Status of the Experimental Search for the CME

Fuqiang Wang
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OUTLINE

- Brief introduction to CME
- The background issue
- A few selected experimental observables
  - -- Event-shape engineering
  - -- Invariant mass
  - -- The R variable
- New STAR measurement by spectator/participant planes
  - -- STAR data (arXiv:2106.09243)
  - -- Study of remaining nonflow effects
- Outlook (isobar and beyond)
- Summary

CHIRAL MAGNETIC EFFECT (CME)

The strong interaction

$$\mathcal{L}_{QCD} = \sum_q \left(\bar{\psi}_{qi} i\gamma^\mu \left[\delta_{ij}\partial_\mu + ig\left(G^\alpha_\mu t_\alpha\right)_{ij} \right] \psi_{qj} - m_q \bar{\psi}_{qi}\psi_{qi} \right) - \frac{1}{4} G^\alpha_{\mu\nu} G^{\mu\nu}_\alpha$$

quarks

quark-gluon interactions

quarks

$= \frac{1}{2}\left(E_\alpha^2 - B_\alpha^2\right)$

gluons

'‘t Hooft vacuum

$$+\theta \frac{\alpha_s}{8\pi} G^\alpha_{\mu\nu} \tilde{G}^{\mu\nu}_\alpha$$

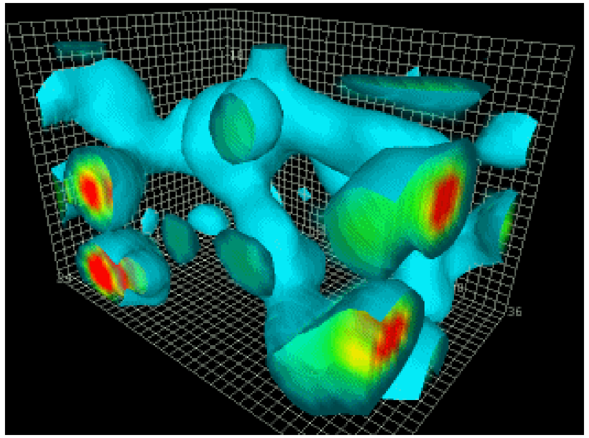
$$= -\theta \frac{\alpha_s}{2\pi} \vec{E}_\alpha \cdot \vec{B}_\alpha$$

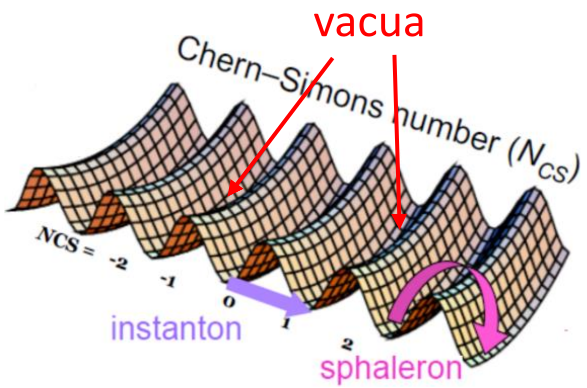
to solve the U(1)$_A$ problem (1976)

E: C-odd, P-odd, T-even
B: C-odd, P-even, T-odd

Explicitly breaks CP

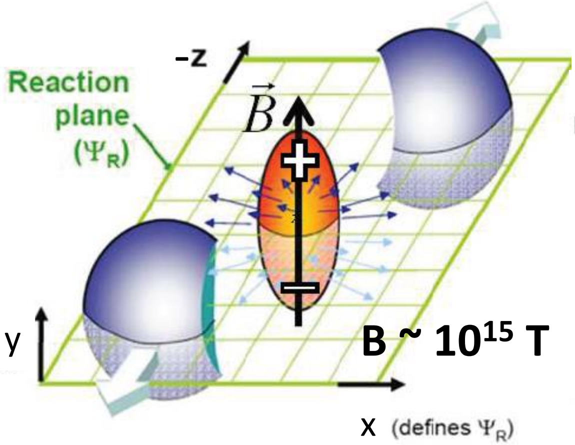
Early universe ultraviolet θ ≈ 1 ?? >> current infrared θ ≈ 0



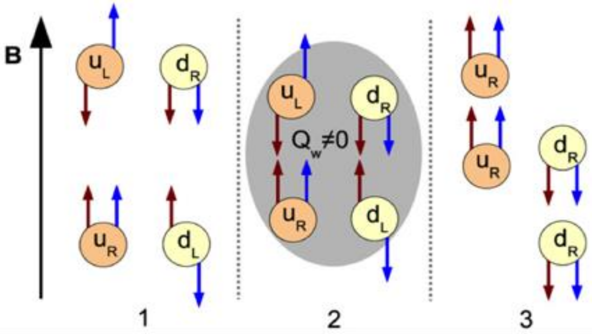


Kharzeev,Pisarski,Tytgat,PRL81(1998)512

QCD vacuum fluctuation, chiral anomaly, topological gluon field



Kharzeev, et al. NPA 803 (2008) 227

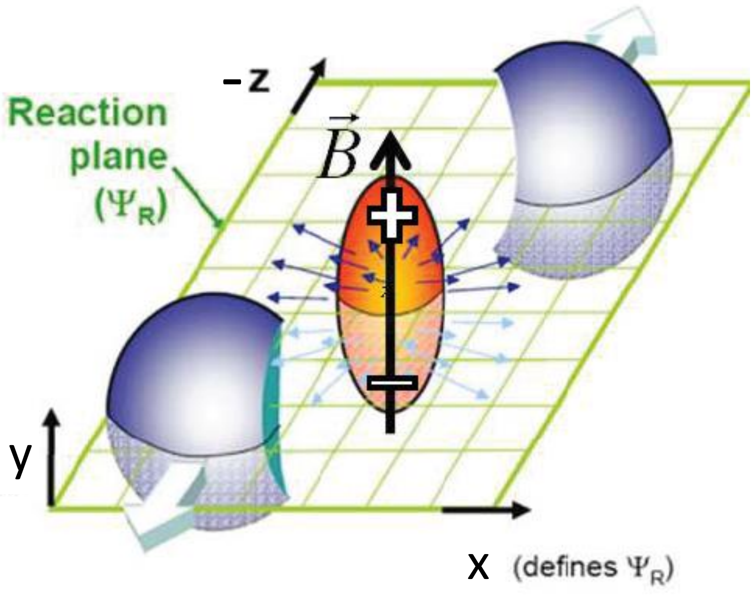


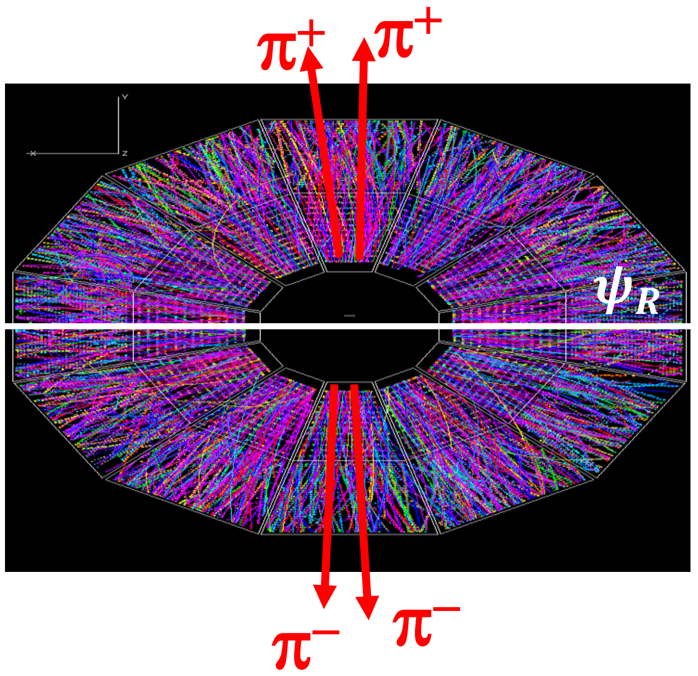
Chiral Magnetic Effect (CME)

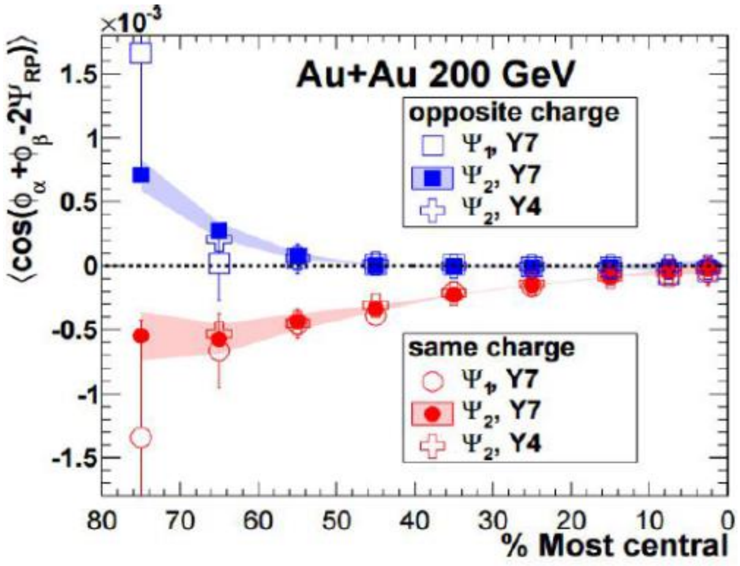
Discovery of the CME would imply: Chiral symmetry restoration (current-quark DOF & deconfinement); Local P/CP violation that may solve the strong CP problem (matter-antimatter asymmetry)

THE COMMON γ VARIABLE

Voloshin, PRC 70 (2004) 057901







STAR'09,'10;
STAR, PRC 88 (2013) 064911

$$\gamma_{\alpha\beta} = \langle\cos(\varphi_\alpha + \varphi_\beta - 2\psi_R)\rangle$$

$$\gamma_{\substack{+-\\-+}} > 0\,,\ \gamma_{\substack{++\\--}} < 0$$

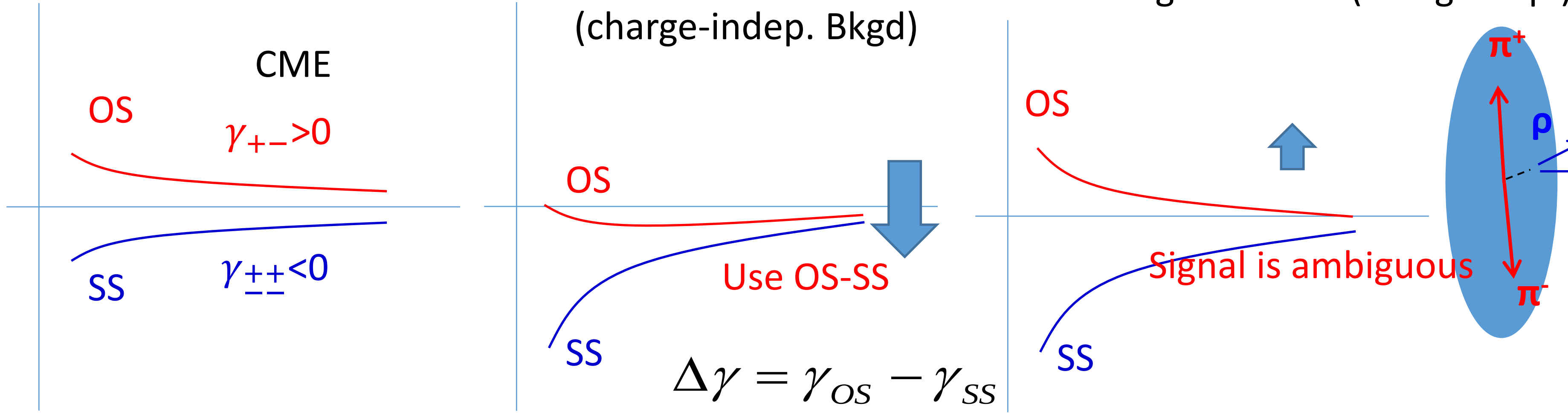
BACKGROUNDS IN γ CORRELATORS

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

$$\boxed{\gamma_{\alpha\beta} = \left\langle \cos(\varphi_\alpha + \varphi_\beta - 2\psi_{RP}) \right\rangle}$$

CME
+ mom. conserv.
(charge-indep. Bkgd)

CME
+ mom. conserv. (charge-indep.)
+ charge conserv. (charge-dep.)



$$\Delta\gamma = \gamma_{OS} - \gamma_{SS}$$

$$dN_\pm / d\varphi \propto 1 + 2v_1 \cos\varphi^\pm + 2a_\pm \cdot \sin\varphi^\pm + 2v_2 \cos 2\varphi^\pm + \ldots$$

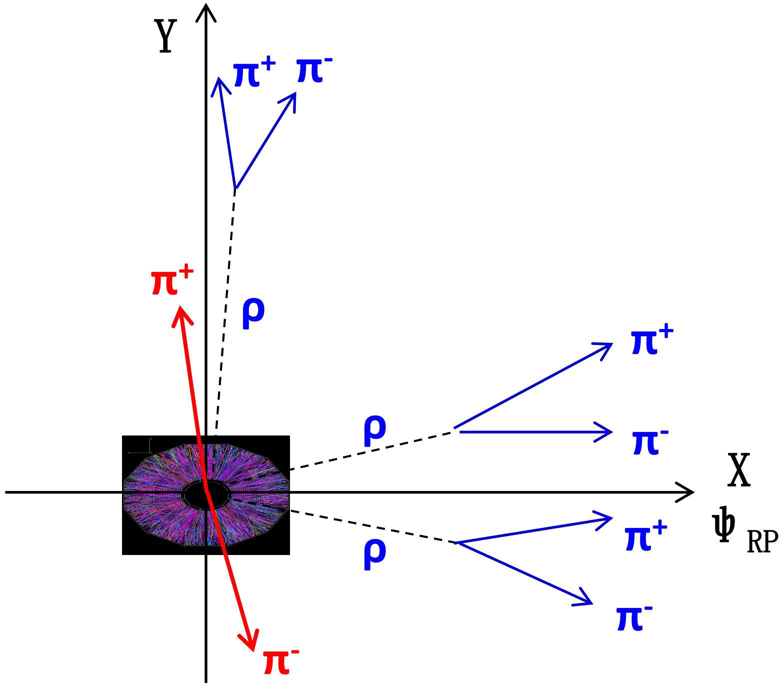
$$\gamma_{\alpha\beta} = \left[\underbrace{\left\langle \cos(\varphi_\alpha - \psi_{RP}) \cos(\varphi_\beta - \psi_{RP}) \right\rangle}_{\left\langle v_{1,\alpha} v_{1,\beta} \right\rangle \approx 0} - \underbrace{\left\langle \sin(\varphi_\alpha - \psi_{RP}) \sin(\varphi_\beta - \psi_{RP}) \right\rangle}_{\text{CME: } \left\langle a_\alpha a_\beta \right\rangle} \right] + \left[\underbrace{\frac{N_{cluster}}{N_\alpha N_\beta} \left\langle \cos(\varphi_\alpha + \varphi_\beta - 2\varphi_{cluster}) \cos(2\varphi_{cluster} - 2\varphi_{RP}) \right\rangle}_{\text{charge-indep. + charge-dep.}} \right]$$

BACKGROUND IN Δγ CORRELATOR

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

$$\boxed{\Delta\gamma = \gamma_{OS} - \gamma_{SS}}$$

$$\gamma_{\alpha\beta} = \left[\left\langle v_{1,\alpha} v_{1,\beta}\right\rangle - \left\langle a_\alpha a_\beta\right\rangle\right] + \frac{N_{cluster}}{N_\alpha N_\beta}\left\langle \cos(\varphi_\alpha + \varphi_\beta - 2\varphi_{cluster})\right\rangle v_{2,cluster}$$



$$\Delta\gamma = 2\left\langle a_1^2\right\rangle + \boxed{\frac{N_\rho}{N_\alpha N_\beta}\left\langle \cos(\varphi_\alpha + \varphi_\beta - 2\varphi_\rho)\right\rangle v_{2,\rho}}$$

Flow-induced charge-dependent background:
nonflow coupled with flow

$$\propto v_{2,\rho} / N$$

HANDLING BACKGROUND

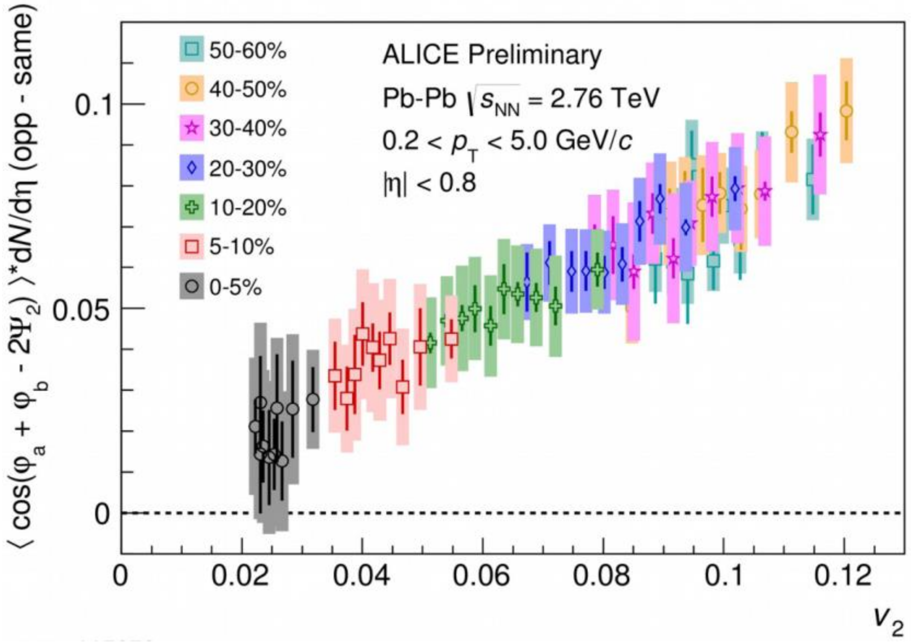
- When background is small
  - Can be a bit sloppy in background estimation. Imprecision can be afforded by syst. uncertainty
  - Can be somewhat model-dependent (theo. syst. uncertainty)

- **When background is large**
  - Have to cleanly remove background
  - Extreme care should be taken. Small error in background can result in big mistake in signal
  - Should not rely on theory/model/trends (unless theory is very precise)
  - Better be data-driven, often leading to new observables and methods

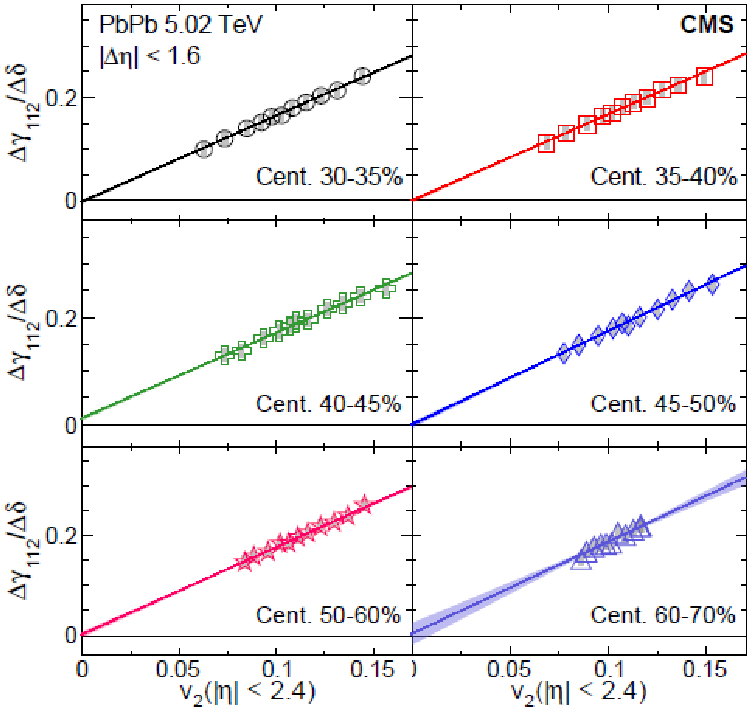
EVENT-SHAPE ENGINEERING METHOD

Schukraft,Timmins,Voloshin, PLB719 (2013) 394

ALICE PLB777(2018)151



CMS PRC97(2018)044912



Pb+Pb upper limits at 95% CL:

ALICE: 26% (10-50%, MC-KLN CGC)

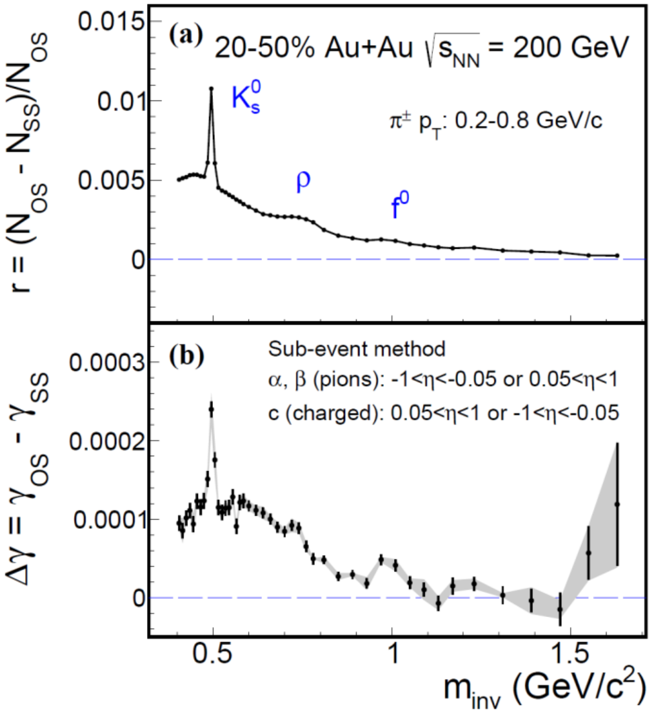
CMS: 7% (MB)

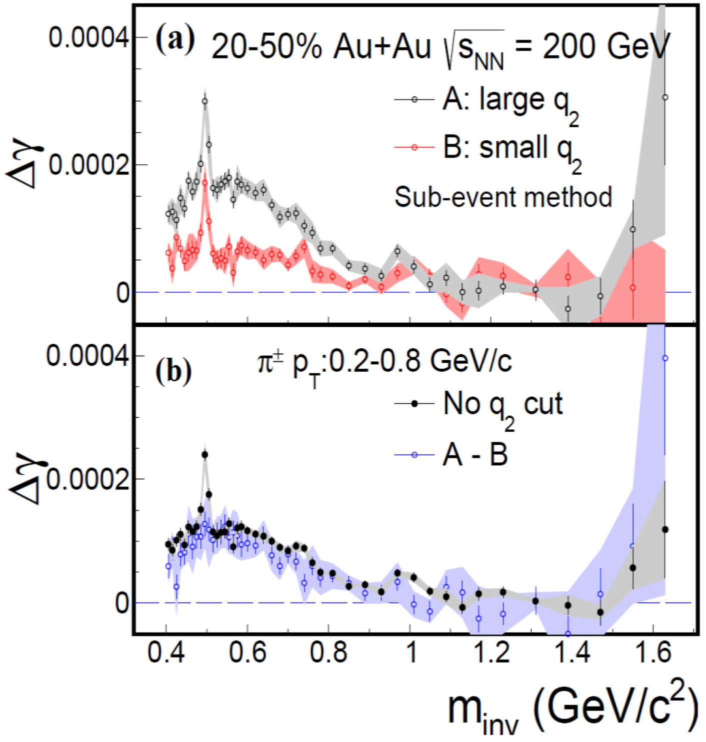
THE INVARIANT MASS METHOD

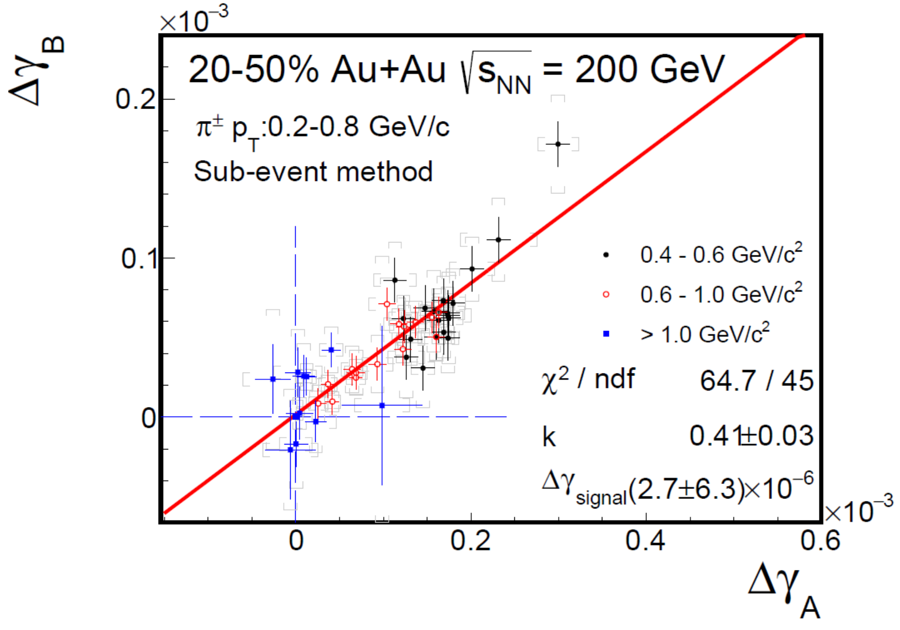
Zhao, Li, Wang, Eur.Phys.J.C 79 (2019) 2, 168

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

STAR, arXiv:2006.05035







CME fraction = $(2 \pm 4 \pm 5)\%$

CME upper limit 15% at 95% CL

THE R-VARIABLE

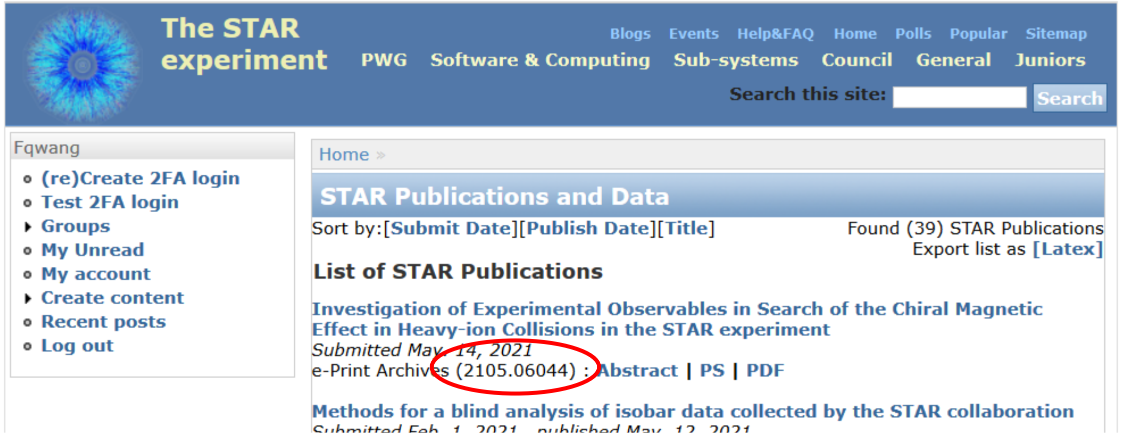
Ajitanand, Lacey, et al., PRC **83** (2011) 011901
Magdy, Lacey, et al., PRC **97** (2018) 061901(R)

$$\Delta S = \frac{\sum_1^p \sin\left(\frac{m}{2}\Delta\varphi_m\right)}{p} - \frac{\sum_1^n \sin\left(\frac{m}{2}\Delta\varphi_m\right)}{n}$$

$$R(\Delta S_m) \equiv \frac{N(\Delta S_{m,\mathrm{real}})}{N(\Delta S_{m,\mathrm{shuffled}})} \Big/ \frac{N(\Delta S^{\perp}_{m,\mathrm{real}})}{N(\Delta S^{\perp}_{m,\mathrm{shuffled}})}, \quad m = 2, 3, \ldots,$$

Width of R(ΔS) distribution reduces to variance sin*sin, cos*cos → equivalently the Δγ variable

$$\frac{S_{\mathrm{concavity}}}{\sigma^2_{R2}} \approx -\frac{M}{2}(M-1)\Delta\gamma_{112}$$



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Investigation of Experimental Observables in Search of the Chiral Magnetic Effect in Heavy-ion Collisions in the STAR experiment
Submitted May. 14, 2021
e-Print Archives (2105.06044) : Abstract | PS | PDF

Methods for a blind analysis of isobar data collected by the STAR collaboration

Investigation of Experimental Observables in Search of the Chiral Magnetic Effect in Heavy-ion Collisions in the STAR experiment

Subikash Choudhury,[1] Xin Dong,[2] Jim Drachenberg,[3] James Dunlop,[4] ShinIchi Esumi,[5] Yicheng Feng,[6] Evan Finch,[7] Yu Hu,[1,4] Jiangyong Jia,[4,8] Jerome Lauret,[4] Wei Li,[9] Jinfeng Liao,[10] Yufu Lin,[11] Mike Lisa,[12] Takafumi Niida,[5] Robert Lanny Ray,[13] Masha Sergeeva,[14] Diyu Shen,[15,16] Shuzhe Shi,[17] Paul Sorensen,[4] Aihong Tang,[4] Prithwish Tribedy,[4] Gene Van Buren,[4] Sergei Voloshin,[18] Fuqiang Wang,[6] Gang Wang,[14] Haojie Xu,[19] Zhiwan Xu,[14] Nanxi Yao,[14] and Jie Zhao[6]

Except the R-variable proponents, all other CME experts are convinced that R and the inclusive Δγ are similar.

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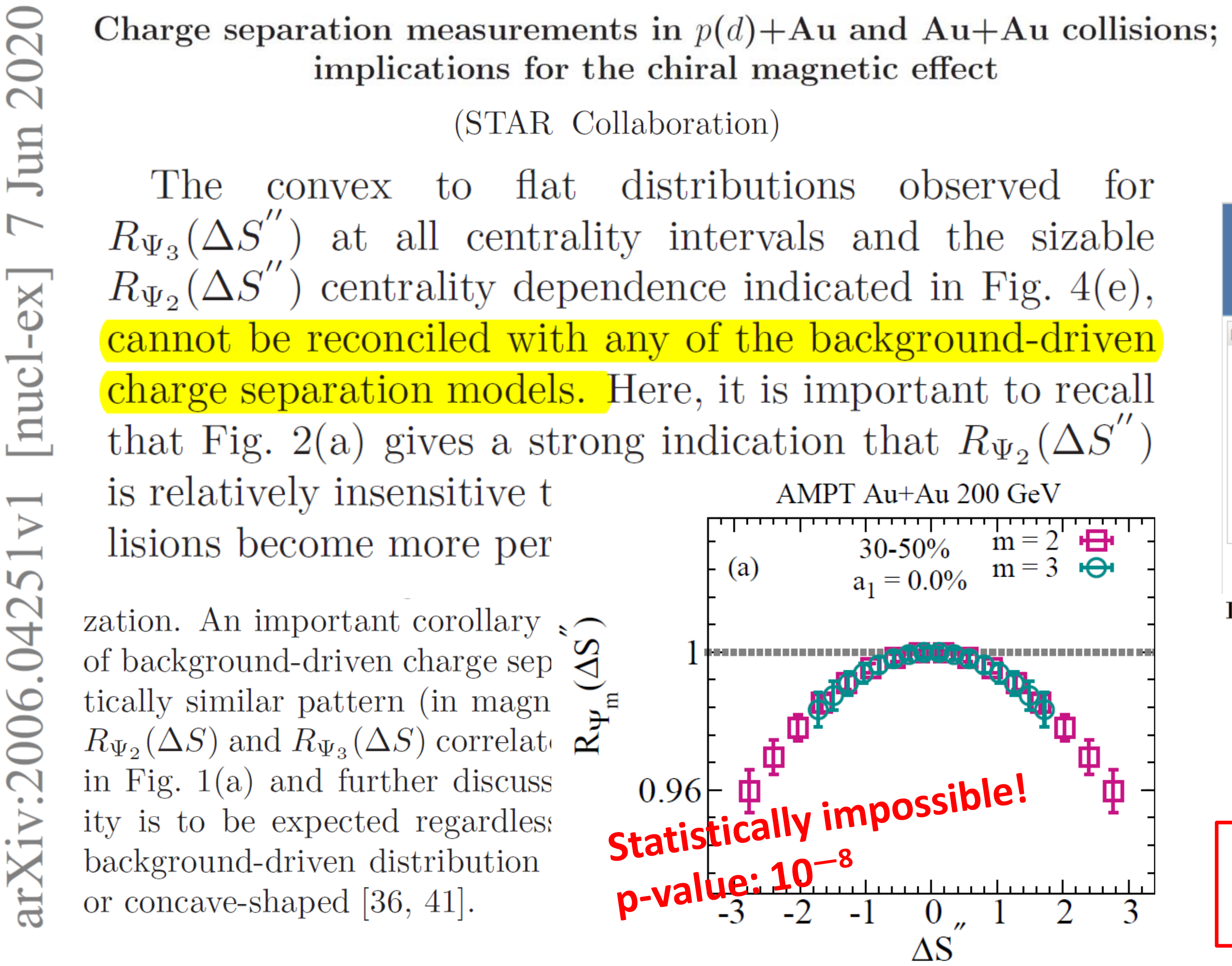

Charge separation measurements in $p(d)$+Au and Au+Au collisions; implications for the chiral magnetic effect

(STAR Collaboration)

The convex to flat distributions observed for $R_{\Psi_3}(\Delta S'')$ at all centrality intervals and the sizable $R_{\Psi_2}(\Delta S'')$ centrality dependence indicated in Fig. 4(e), cannot be reconciled with any of the background-driven charge separation models. Here, it is important to recall that Fig. 2(a) gives a strong indication that $R_{\Psi_2}(\Delta S'')$ is relatively insensitive t lisions become more per

zation. An important corollary of background-driven charge sep tically similar pattern (in magn $R_{\Psi_2}(\Delta S)$ and $R_{\Psi_3}(\Delta S)$ correlat in Fig. 1(a) and further discuss ity is to be expected regardless background-driven distribution or concave-shaped [36, 41].

Statistically impossible!
p-value: 10^{-8}

$$\Delta S = \frac{\sum_1^p \sin\left(\frac{m}{2}\Delta\varphi_m\right)}{p} - \frac{\sum_1^n \sin\left(\frac{m}{2}\Delta\varphi_m\right)}{n}$$

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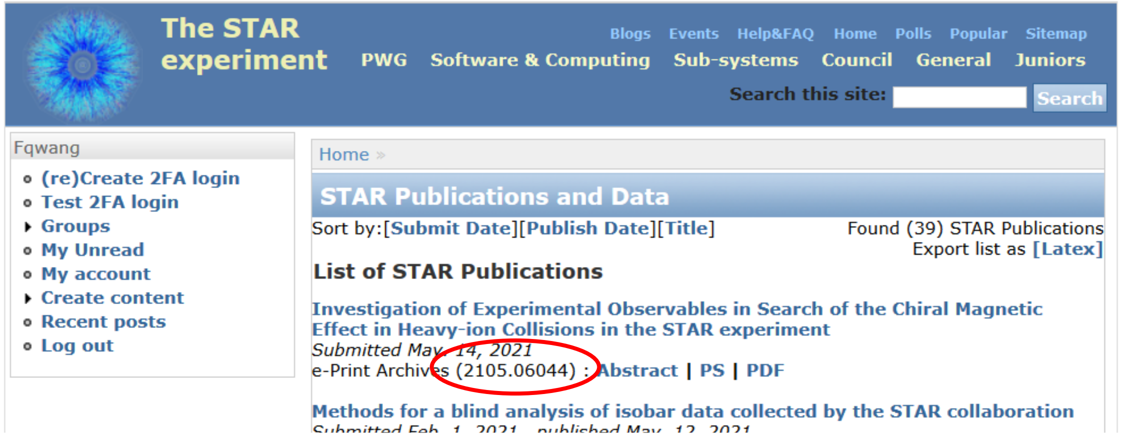

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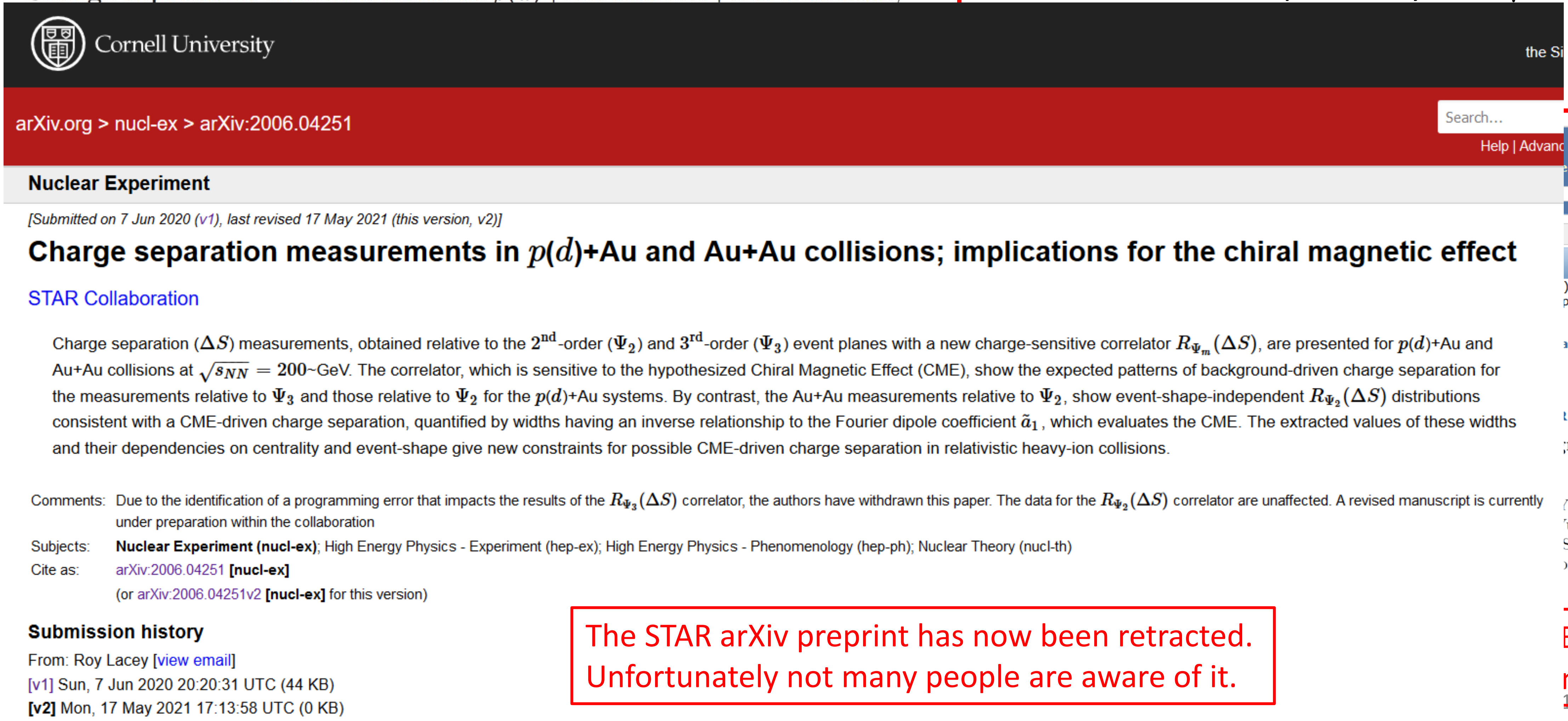
Charge separation measurements in $p(d)$+Au and Au+Au collisions;



Cornell University

the Si

arXiv.org > nucl-ex > arXiv:2006.04251

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Nuclear Experiment

[Submitted on 7 Jun 2020 (v1), last revised 17 May 2021 (this version, v2)]

Charge separation measurements in $p(d)$+Au and Au+Au collisions; implications for the chiral magnetic effect

STAR Collaboration

Charge separation (ΔS) measurements, obtained relative to the 2^{nd}-order (Ψ_2) and 3^{rd}-order (Ψ_3) event planes with a new charge-sensitive correlator $R_{\Psi_m}(\Delta S)$, are presented for $p(d)$+Au and Au+Au collisions at $\sqrt{s_{NN}} = 200$~GeV. The correlator, which is sensitive to the hypothesized Chiral Magnetic Effect (CME), show the expected patterns of background-driven charge separation for the measurements relative to Ψ_3 and those relative to Ψ_2 for the $p(d)$+Au systems. By contrast, the Au+Au measurements relative to Ψ_2, show event-shape-independent $R_{\Psi_2}(\Delta S)$ distributions consistent with a CME-driven charge separation, quantified by widths having an inverse relationship to the Fourier dipole coefficient $\tilde{a}_1$, which evaluates the CME. The extracted values of these widths and their dependencies on centrality and event-shape give new constraints for possible CME-driven charge separation in relativistic heavy-ion collisions.

Comments: Due to the identification of a programming error that impacts the results of the $R_{\Psi_3}(\Delta S)$ correlator, the authors have withdrawn this paper. The data for the $R_{\Psi_2}(\Delta S)$ correlator are unaffected. A revised manuscript is currently under preparation within the collaboration
Subjects: **Nuclear Experiment (nucl-ex)**; High Energy Physics - Experiment (hep-ex); High Energy Physics - Phenomenology (hep-ph); Nuclear Theory (nucl-th)
Cite as: arXiv:2006.04251 **[nucl-ex]**
(or arXiv:2006.04251v2 **[nucl-ex]** for this version)

Submission history

From: Roy Lacey [view email]
[v1] Sun, 7 Jun 2020 20:20:31 UTC (44 KB)
[v2] Mon, 17 May 2021 17:13:58 UTC (0 KB)

gnetic Effect in

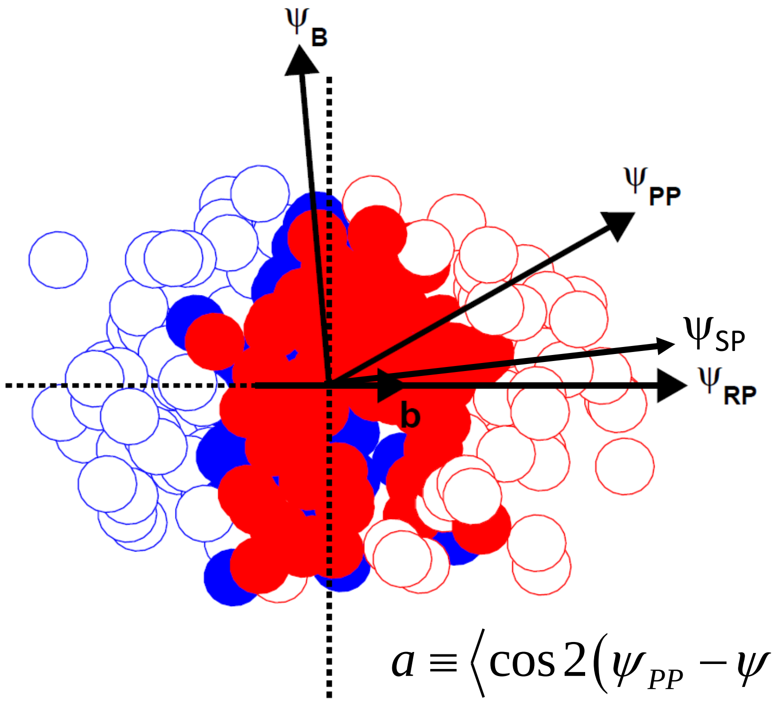
icheng Feng,[6]
ufu Lin,[11]
Shuzhe Shi,[17]
shin,[18]
Zhao[6]

The STAR arXiv preprint has now been retracted.
Unfortunately not many people are aware of it.

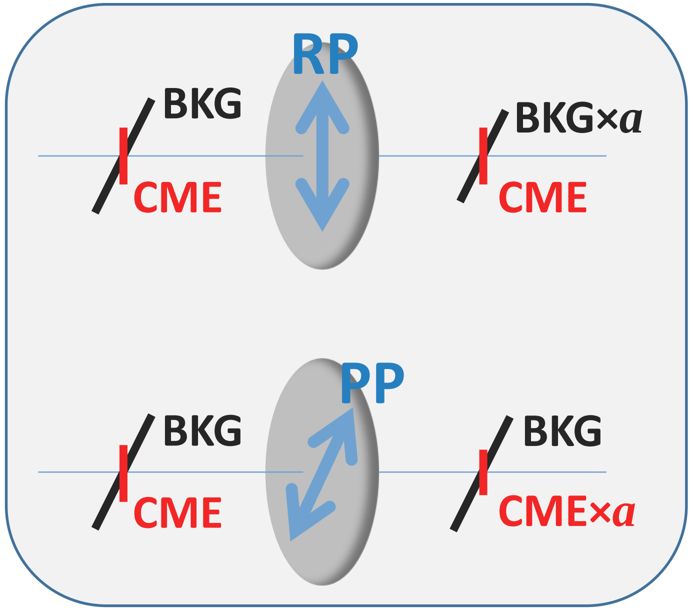
E experts
milar.

SP/PP METHOD: INTRA-EVENT “CME-v_2 FILTER”

H. Xu et al., CPC 42 (2018) 084103, arXiv:1710.07265



$$a \equiv \langle \cos 2(\psi_{PP} - \psi_{RP}) \rangle$$



IN THE SAME EVENT

$$\Delta\gamma\{\mathrm{SP}\} = a\Delta\gamma_{Bkg}\{\mathrm{PP}\} + \Delta\gamma_{CME}\{\mathrm{PP}\}/a$$

$$\Delta\gamma\{\mathrm{PP}\} = \Delta\gamma_{Bkg}\{\mathrm{PP}\} + \Delta\gamma_{CME}\{\mathrm{PP}\}$$

$$\Delta\gamma\{\mathrm{SP}\}/a - \Delta\gamma\{\mathrm{PP}\} = (1/a^2 - 1)\Delta\gamma_{CME}\{\mathrm{PP}\}$$

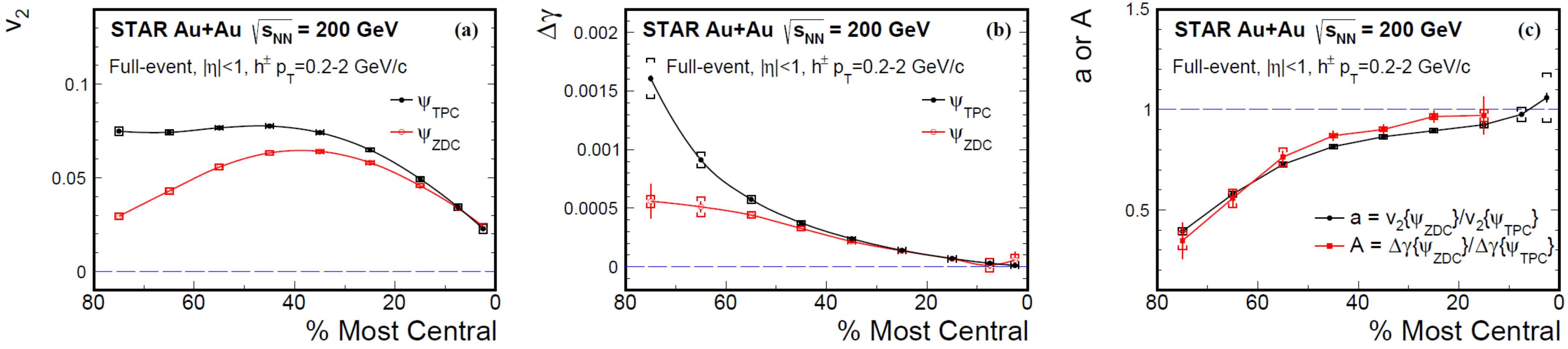
$$A = \Delta\gamma\{\mathrm{SP}\}/\Delta\gamma\{\mathrm{PP}\}$$

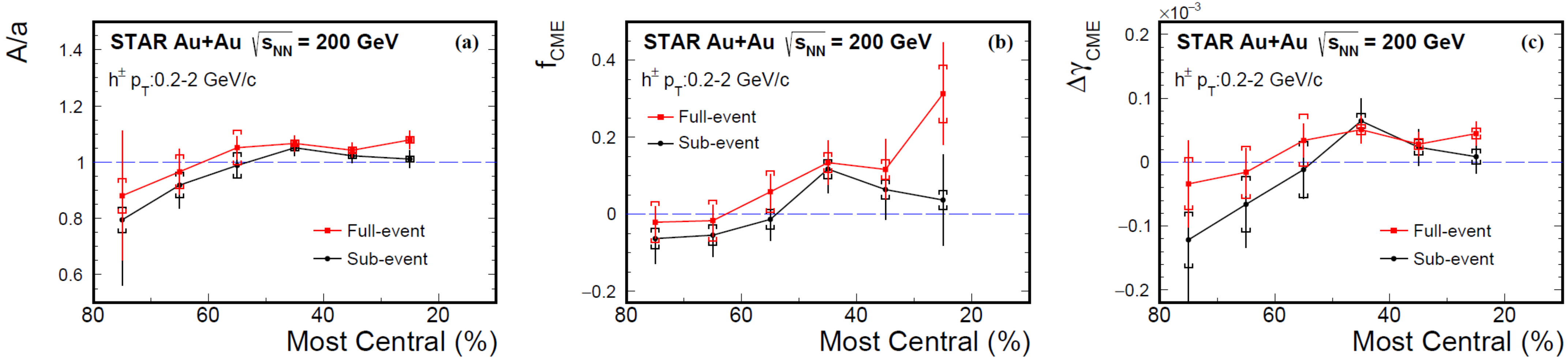
$$a = v_2\{\mathrm{SP}\}/v_2\{\mathrm{PP}\}$$

$$f_{CME} = \frac{\Delta\gamma_{CME}\{\mathrm{PP}\}}{\Delta\gamma\{\mathrm{PP}\}} = \frac{A/a - 1}{1/a^2 - 1}$$

Au+Au Collisions at 200 GeV (2.4B MB)

STAR, arXiv:2106.09243





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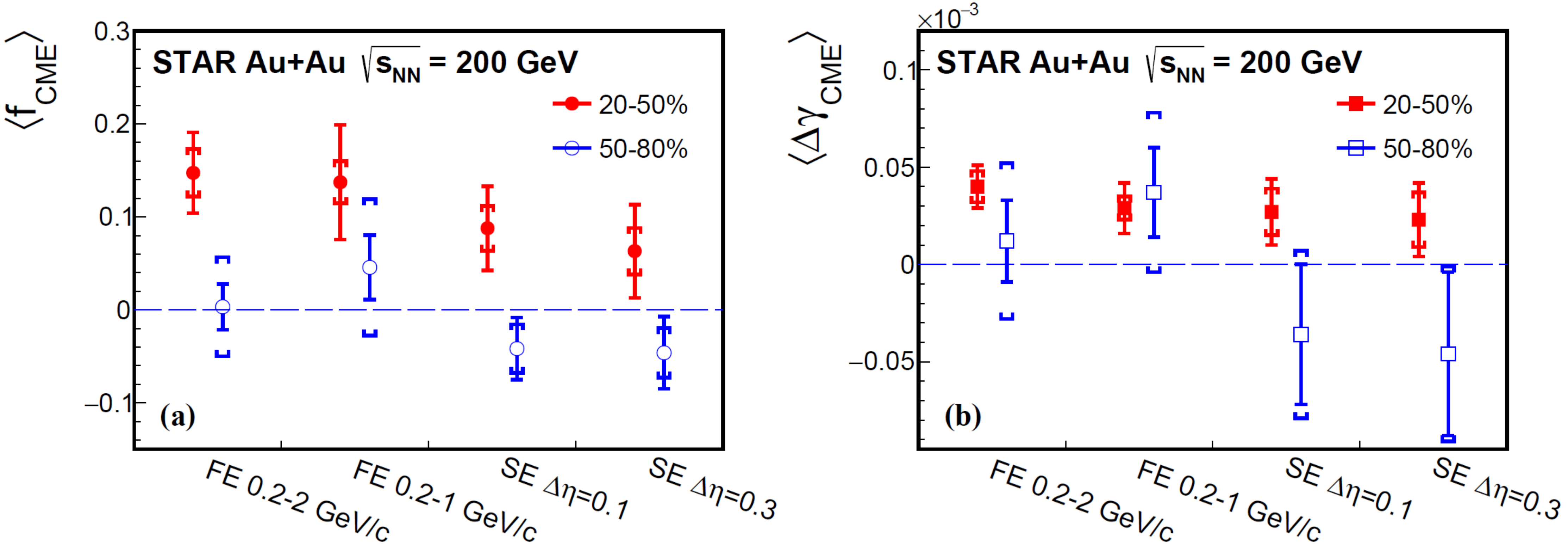


- Consistent-with-zero signal in peripheral 50-80% collisions with relatively large errors
- Indications of finite signal in mid-central 20-50% collisions, with 1-3σ significance
- Possible remaining nonflow effects

REMAINING NONFLOW EFFECTS

Feng et al., arXiv:2106.15595

$$f_{\rm CME} = \frac{\Delta\gamma_{\rm CME}\{\rm PP\}}{\Delta\gamma\{\rm PP\}} = \frac{A/a - 1}{1/a^2 - 1}$$

$$\frac{A}{a} = \frac{\Delta\gamma\{\rm SP\}}{v_2\{\rm SP\}} \cdot \frac{v_2\{\rm PP\}^*}{\Delta\gamma\{\rm PP\}^*} = \frac{C_3\{\rm SP\}}{v_2^2\{\rm SP\}} \cdot \frac{v_2^2\{\rm PP\}^*}{C_3\{\rm PP\}^*} = \frac{1+\varepsilon_{\rm nf}}{1+\dfrac{\varepsilon_3/\varepsilon_2}{Nv_2^2\{\rm PP\}}}$$

$$C_3\{\rm SP\} = \frac{C_{\rm 2p}N_{\rm 2p}}{N^2} v_{2,\rm 2p}\{\rm SP\} v_2\{\rm SP\}\,,$$

$$C_3^*\{\rm EP\} = \frac{C_{\rm 2p}N_{\rm 2p}}{N^2} v_{2,\rm 2p}\{\rm EP\} v_2\{\rm EP\} + \frac{C_{\rm 3p}N_{\rm 3p}}{2N^3}\,.$$

Nonflow in Δγ
→ negative $f_{\rm CME}$

$$\epsilon_2 \equiv \frac{C_{\rm 2p}N_{\rm 2p}v_{2,\rm 2p}}{Nv_2} \qquad \epsilon_3 \equiv \frac{C_{\rm 3p}N_{\rm 3p}}{2N}$$

$$\Delta\gamma_{\rm bkgd} = \frac{N_{\rm 2p}}{N^2}\langle\cos(\phi_\alpha+\phi_\beta-2\phi_{\rm 2p})\rangle v_{2,\rm 2p}$$

$$C_{\rm 2p} = \langle\cos(\phi_\alpha+\phi_\beta-2\phi_{\rm 2p})\rangle$$

$$C_{\rm 3p} = \langle\cos(\phi_\alpha+\phi_\beta-2\phi_c)\rangle_{\rm 3p}$$

$$v_2^*\{\rm EP\} = \sqrt{v_2^2\{\rm EP\} + v_{2,\rm nf}^2}$$

$$\epsilon_{\rm nf} \equiv v_{2,\rm nf}^2/v_2^2$$

Nonflow in v$_2$
→ positive $f_{\rm CME}$

$$f_{\rm CME}^* \approx \left(\epsilon_{\rm nf} - \frac{\epsilon_3/\epsilon_2}{Nv_2^2\{\rm EP\}}\right)\Big/\left(\frac{1+\epsilon_{\rm nf}}{a^2} - 1\right)$$

$$f_{\rm CME}^* = \left(\frac{1+\epsilon_{\rm nf}}{1+\frac{\epsilon_3/\epsilon_2}{Nv_2^2\{\rm EP\}}} - 1\right)\Big/\left(\frac{1+\epsilon_{\rm nf}}{a^2} - 1\right)$$

$$= \left(\frac{1+\epsilon_{\rm nf}}{1+\frac{(1+\epsilon_{\rm nf})\epsilon_3/\epsilon_2}{N{v_2^*}^2\{\rm EP\}}} - 1\right)\Big/\left(\frac{1}{{a^*}^2} - 1\right)$$

Feng et al., arXiv:2106.15595

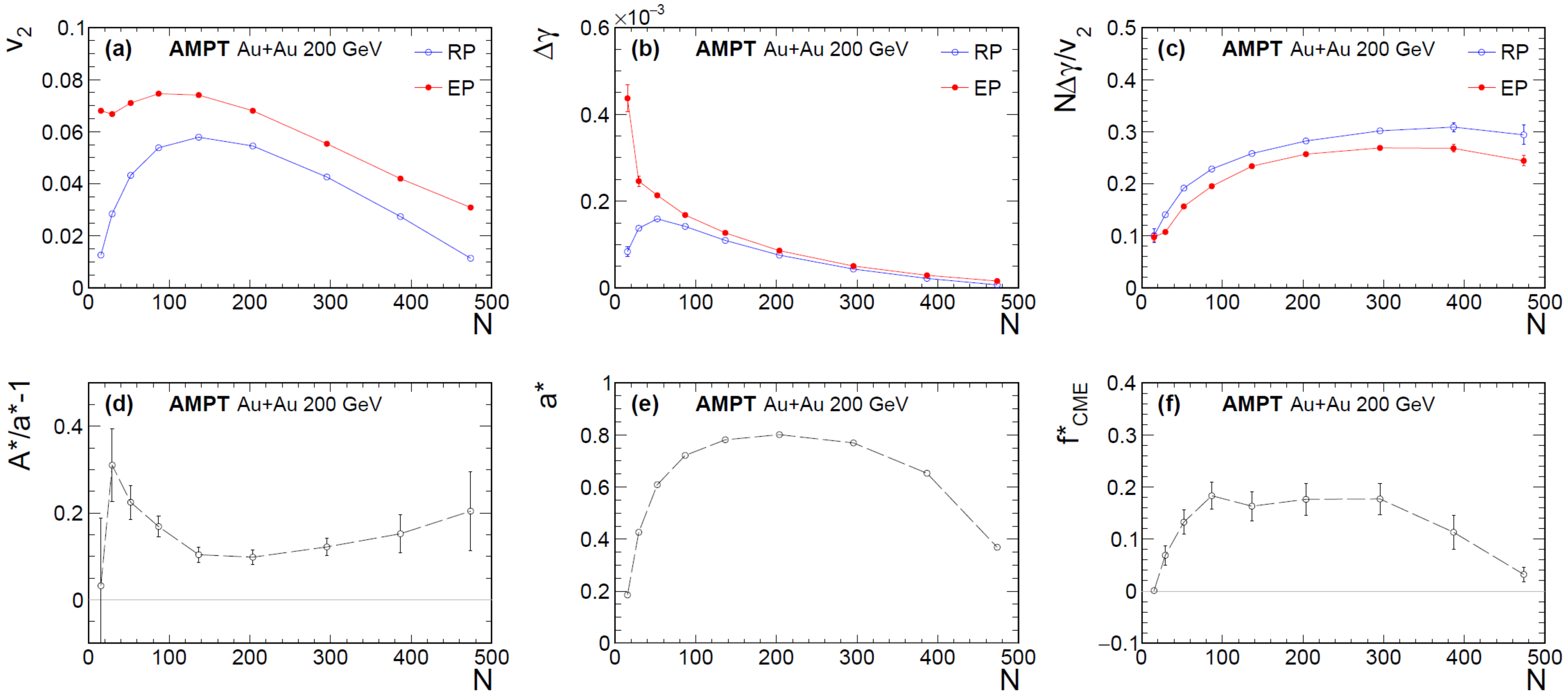


FIG. 1. AMPT simulation results as functions of $N = (N_+ + N_-)/2$, the POI single-charge multiplicity, in 200 GeV Au+Au collisions: (a) elliptic flow v_2, (b) charge-dependent 3p correlator $\Delta\gamma$, (c) $N\Delta\gamma/v_2$ w.r.t. RP and EP (the former is referred to as $\epsilon_2^{\rm AMPT}$, see Eqs. (2) and (13)), (d) $A^*/a^* - 1$ ($\equiv \epsilon_{\rm AMPT}$, which approximately equals to the nonflow contamination $\epsilon_{\rm nf}$ in v_2, see Eqs. (15) and (17)), (e) a^* by Eq. (18), and (f) the calculated $f^*_{\rm CME}$ by Eq. (3). The POI and particle c (for EP) are from $|\eta| < 1$ and $0.2 < p_T < 2$ GeV/c. All errors are statistical, with total 377 million AMPT mini-bias events.

Feng et al., arXiv:2106.15595

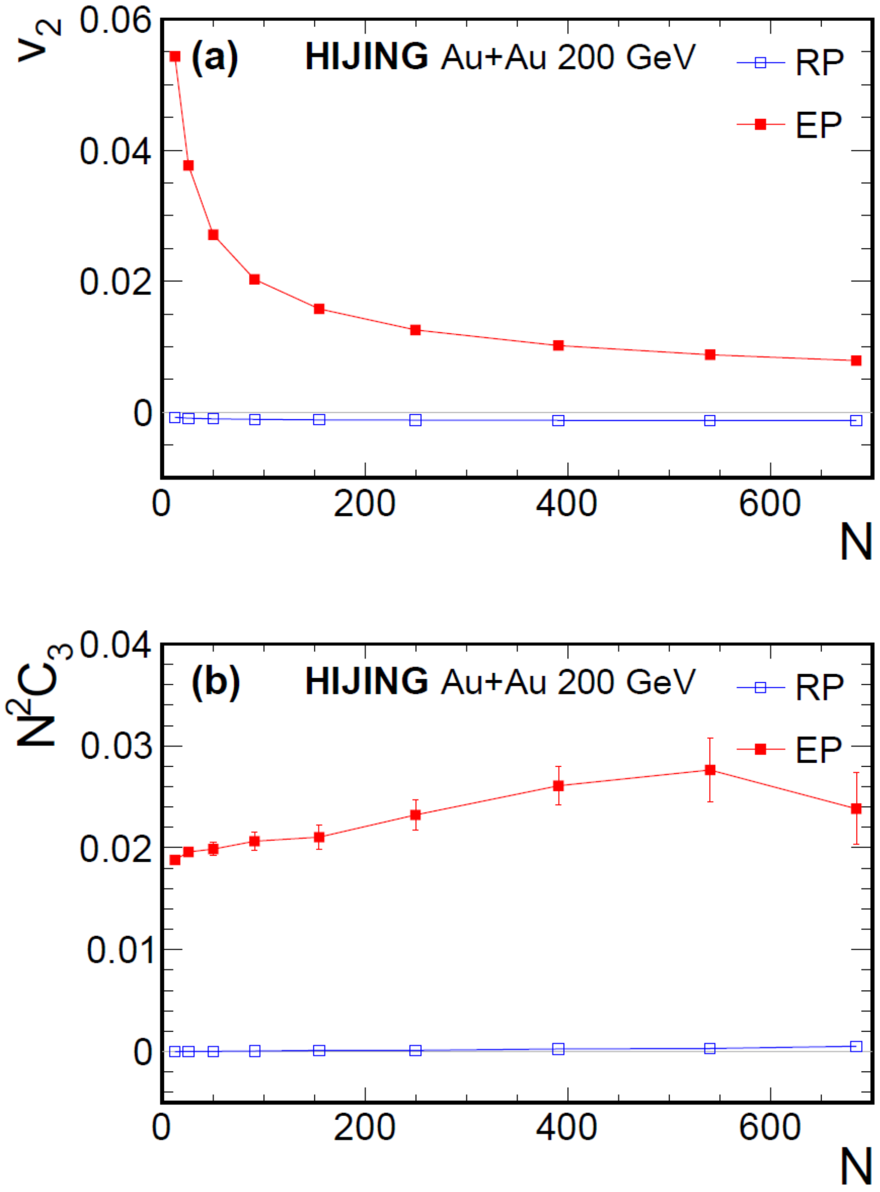
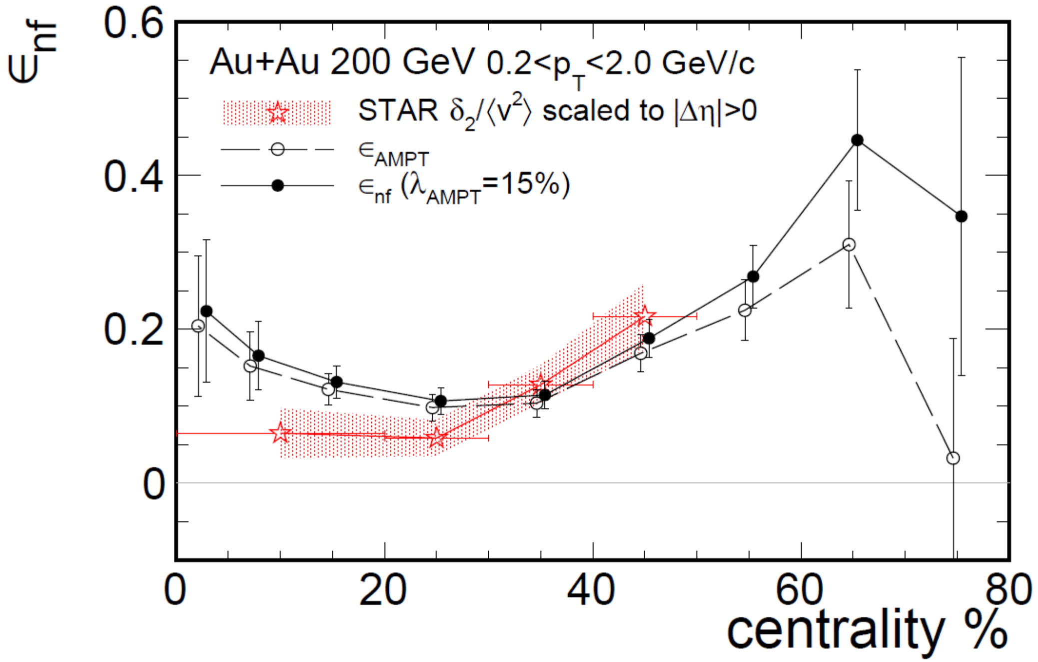


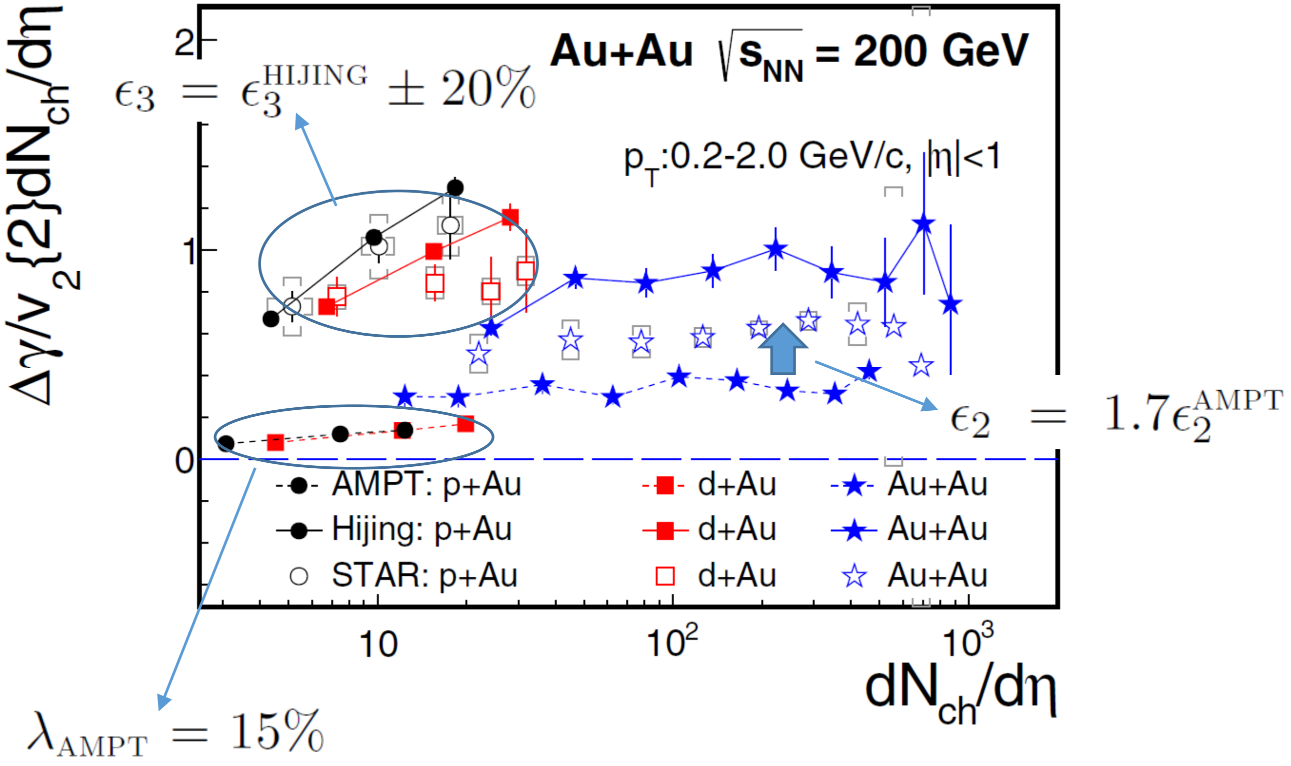
FIG. 2. HIJING simulation results as functions of $N = (N_+ + N_-)/2$, the POI single-charge multiplicity, in 200 GeV Au+Au collisions: (a) elliptic anisotropy v_2, and (b) charge-dependent 3p correlator N^2C_3 w.r.t. RP and EP (the latter is referred to as $\epsilon_3 = \epsilon_3^{\text{HIJING}}$, see Eqs.(11), (12b), and (19)). The POI and particle c are from $|\eta| < 1$ and $0.2 < p_T < 2$ GeV$/c$. All errors are statistical, with 592 million HIJING mini-bias events.

USE DATA WHEREVER POSSIBLE



STAR, PLB 745 (2015) 40

Zhao, Feng, et al. PRC **101**, 034912 (2020)

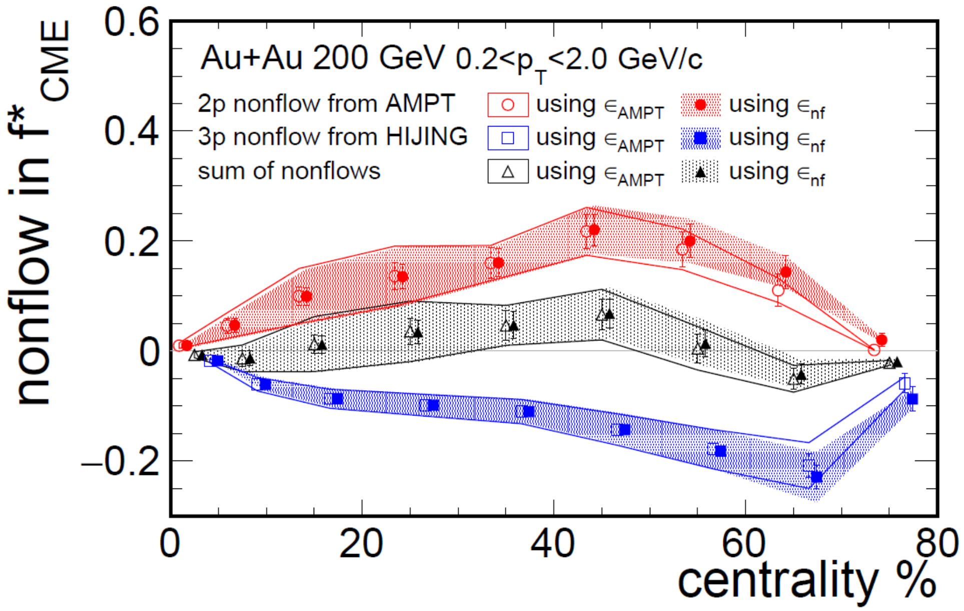


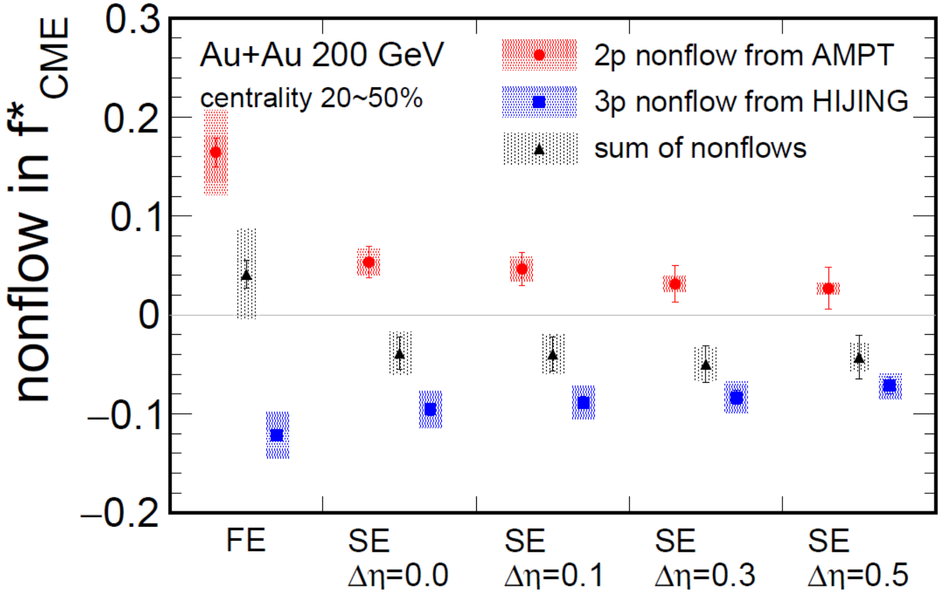
$\epsilon_3 = \epsilon_3^{\rm HIJING} \pm 20\%$

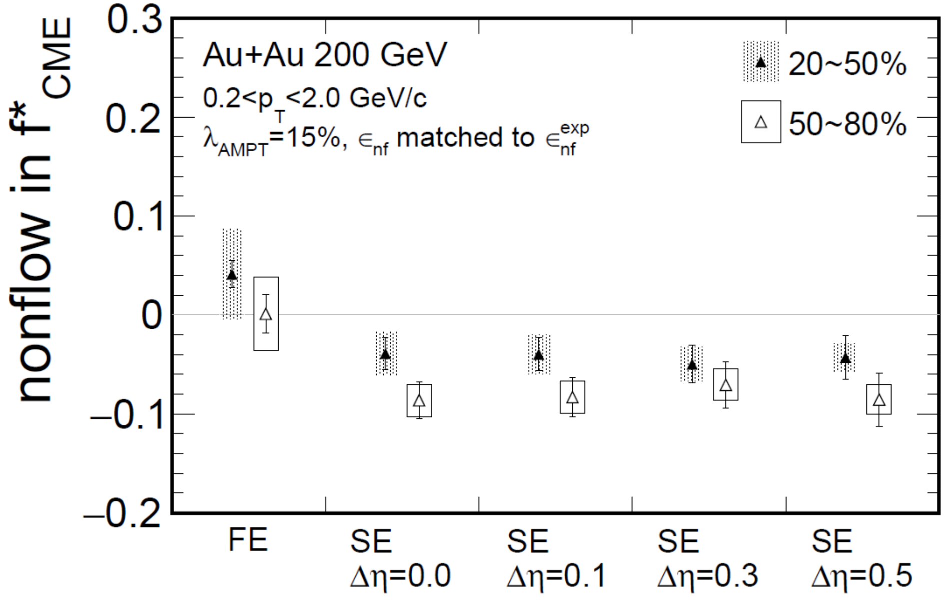
$\epsilon_2 = 1.7\epsilon_2^{\rm AMPT}$

$\lambda_{\rm AMPT} = 15\%$

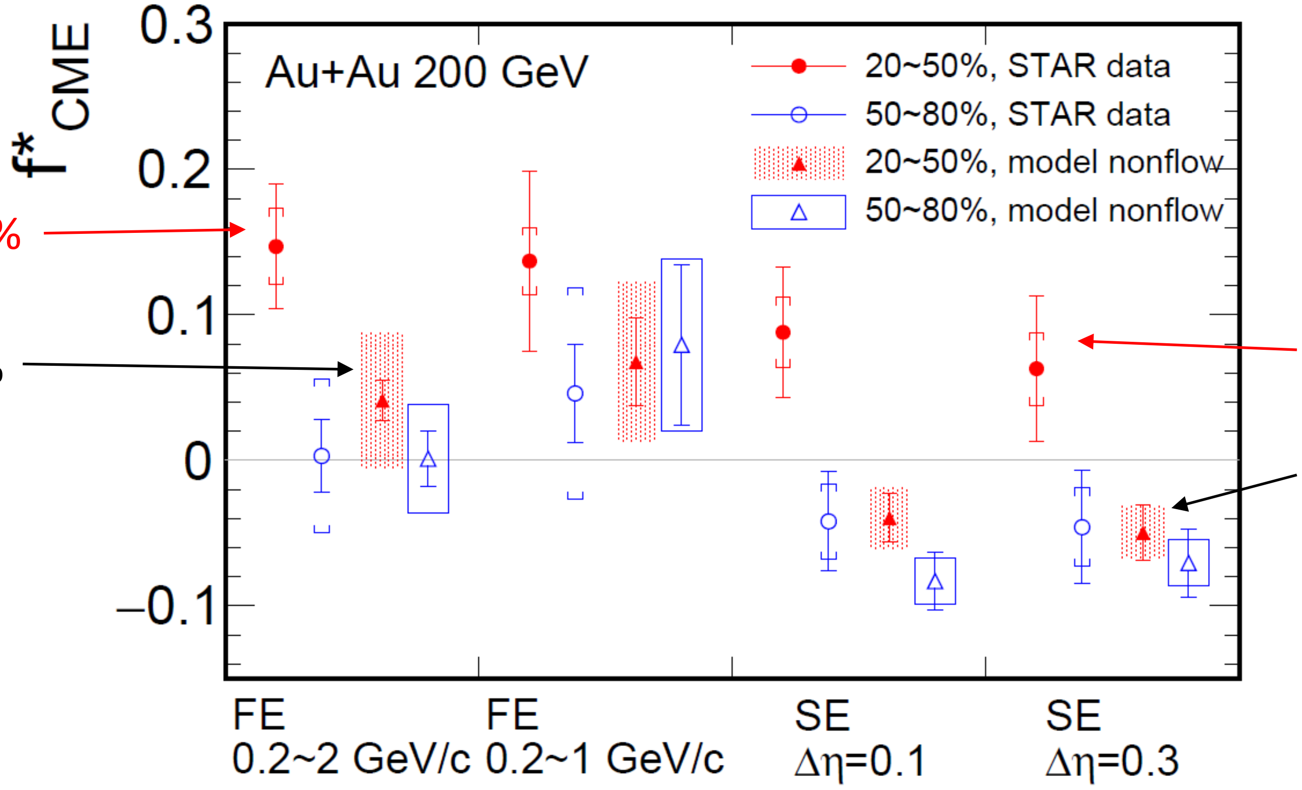
MODEL ESTIMATES







IMPLICATIONS TO DATA



(14.7 ± 5.0)%

(4.1 ± 4.8)%

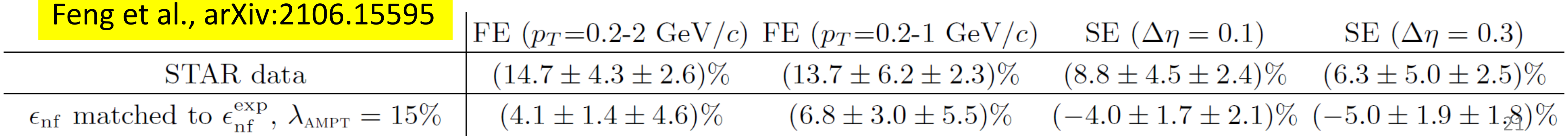
(6.3 ± 5.6)%

(−5.0 ± 2.6)%

There may indeed be hint of CME in the data

STAR, arXiv:2106.09243

Feng et al., arXiv:2106.15595



	FE (p_T=0.2-2 GeV/c)	FE (p_T=0.2-1 GeV/c)	SE ($\Delta\eta = 0.1$)	SE ($\Delta\eta = 0.3$)
STAR data	$(14.7 \pm 4.3 \pm 2.6)\%$	$(13.7 \pm 6.2 \pm 2.3)\%$	$(8.8 \pm 4.5 \pm 2.4)\%$	$(6.3 \pm 5.0 \pm 2.5)\%$
ϵ_{nf} matched to $\epsilon_{\mathrm{nf}}^{\mathrm{exp}}$, $\lambda_{\mathrm{AMPT}} = 15\%$	$(4.1 \pm 1.4 \pm 4.6)\%$	$(6.8 \pm 3.0 \pm 5.5)\%$	$(-4.0 \pm 1.7 \pm 2.1)\%$	$(-5.0 \pm 1.9 \pm 1.8)\%$

SP/PP VS. ISOBAR: PROS & CONS

$$\Delta\gamma = \frac{N_{2\mathrm{p}}}{N^2}\left\langle \cos\left(\alpha+\beta-2\varphi_{2\mathrm{p}}\right)\right\rangle \frac{v_{2,2\mathrm{p}}}{v_2}\cdot\left(\frac{v_2}{v_2^*}\right)^2 \cdot v_2^* + \frac{N_{3\mathrm{p}}}{2N^3}\left\langle\cos\left(\alpha+\beta-2\varphi_c\right)\right\rangle_{3\mathrm{p}}$$

SP/PP:

- All in magenta are identical
- 2p nonflow $v_2{}^*/v_2$ differ
- 3p nonflow differ
- ZDC EP resolution poor; need more statistics

Nonflow studies, model estimates…

ISOBAR:

- All terms slightly differ
- TPC EP resolution is good

➢ $\frac{N^2}{N_{2\mathrm{p}}}\frac{\Delta\gamma}{v_2^*}$ might be better than $N\frac{\Delta\gamma}{v_2^*}$

➢ Nonflow partially cancel: $\left\langle\cos\left(\alpha+\beta-2\varphi_{2\mathrm{p}}\right)\right\rangle\Big/\left(v_2^*/v_2\right)^2$?

➢ $\kappa = \frac{\Delta\gamma}{v_2^*\Delta\delta} = \frac{\left\langle\cos\left(\alpha+\beta-2\varphi_{2\mathrm{p}}\right)\right\rangle}{\left\langle\cos\left(\alpha-\beta\right)\right\rangle_{2\mathrm{p}}}\cdot\left(\frac{v_2}{v_2^*}\right)^2$: nonflow overcounted?

Isobar conclusion will need detailed nonflow studies

ISOBAR EXPECTATION

Yicheng Feng, Yufu Lin, et al., arXiv:2103.10378

Background $\propto 1/N$
isobar/AuAu ~ 2

Mag. field B ~ $A/A^{2/3} \sim A^{1/3}$
$\Delta\gamma_{CME} \sim B^2 \sim A^{2/3}$
Signal: AuAu/isobar ~ 1.5

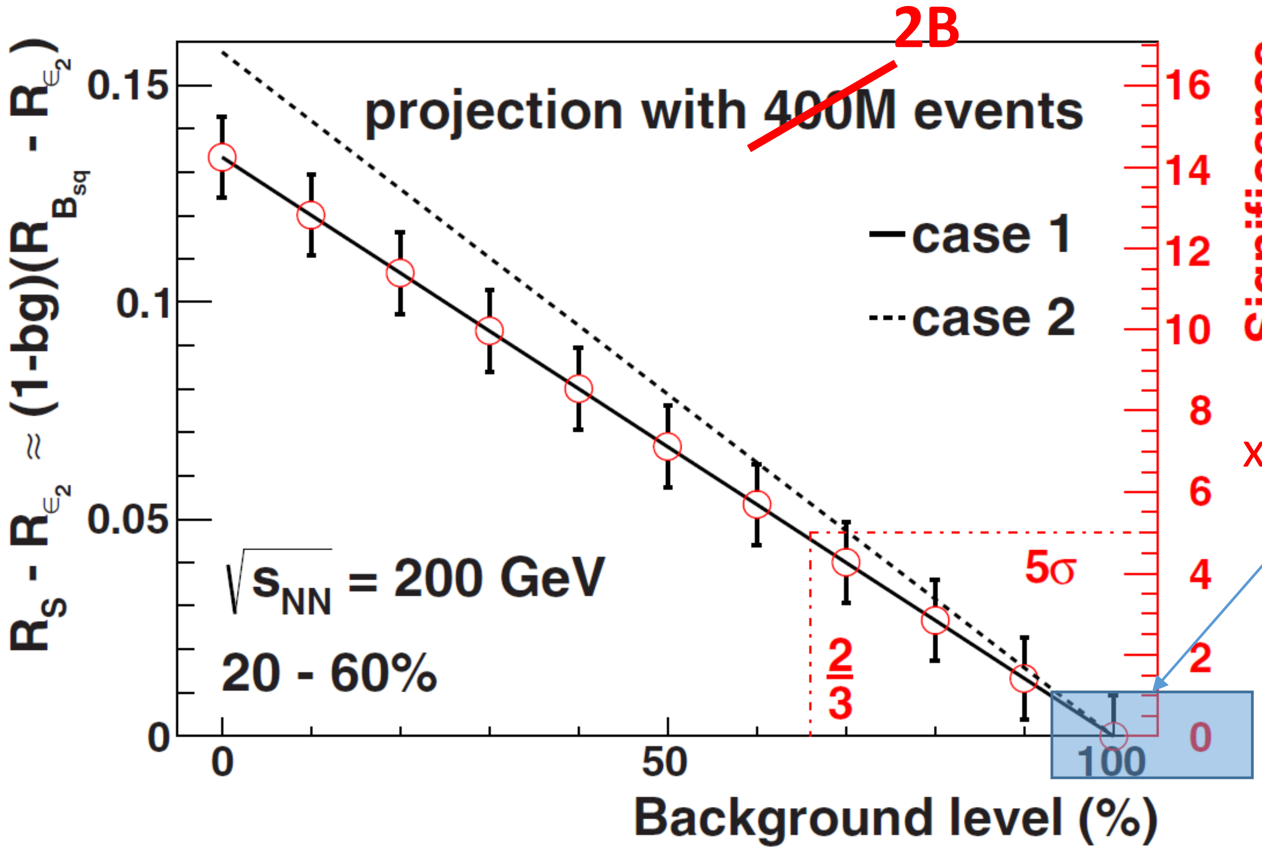
x3 reduction!

If AuAu f_{CME}=10%, then isobar 3% (1σ effect)

AVFD-glasma μ_5/s: isobar/AuAu ~ 1.5
$\Delta\gamma_{CME} \sim (\mu_5/s)^2$ → x2 gain in signal

If AuAu f_{CME}=10%, then isobar 7% (2σ effect)

Deng et al. PHYSICAL REVIEW C **94**, 041901(R) (2016)



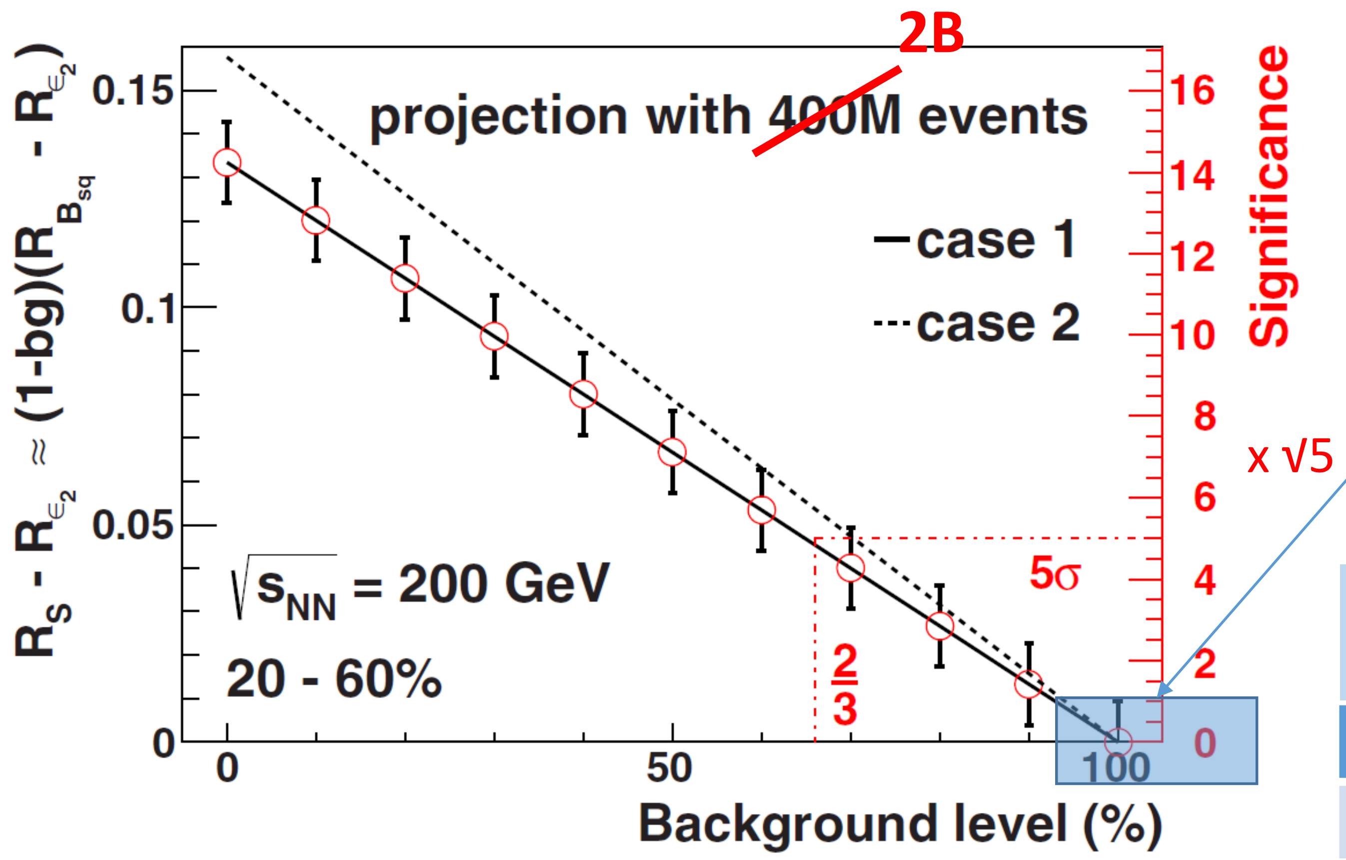
x √5

This is going to be only 1-2σ effect! ☹

5σ x √5 / 33% x 10%/3 = 1σ , Ru/Zr = 1 + 15%*3% = 1.005

ISOBAR EXPECTATION

Deng et al. PHYSICAL REVIEW C **94**, 041901(R) (2016)



Yicheng Feng, Yufu Lin, et al., arXiv:2103.10378

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5σ x √5 / 33% x 10%/3 = 1σ , Ru/Zr = 1 + 15%*3% = 1.005

Signal differs by 15%, but still background in isobar: v_2 differs by 2-3% (Xu etal PRL121(2018)022301, Lin etal PRC98(2018)054907)

CME Signal (isobar x0.15)	**x 1**	**x 1/1.5**	**x 1.5^2/1.5**
Background (isobar x0.025)	x 1	x 2	x 2
Isobar S/B improvement	x 6	x 2	x 4.5
Isobar S/√B improvement	**x 1**	**x 1/2**	**x 1**

OUTLOOK

- Isobar data will be available soon…
- Current data (2.4B MB Au+Au) yield ~5% statistical uncertainties
  Expect 20B from 2023+25 runs → 1.7% stat uncertainty
- Systematic uncertainties should be small (ratios of ratios), and can be beaten down to 1% level.
- Total 2% uncertainty can be achieved in Au+Au collisions.

- Depending on Mother Nature, we should have a firm conclusion by 2025 at latest.

SUMMARY

- CME is a very important physics
- Backgrounds dominate in inclusive $\Delta\gamma$;
  Rigorous treatment of backgrounds is critical.
- STAR data indicate a finite CME signal with 1-3σ significance;
  nonflow does not seem to fully account for it.
- Looking forward to isobar data, but it will not be the end of journey.

THE INFAMOUS R-VARIABLE

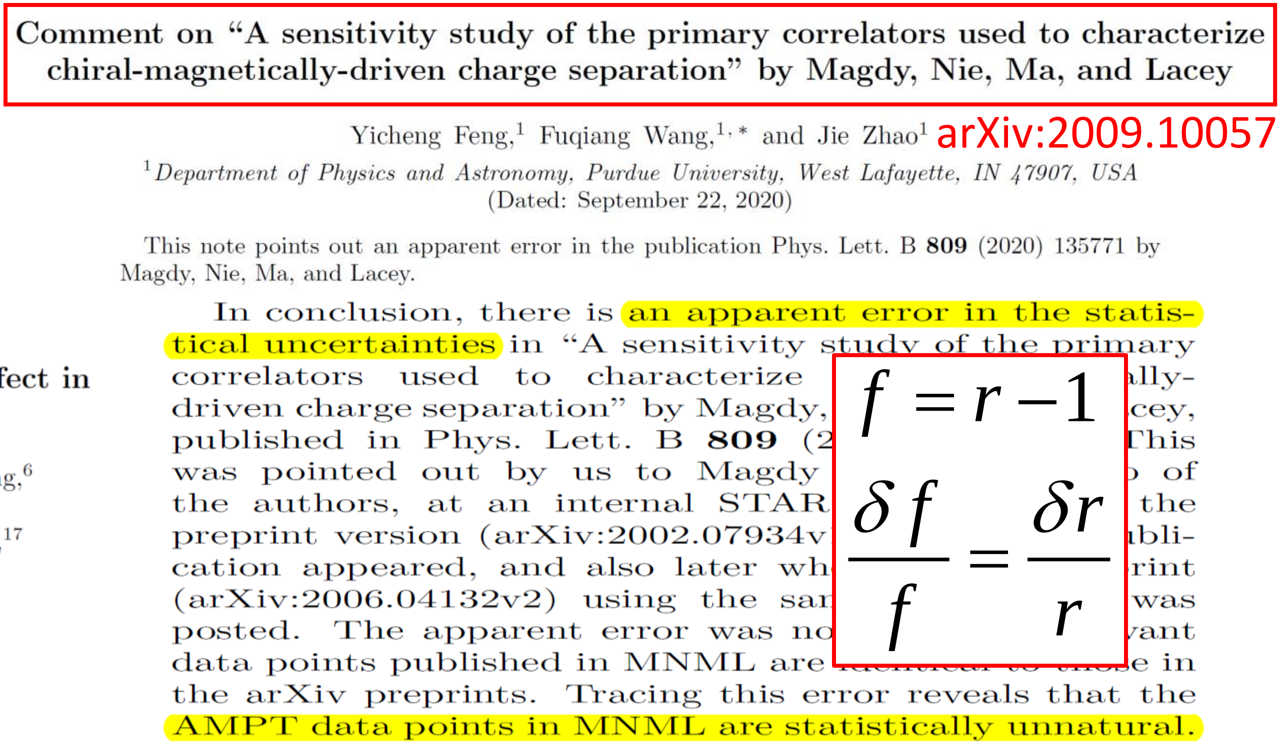
N. N. Ajitanand, R. A. Lacey, A.Taranenko, and J.M.Alexander, Phys. Rev. C **83**, 011901 (2011)
N. Magdy, S. Shi, J. Liao, N. Ajitanand, and R. A. Lacey, Phys. Rev. C **97**, 061901(R) (2018)
N. Magdy, S. Shi, J. Liao, P. Liu, and R. A. Lacey, Phys. Rev. C **98**, 061902(R) (2018)
Yifeng Sun and Che Ming Ko, Phys. Rev. C **98**, 014911 (2018)
N. Magdy, M.-W. Nie, G.-L. Ma, and R. A. Lacey, Phys. Lett. B **809**, 135771 (2020) Several mistakes and data are unnatural!
Ling Huang, Mao-Wu Nie, Guo-Liang Ma, Phys. Rev. C **101** (2020), 024916, 1906.11631 [nucl-th] Results are erroneous!
Shuzhe Shi, Hui Zhang, Defu Hou, and Jinfeng Liao, Phys. Rev. Lett. **125**, 242301 (2020)

R proponents and a few
uninformed theorists

Piotr Bożek, Phys. Rev. C **97**, 034907 (2018)
Y. Feng, J. Zhao, and F.Wang, Phys. Rev. C **98**, 034904 (2018)
Y. Feng et al, PRC**103**, 034912 (2021)
Y. Feng, F. Wang, and J. Zhao, arXiv:2009.10057
Choudhury et al. (STAR technique paper), arXiv:2105.06044

Investigation of Experimental Observables in Search of the Chiral Magnetic Effect in Heavy-ion Collisions in the STAR experiment

Subikash Choudhury,[1] Xin Dong,[2] Jim Drachenberg,[3] James Dunlop,[4] ShinIchi Esumi,[5] Yicheng Feng,[6] Evan Finch,[7] Yu Hu,[1,4] Jiangyong Jia,[4,8] Jerome Lauret,[4] Wei Li,[9] Jinfeng Liao,[10] Yufu Lin,[11] Mike Lisa,[12] Takafumi Niida,[5] Robert Lanny Ray,[13] Masha Sergeeva,[14] Diyu Shen,[15,16] Shuzhe Shi,[17] Paul Sorensen,[4] Aihong Tang,[4] Prithwish Tribedy,[4] Gene Van Buren,[4] Sergei Voloshin,[18] Fuqiang Wang,[6] Gang Wang,[14] Haojie Xu,[19] Zhiwan Xu,[14] Nanxi Yao,[14] and Jie Zhao[6]



Comment on "A sensitivity study of the primary correlators used to characterize chiral-magnetically-driven charge separation" by Magdy, Nie, Ma, and Lacey

Yicheng Feng,[1] Fuqiang Wang,[1,*] and Jie Zhao[1] arXiv:2009.10057

[1] *Department of Physics and Astronomy, Purdue University, West Lafayette, IN 47907, USA*
(Dated: September 22, 2020)

This note points out an apparent error in the publication Phys. Lett. B **809** (2020) 135771 by Magdy, Nie, Ma, and Lacey.

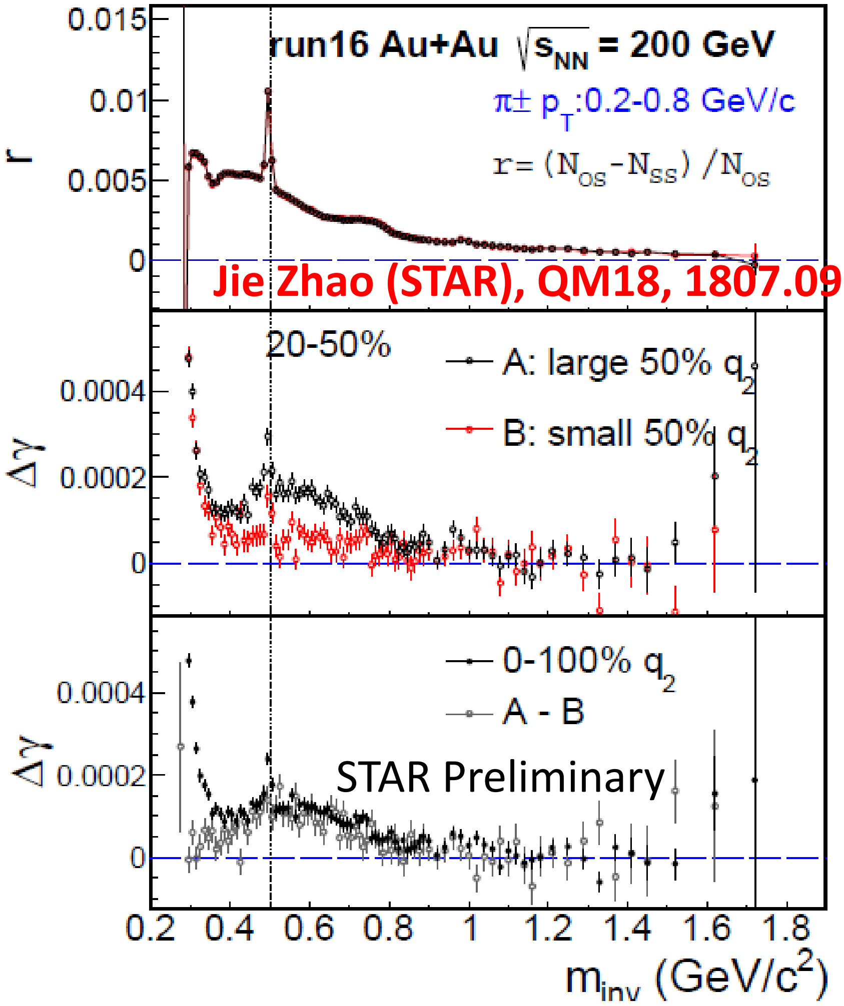
In conclusion, there is an apparent error in the statis-
tical uncertainties in "A sensitivity study of the primary
correlators used to characterize
driven charge separation" by Magdy,
published in Phys. Lett. B 809 (2
was pointed out by us to Magdy
the authors, at an internal STAR
preprint version (arXiv:2002.07934v
cation appeared, and also later wh
(arXiv:2006.04132v2) using the sa
posted. The apparent error was no
data points published in MNML are
the arXiv preprints. Tracing this error reveals that the
AMPT data points in MNML are statistically unnatural.

$$f = r - 1$$

$$\frac{\delta f}{f} = \frac{\delta r}{r}$$

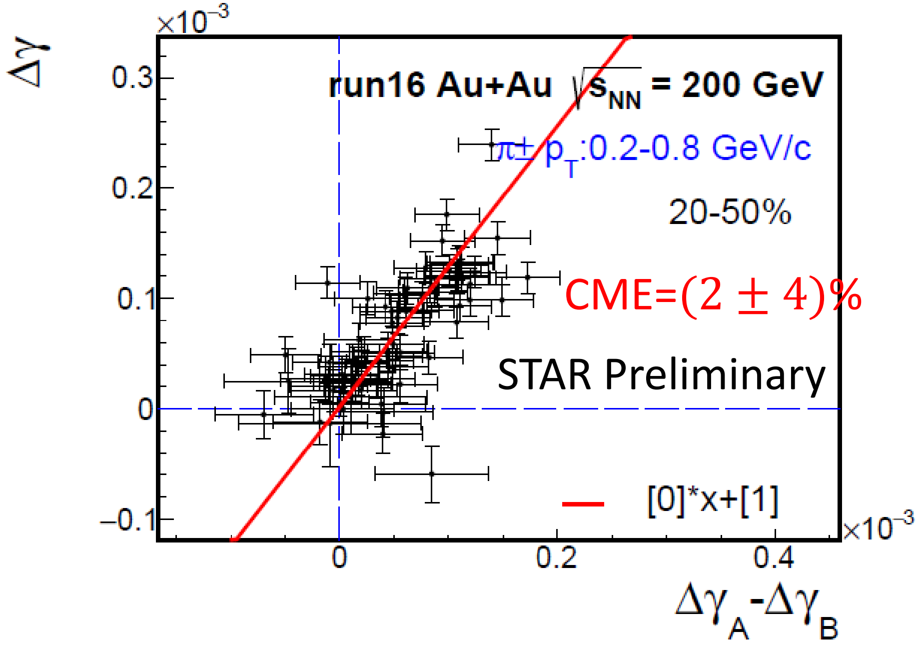
Indulge into the resonance region

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



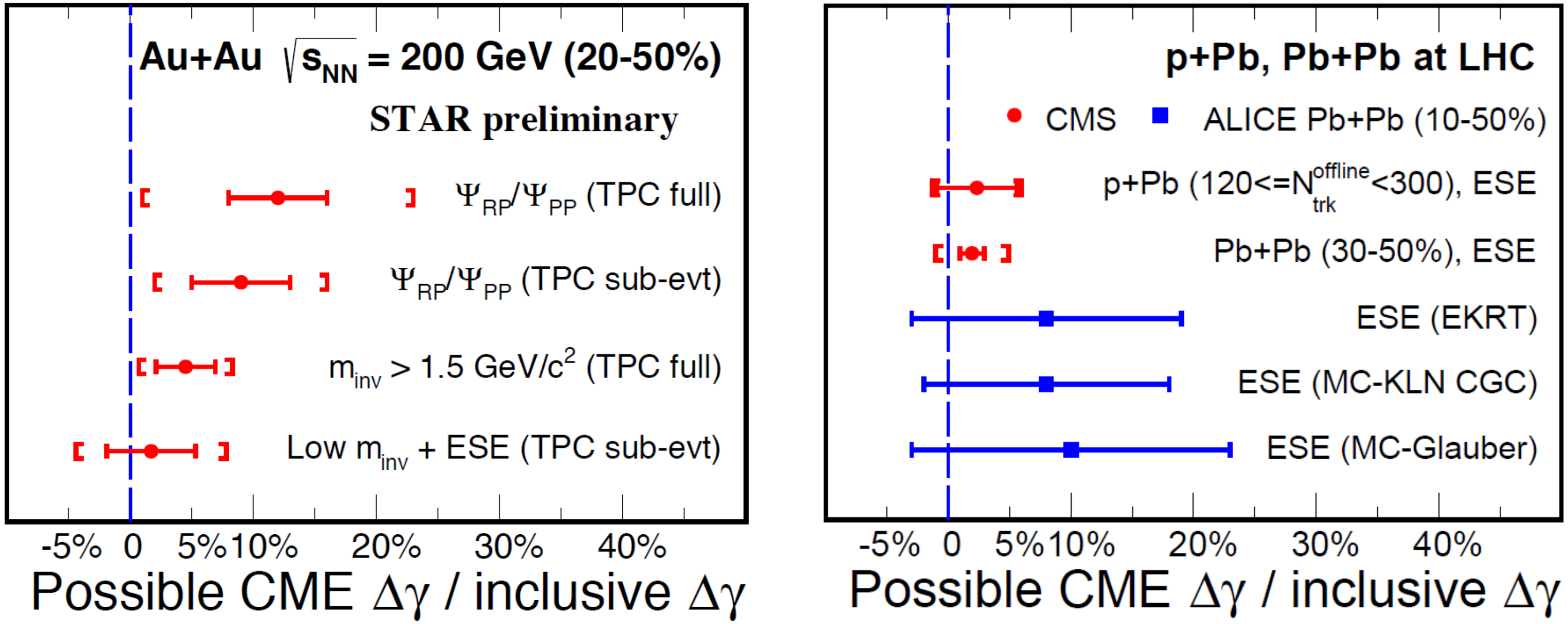
Jie Zhao (STAR), QM18, 1807.09925

- 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*(Bkg shape) + CME
- **Fit does not assume $\Delta\gamma \propto v_2$; works as long as it is dependent of v_2**
- Fit assumes constant CME. Fit χ^2/ndf tells whether it's a good assumption



Summary of Possible CME Signal

Jie Zhao (STAR) Quark Matter 2018,arXiv:1807.09925

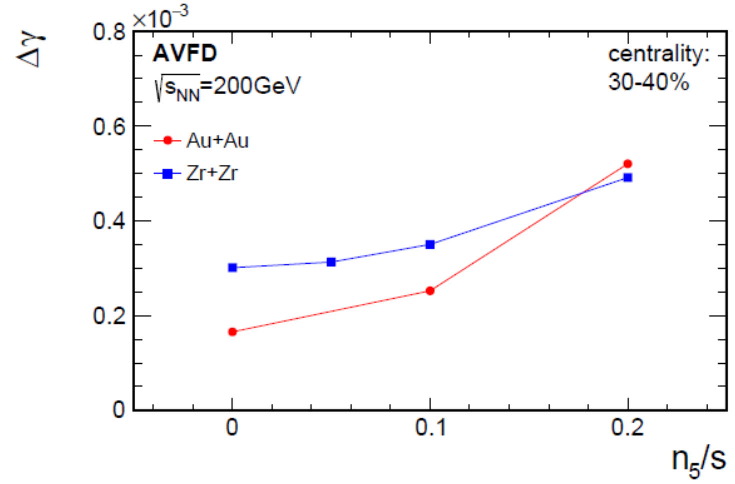


- **Major physics backgrounds**
- **Possible CME signal ~ a few %, 1-2σ from zero.**

AVFD

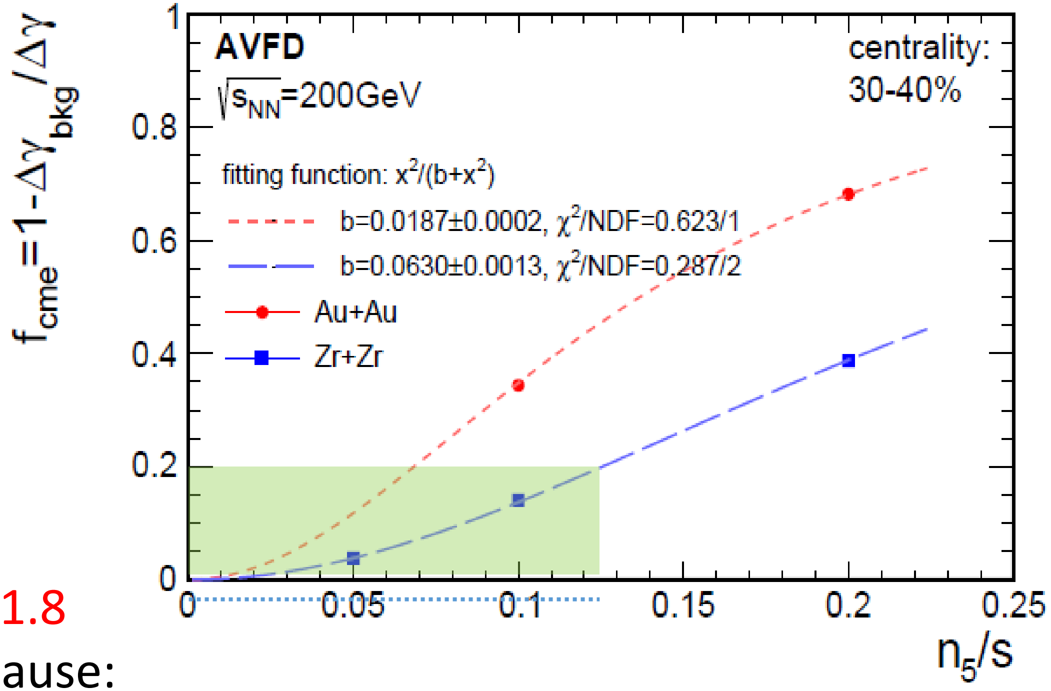
Yicheng Feng, Yufu Lin, et al., arXiv:2103.10378

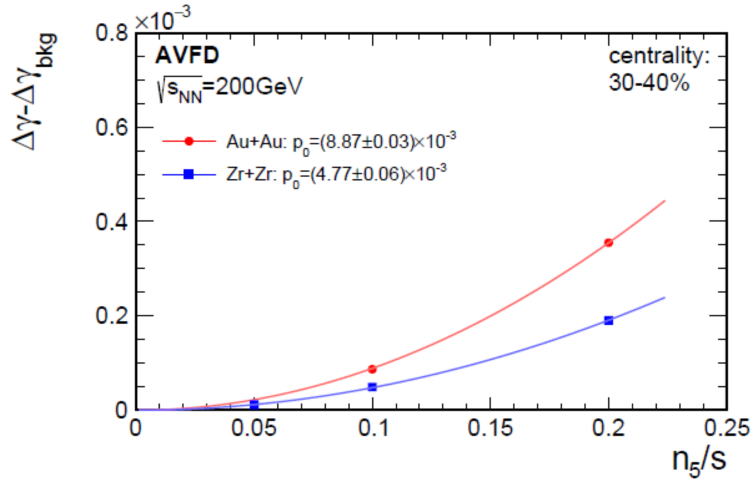
Results from Yufu and Yicheng.
Each has run both AuAu and Isobar, and results are consistent.



Background ∝ 1/N

ZrZr/AuAu ~ A_{Au}/A_{Zr} ~ 2





CME signal: AuAu/ZrZr ~ 1.8

This may make sense because:

$B \sim A^{1/3}$; $\Delta\gamma_{CME} \sim B^2 \sim A^{2/3}$

AuAu/ZrZr ~ $2^{2/3}$ ~ 1.5

Final-state effect may alter it