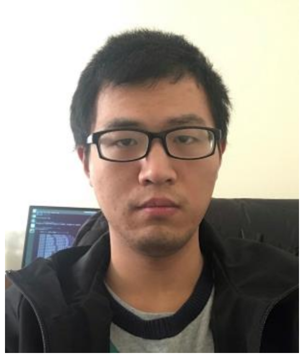
Experimental Status of the Chiral Magnetic Effect

Jie Zhao



Yicheng Feng

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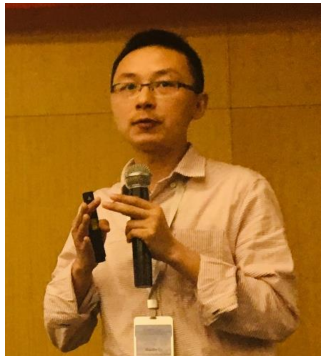


Hanlin Li

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 (arXiv:2106.15595)
- 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

$$= \frac{1}{2}\left(E^2_\alpha - B^2_\alpha\right)$$

gluons

't Hooft vacuum

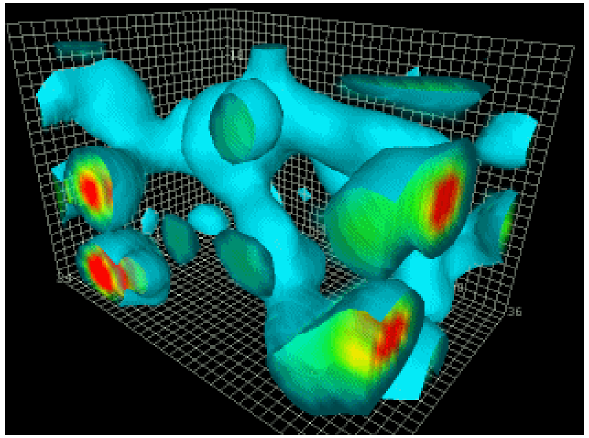
$$+\theta \frac{\alpha_s}{8\pi} G^\alpha_{\mu\nu} \tilde{G}^{\mu\nu}_\alpha = -\theta \frac{\alpha_s}{2\pi} \vec{E}_\alpha \cdot \vec{B}_\alpha$$

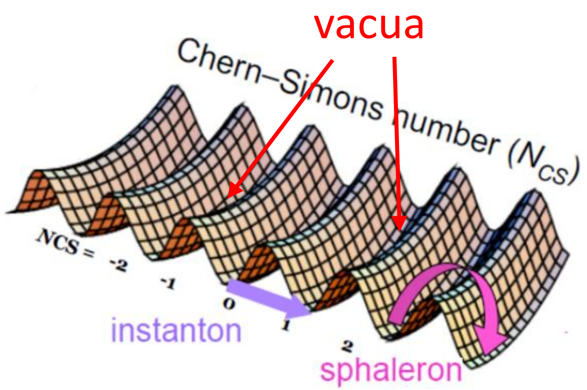
to solve the $U(1)_A$ problem (1976)

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

Explicitly breaks CP

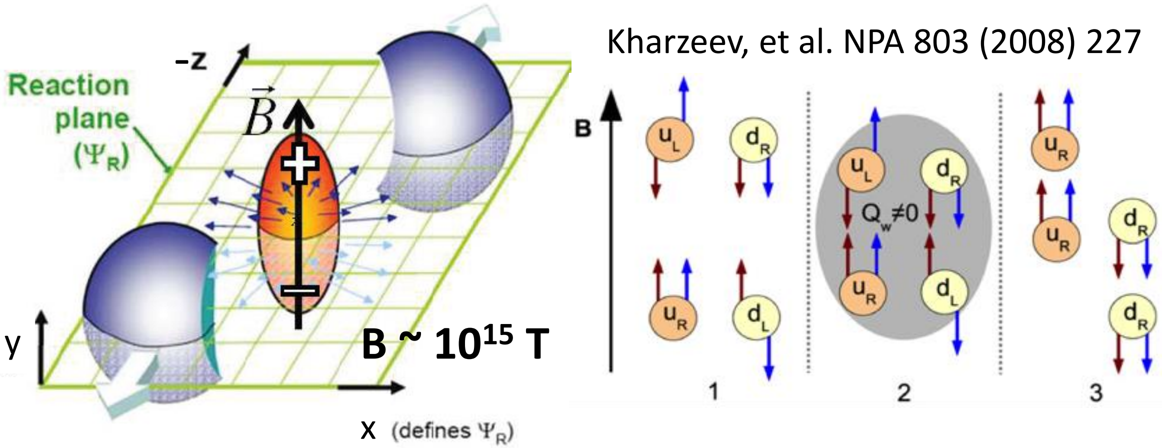
Early universe ultraviolet $\theta \approx 1$?? >> current infrared $\theta \approx 0$





Kharzeev,Pisarski,Tytgat,PRL81(1998)512

QCD vacuum fluctuation, chiral anomaly, topological gluon field



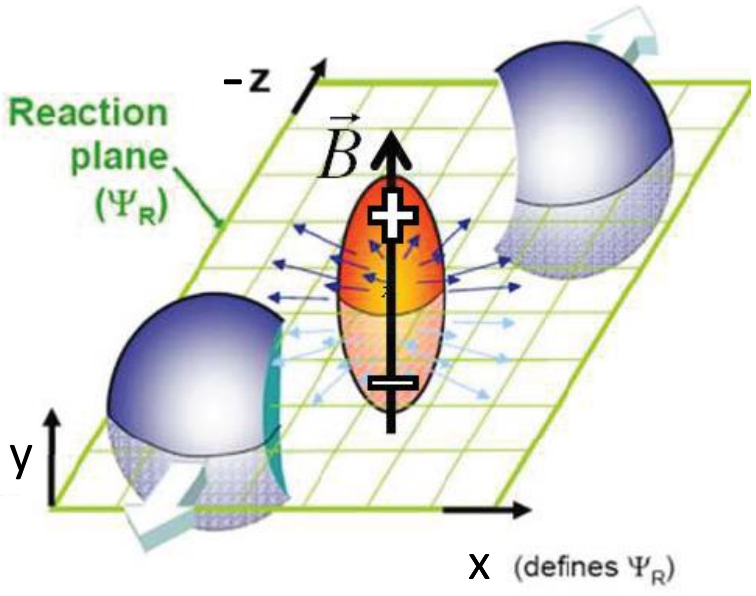
Kharzeev, et al. NPA 803 (2008) 227

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)

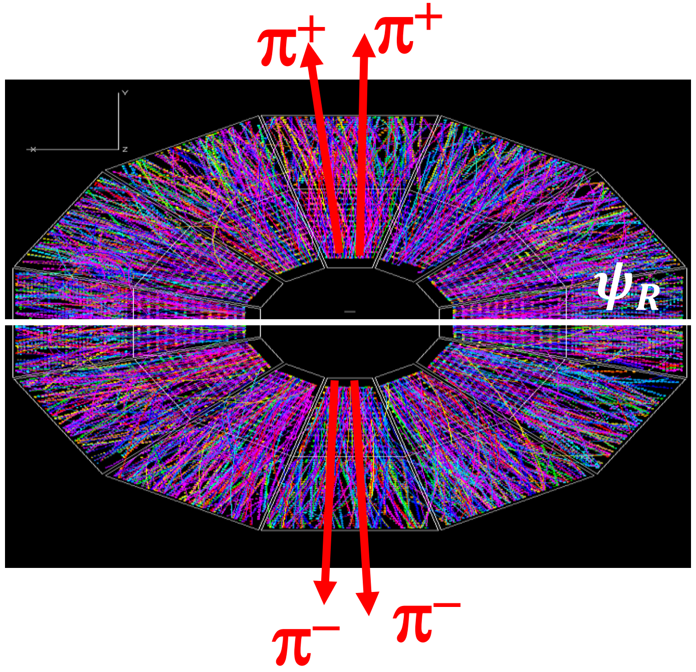
THE COMMON γ VARIABLE

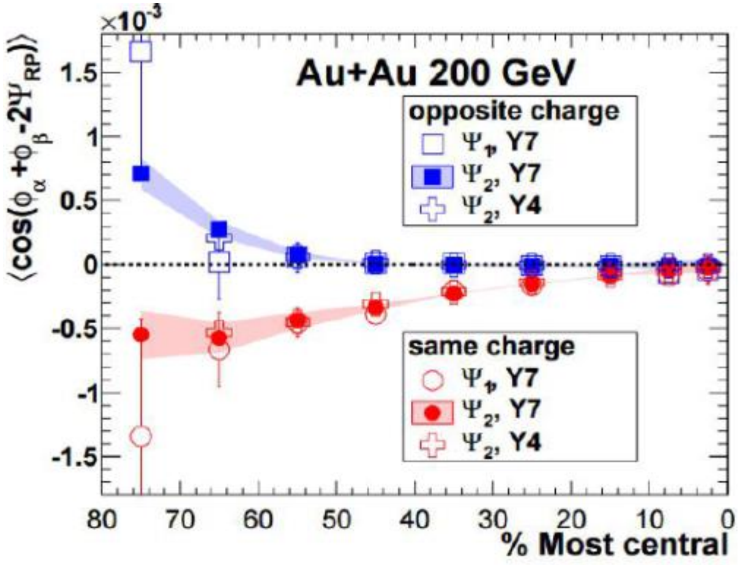
Voloshin, PRC 70 (2004) 057901



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

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

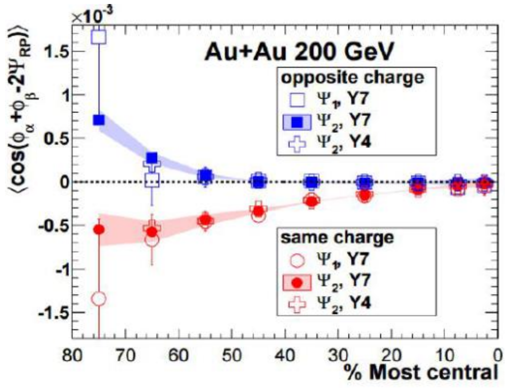




STAR'09,'10; STAR, PRC 88 (2013) 064911

BACKGROUNDS IN γ CORRELATORS

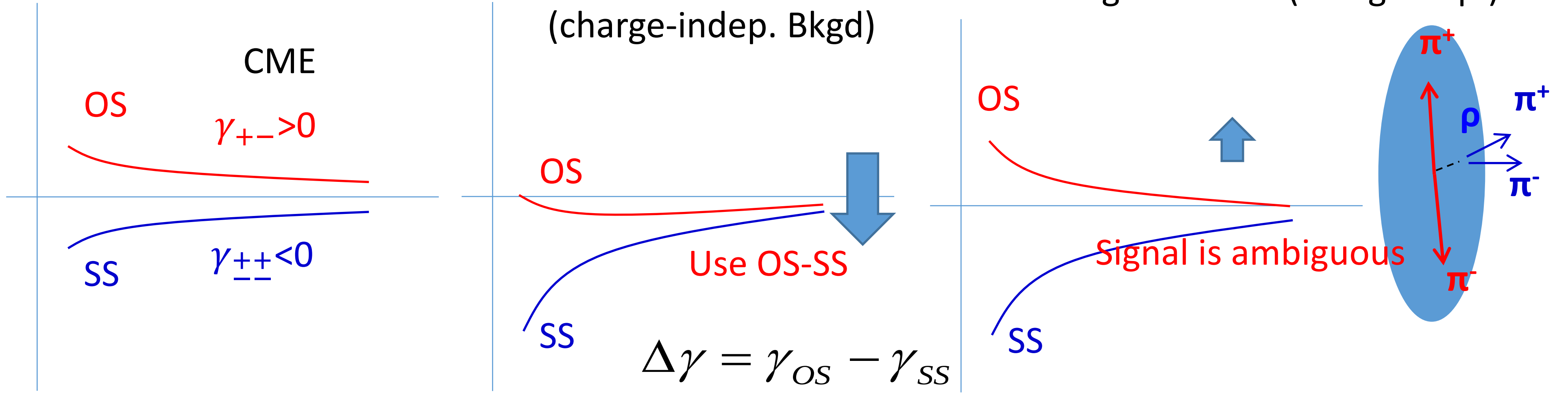
Voloshin 2004; FW 2009; Bzdak, Koch, Liao 2010; Pratt, Schlichting 2010; …



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

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

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



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

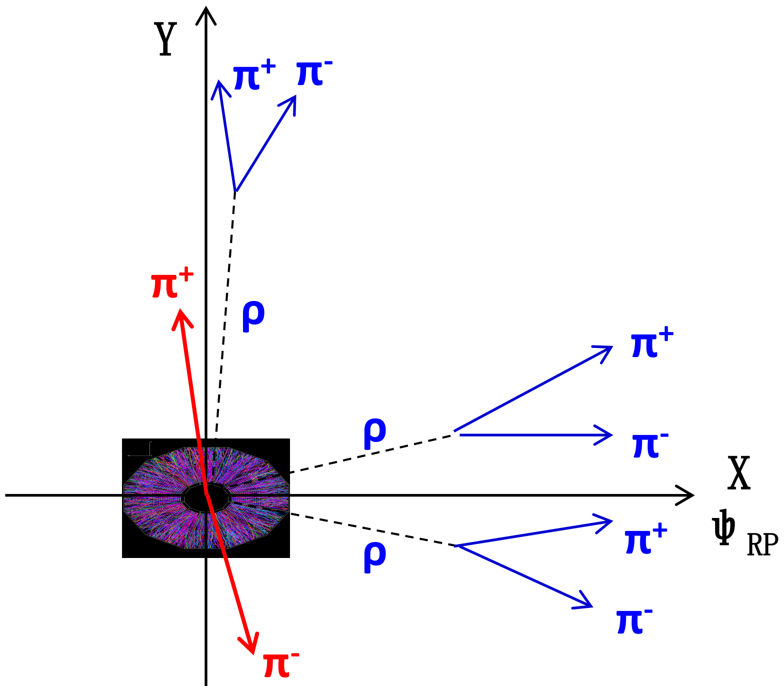
$$\gamma_{\alpha\beta} = \left[\underbrace{\left\langle \cos(\varphi_\alpha - \psi_{RP}) \cos(\varphi_\beta - \psi_{RP}) \right\rangle}_{\langle v_{1,\alpha} v_{1,\beta} \rangle \approx 0} - \underbrace{\left\langle \sin(\varphi_\alpha - \psi_{RP}) \sin(\varphi_\beta - \psi_{RP}) \right\rangle}_{\text{CME: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

BACKGROUND IN Δγ CORRELATOR

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

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

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



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

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

$$\propto v_2 / N$$

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

Initial idea re HIC
Kharzeev et al.
End of the 1990's

→

Slow momentum building, the first decade of 2000's

→

First measurement
STAR (and ALICE)
~2010, beginning of the decade

→

Vigorous interests
Ups and downs
The decade 2010's

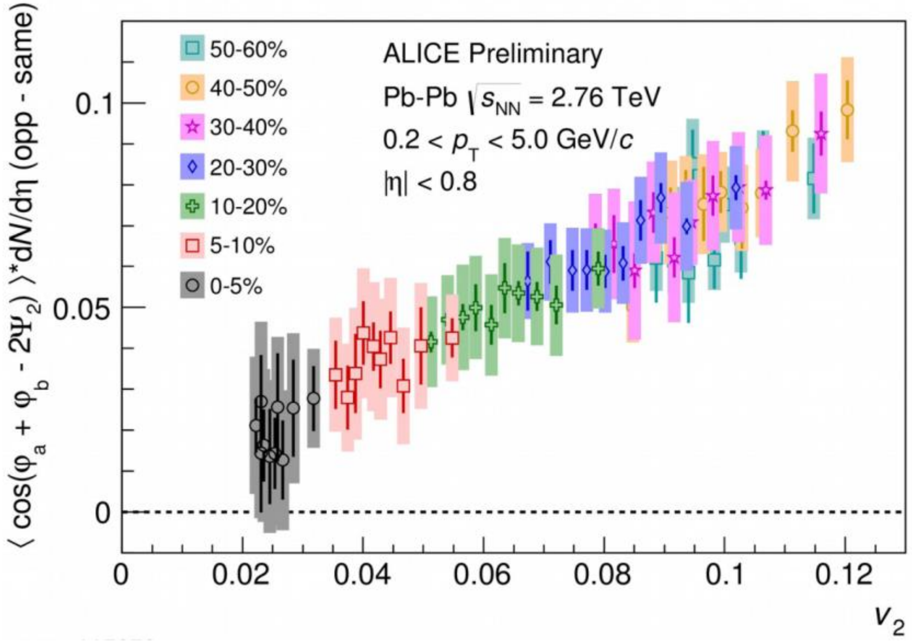
→

Small system results
CMS (and STAR)
Revived interests, isobars, toward end of the decade 2010's

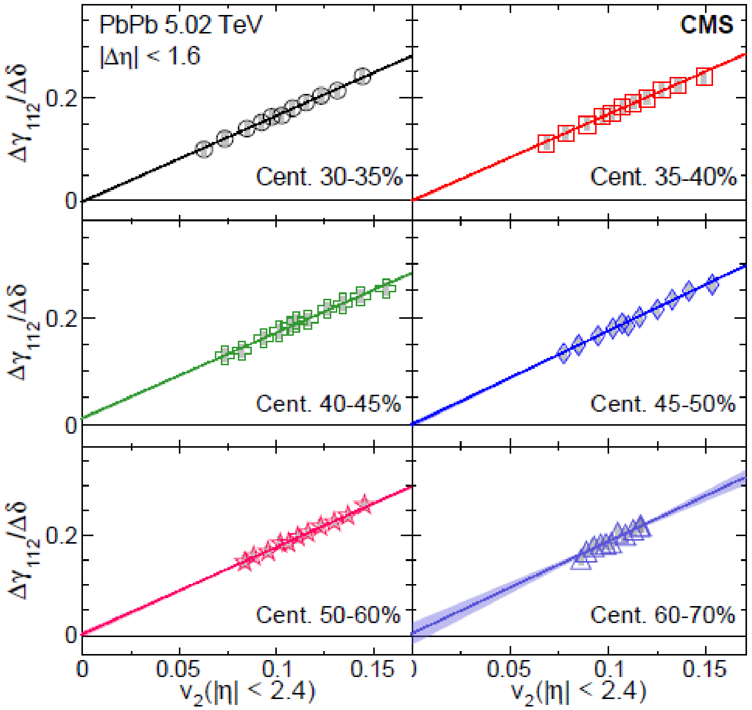
EVENT-SHAPE ENGINEERING METHOD

Schukraft,Timmins,Voloshin, PLB719 (2013) 394

ALICE PLB777(2018)151



CMS PRC97(2018)044912



<u>Pb+Pb upper limits at 95% CL:</u>

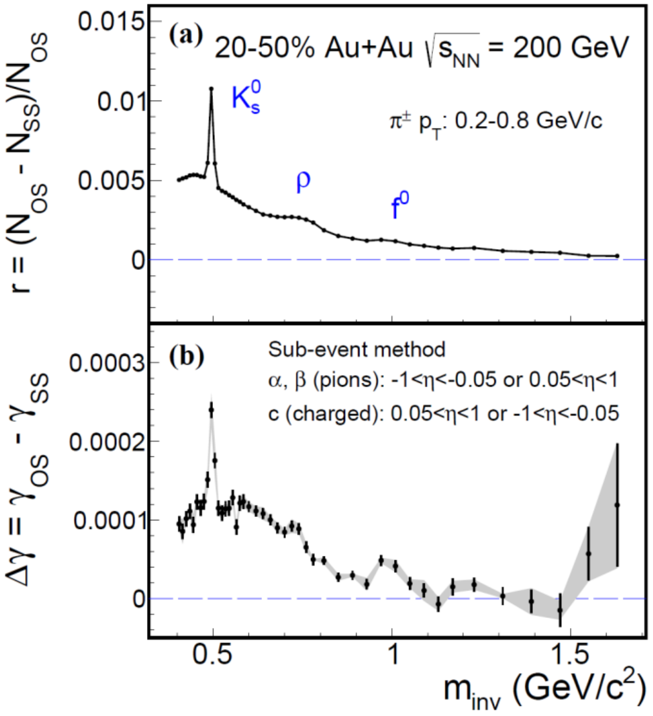
ALICE: 26% (10-50%, MC-KLN CGC)
CMS: 7% (MB)

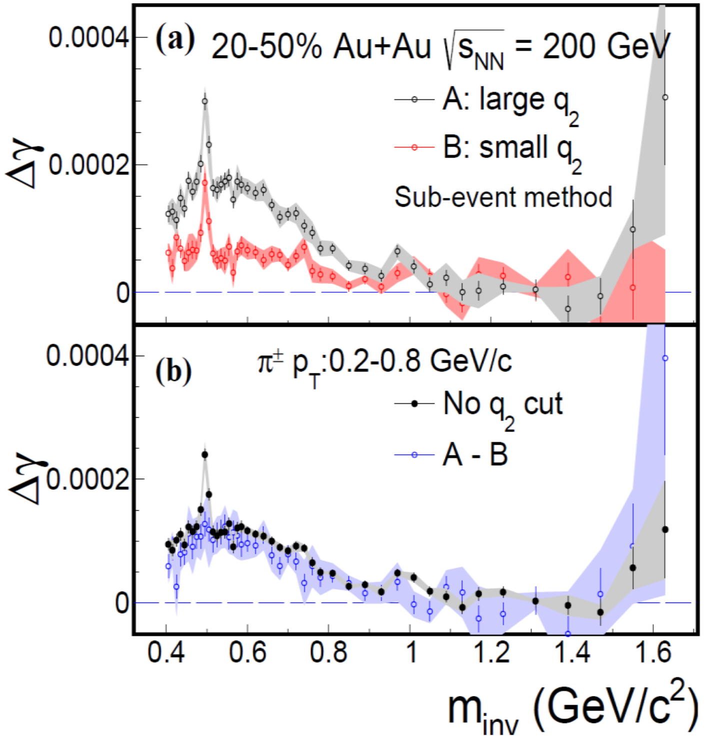
THE INVARIANT MASS METHOD

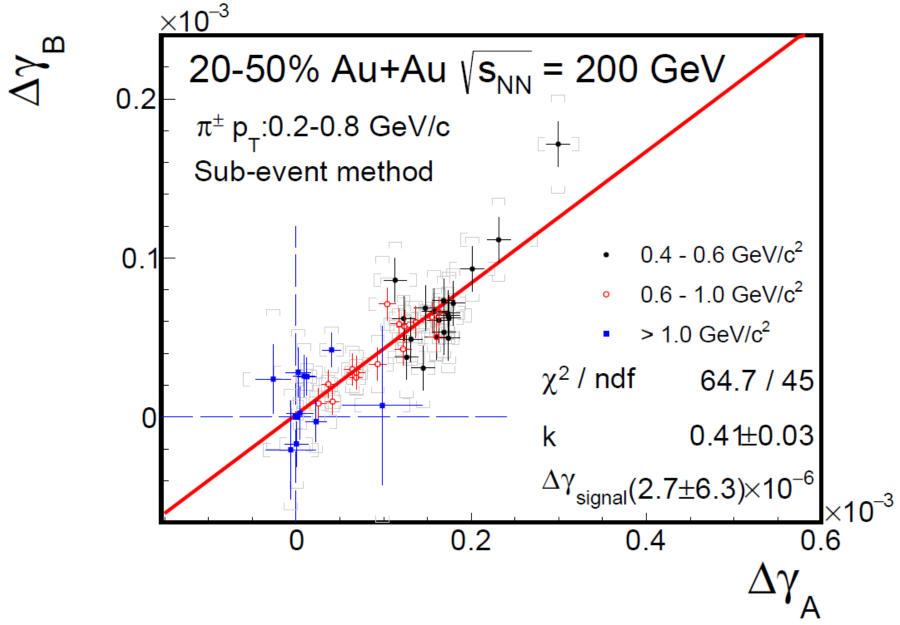
Zhao, Li, Wang, Eur.Phys.J.C 79 (2019) 2, 168

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

STAR, arXiv:2006.05035







CME fraction = $(2 \pm 4 \pm 5)\%$
CME upper limit 15% at 95% CL

THE R-VARIABLE

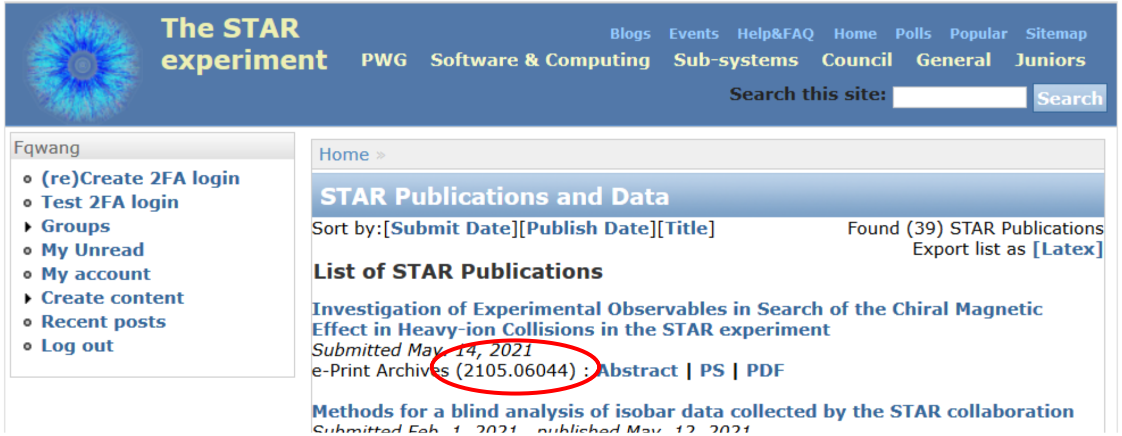
Ajitanand, Lacey, et al., PRC **83** (2011) 011901
Magdy, Lacey, et al., PRC **97** (2018) 061901(R)

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

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

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

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



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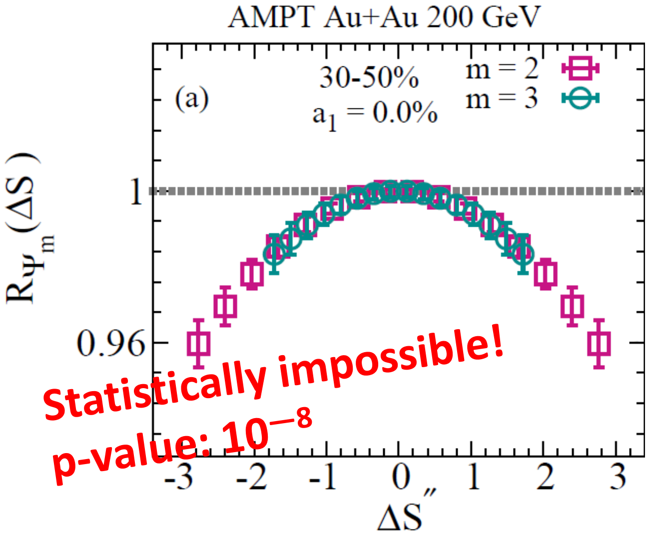
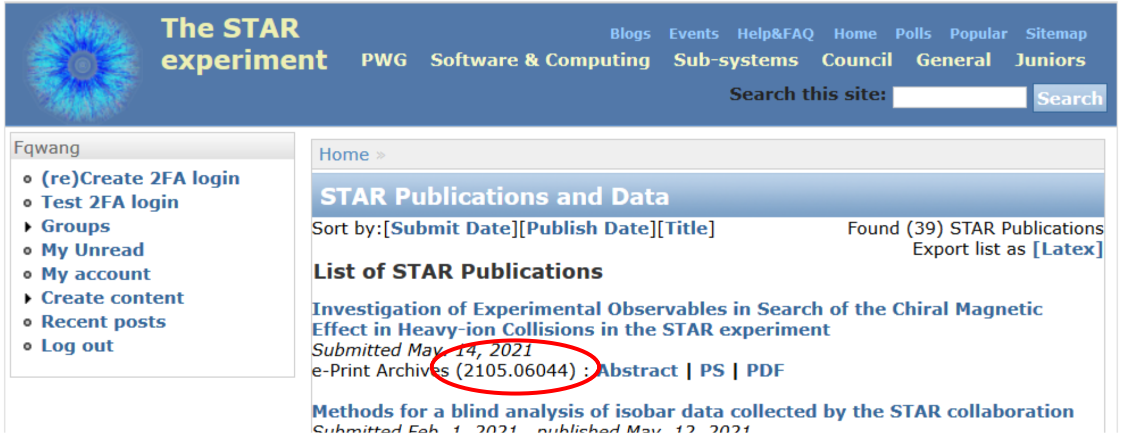
Charge separation measurements in $p(d)$+Au and Au+Au collisions; implications for the chiral magnetic effect

(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].





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

Cornell University

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 2nd-order (Ψ_2) and 3rd-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)

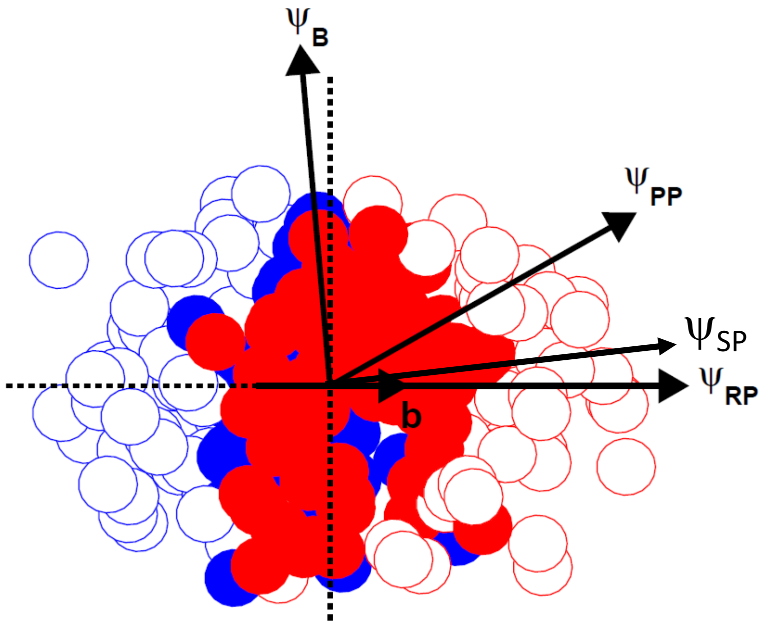
Submission history
From: Roy Lacey [view email]
[v1] Sun, 7 Jun 2020 20:20:31 UTC (44 KB)
[v2] Mon, 17 May 2021 17:13:58 UTC (0 KB)

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

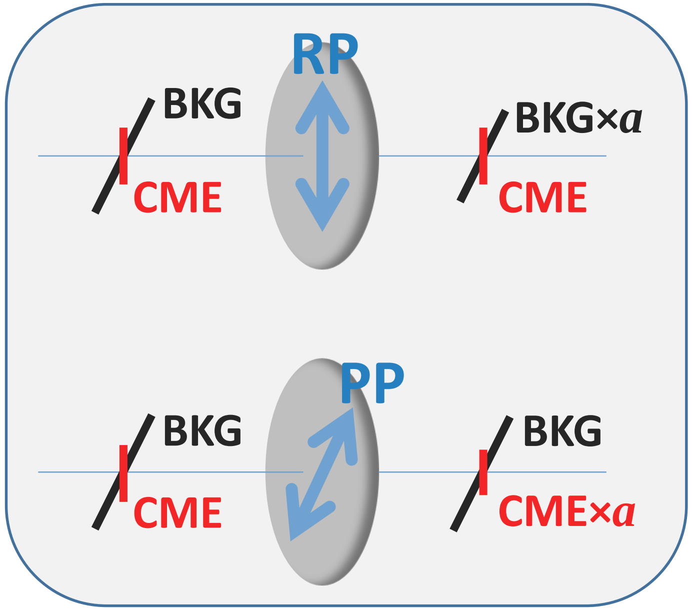
E experts
milar.

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

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

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

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

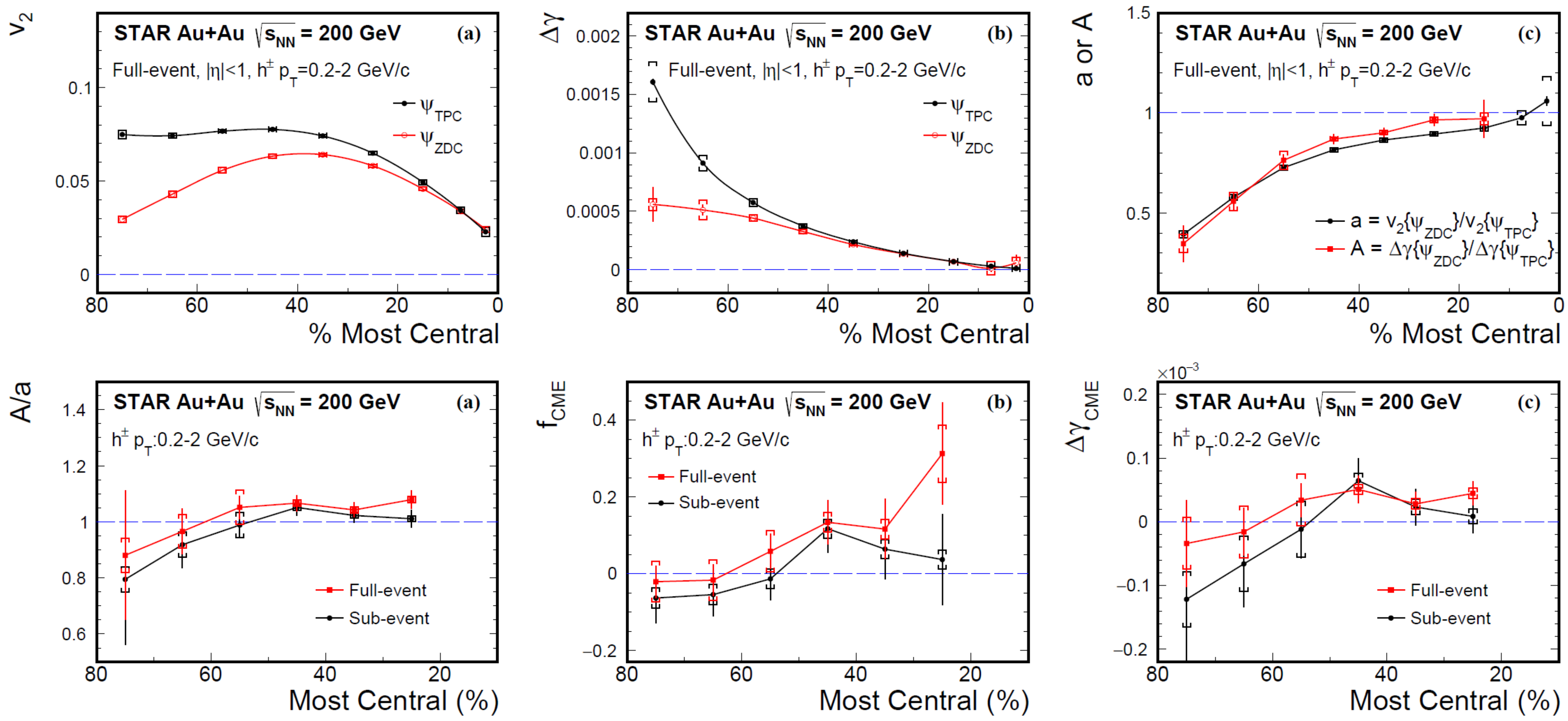
$$\Delta\gamma\{\mathrm{PP}\} = \Delta\gamma_{Bkg}\{\mathrm{PP}\} + \Delta\gamma_{CME}\{\mathrm{PP}\}$$

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

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

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

STAR, arXiv:2106.09243



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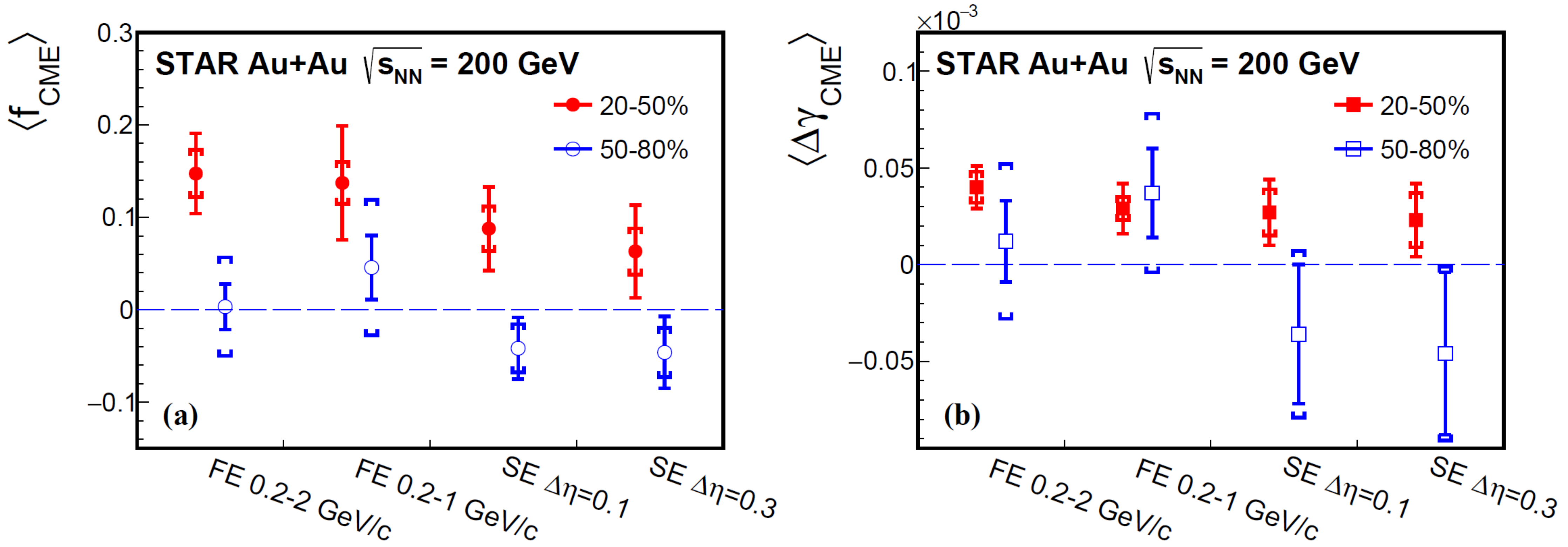


- Consistent-with-zero signal in peripheral 50-80% collisions with relatively large errors
- Indications of finite signal in mid-central 20-50% collisions, with 1-3σ significance
- Possible remaining nonflow effects

REMAINING NONFLOW EFFECTS

Feng et al., arXiv:2106.15595

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

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

Nonflow in $\Delta\gamma$
→ negative $f_{\rm CME}$

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

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

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

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

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

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

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

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

Nonflow in v_2
→ positive $f_{\rm CME}$

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

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

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

Feng et al., arXiv:2106.15595

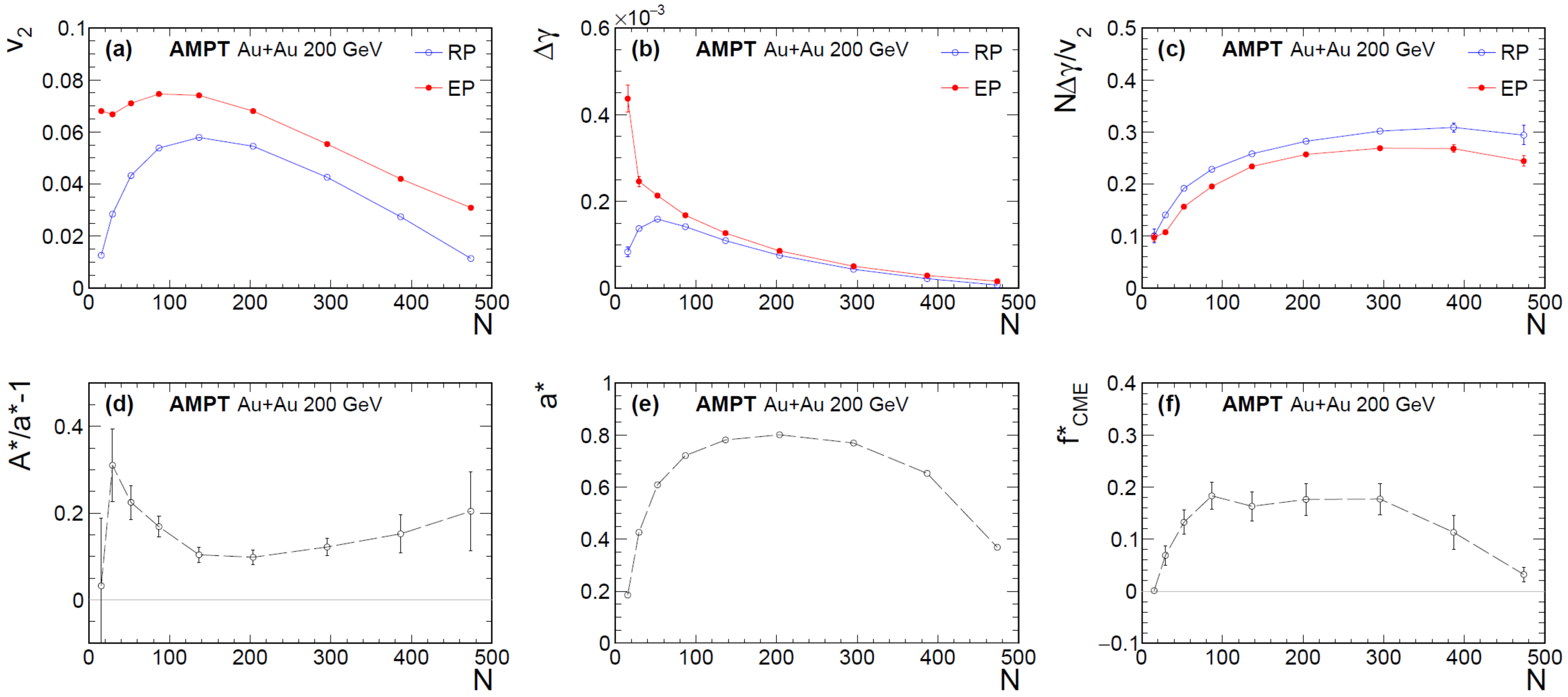


FIG. 1. AMPT simulation results as functions of $N = (N_+ + N_-)/2$, the POI single-charge multiplicity, in 200 GeV Au+Au collisions: (a) elliptic flow v_2, (b) charge-dependent 3p correlator $\Delta\gamma$, (c) $N\Delta\gamma/v_2$ w.r.t. RP and EP (the former is referred to as $\epsilon_2^{\rm AMPT}$, 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

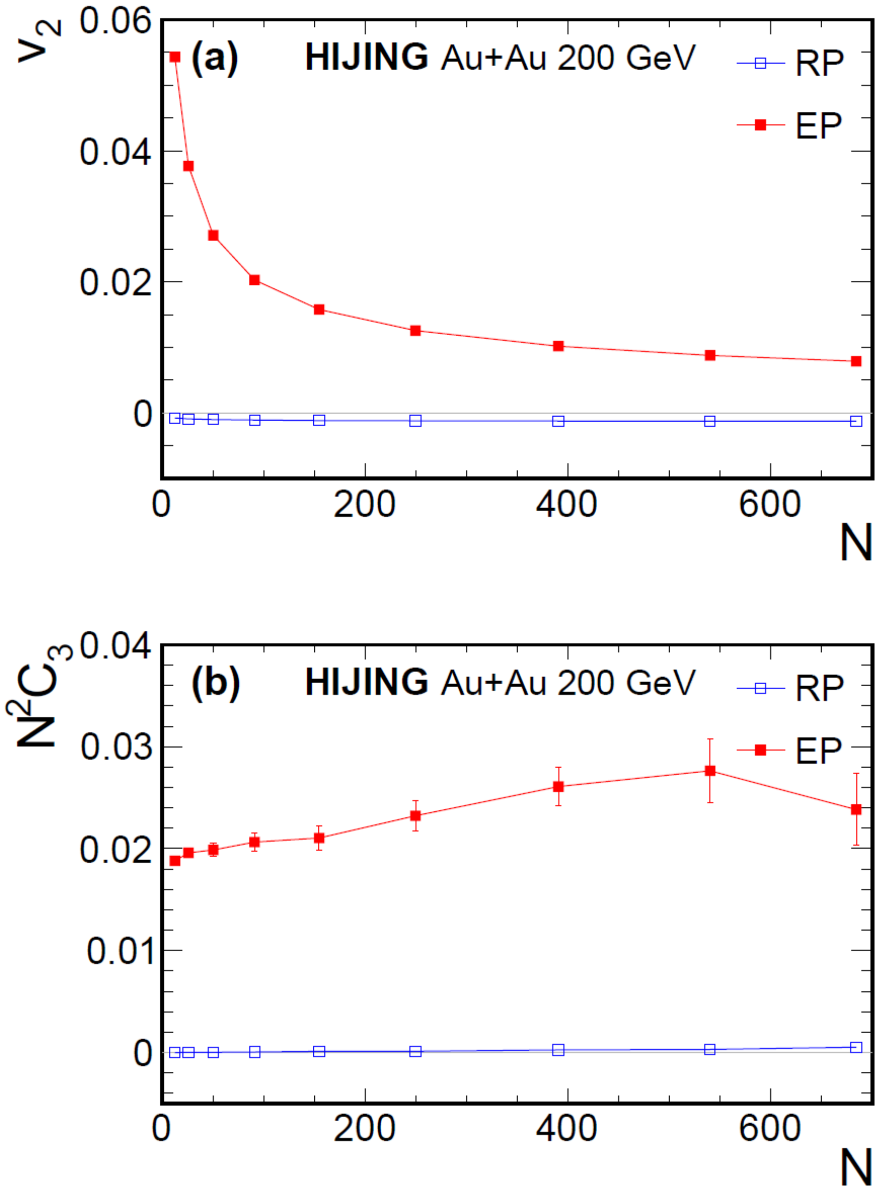
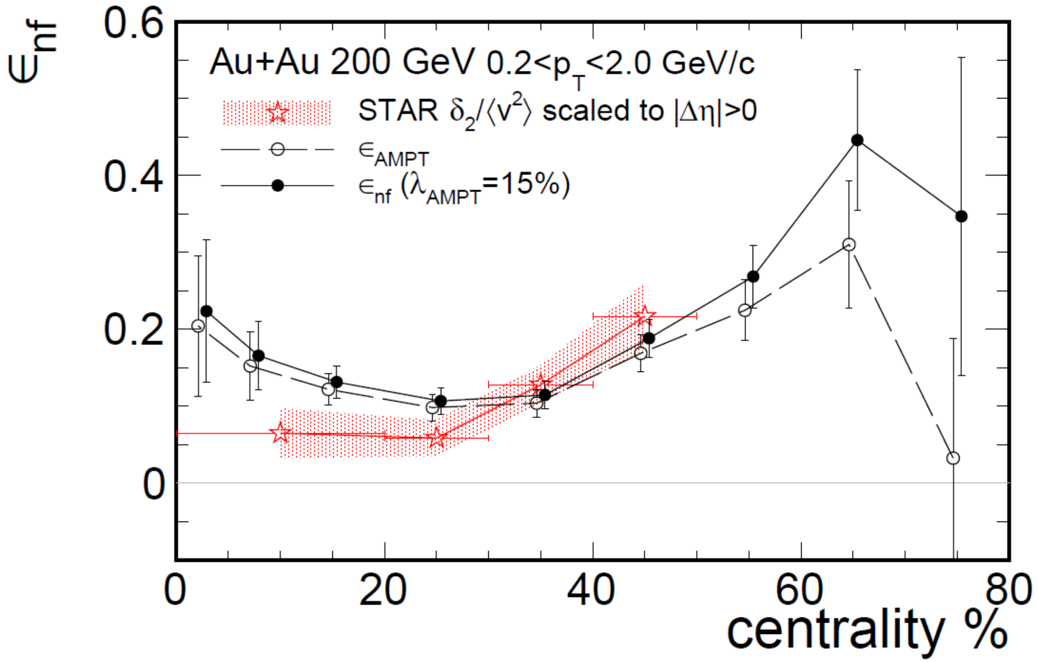


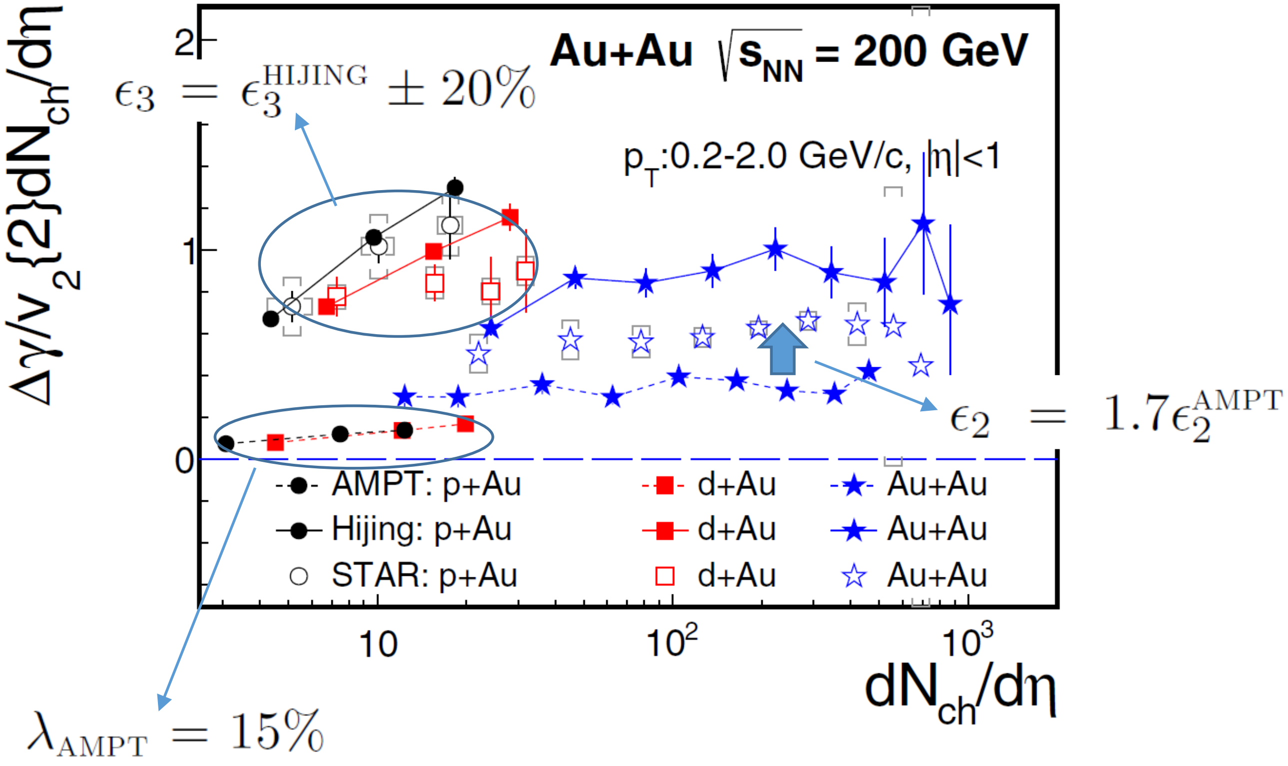
FIG. 2. HIJING simulation results as functions of $N = (N_+ + N_-)/2$, the POI single-charge multiplicity, in 200 GeV Au+Au collisions: (a) elliptic anisotropy v_2, and (b) charge-dependent 3p correlator N^2C_3 w.r.t. RP and EP (the latter is referred to as $\epsilon_3 = \epsilon_3^{\text{HIJING}}$, 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



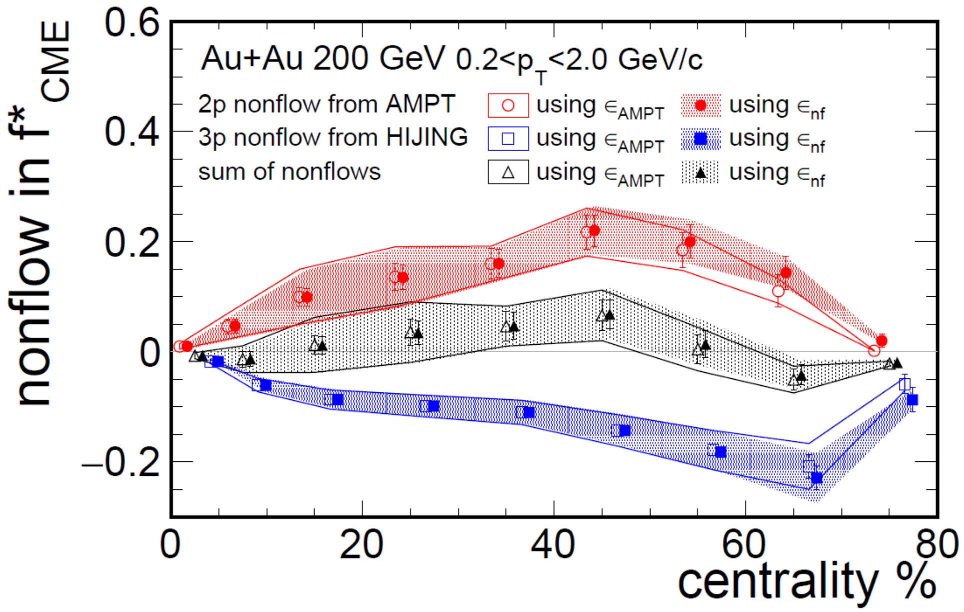
STAR, PLB 745 (2015) 40

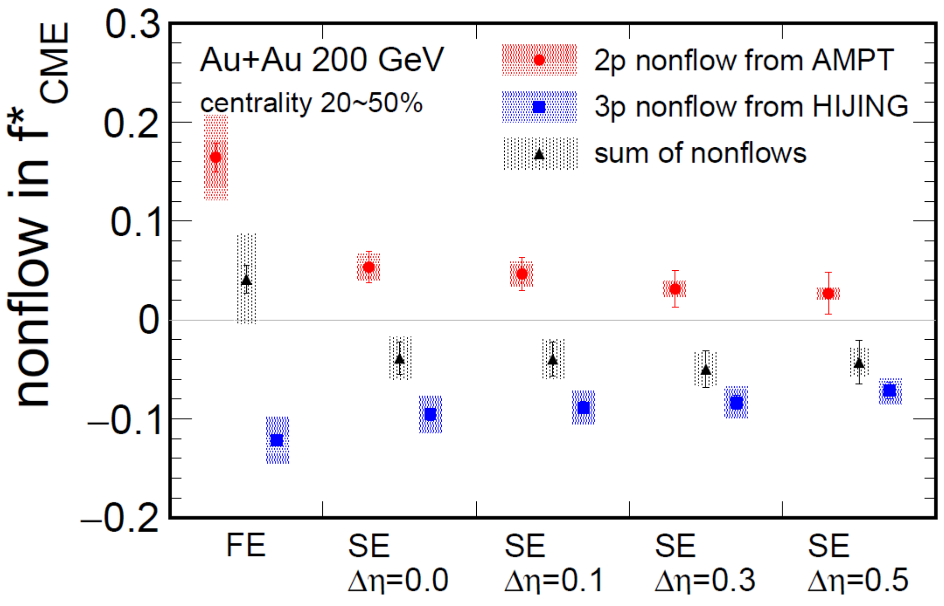
Zhao, Feng, et al. PRC **101**, 034912 (2020)

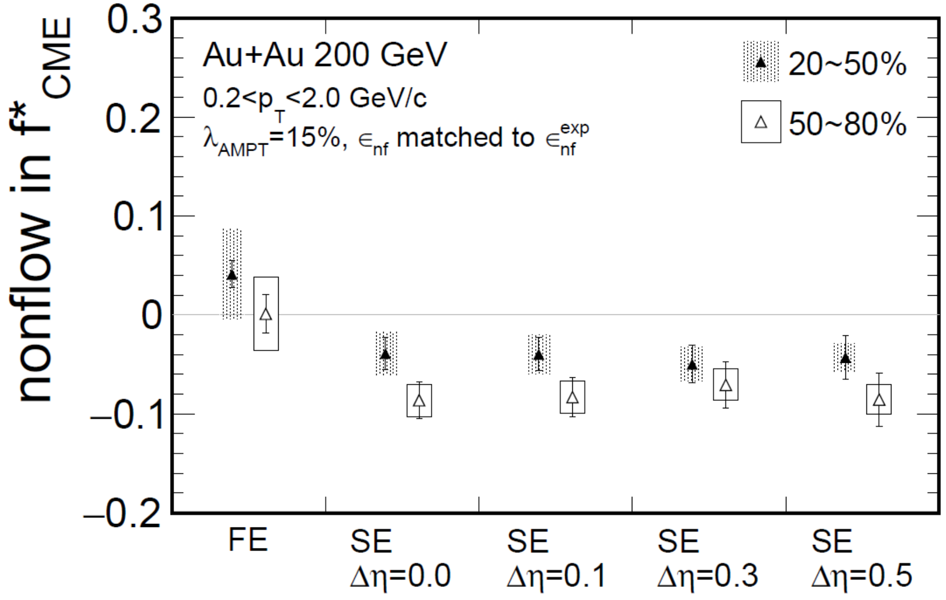


MODEL ESTIMATES

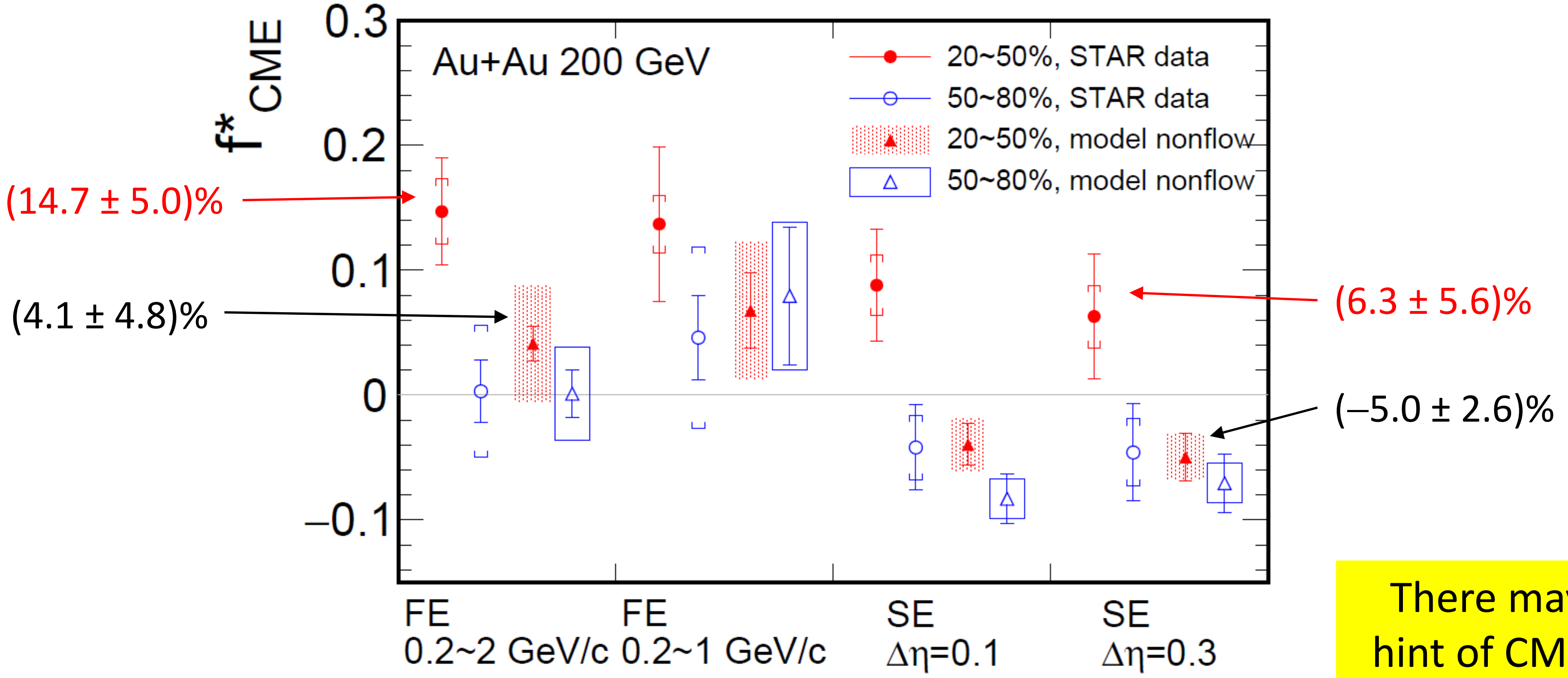
Feng et al., arXiv:2106.15595







IMPLICATIONS TO DATA



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	$(14.7 \pm 4.3 \pm 2.6)\%$	$(13.7 \pm 6.2 \pm 2.3)\%$	$(8.8 \pm 4.5 \pm 2.4)\%$	$(6.3 \pm 5.0 \pm 2.5)\%$
$\epsilon_{\rm nf}$ matched to $\epsilon^{\rm exp}_{\rm nf}$, $\lambda_{\rm AMPT} = 15\%$	$(4.1 \pm 1.4 \pm 4.6)\%$	$(6.8 \pm 3.0 \pm 5.5)\%$	$(-4.0 \pm 1.7 \pm 2.1)\%$	$(-5.0 \pm 1.9 \pm 1.8)\%$

SP/PP VS. ISOBAR: PROS & CONS

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

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

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

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

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

Isobar conclusion will need detailed nonflow studies

ISOBAR EXPECTATION

Yicheng Feng, Yufu Lin, et al.,
PLB 820 (2021) 136549, arXiv:2103.10378

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

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

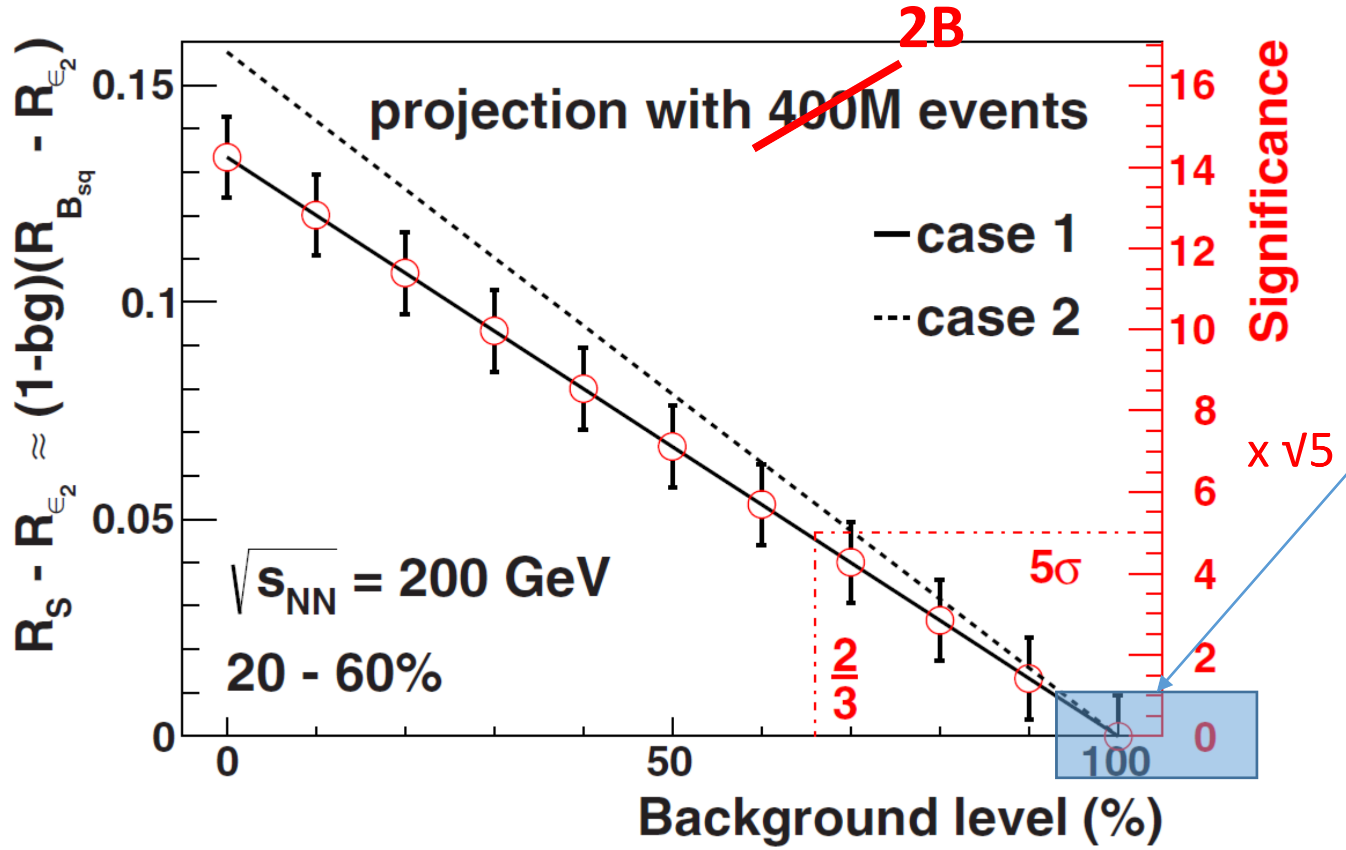
x3 reduction!

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

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

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

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



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

Yicheng Feng, Yufu Lin, et al.,
PLB 820 (2021) 136549, arXiv:2103.10378

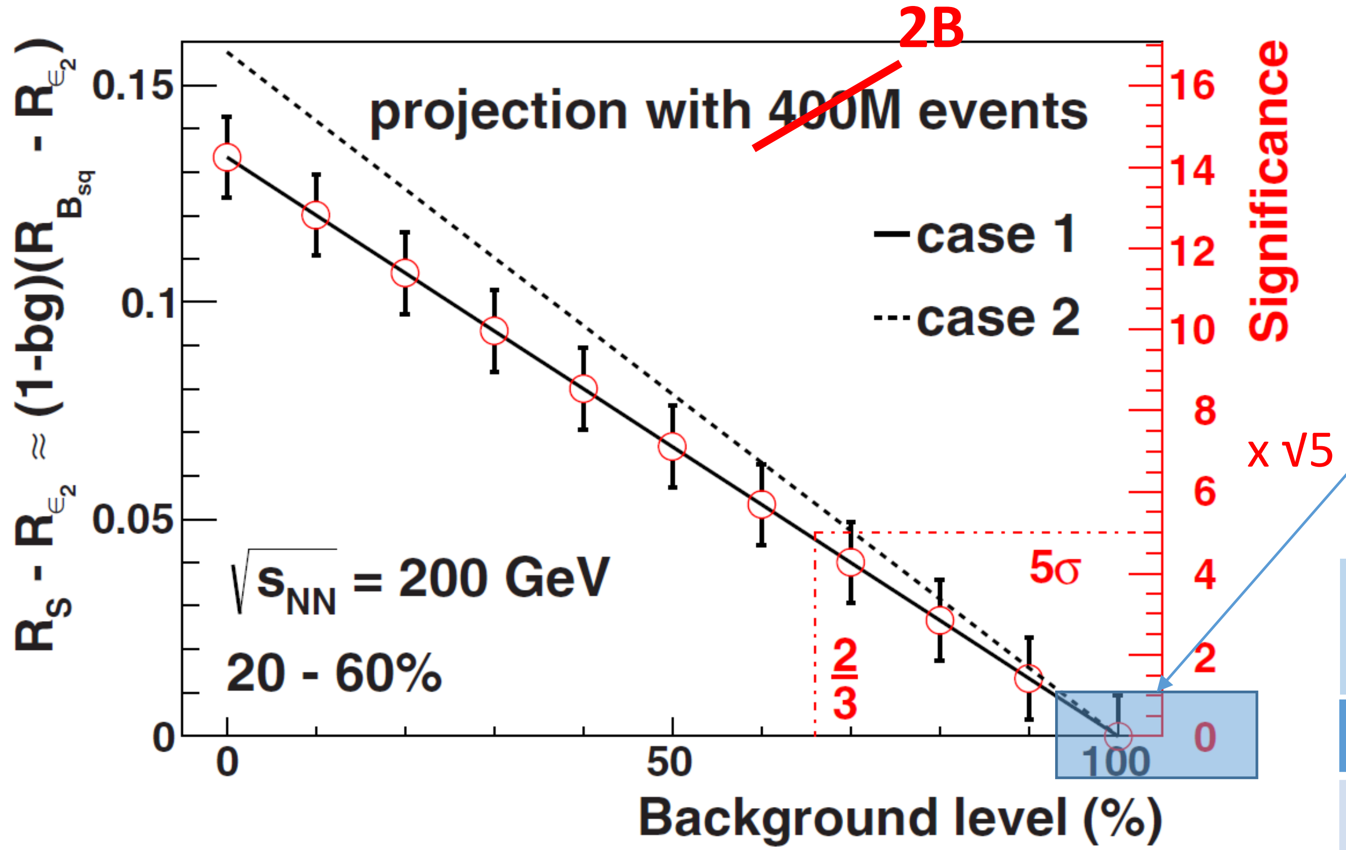
Background $\propto 1/N$
isobar/AuAu ~ 2

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

x3 reduction!

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

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



AVFD-glasma μ_5/s: isobar/AuAu ~ 1.5
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If AuAu f_{CME}=10%, then isobar 7% (2σ effect)

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

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 (2.4 B MB Au+Au) yield ~5% statistical uncertainties
  Expect 20 B 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.

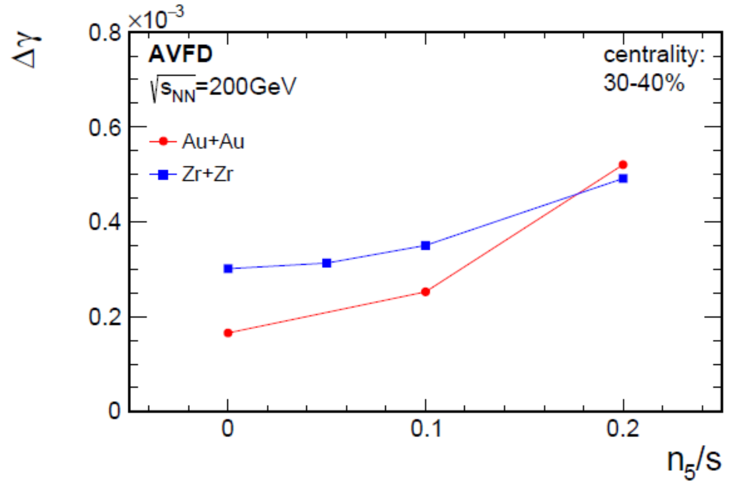
SUMMARY

- CME is a very important physics
- Backgrounds dominate in inclusive $\Delta\gamma$;
  Rigorous treatment of backgrounds is essential.
- 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.

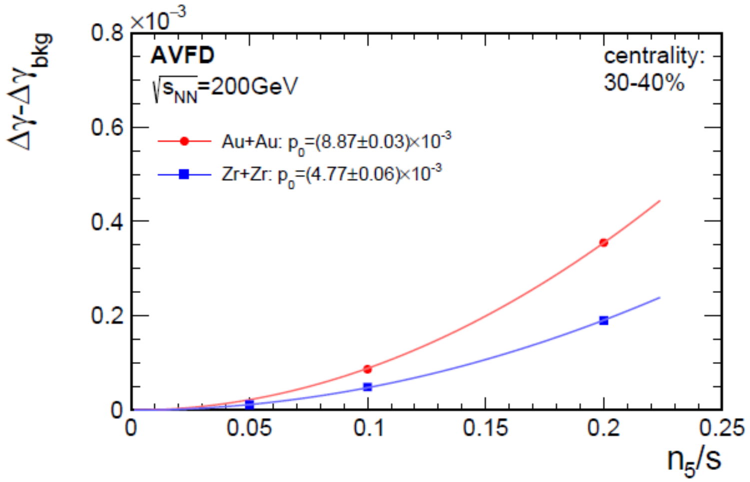
AVFD

Yicheng Feng, Yufu Lin, et al.,
PLB 820 (2021) 136549, arXiv:2103.10378

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



Background $\propto 1/N$
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 effects may alter it