Background Control and Upper Limit on the Chiral Magnetic Effect in Isobar Collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV from STAR

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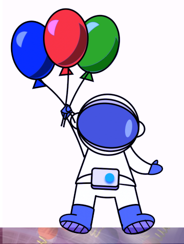

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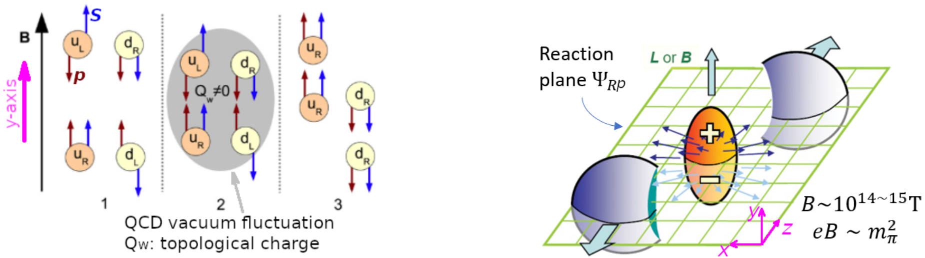
Overview

1. Introduction
2. Forced match of multiplicity and elliptic flow between isobars
3. Background baseline for isobar ratio observable and CME upper limit
4. Summary

The Chiral Magnetic Effect (CME)



CME schematics. [Kharzeev et al., NPA **803**, 227 (2008)]

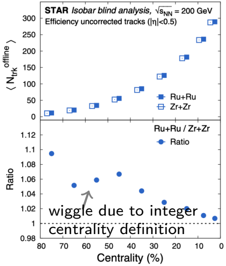
QCD vacuum fluctuation → nonzero topological charge → imbalanced chirality →

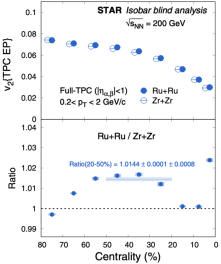
noncentral heavy-ion collisions → magnetic field $\vec{B}$ → opposite spins along $\vec{B}$ for $+/-$ charges →

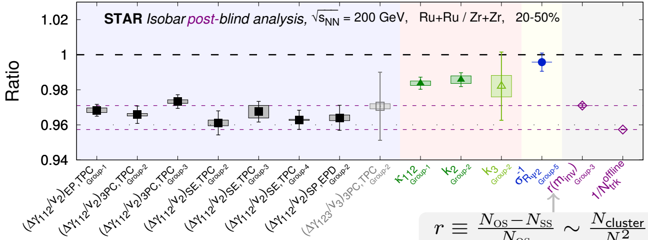
opposite momenta along $\vec{B}$ for $+/-$ charges, charge separation, CME

Motivation

STAR isobar blind analysis [STAR, PRC105(2022)014901] : no predefined signal observed







$$r \equiv \frac{N_{\rm OS} - N_{\rm SS}}{N_{\rm OS}} \sim \frac{N_{\rm cluster}}{N^2}$$

relative pair multiplicity

- $^{96}_{44}$Ru and $^{96}_{40}$Zr collisions differ in N, v_2, due to nuclear structure. [Xu et al., PRL121(2018)022301]
- Isobar blind analysis shows $\frac{(\Delta\gamma/v_2)^{\rm Ru}}{(\Delta\gamma/v_2)^{\rm Zr}}$ below unity, contrary to initial expectation.
- $\frac{(\Delta\gamma/v_2)^{\rm Ru}}{(\Delta\gamma/v_2)^{\rm Zr}}$ is higher than multiplicity scaling $\frac{(1/N)^{\rm Ru}}{(1/N)^{\rm Zr}}$, but lower than pair multiplicity scaling $\frac{r^{\rm Ru}}{r^{\rm Zr}}$.

Forced match method *New*

- Re-weight events according to N, $v_2^{\rm obs}$, EP resolution.
- Mitigate isobar differences

Background baseline study *New*

- Estimate nonflow backgrounds in $\frac{(\Delta\gamma/v_2)^{\rm Ru}}{(\Delta\gamma/v_2)^{\rm Zr}}$
- Set upper limit on CME fraction

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Forced match

Re-weight events of Ru+Ru to match Zr+Zr.

$$\begin{aligned} f_{W,\text{bin}} &= N_{\text{bin}(\mathrm{Zr})}/N_{\text{bin}(\mathrm{Ru})} \\ S_O &= \sum_{\text{bin}} O_{\text{bin}(\mathrm{Ru})} N_{\text{bin}(\mathrm{Ru})} f_{W,\text{bin}} \\ S_W &= \sum_{\text{bin}} N_{\text{bin}(\mathrm{Ru})} f_{W,\text{bin}} \end{aligned}$$

Finally

$$O_{\text{matched}(\mathrm{Ru})} = S_O/S_W$$

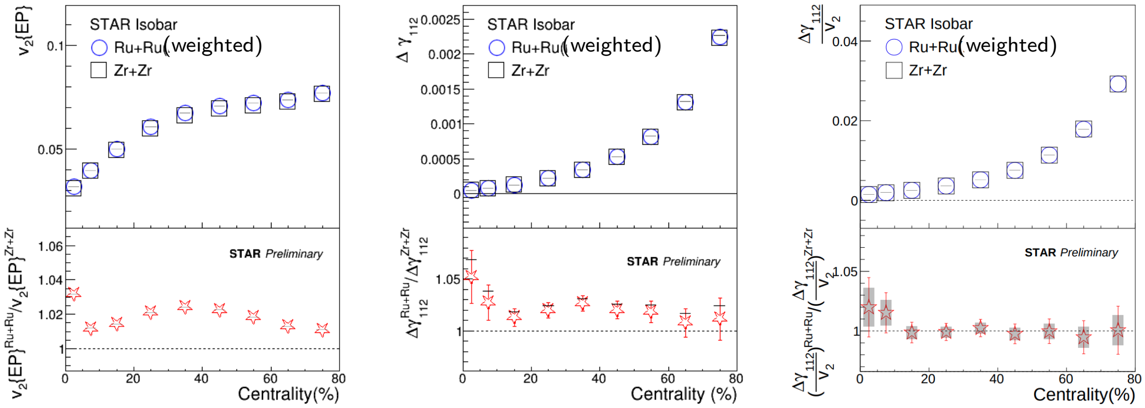
For the corresponding bin:

- N_{bin}: number of events
- $f_{W,\text{bin}}$: weight factor
- O_{bin}: observables

S_O and S_W are the sum of the observable and weight entries in total, respectively.

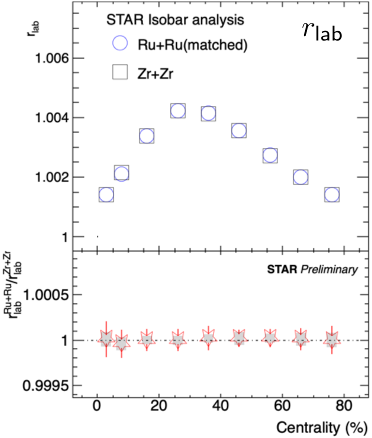
- POI multiplicity (N), observed elliptic flow (v_2^{obs}), and EP resolution are used for matching.
- After matching, comparisons between two isobar collision systems in the other quantities would be more straightforward.

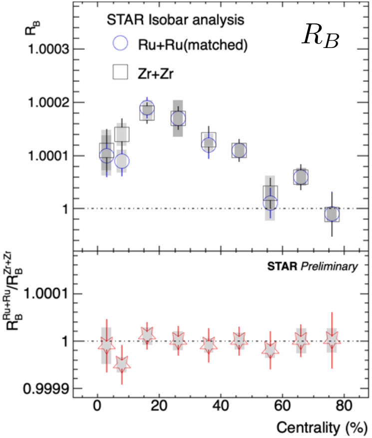
$\Delta\gamma$ correlator after N matched



- After matching, Ru+Ru/Zr+Zr ratio seems consistent with unity for $\Delta\gamma/v_2$.

Signed balance function after N, $v_2^{\rm obs}$, EP resolution matched





[Tang, Chin. Phys. C 44, 054101 (2020)]

By accounting momentum ordering:

1) Count pair's momentum ordering in p_y:

$$B_{P,y}(S_y) = \frac{N_{+-}(S_y) - N_{++}(S_y)}{N_+},$$

$$B_{N,y}(S_y) = \frac{N_{-+}(S_y) - N_{--}(S_y)}{N_-}.$$

2) Count net-ordering (e.g. excess of pos. leading neg.) for each event :

$$\delta B_y(S_y) = B_{P,y}(S_y) - B_{N,y}(S_y),$$

$$\Delta B_y = \delta B_y(+1) - \delta B_y(-1)$$

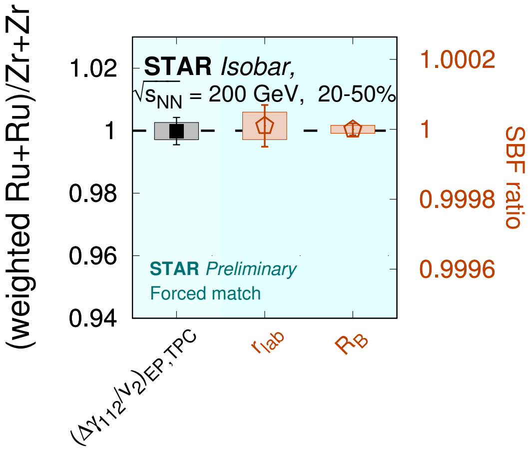
$$= \frac{N_+ + N_-}{N_+ N_-}\left[N_{y(+-)} - N_{y(-+)}\right].$$

3) Look for enhanced event-by-event fluctuation of net ordering in y direction.

$$r = \frac{\sigma_{\Delta B_y}}{\sigma_{\Delta B_x}}, \quad R_B = \frac{r_{\rm rest}}{r_{\rm lab}}.$$

- After matching, Ru+Ru/Zr+Zr ratios are consistent with unity for both $r_{\rm lab}$ and R_B.

Results from the forced match method



- After the match, isobar ratios in $\Delta\gamma/v_2$, signed balance function consistent with unity.

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Isobar background baseline

$\Delta\gamma$ measurement using 3p correlation

$$C_{3,\alpha\beta} = \langle \cos(\phi_\alpha + \phi_\beta - 2\phi_c) \rangle, \quad \Delta\gamma = (C_{3,\mathrm{os}} - C_{3,\mathrm{ss}})/v_2^* = C_3/v_2^*.$$

- background decomposition [Feng et al., PRC105(2022)024913] :

$$\frac{\Delta\gamma_{\mathrm{bkgd}}}{v_2^*} = \frac{C_3}{v_2^{*2}} = C_{\mathrm{2p}}\frac{v_2^2}{N v_2^{*2}} + \frac{C_{\mathrm{3p}}}{N^2 v_2^{*2}} = \frac{C_{\mathrm{2p}} v_2^2}{N v_2^{*2}}\left(1 + \frac{C_{\mathrm{3p}}/C_{\mathrm{2p}}}{N v_2^2}\right)$$

  - over the correlated pairs $C_{\mathrm{2p}} = \langle \cos(\phi_\alpha + \phi_\beta - 2\phi_{\mathrm{2p}}) \rangle_{\mathrm{2p}}$
  - over the correlated triplets $C_{\mathrm{3p}} = \langle \cos(\phi_\alpha + \phi_\beta - 2\phi_c) \rangle_{\mathrm{3p}}$

$$Y_{\mathrm{bkgd}} \equiv \frac{\left(\Delta\gamma_{\mathrm{bkgd}}/v_2^*\right)^{\mathrm{Ru}}}{\left(\Delta\gamma_{\mathrm{bkgd}}/v_2^*\right)^{\mathrm{Zr}}} \approx 1 + \frac{\delta(C_{\mathrm{2p}}/N)}{C_{\mathrm{2p}}/N} - \frac{\delta\epsilon_{\mathrm{nf}}}{1+\epsilon_{\mathrm{nf}}} + \frac{1}{1 + \frac{N v_2^2}{C_{\mathrm{3p}}/C_{\mathrm{2p}}}}\left(\frac{\delta C_{\mathrm{3p}}}{C_{\mathrm{3p}}} - \frac{\delta C_{\mathrm{2p}}}{C_{\mathrm{2p}}} - \frac{\delta N}{N} - \frac{\delta v_2^2}{v_2^2}\right)$$

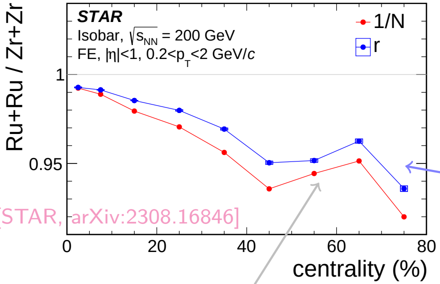
$\delta X = X^{\mathrm{Ru}} - X^{\mathrm{Zr}}$
X w/o label is for Zr

flow-induced background:
correlated pairs coupled with flow (e.g., resonance decay ...)
- Resonance/cluster multiplicity not strictly proportional to N

nonflow in v_2^*: $\epsilon_{\mathrm{nf}} = v_2^{*2}/v_2^2 - 1$
- 2p-cumulant $v_2^{*2} = \langle \cos 2(\phi_\alpha - \phi_\beta) \rangle$ contains flow and nonflow $v_2^{*2} = v_2^2 + v_{2,\mathrm{nf}}^2$
- 2D fit on $(\Delta\eta, \Delta\phi)$ distribution

3p nonflow: correlated triplets (e.g., jets, di-jets ...)
- HIJING simulations

Pair multiplicity ratio



[STAR, arXiv:2308.16846]

wiggles due to integer centrality definition
[STAR, PRC 105(2022)014901]

- Relative pair multiplicity

$$r = \frac{N_{2\mathrm{p}}}{N_{\mathrm{OS}}} = \frac{N_{\mathrm{OS}} - N_{\mathrm{SS}}}{N_{\mathrm{OS}}}$$

- 2p nonflow (average from correlated pairs)

$$C_{2\mathrm{p}} = \langle \cos(\phi_\alpha + \phi_\beta - 2\phi_{2\mathrm{p}}) \rangle_{2\mathrm{p}} \approx Nr \times \text{(decay kinematics)}$$

- similar decay kinematics between isobars, then

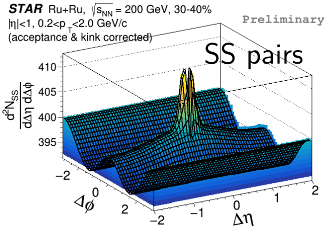
$$\frac{\delta(C_{2\mathrm{p}}/N)}{C_{2\mathrm{p}}/N} = \frac{\delta r}{r}$$

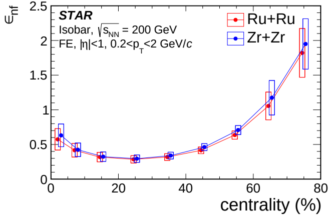
to be used in baseline estimate

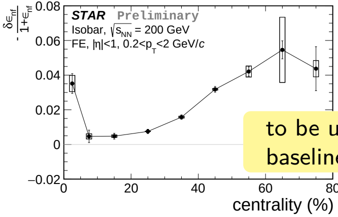
The difference between two isobar systems in relative pair multiplicity is used to estimate the difference in 2p nonflow.

Nonflow in v_2^* estimated from $(\Delta\eta, \Delta\phi)$ fit

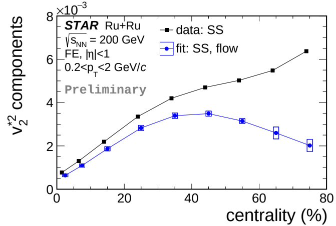
[STAR, arXiv:2308.16846]

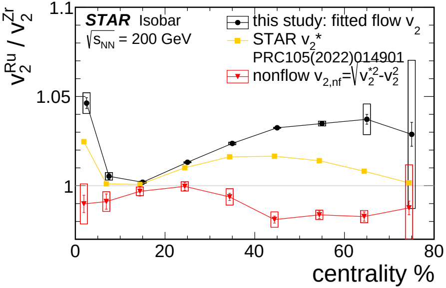






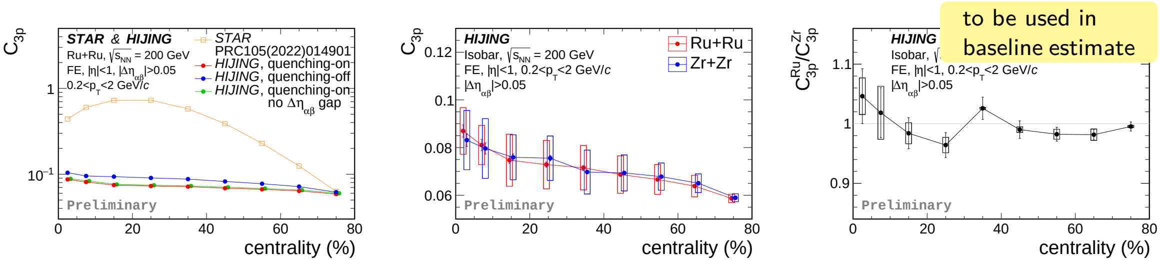
to be used in baseline estimate





- isobar ratio of v_2: fitted flow $>$ inclusive measurement $> 1 >$ nonflow
- Ru has smaller nonflow due to larger N, as nonflow $\sim 1/N$.

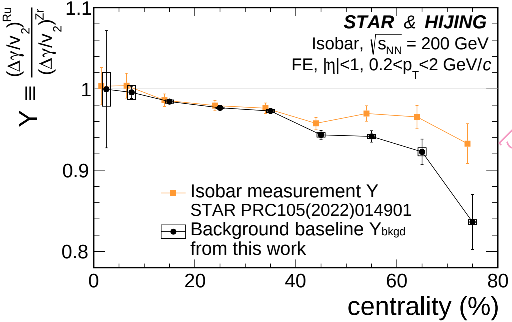
3p nonflow estimated from HIJING



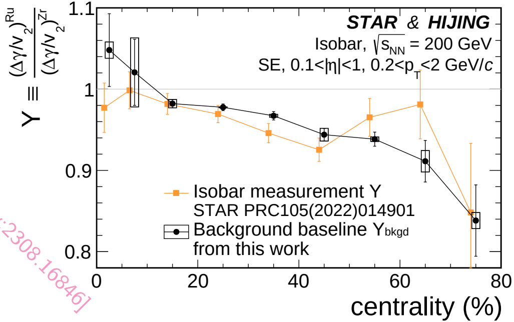
- Since HIJING does not have flow, the inclusive C_3 in HIJING all comes from 3p nonflow correlations $C_{3\mathrm{p}}$.
- Data agree with HIJING in most peripheral collisions.
  Difference at other centralities are presumably from flow.

Measurement and background baseline for isobar ratio of $\Delta\gamma/v_2$

full-event (FE) method



subevent (SE) method

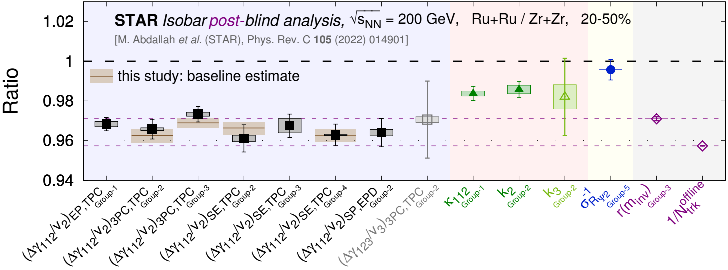


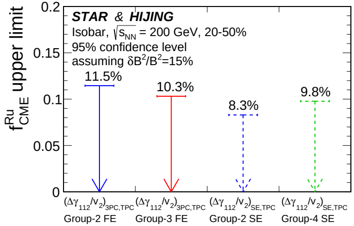
[STAR, arXiv:2308.16846]

$$Y_{\mathrm{bkgd}} \equiv \frac{(\Delta\gamma_{\mathrm{bkgd}}/v_2^*)^{\mathrm{Ru}}}{(\Delta\gamma_{\mathrm{bkgd}}/v_2^*)^{\mathrm{Zr}}} \approx 1 + \frac{\delta(C_{2\mathrm{p}}/N)}{C_{2\mathrm{p}}/N} - \frac{\delta\epsilon_{\mathrm{nf}}}{1+\epsilon_{\mathrm{nf}}} + \frac{1}{1+\frac{Nv_2^2}{C_{3\mathrm{p}}/C_{2\mathrm{p}}}}\left(\frac{\delta C_{3\mathrm{p}}}{C_{3\mathrm{p}}} - \frac{\delta C_{2\mathrm{p}}}{C_{2\mathrm{p}}} - \frac{\delta N}{N} - \frac{\delta v_2^2}{v_2^2}\right)$$

Background baseline estimates and CME upper limit

[STAR, arXiv:2308.16846]





- Data are consistent with estimated baseline.
- CME fraction upper limit $\sim 10\%$ at 95% CL

Rough estimate:
Data + baseline uncertainty $\sim 0.7\%$
Assuming B^2 difference 15%
$f_{\rm CME}$ uncertainty $\sim 0.7\%/15\% \sim 5\%$
$\rightarrow 2\sigma$ upper limit $\sim 10\%$

$$Y_{\rm bkgd} \equiv \frac{(\Delta\gamma_{\rm bkgd}/v_2^*)^{\rm Ru}}{(\Delta\gamma_{\rm bkgd}/v_2^*)^{\rm Zr}} \approx 1 + \frac{\delta(C_{2\rm p}/N)}{C_{2\rm p}/N} - \frac{\delta\epsilon_{\rm nf}}{1+\epsilon_{\rm nf}} + \frac{1}{1+\frac{Nv_2^2}{C_{3\rm p}/C_{2\rm p}}}\left(\frac{\delta C_{3\rm p}}{C_{3\rm p}} - \frac{\delta C_{2\rm p}}{C_{2\rm p}} - \frac{\delta N}{N} - \frac{\delta v_2^2}{v_2^2}\right)$$

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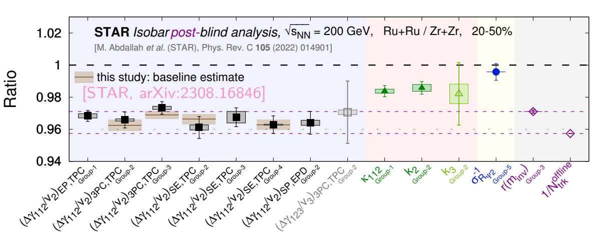
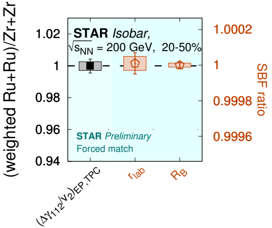




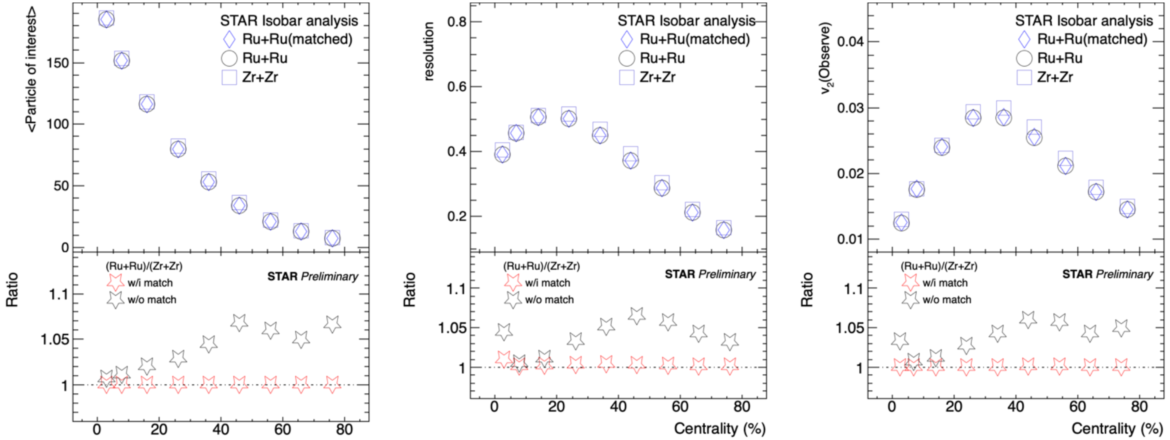
- Blind analysis [STAR, PRC 105(2022)014901] : Ru and Zr differ in N, v_2;
  Isobar ratios of CME observable $\Delta\gamma/v_2$ below unity, contrary to initial expectations.
- Forced match of N, v_2^{obs}, and EP resolution:
  Isobar ratios in $\Delta\gamma/v_2$ and signed balance function consistent with unity.
- Background baselines accounting for pair multiplicity, v_2^* nonflow, 2p/3p nonflow:
  Data consistent with background baseline;
  Assuming 15% isobar difference in B^2, CME fraction upper limit $\sim 10\%$ with 95% CL.

Backups

Analysis information

- **Dataset:** Isobar collisions, Ru+Ru and Zr+Zr, at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV
- **Year:** 2018
- **Production tag:** `production_isobar_2018`
- **Trigger used:** 600001, 600011, 600021, 600031
- **Selections:** identical event selection and analysis cuts as used in isobar paper
  - standard `StRefMultCorr` and pileup removal
  - bad run removed as isobar blind analysis
  - $-35 < V_z < 25$ cm
  - $V_r < 2$ cm
  - $|V_z - V_z^{\mathrm{VPD}}| < 5$ cm
  - Ru+Ru ~ 1.8B, Zr+Zr ~ 2.0B
  - $0.2 < p_T < 2.0$ GeV
  - $15 < \mathtt{nHitsFit} < 50$
  - $|\eta| < 1.0$
  - $\mathtt{DCA} < 3$ cm

Matching check



- The isobar difference in N_{POI}, v_2(observed), and resolution are removed with match.
- $\Delta\gamma$ correlator: N_{POI} only as the matching dimension.
- Balance function: N_{POI}, v_2(observed), and resolution all as the matching dimensions.

By accounting momentum ordering:

1) Count pair's momentum ordering in p_y:

$$B_{P,y}(S_y) = \frac{N_{+-}(S_y) - N_{++}(S_y)}{N_+},$$

$$B_{N,y}(S_y) = \frac{N_{-+}(S_y) - N_{--}(S_y)}{N_-}.$$

2) Count net-ordering (e.g. excess of pos. leading neg.) for each event :

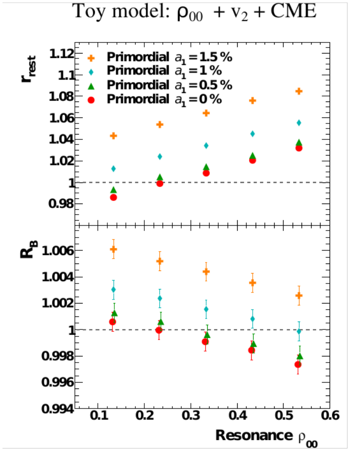
$$\delta B_y(S_y) = B_{P,y}(S_y) - B_{N,y}(S_y),$$

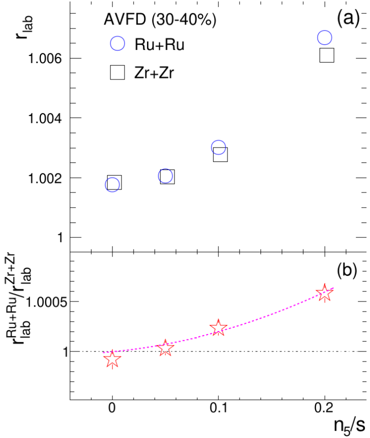
$$\Delta B_y = \delta B_y(+1) - \delta B_y(-1)$$

$$= \frac{N_+ + N_-}{N_+ N_-}\left[N_{y(+-)} - N_{y(-+)}\right].$$

3) Look for enhanced event-by-event fluctuation of net ordering in y direction.

$$r = \frac{\sigma_{\Delta B_y}}{\sigma_{\Delta B_x}}, \quad R_B = \frac{r_{\text{rest}}}{r_{\text{lab}}}.$$





▶ With CME signal, both r and R_B would be larger than 1.

[A.H. Tang, Chin. Phys. C 44, 054101 (2020)]
[S. Choudhury, et al., Chin. Phys. C 46, 014101 (2022)]

Algebra from $(Y - Y_{\text{bkgd}})$ to f_{CME}

$$f_{\text{CME}} = \frac{\Delta\gamma_{\text{CME}}}{\Delta\gamma} = \frac{\Delta\gamma_{\text{CME}}}{\Delta\gamma_{\text{CME}} + \Delta\gamma_{\text{bkgd}}} \tag{1}$$

$$\begin{aligned} Y_{\text{signal}} \equiv & Y - Y_{\text{bkgd}} = \frac{(\Delta\gamma/v_2^*)^{\text{Ru}}}{(\Delta\gamma/v_2^*)^{\text{Zr}}} - Y_{\text{bkgd}} = \frac{[\Delta\gamma_{\text{bkgd}}/v_2^*/(1-f_{\text{CME}})]^{\text{Ru}}}{[\Delta\gamma_{\text{bkgd}}/v_2^*/(1-f_{\text{CME}})]^{\text{Zr}}} - Y_{\text{bkgd}} \\ = & Y_{\text{bkgd}} \left(\frac{[1/(1-f_{\text{CME}})]^{\text{Ru}}}{[1/(1-f_{\text{CME}})]^{\text{Zr}}} - 1 \right) = Y_{\text{bkgd}} \frac{\delta f_{\text{CME}}}{1 - f_{\text{CME}}^{\text{Ru}}} \end{aligned} \tag{2}$$

$$\frac{f_{\text{CME}}^{\text{Zr}}}{f_{\text{CME}}^{\text{Ru}}} = \frac{\Delta\gamma_{\text{CME}}^{\text{Zr}}}{\Delta\gamma_{\text{CME}}^{\text{Ru}}} \cdot \frac{\Delta\gamma^{\text{Ru}}/v_2^{*\text{Ru}}}{\Delta\gamma^{\text{Zr}}/v_2^{*\text{Zr}}} \cdot \frac{v_2^{*\text{Ru}}}{v_2^{*\text{Zr}}} = \frac{(B^2)^{\text{Zr}}}{(B^2)^{\text{Ru}}} Y \frac{v_2^{*\text{Ru}}}{v_2^{*\text{Zr}}} \tag{3}$$

$$\delta f_{\text{CME}} = f_{\text{CME}}^{\text{Ru}} - f_{\text{CME}}^{\text{Zr}} = f_{\text{CME}}^{\text{Ru}} \left(1 - \frac{(B^2)^{\text{Zr}}}{(B^2)^{\text{Ru}}} Y \frac{v_2^{*\text{Ru}}}{v_2^{*\text{Zr}}} \right) \tag{4}$$

$$\begin{aligned} f_{\text{CME}}^{\text{Ru}} = & \frac{Y_{\text{signal}}}{Y} \Bigg/ \left[1 - Y_{\text{bkgd}} \Bigg/ \frac{(B^2/v_2^*)^{\text{Ru}}}{(B^2/v_2^*)^{\text{Zr}}} \right] \\ \approx & \frac{Y_{\text{signal}}}{Y} \Bigg/ \left[1 - Y_{\text{bkgd}} \left(1 + \frac{\delta v_2^*}{v_2^*} - \frac{\delta B^2}{B^2} \right) \right] \end{aligned} \tag{5}$$

More roughly $f_{\text{CME}}^{\text{Ru}} \approx Y_{\text{signal}} \Big/ \left(\frac{\delta B^2}{B^2} \right)$

Isobar background baseline

elliptic flow measurement using 2p correlation

$$v_2^* = \sqrt{\langle \cos 2(\phi_\alpha - \phi_\beta) \rangle}$$

- decomposition $v_2^{*2} = v_2^2 + v_{2,\text{nf}}^2$
  - v_2: true elliptic flow
  - $v_{2,\text{nf}}$: nonflow backgrounds (resonance decay pairs, jets, ...)
- nonflow fraction $\epsilon_{\text{nf}} = v_2^{*2}/v_2^2 - 1$

N multiplicity
OS opposite-sign, SS same-sign pair
N_{2p} correlated pair number
N_{3p} correlated triplet number

$\Delta\gamma$ measurement using 3p correlation

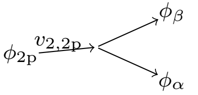
$$C_{3,\text{OS}} = \langle \cos(\phi_\alpha^\pm + \phi_\beta^\mp - 2\phi_c) \rangle, \quad C_{3,\text{SS}} = \langle \cos(\phi_\alpha^\pm + \phi_\beta^\pm - 2\phi_c) \rangle,$$

$$\Delta\gamma = \gamma_{\text{OS}} - \gamma_{\text{SS}} = (C_{3,\text{OS}} - C_{3,\text{SS}})/v_2^* = C_3/v_2^*.$$

- background components
  - 2p nonflow: correlated pairs coupled with flow (e.g., resonance decays ...)

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

    $$\text{OS} - \text{SS excess, } \frac{C_{2\text{p}}}{N} = \frac{N_{2\text{p}}}{N_{\text{OS}}} \left(C_{2\text{p,OS}} \frac{v_{2,2\text{p}}}{v_2} - \frac{\gamma_{\text{SS}}}{v_2} \right)$$



  - 3p nonflow: correlated triplets (e.g., jets ...)

    $$C_{3\text{p,OS}} = \langle \cos(\phi_\alpha + \phi_\beta - 2\phi_c) \rangle_{3\text{p,OS}}, \quad C_{3\text{p,SS}} = \langle \cos(\phi_\alpha + \phi_\beta - 2\phi_c) \rangle_{3\text{p,SS}}$$

    $$\text{OS} - \text{SS excess, } \frac{C_{3\text{p}}}{N} = \frac{N_{3\text{p,OS}}}{N_{\text{OS}}} C_{3\text{p,OS}} - \frac{N_{3\text{p,SS}}}{N_{\text{SS}}} C_{3\text{p,SS}}$$

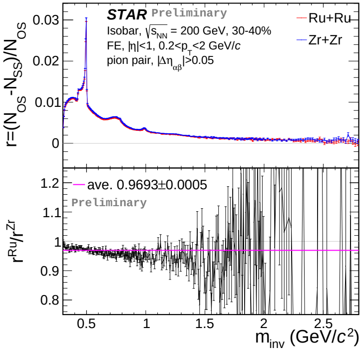
- decomposition $\dfrac{\Delta\gamma_{\text{bkgd}}}{v_2^*} = C_{2\text{p}} \dfrac{v_2^2}{N v_2^{*2}} + \dfrac{C_{3p}}{N^2 v_2^{*2}} = \dfrac{C_{2\text{p}} v_2^2}{N v_2^{*2}} \left(1 + \dfrac{C_{3\text{p}}/C_{2\text{p}}}{N v_2^2} \right)$

$$C_{3,\text{OS}}^{\text{bkgd}} = \frac{N_{\text{SS}}}{N_{\text{OS}}} \gamma_{\text{SS}} v_2 + \frac{N_{2\text{p}}}{N_{\text{OS}}} C_{2\text{p,OS}} v_{2,2\text{p}} v_2 + \frac{N_{3\text{p,OS}}}{N_{\text{OS}} N} C_{3\text{p,OS}}, \quad C_{3,\text{SS}}^{\text{bkgd}} = \gamma_{\text{SS}} v_2 + \frac{N_{3\text{p,SS}}}{N_{\text{SS}} N} C_{3\text{p,SS}}$$

$$Y_{\text{bkgd}} \equiv \frac{\left(\Delta\gamma_{\text{bkgd}}/v_2^*\right)^{\text{Ru}}}{\left(\Delta\gamma_{\text{bkgd}}/v_2^*\right)^{\text{Zr}}} \approx 1 + \frac{\delta(C_{2\text{p}}/N)}{C_{2\text{p}}/N} - \frac{\delta\epsilon_{\text{nf}}}{1+\epsilon_{\text{nf}}} + \frac{1}{1 + \frac{N v_2^2}{C_{3\text{p}}/C_{2\text{p}}}} \left(\frac{\delta C_{3\text{p}}}{C_{3\text{p}}} - \frac{\delta C_{2\text{p}}}{C_{2\text{p}}} - \frac{\delta N}{N} - \frac{\delta v_2^2}{v_2^2} \right)$$

2p nonflow pair multiplicity | nonflow in v_2^* $(\Delta\eta, \Delta\phi)$ fit | 3p nonflow HIJING

2p nonflow estimated from pair multiplicity

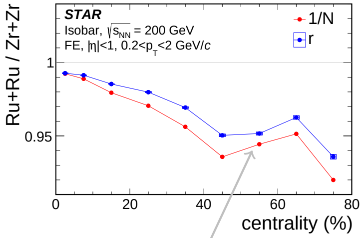


$$r = \frac{N_{2\mathrm{p}}}{N_{\mathrm{OS}}} = \frac{N_{\mathrm{OS}} - N_{\mathrm{SS}}}{N_{\mathrm{OS}}}$$

- ← r as a function of m_{inv} of the pion pair
- ↙ the ratio between $r^{\mathrm{Ru}}(m_{\mathrm{inv}})$ and $r^{\mathrm{Zr}}(m_{\mathrm{inv}})$, whose average gives $1 + \delta r/r$.
- similar decay kinematics between isobars assumed, then

$$\frac{\delta(C_{2\mathrm{p}}/N)}{C_{2\mathrm{p}}/N} = \frac{\delta r}{r}$$

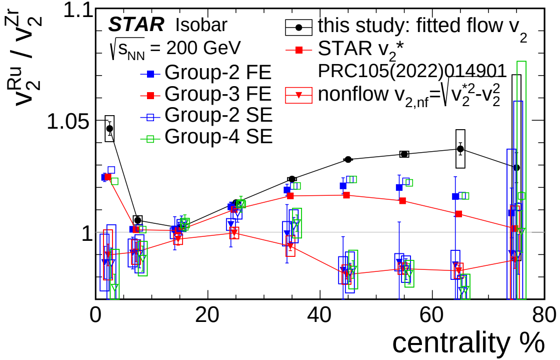
[STAR, arXiv:2308.16846]



wiggles due to centrality definition feature

$$Y_{\text{bkgd}} \equiv \frac{(\Delta\gamma_{\text{bkgd}}/v_2^*)^{\text{Ru}}}{(\Delta\gamma_{\text{bkgd}}/v_2^*)^{\text{Zr}}} \approx 1 + \frac{\delta(C_{2\mathrm{p}}/N)}{C_{2\mathrm{p}}/N} - \frac{\delta\epsilon_{\mathrm{nf}}}{1+\epsilon_{\mathrm{nf}}} + \frac{1}{1 + \frac{N v_2^2}{C_{3\mathrm{p}}/C_{2\mathrm{p}}}} \left(\frac{\delta C_{3\mathrm{p}}}{C_{3\mathrm{p}}} - \frac{\delta C_{2\mathrm{p}}}{C_{2\mathrm{p}}} - \frac{\delta N}{N} - \frac{\delta v_2^2}{v_2^2} \right)$$

Nonflow in v_2^* estimated from $(\Delta\eta, \Delta\phi)$ fit

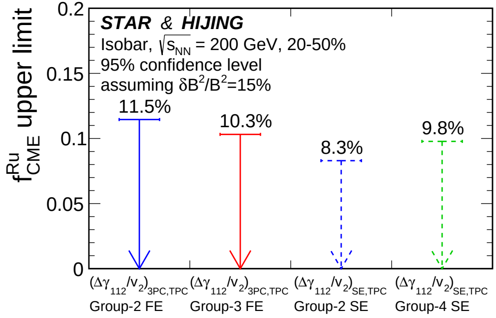


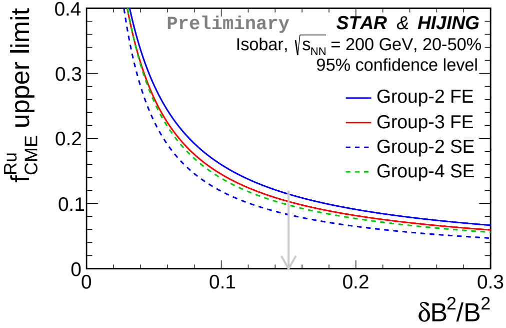
0-5% centrality **STAR** Preliminary

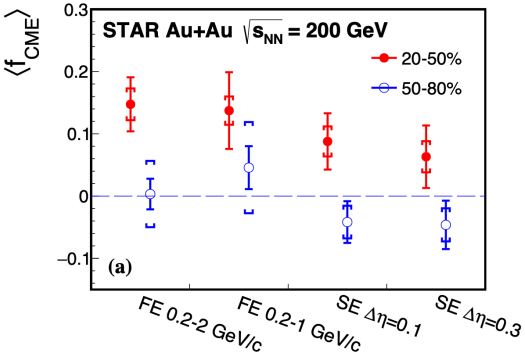
	0-5%	v_2^*	v_2	$v_{2,\text{nf}}$
Group-3 FE	Ru	3.18%	2.54%	1.92%
	Zr	3.11%	2.43%	1.94%
	Ru/Zr	1.025	1.046	0.990
Group-2 SE	Ru	3.01%	2.54%	1.62%
	Zr	2.93%	2.42%	1.64%
	Ru/Zr	1.028	1.046	0.986

Upper limits of the CME signal

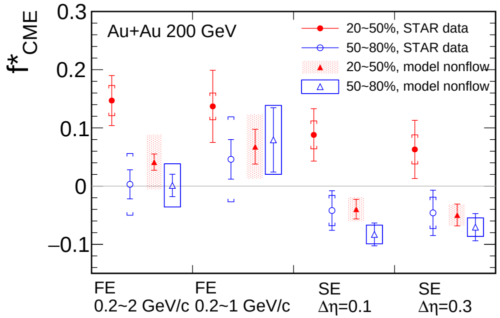
[STAR, arXiv:2308.16846]







[STAR, PRL128(2022)092301]



[Feng et al., PRC105(2022)024913]