

Baryon dynamics as a background to EM field signatures in v_1 observables at RHIC

Tribhuban Parida

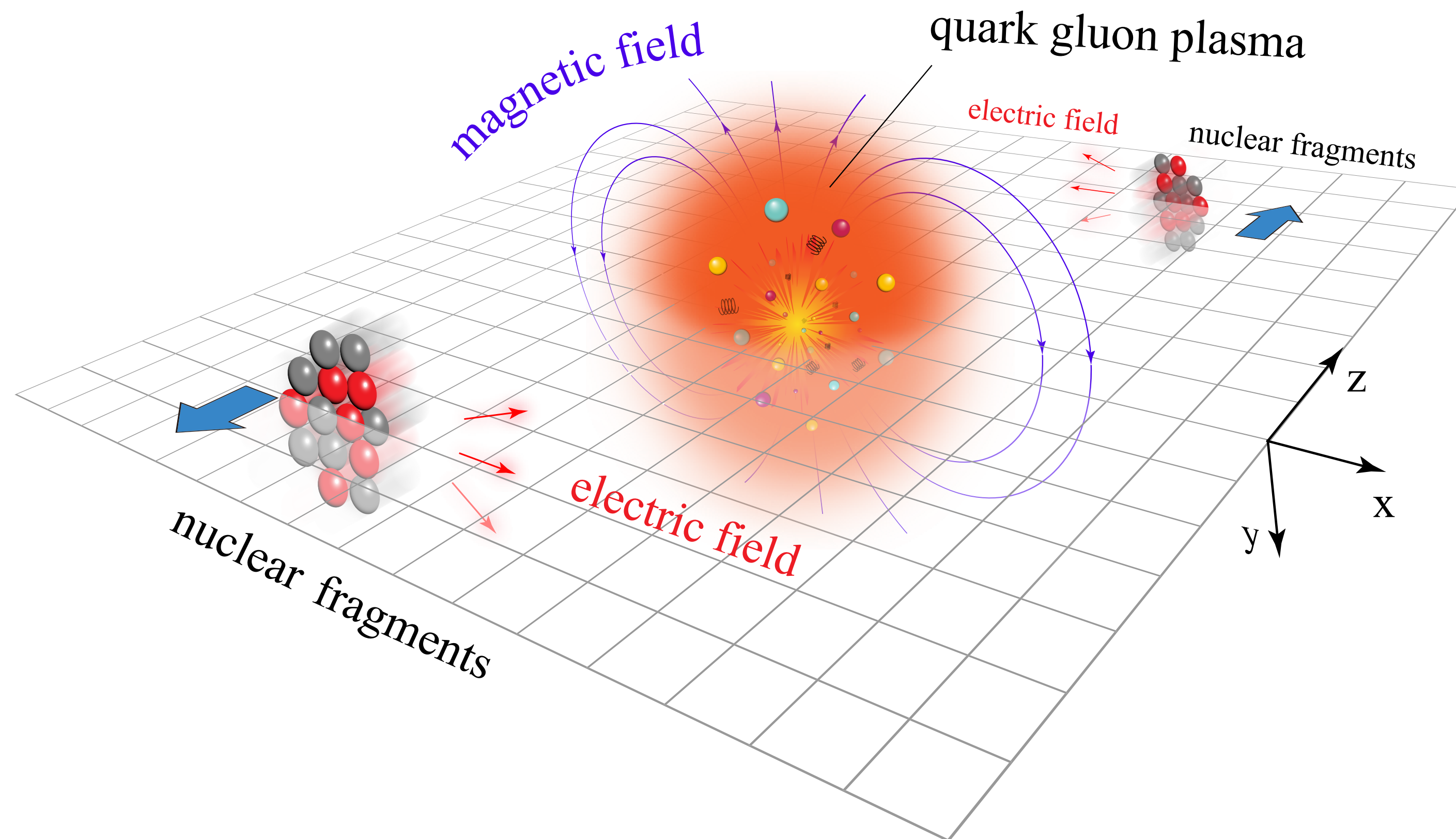
AGH University of Krakow, Poland



XVIII Polish workshop on Relativistic Heavy-ion Collisions
14th Dec 2025

EM field in heavy-ion collisions

10^{14} Tesla



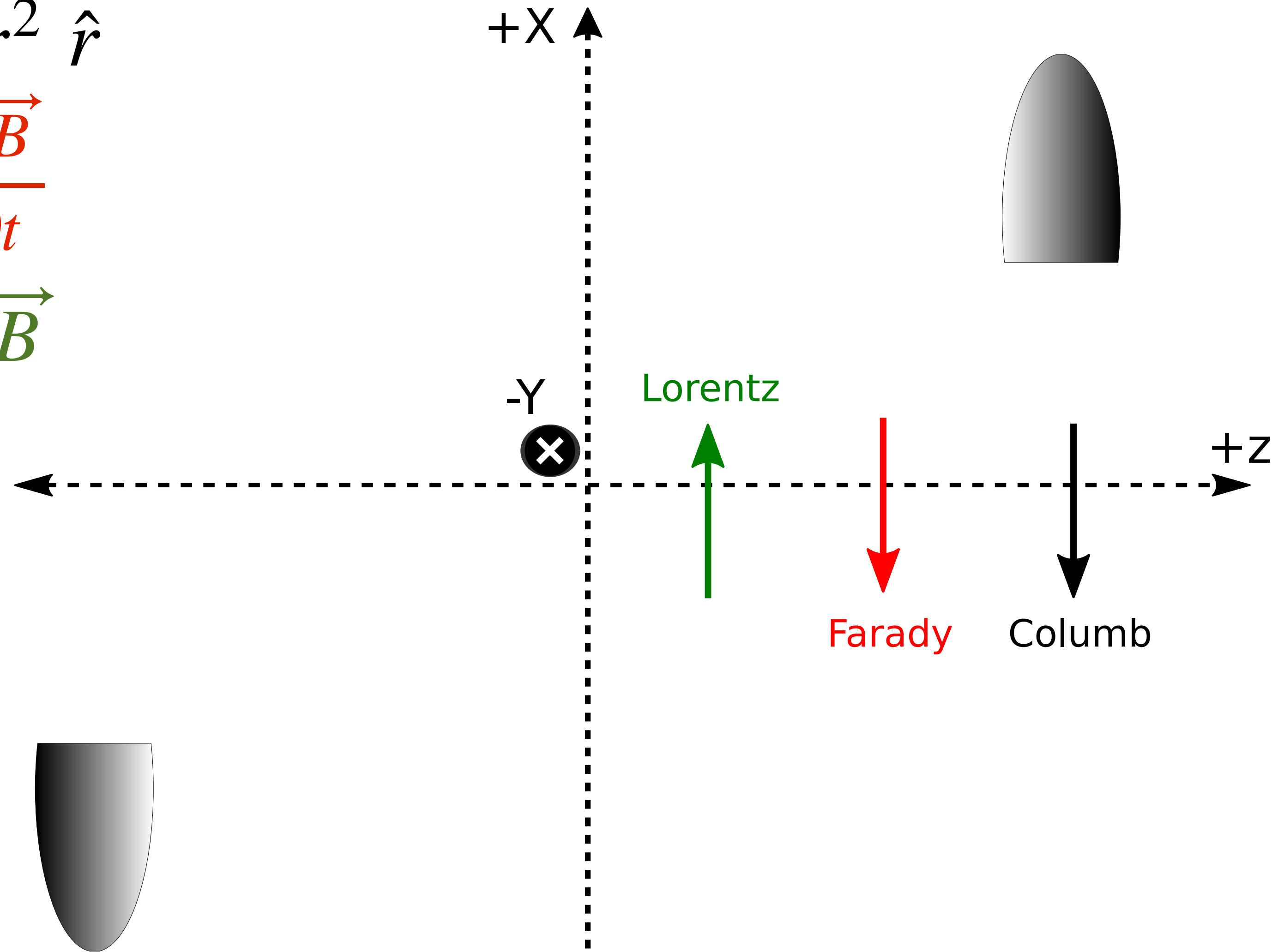
PRX (2024) 14, 011028 (STAR collaboration)

EM field in heavy-ion collisions

$$\vec{E} = kQ/r^2 \hat{r}$$

$$\vec{\nabla} \times \vec{E} = \frac{\partial \vec{B}}{\partial t}$$

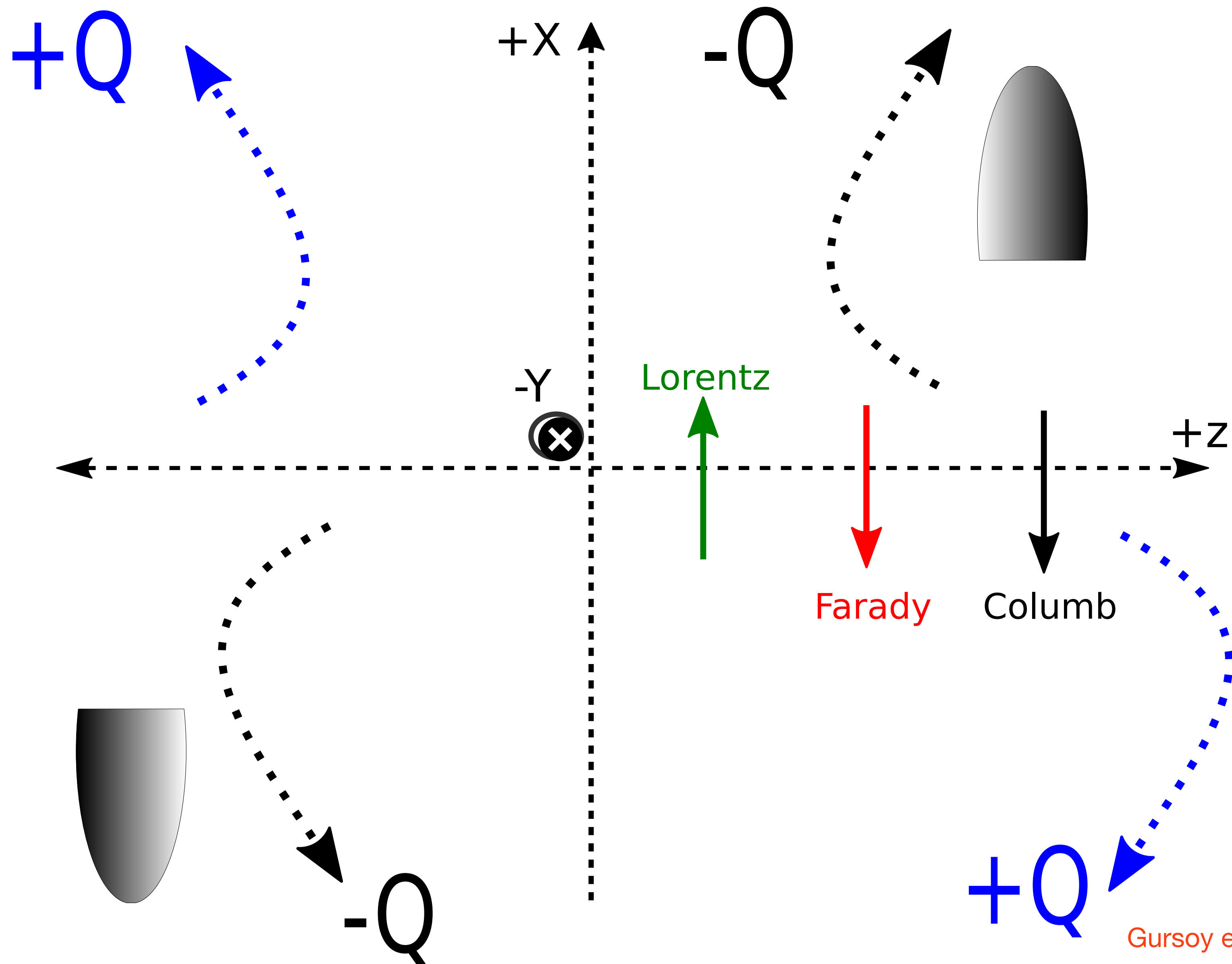
$$\vec{E} \propto \vec{v} \times \vec{B}$$



Gursoy et. al. PRC,89, 054905 (2014)

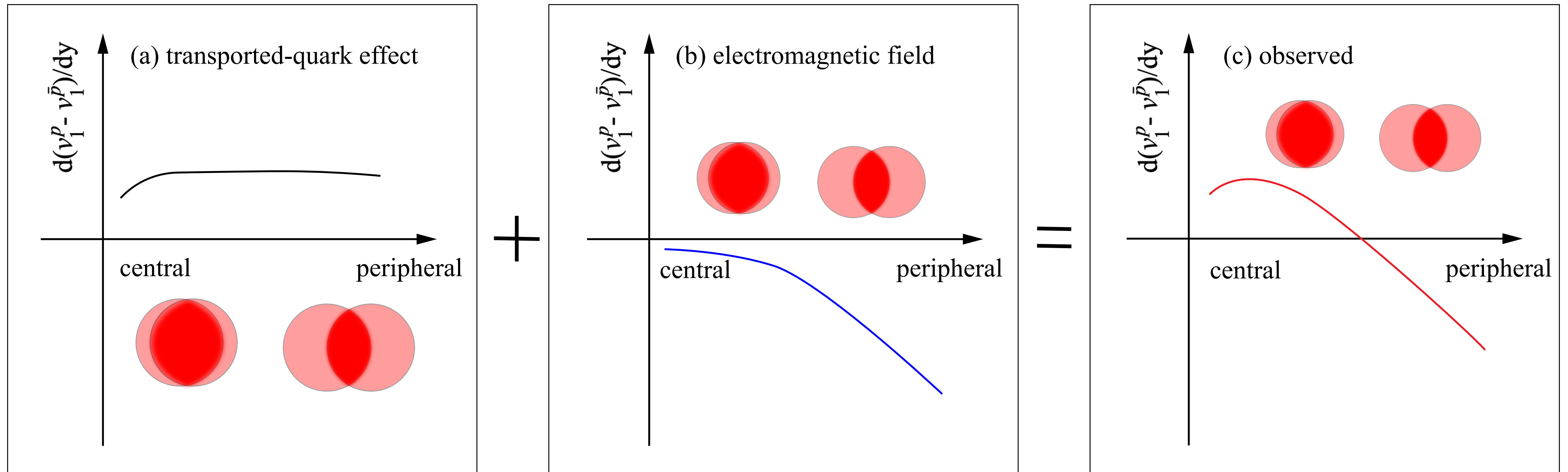
Gursoy et. al. PRC,98, 055201 (2018)

EM field in heavy-ion collisions



Search of EM field signals

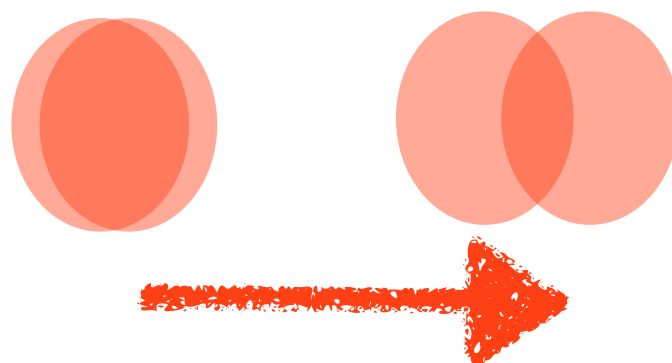
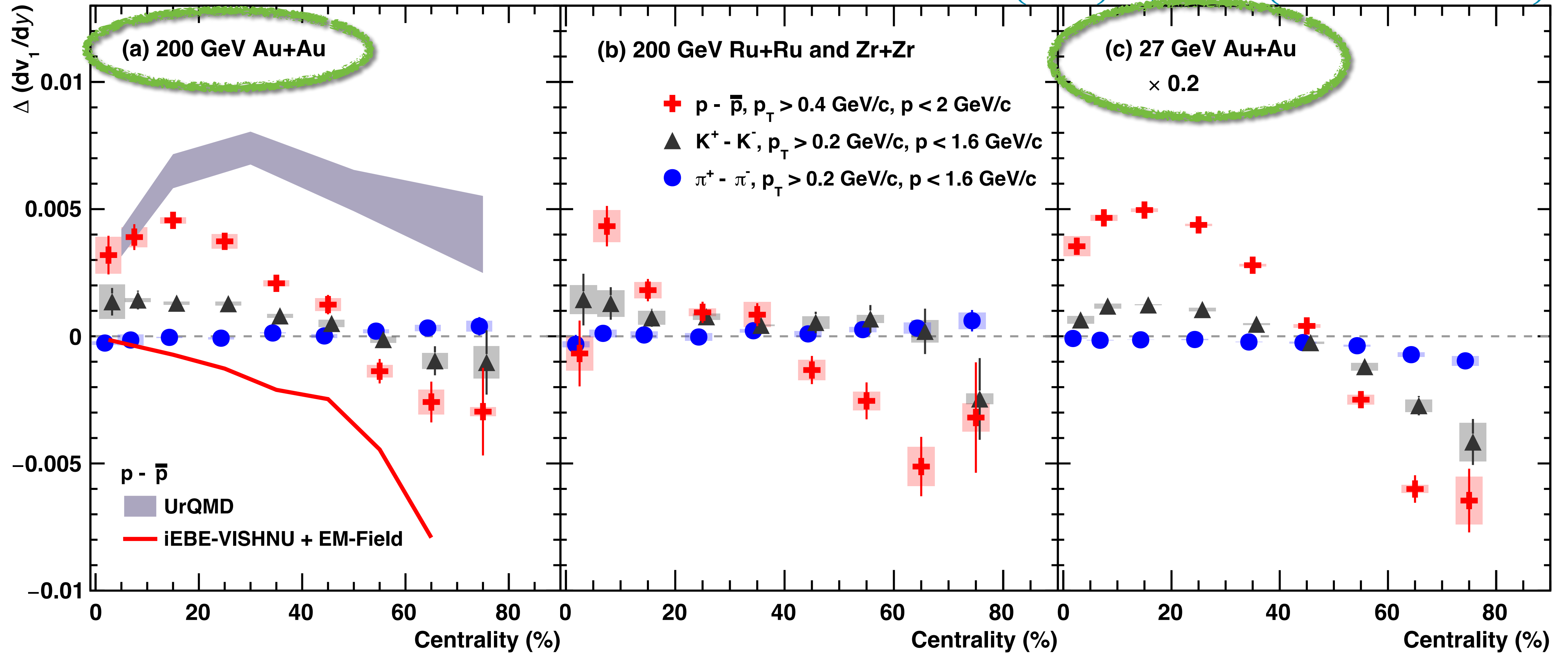
PRX (2024) 14, 011028 (STAR collaboration)



Sign change from central to peripheral could be a signature of EM field.

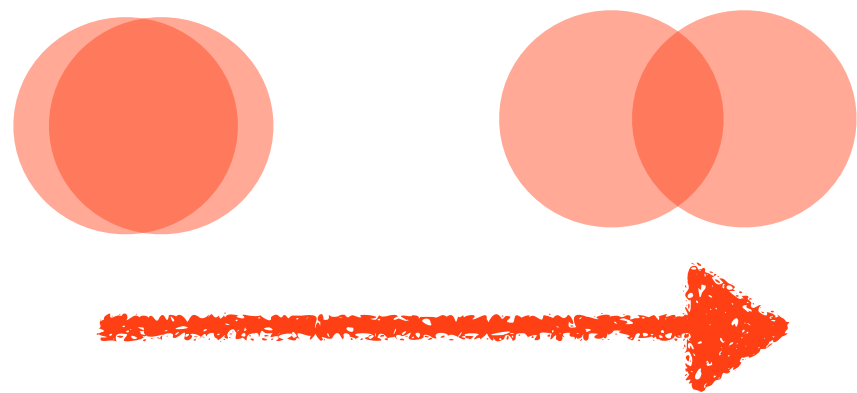
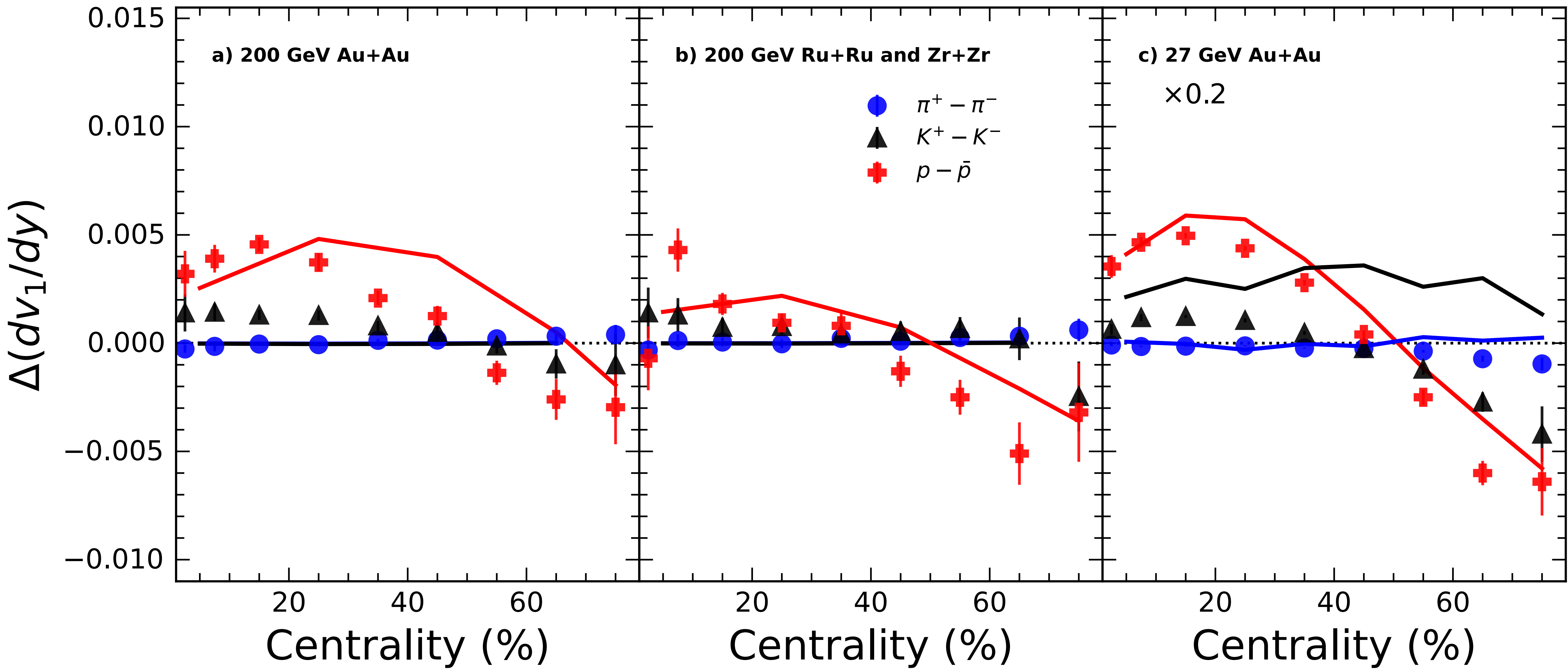
Search of EM field signals (STAR data)

PRX (2024) 14, 011028 (STAR collaboration)



Hydro Model calculation w/o EM field but with baryon diffusion

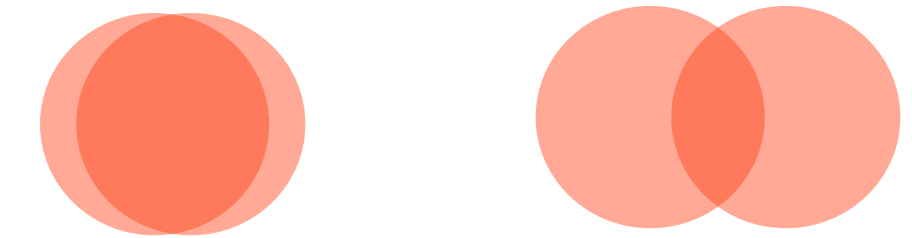
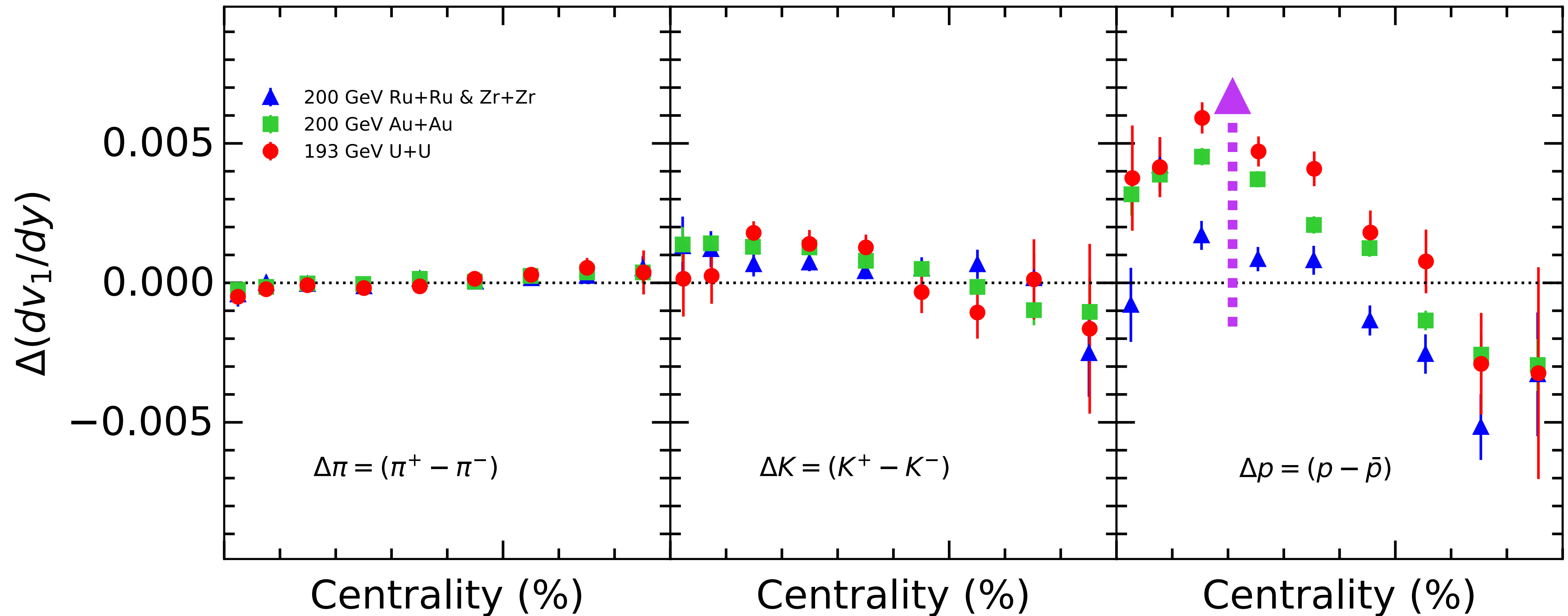
PRX (2024) 14, 011028 (STAR collaboration)



Parida, Chatterjee (2023)

Search of EM field signals

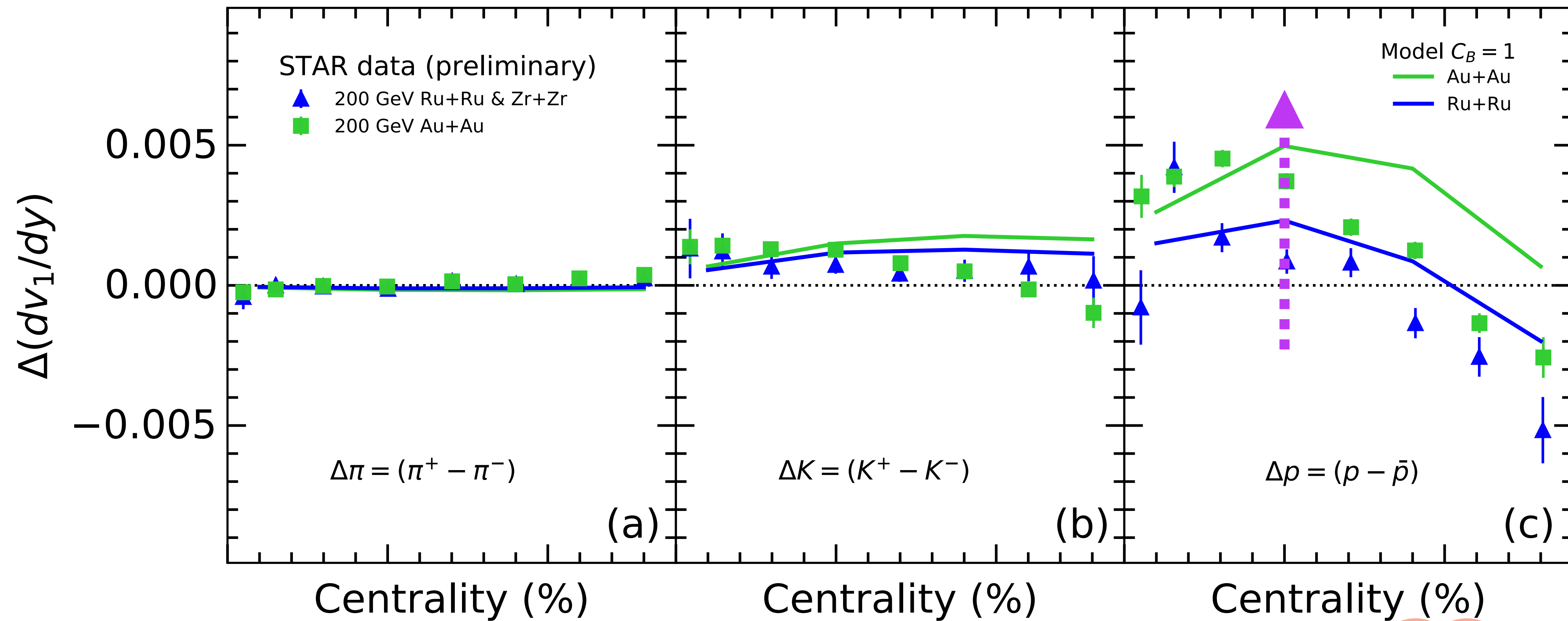
STAR collab. SQM, Strasbourg, 2024



☑ $p - \bar{p}$ shows the most system size dependence

Hydro Model calculation w/o EM field but with baryon diffusion

STAR collab. SQM, Strasbourg, 2024



Parida, Chatterjee, Singha (2025)

Observation

Hydro model calculations **w/o EM field** + w baryon diffusion ($C_B = 1$) captures centrality and system size dependence of $dv_1/dy(p - \bar{p}) \implies$ a large background contribution from physics of baryon stopping and dynamics.

Questions

1. What is the model ?
2. How good the model is in explaining the v_1 across BES ?
3. What is the phenomena, making the sign change of $\Delta dv_1/dy(p - \bar{p})$ from central to peripheral or explaining the system size dependence in the absence of EM field ?
4. What about pions and kaons ?

Hydrodynamic Model

Denicol et. al., Phys. Rev. C 98, 034916 (2018)

Conservation Equations

$$\partial_{\mu} T^{\mu\nu} = 0$$

Conservation of energy-momentum

$$\partial_{\mu} J_B^{\mu} = 0$$

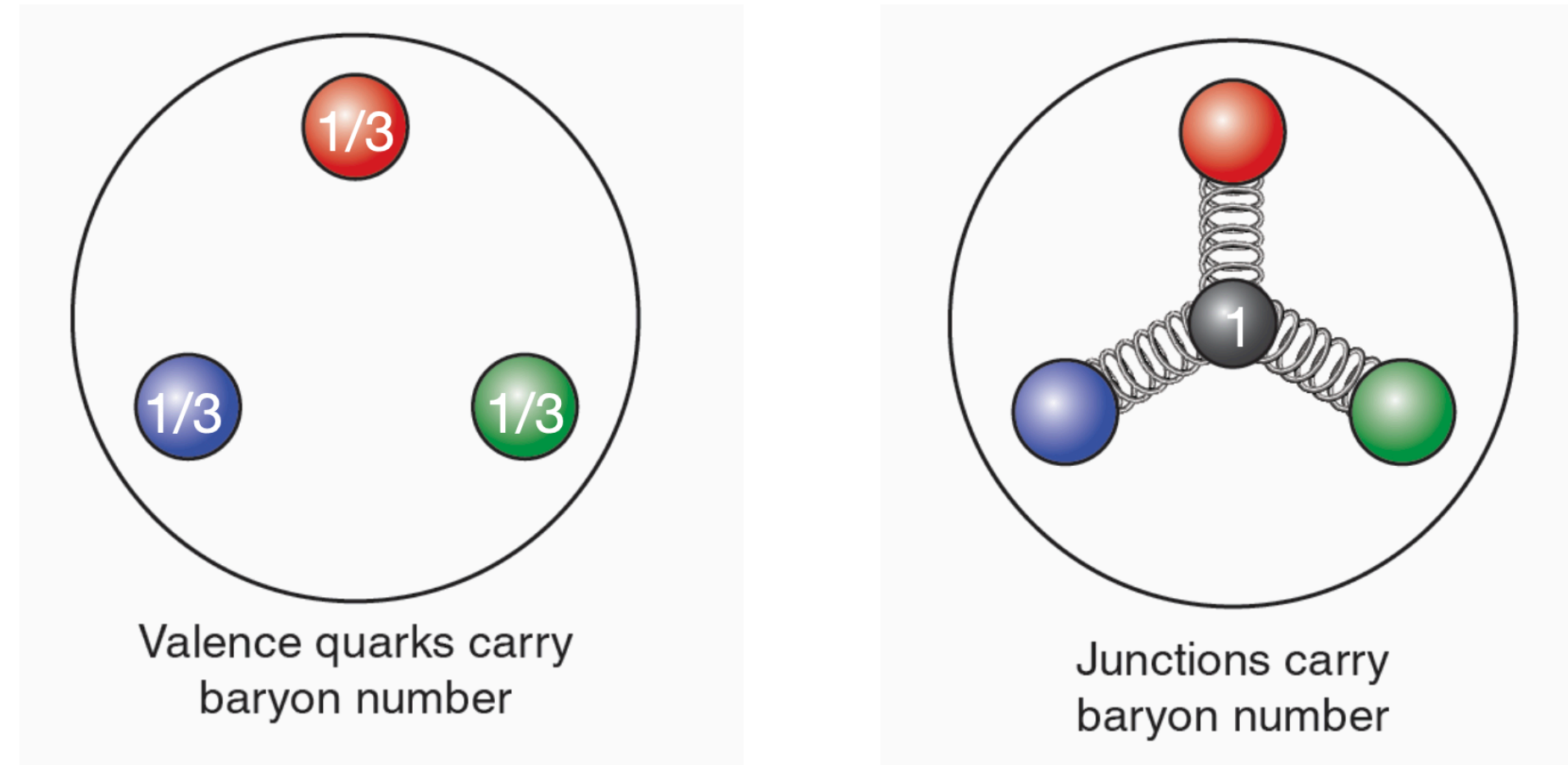
Conservation of net-baryon

- ◆ These are differential equations and needs the initial condition (IC).
- ◆ For energy-momentum : we take the 3D **tilted IC** model. (Bozek, Wyskiel, 2010) and assume Bjorken flow initially.
- ◆ For baryons : Initial condition and evolution ?

Model

Kharzeev, PLB (1996)

Single + double junction stopping motivated initial baryon deposition



Denicol et al., Phys. Rev. C 98, 034916 (2018)

Hydro with baryon diffusion



Diffusion

~~$$n_B(x, y) \propto N_{\text{participants}}$$~~

$$n_B(x, y) \propto (1 - \omega)N_{\text{participants}} + \omega N_{\text{binary collisions}}$$

participants

Single junction stopping

binary collisions

double junction stopping

- Support from microscopic models - in microscopic models rapidity loss depends on number of binary collisions.

Fick's law :

$$j_B^\mu = \kappa_B \nabla^\mu (n_B)$$

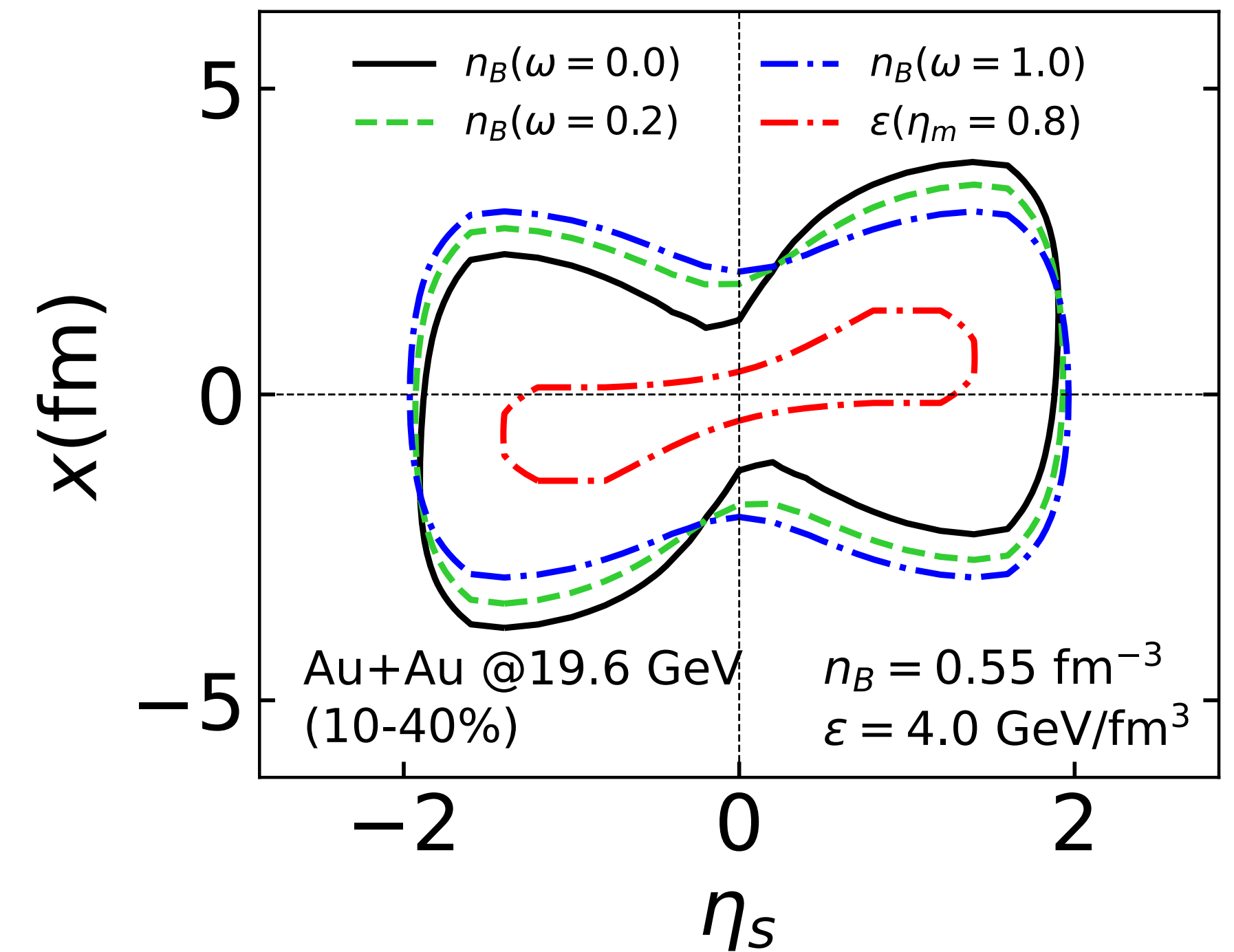
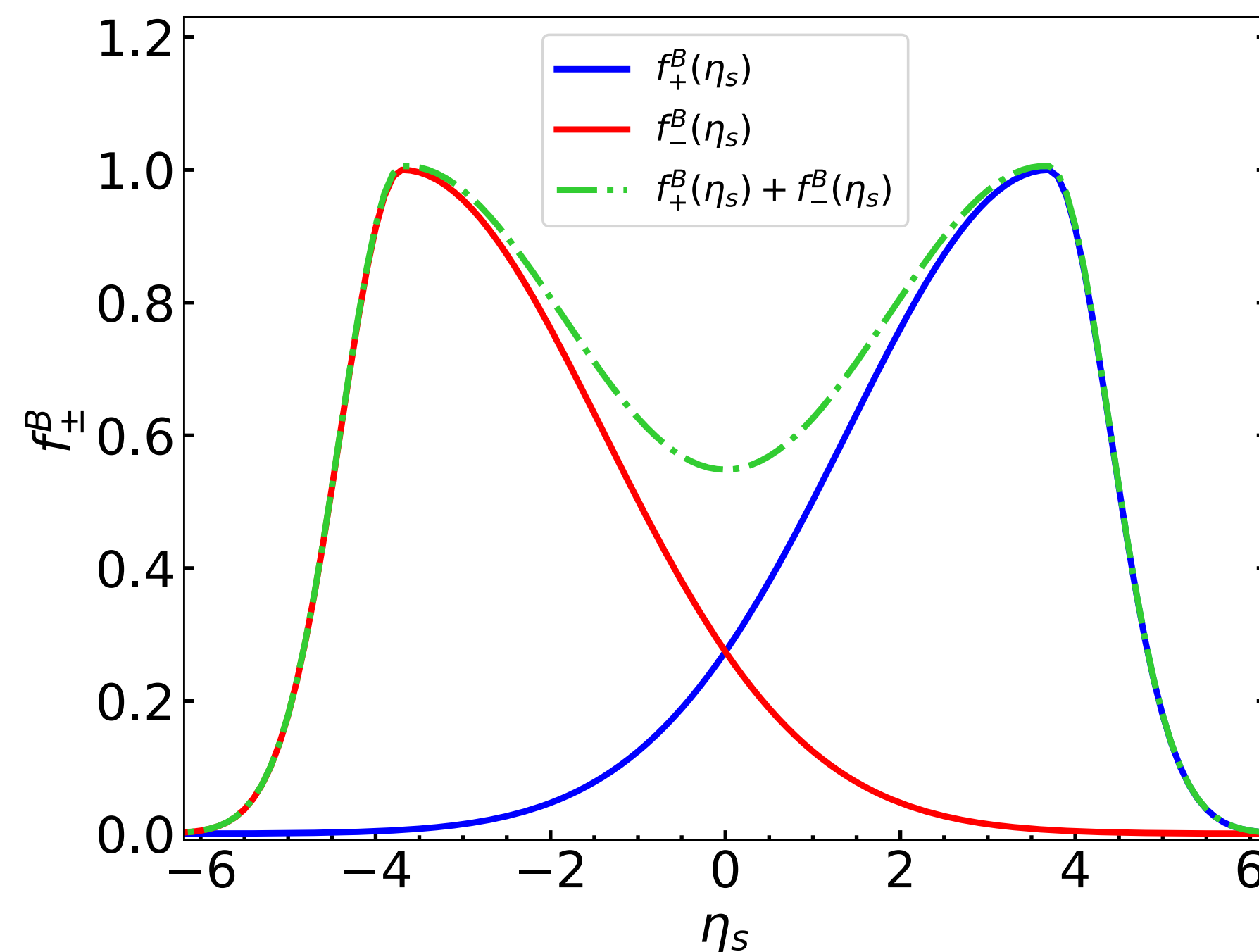
Diffusion current

Diffusion coefficient

Our model of initial baryon distribution : rapidity profiles

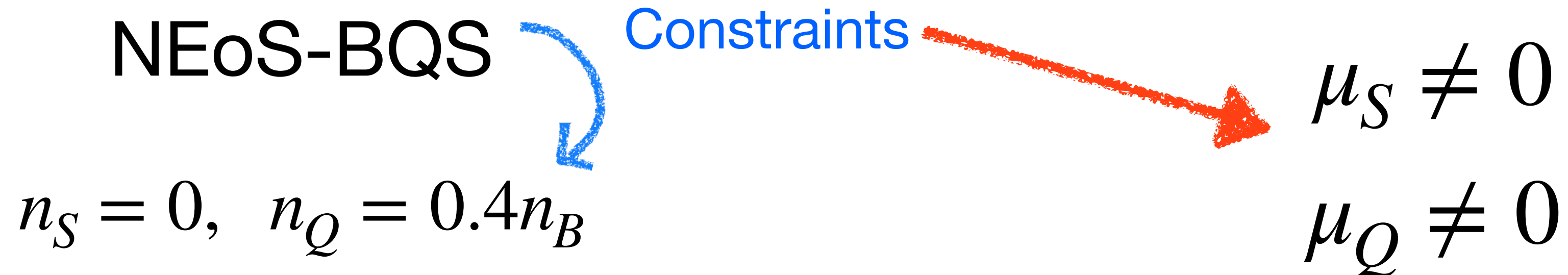
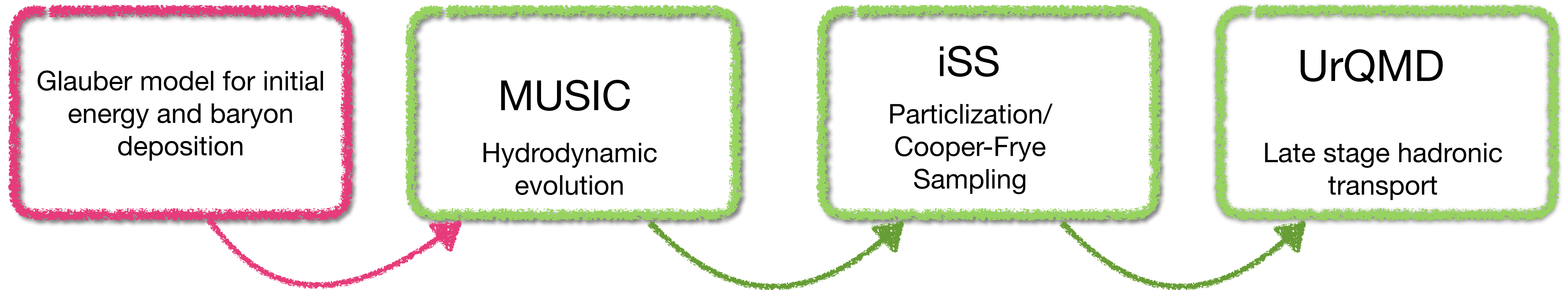
$$n_B(x, y, \eta_s) = N_B \left[(1 - \omega) \left(N_+(x, y) f_+^B(\eta_s) + N_-(x, y) f_-^B(\eta_s) \right) + \omega N_{coll}(x, y) \left(f_+^B(\eta_s) + f_-^B(\eta_s) \right) \right]$$

- Participants : forward-backward asymmetric rapidity profile.
- Binary collision : rapidity symmetric profile.



Model

Denicol et. al., Phys. Rev. C 98, 034916 (2018)



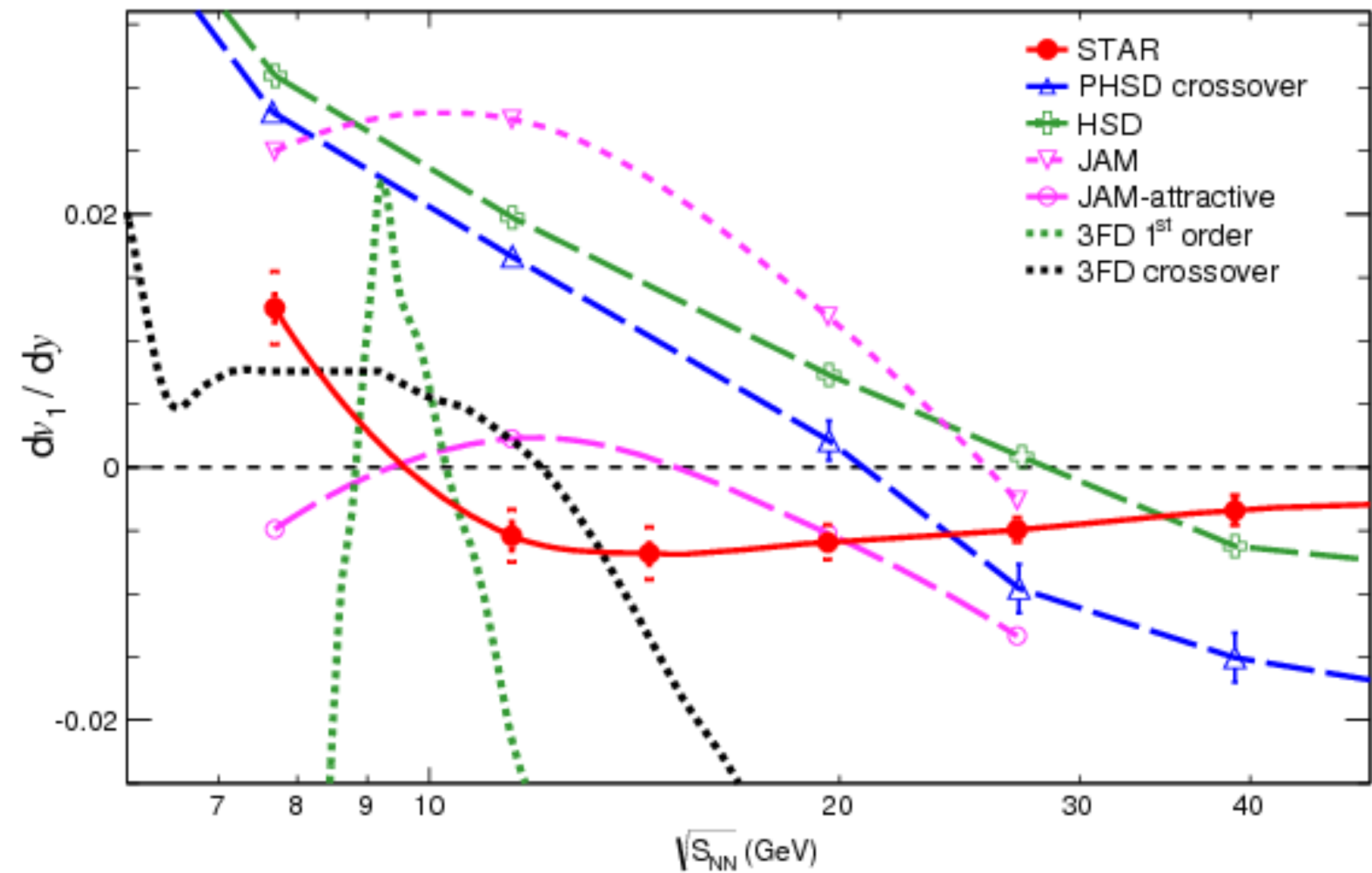
A. Monnai, C. Shen and B. Schenke,
Phys. Rev. C 100, 024907 (2019)

Questions

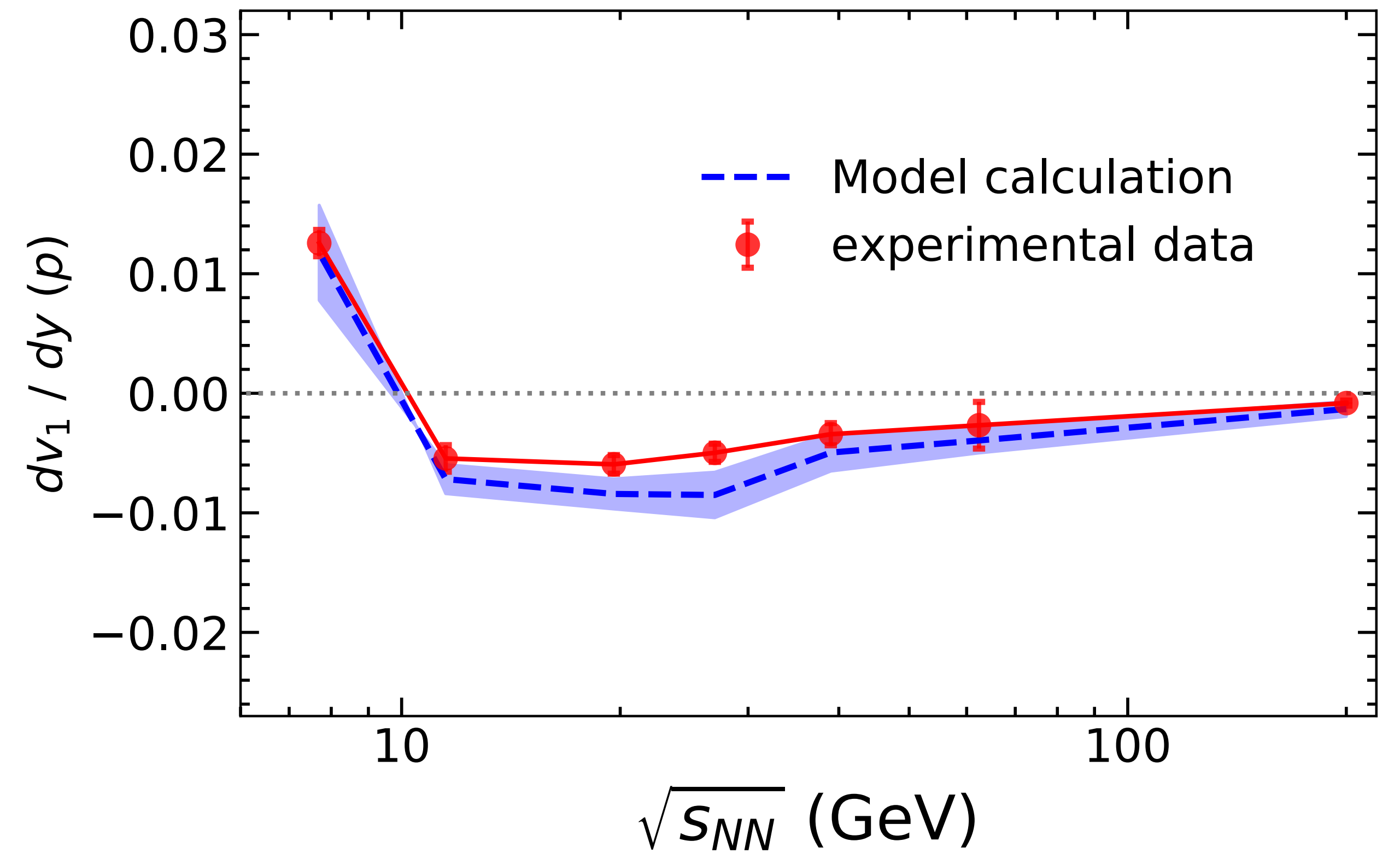
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Results

Earlier



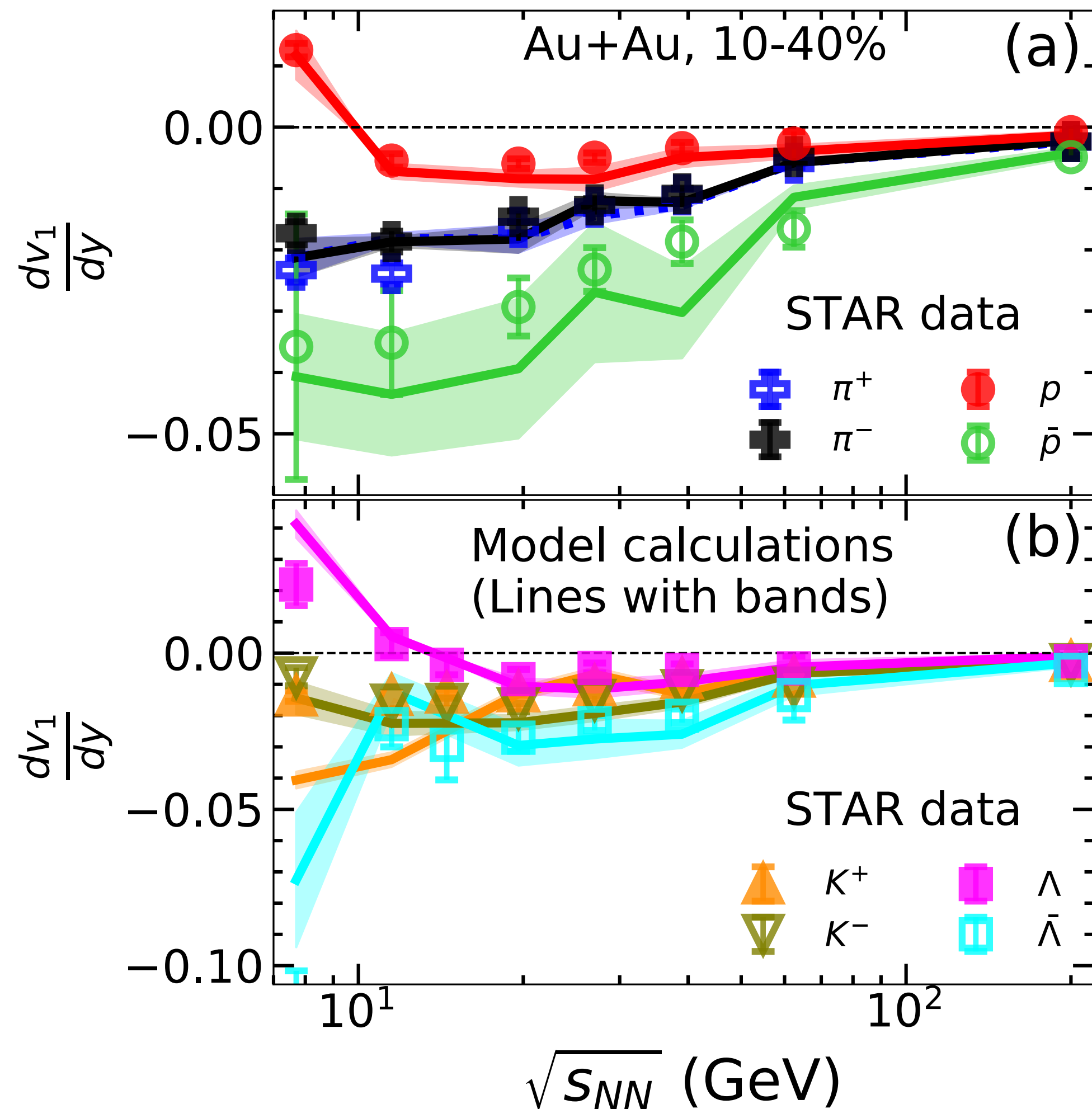
With our model



S. Singha, P. Shanmuganathan and D. Keane,
Adv. High Energy Phys. (2016), 2836989

dv_1/dy of all identified hadrons.

TP and S. Chatterjee, arXiv : 2211.15659



- ✓ Model calculation captures the splitting of v_1 between baryons and anti-baryons.
- ✓ Sign change of dv_1/dy of p and Λ @7.7 GeV captured.
- ✓ Splitting between v_1 of K^+ and K^- due to the employed constraints $n_S = 0$ and $n_Q = 0.4n_B$. Model calculation overpredicts the experimental measurement which suggests to evolve the conserve charge of net strangeness in hydrodynamic simulation.

Questions

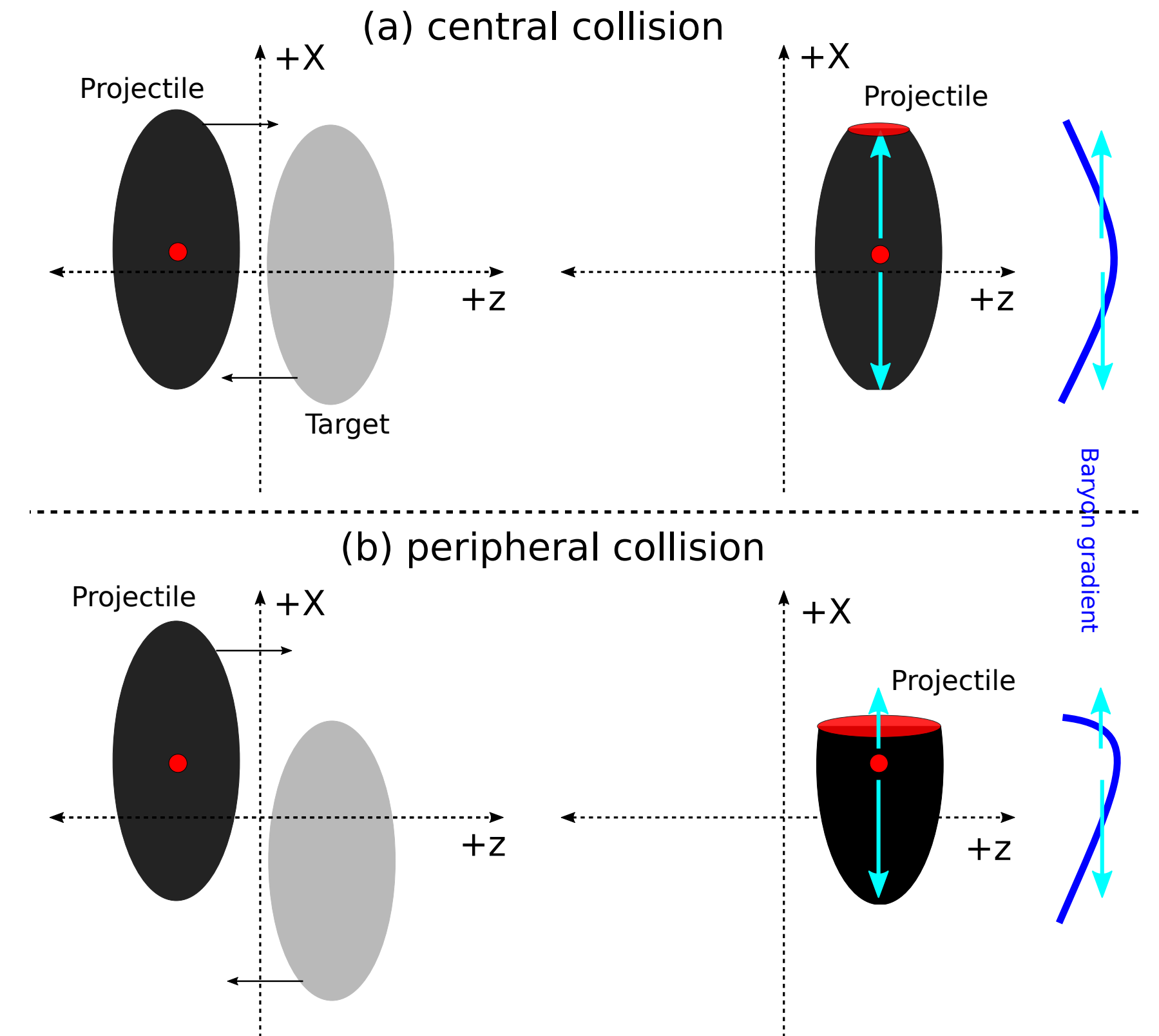
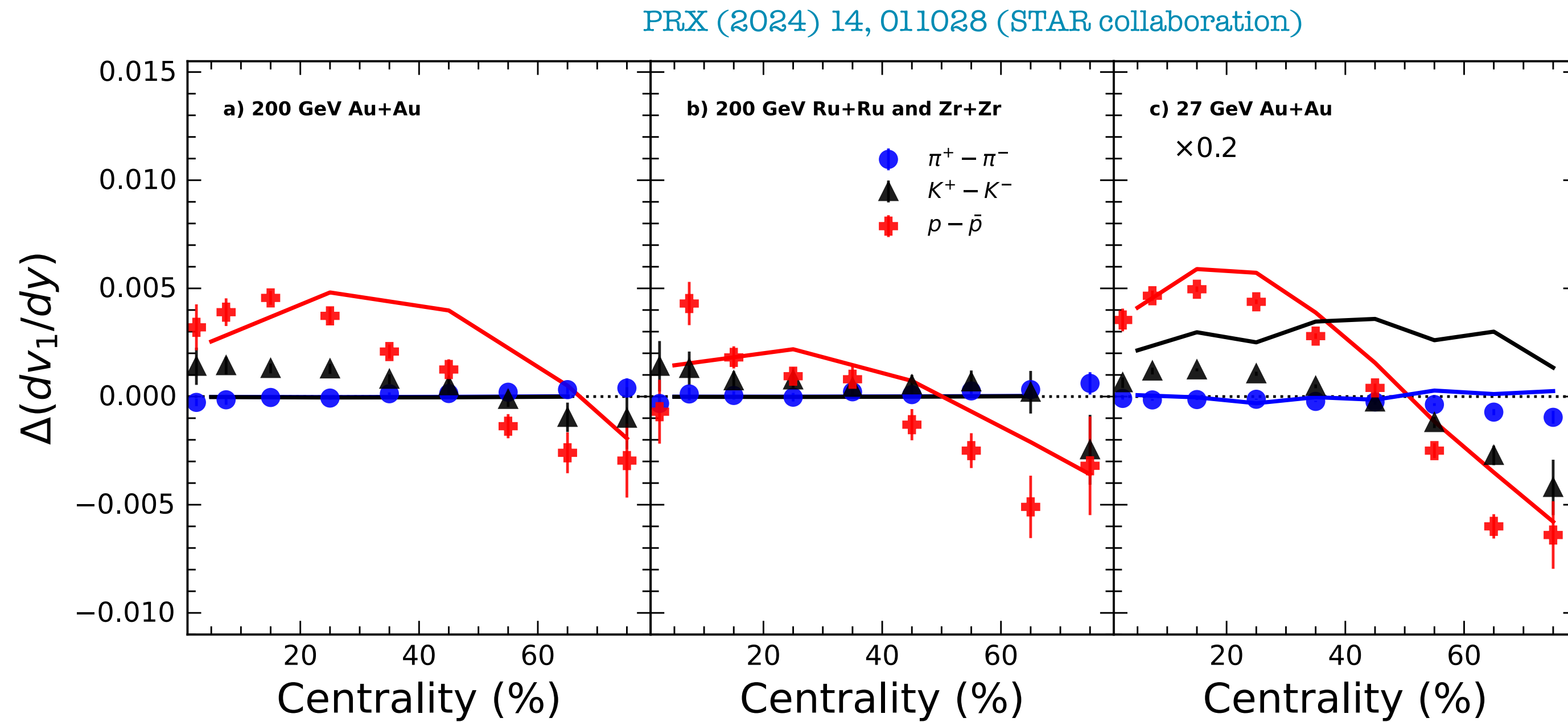
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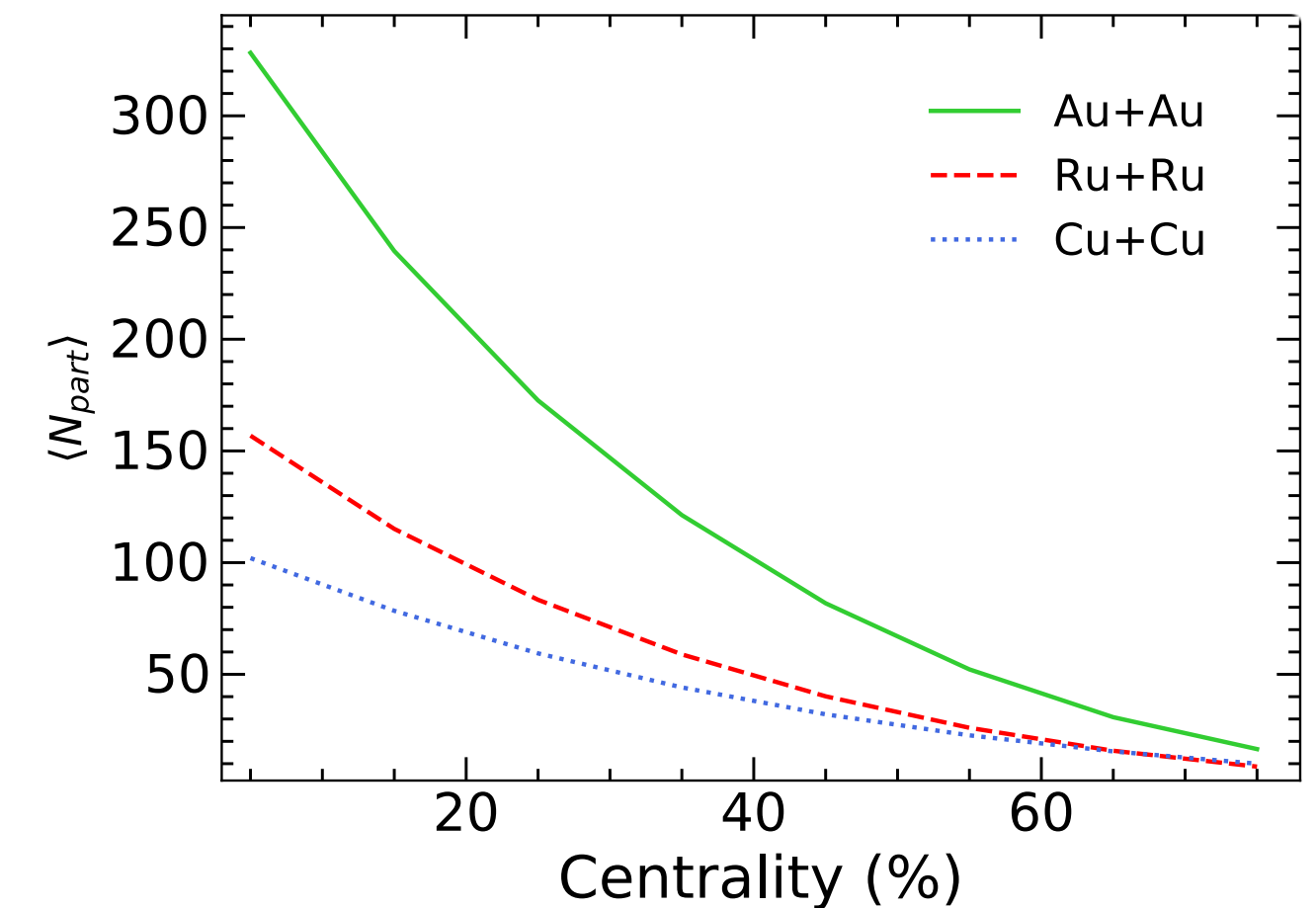
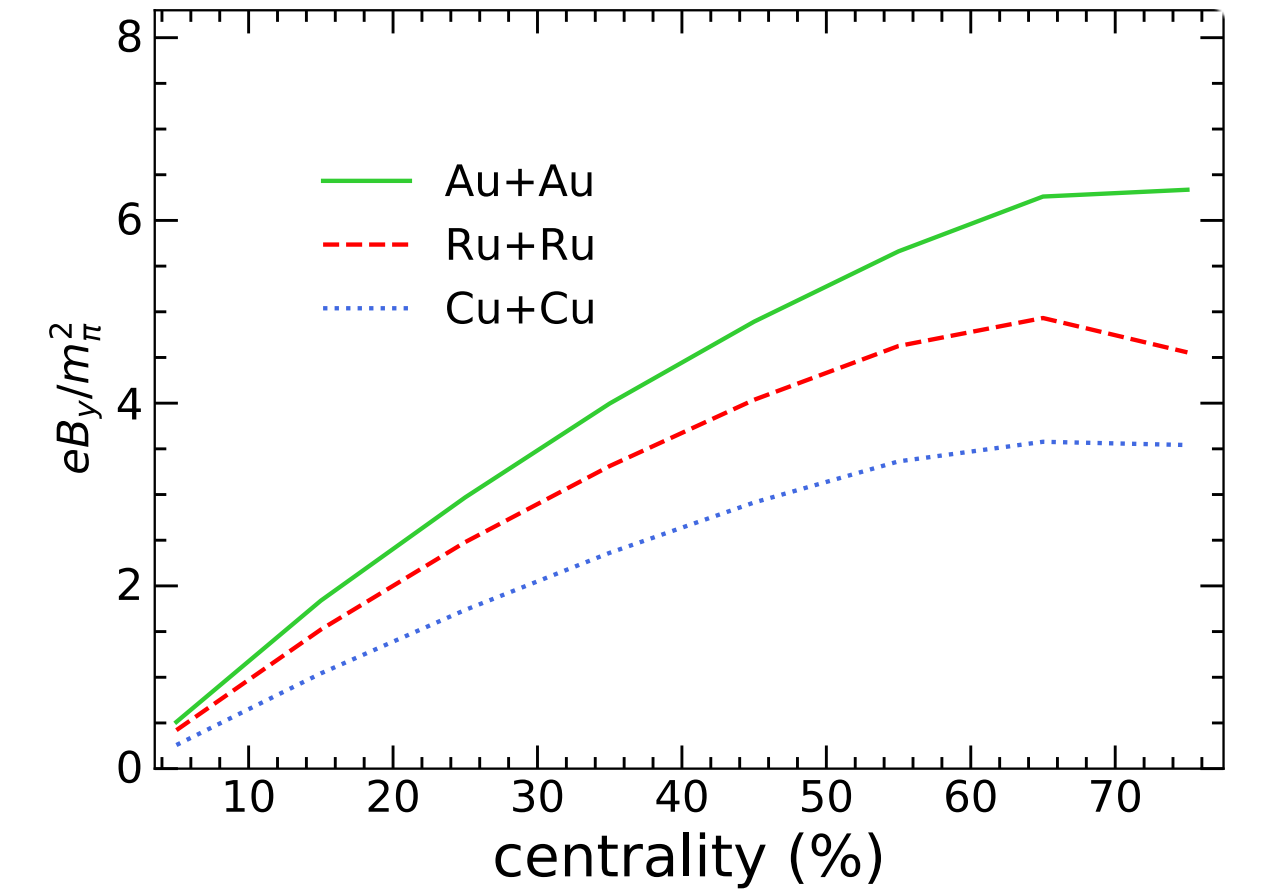
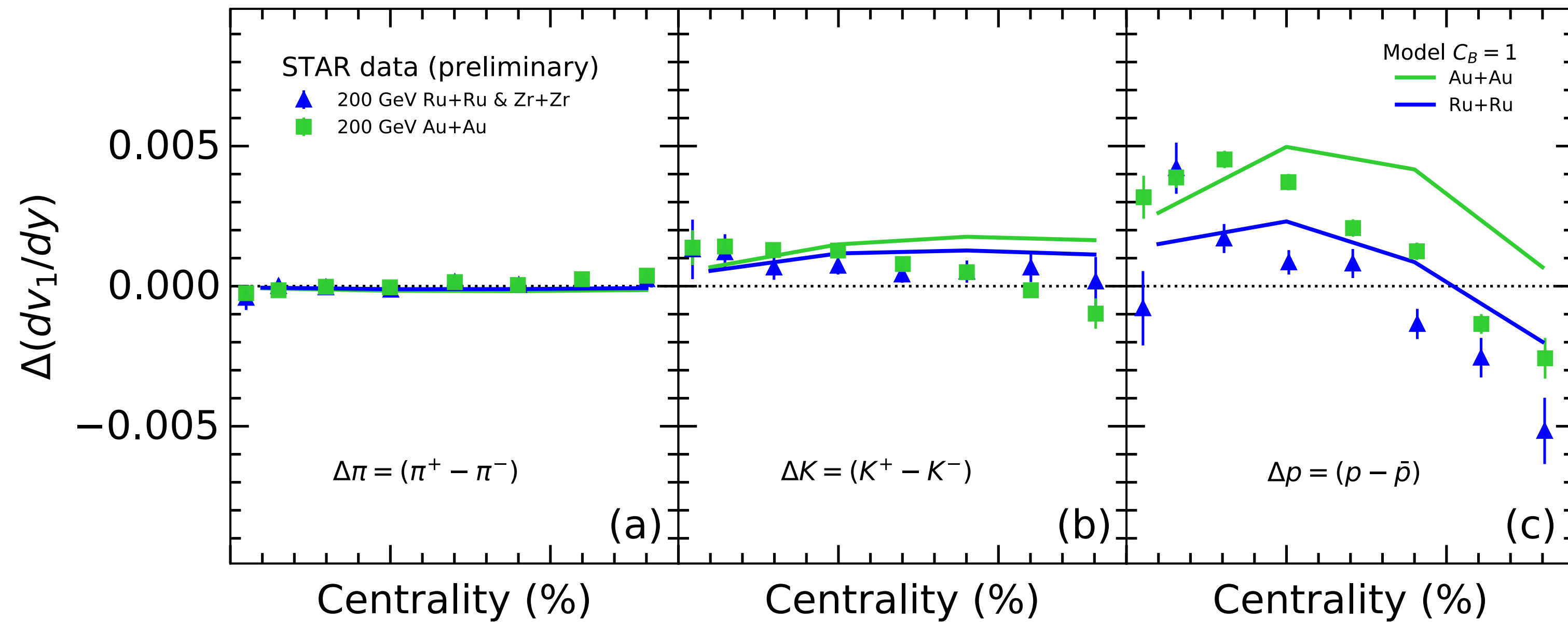
Baryon Phenomena driving the v_1 splitting in the similar direction like EM field effect does.



- ◆ Change in baryon gradient from central to peripheral collisions and hence the baryon diffusion affects the v_1 splitting between p and $\bar{p}$.

Baryon Phenomena driving the v_1 splitting in the similar direction like EM field effect does.

STAR collab. SQM, Strasbourg, 2024



Parida, Chatterjee, Singha (2025)

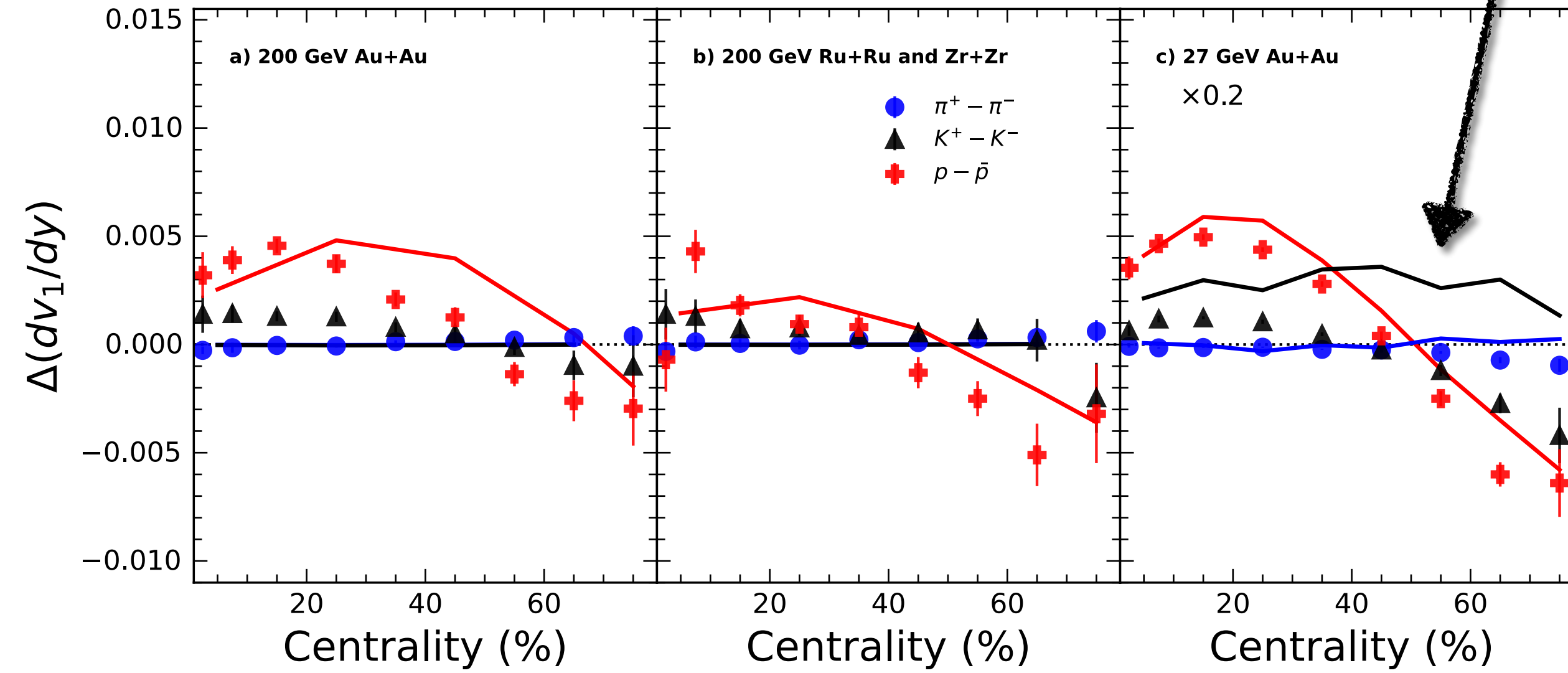
- ◆ Not only EM field strength changes with system size but also the net baryon deposition also changes.

Questions

1. What is the model ?
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The model limitations

$$K^+ - K^-$$



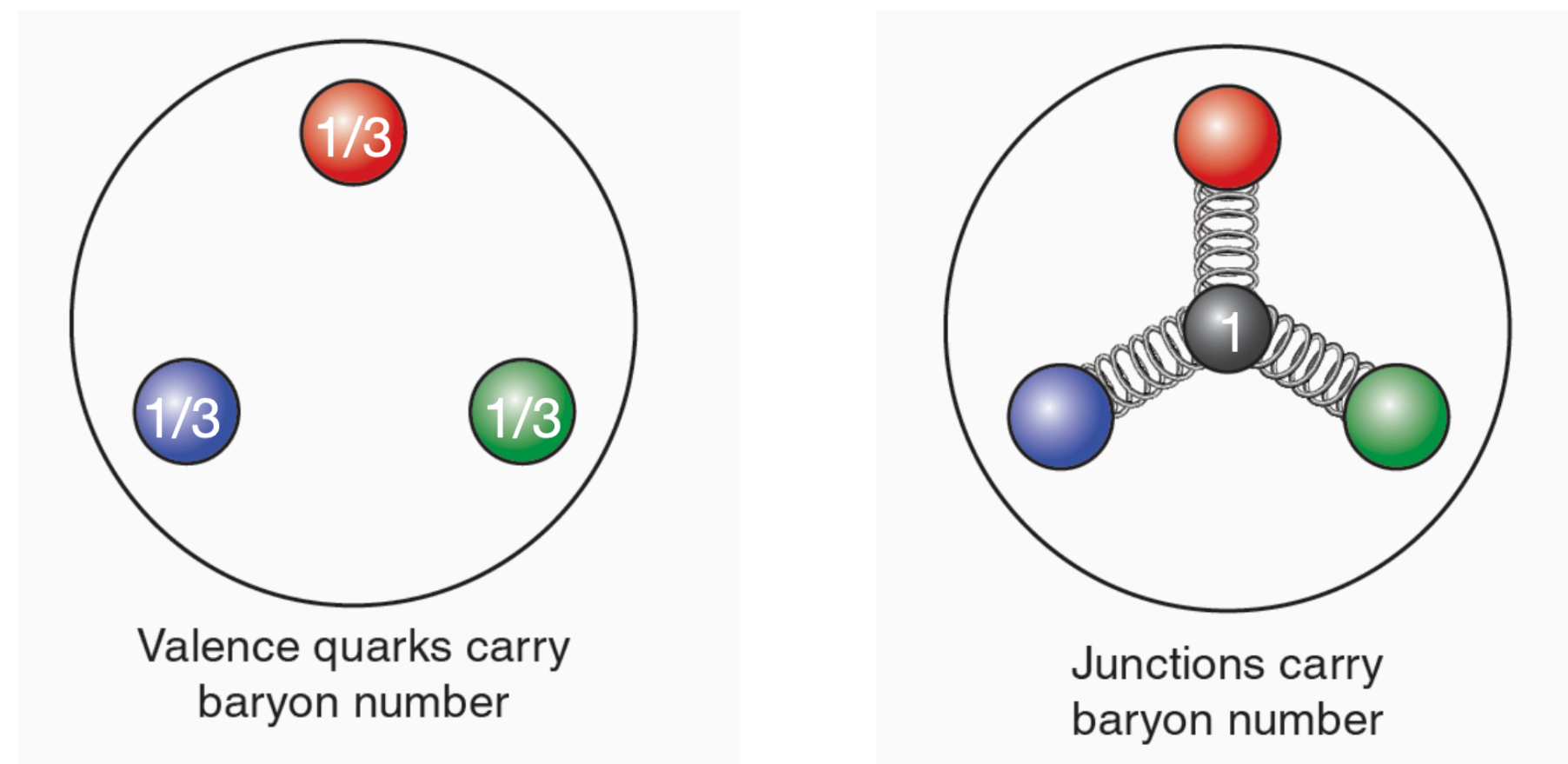
- ☑ Splitting between v_1 of K^+ and K^- is due to the employed constraints in EoS during hydro evolution $n_S = 0$ and $n_Q = 0.4n_B$.
- ☑ Independent evolution and diffusion of other conserved charges, (S and Q) also required. Hence the interpretation of v_1 splitting between kaons and pions are still open.

Summary

- ☑ We provide a baryon initial condition model that shows good agreement with experimental data of v_1 of identified hadrons, especially it captures the splitting between baryon and anti-baryon.
- ☑ Current measurements by STAR on **signals of EM field receive a strong background contribution** from the physics of baryon stopping.
- ☑ Our initial baryon stopping model can be used in hydrodynamic model which can provide a non-critical baryonic **baseline** that is crucial in the ongoing searches for the **QCD critical point** and **signatures of EM field**.

Backup

Our model of initial baryon distribution : a two component baryon deposition scheme



In p+p collisions [Kharzeev \(1996\)](#)

Junction type	Baryon units	Rapidity dependence
Single junction stopping	1	$\sigma^J \sim e^{-\alpha_2 y}$
Double junction stopping	2	No rapidity dependence

Modelling in A+A collisions

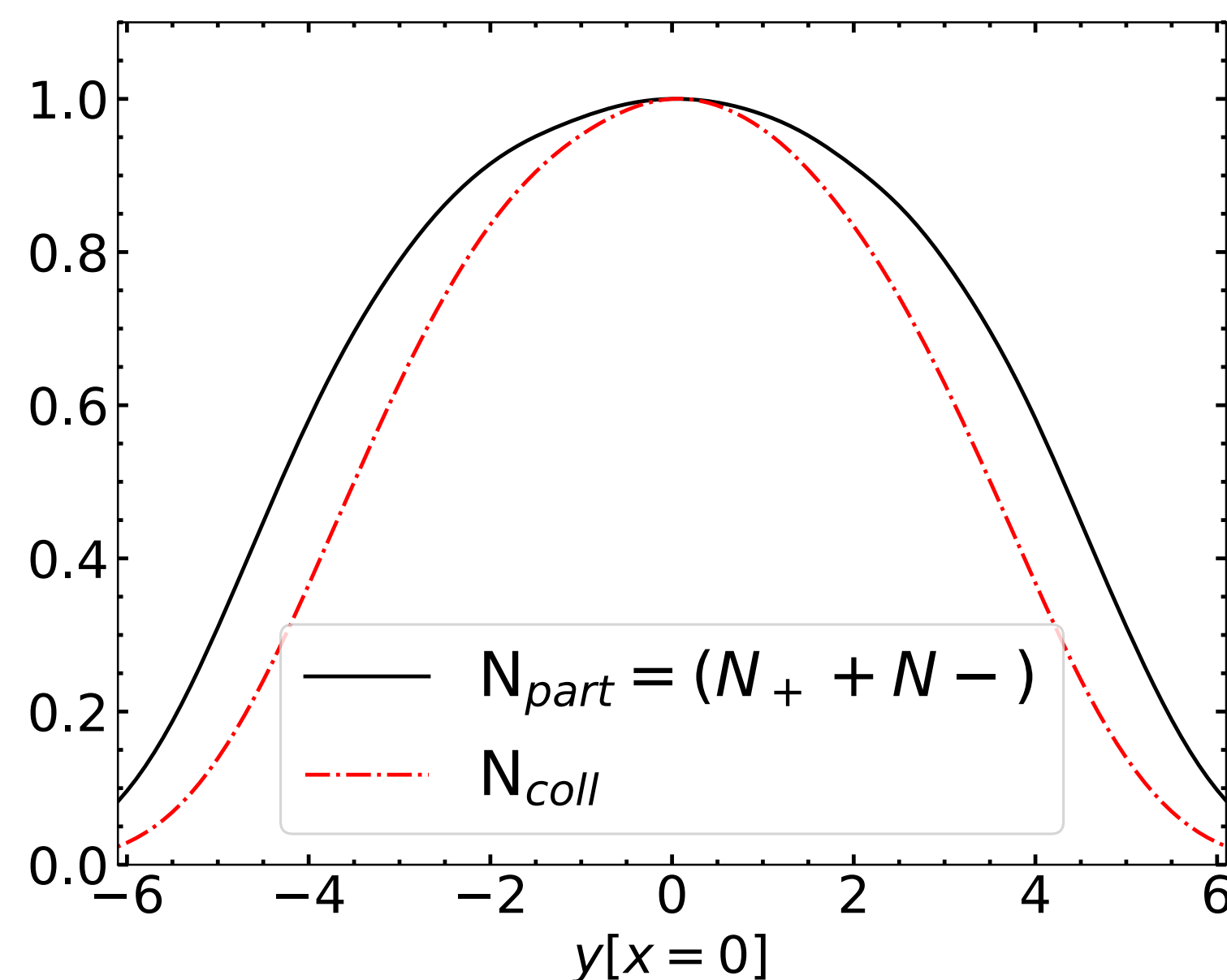
$$n_B(x, y) \sim (1 - \omega)N_{part}(x, y) + \omega N_{coll}(x, y)$$

participants

binary collisions

Single junction
stopping

double junction
stopping

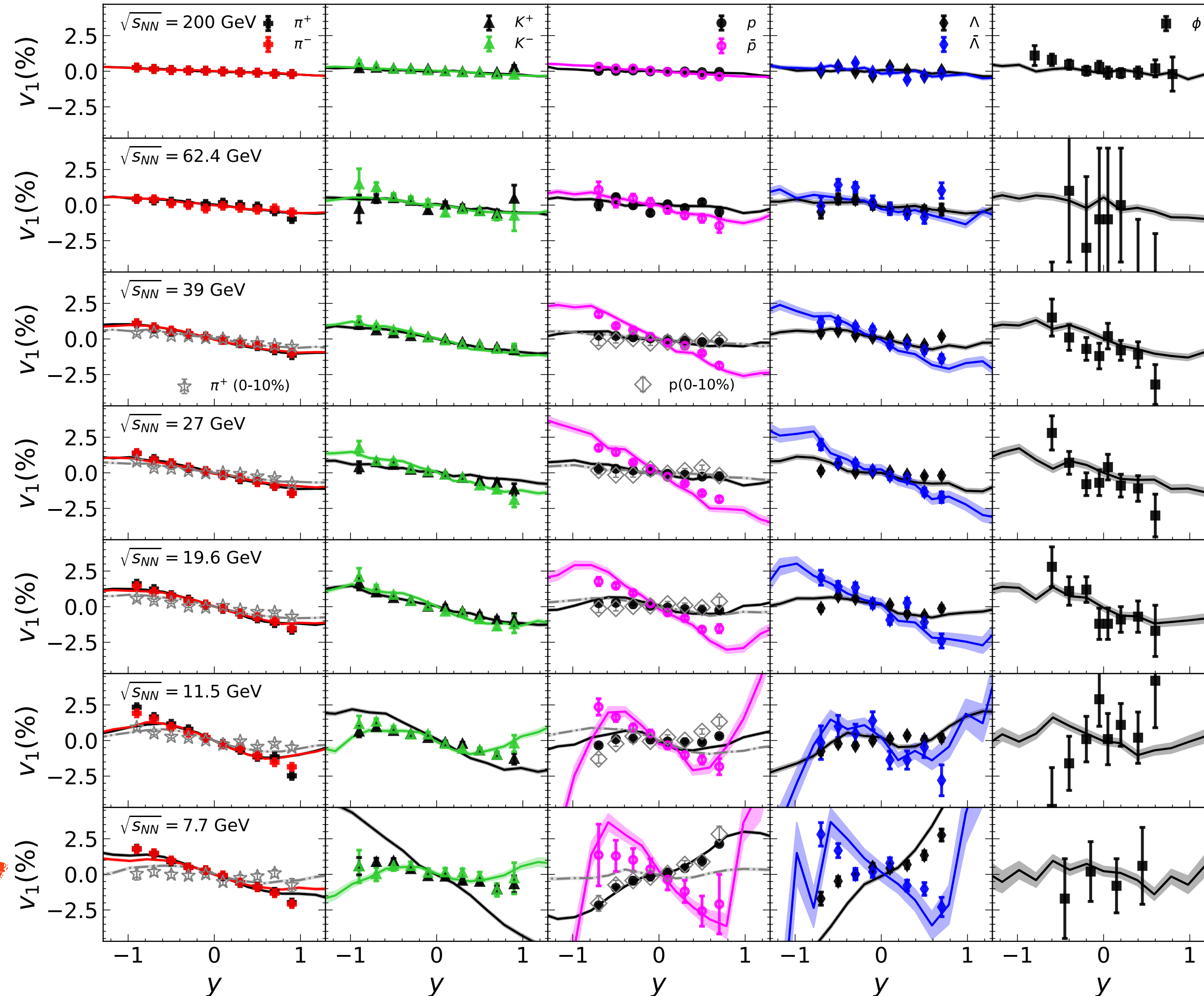


- Support from microscopic models - in microscopic models rapidity loss depends on number of binary collisions.

Directed flow of all identified hadrons.

Particle species

Collision energy



TP and S. Chatterjee, arXiv : 2211.15659

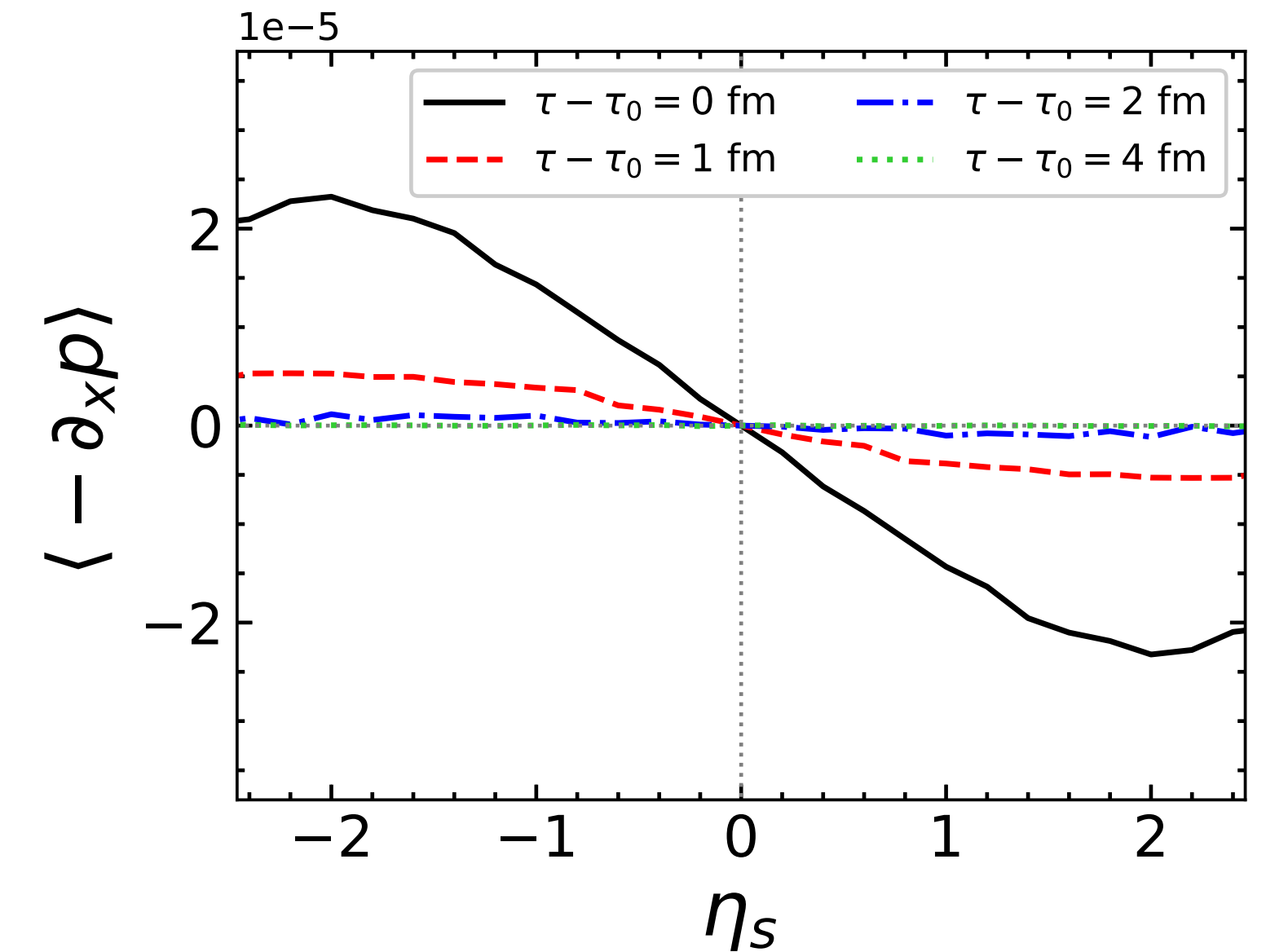
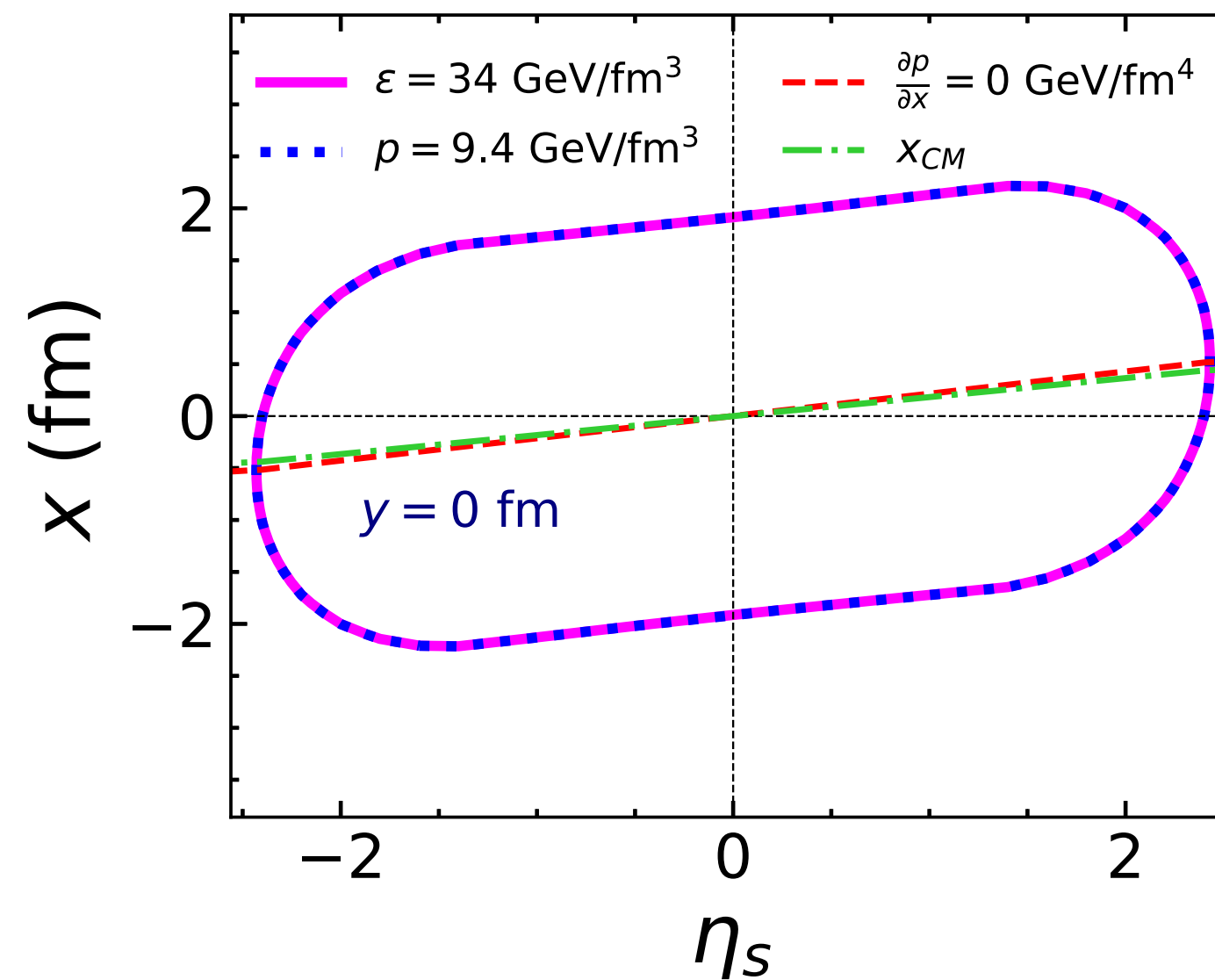
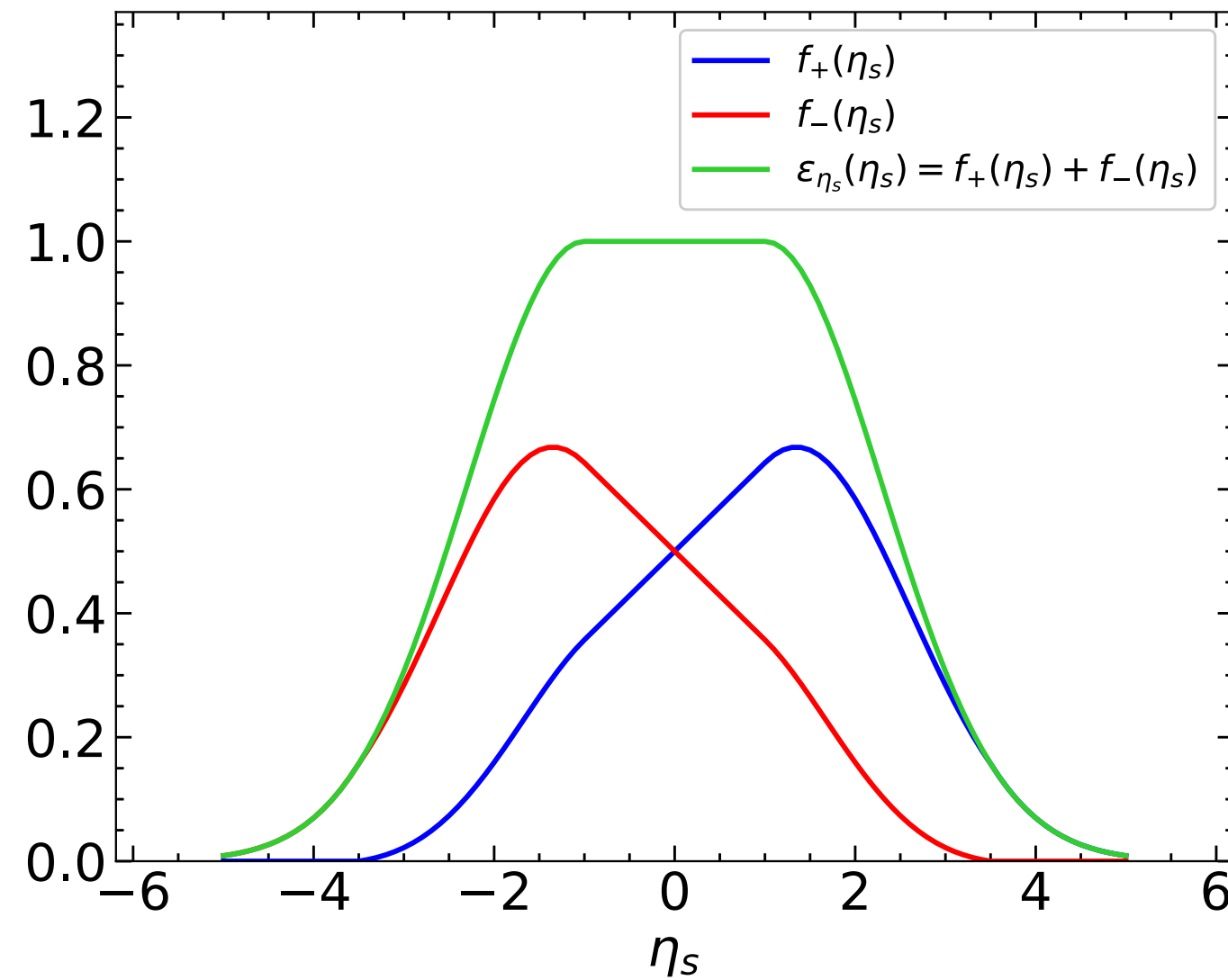
Model calculations (lines with bands) are compared with experimental measurements (symbols).

Tilted energy deposition and v_1 of charged hadrons

P. Bozek and I. Wyskiel, Phys. Rev. C 81, 054902 (2010)

A participant nucleon deposits more energy along it's direction of motion.

$$\epsilon(x, y, \eta_s) = \epsilon_0 \left[\left(N_+(x, y) f_+(\eta_s) + N_-(x, y) f_-(\eta_s) \right) (1 - \alpha) + N_{coll}(x, y) \epsilon_{\eta_s}(\eta_s) \alpha \right]$$



$$\langle (-\partial_x p) \rangle = \frac{\int dx (-\partial_x p) \epsilon(x)}{\int dx \epsilon(x)}$$