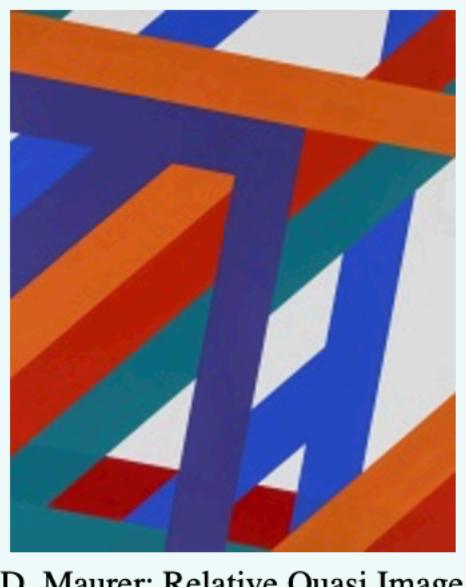




Chiral Magnetic Effect (CME) from Anomalous-Viscous Fluid Dynamics (AVFD) simulation framework

Shuzhe Shi (Stony Brook Univ.)

ZIMÁNYI SCHOOL 2021



21st ZIMÁNYI SCHOOL
WINTER WORKSHOP
ON HEAVY ION PHYSICS

December 6-10, 2021

Budapest, Hungary



József Zimányi (1931 - 2006)

refs:

- w/ Kharzeev, Liao, in progress;
SS, Zhang, Hou, and Liao, Phys.Rev.Lett. 125 (2020) 242301;
SS, Jiang, Lilleskov, and Liao, Annals Phys. 394 (2018) 50;
Jiang, SS, Yin, and Liao, Chin.Phys.C 42 (2018) 1, 011001.

Chiral Magnetic Effect

For right-handed particles w/ positive charge:

$$1. p \parallel \vec{S} \parallel \vec{\mu}$$

$$2. \text{Energy} = -\vec{\mu} \cdot \vec{B}$$

⇒ lower energy if moving along B field direction

$$\mathbf{J} = \sigma_5 \mu_5 \mathbf{B}$$

Transport Equations

$$D_\mu J_R^\mu = + \frac{N_c q^2}{4\pi^2} E_\mu B^\mu$$

$$D_\mu J_L^\mu = - \frac{N_c q^2}{4\pi^2} E_\mu B^\mu$$

$$J_R^\mu = n_R u^\mu + \nu_R^\mu + \frac{N_c q}{4\pi^2} \mu_R B^\mu$$

$$J_L^\mu = n_R u^\mu + \nu_R^\mu - \frac{N_c q}{4\pi^2} \mu_R B^\mu$$

CME

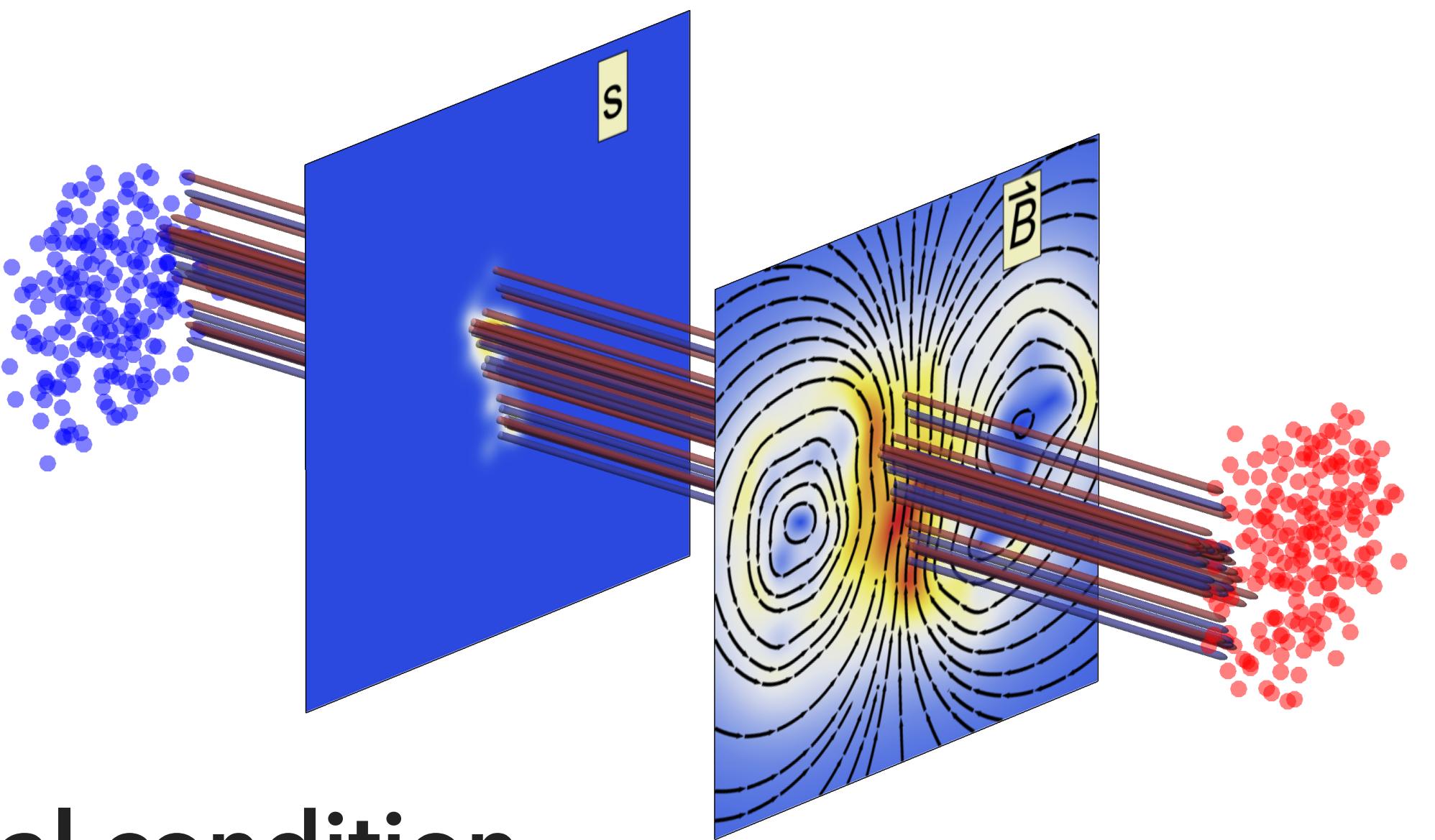
Viscous Effect

$$\Delta^\mu{}_\nu d\nu_{R/L}^\mu = - \frac{1}{\tau_r} (\nu_{R/L}^\mu - \nu_{NS}^\mu)$$

$$\nu_{NS}^\mu = \frac{\sigma}{2} T \nabla^\mu \frac{\mu}{T} + \frac{\sigma}{2} q E^\mu$$

The AVFD simulation package

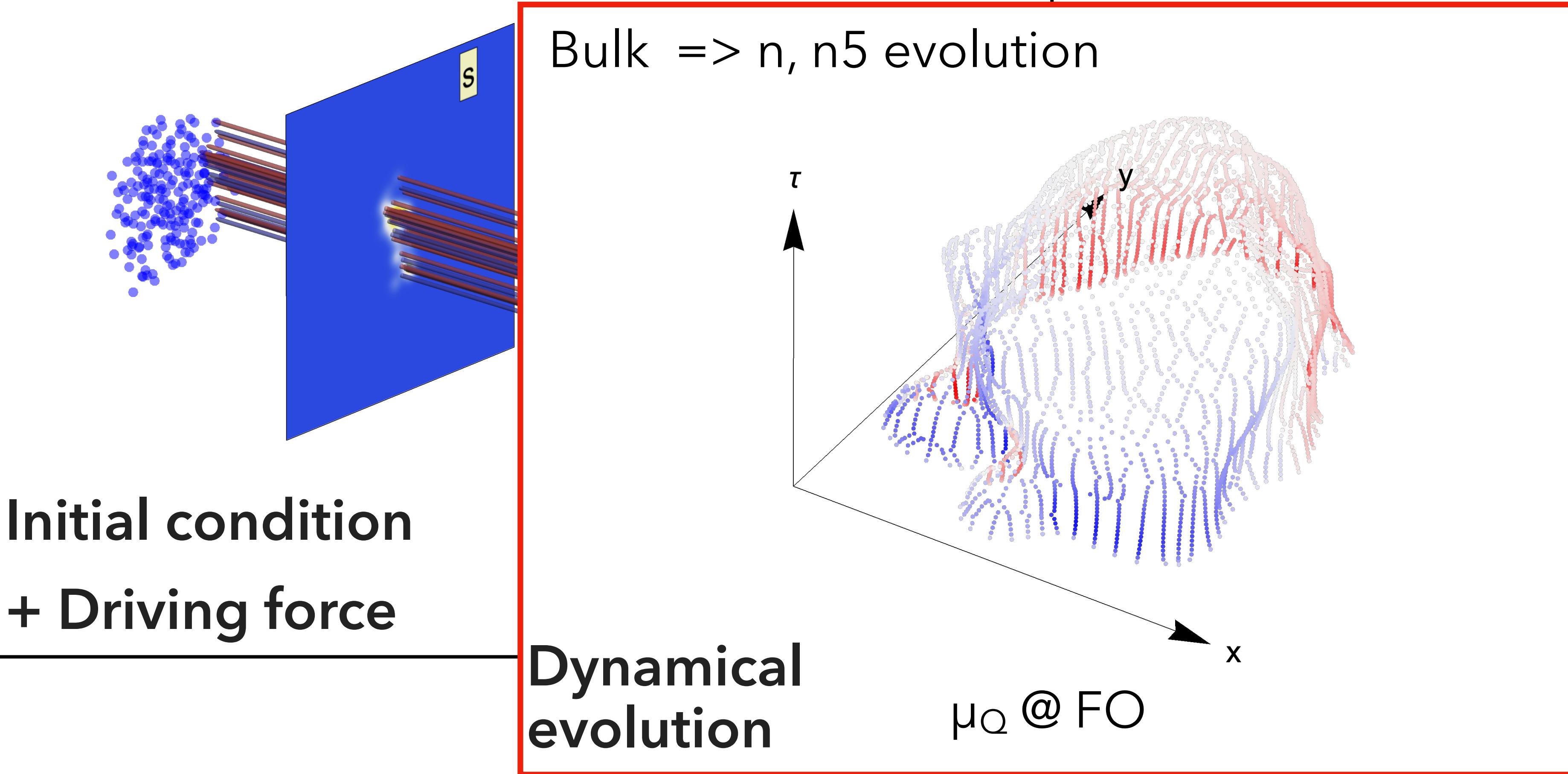
E-by-E IC of Bulk, n, n5, and B field



**Initial condition
+ Driving force**

The AVFD simulation package

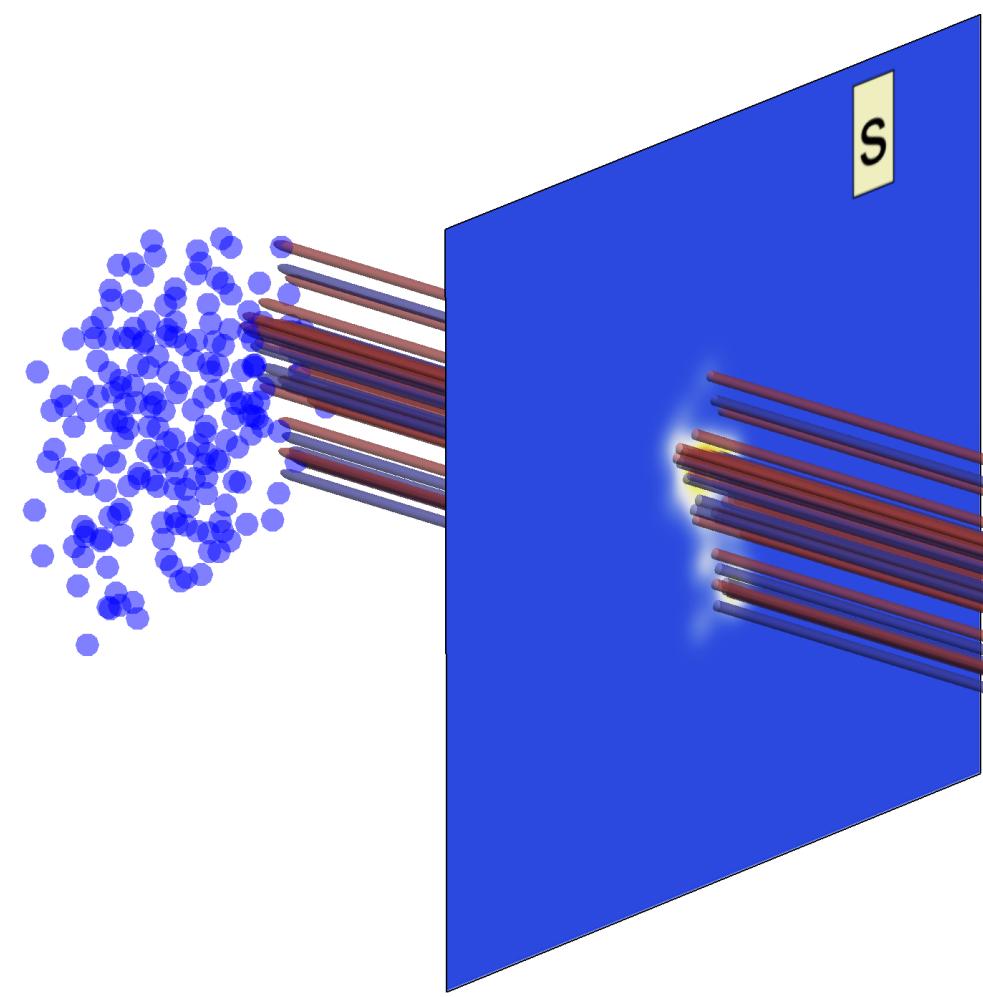
E-by-E IC of Bulk, n, n5, and B field



Anomalous-**V**iscous
Fluid **D**ynamics

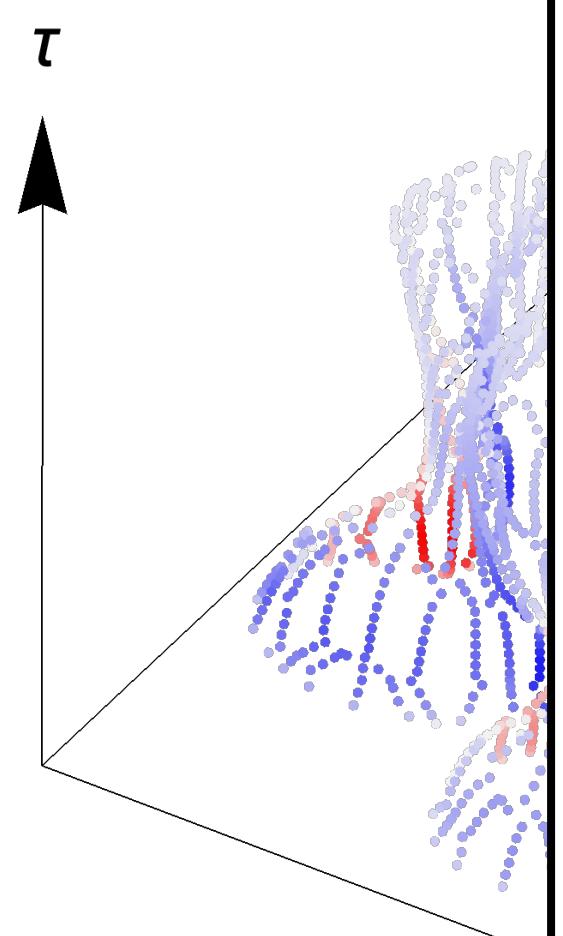
The AVFD simulation package

E-by-E IC of Bulk, n, n5, and B field



Initial condition
+ Driving force

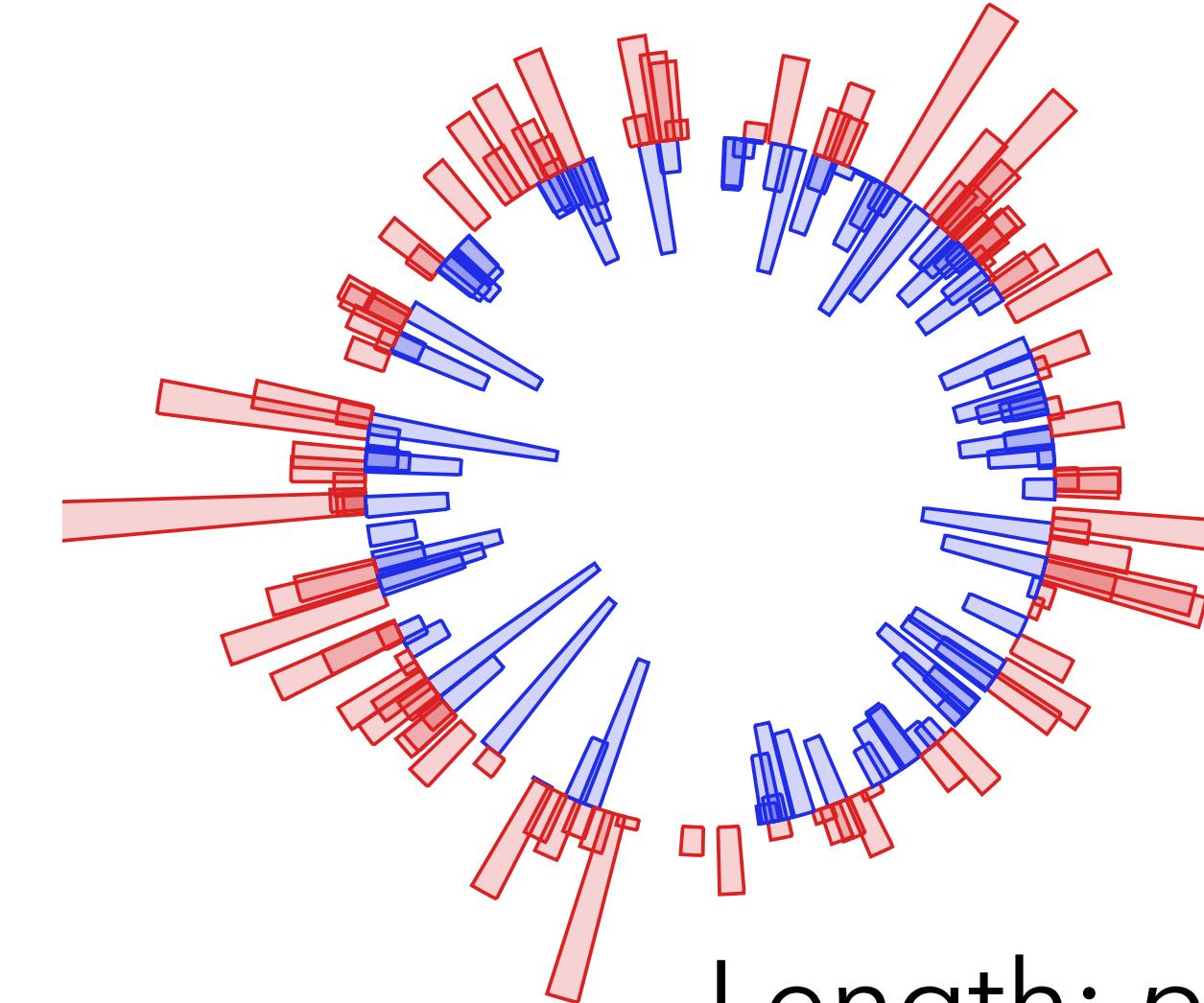
Bulk => n, n5 evolution



Dynamical evolution

Anomalous-Viscous
Fluid Dynamics

Freeze-Out (LCC) + Hadron Cascade



Hadron distribution

Length: p_T , Angel: φ

Distribution of (+) / (-) ch.

Two particle correlations:
 $\gamma = \langle \cos(\Delta\phi_i + \Delta\phi_j) \rangle = \langle \cos\Delta\phi_i \cos\Delta\phi_j \rangle - \langle \sin\Delta\phi_i \sin\Delta\phi_j \rangle$
 $\delta = \langle \cos(\Delta\phi_i - \Delta\phi_j) \rangle = \langle \cos\Delta\phi_i \cos\Delta\phi_j \rangle + \langle \sin\Delta\phi_i \sin\Delta\phi_j \rangle$

AVFD used by experimentalists

EPJC 81 (2021) 8, 717

see also P. Christakoglou
Monday 08:56-09:21

arXiv: 2105.06044

arXiv: 2110.01435

Eur. Phys. J. C (2021) 81:717
<https://doi.org/10.1140/epjc/s10052-021-09498-7>

THE EUROPEAN
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Regular Article - Experimental Physics

Systematic study of the chiral magnetic effect with the AVFD model at LHC energies

Panos Christakoglou^a , Shi Qiu^b, Joey Staa^c

Nikhef, Amsterdam, The Netherlands

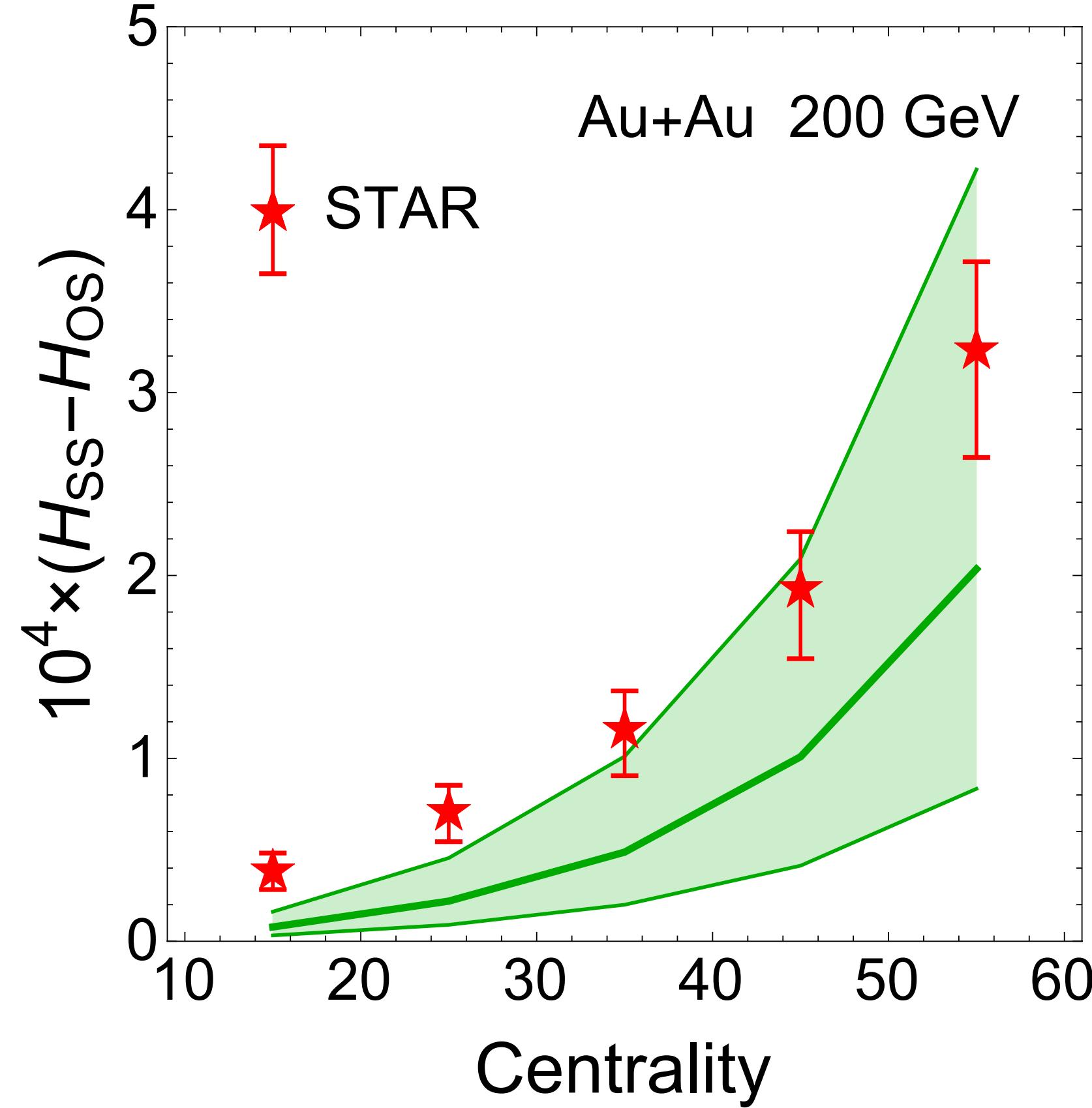
Investigation of Experimental Observables in Search of the Chiral Magnetic Effect in Heavy-ion Collisions in the STAR experiment

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,^{11,12,*} Mike Lisa,¹³ Takafumi Niida,⁵ Robert Lanny Ray,¹⁴ Masha Sergeeva,¹⁵ Diyu Shen,^{1,†} Shuzhe Shi,¹⁶ Paul Sorensen,⁴ Aihong Tang,⁴ Prithwish Tribedy,⁴ Gene Van Buren,⁴ Sergei Voloshin,¹⁷ Fuqiang Wang,⁶ Gang Wang,¹⁵ Haojie Xu,¹⁸ Zhiwan Xu,¹⁵ Nanxi Yao,^{15,‡} and Jie Zhao⁶

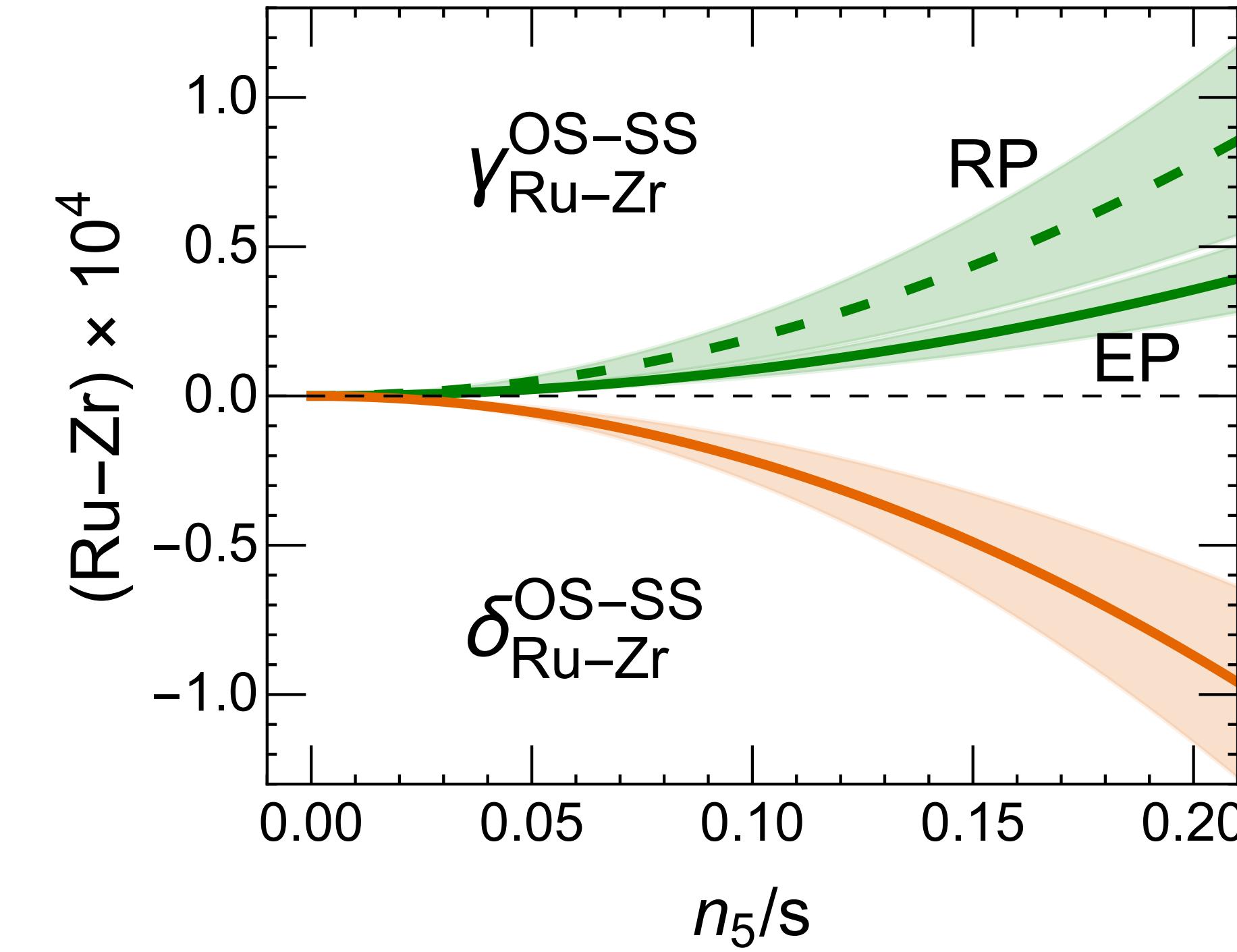
Utilization of Event Shape in Search of the Chiral Magnetic Effect in Heavy-ion Collisions

Ryan Milton,^{1,*} Gang Wang,^{1,†} Maria Sergeeva,¹ Shuzhe Shi,² Jinfeng Liao,³ and Huan Zhong Huang^{1,4}

CME in AuAu and Isobar

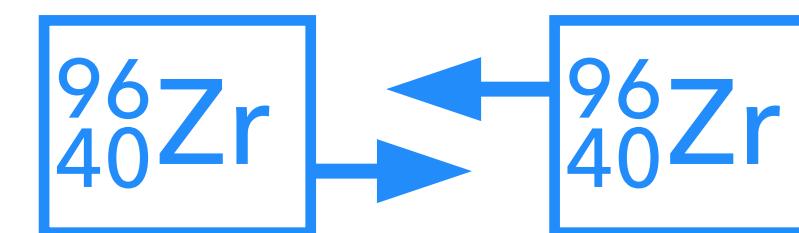
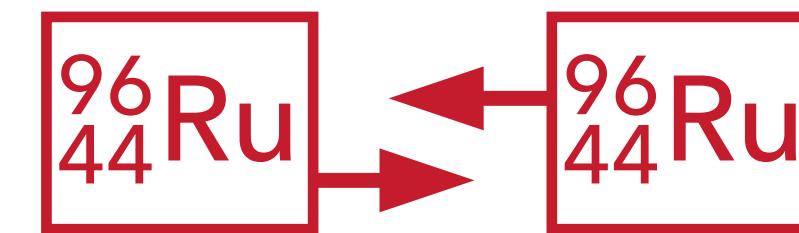


Be able to describe the possible CME signal in Au-Au.



Predictions for isobar collisions:
Joint cut of Multiplicity \otimes Eccentricity to control difference in background

expectation before the isobar program:



Different
Proton #



Different
CME Signal

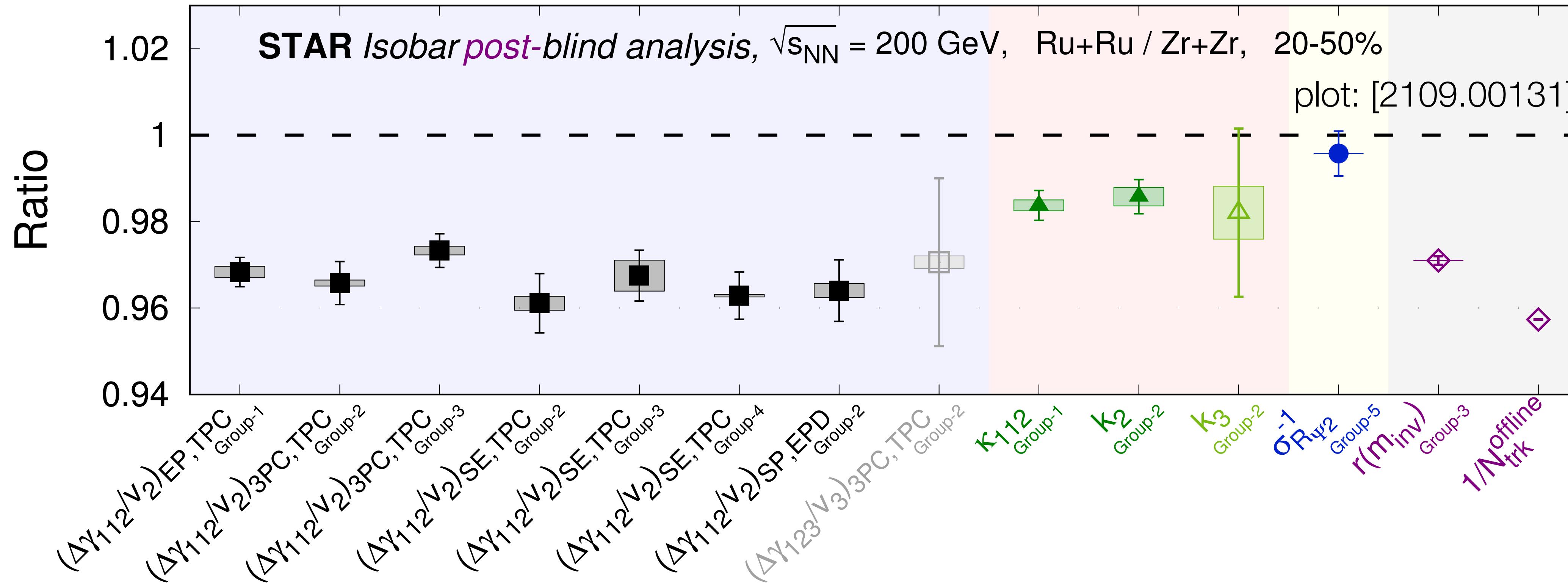
Same
Baryon #



Same
Background

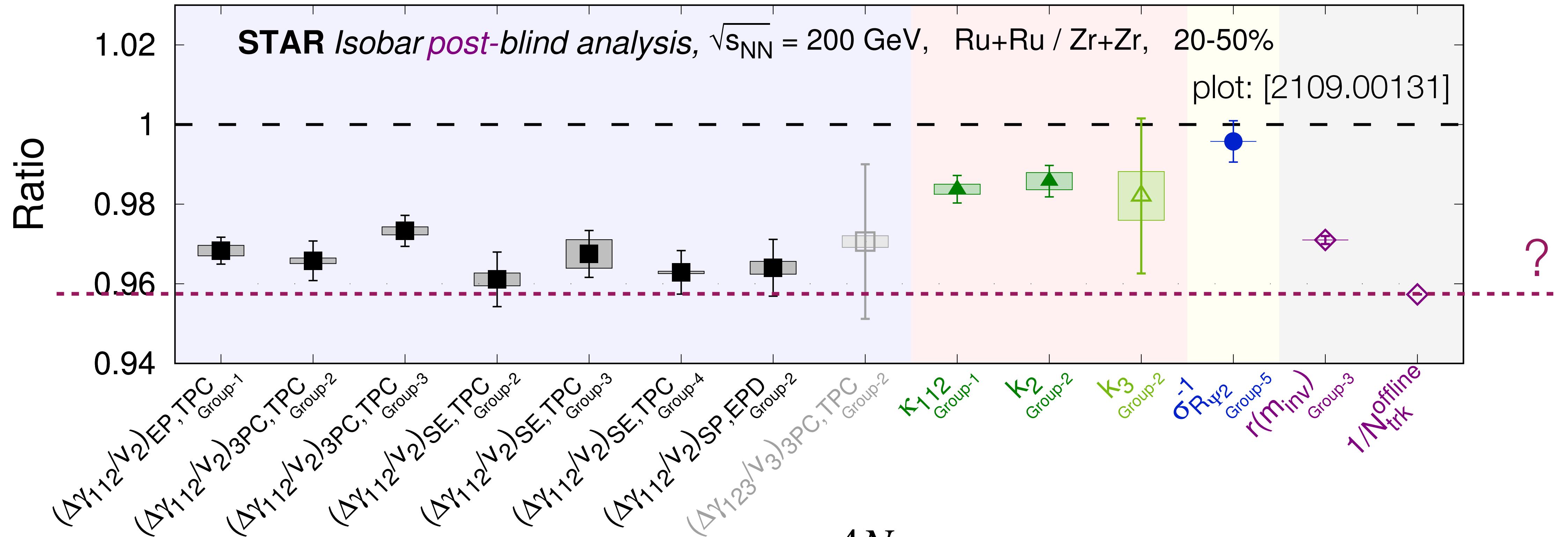


expectation of the baseline failed



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

what is the appropriate baseline?

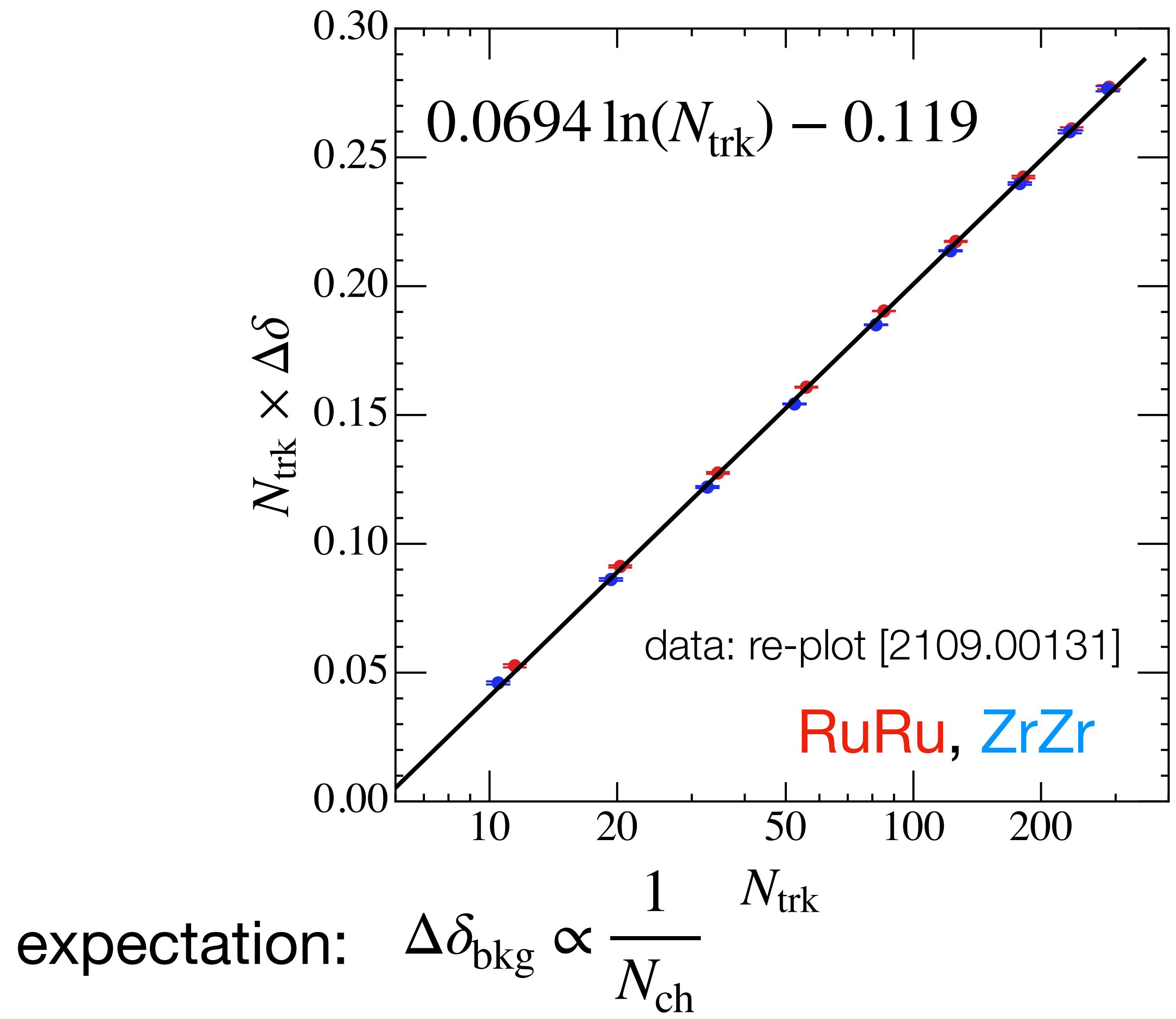


$$\Delta\gamma_{112,\text{bkg}} = \frac{4N_{2p}\nu_{2,2p}}{N_{\text{ch}}^2} \langle \cos(\phi_\alpha + \phi_\beta - 2\phi_{2p}) \rangle \propto \frac{\nu_2}{N_{\text{ch}}}$$

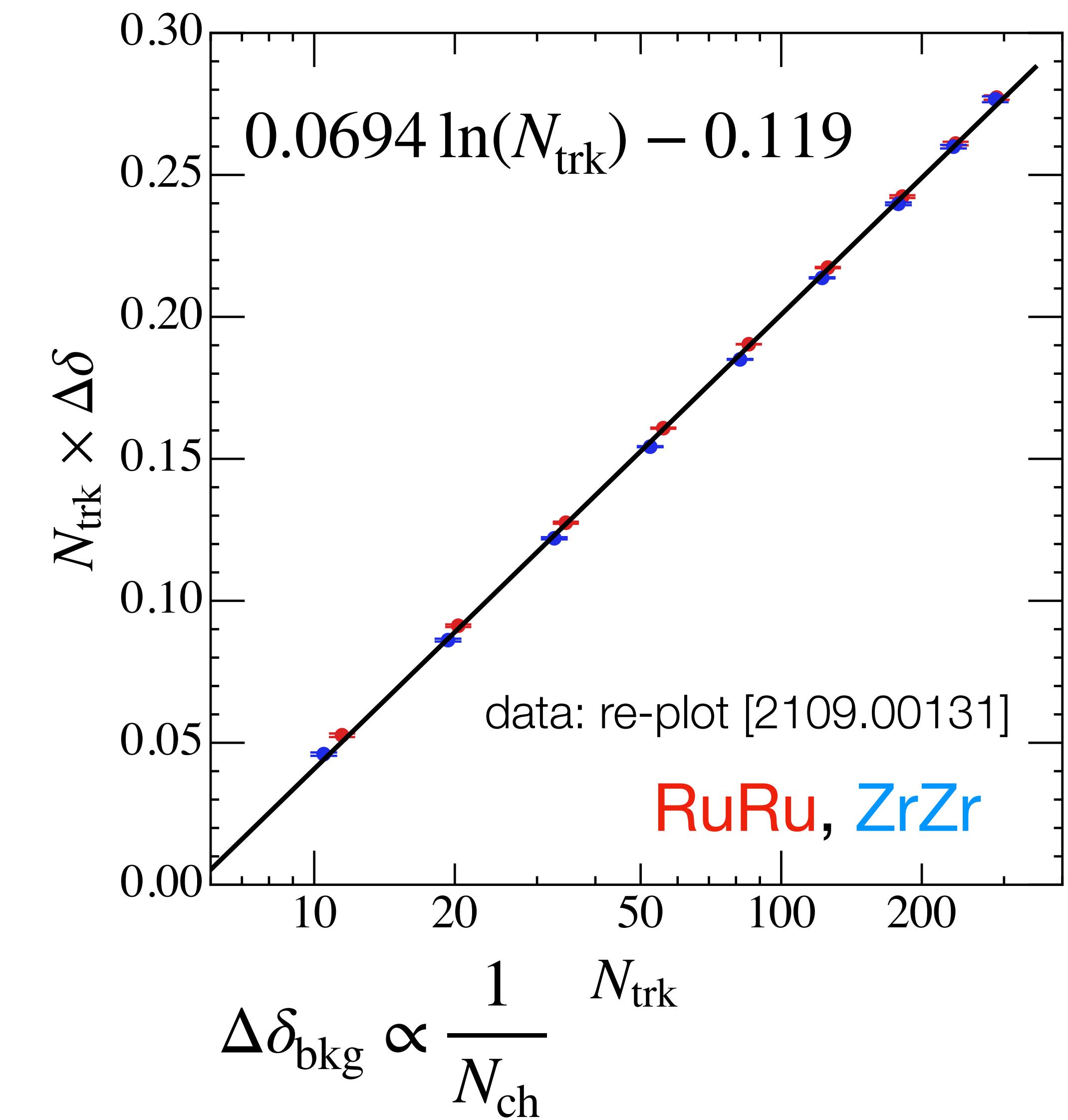
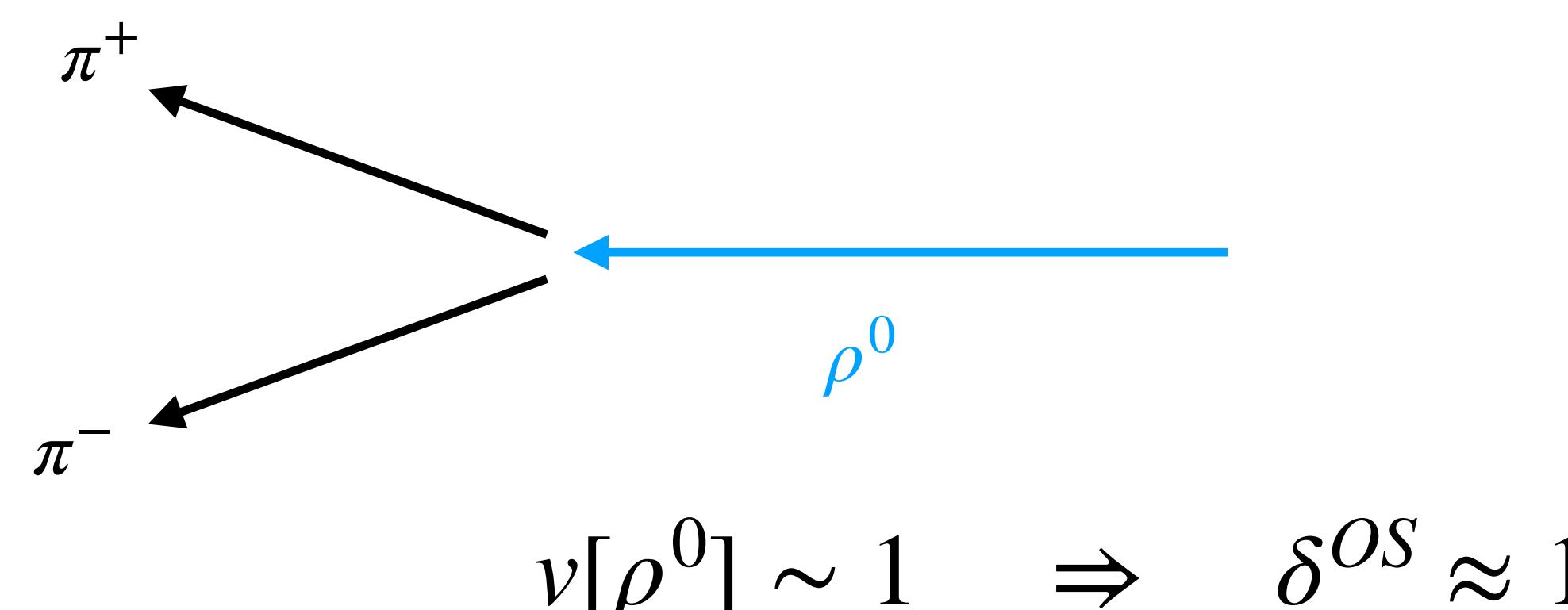
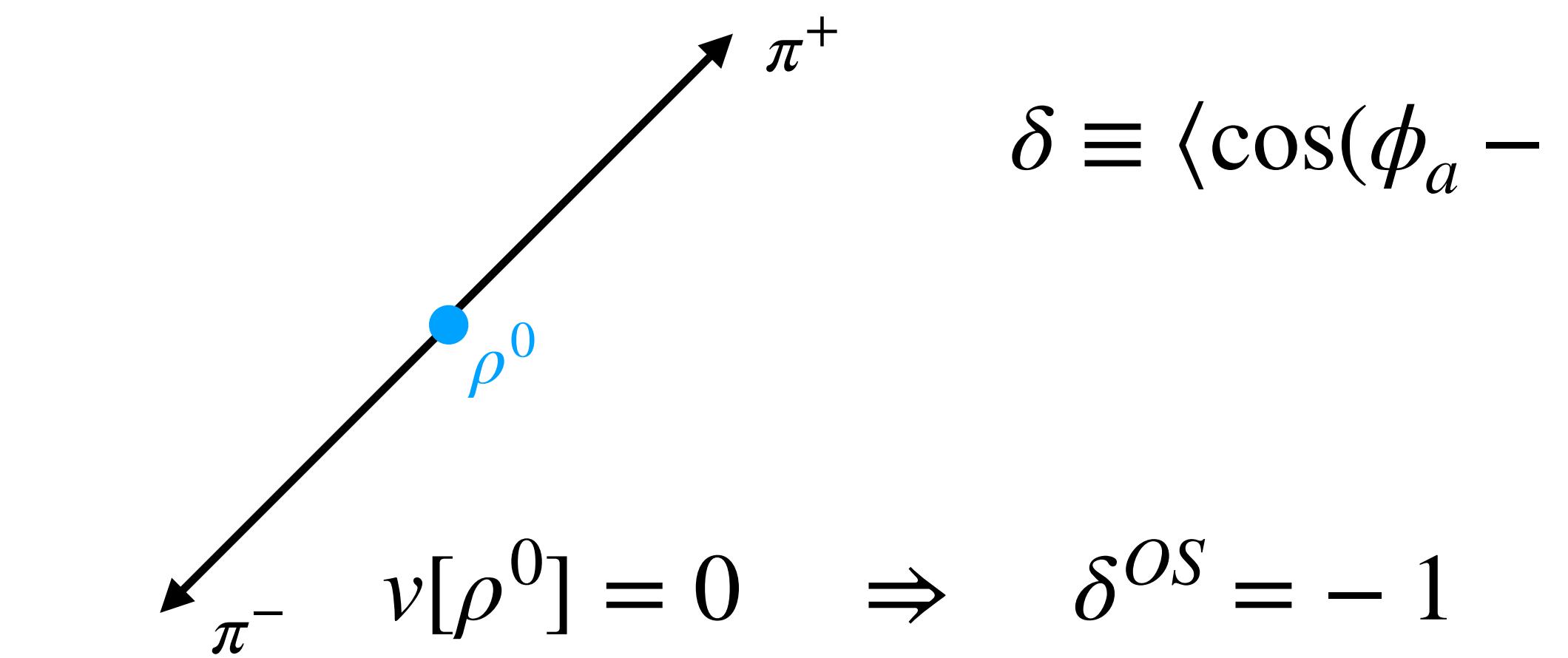
$$\Delta\delta_{\text{bkg}} \propto \frac{1}{N_{\text{ch}}}$$

2p = 2-particle cluster

radial flow dependence of background

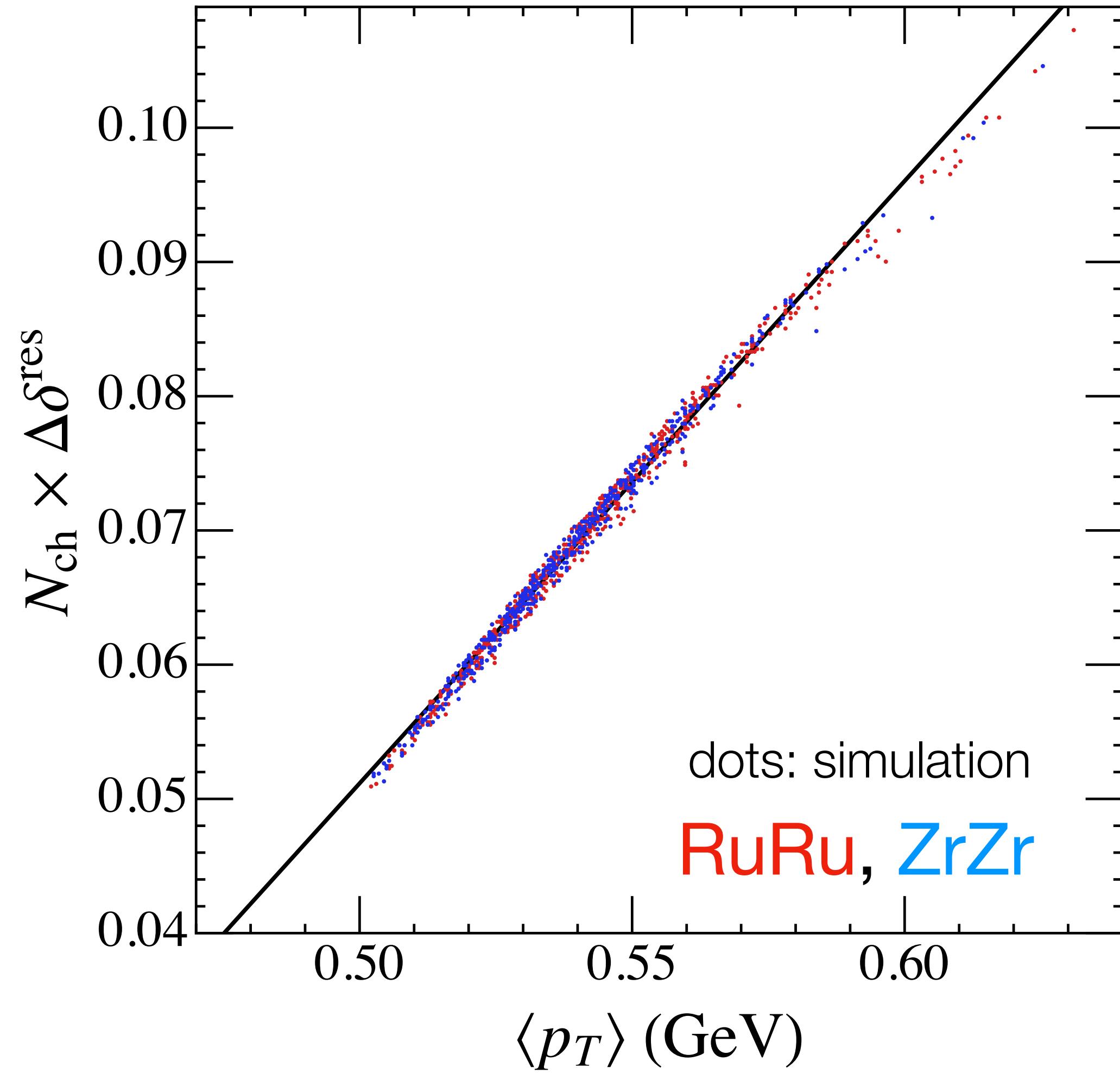


radial flow dependence of background

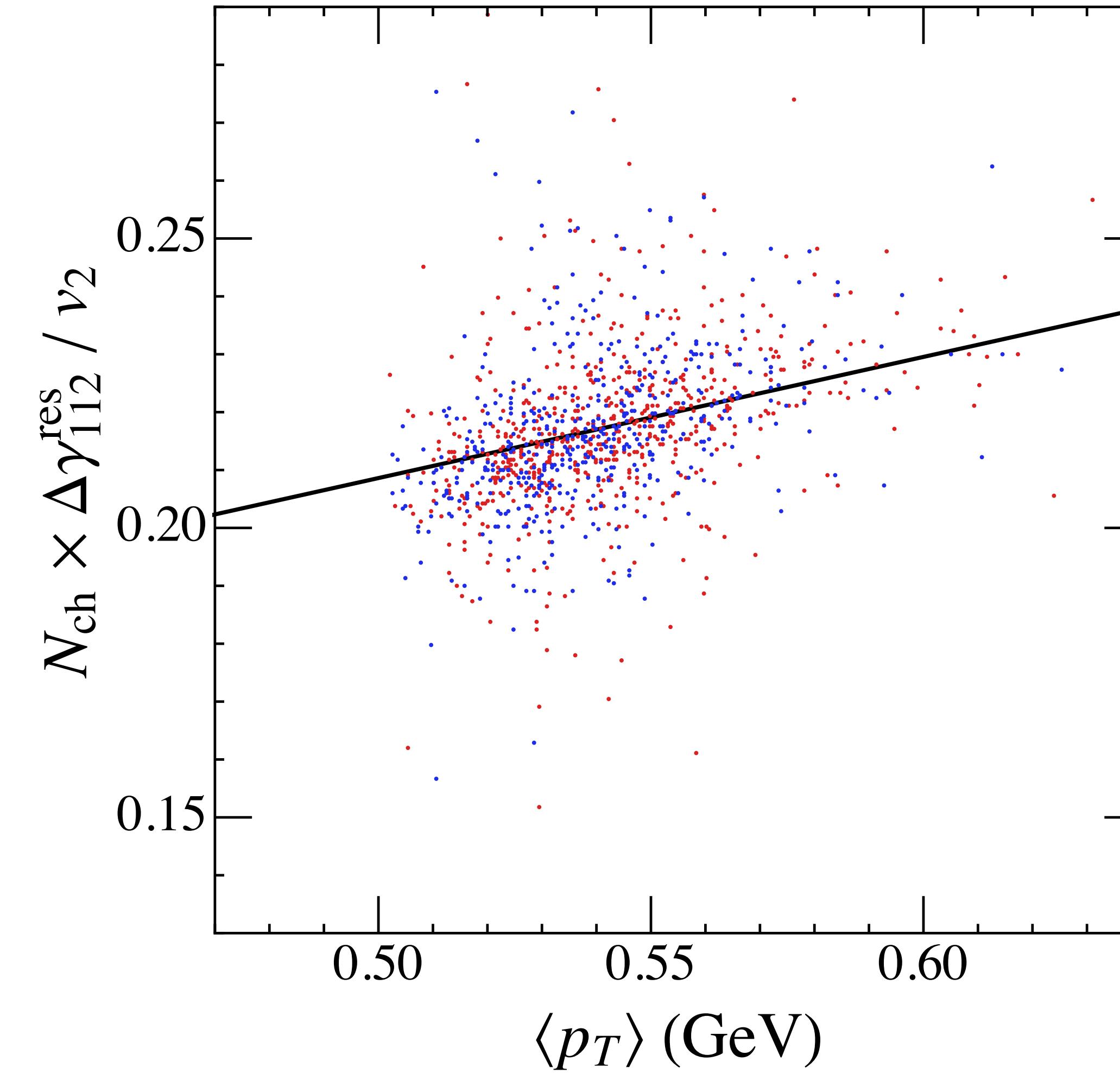


$\langle p_T \rangle$ -dependence of background [hydro+CooperFrye+resonance]⁰⁸

$$\Delta\delta_{\text{bkg}} = \frac{1}{N_{\text{ch}}} (d_0 + d_1 \times \langle p_T \rangle)$$



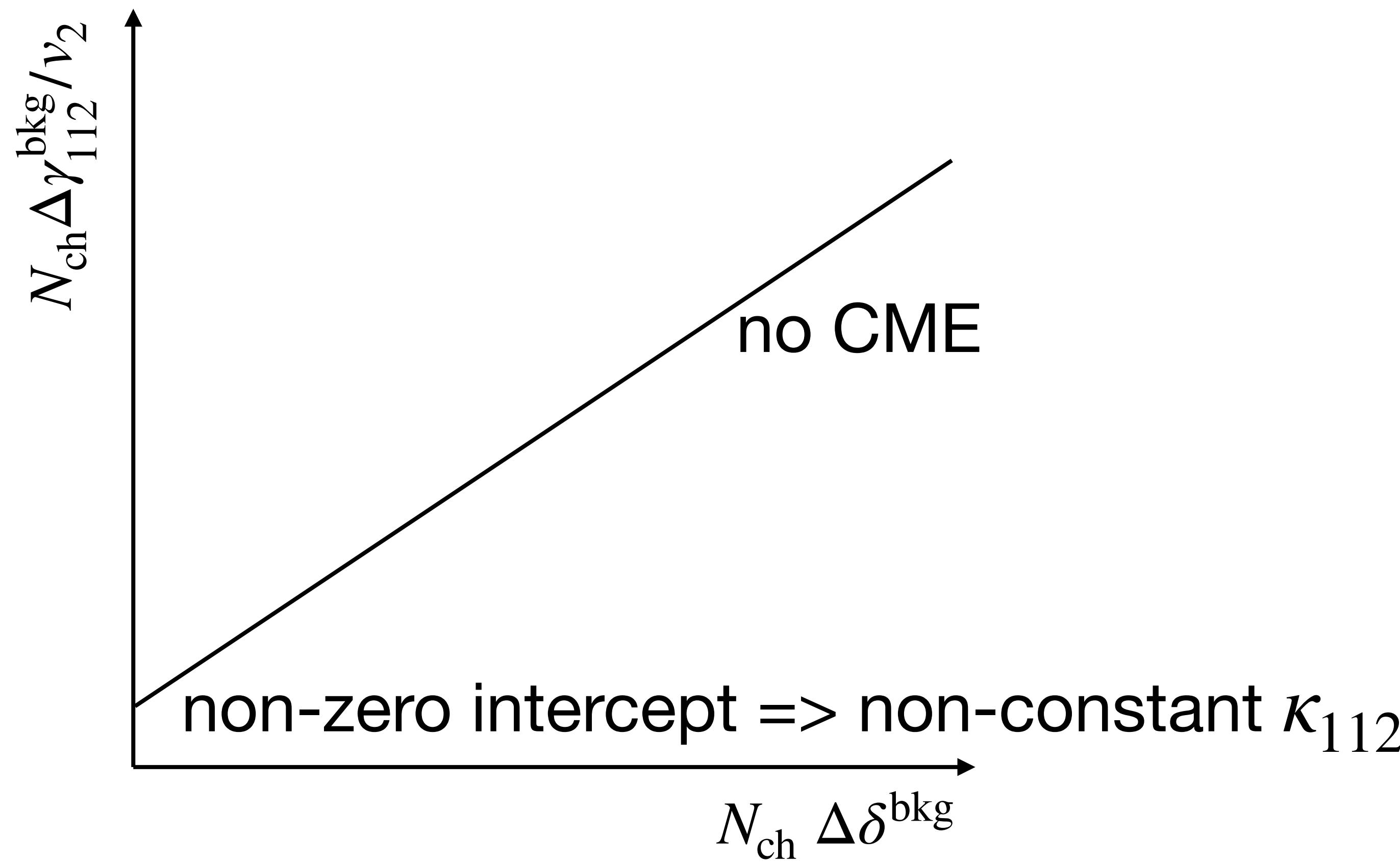
$$\Delta\gamma_{\text{bkg}} = \frac{v_2}{N_{\text{ch}}} (g_0 + g_1 \times \langle p_T \rangle)$$



a new baseline

$$\Delta\delta_{\text{bkg}} = \frac{1}{N_{\text{ch}}} (d_0 + d_1 \times \langle p_T \rangle)$$

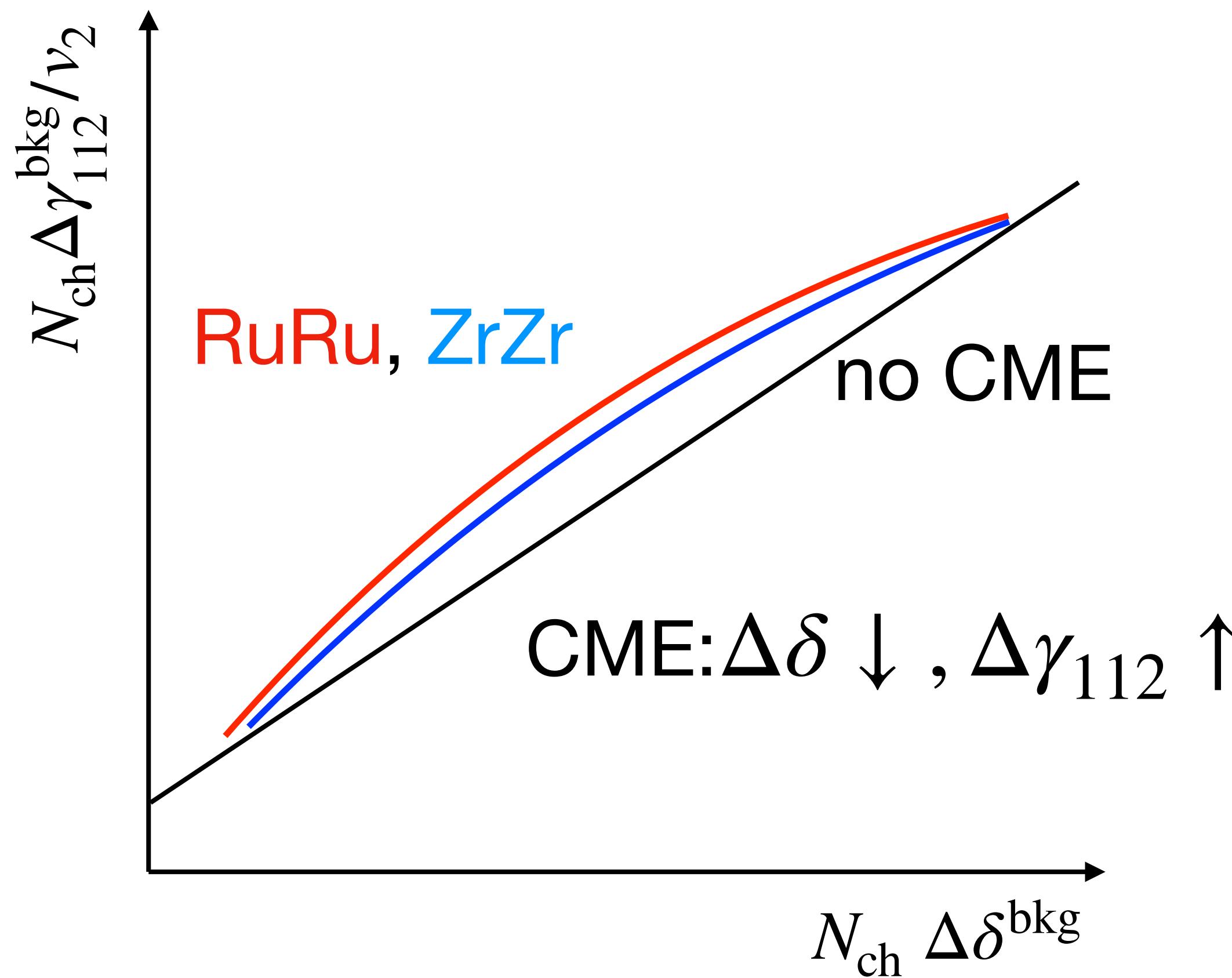
$$\Delta\gamma_{\text{bkg}} = \frac{v_2}{N_{\text{ch}}} (g_0 + g_1 \times \langle p_T \rangle)$$



a new baseline

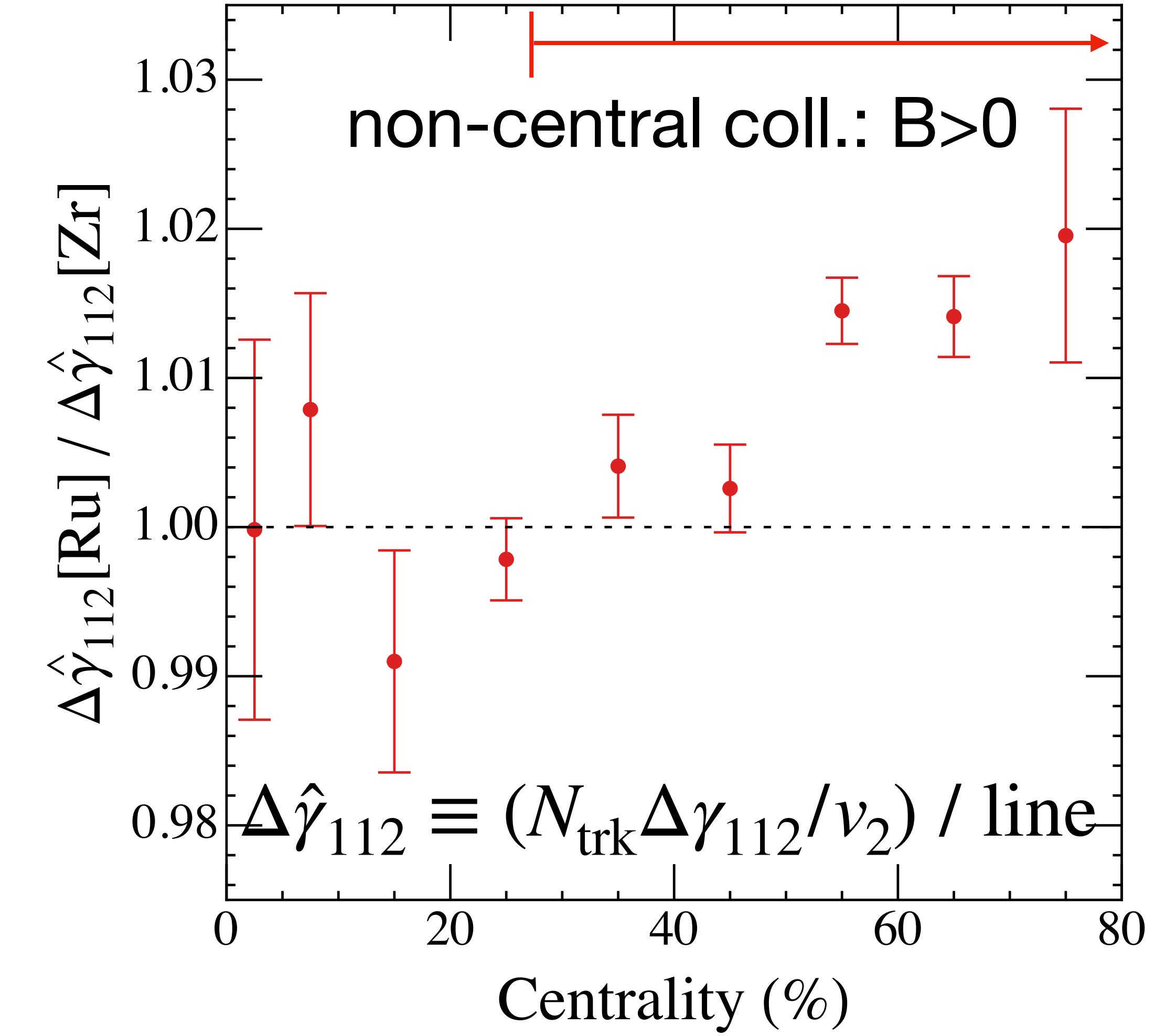
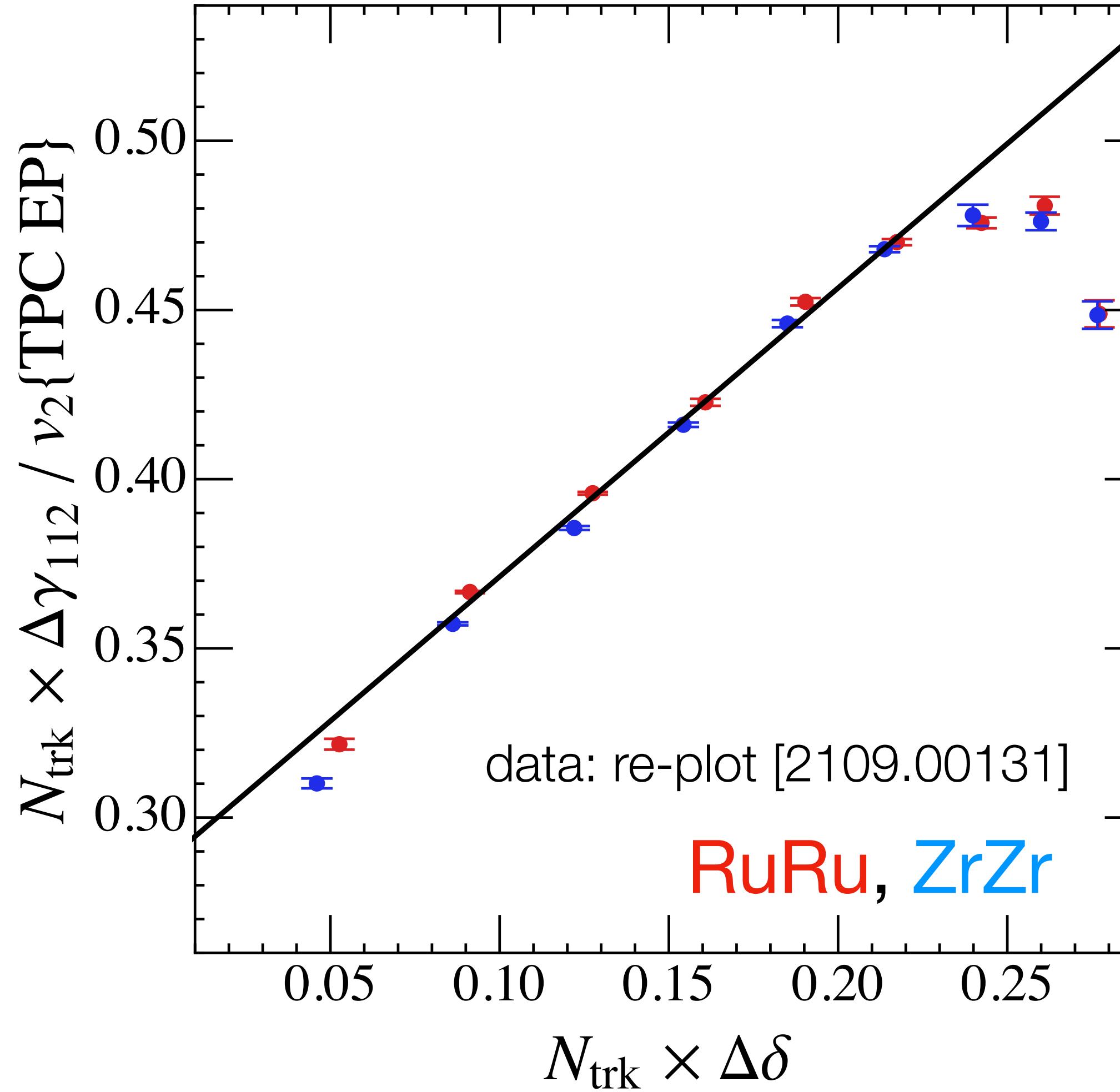
$$\Delta\delta_{\text{bkg}} = \frac{1}{N_{\text{ch}}} (d_0 + d_1 \times \langle p_T \rangle)$$

$$\Delta\gamma_{\text{bkg}} = \frac{v_2}{N_{\text{ch}}} (g_0 + g_1 \times \langle p_T \rangle)$$



can the exp. result be understood by no-CME baseline?

experiment: inconsistent with pure background
expectation in non-central collisions \rightarrow CME?

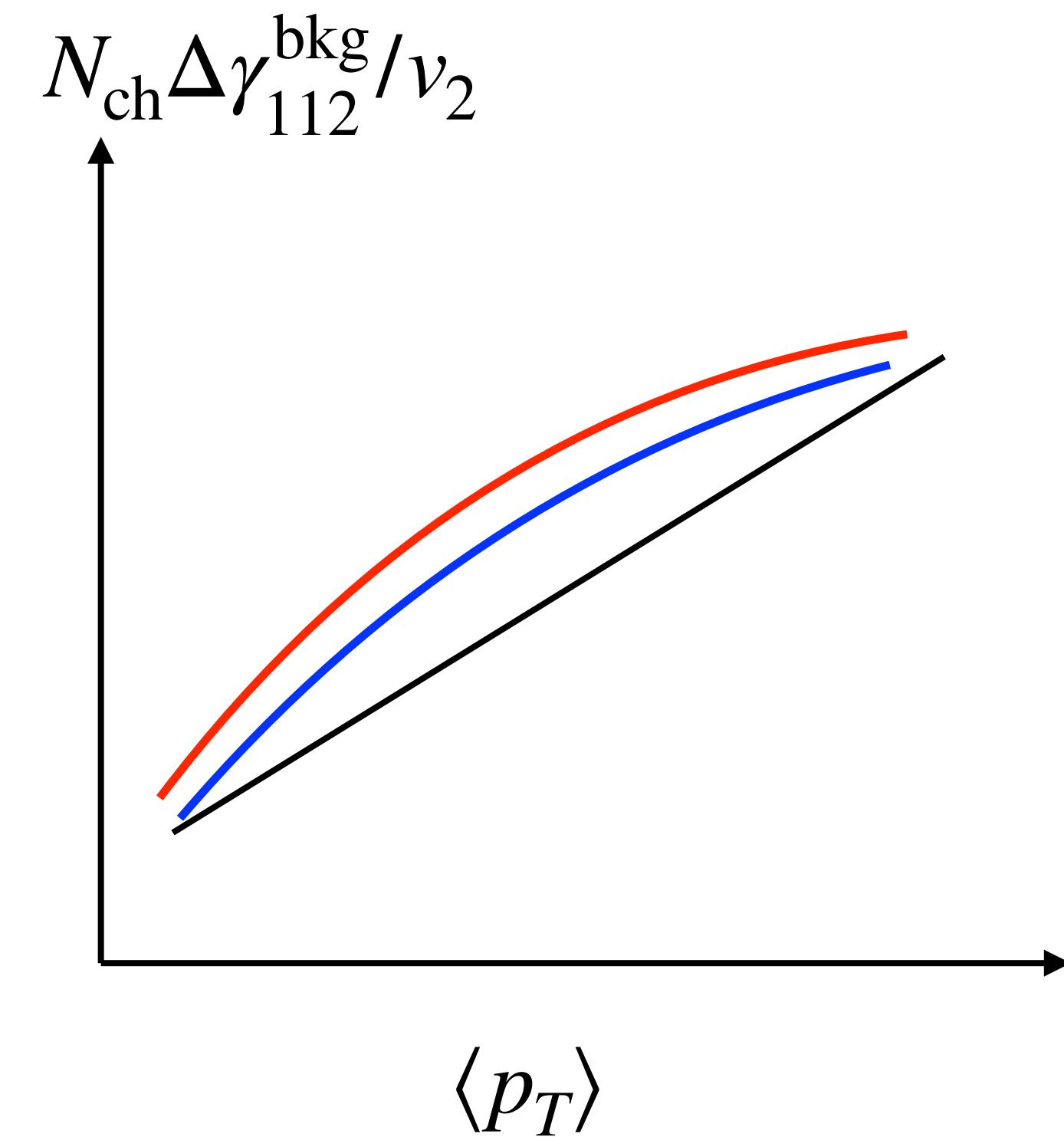
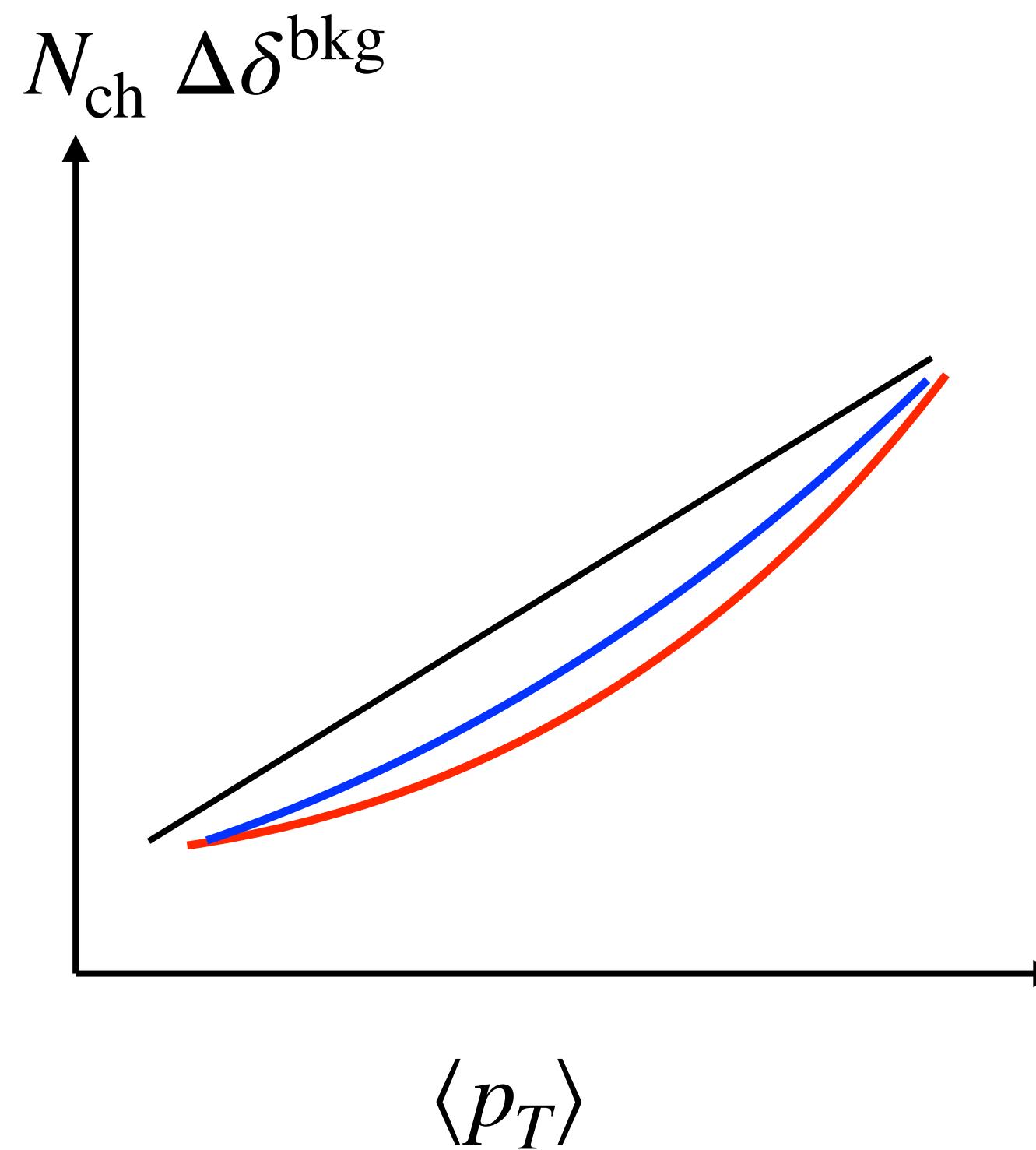


a new baseline

[if $\langle p_T \rangle$ is measured]

$$\Delta\delta_{\text{bkg}} = \frac{1}{N_{\text{ch}}} (d_0 + d_1 \times \langle p_T \rangle)$$

$$\Delta\gamma_{\text{bkg}} = \frac{v_2}{N_{\text{ch}}} (g_0 + g_1 \times \langle p_T \rangle)$$



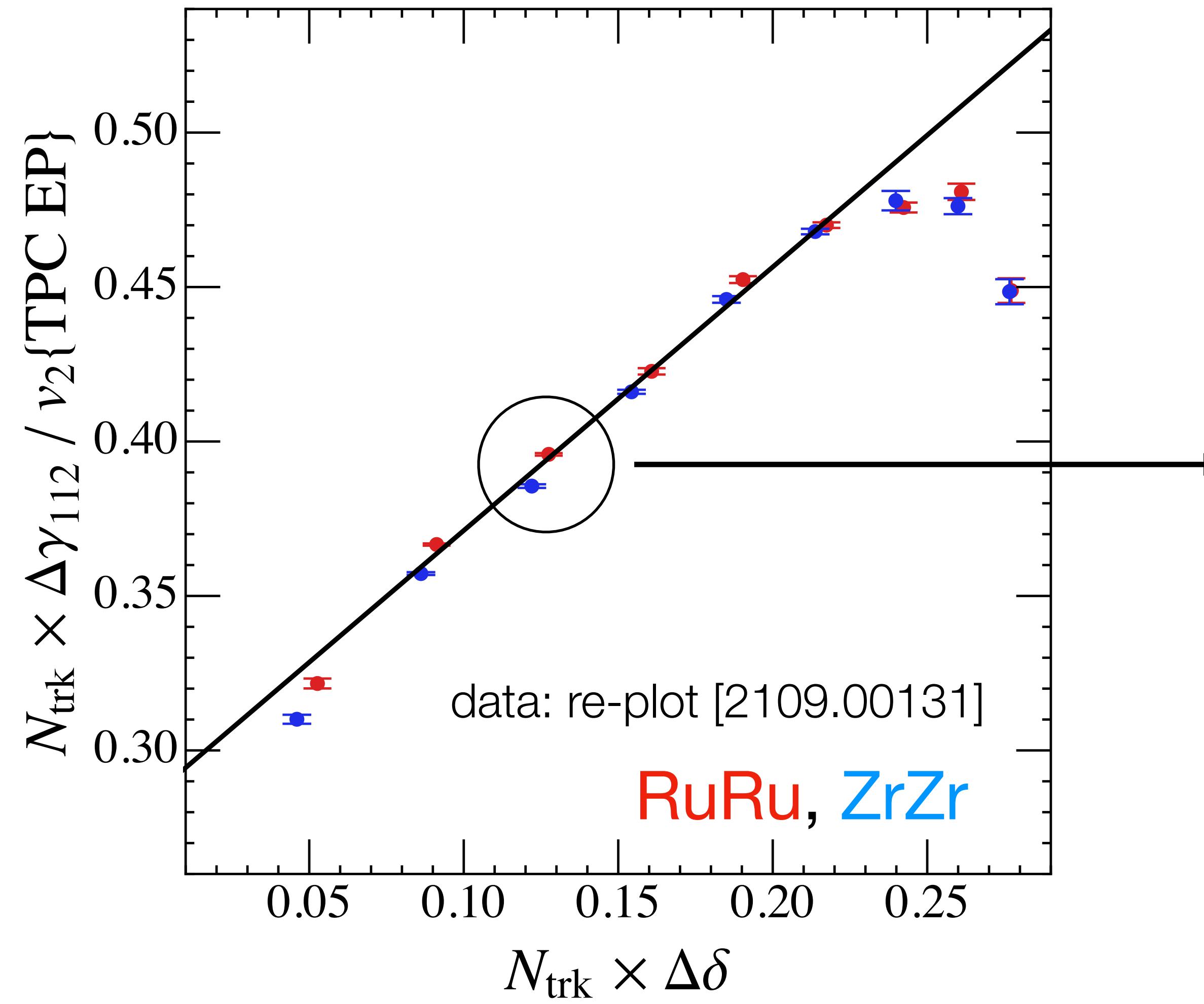
CME: $\Delta\delta \downarrow$, $\Delta\gamma_{112} \uparrow$

red: CME[RuRu]
blue: CME[ZrZr]
black: no CME

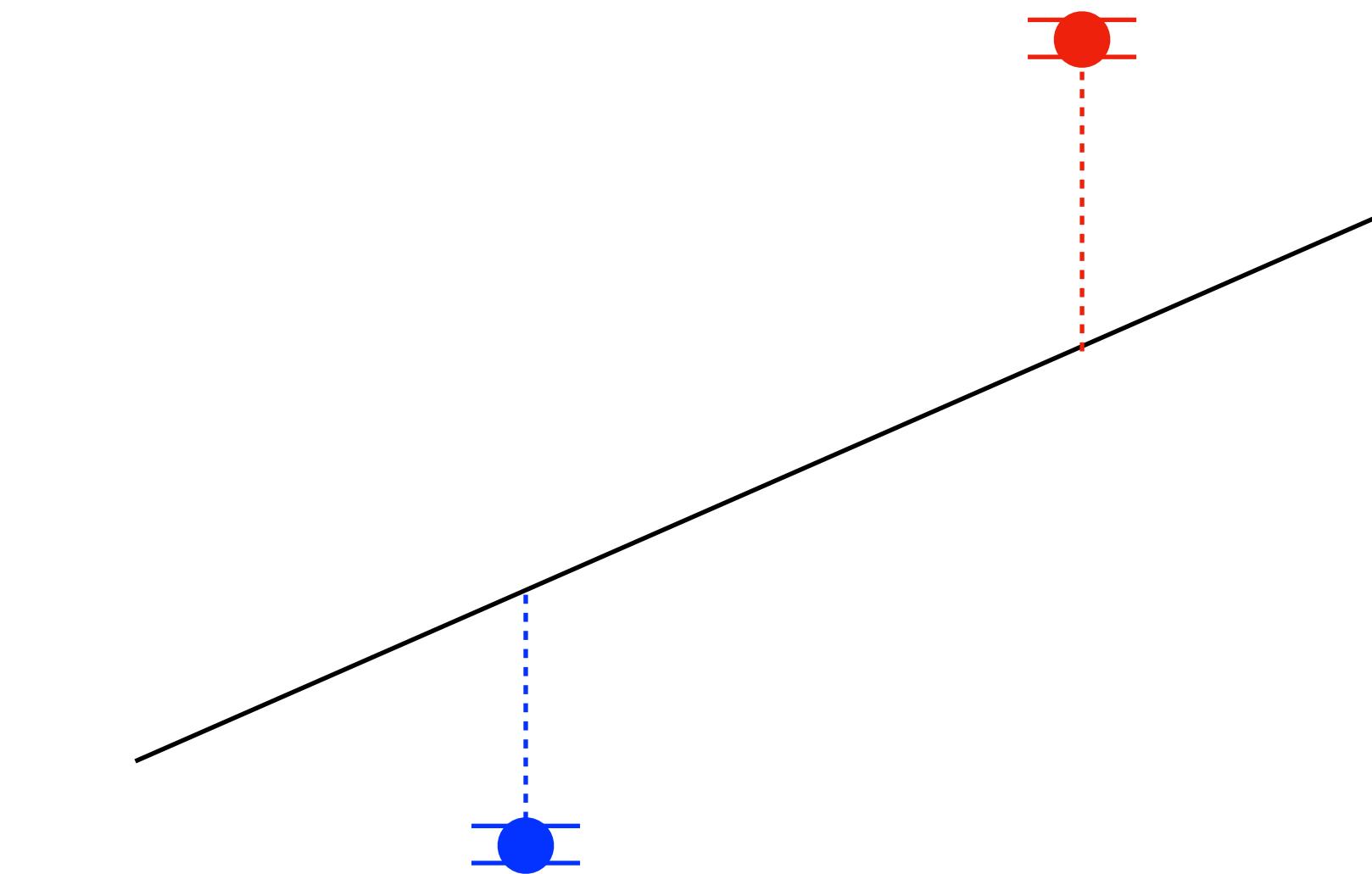
Summary

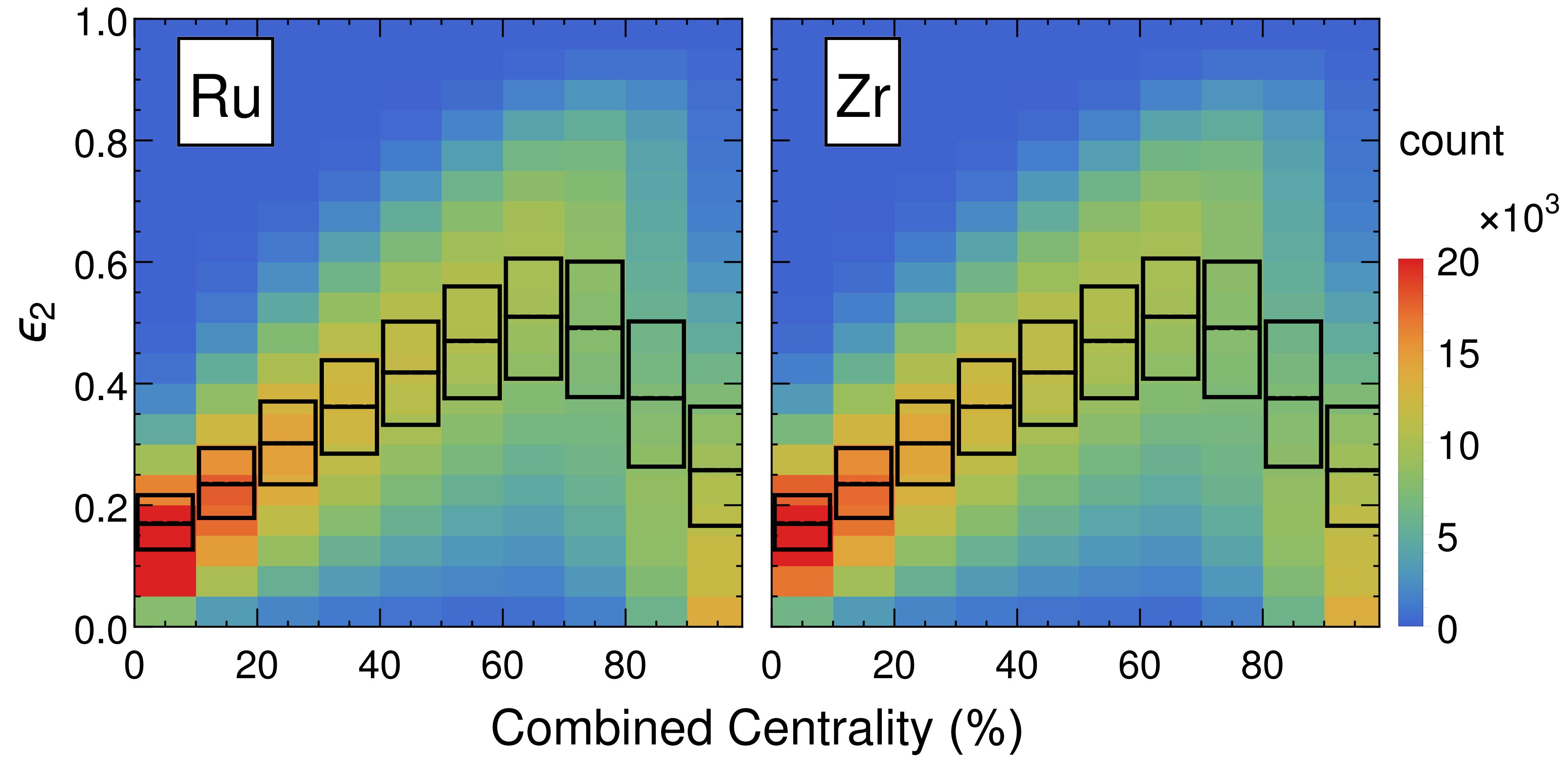
- the AVFD framework is developed to quantitatively study CME
- non-CME baseline in isobar collisions is different from unity
- simulation shows $\langle p_T \rangle$ -dependence of background
- present analysis is inconsistent with pure-background expectation, and indicates room for CME in non-central collisions where magnetic field should be present
- more experimental and theoretical work is needed

backup



assume system-independent trend:





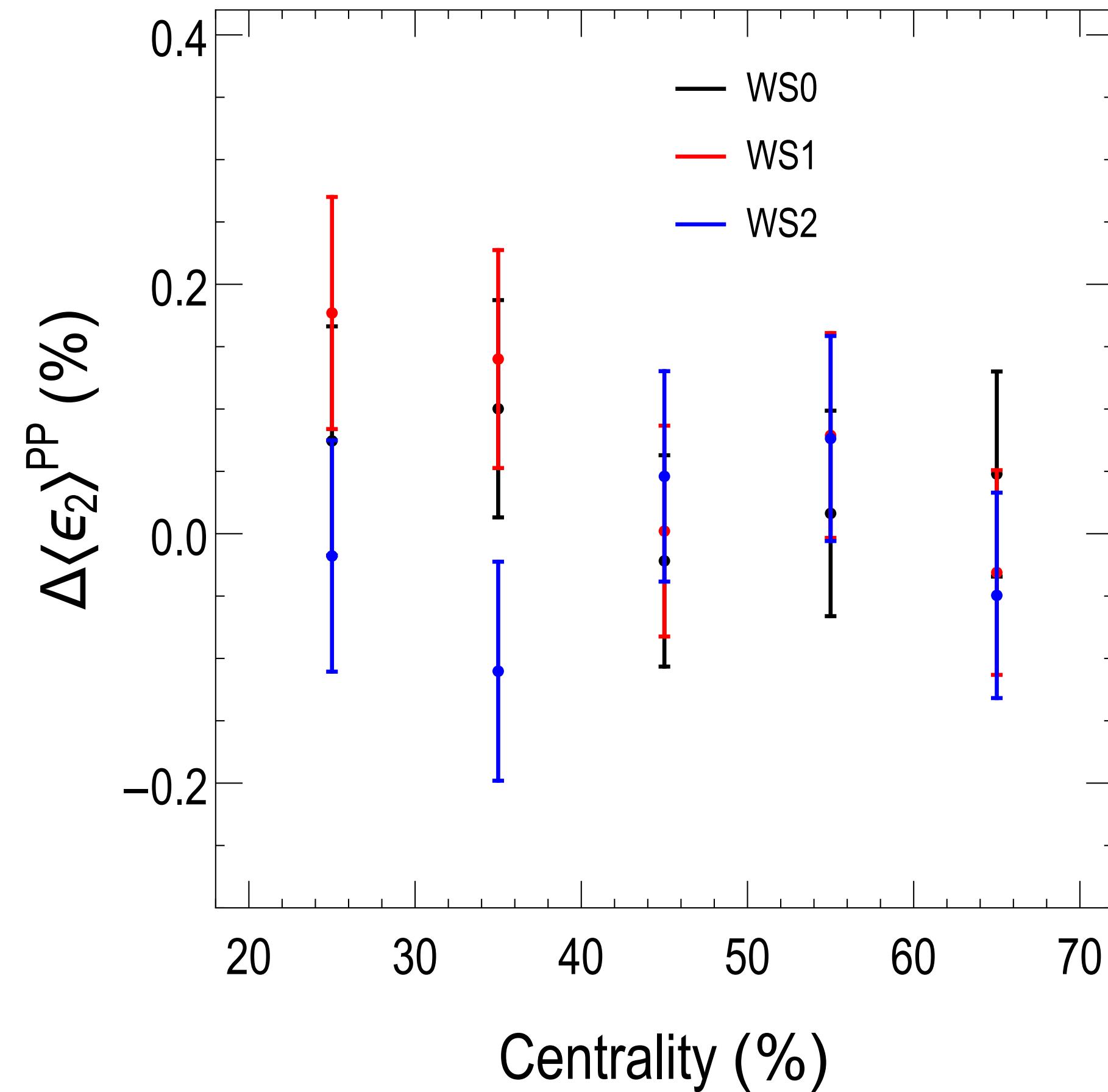
Joint cut of Multiplicity \otimes Eccentricity \Rightarrow same background!

Different deformation schemes:

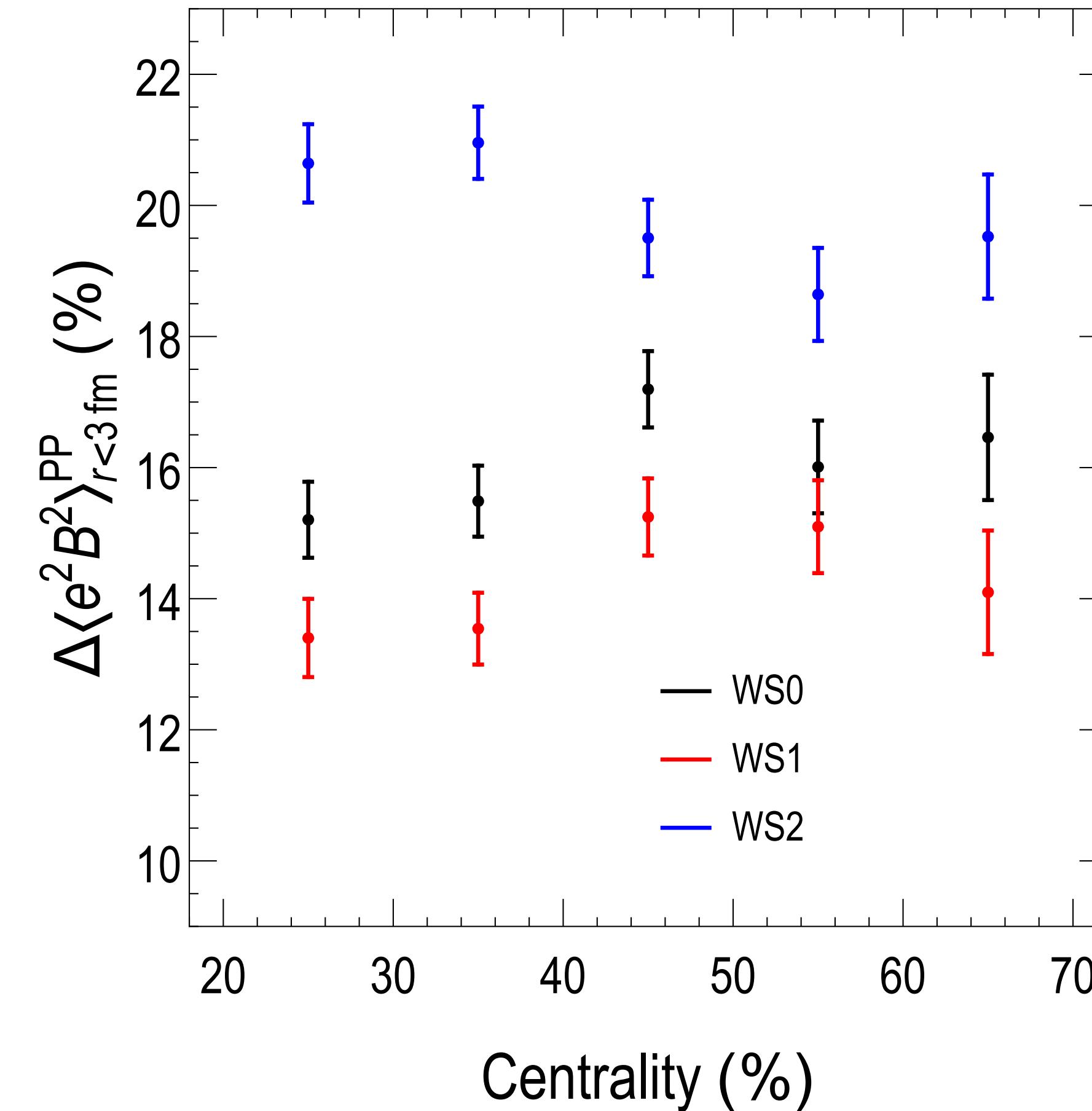
black - no deformation (both are spheric)

red - Ru is more deformed

blue - Zr is more deformed



$|\text{background difference}| < 0.5\%$



$|\text{signal difference}| \sim 15\%$