What we have learned from isobar data and future perspective

Shuzhe Shi (Stony Brook University)

references:

D. Kharzeev, J. Liao, *SS*, PhyRevC.106.L051903

M. Buzzegoli, D. Kharzeev, Y.-C. Liu, *SS*, S. Voloshin, H.-U. Yee, PhyRevC.106.L051902

expectation before the isobar collisions:

Correlator[Ru] **>** *Correlator*[Zr] → **CME**

Correlator[Ru] **=** *Correlator*[Zr] → **no CME**

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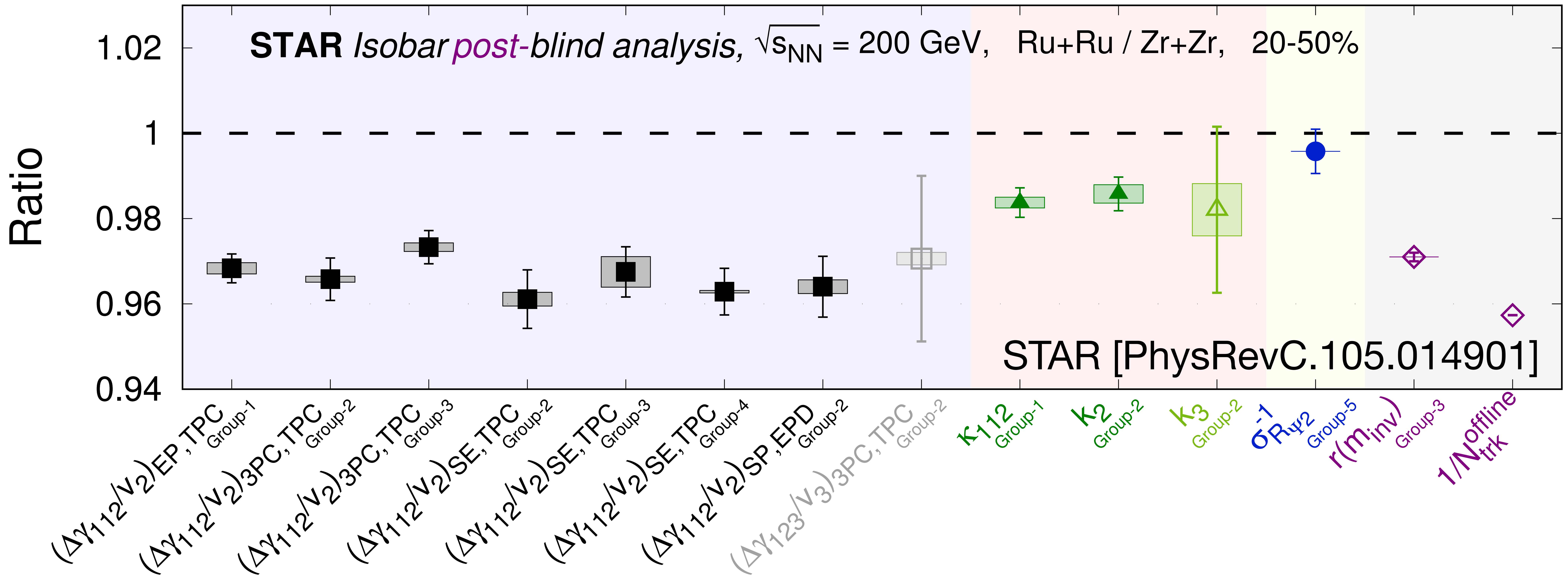
measurement in the isobar collisions:

Correlator[Ru] < *Correlator*[Zr]



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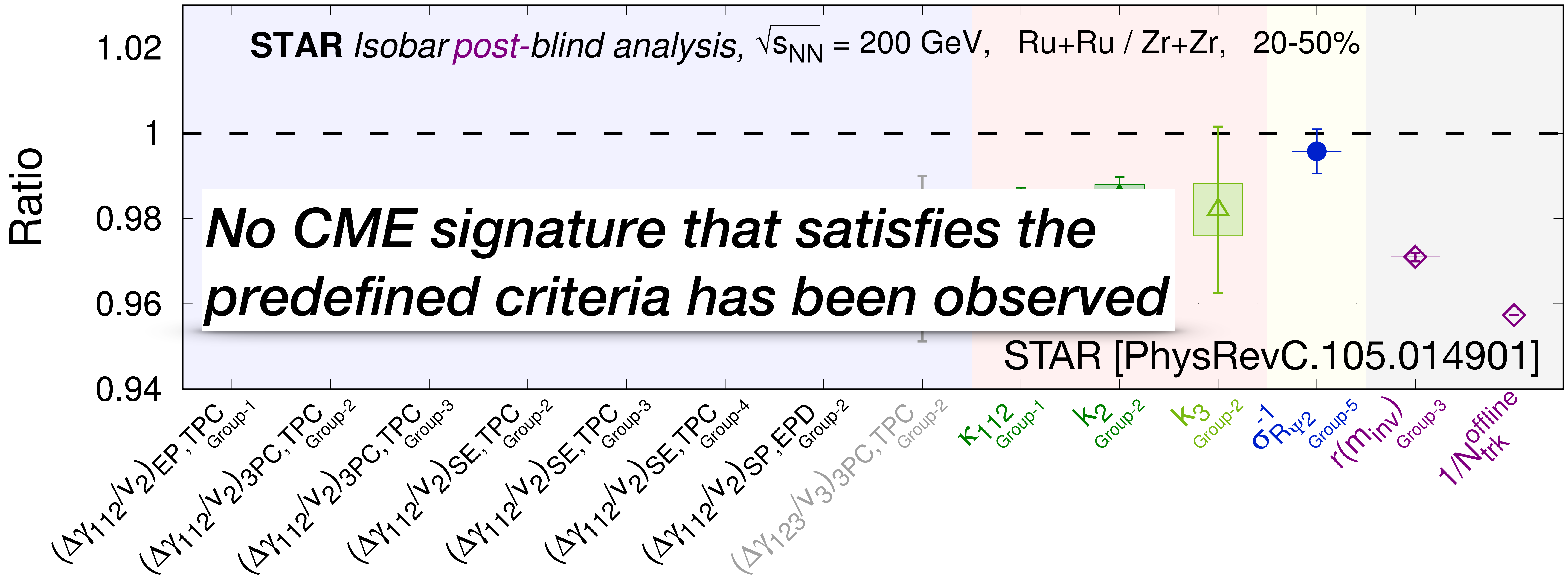

No CME signature that satisfies the predefined criteria has been observed

expectation before the isobar collisions:

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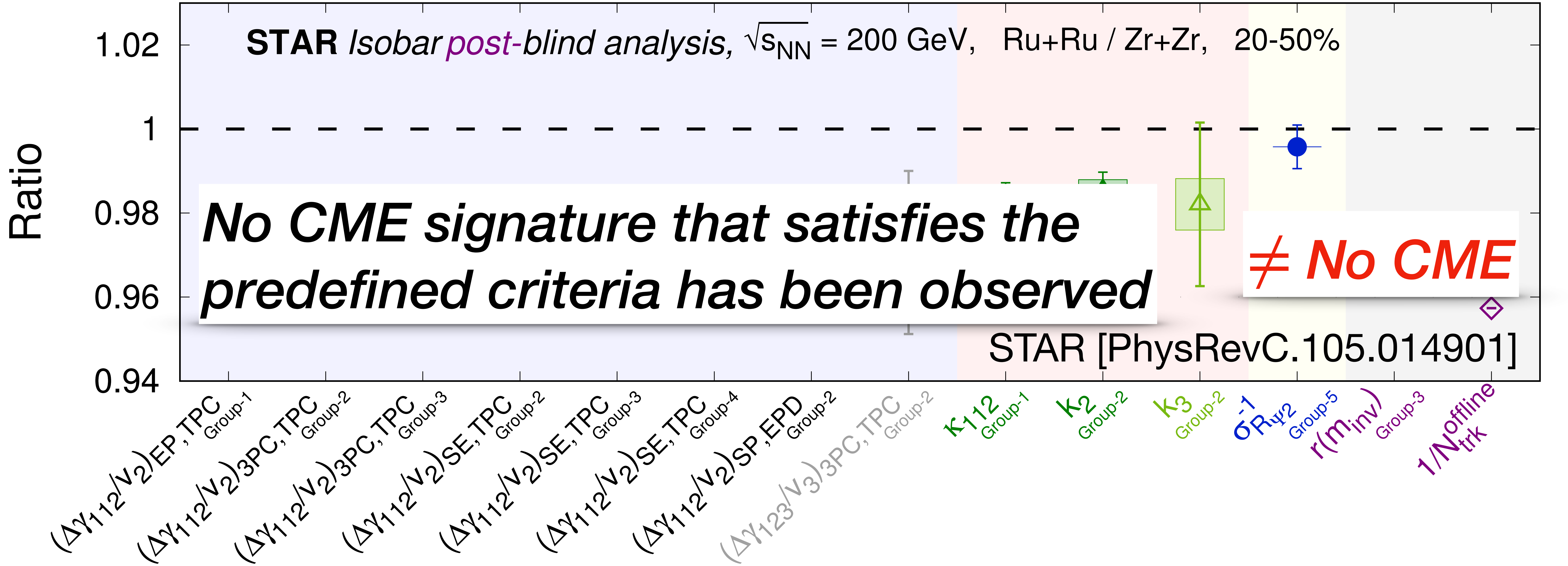

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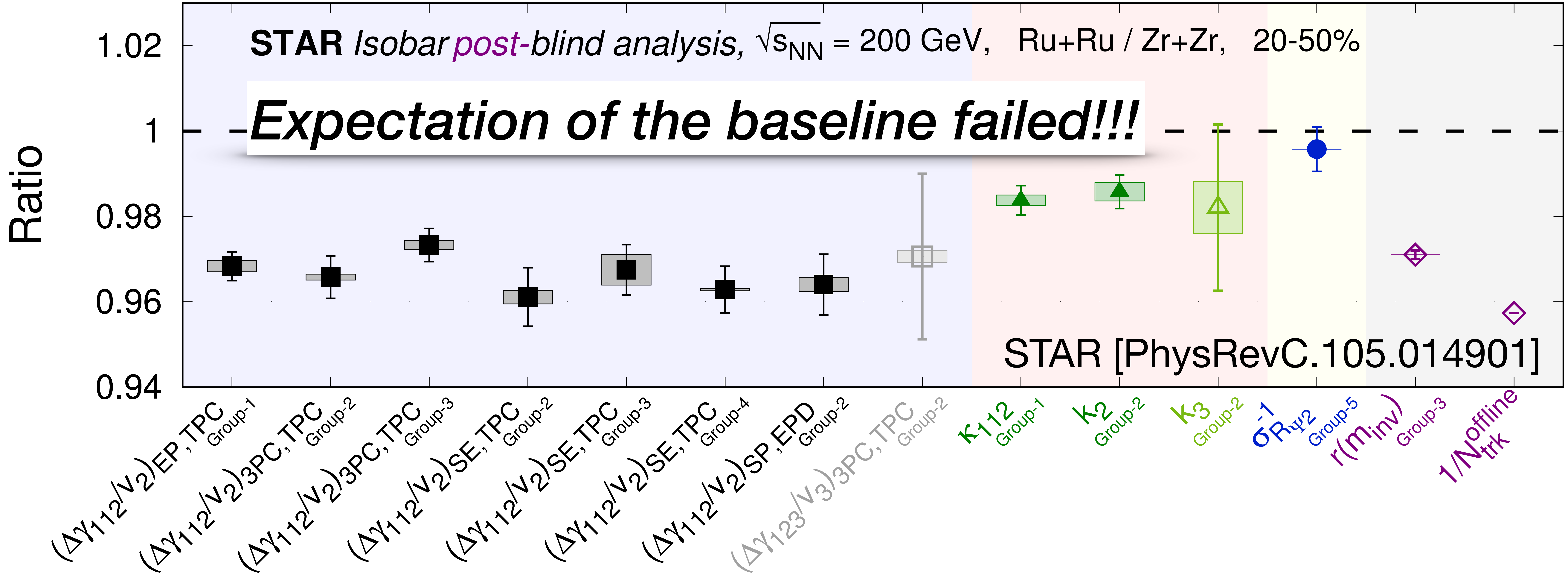
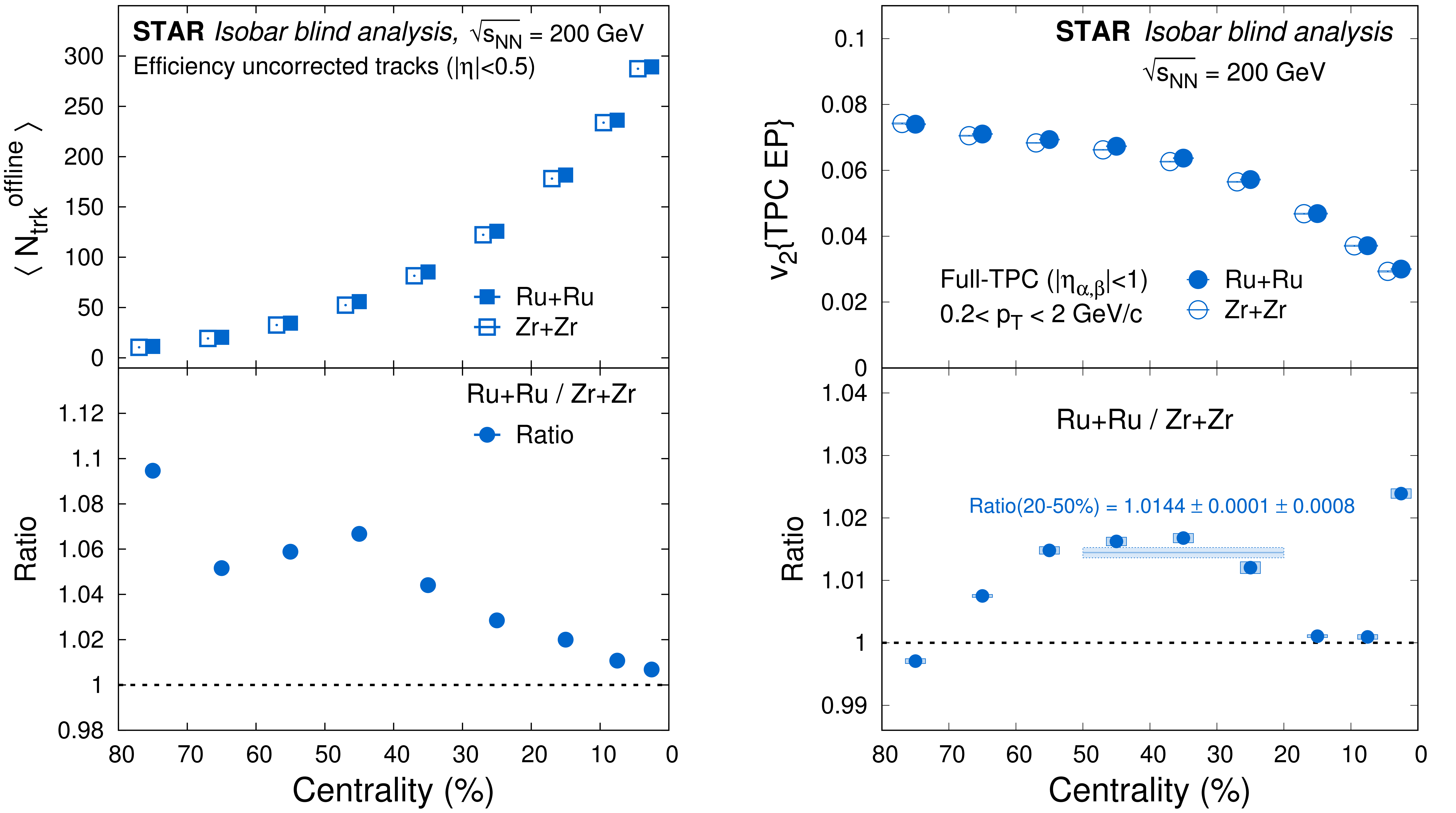
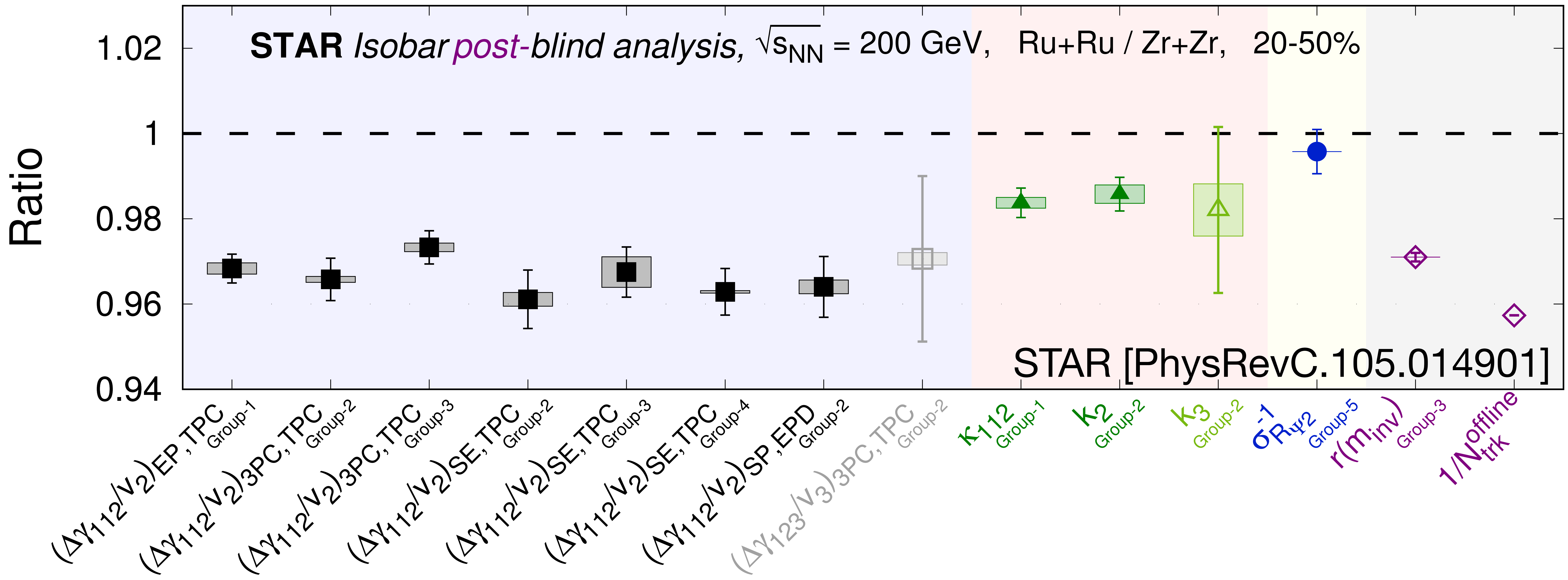


Bulk properties are not identical!



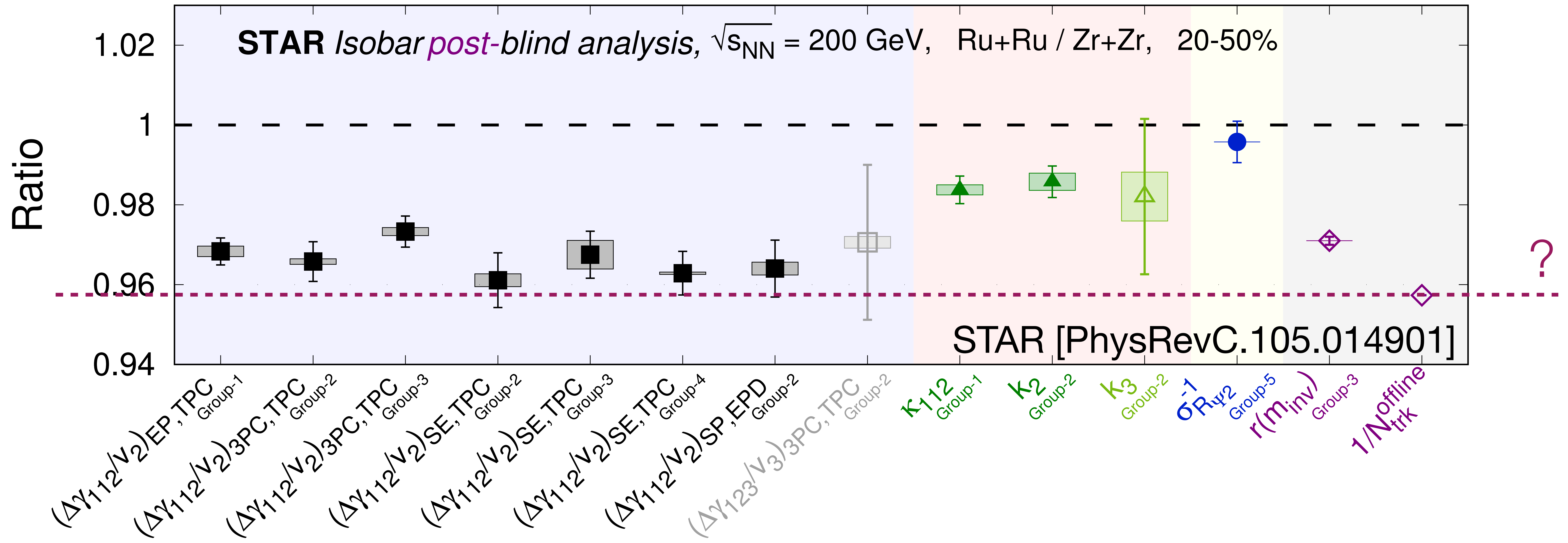
STAR [PhysRevC.105.014901]

appropriate baseline?



- what causes the difference in background?
- what the no-CME baseline should be?

appropriate baseline?



$$\Delta\gamma_{112,\mathrm{bkg}} = \frac{4N_{2\mathrm{p}}v_{2,2\mathrm{p}}}{N_{\mathrm{ch}}^2}\langle\cos(\phi_\alpha + \phi_\beta - 2\phi_{2\mathrm{p}})\rangle \propto \frac{v_2}{N_{\mathrm{ch}}}$$

$$\Delta\delta_{\mathrm{bkg}} \propto \frac{N_{2\mathrm{p}}}{N_{\mathrm{ch}}^2} \propto \frac{1}{N_{\mathrm{ch}}}$$

2p = 2-particle cluster

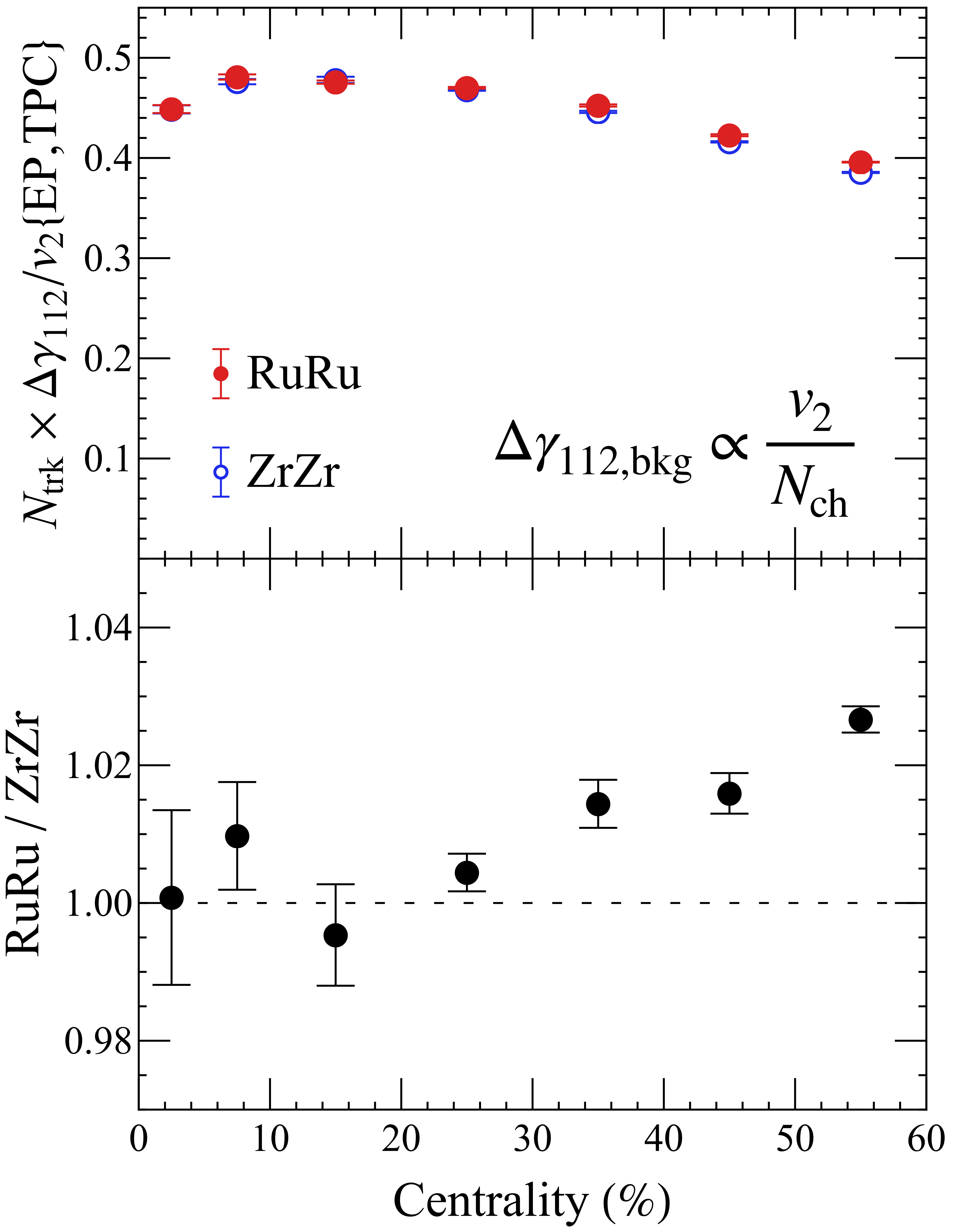
what is the appropriate baseline?

- what can we learn by relooking at the experimental results?

- how phenomenological simulations can help providing the baseline?

finding the appropriate baseline

data: re-plot [STAR,PhysRevC.105.014901]



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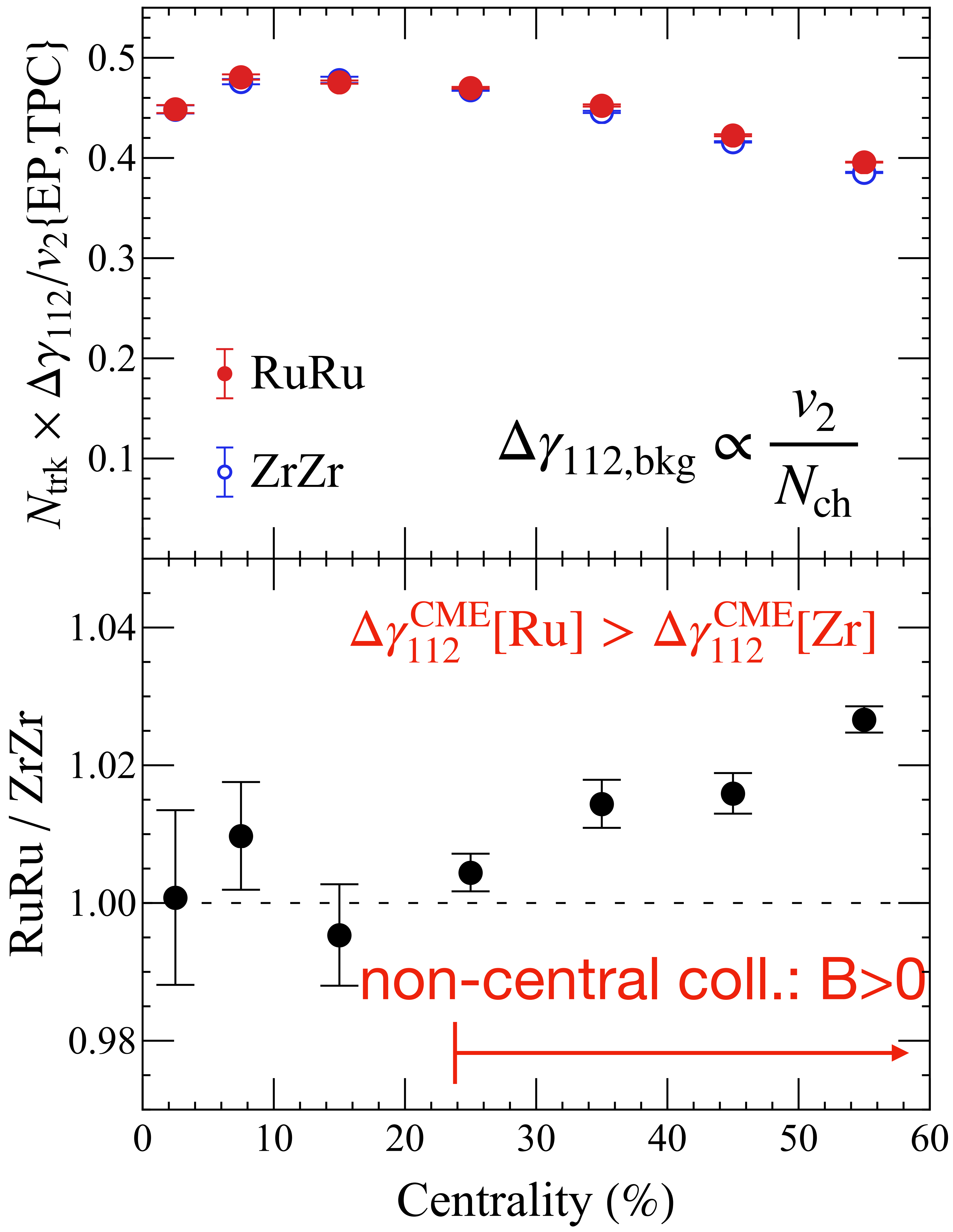

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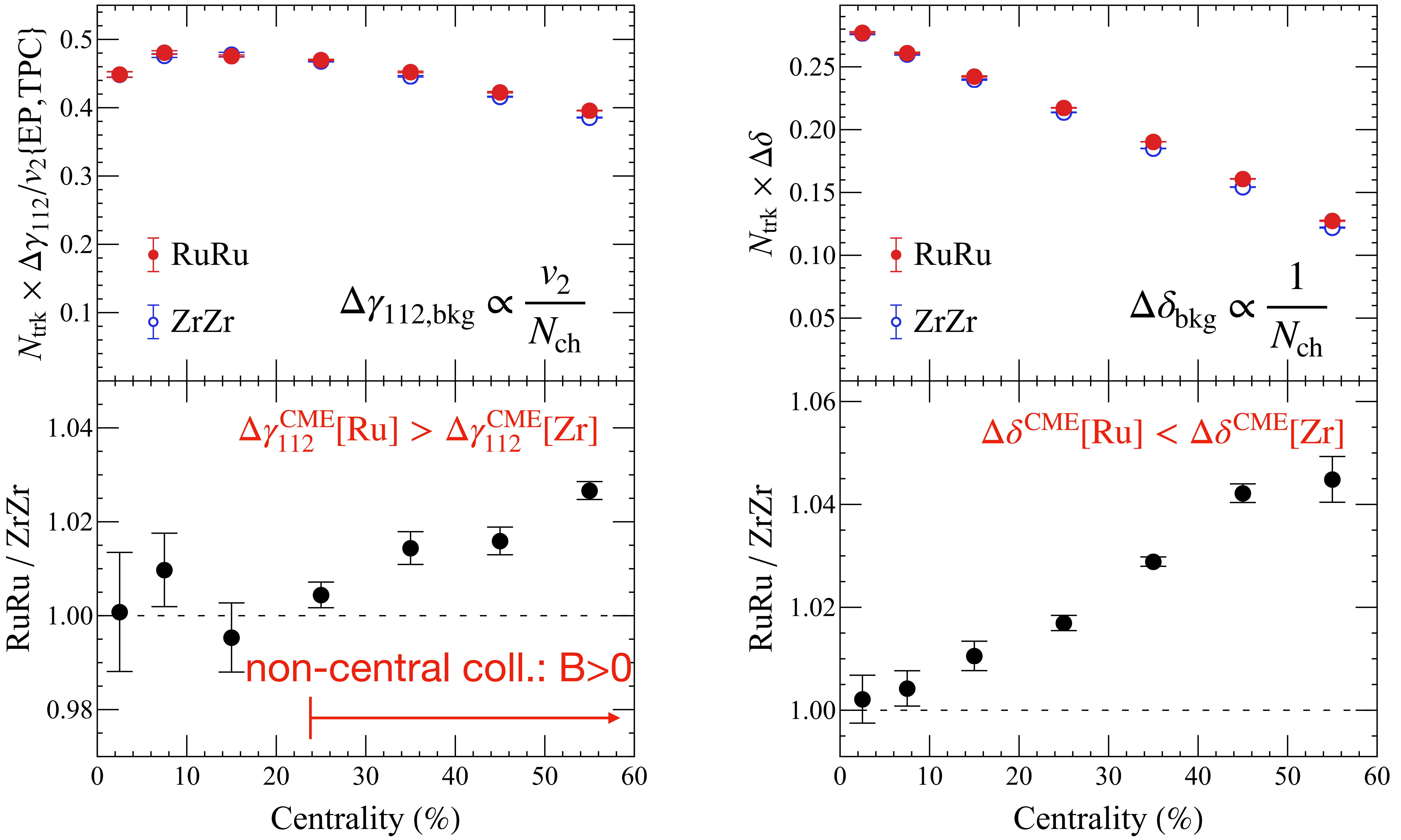

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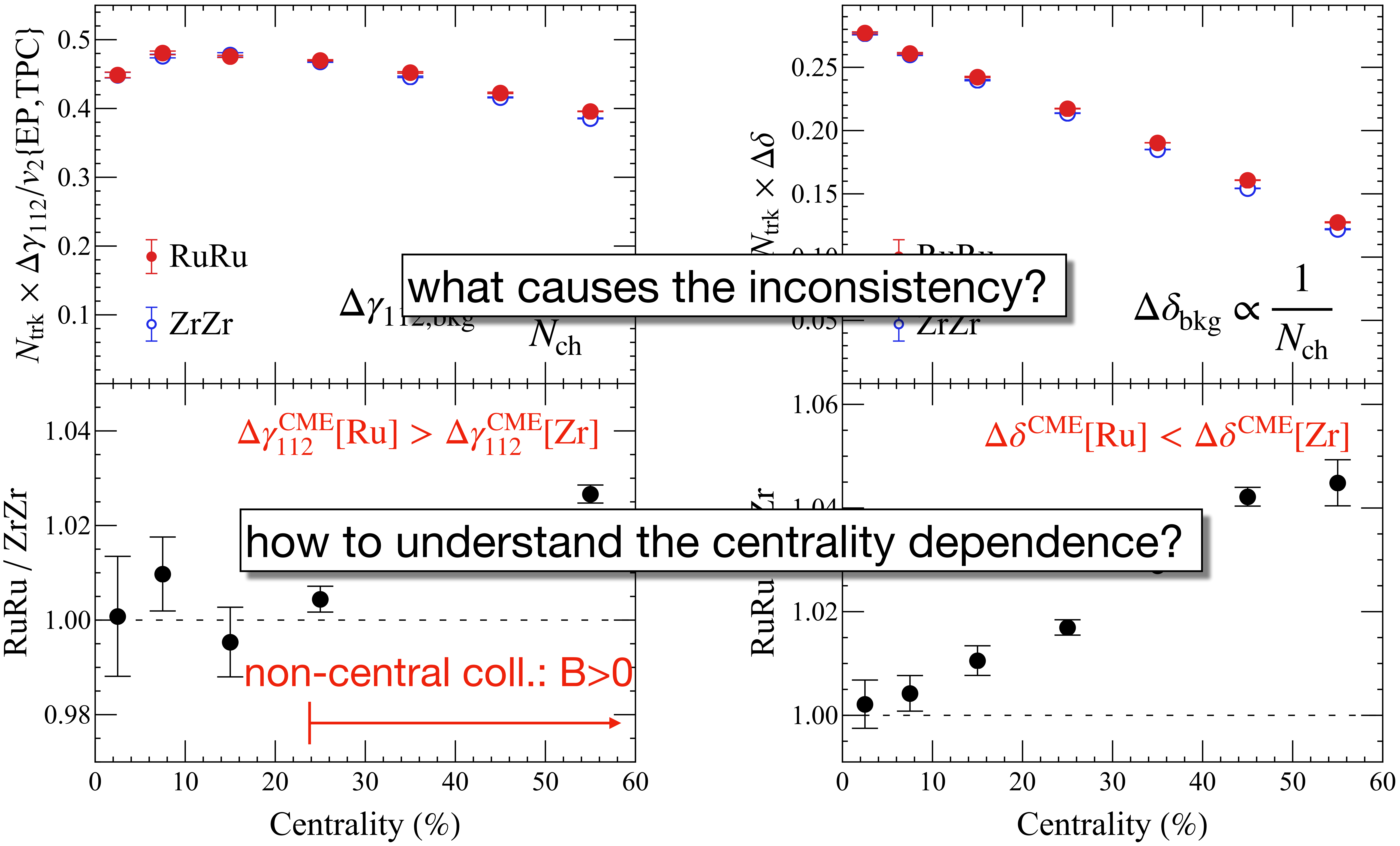
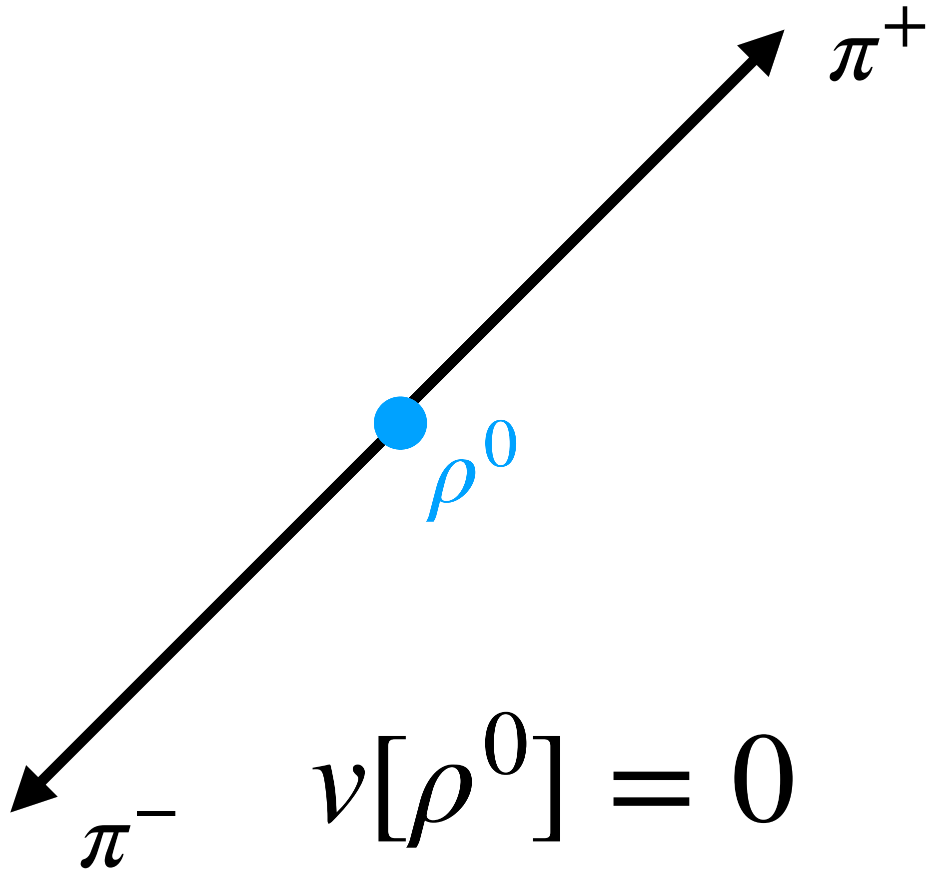
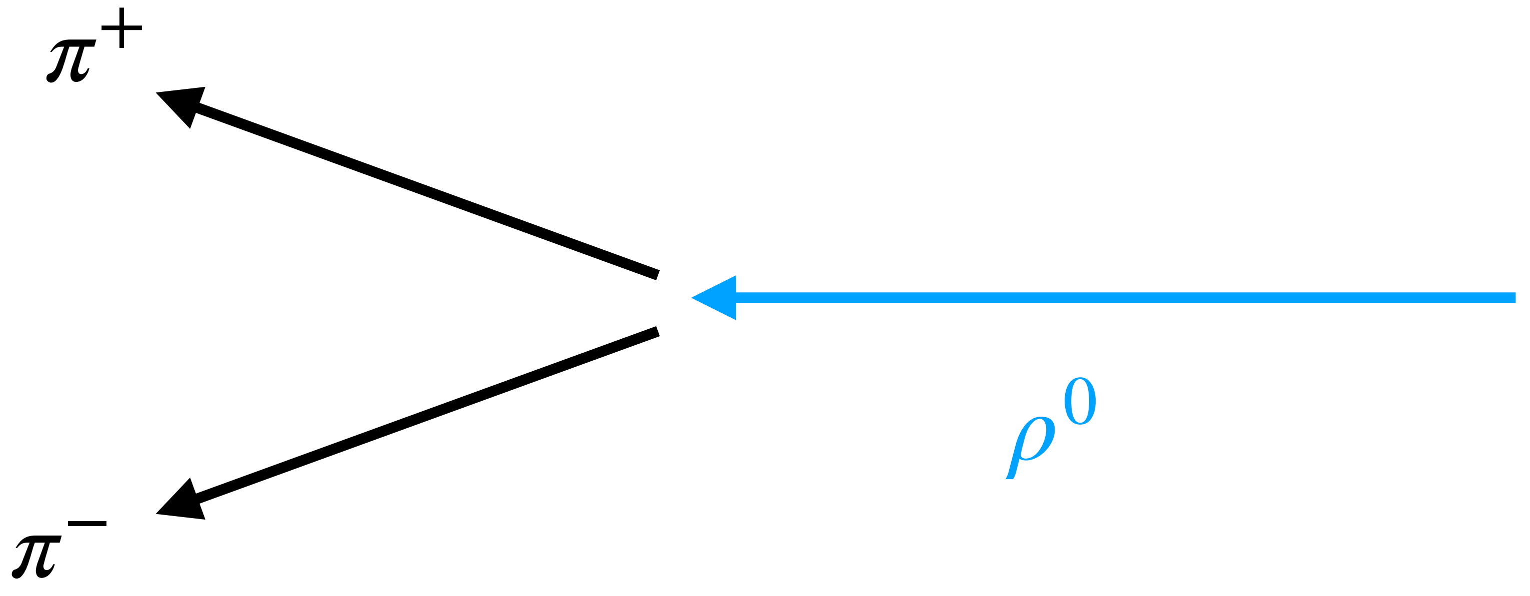


(extra) centrality dependence of background properties



$$\delta \equiv \langle \cos(\phi_a - \phi_b) \rangle$$

$$v[\rho^0] = 0 \quad \Rightarrow \quad \delta^{OS} = -1$$



$$v[\rho^0] \sim 1 \quad \Rightarrow \quad \delta^{OS} \approx 1$$

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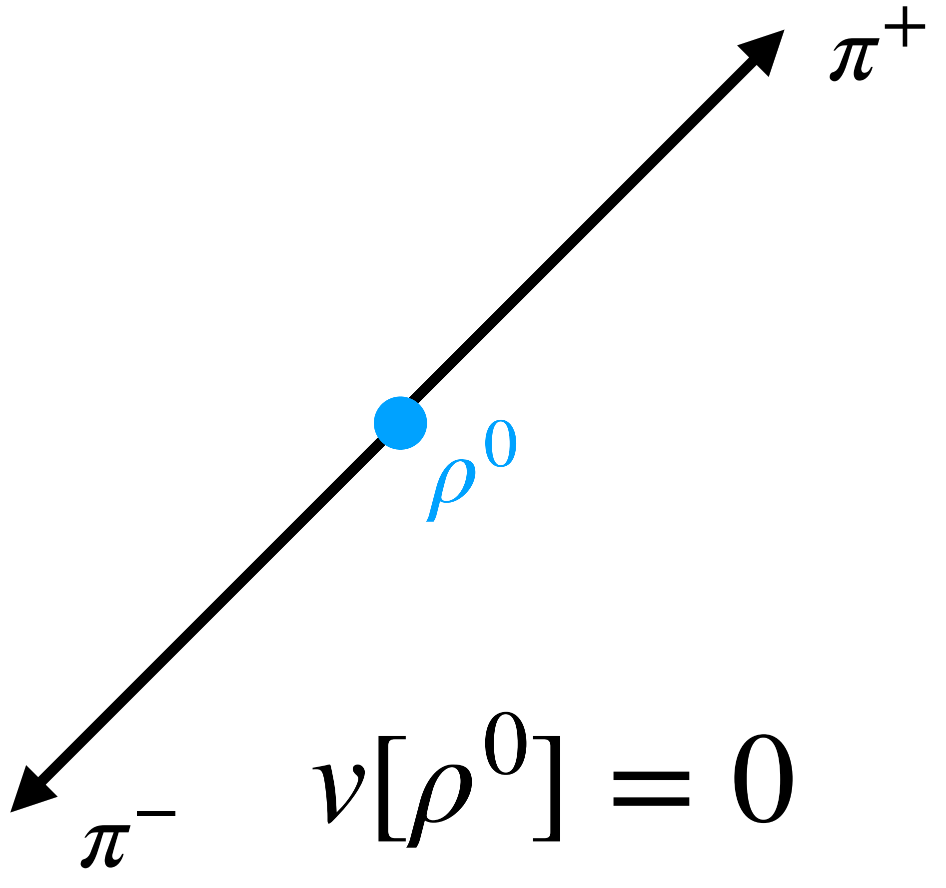

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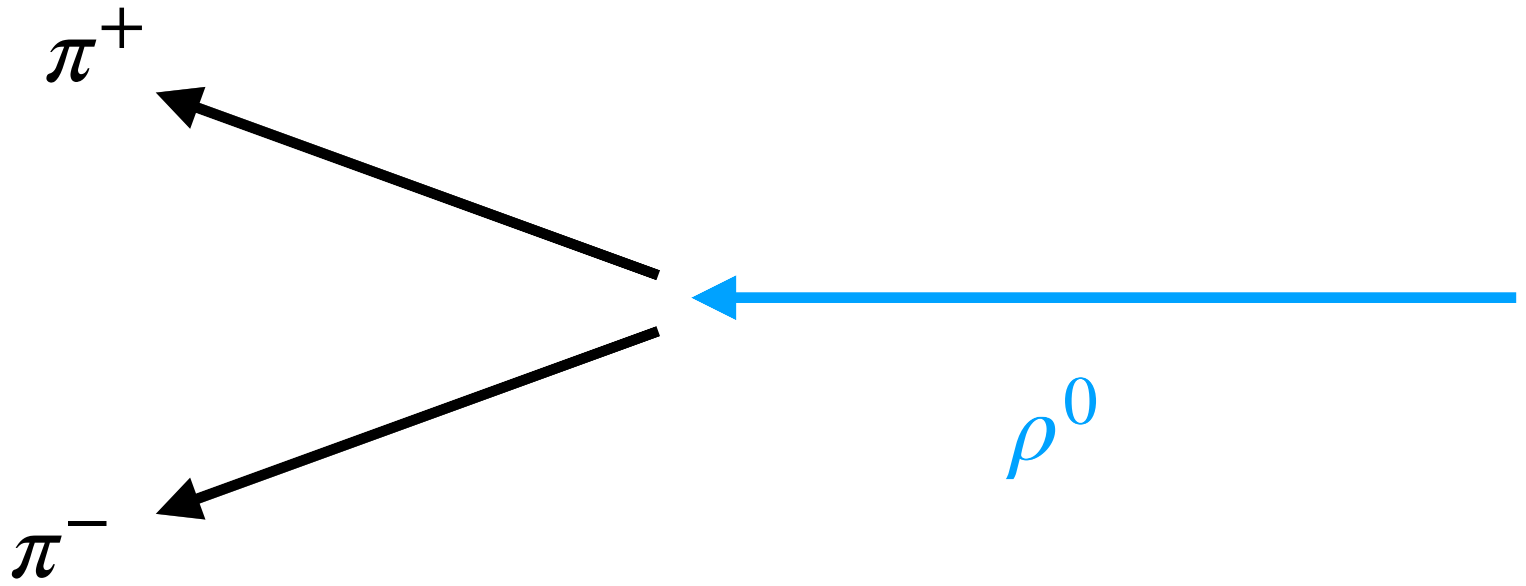

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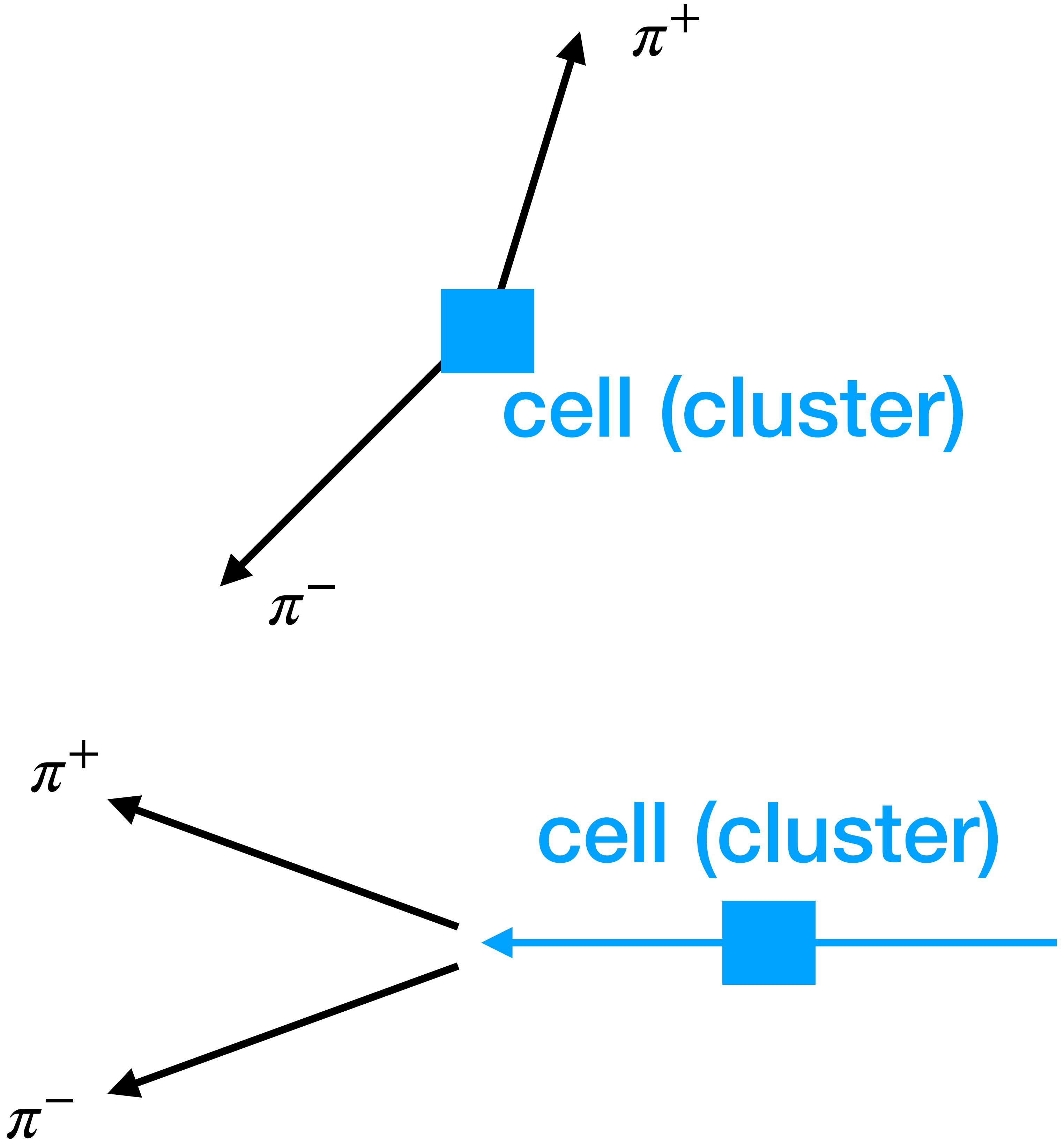
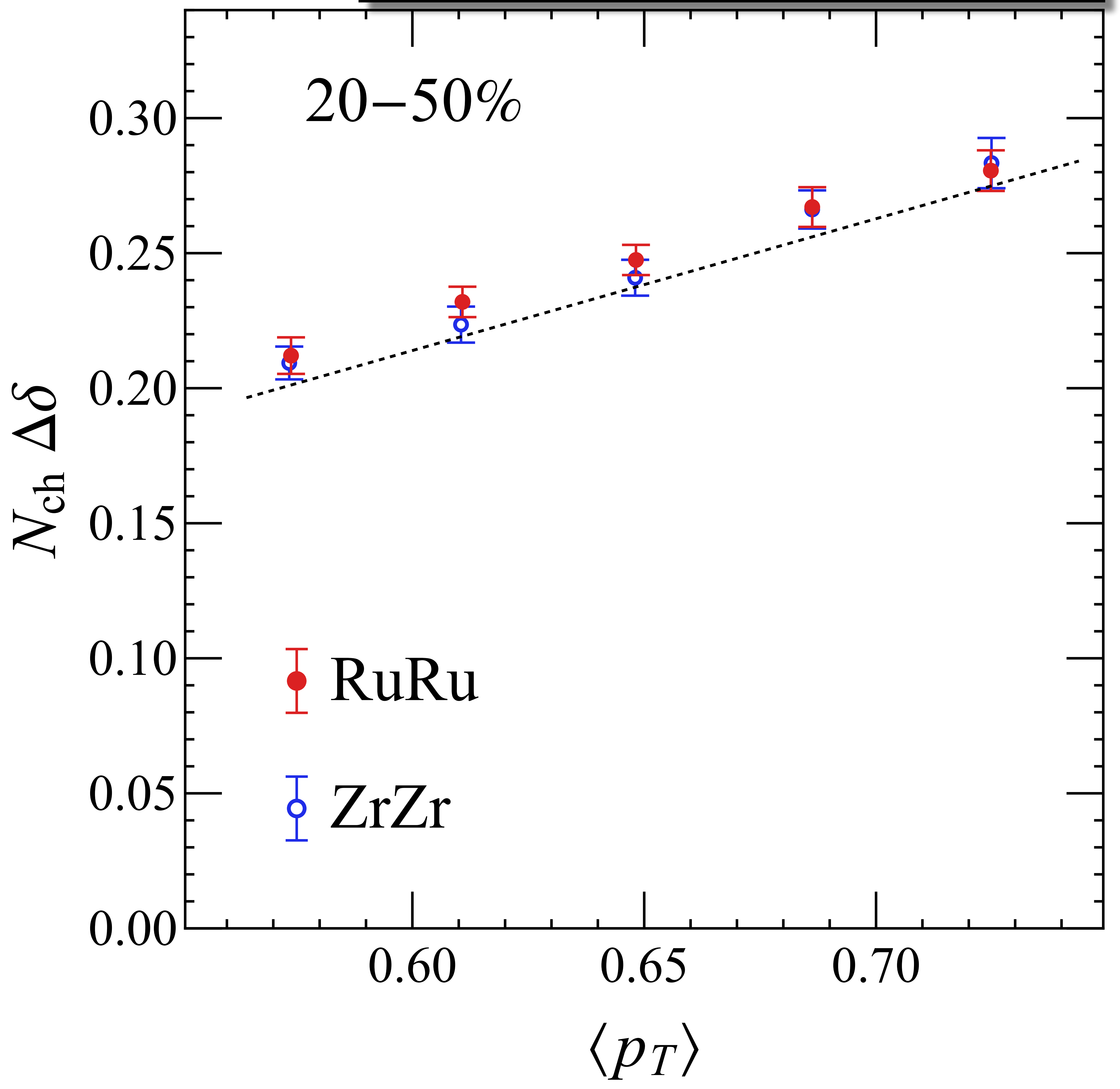
analog picture for
local charge conservation



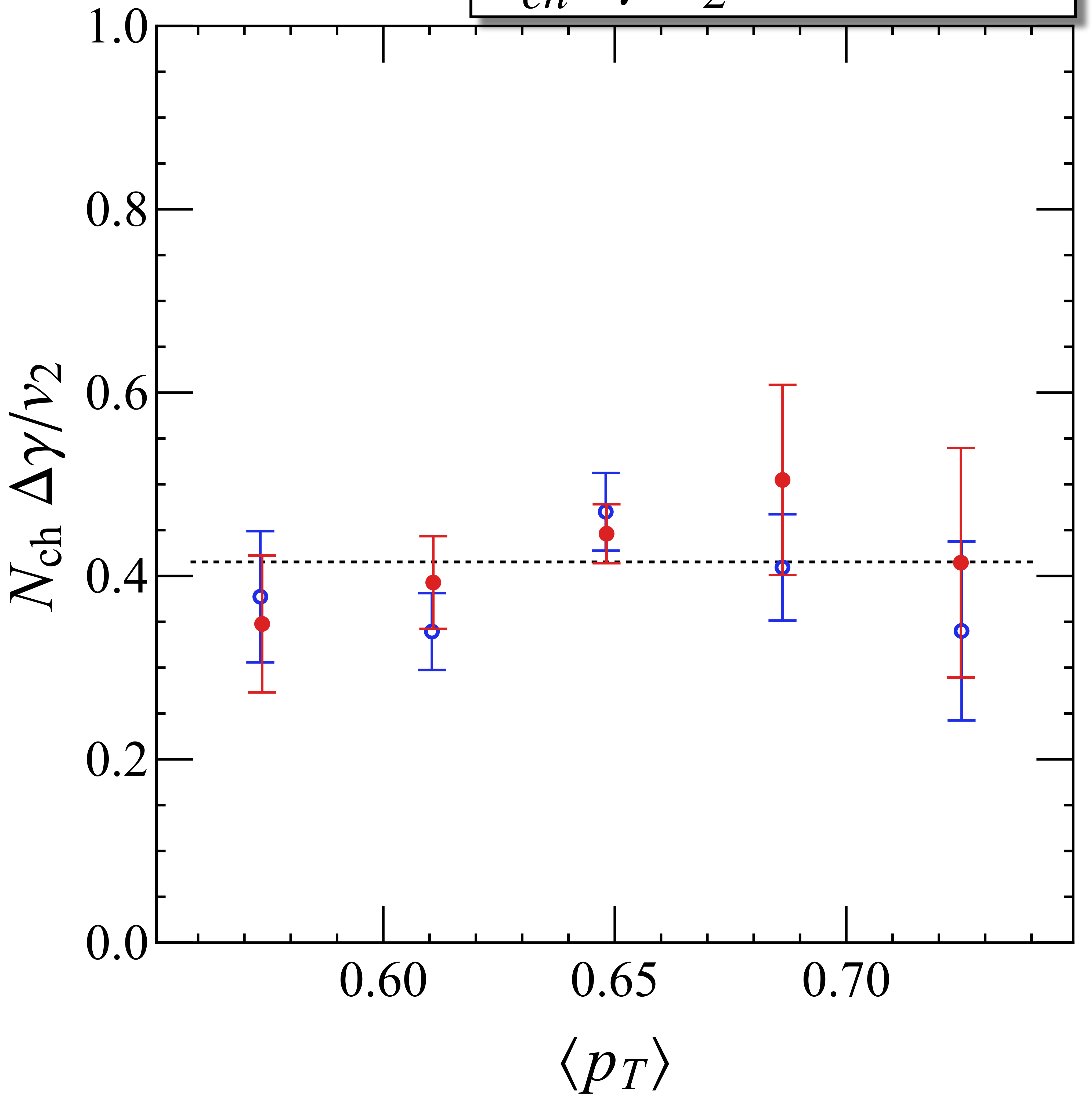
$\langle p_T \rangle$-dependence of background   [hydro simulation]

CME turned-off in simulations; divide the event-set into five bins, according to $\langle p_T \rangle$

linear dependence of $N_{ch}\Delta\delta$



$N_{ch}\Delta\gamma/v_2$ is insensitive



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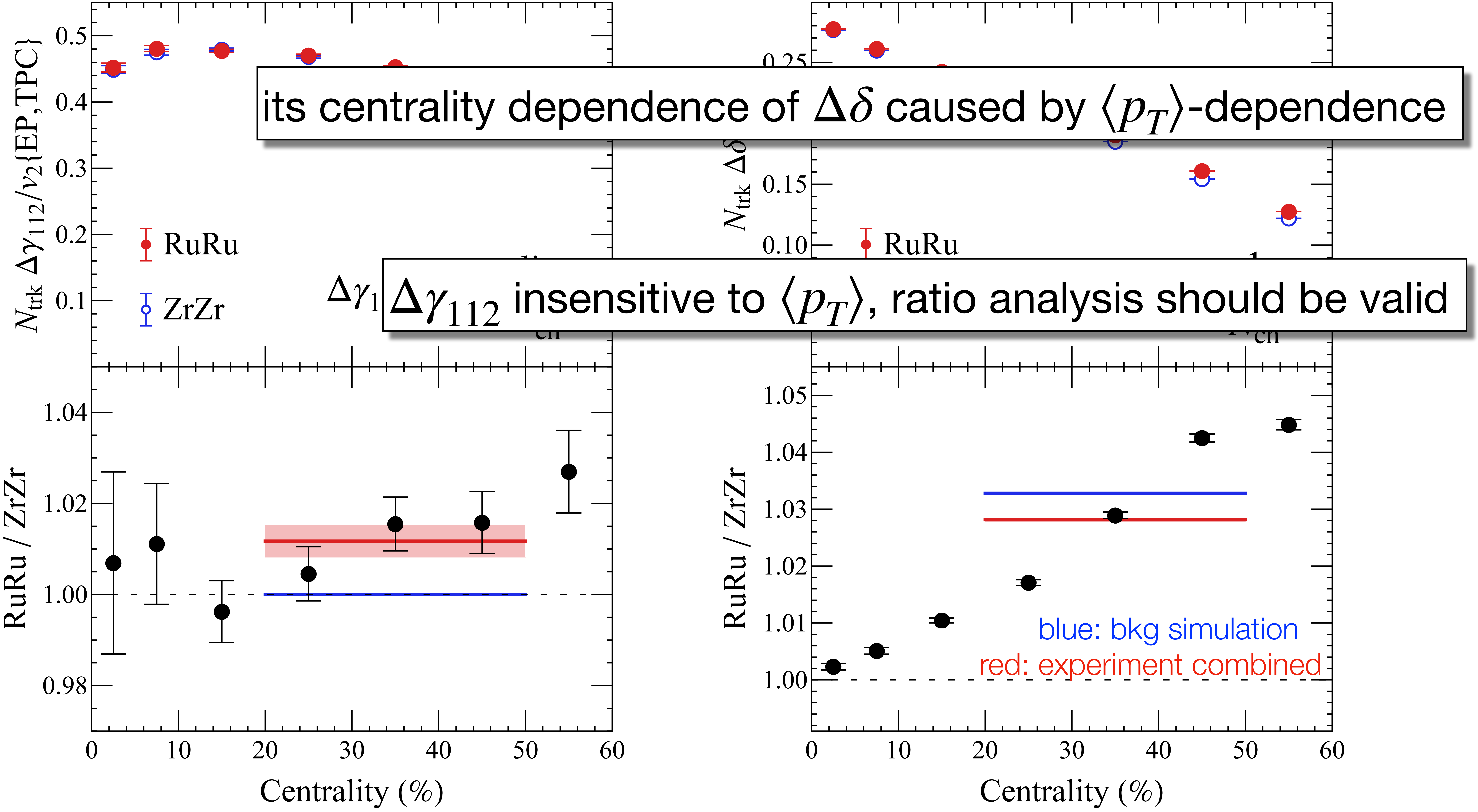

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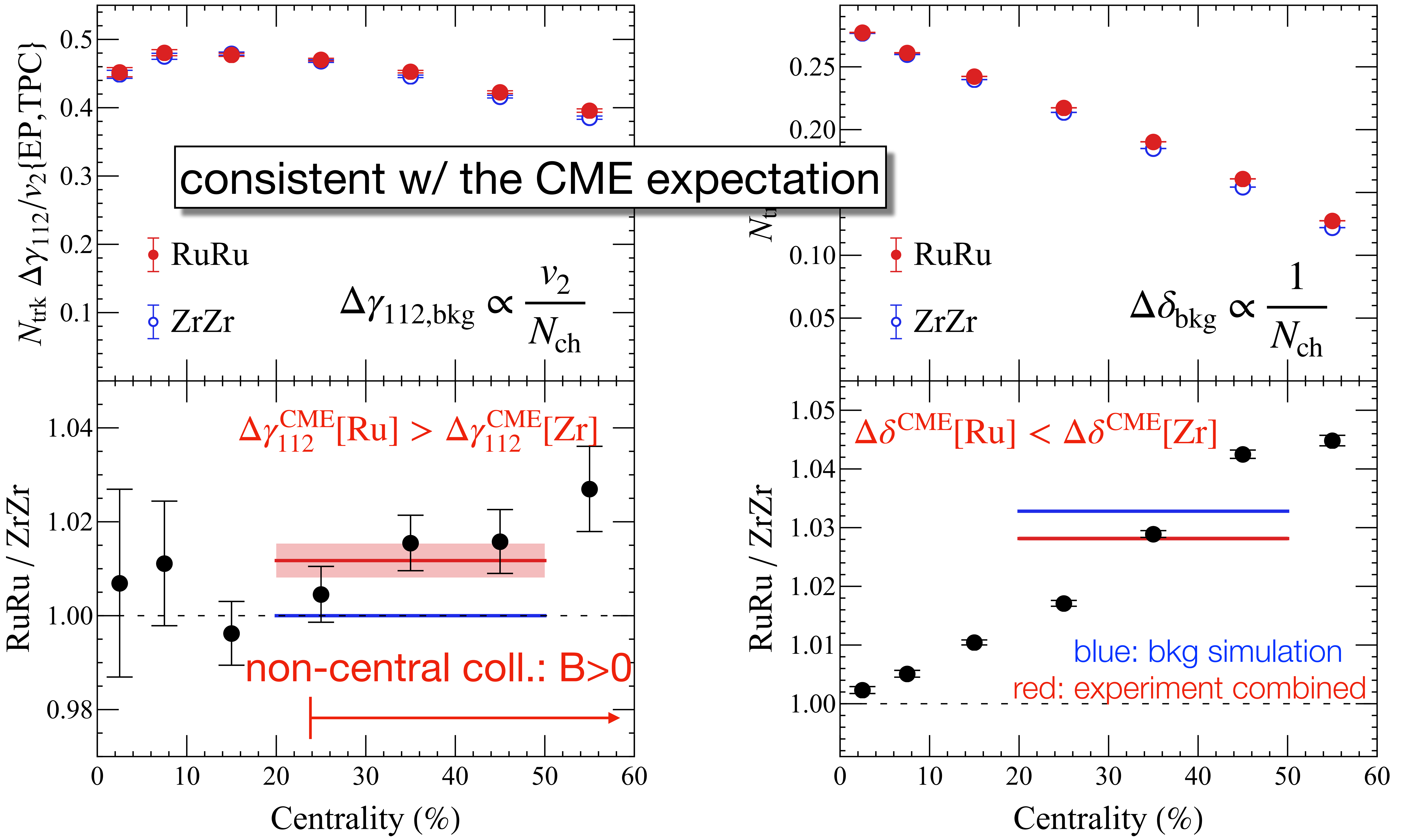
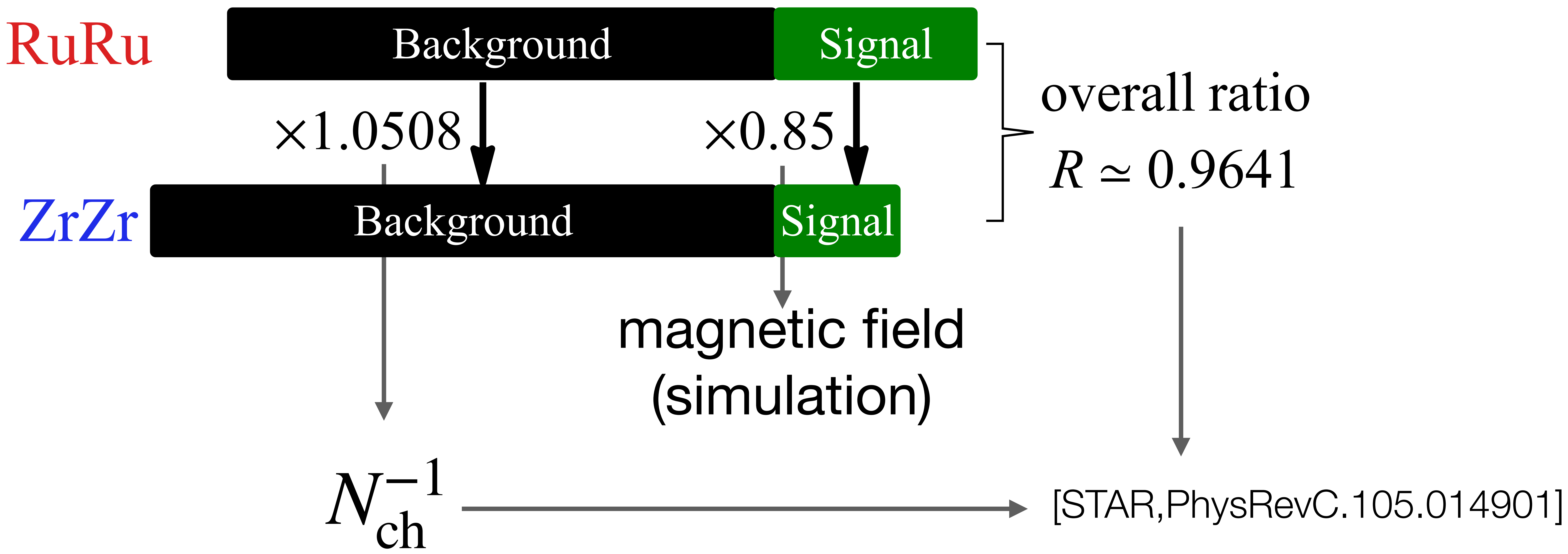


what we learned from the ratio of $\bar{\gamma} \equiv \gamma / v_2$



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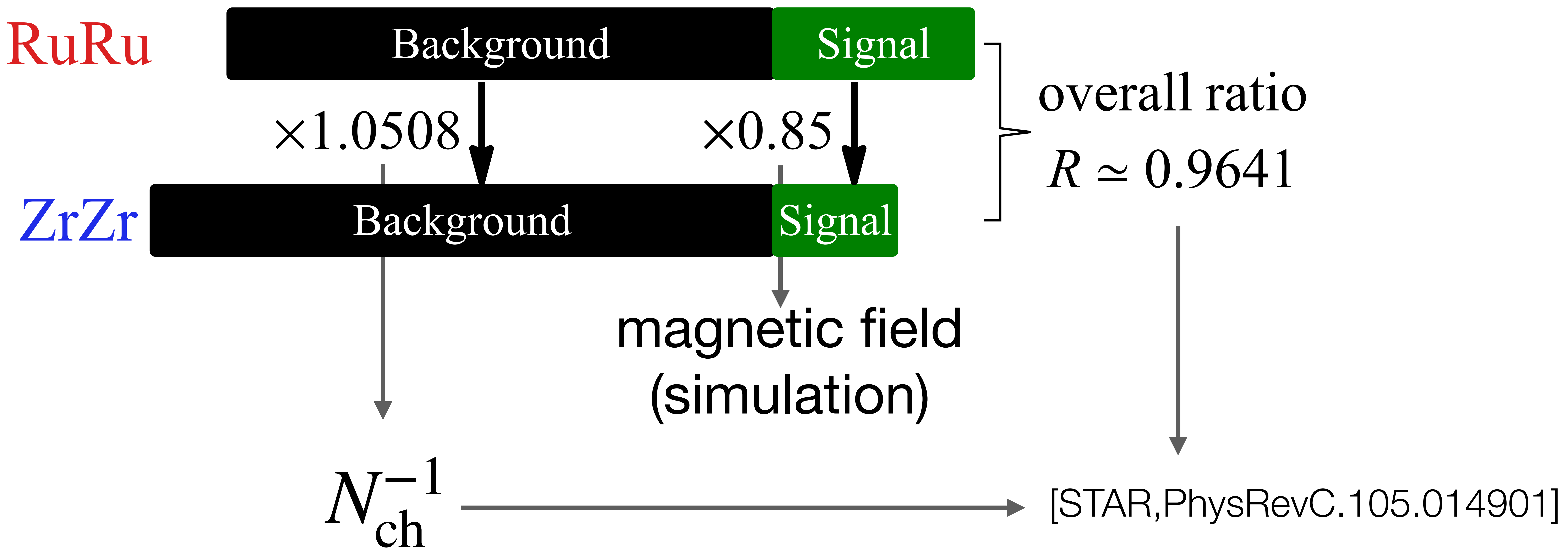
$$f_s \equiv \bar{\gamma}_{\mathrm{sgn}}/\bar{\gamma}$$

$$\bar{\gamma}_{\mathrm{Ru}} = (1 - f_s)\bar{\gamma}_{\mathrm{Ru}} + f_s\,\bar{\gamma}_{\mathrm{Ru}}$$

$$\bar{\gamma}_{\mathrm{Zr}} = 0.9641\,\bar{\gamma}_{\mathrm{Ru}} = 1.0508\,(1 - f_s)\bar{\gamma}_{\mathrm{Ru}} + 0.85\,f_s\,\bar{\gamma}_{\mathrm{Ru}}$$



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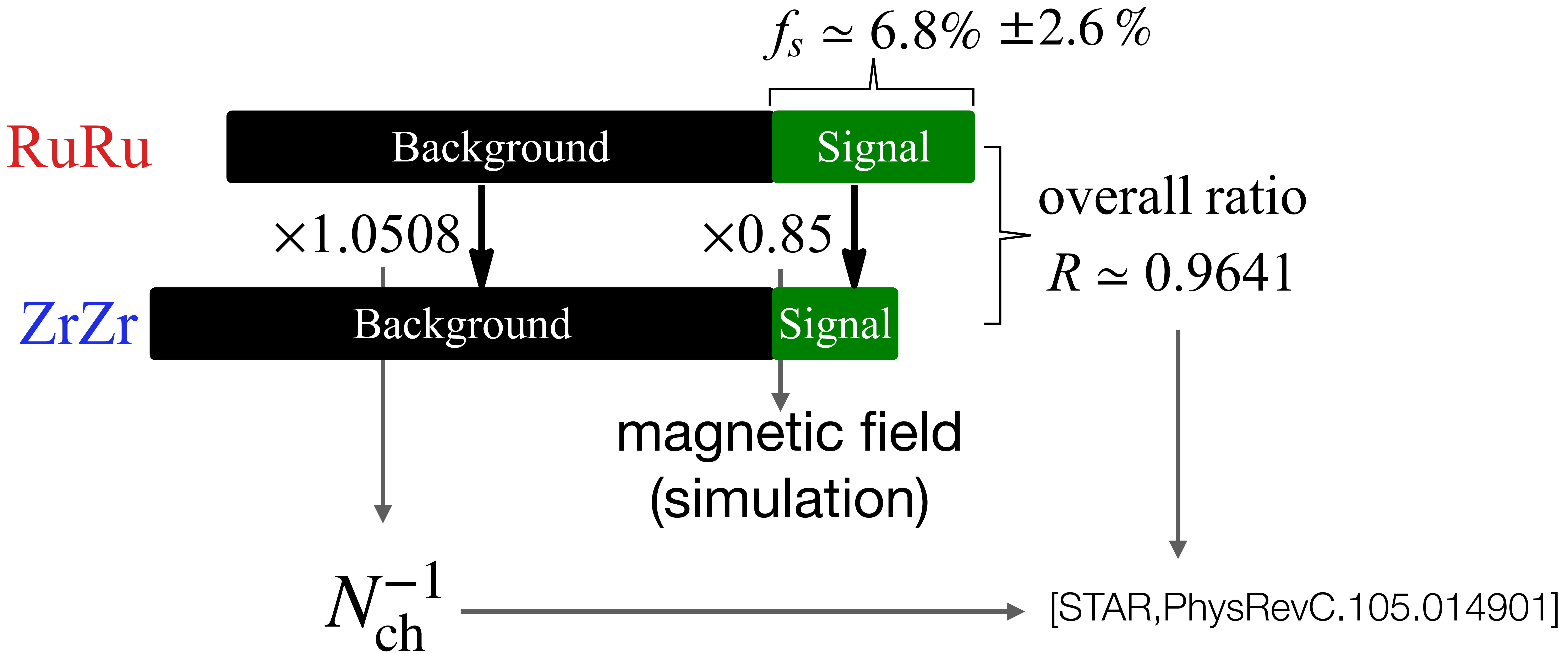

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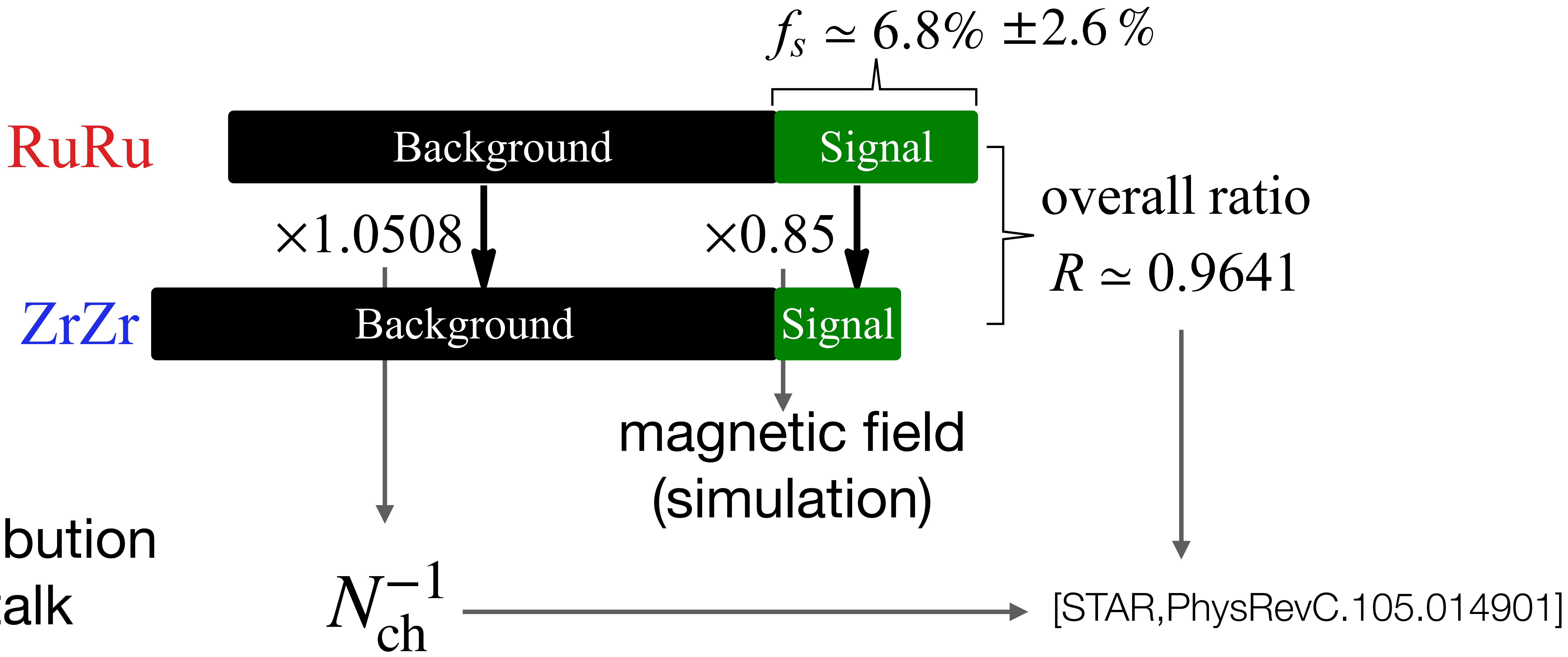

non-flow contribution
see F. Wang's talk

other effects?

M. Buzzegoli, D. Kharzeev, Y.-C. Liu, *SS*, S. Voloshin, H.-U. Yee, PhyRevC.106.L051902

shear-induced chiral effects

shear-induced
CME and CVE

$$J^{\mu}_{\mathrm{siCME}} \propto \mu_5\, \sigma^{\mu\nu} B_{\nu}$$

$$J^{\mu}_{\mathrm{siCVE}} \propto \mu_5\, \mu\, \sigma^{\mu\nu} \omega_{\nu}$$

shear-induced chiral effects

shear-induced CME and CVE	CME and CVE
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$J^{\mu}_{\mathrm{siCVE}} \propto \mu_5\, \mu\, \sigma^{\mu\nu} \omega_{\nu}$	$J^{\mu}_{\mathrm{CVE}} \propto \mu_5\, \mu\, \omega^{\mu}$
~ perpendicular	parallel/antiparallel

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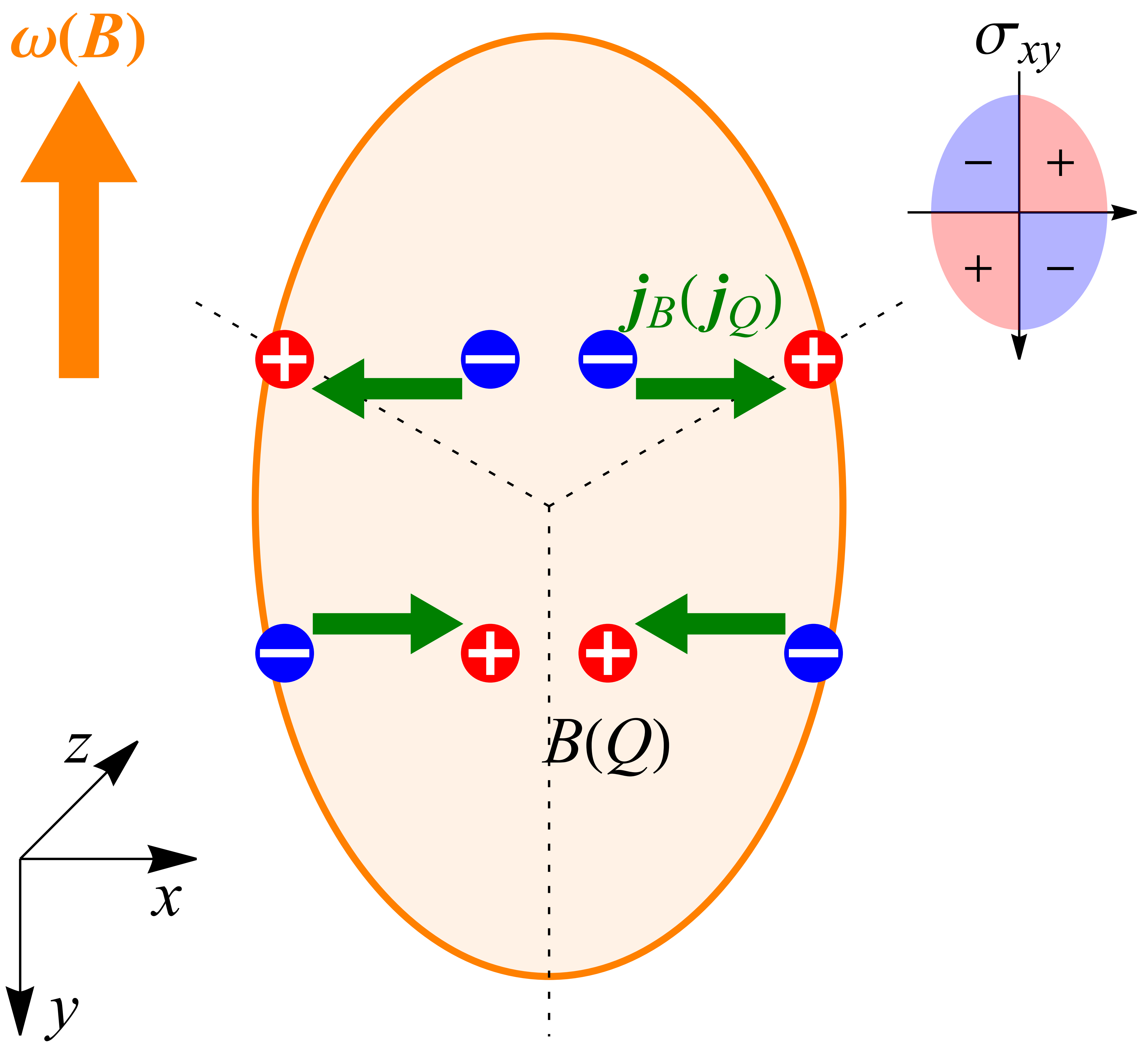

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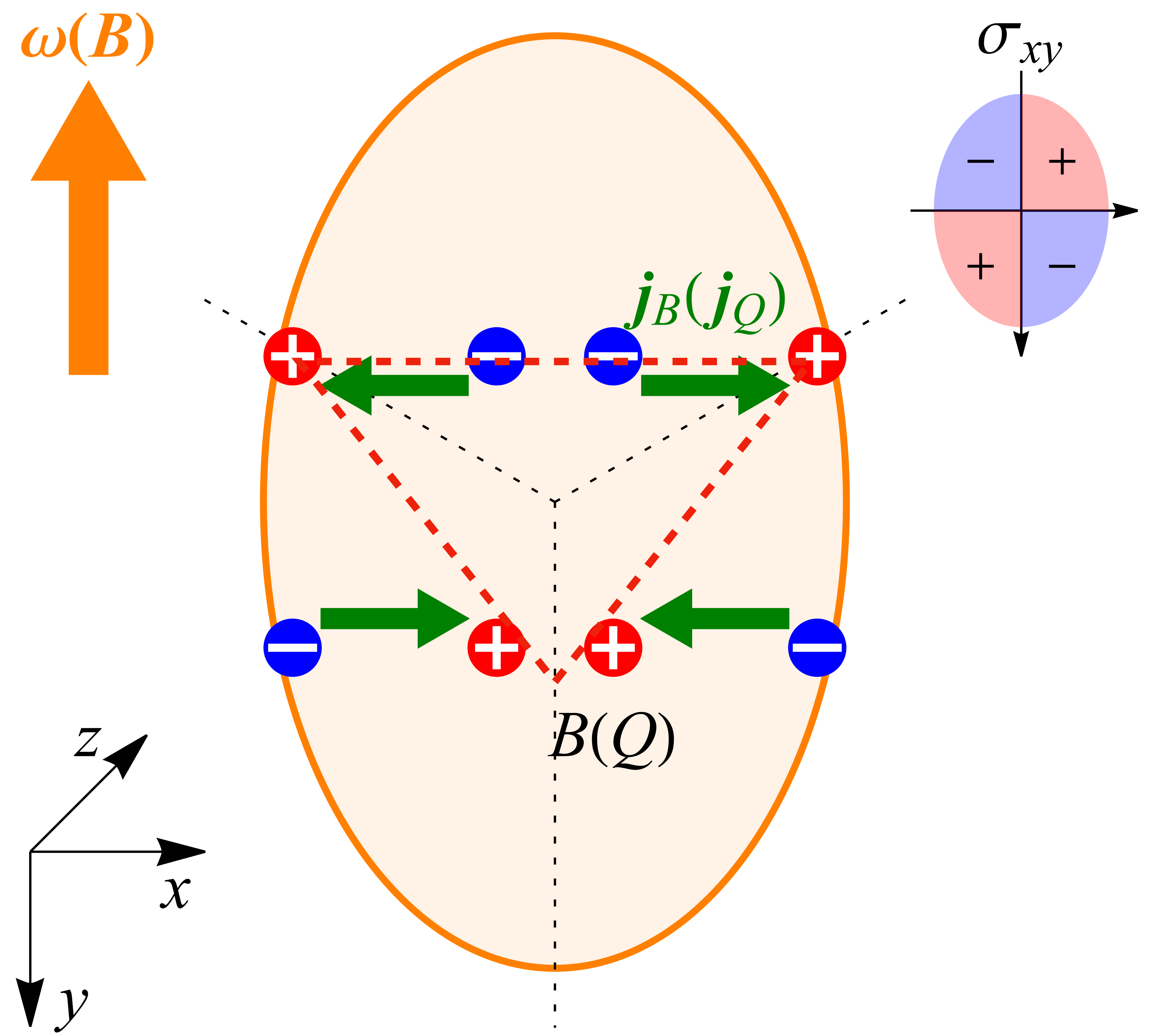

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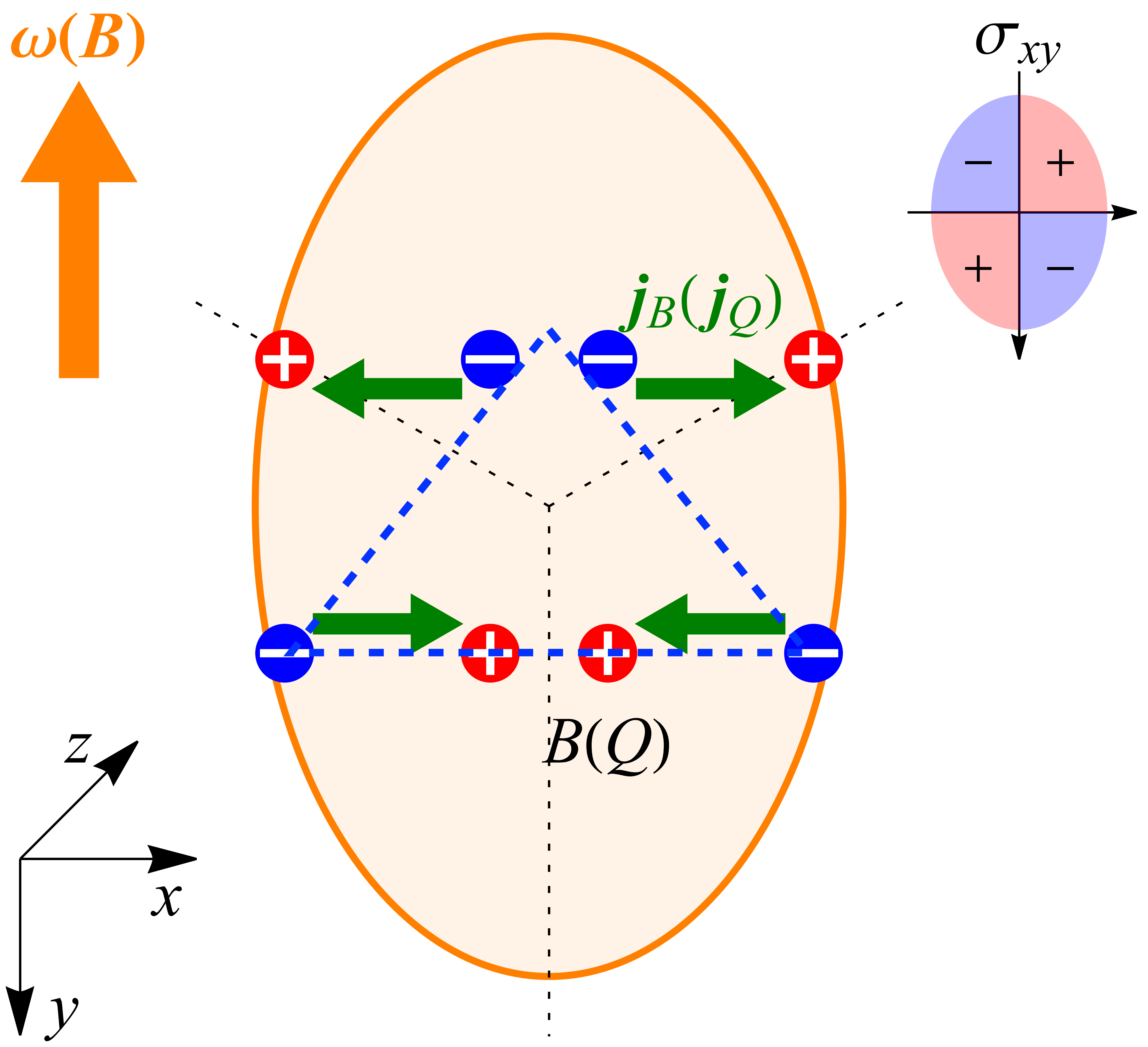
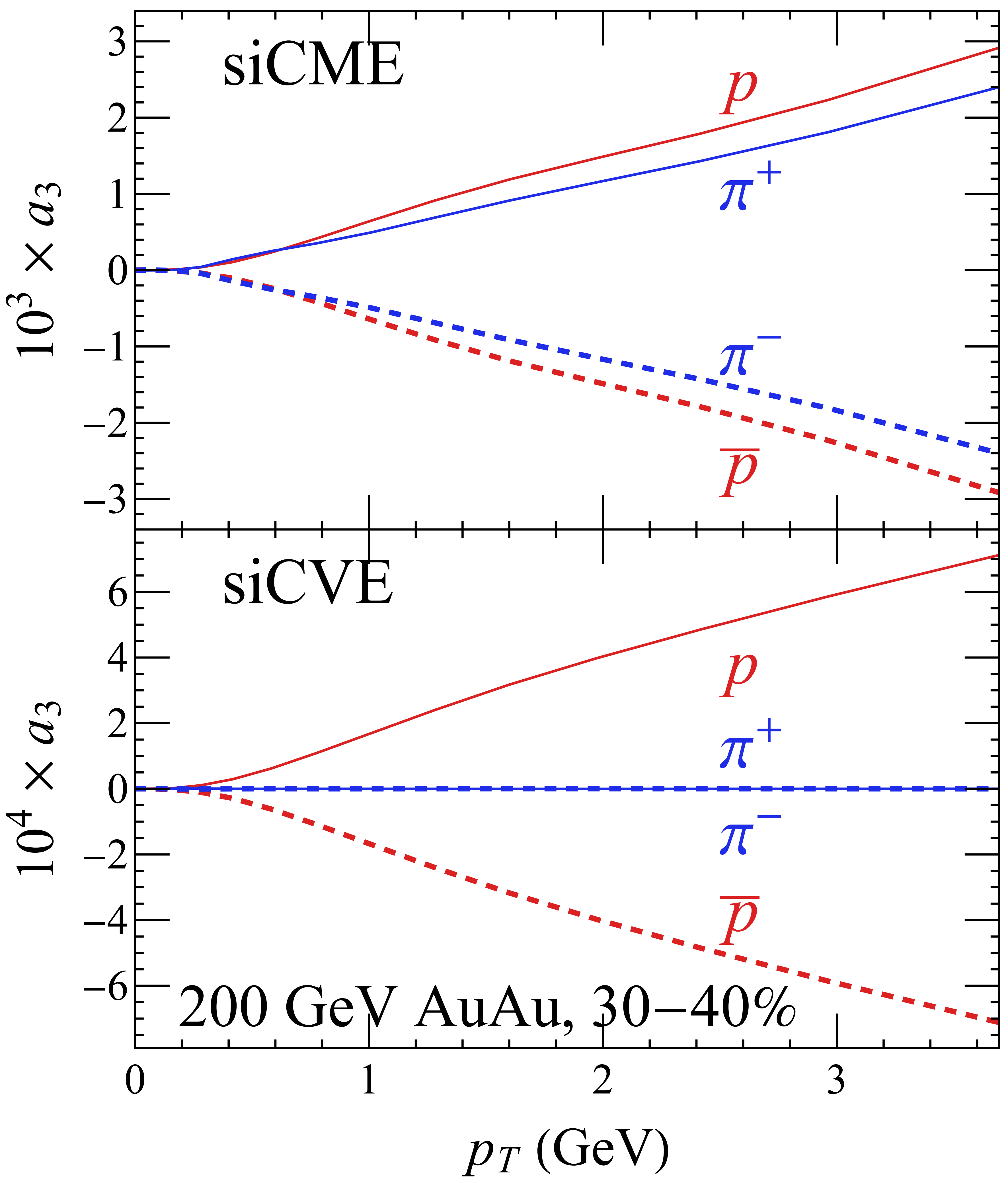
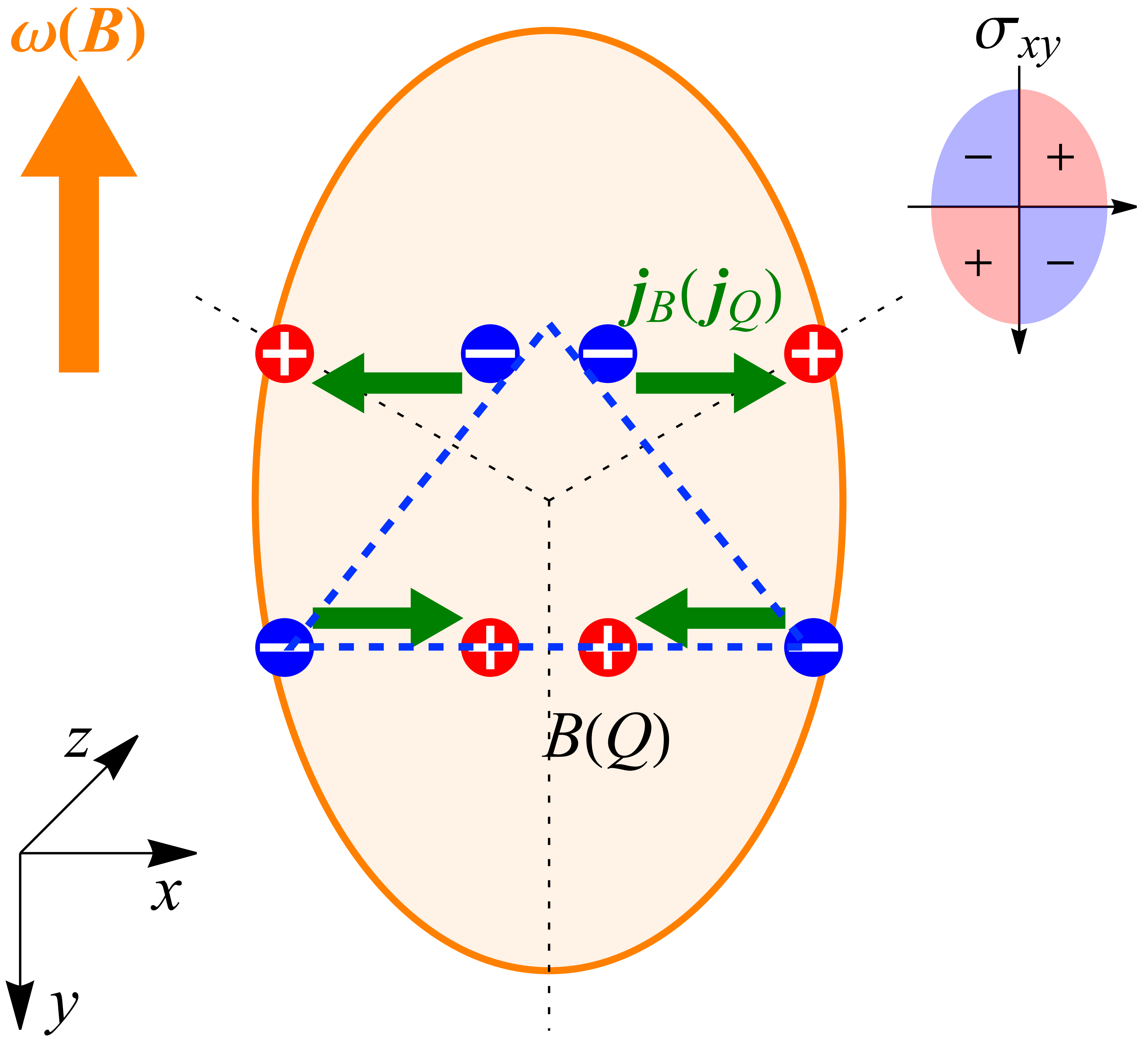


$$a^{+}_{3,\rm RP} = -\, a^{-}_{3,\rm RP} \neq 0$$

shear-induced chiral effects



(events with $\mu_5 > 0$)



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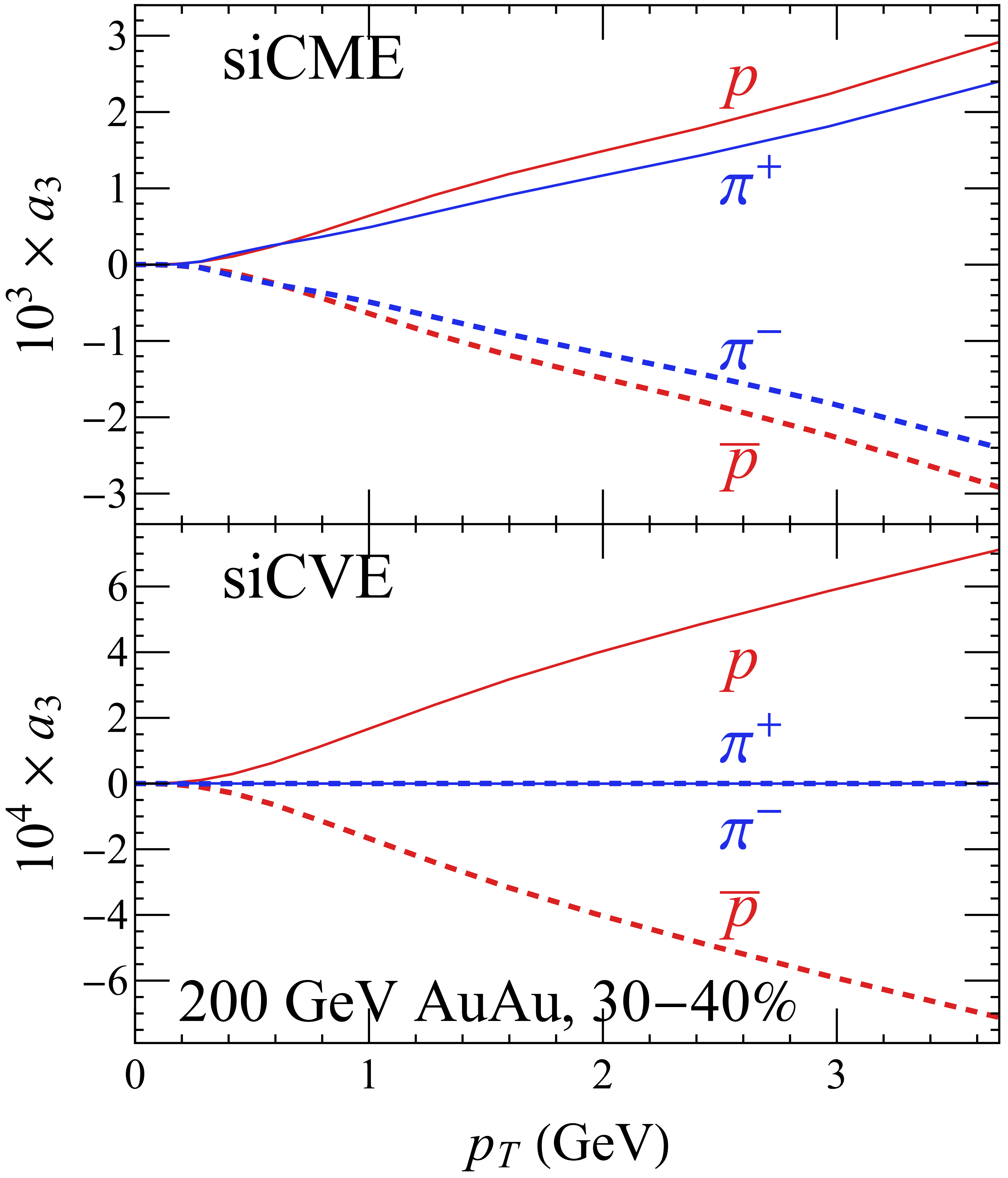
shear-induced chiral effects

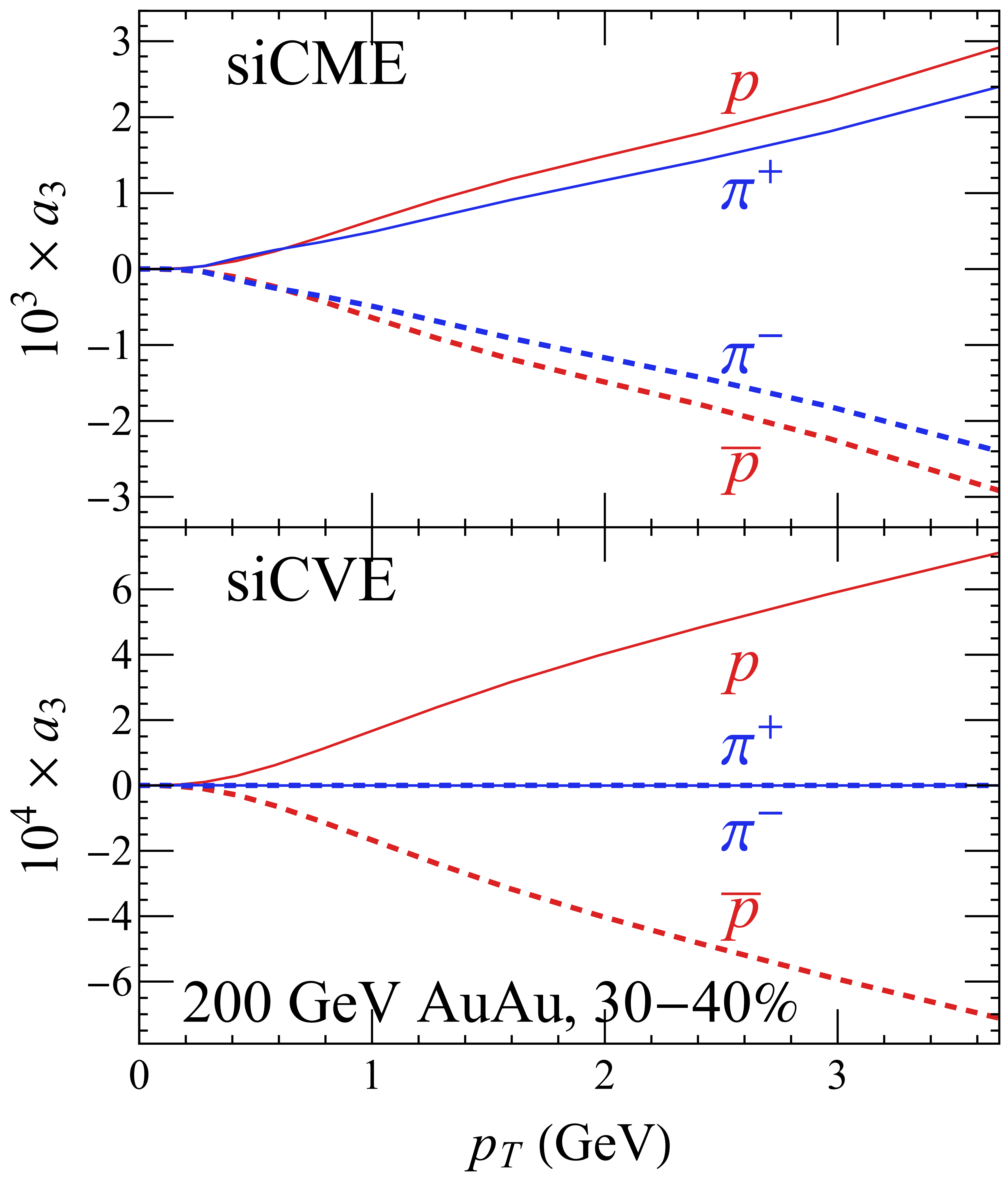


(events with $\mu_5 > 0$)

$$\gamma_3^{ab} \equiv \cos(3\phi_a + 3\phi_b - 6\Psi_{\rm RP})$$

$$a^+_{3,\rm RP} = -a^-_{3,\rm RP} \neq 0$$

shear-induced chiral effects



(events with $\mu_5 > 0$)

$$\Delta\gamma_3 \equiv \gamma_3^{\mathrm{SS}} - \gamma_3^{\mathrm{OS}}$$

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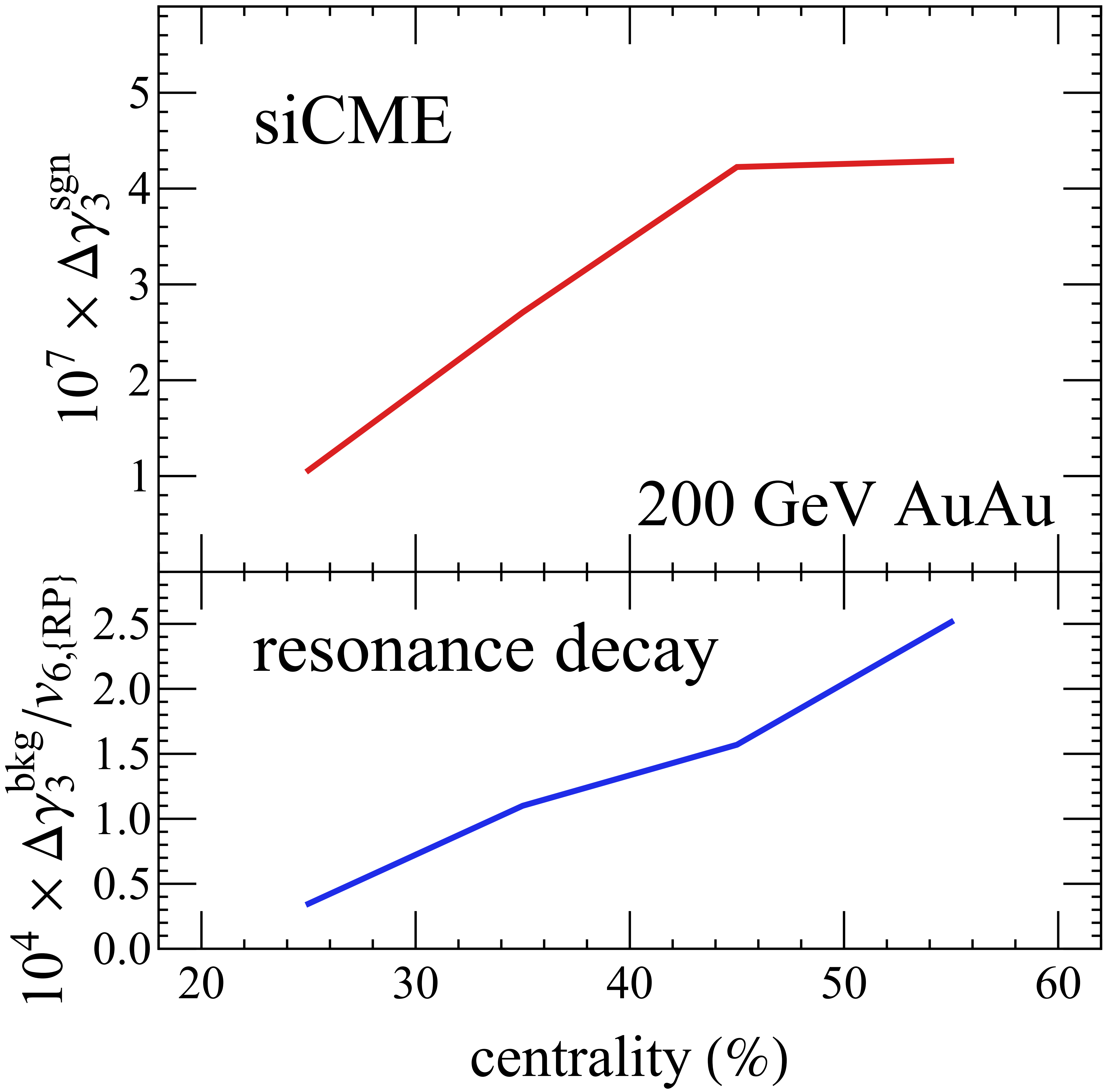
shear-induced chiral effects

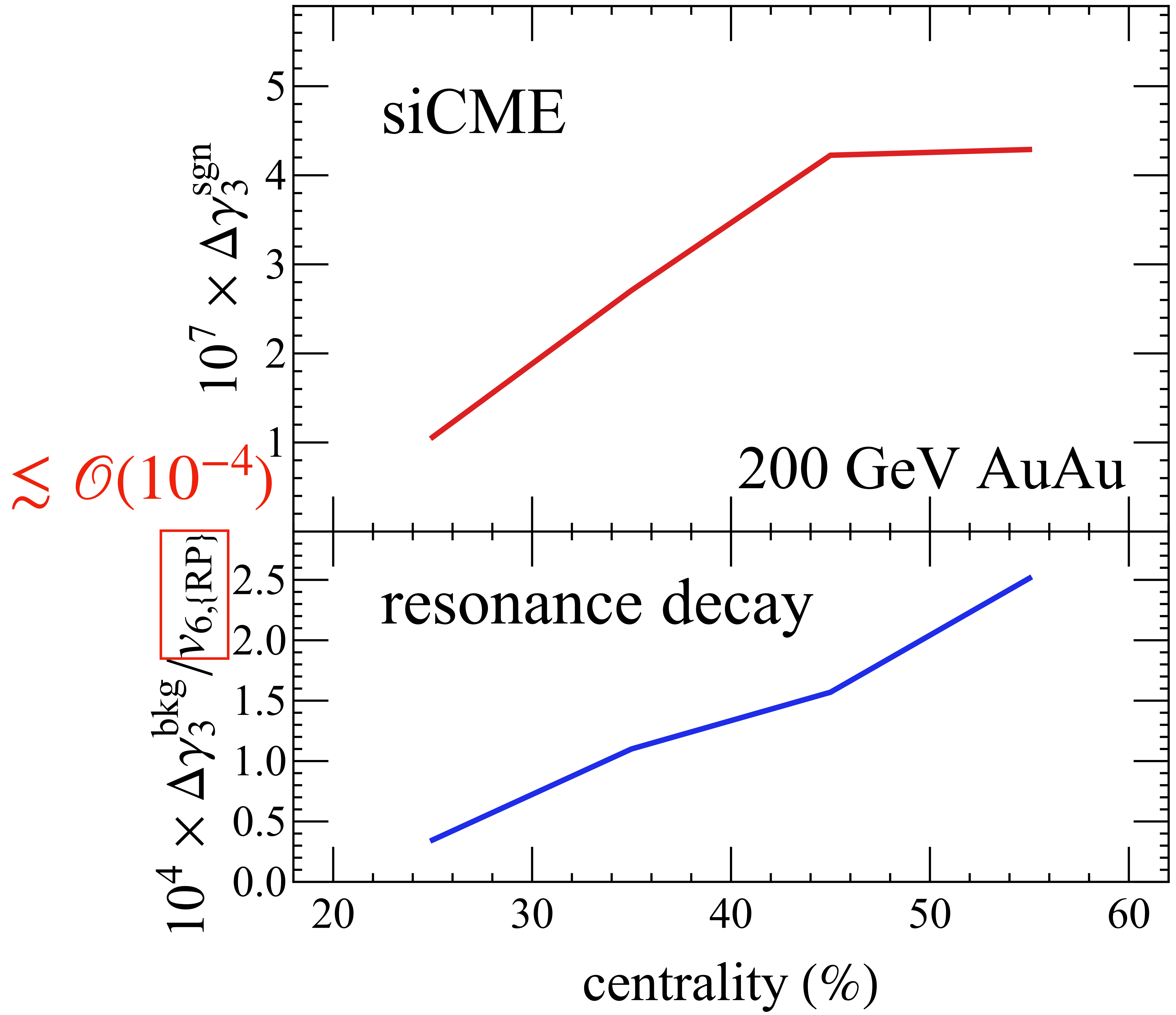


$$\Delta\gamma_3 \equiv \gamma_3^{SS} - \gamma_3^{OS}$$

(resonance) background:

$$\begin{aligned}
&\cos(3\phi_a + 3\phi_b - 6\Psi_{\rm RP}) \\
\approx\ &\cos(3\phi_a + 3\phi_b - 6\phi_{\rm res}) \\
&\times \cos(6\phi_{\rm res} - 6\Psi_{\rm RP}) \\
=\ &\cos(3\phi_a + 3\phi_b - 6\phi_{\rm res})\, v_{6,\rm RP}^{\rm res}
\end{aligned}$$

shear-induced chiral effects



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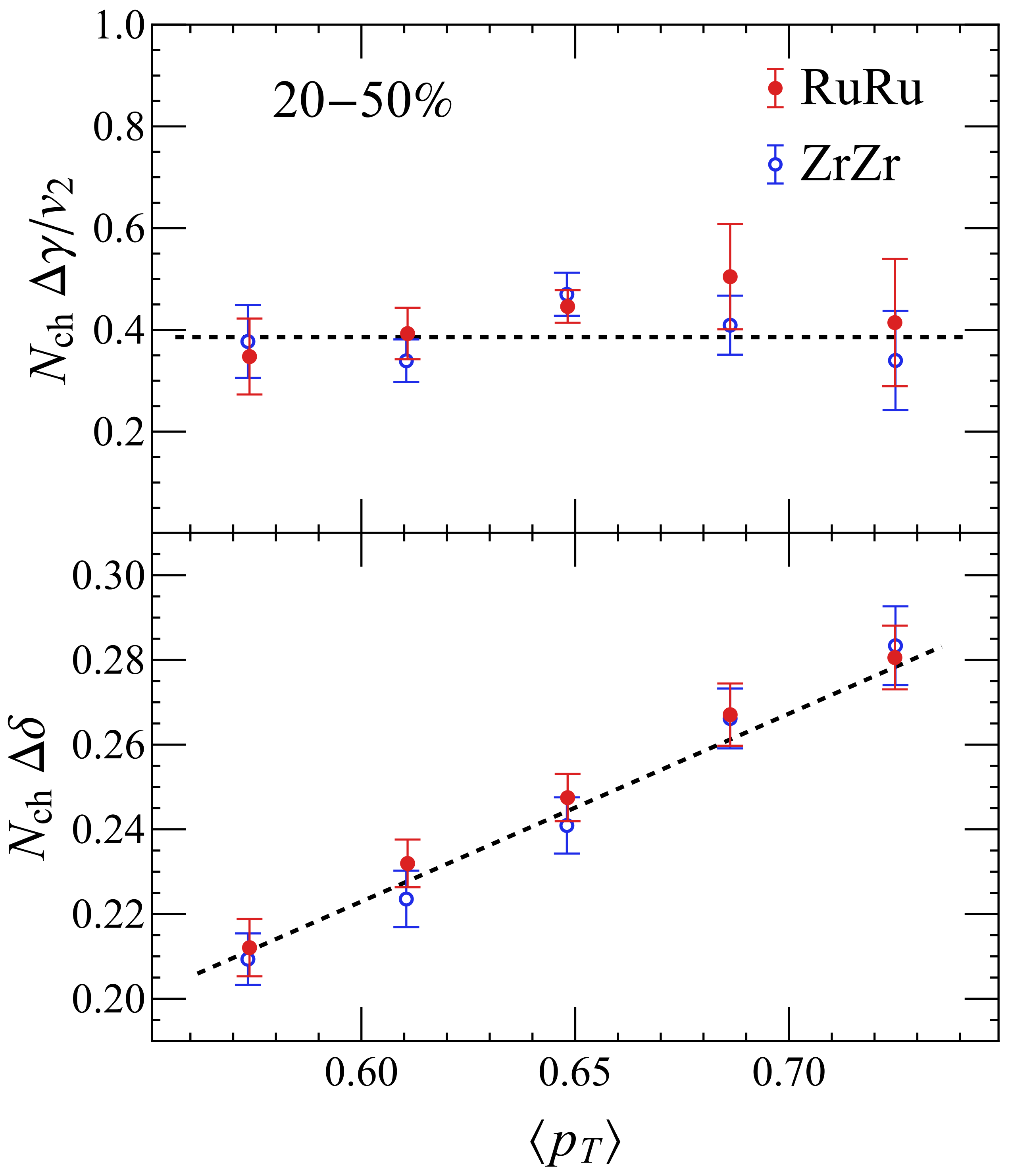
&\quad \times \cos(6\phi_{\rm res} - 6\Psi_{\rm RP}) \\
&= \cos(3\phi_a + 3\phi_b - 6\phi_{\rm res})\, v_{6,\rm RP}^{\rm res}
\end{aligned}$$

Summary

- centrality dependence of scaled-$\Delta\delta$ caused by $\langle p_T \rangle$
- $\Delta\gamma_{112}$ insensitive to $\langle p_T \rangle$
- can be tested in experiments!!!
- given these Ansatzes, STAR-isobar results are consistent with CME expectation.



- shear-induced chiral effects predicts 3rd order sign-sensitive correlations. A small background is expected.

backup

hydro results: Govert Nijs, Wilke van der Schee, 2112.13771 [nucl-th]

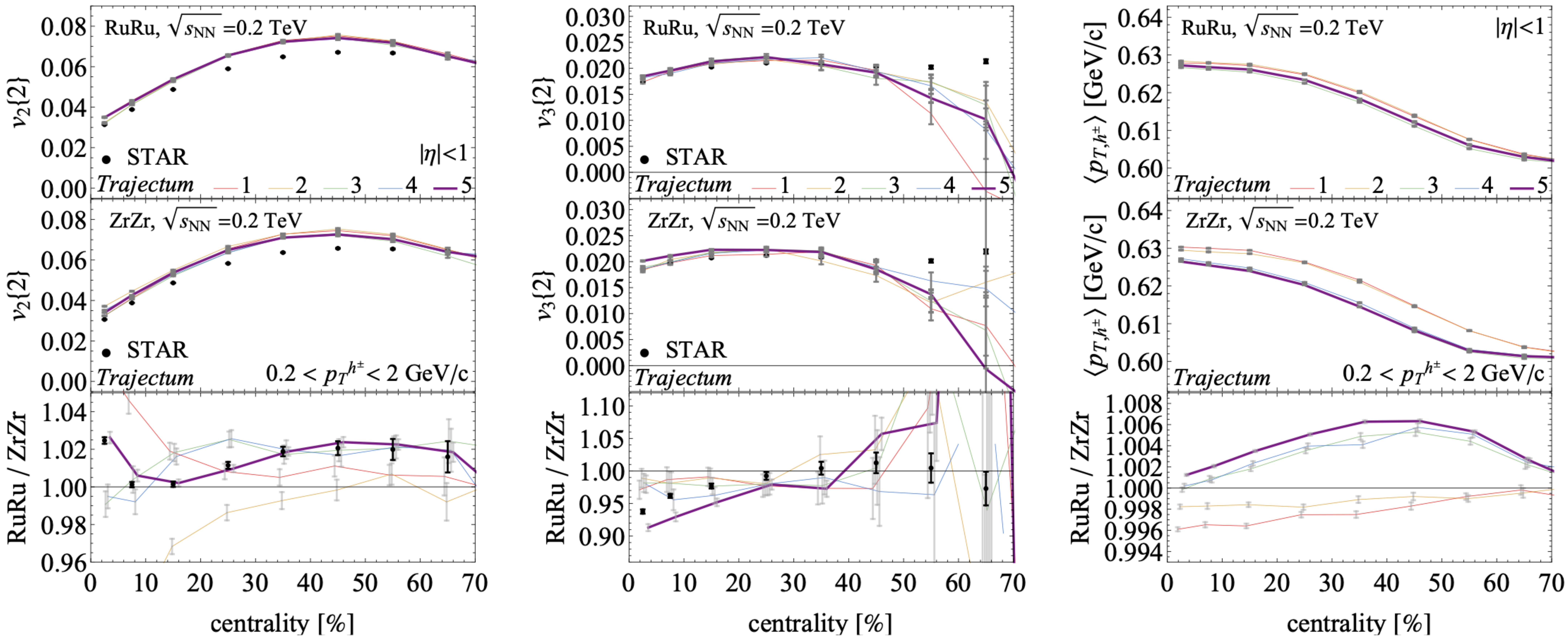
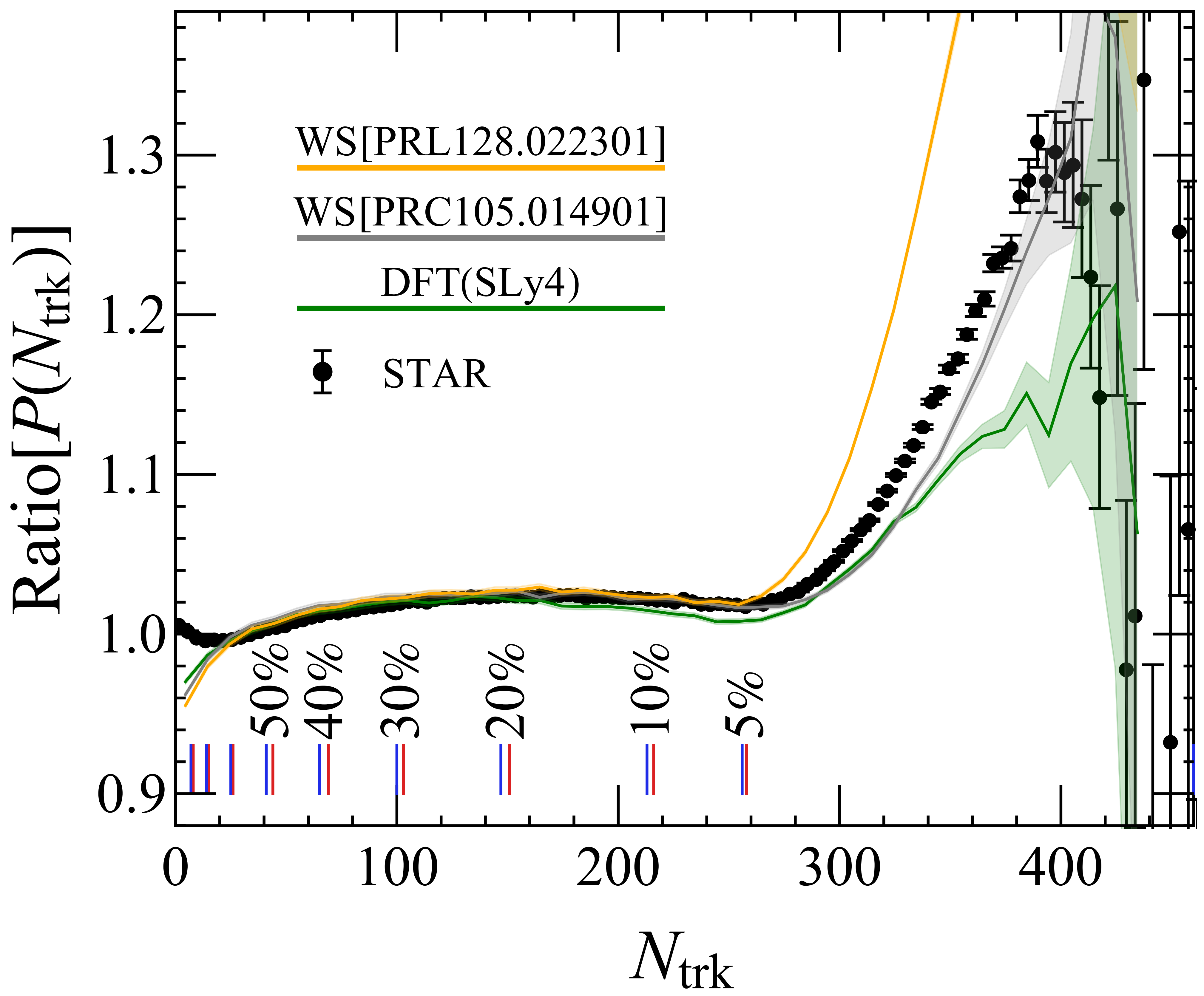
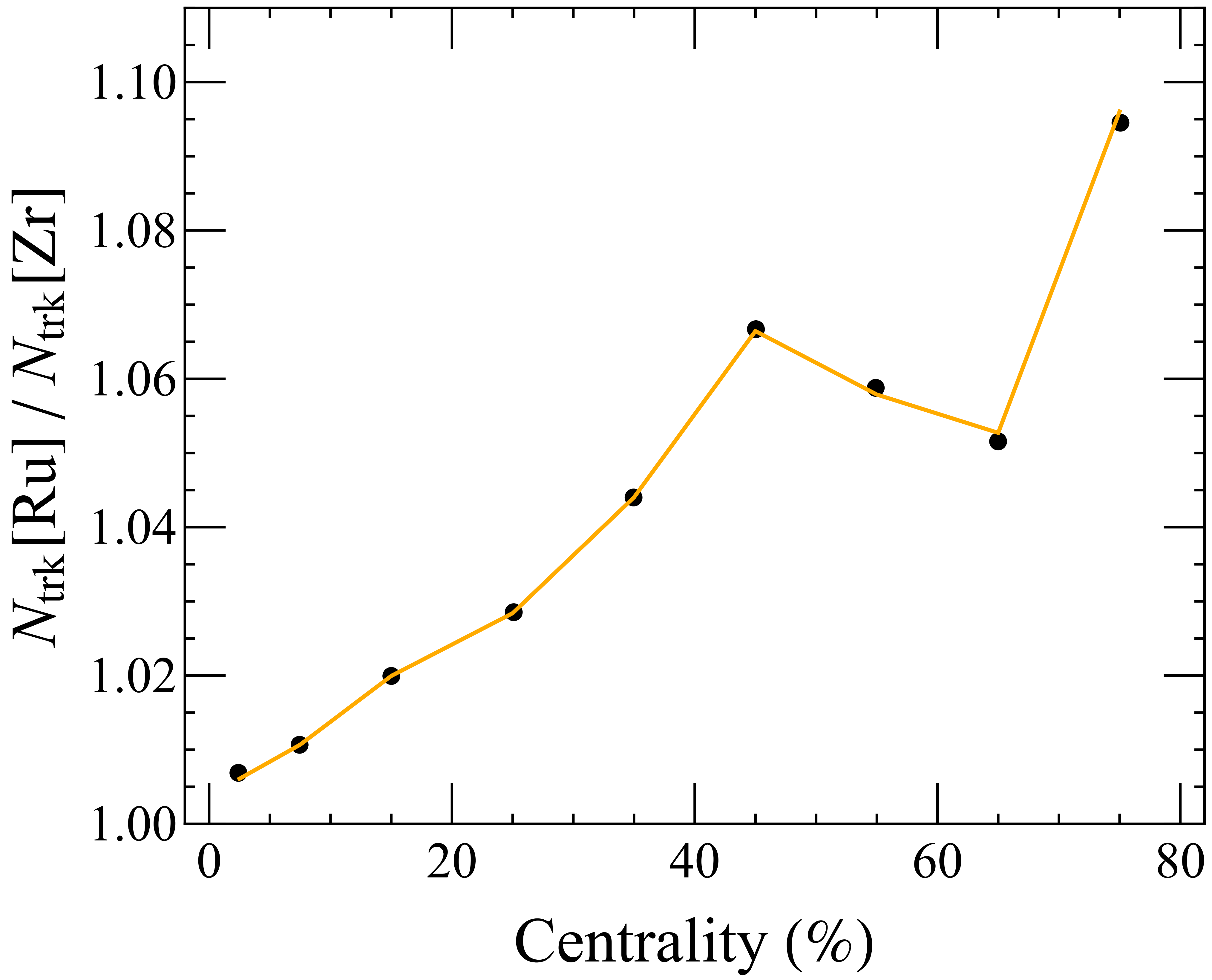


FIG. 2. We show $v_2\{2\}$ (left), $v_3\{2\}$ (middle) and $\langle p_T \rangle$ (right) for $^{96}_{44}$Ru (top), $^{96}_{40}$Zr (middle) and their ratio (bottom) for all five cases of Tab. I together with STAR data [1]. Note that *Trajectum* is only tuned to LHC energies and hence an absolute agreement is not expected. Case 5 is the only case with an octupole deformation β_3, which leads to a qualitative agreement for the $v_3\{2\}$ ratios and full consistency for the $v_2\{2\}$ ratios. All theoretical uncertainties are statistical only (gray).





difference in bulk background reproduced