect*, arXiv:1705.05410

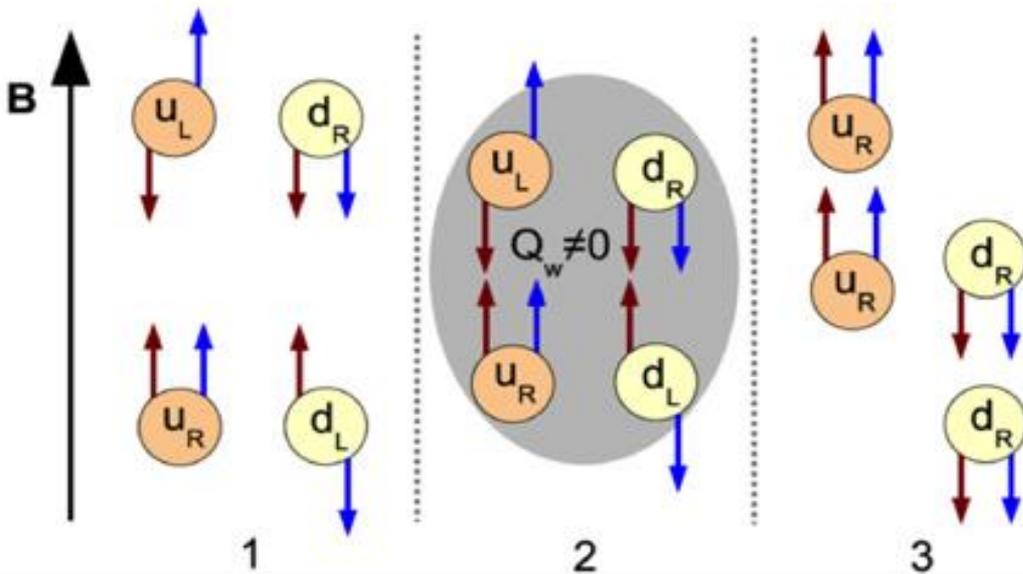


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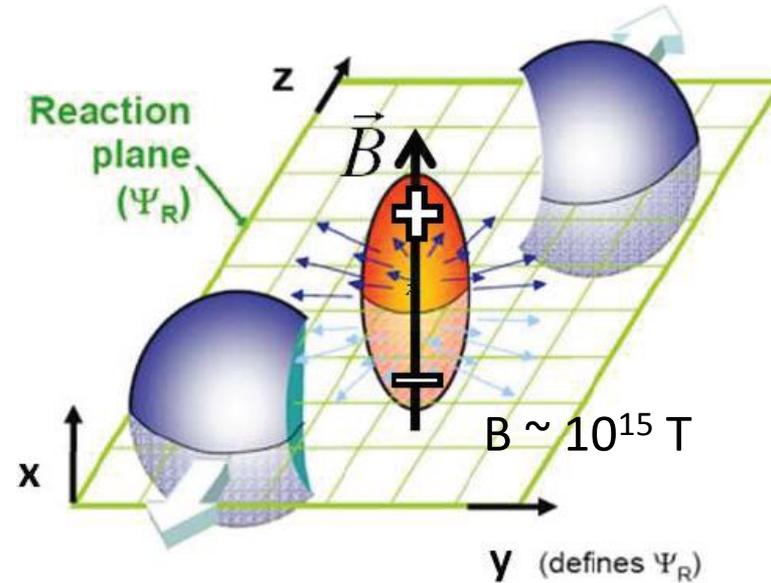
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Science

Chiral Magnetic Effect (CME)

Kharzeev, Pisarski, Tytgat, PRL 81 (1998) 512; Kharzeev, et al. NPA 803 (2008) 227



Electric charge separation



Non-conservation of axial currents

$$\partial^\mu j_\mu^5 = 2 \sum_f m_f \langle \bar{\psi}_f i \gamma_5 \psi_f \rangle_A - \frac{N_f g^2}{16\pi^2} F_{\mu\nu}^a \tilde{F}_a^{\mu\nu}$$

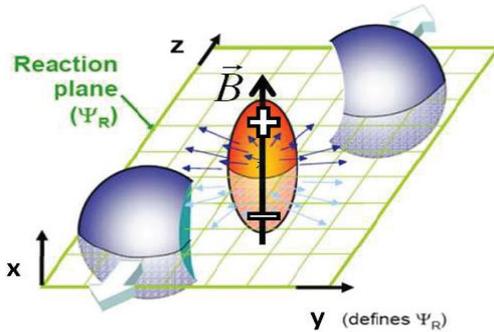
$$Q_w = \frac{g^2}{32\pi^2} \int d^4x F_{\mu\nu}^a \tilde{F}_a^{\mu\nu}$$

$$(N_L - N_R)_{t=\infty} = 2N_f Q_w$$

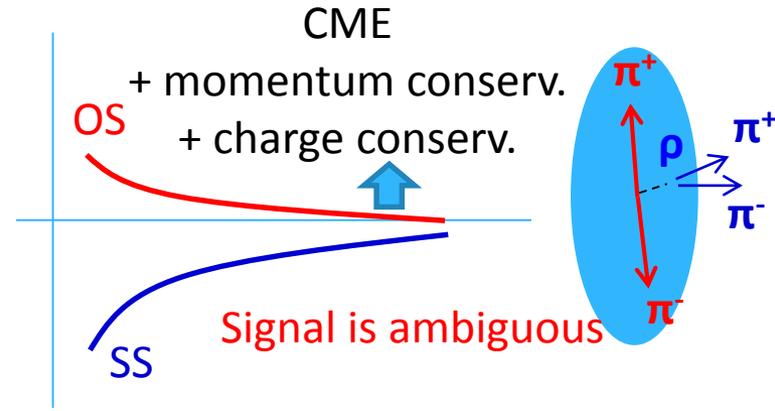
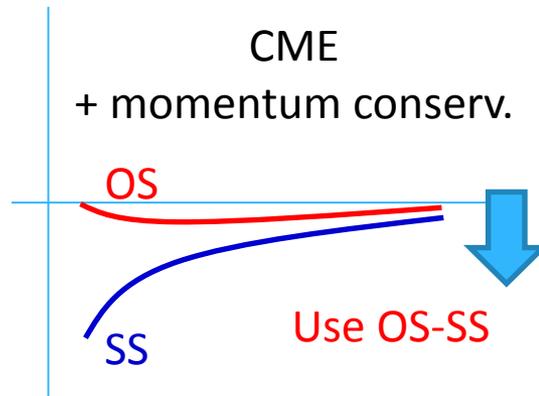
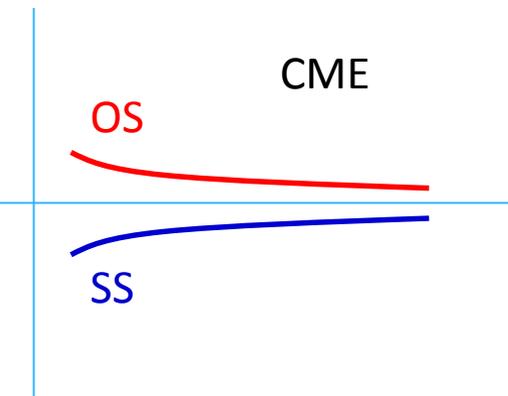
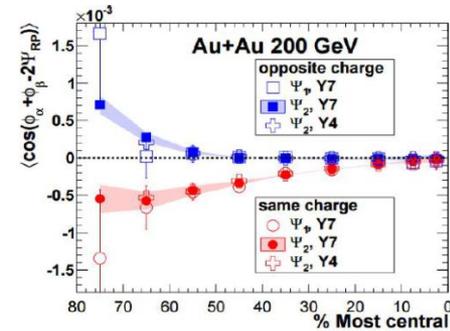
- Quark degree of freedom, Approx. chiral sym. restoration
- QCD vacuum fluctuations, Topological gluon field, $Q_w \neq 0$.
- Local P, CP violations
- Strong magnetic field

The γ Correlator & Background

Voloshin, PRC 70 (2004) 057901



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



Voloshin 2004, FW 2009, Bzdak, Koch, Liao 2010, Pratt, Schlichting 2010,

$$\gamma = \langle \cos(\varphi_\alpha + \varphi_\beta - 2\psi_{RP}) \rangle = \frac{N_{cluster}}{N_\alpha N_\beta} \langle \cos(\varphi_\alpha + \varphi_\beta - 2\varphi_{cluster}) \cos(2\varphi_{cluster} - 2\varphi_{RP}) \rangle$$

Background: nonflow coupled with flow $\propto v_{2,\rho} / N$

Background estimate

Voloshin PHYSICAL REVIEW C 70, 057901 (2004)

respect to the resonance azimuth, and $v_{2,res}$ is the resonance elliptic flow. The factor $1/N_\pi$ reflects the probability that both pions in the pair are from the same resonance. Considering an estimate of such contribution note that $\langle \cos(\phi_a + \phi_b - 2\phi_{res}) \rangle$ is zero if the resonance is at rest, and becomes nonzero only due to resonance motion. More accurate estimate could be done with proper simulations of such effects, but the total contribution should be smaller than $\langle \cos(\phi_a + \phi_b - 2\phi_c) \rangle \leq 10^{-3} v_{2,res} v_{2,c}$, where the factor 10^{-3} is coming from the estimates of nonflow azimuthal correlations [7]. Taking all together, one finds the systematic uncertainty in measurements of a_π parameter below one percent level.

$$\begin{aligned} & \langle \cos(\phi_a + \phi_b - 2\phi_c) \rangle \\ &= \langle \cos((\phi_a + \phi_b - 2\phi_{res}) + 2(\phi_{res} - \phi_c)) \rangle \\ &\approx \frac{f_{res} \langle \cos(\phi_a + \phi_b - 2\phi_{res}) \rangle v_{2,res}}{N_\pi} v_{2,c} \end{aligned}$$

$$0.17/100 * 0.65 \sim 10^{-3}$$

Claimed resonance background is negligible.

Wrong claim – Wrong by a factor of v_2 !

$\sim 100\%$ background level !!!

FW, Jie Zhao, PRC95 (2017) 051901(R)

PHYSICAL REVIEW C 81, 064902 (2010)

Effects of cluster particle correlations on local parity violation observables

Fuqiang Wang

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(Received 20 November 2009; revised manuscript received 15 April 2010; published 7 June 2010)

Bzdak,Koch,Liao 2010; Pratt,Schlichting 2011; Petersen 2011; Ma,Zhang 2011; Bzdak 2012; Toneev 2012; ...

Consensus now: major background in experimental measurements!

Background

Background $\Delta\gamma =$

$$\frac{N_\rho}{N_\alpha N_\beta} \left\langle \cos(\varphi_\alpha + \varphi_\beta - 2\varphi_{clus}) \right\rangle v_{2,clus}$$

Make v_2 zero...

PHYSICAL REVIEW C 89, 044908 (2014)

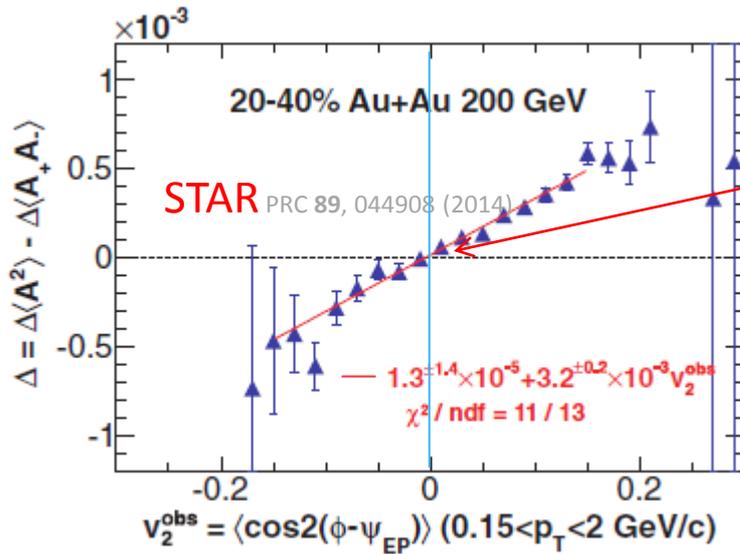
Measurement of charge multiplicity asymmetry correlations in high-energy nucleus-nucleus collisions at $\sqrt{s_{NN}} = 200$ GeV

STAR

Quan Wang, Purdue University, Ph.D. thesis, 2012

Make v_2 “zero”

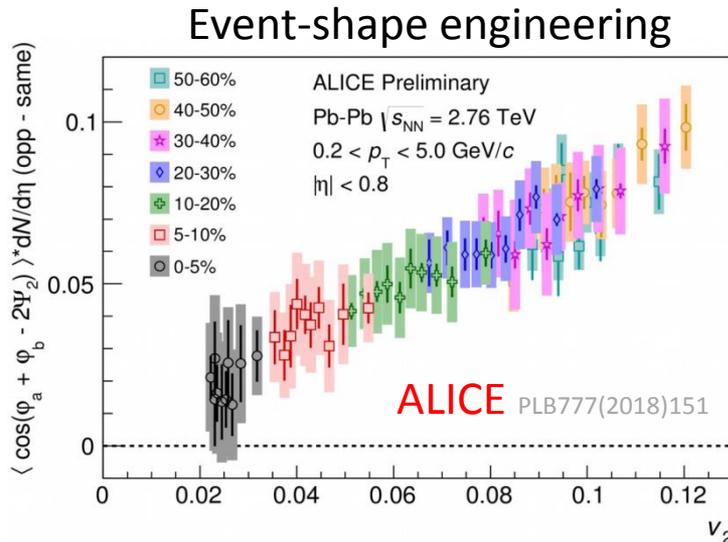
Here Δ is similar to $\cos(\alpha+\beta-2\psi)$ correlator



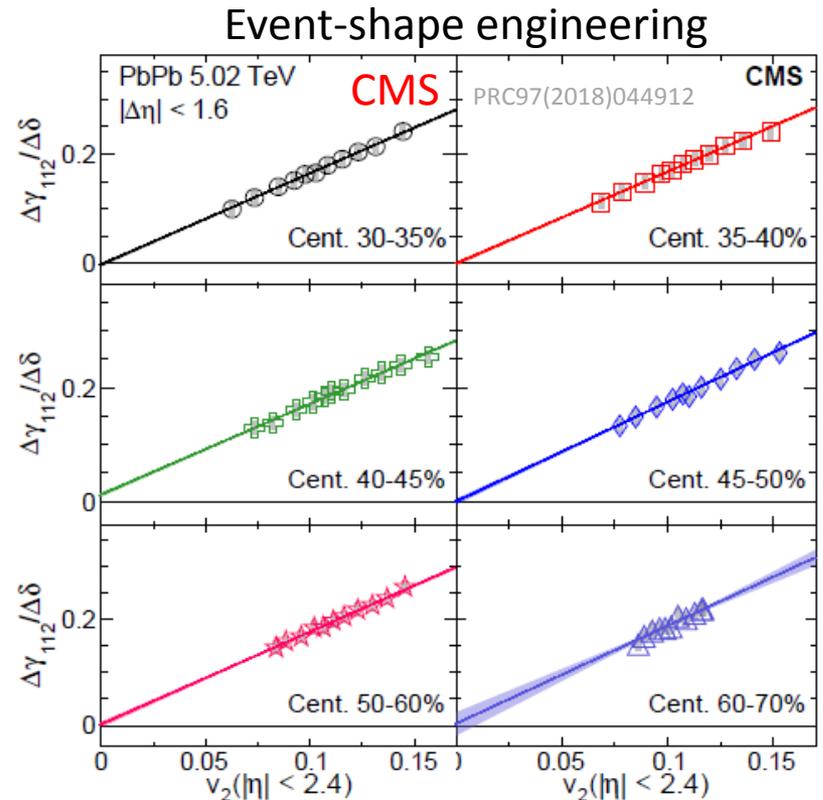
Event-by-event v_2 technique

Still has residual background, because background $\sim v_{2,\rho}$ not $v_{2,\pi}$

FW, Jie Zhao, PRC95(2017)051901(R), arXiv:1608.06610



Event-shape engineering



Event-shape engineering

Background

Background $\Delta\gamma =$

$$\frac{N_\rho}{N_\alpha N_\beta} \left\langle \cos(\varphi_\alpha + \varphi_\beta - 2\varphi_{clus}) \right\rangle v_{2,clus}$$

Get rid of resonances, or utilize them...

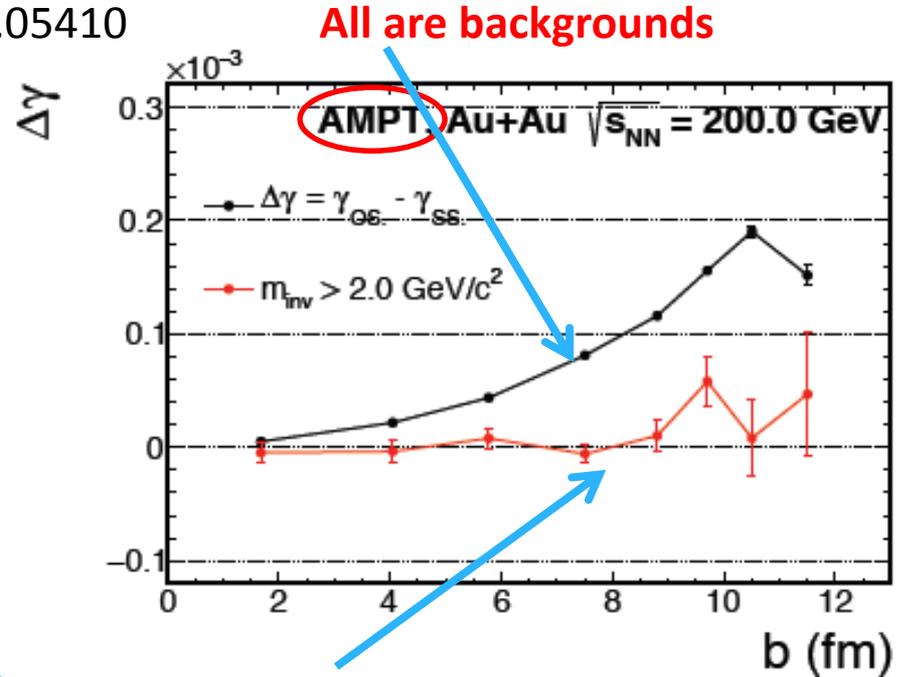
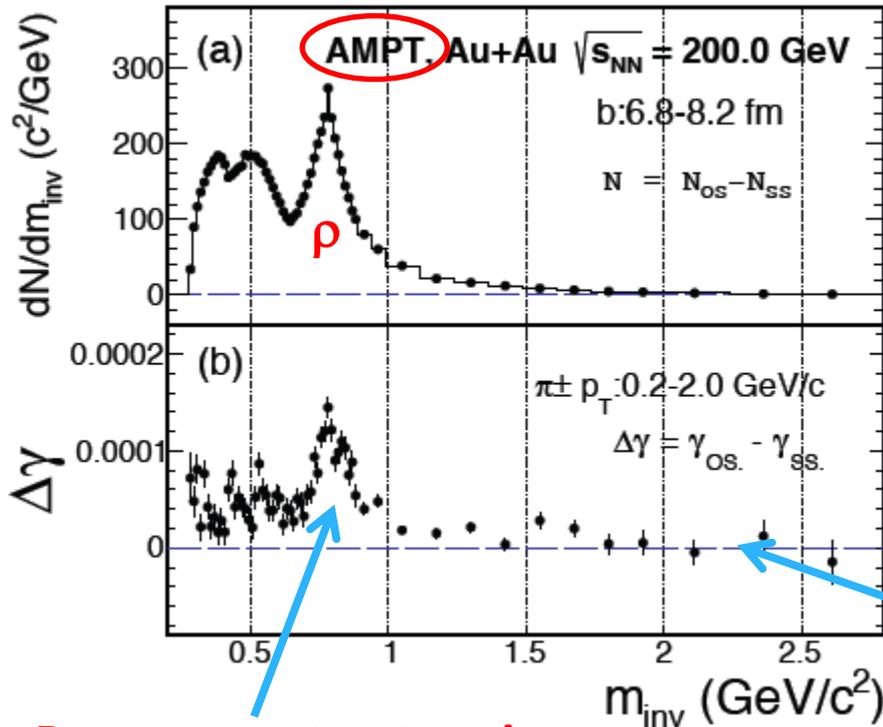
Identify the backgrounds by invariant mass

Isolating the chiral magnetic effect from backgrounds by pair invariant mass

Jie Zhao,^{1,2} Hanlin Li,^{3,2} and Fuqiang Wang^{1,2,*} arXiv:1705.05410

Check with AMPT

Jie Zhao, Hanlin Li, FW, arXiv:1705.05410

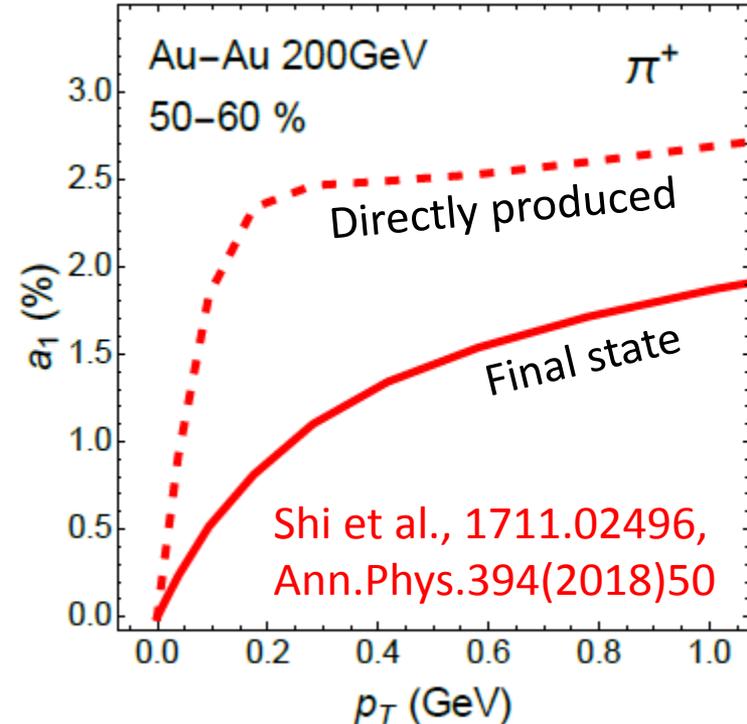
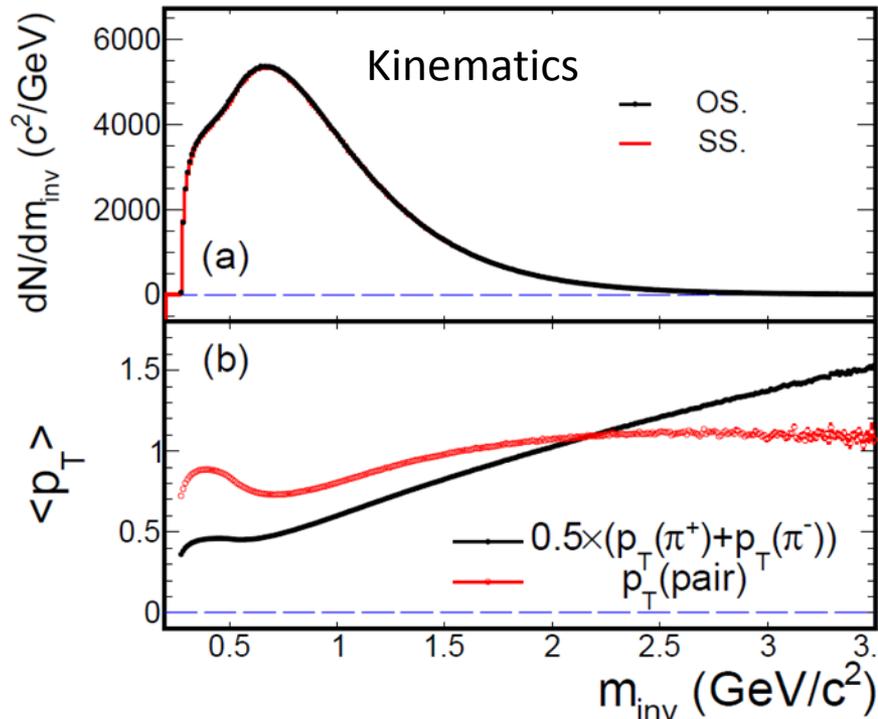


Resonance structure in $\Delta\gamma$ as function of m_{inv}

High mass $\Delta\gamma$ consistent with 0 as it should be

- Resonance background should be nearly zero at high mass
- CME at large mass may also be zero...

Can CME survive to high mass?

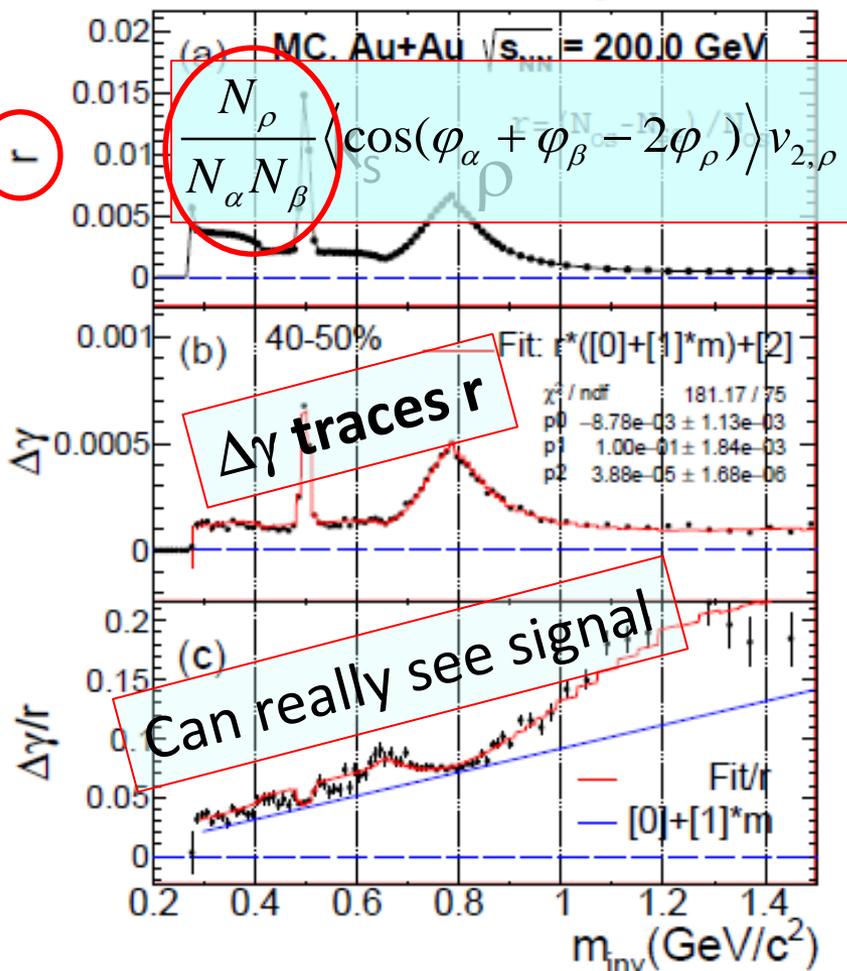


- $m_{inv} > 2 \text{ GeV}/c^2$ contains appreciable low p_T pions
- CME signal may not be limited only to low p_T
- High mass should still contain CME

Can we access CME at low p_T ?

Two component model: Resonances + CME: Jie Zhao, Hanlin Li, FW, arXiv:1705.05410

Low mass region



$$\frac{d^2 N}{dp_T d\eta d\phi} = \frac{d^2 N}{2\pi dp_T d\eta} (1 + 2v_2 \cos 2\phi + 2a_1 \sin \phi)$$

$$\Delta\gamma = (24.5 \pm 0.1) \times 10^{-5}$$

Input CME: $a_1 = 0.008$

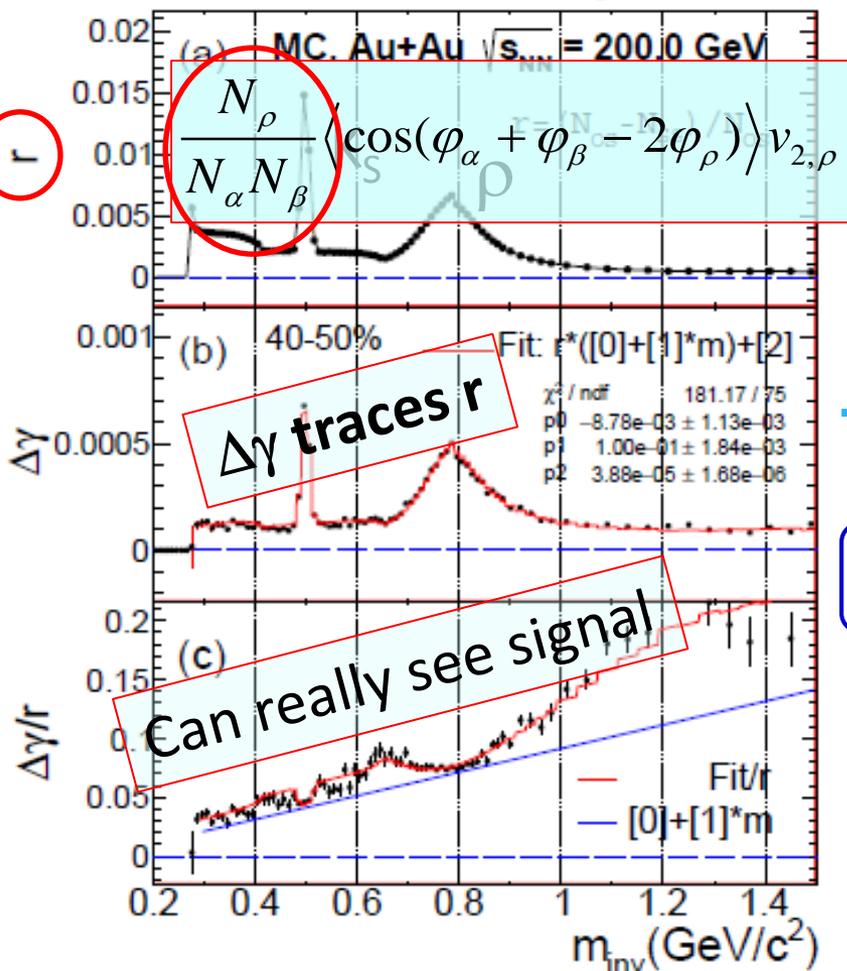
$$\text{CME frac: } 2a_1^2 (N_{\text{prim}}/N_\pi)^2 = 4.6 \times 10^{-5} \text{ (20\%)} \quad \text{Input}$$

$$\Delta\gamma (m_{\text{inv}} > 2 \text{ GeV}/c^2) = (4.5 \pm 0.8) \times 10^{-5}$$

Can we access CME at low p_T ?

Two component model: Resonances + CME: Jie Zhao, Hanlin Li, FW, arXiv:1705.05410

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$$\frac{d^2 N}{dp_T d\eta d\phi} = \frac{d^2 N}{2\pi dp_T d\eta} (1 + 2v_2 \cos 2\phi + 2a_1 \sin \phi)$$

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$$\Delta\gamma (m_{\text{inv}} > 2 \text{ GeV}/c^2) = (4.5 \pm 0.8) \times 10^{-5}$$

$$\Delta\gamma(m_{\text{inv}}) =$$

$$r(m_{\text{inv}}) \langle f(m_{\text{inv}}) v_2(m_{\text{inv}}) \rangle + \Delta\gamma_{\text{CME}}(m_{\text{inv}})$$

peaked

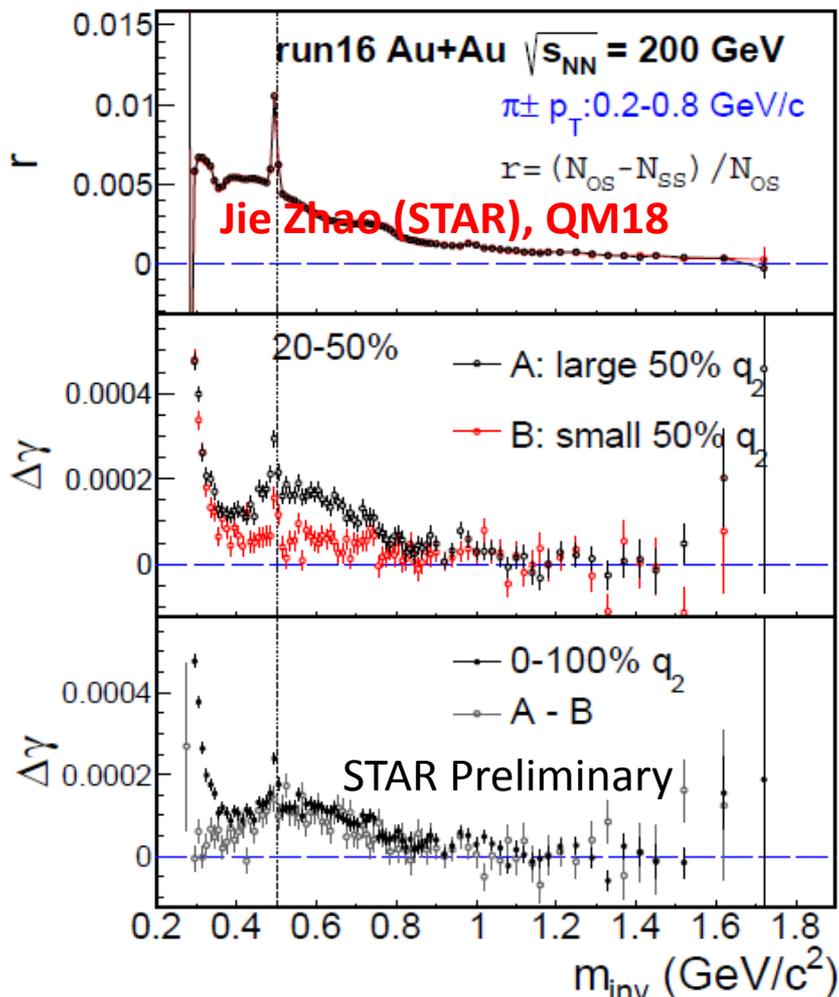
smooth

$$r(m_{\text{inv}}) * (P_0 + P_1 * m_{\text{inv}}) + P_2$$

$$\text{Fit result: } P_2 = (3.9 \pm 0.2) \times 10^{-5}$$

ESE to constrain Bkg shape

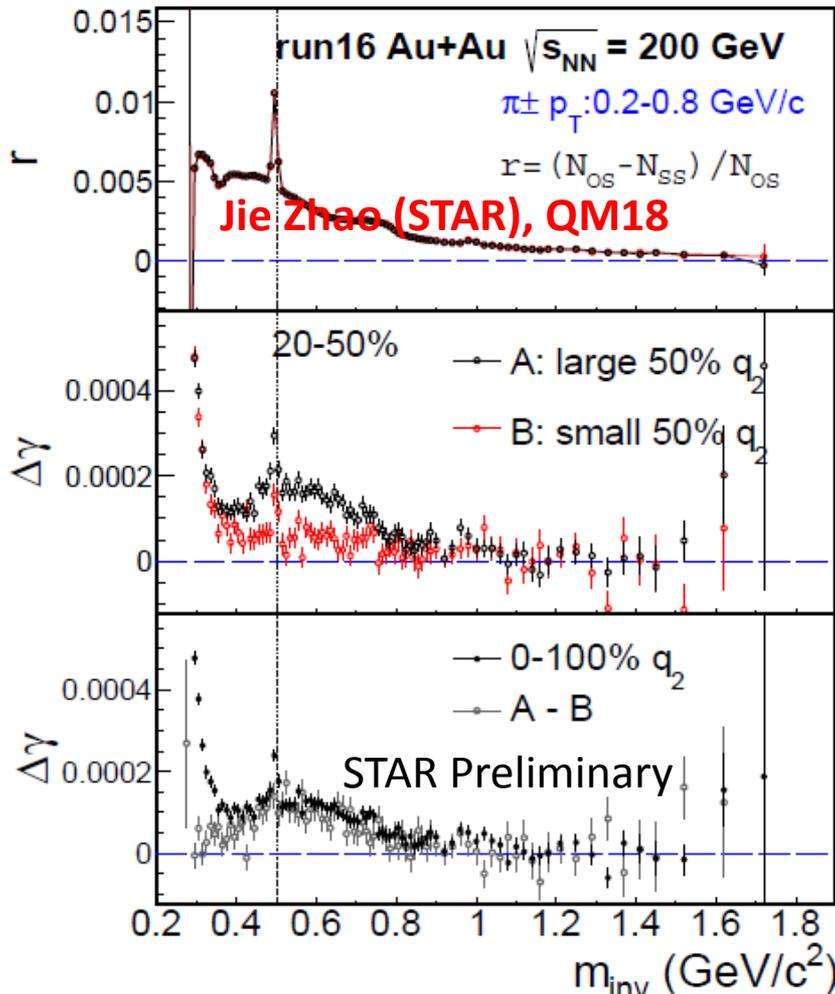
$$\frac{N_\rho}{N_\alpha N_\beta} \langle \cos(\varphi_\alpha + \varphi_\beta - 2\varphi_{clus}) \rangle \times v_{2,clus}$$



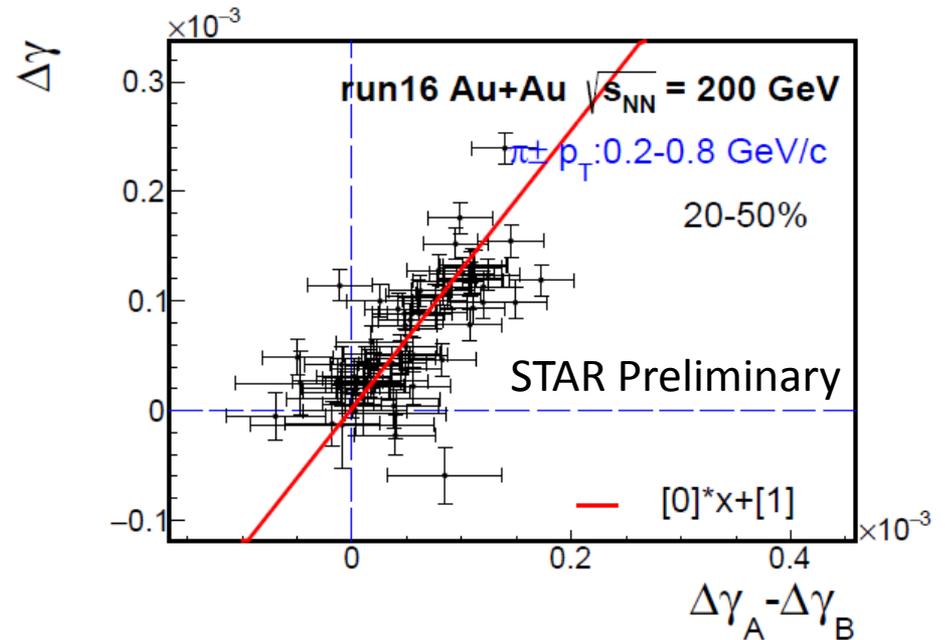
- ESE q_2 selects different v_2 , but does not bias spectators or magnetic field
- $\Delta\gamma_A - \Delta\gamma_B$ represents background shape
- Fit $\Delta\gamma = k * (\text{Bkg shape}) + \text{CME}$

ESE to constrain Bkg shape

$$\frac{N_\rho}{N_\alpha N_\beta} \langle \cos(\varphi_\alpha + \varphi_\beta - 2\varphi_{clus}) \rangle \times v_{2,clus}$$

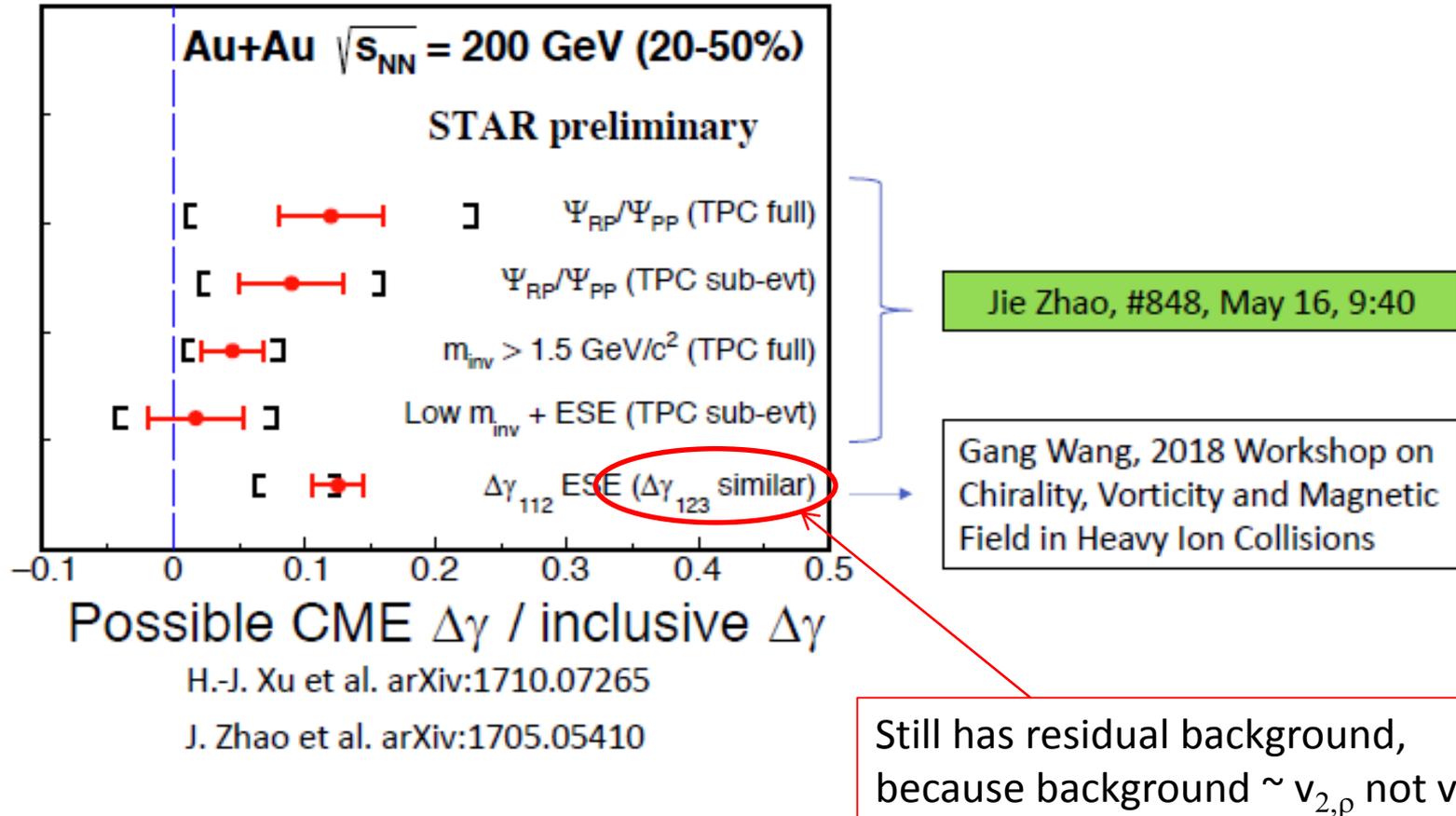


- ESE q_2 selects different v_2 , but does not bias spectators or magnetic field
- $\Delta\gamma_A - \Delta\gamma_B$ represents background shape
- Fit $\Delta\gamma = k * (\text{Bkg shape}) + \text{CME}$
- Fit does not assume $\Delta\gamma \propto v_2$, but only dependent of v_2
- Fit assumes constant CME. Fit χ^2/ndf tells whether it's a good assumption



Current STAR Data

Zhenyu Ye, STAR Highlights, QM18

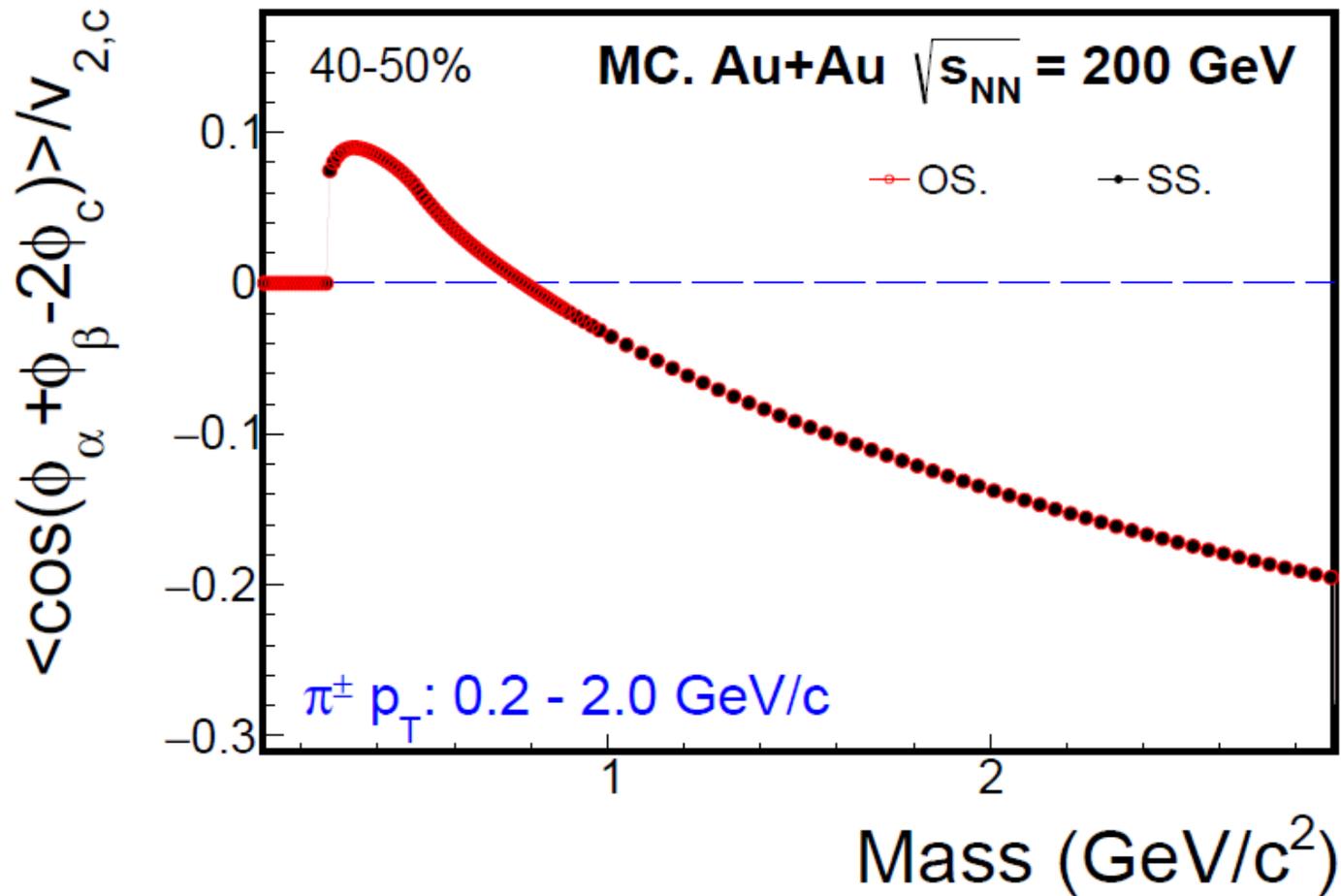


FW, Jie Zhao, PRC95(2017)051901(R), arXiv:1608.06610

Summary Remarks

- **CME is important physics in QCD**
 - Extraordinary claims require extraordinary proofs.
- **Major v_2 -induced background in the CME observable**
 - No way around but to reduce/eliminate backgrounds. Data-based techniques strongly preferred. Have to base our conclusions on and only on DATA.
 - If null signal, all we can say is “*CME is not observed.*” \neq “No CME.”
 - Only when there’s unambiguous/overwhelming evidence of a positive signal (5σ), can one claim the important physics of CME.
- **Novel methods to reduce/eliminate background**
 - Event-shape engineering
 - **Invariant mass** (arXiv:1705.05410, this talk)
 - **Intra-event “CME- v_2 Filter”** (arXiv:1710.07265. Haojie Xu talk Wed.)
 - It is hopeful to eventually measure the CME (Jie Zhao, STAR talk Wed.)

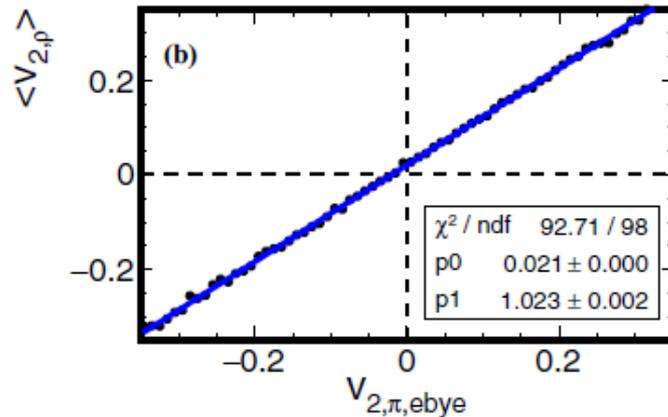
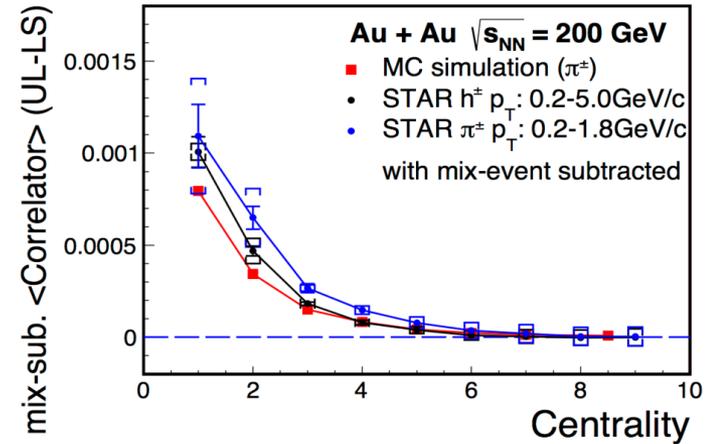
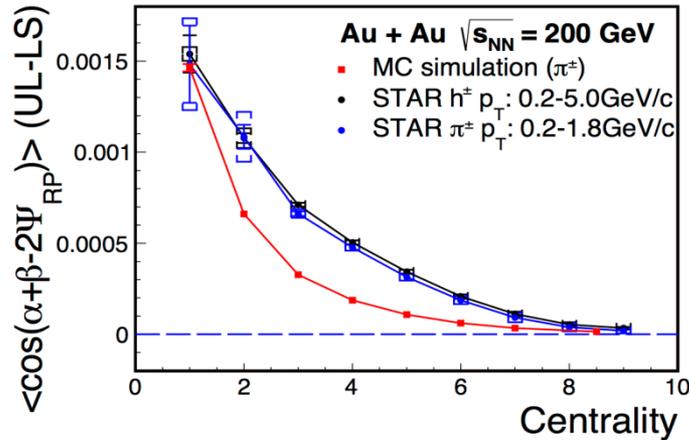
γ_{OS} and γ_{SS} correlators



Resonances decay toy simulation

FW, Jie Zhao, PRC95 (2017) 051901(R), arXiv:1608.06610

Toy model



Mix α, β in one event with ψ from another event, plot signal vs E-by-E final-state particle v_2 , weighted with $\text{Prob}(E \text{ by } E \ v_2)$.

Does not subtract background completely, because background $\propto v_{2,\rho} / N$