Baryon stopping and flowing

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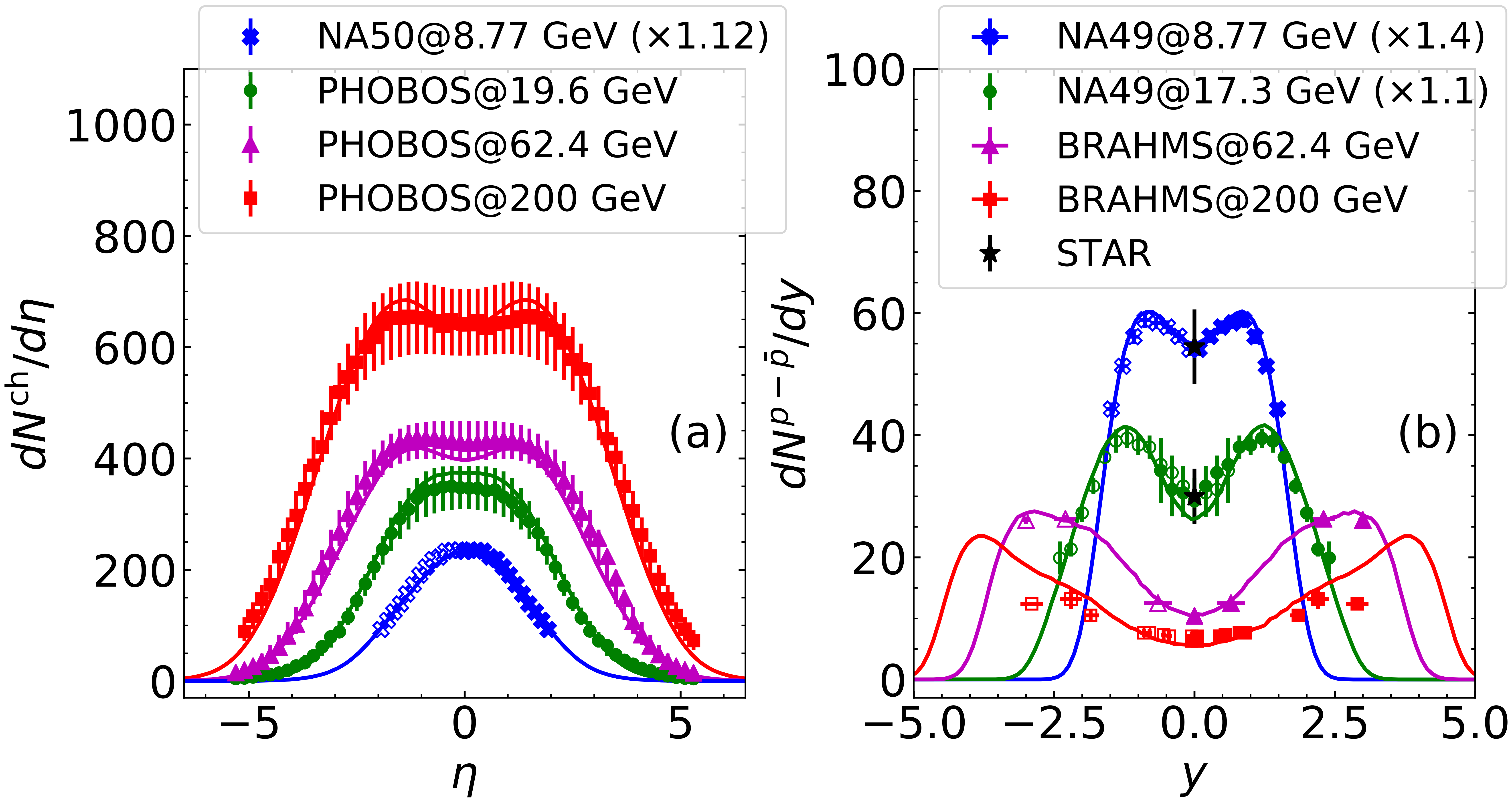
$T^{\mu\nu}, J_B^\mu$: a tale of 2 currents

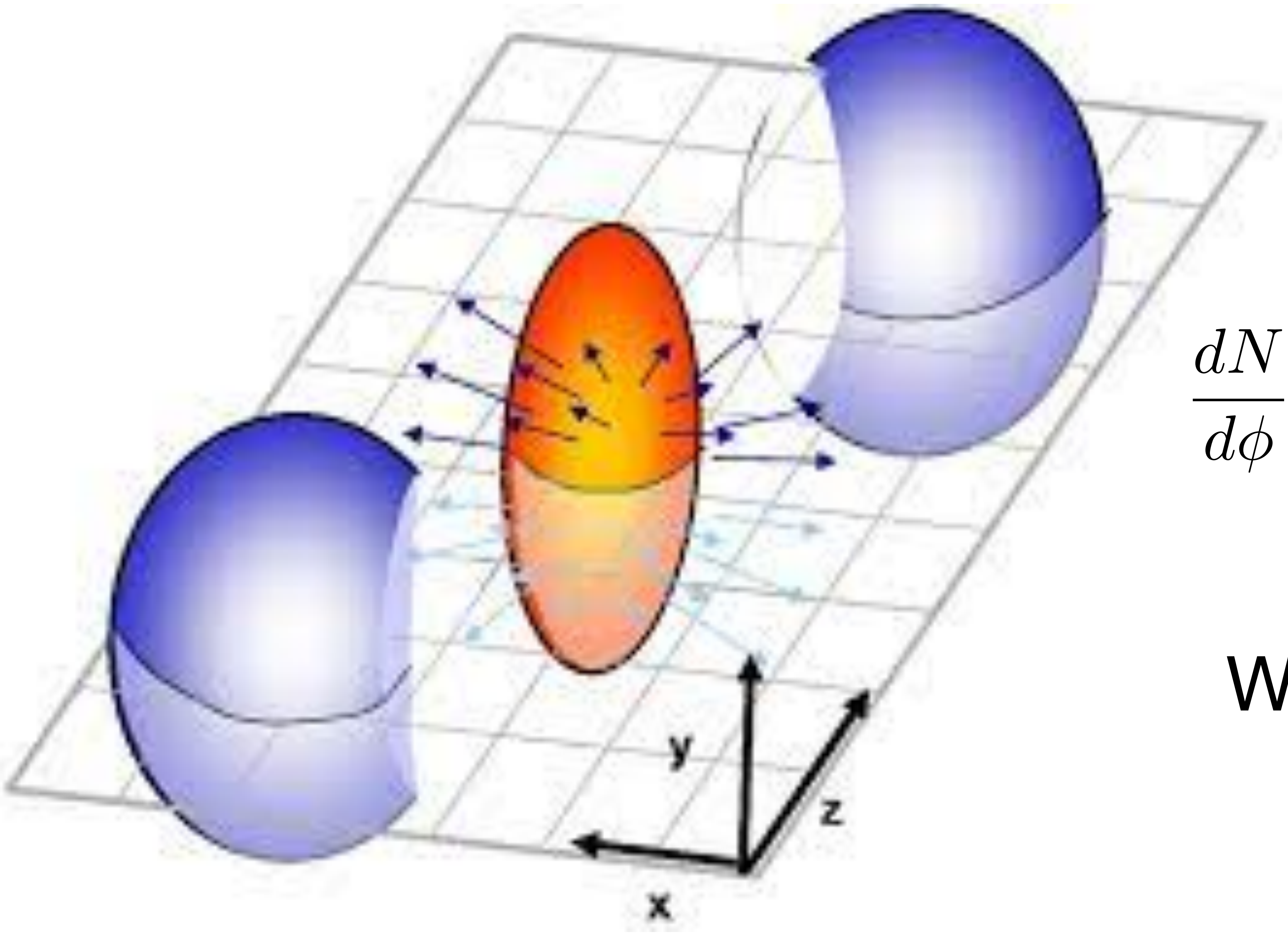


arXiv: 2211.16408

As we go to lower energies, the baryon current plays an increasingly important role: essential to understand

How well do we understand the baryon current? (Flow is the focus in this talk; in particular, directed flow)

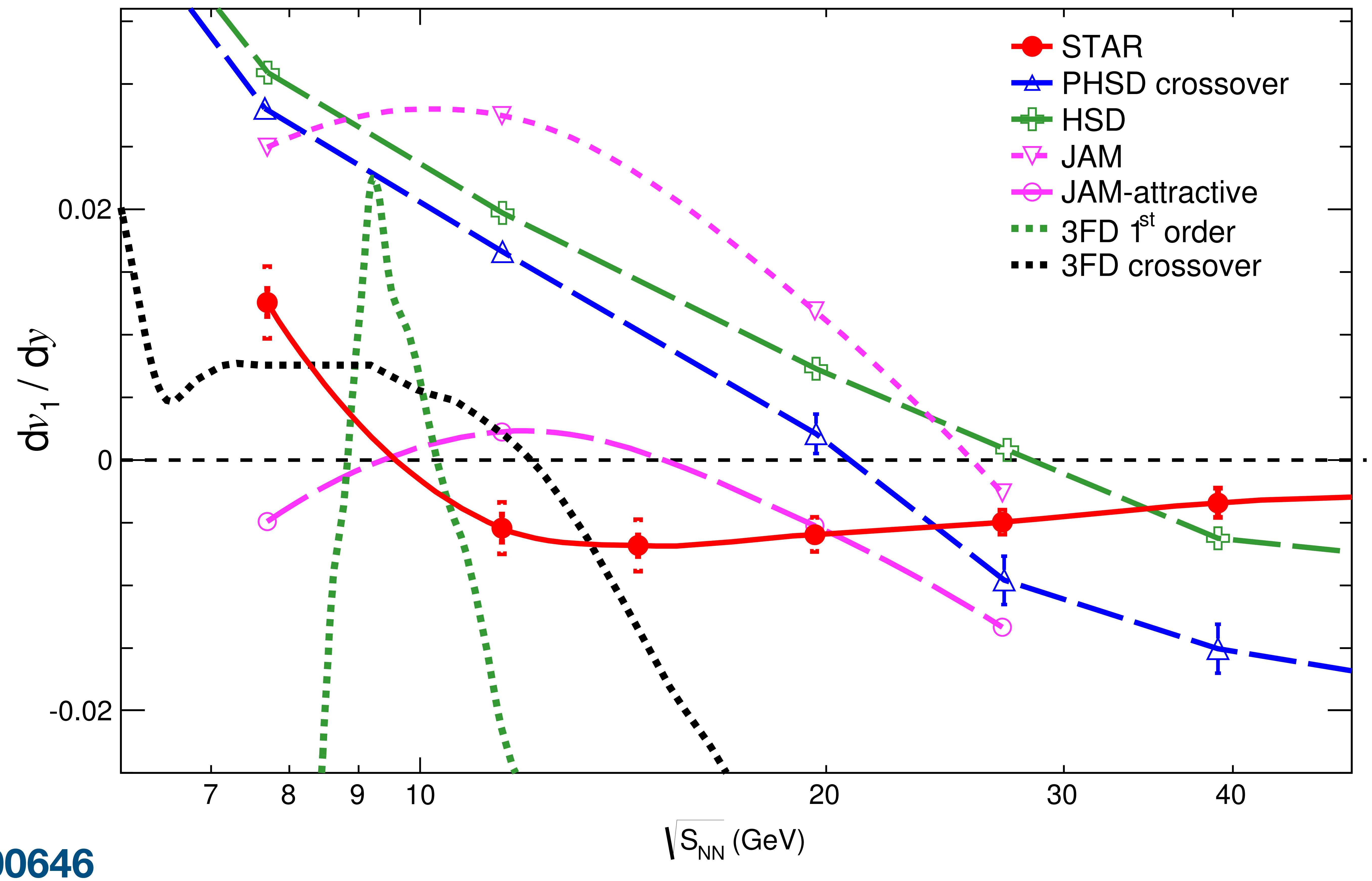
Flow observables



$$\frac{dN}{d\phi} = \frac{1}{2\pi}\left(1 + 2\sum_n \left(v_n \cos(n(\phi - \psi_{\mathrm{RP}})) + s_n \sin(n(\phi - \psi_{\mathrm{RP}}))\right)\right)$$

We will focus on v_1

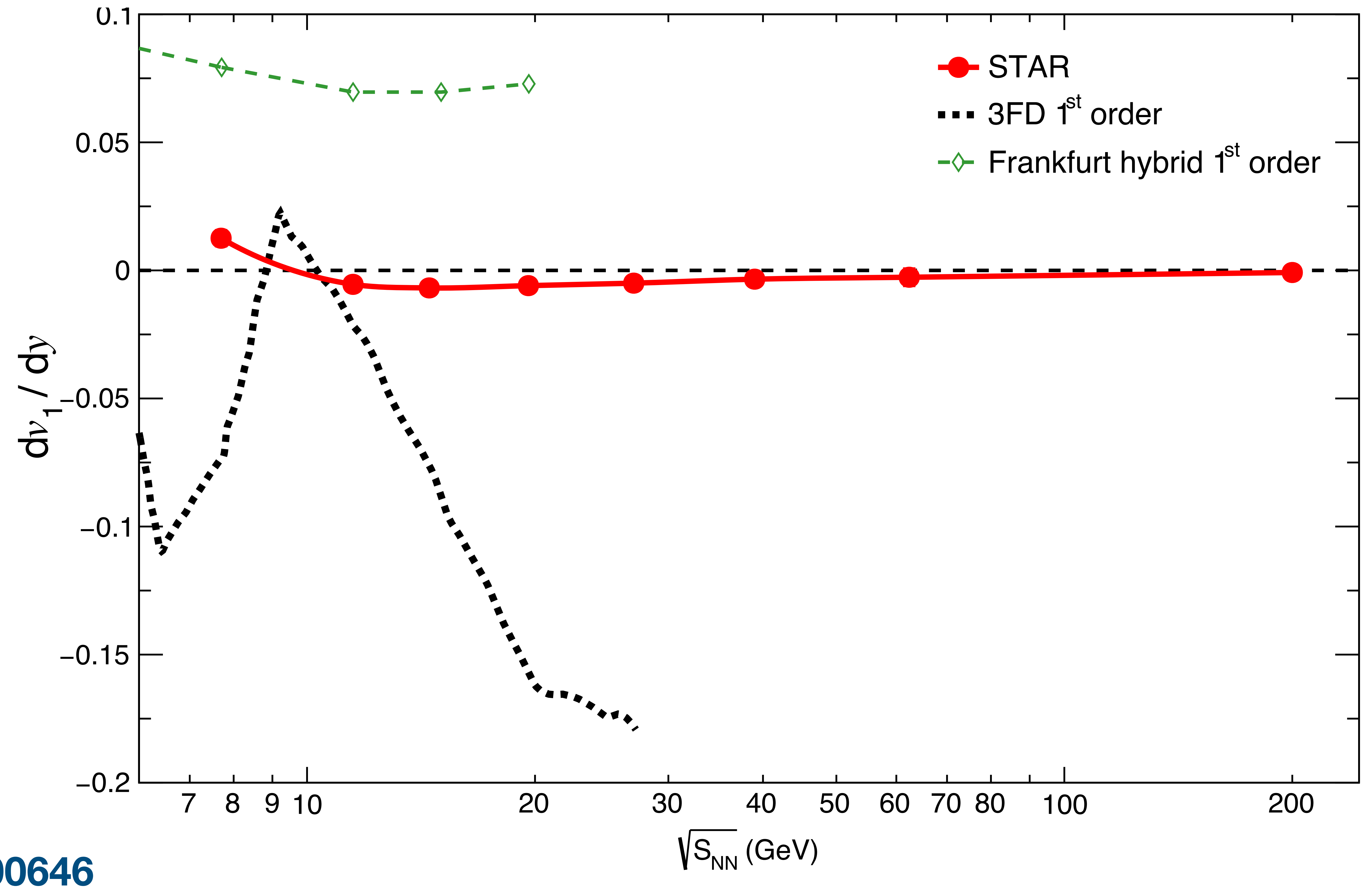
The status



arXiv: 1610.00646

FIG. 13. (Color online) Beam energy dependence of directed flow slope for protons in 10-40% centrality Au+Au from the STAR experiment, compared with recent available model calculations [19, 20, 95]. All the experimental data are from Ref. [46] except for one energy point, $\sqrt{s_{NN}}$ = 14.5 GeV [90], which should be considered a preliminary measurement. The Frankfurt hybrid model [94] as well as a pure hydro calculation with particle freeze-out at constant energy density [94] both lie above the data and are off-scale at all BES energies.

The status



Predictions from hydro with Glauber initial conditions need to evolve baryon charge

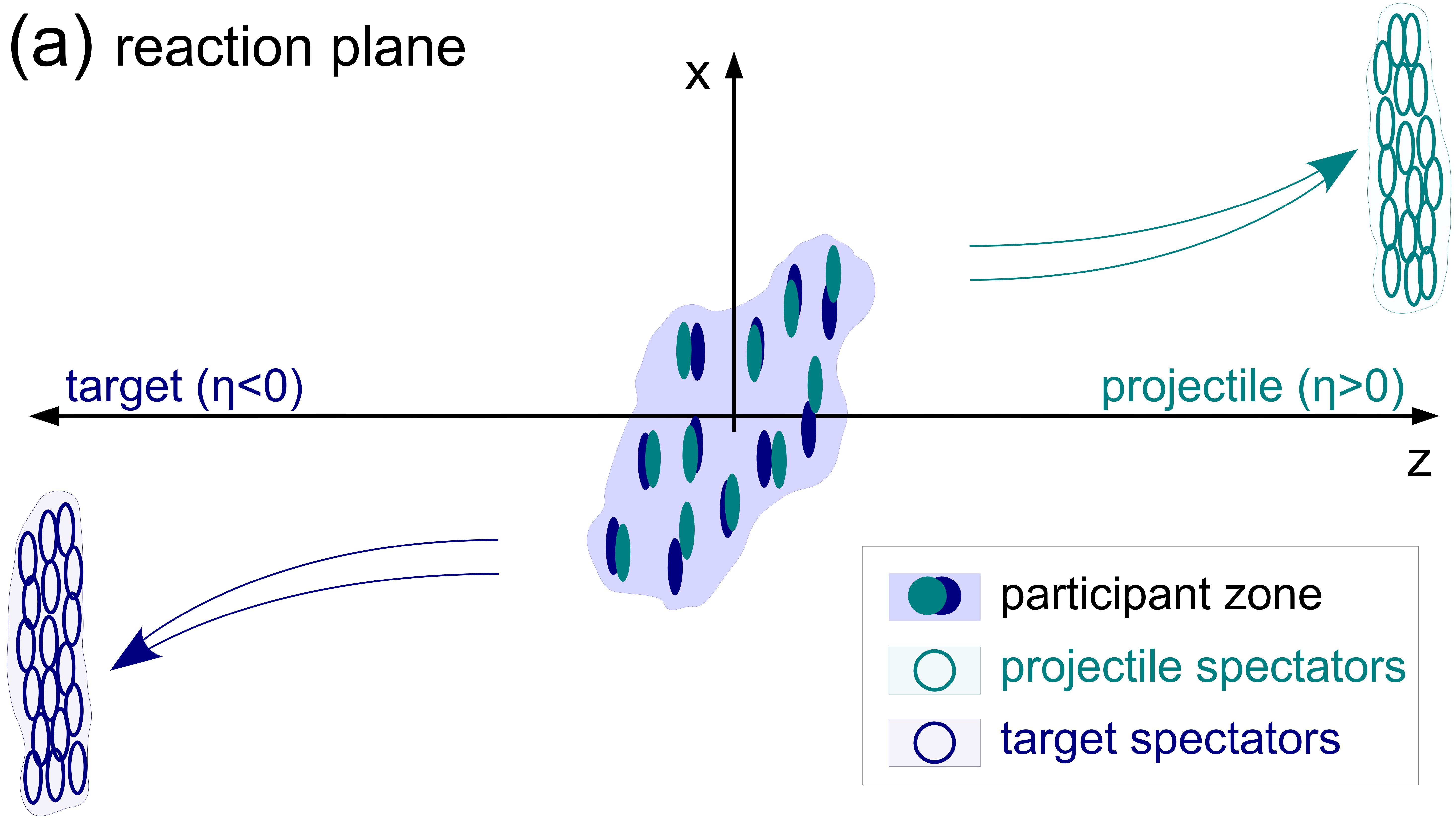
Hence, we focus on baryon directed flow

arXiv: 1610.00646

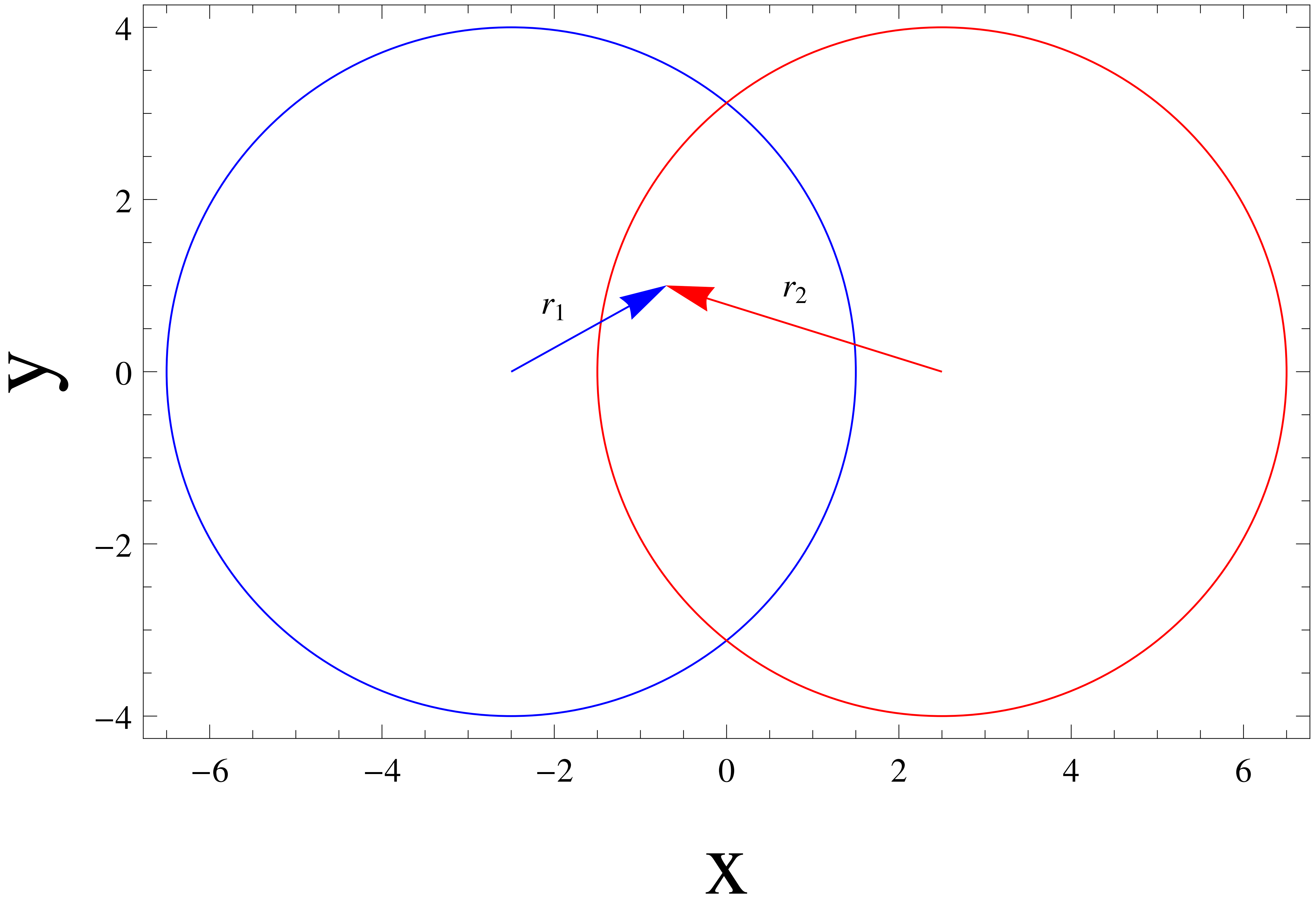
FIG. 14. (Color online) Beam energy dependence of directed flow slope for protons in 10-40% centrality Au+Au from the STAR experiment, compared with recent hybrid [94] and 3FD [95] model calculations. All the experimental data are from Ref. [46] except for one energy point, $\sqrt{s_{NN}} = 14.5$ GeV [90], which should be considered a preliminary measurement.

First, charged particle v_1

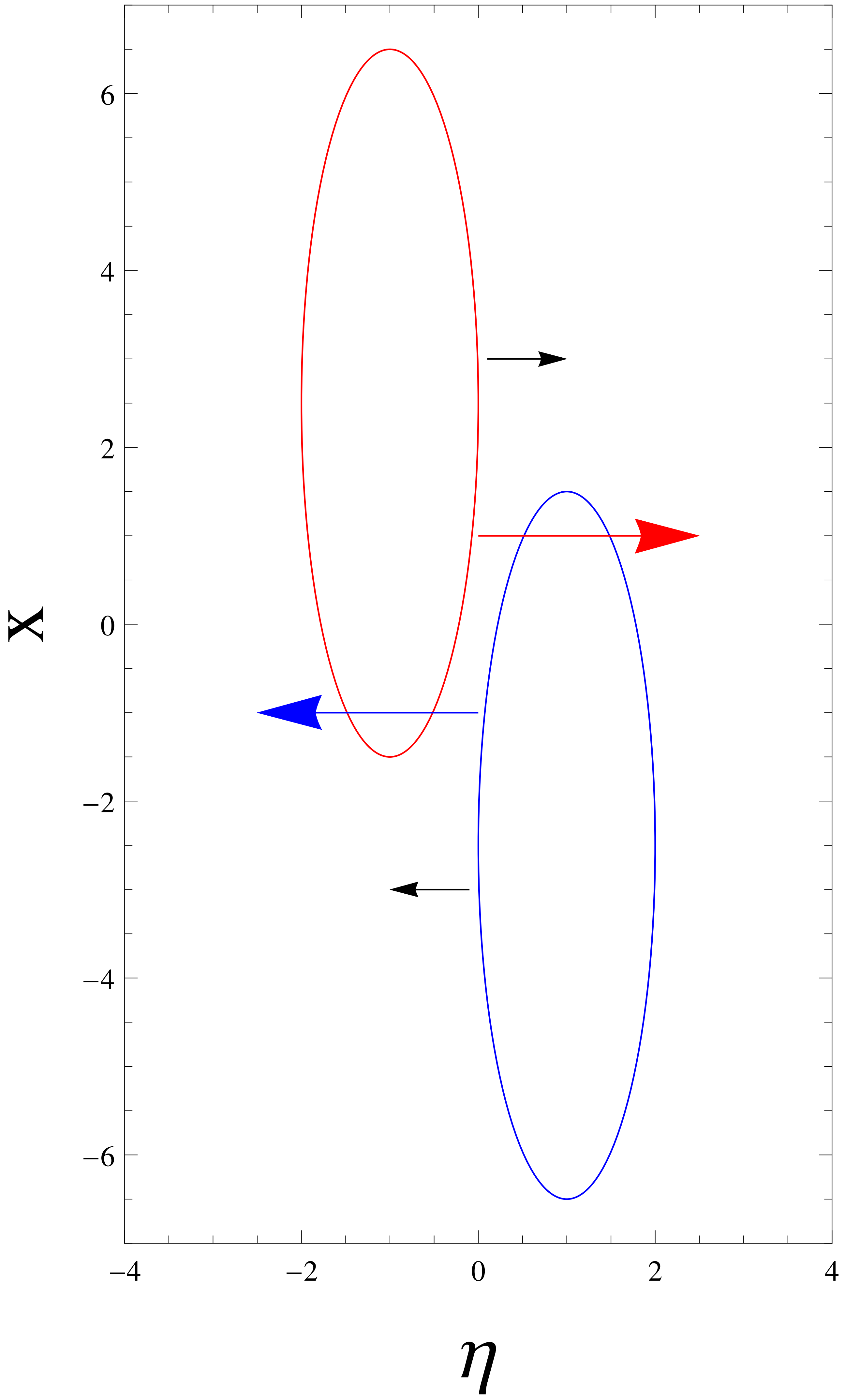
Sign convention of v_1



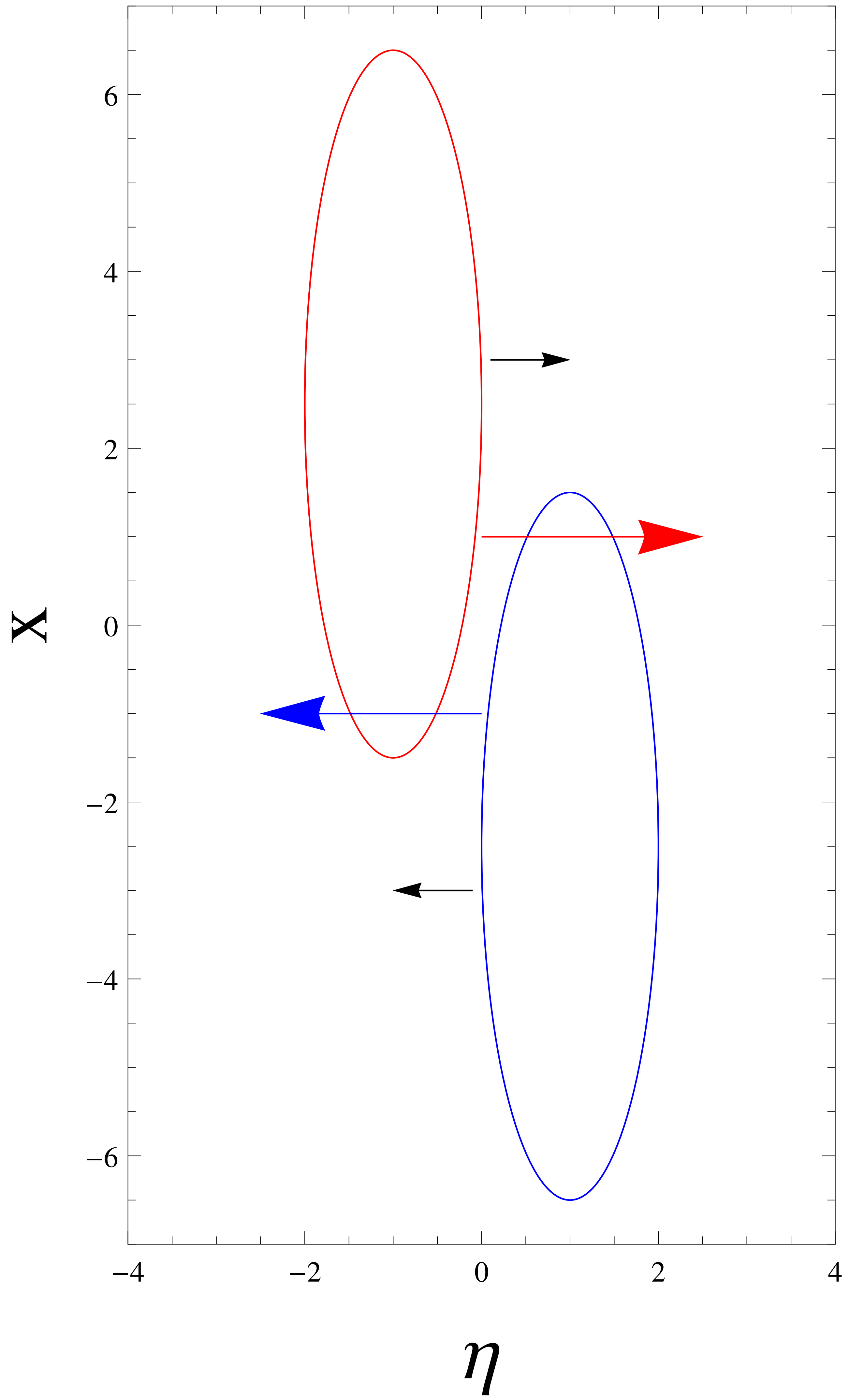
entropy deposition scheme



$$r_1 < r_2 \rightarrow \rho(r_1) > \rho(r_2)$$



entropy deposited scheme



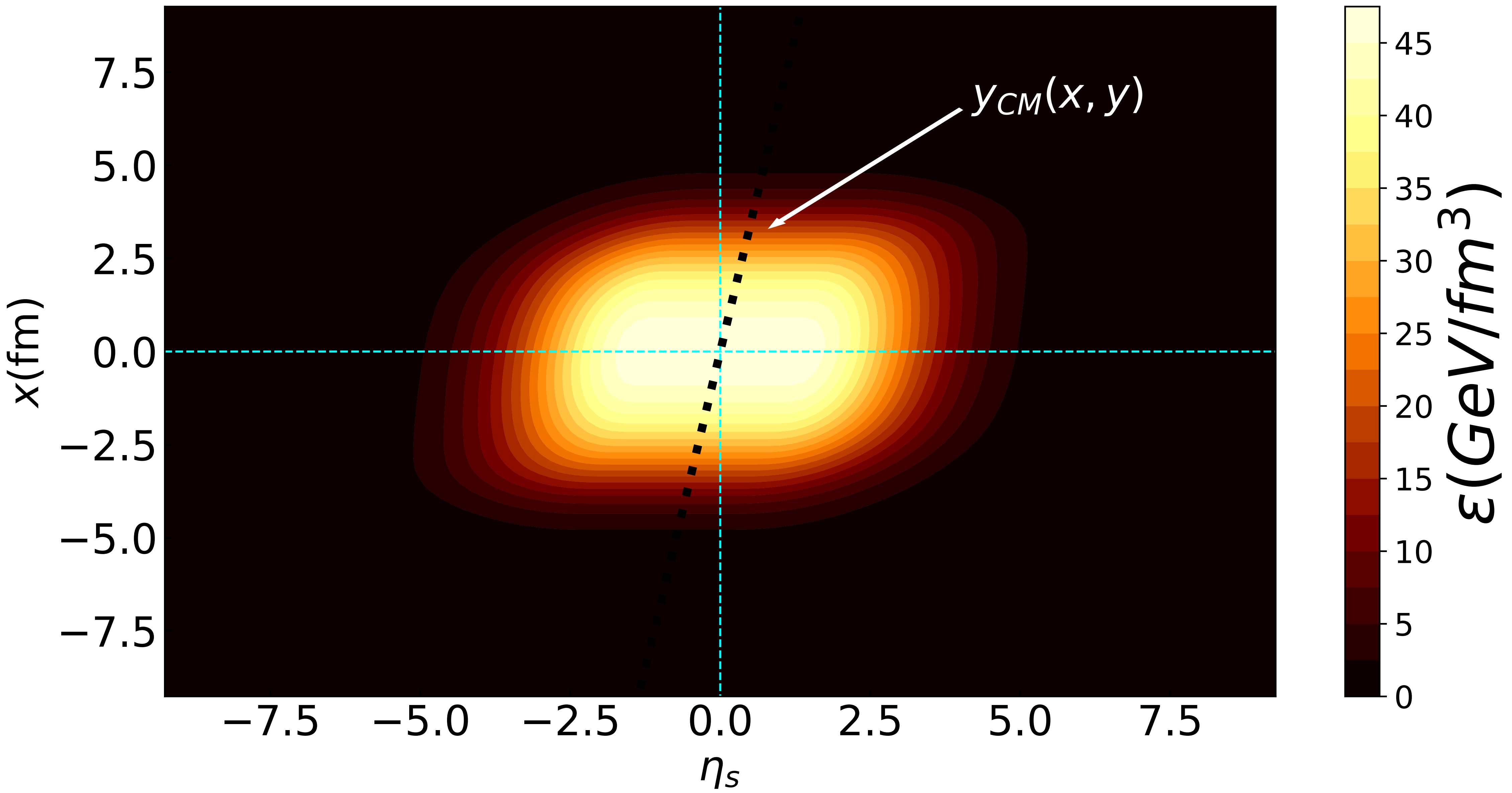
At a generic point (x, y) on the transverse plane, $N_{part}^{+}(x, y) \neq N_{part}^{-}(x, y)$ where '+' and '-' refer to positive and negative η directions.

This geometric asymmetry has been utilised in Glauber type initial condition models to break boost invariance in the initial condition that can be further evolved by hydro to yield interesting rapidity dependencies in different observables.

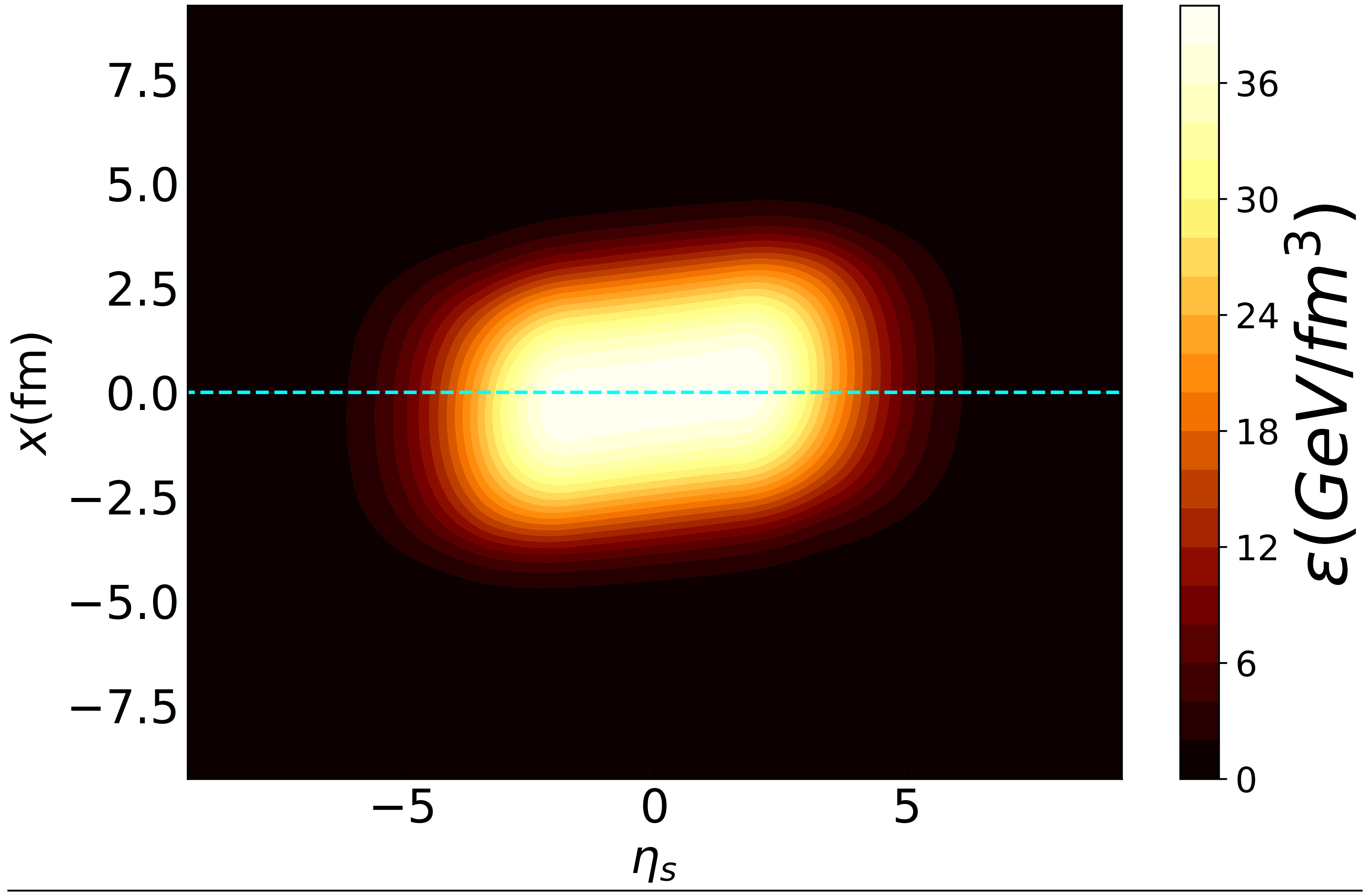
entropy deposited scheme

Broadly, 2 schemes have been studied:

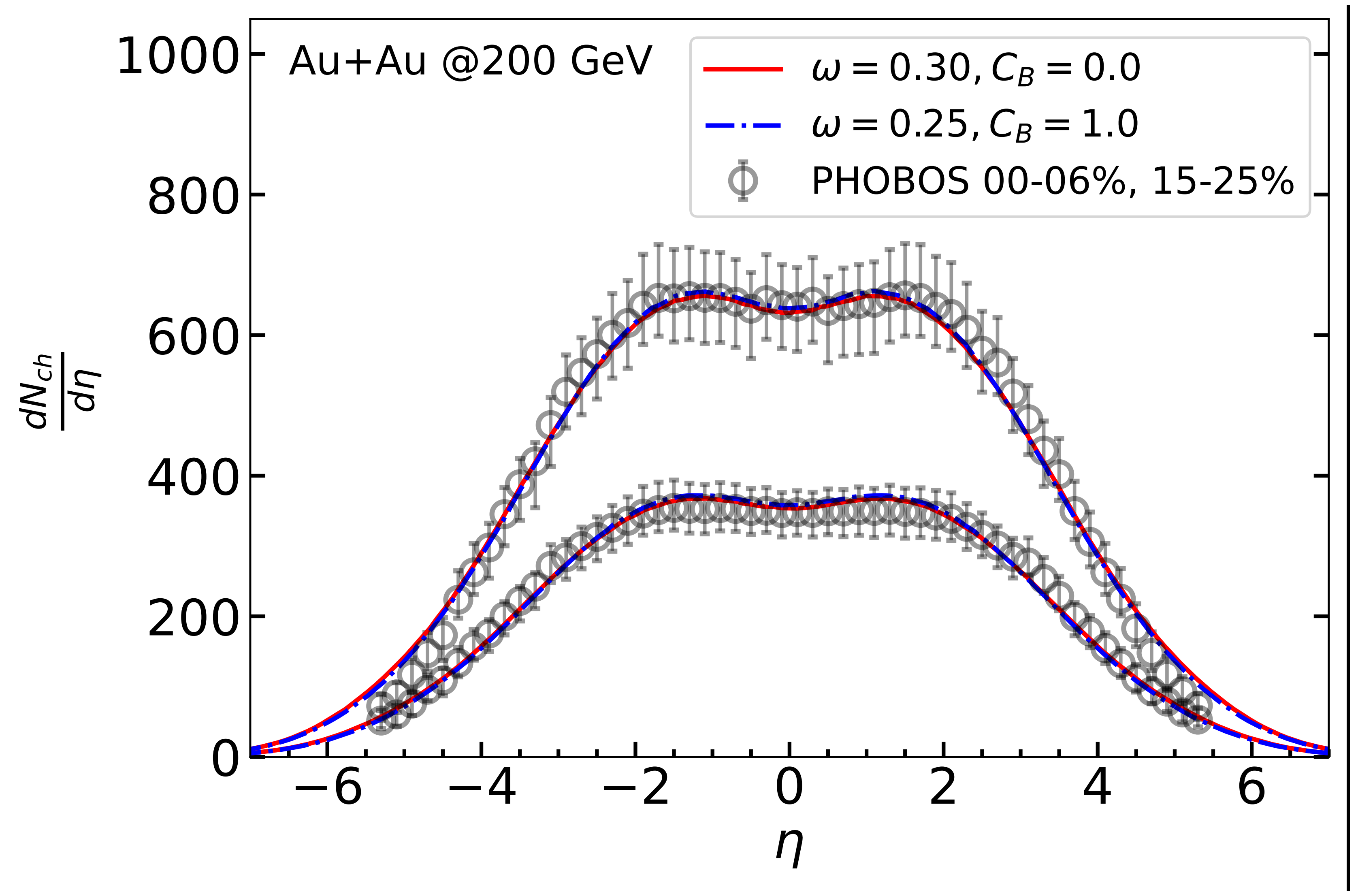
Shifted: assume forward-backward (FB) symmetric deposition by a participant source. $N_{part^+}(x, y) \neq N_{part^-}(x, y)$ gives rise to a shifted centre of mass rapidity y_{cm} (x, y) and this causes a shifted fireball Hirano, Tsuda 2002

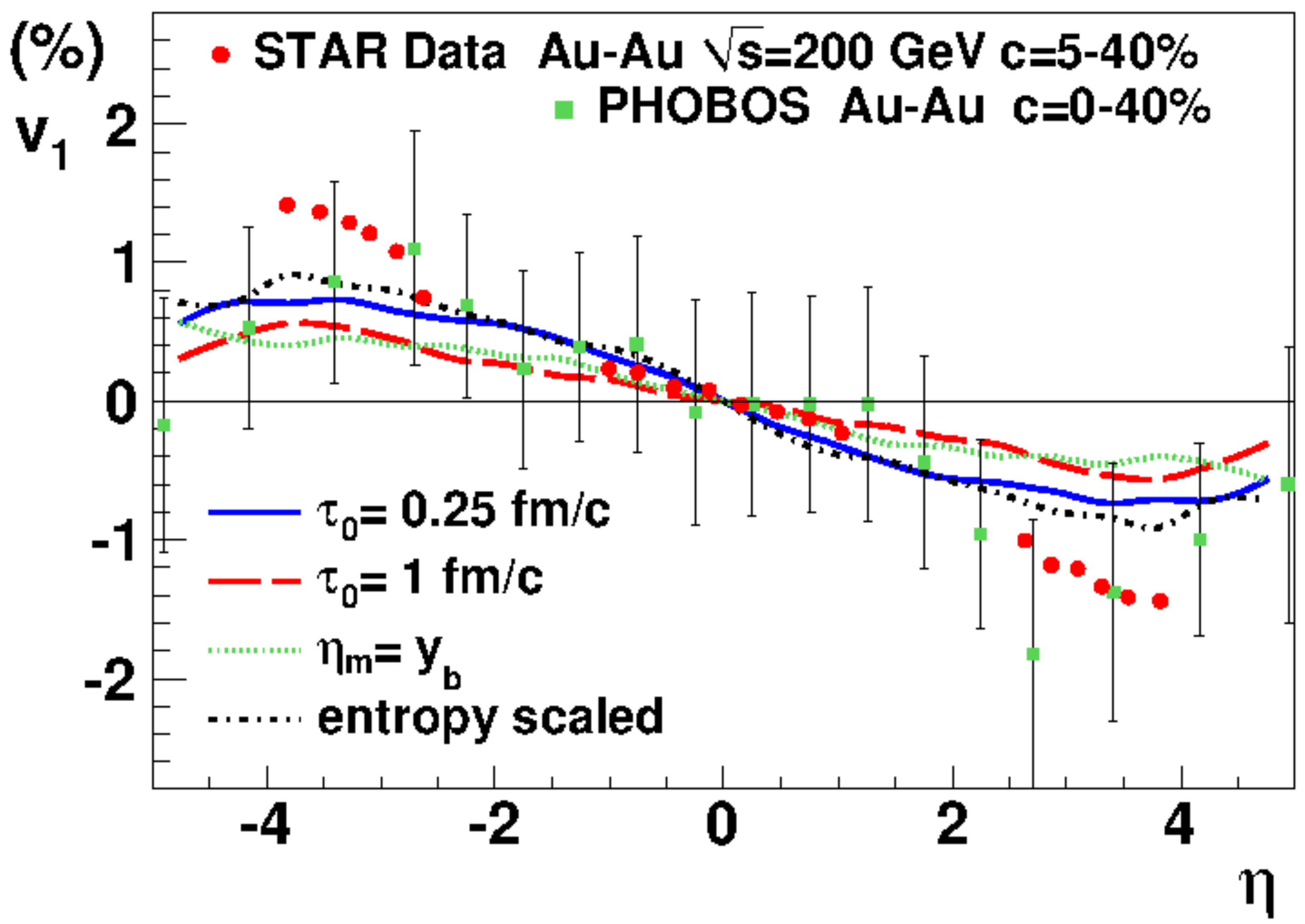


Tilted: assume FB asymmetric deposition by a participant source. $N_{part^+}(x, y) \neq N_{part^-}(x, y)$ gives rise to a fireball not aligned along the beam axis, tilted fireball. Bozek, Wyskiel 2010



Tilt Initial condition





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

$$f_{+,-}(\eta_s) = \epsilon_{\eta_s}(\eta_s)\epsilon_{F,B}(\eta_s)$$

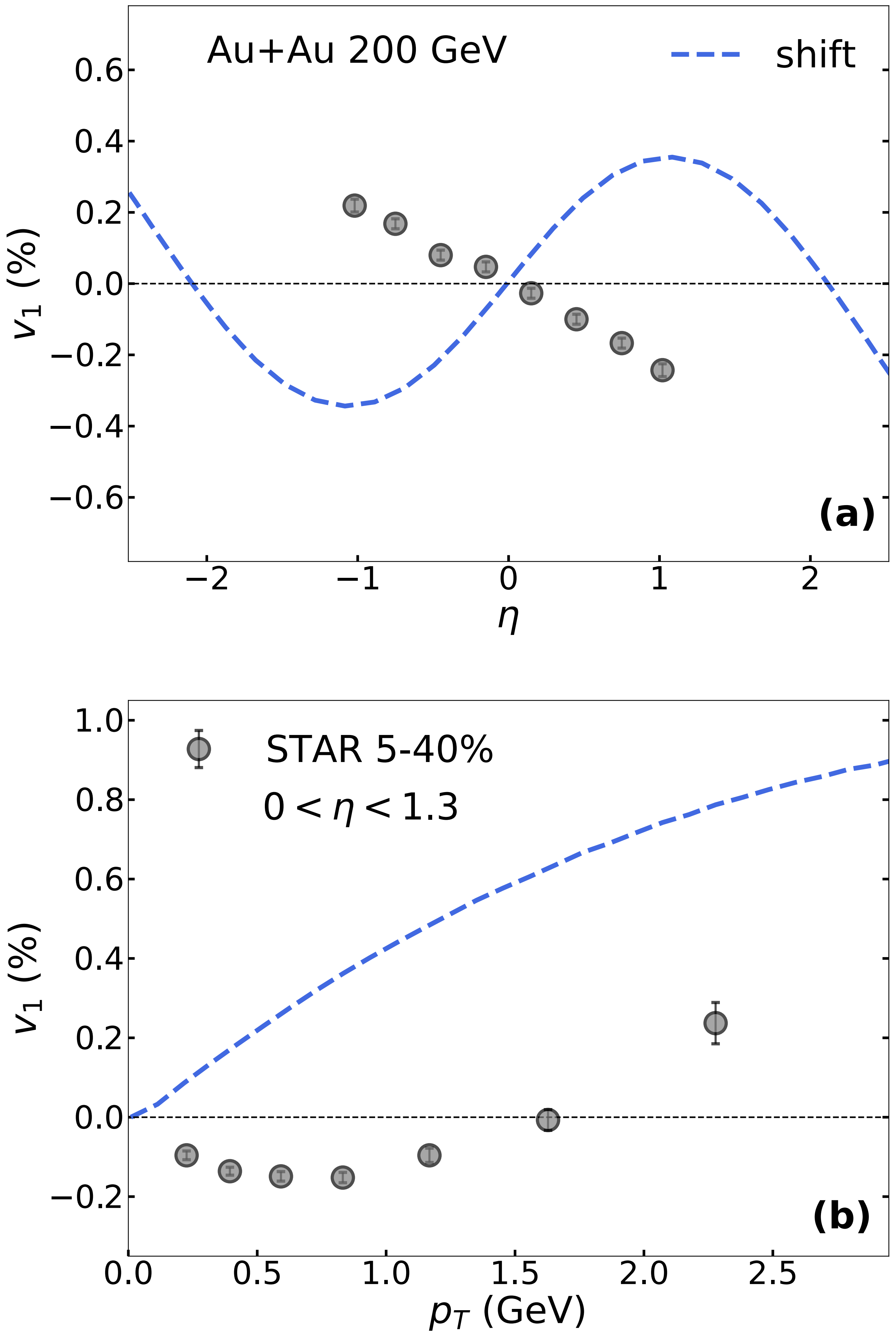
$$\epsilon_F(\eta_s) = \begin{cases} 0, & \text{if } \eta_s < -\eta_m \\ \frac{\eta_s+\eta_m}{2\eta_m}, & \text{if } -\eta_m \le \eta_s \le \eta_m \\ 1, & \text{if } \eta_m < \eta_s \end{cases}$$

$$\epsilon_B(\eta_s) = \epsilon_F(-\eta_s)$$

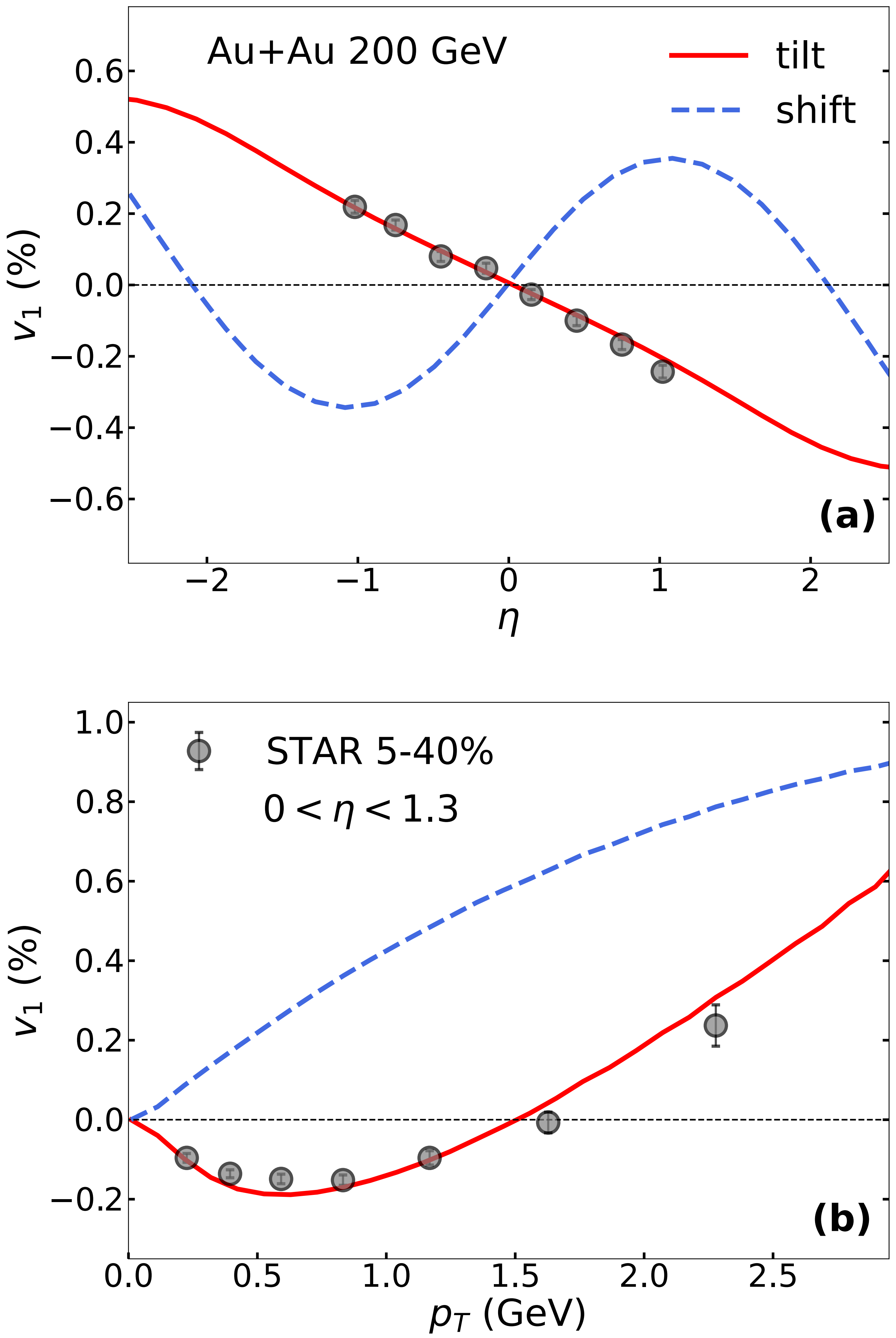
Bozek, Wyskiel 2010

charged particle v_1 chooses tilt

Shifted



Tilted

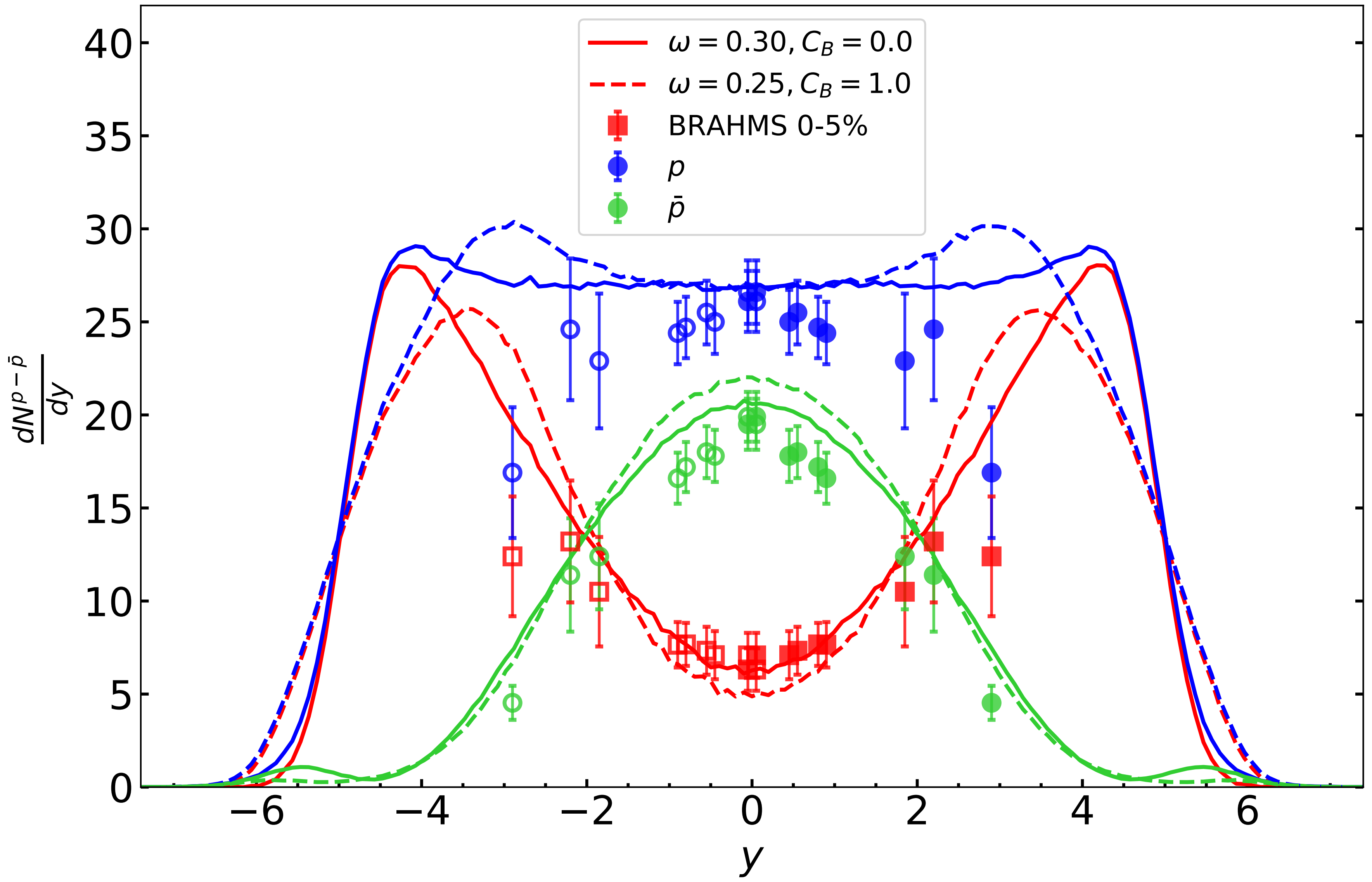


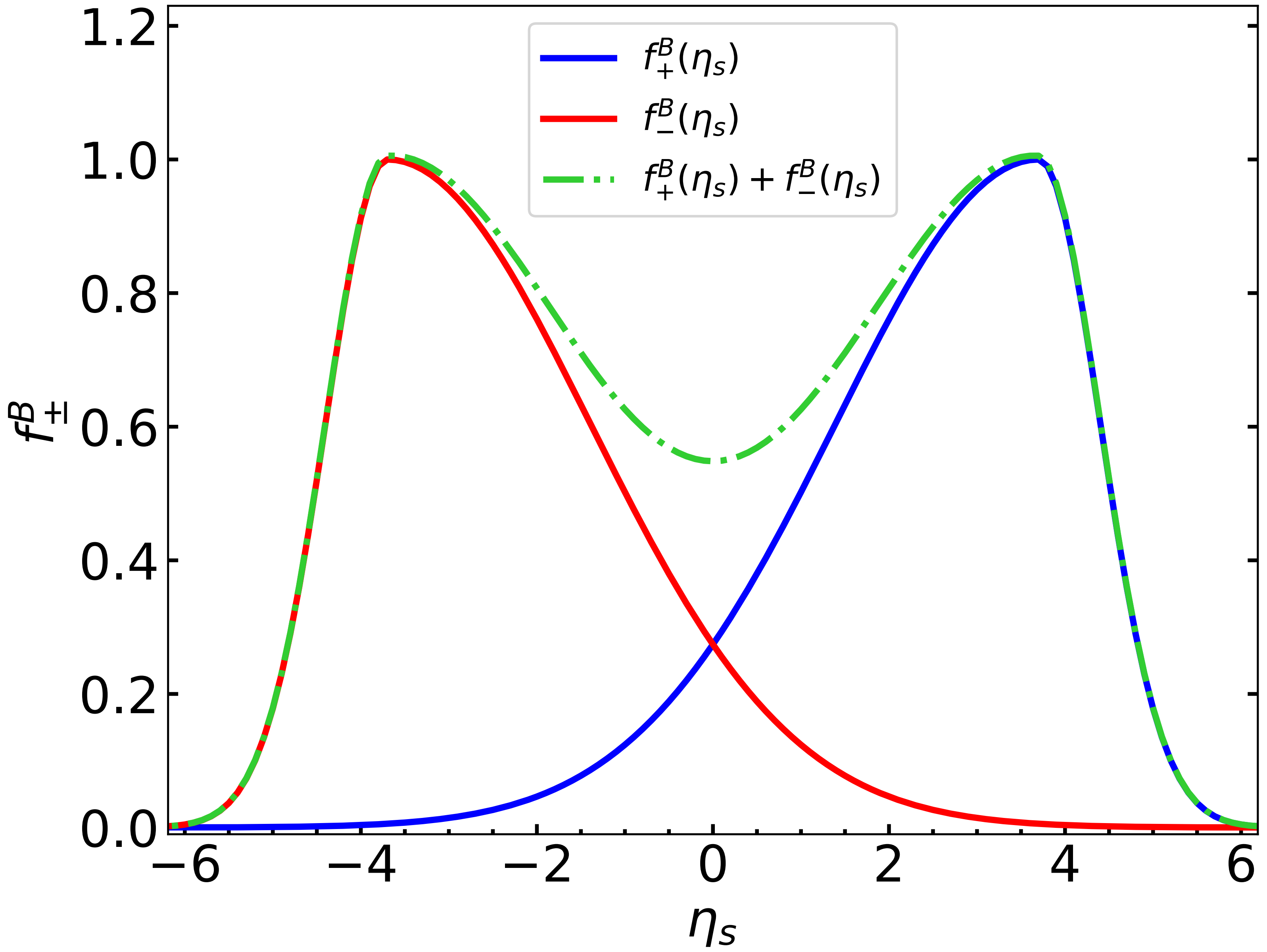
Bozek, Wyskiel 2010
Parida, SC 2022

Now, baryon v_1

arXiv: 2211.15659
arXiv: 2211.15729
……

Initial condition





$$n_B\left(x, y, \eta_s\right)$$

$$N_B\left[W_+^B(x,y) f_+^B(\eta_s) + W_-^B(x,y) f_-^B(\eta_s)\right]$$

$$W_\pm^B(x,y) = (1-\omega)\, N_\pm(x,y) + \omega N_{coll}(x,y)$$

$$\int \tau_0 dx dy d\eta n_B\left(x, y, \eta, \tau_0\right) = N_+ + N_-$$

The transverse profile for baryon, W^B is usually taken $\sim N_{+,-}$. We have allowed for contribution from N_{coll} to account for scenarios that arise in microscopic models like LEXUS where the rapidity loss of the depositing source depends on the number of binary collisions, thus having more baryon deposited where N_{coll} is large.

NOTE: Participant source has rapidity asymmetric profile while collision source has rapidity symmetric profile, thus ω decides relative tilt of baryon wrt matter

Evolution

The hydrodynamic evolution of the baryon conserved charge requires the baryon diffusion coefficient κ_B:

$$\kappa_B = \frac{C_B}{T} n_B \left(\frac{1}{3} coth(\mu_B/T) - \frac{n_b T}{\epsilon + P} \right)$$

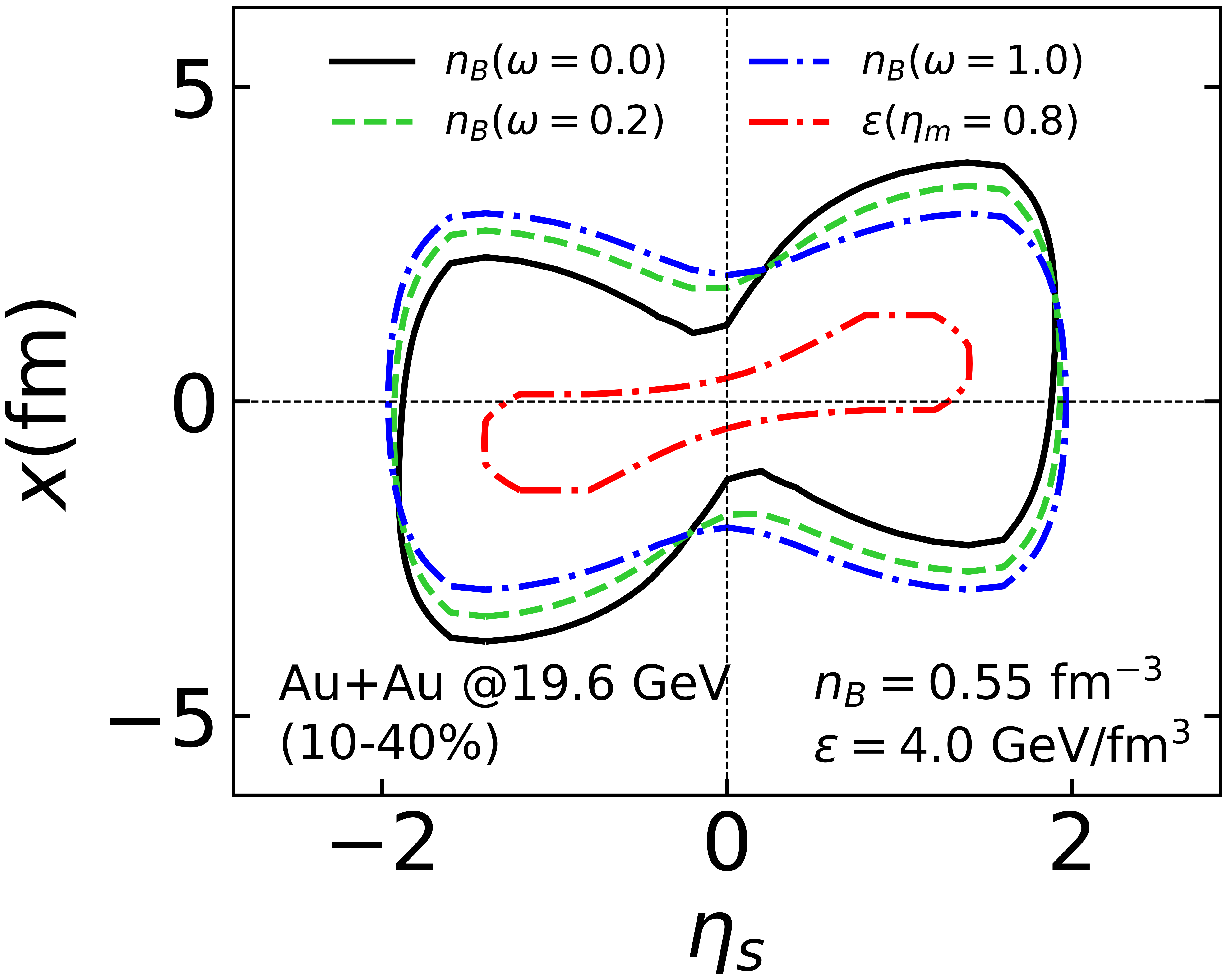
Denicol et al 2018

C_B is to be constrained from data

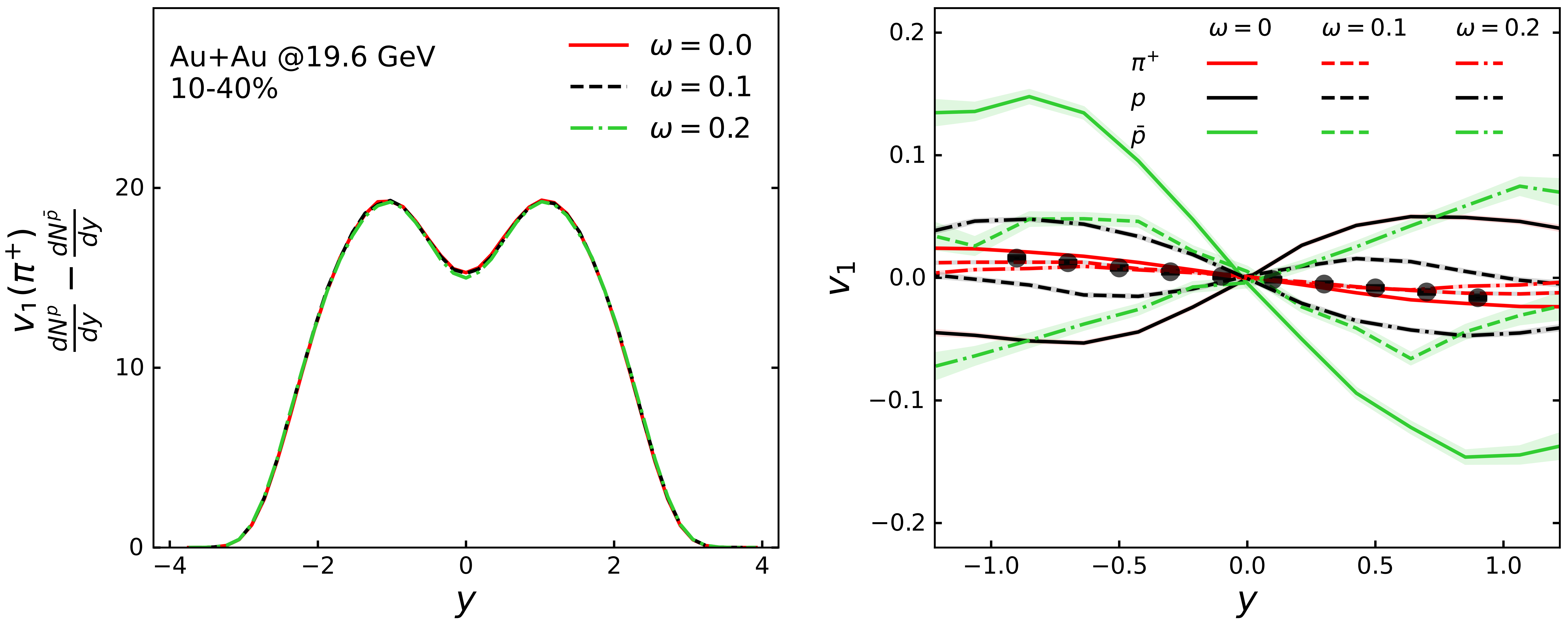
We take, $n_S = 0$, $n_Q = 0.4 n_B$, $\dfrac{\eta T}{\epsilon + P} = 0.08$, $\zeta = 0$, $\epsilon_f = 0.26$ GeV/fm^3

Hybrid approach

Role of ω

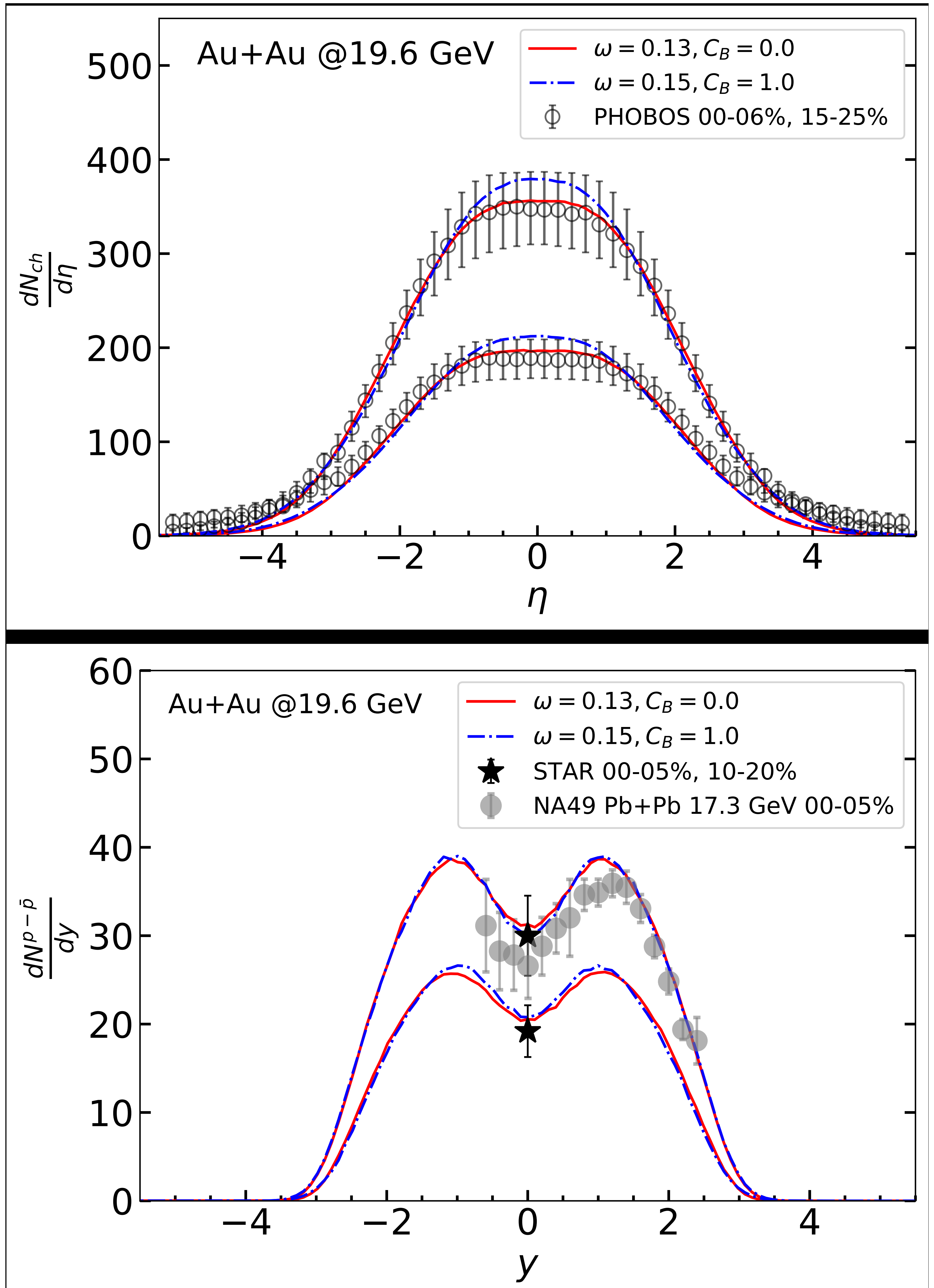


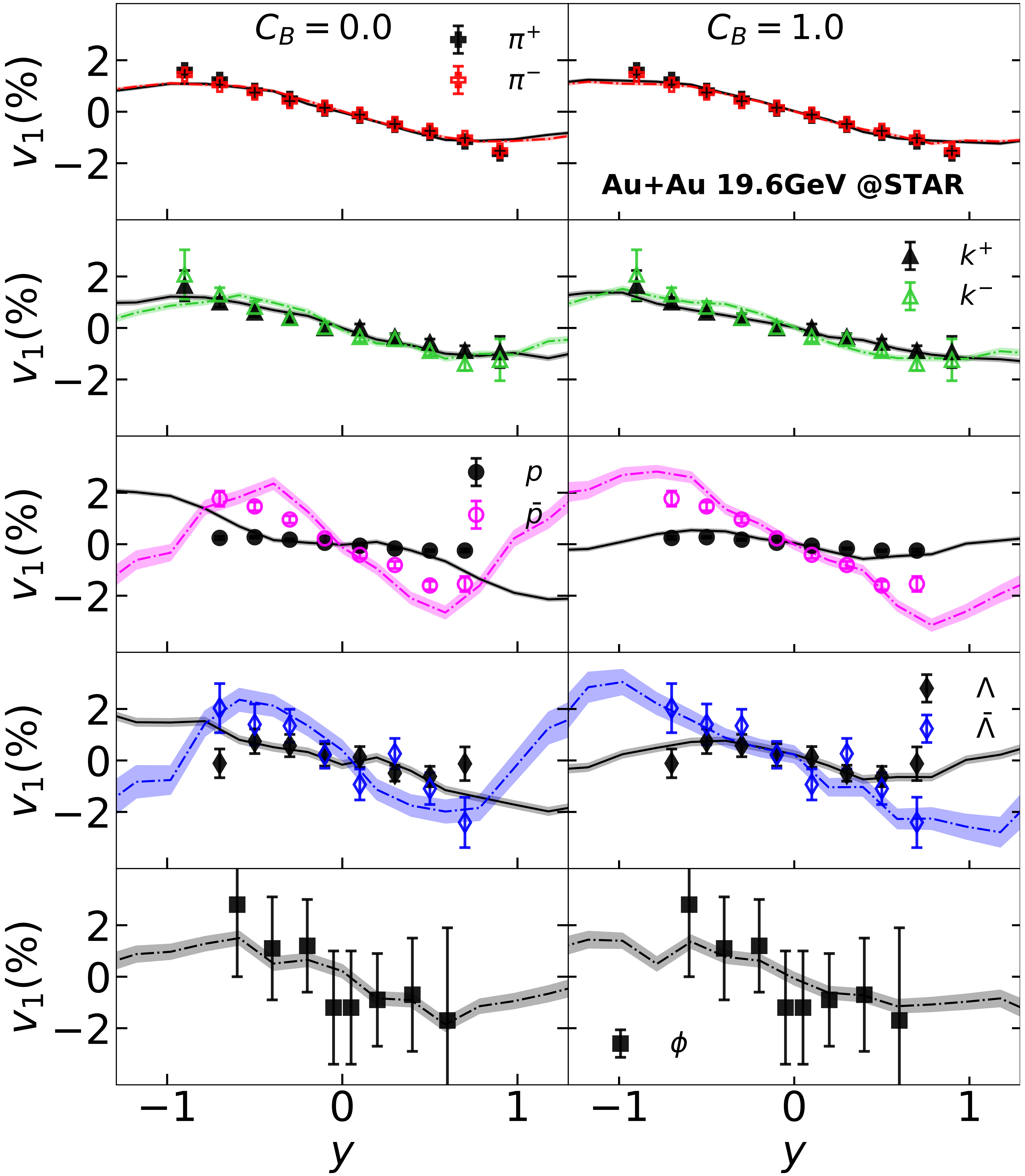
Role of ω



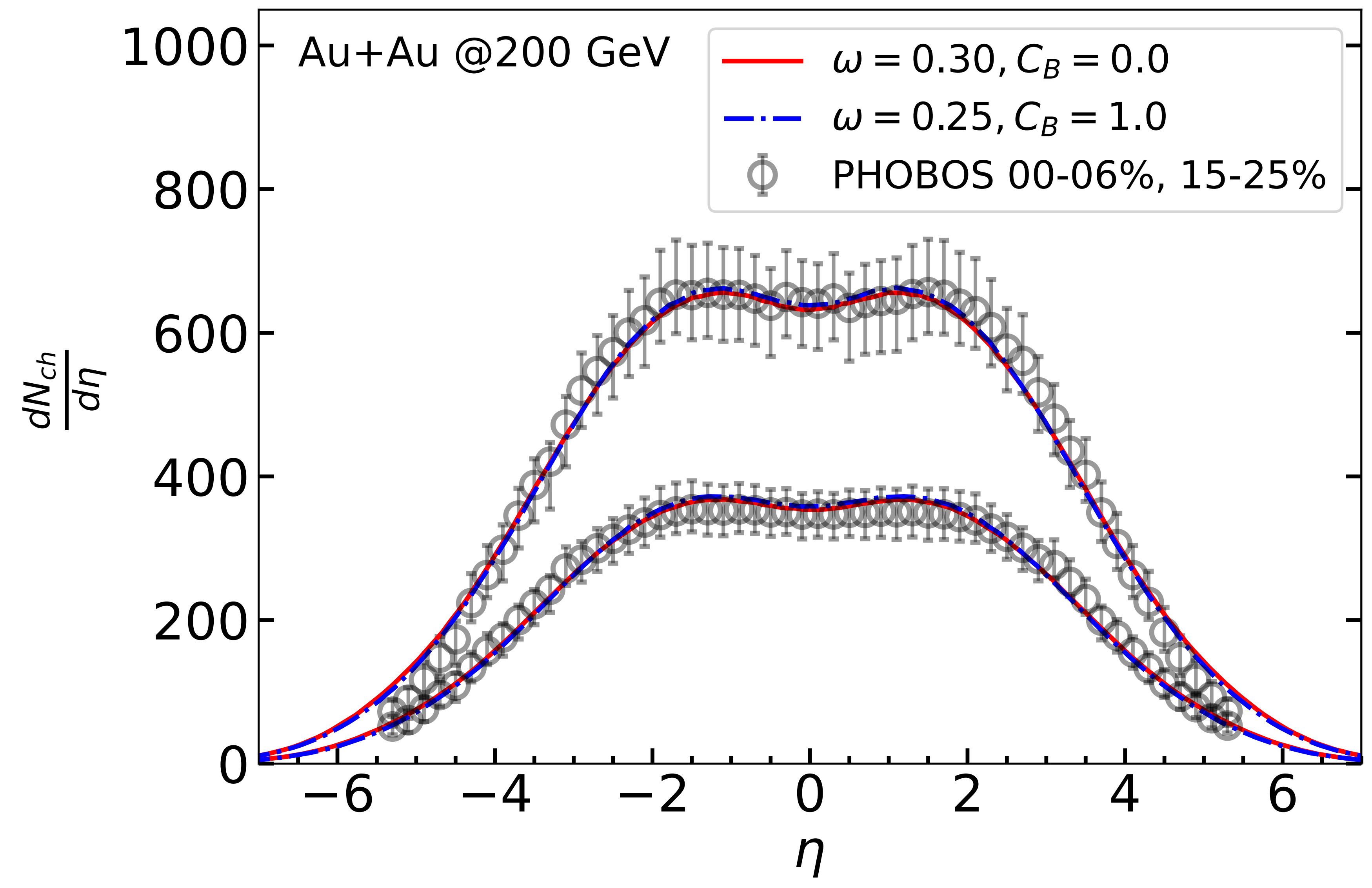
Does not affect rapidity distribution of net proton yield, however the net proton v1 or splitting in proton - antiproton v1 is significantly affected

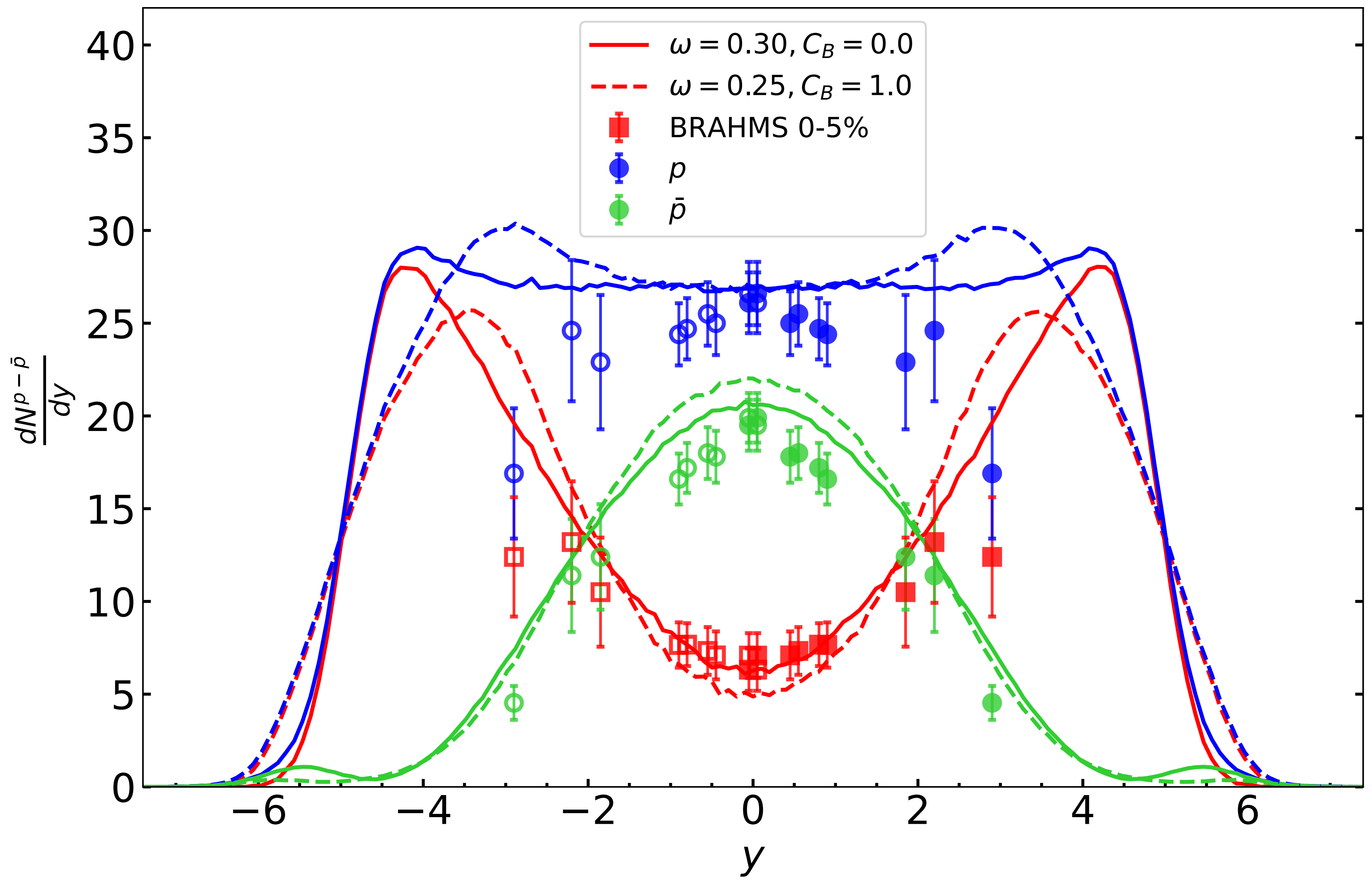
Comparison to data

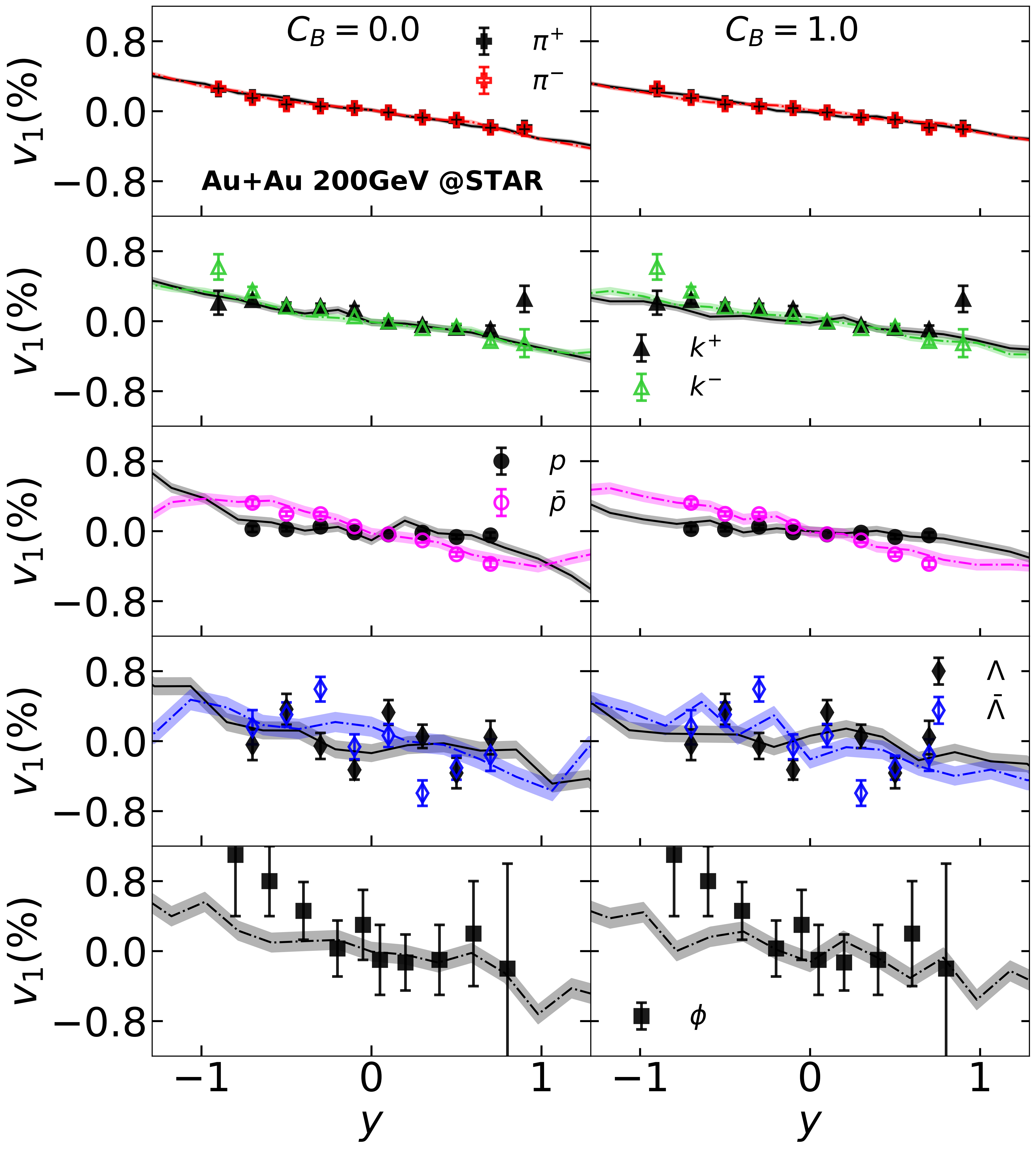


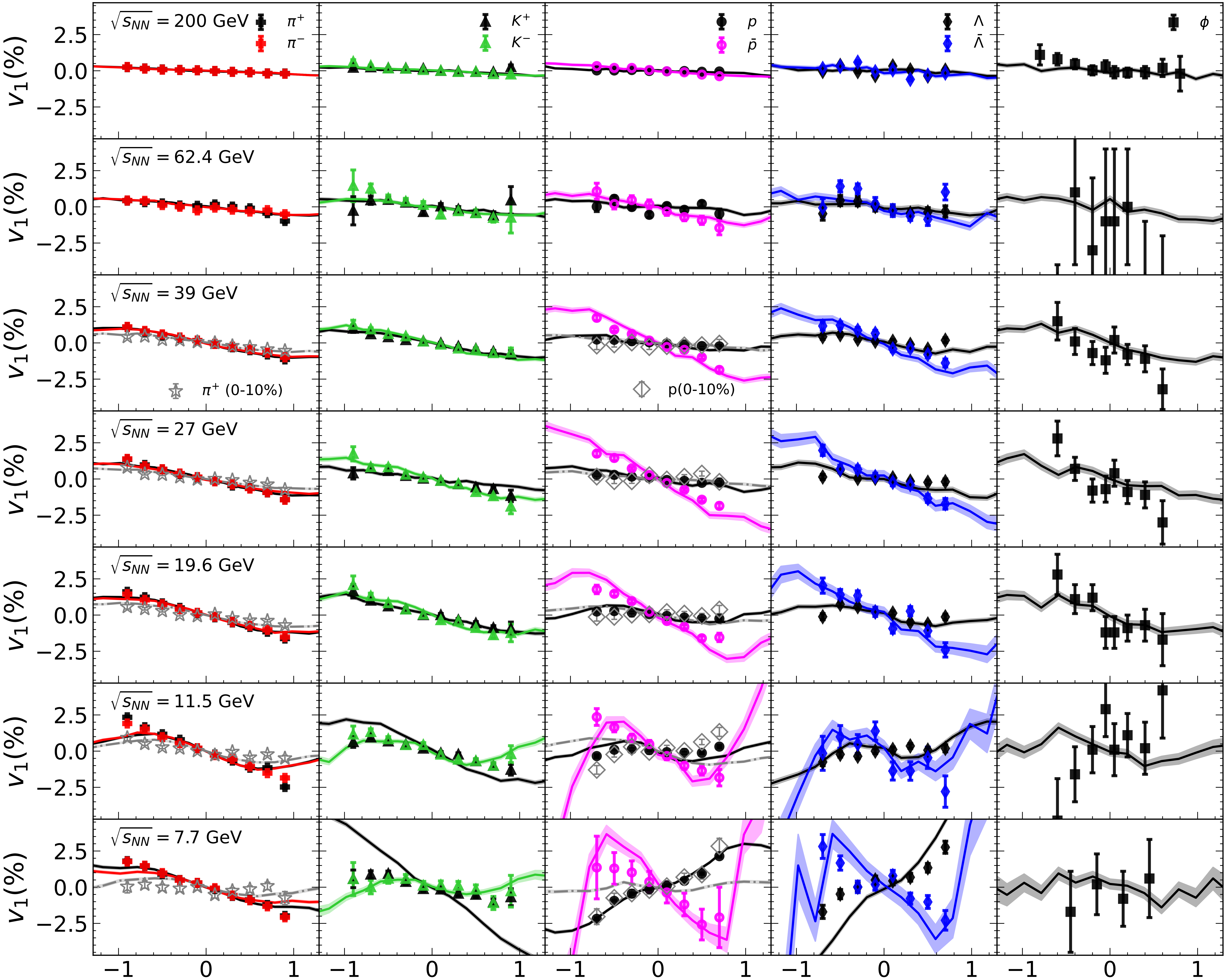


Comparison to data

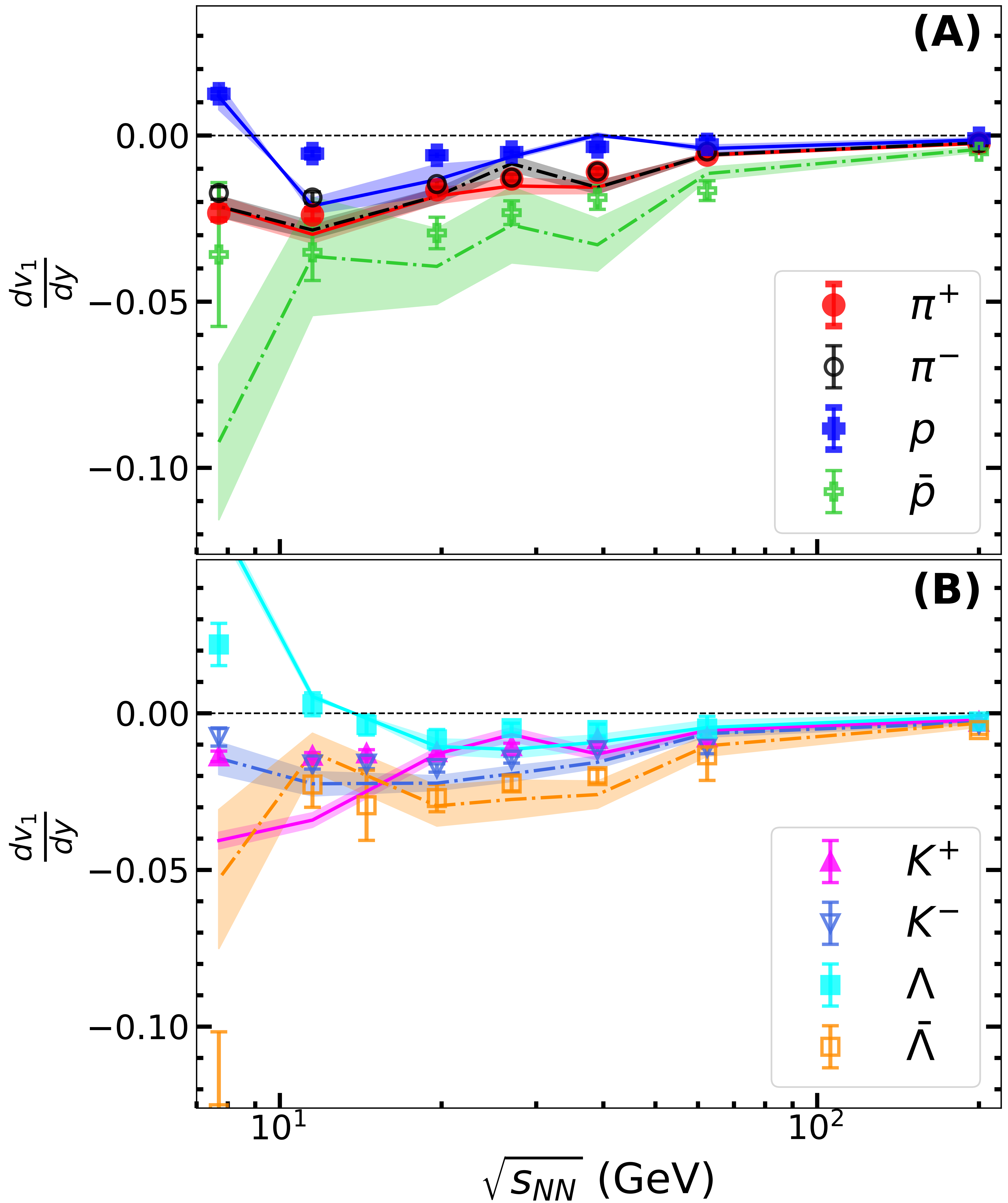




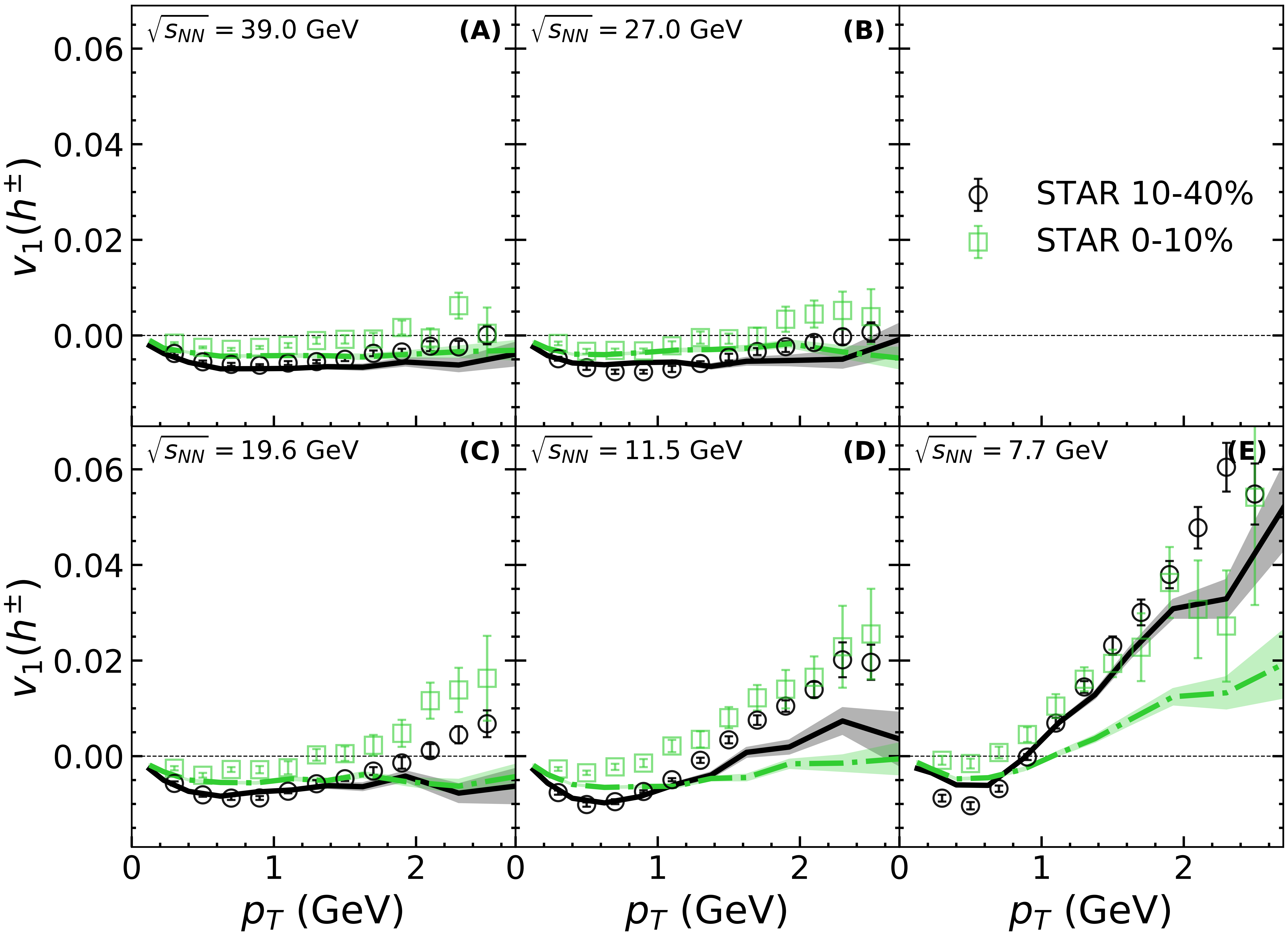




$\sqrt{s_{NN}}$ = 200 GeV
π^+
π^-
K^+
K^-
p
$\bar{p}$
Λ
$\bar{\Lambda}$
ϕ
$\sqrt{s_{NN}}$ = 62.4 GeV
$\sqrt{s_{NN}}$ = 39 GeV
π^+ (0-10%)
p(0-10%)
$\sqrt{s_{NN}}$ = 27 GeV
$\sqrt{s_{NN}}$ = 19.6 GeV
$\sqrt{s_{NN}}$ = 11.5 GeV
$\sqrt{s_{NN}}$ = 7.7 GeV
$v_1(\%)$
2.5
0.0
−2.5
−1
0
1



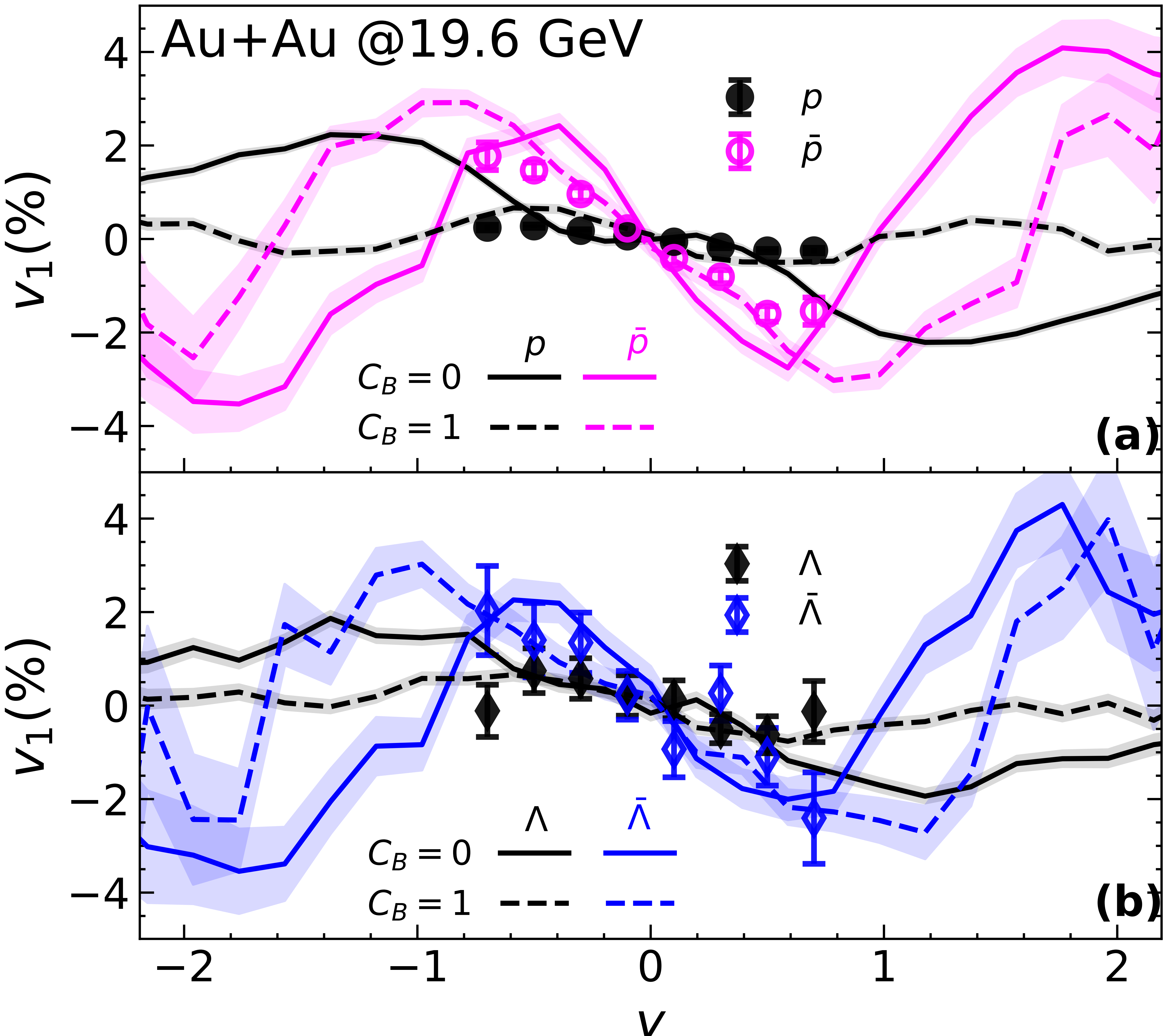
(A)
0.00
−0.05
−0.10
$\frac{dv_1}{dy}$
π^+
π^-
p
$\bar{p}$
(B)
0.00
−0.05
−0.10
$\frac{dv_1}{dy}$
K^+
K^-
Λ
$\bar{\Lambda}$
10^1
10^2
$\sqrt{s_{NN}}$ (GeV)



v_1 vs p_T is a sensitive observable for initial condition:

Tribhuban: Tomorrow, 16:30 hrs

Can we constrain C_B (κ_B)?



Sensitive at larger rapidities (baryon rich),
Need measurement at larger rapidities

There is also hints that at lower $\sqrt{s_{NN}} \sim 10$ GeV that midrapidity data itself could constrain

Possible background to EM field effects?

The splitting of directed flow for identified light hadrons (K and p) and strange baryons (Ξ and Ω) in Au+Au collisions at STAR *

arXiv:2208.01718

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Received August 4, 2022

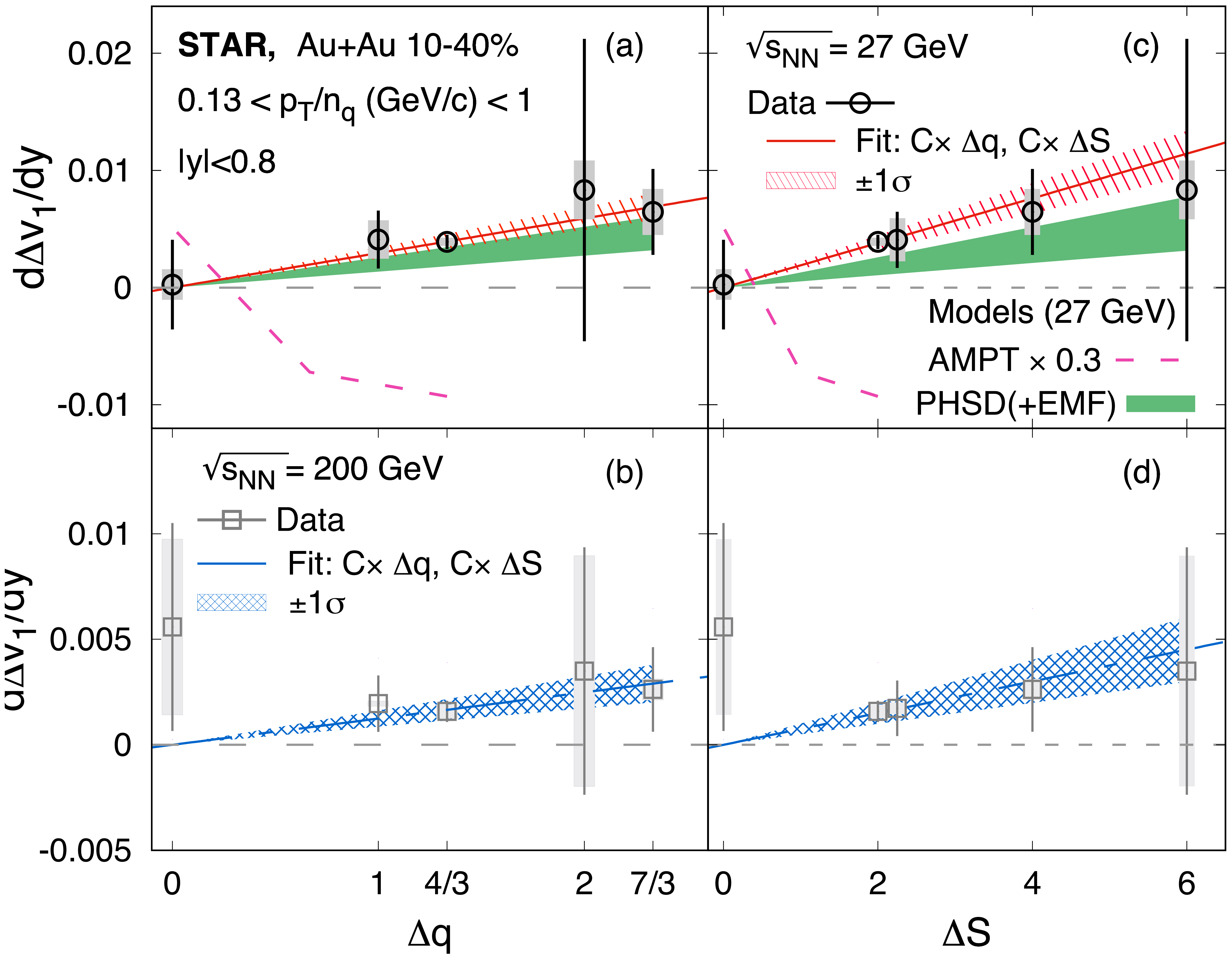
The first measurements for rapidity-odd directed flow of Ξ and Ω in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 27$ and 200 GeV are reported. The coalescence sum rule is examined with various combinations of hadrons where all constituent quarks are produced, such as $K^{-}(\bar{u}s)$, $\bar{p}(\bar{u}\bar{u}\bar{d})$, $\bar{\Lambda}(\bar{u}\bar{d}\bar{s})$, $\phi(s\bar{s})$, $\overline{\Xi}^{+}(\bar{d}\bar{s}\bar{s})$, $\Omega^{-}(sss)$, and $\overline{\Omega}^{+}(\bar{s}\bar{s}\bar{s})$. For such combinations, a systematic violation of the sum rule is observed with increasing difference in the electric charge and the strangeness content of the combinations. Measurements are compared with the calculations of A Multi-Phase Transport (AMPT) model and Parton-Hadron String Dynamics (PHSD) model with electromagnetic (EM) field. The PHSD model with EM field agrees with the measurements within uncertainties.

Possible background to EM field effects?

arXiv:2208.01718

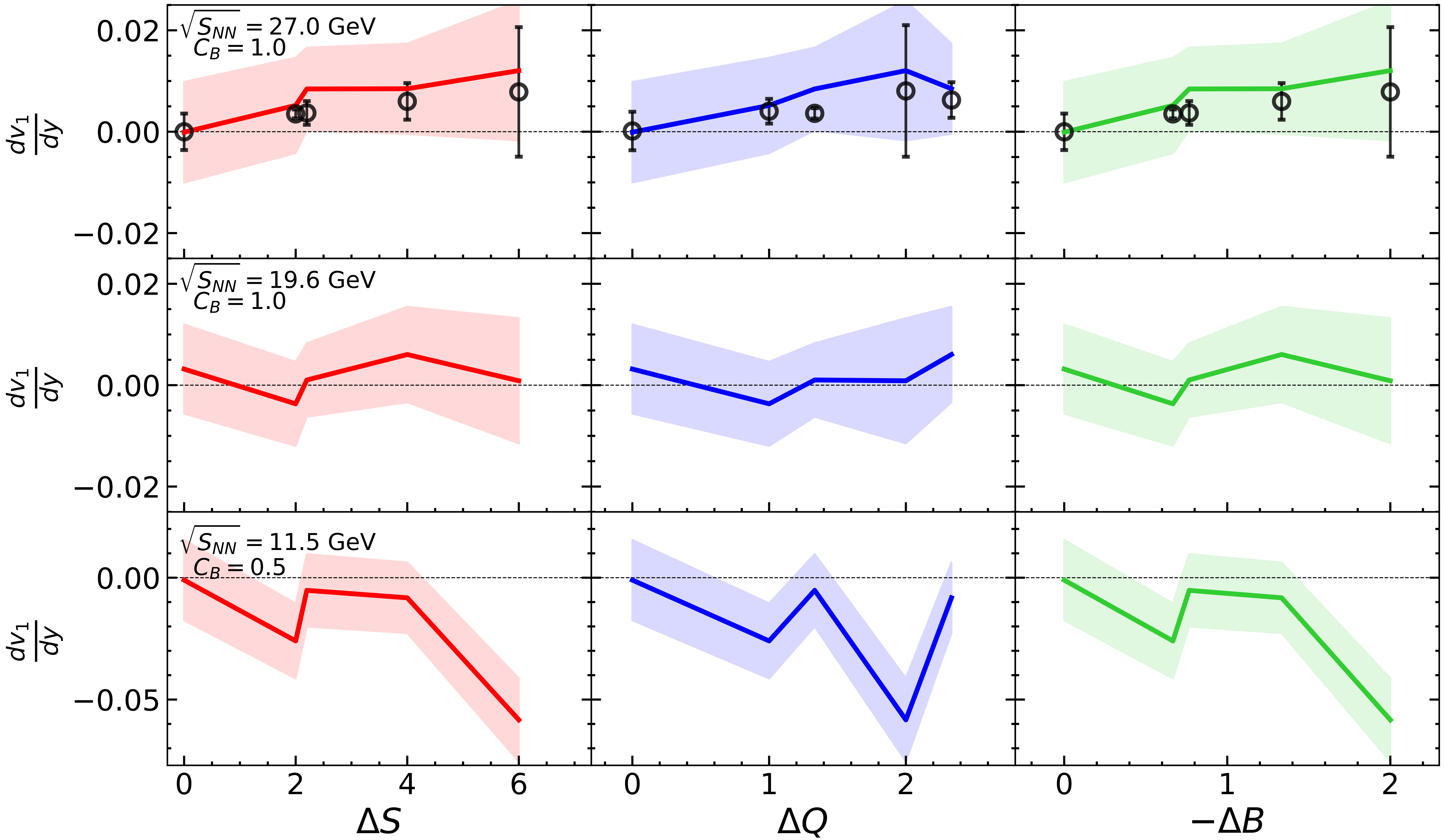
Index	Quark mass	Charge	Strangeness	Δv_1 combination
1	$\Delta m = 0$	$\Delta q = 0$	$\Delta S = 0$	$[\bar{p}(\bar{u}\bar{u}\bar{d}) + \phi(s\bar{s})] - [K^{-}(\bar{u}s) + \bar{\Lambda}(\bar{u}\bar{d}\bar{s})]$
2	$\Delta m \approx 0$	$\Delta q = 1$	$\Delta S = 2$	$[\bar{\Lambda}(\bar{u}\bar{d}\bar{s})] - [\frac{1}{3}\Omega^{-}(sss) + \frac{2}{3}\bar{p}(\bar{u}\bar{u}\bar{d})]$
3	$\Delta m \approx 0$	$\Delta q = \frac{4}{3}$	$\Delta S = 2$	$[\bar{\Lambda}(\bar{u}\bar{d}\bar{s})] - [K^{-}(\bar{u}s) + \frac{1}{3}\bar{p}(\bar{u}\bar{u}\bar{d})]$
4	$\Delta m = 0$	$\Delta q = 2$	$\Delta S = 6$	$[\overline{\Omega}^{+}(\bar{s}\bar{s}\bar{s})] - [\Omega^{-}(sss)]$
5	$\Delta m \approx 0$	$\Delta q = \frac{7}{3}$	$\Delta S = 4$	$[\overline{\Xi}^{+}(\bar{d}\bar{s}\bar{s})] - [K^{-}(\bar{u}s) + \frac{1}{3}\Omega^{-}(sss)]$

Possible background to EM field effects?



arXiv:2208.01718

Possible background to EM field effects?



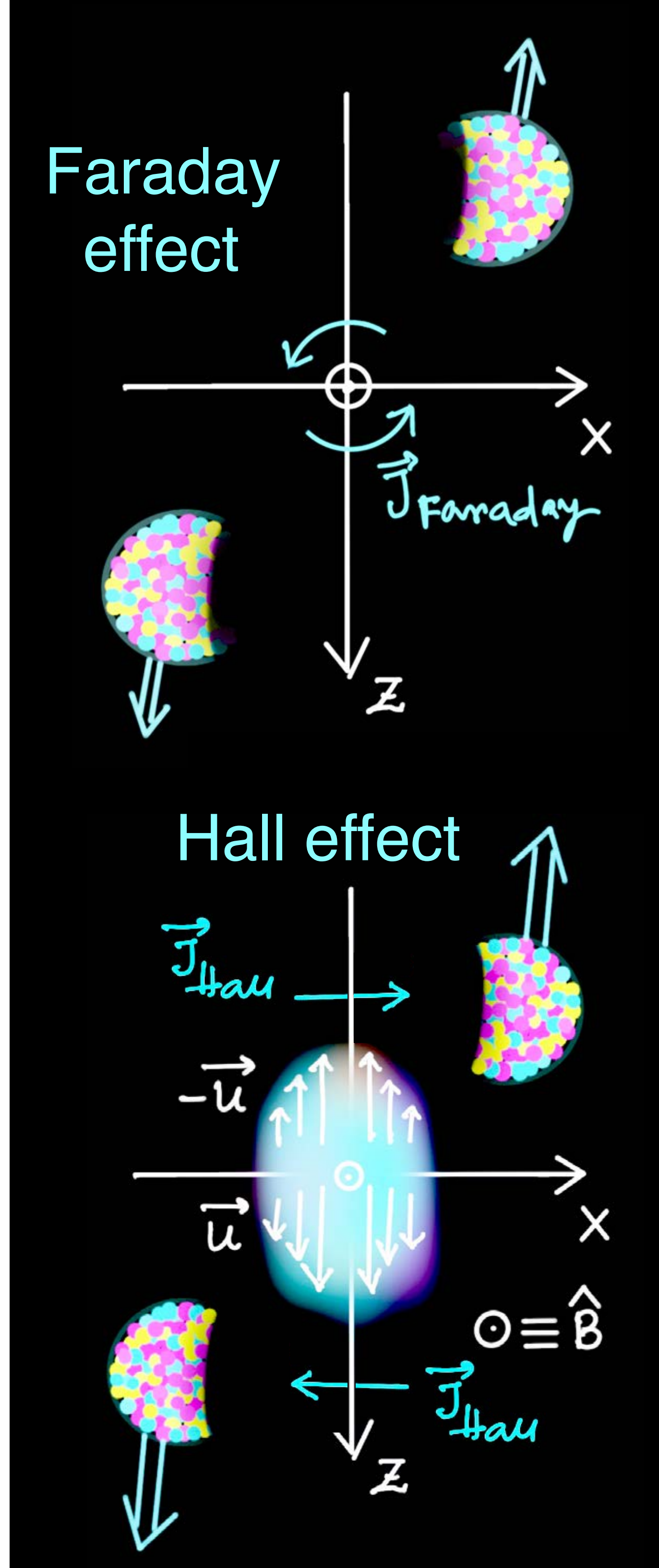
Large contribution from baryon stopping

Possible background to EM field effects?

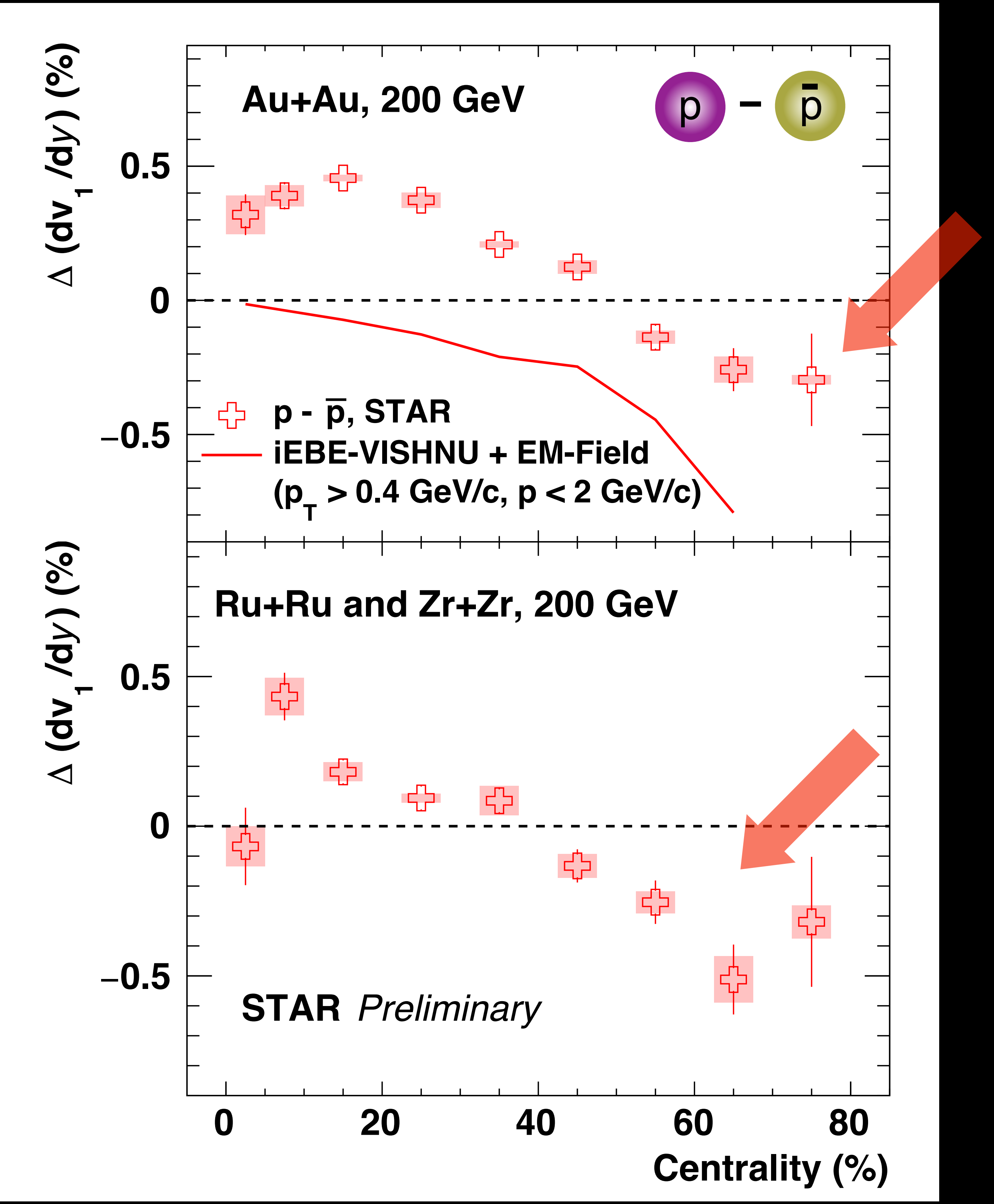
Splitting of charge dependent directed flow

Talk by Ashik Ikbal (Wed T08-I)
Poster by Diyu Shen (Wed T01)

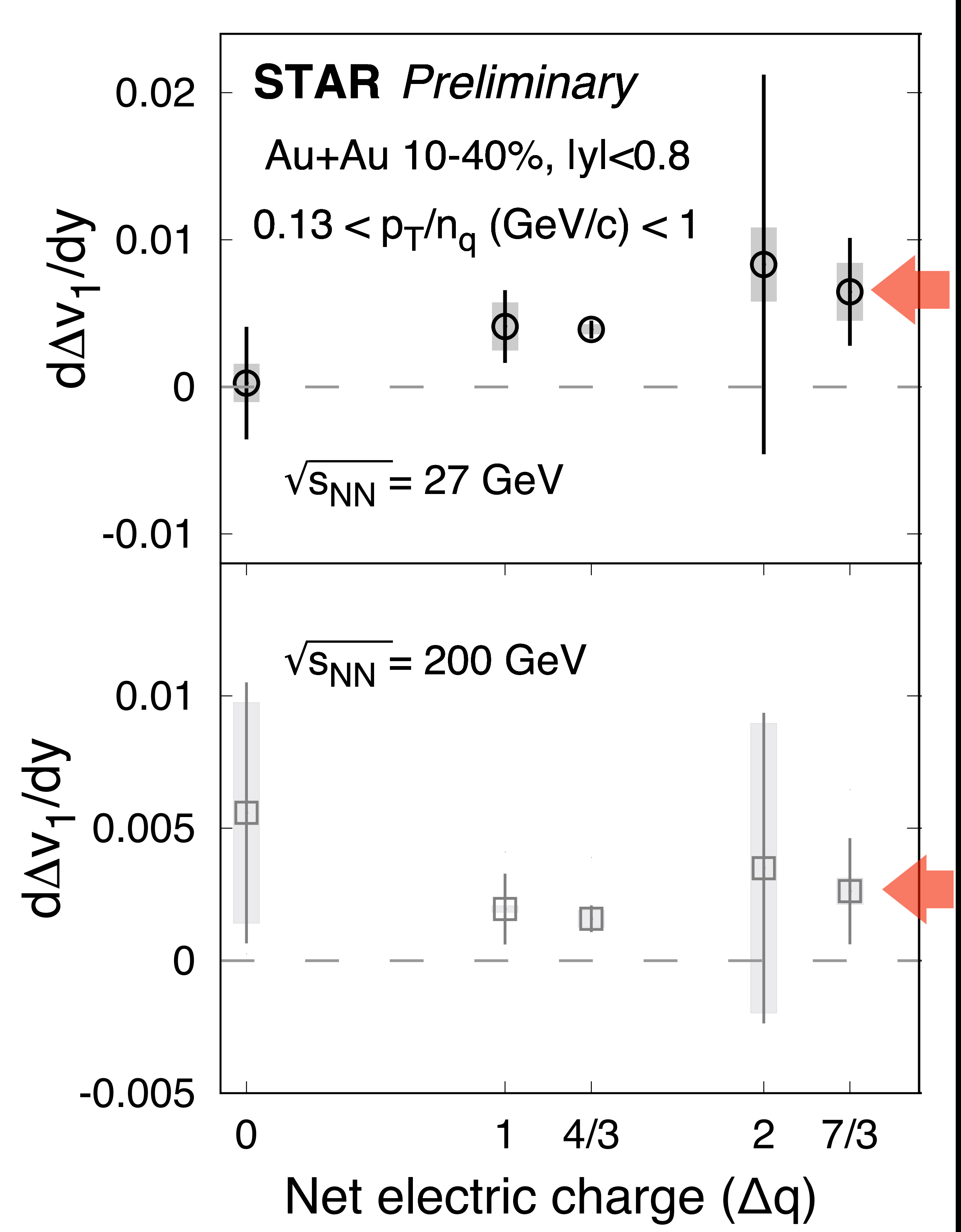
EM-field driven v_1 splitting

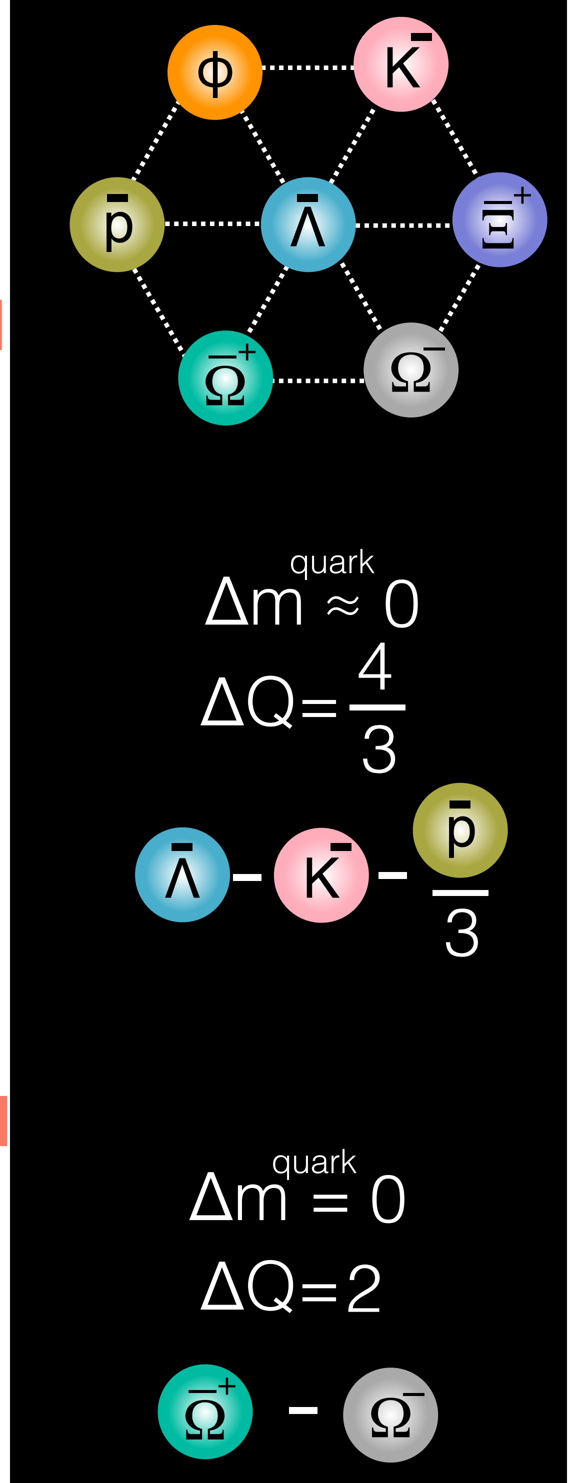


v1 slope difference for p & $\bar{p}$ shows sign change in peripheral events



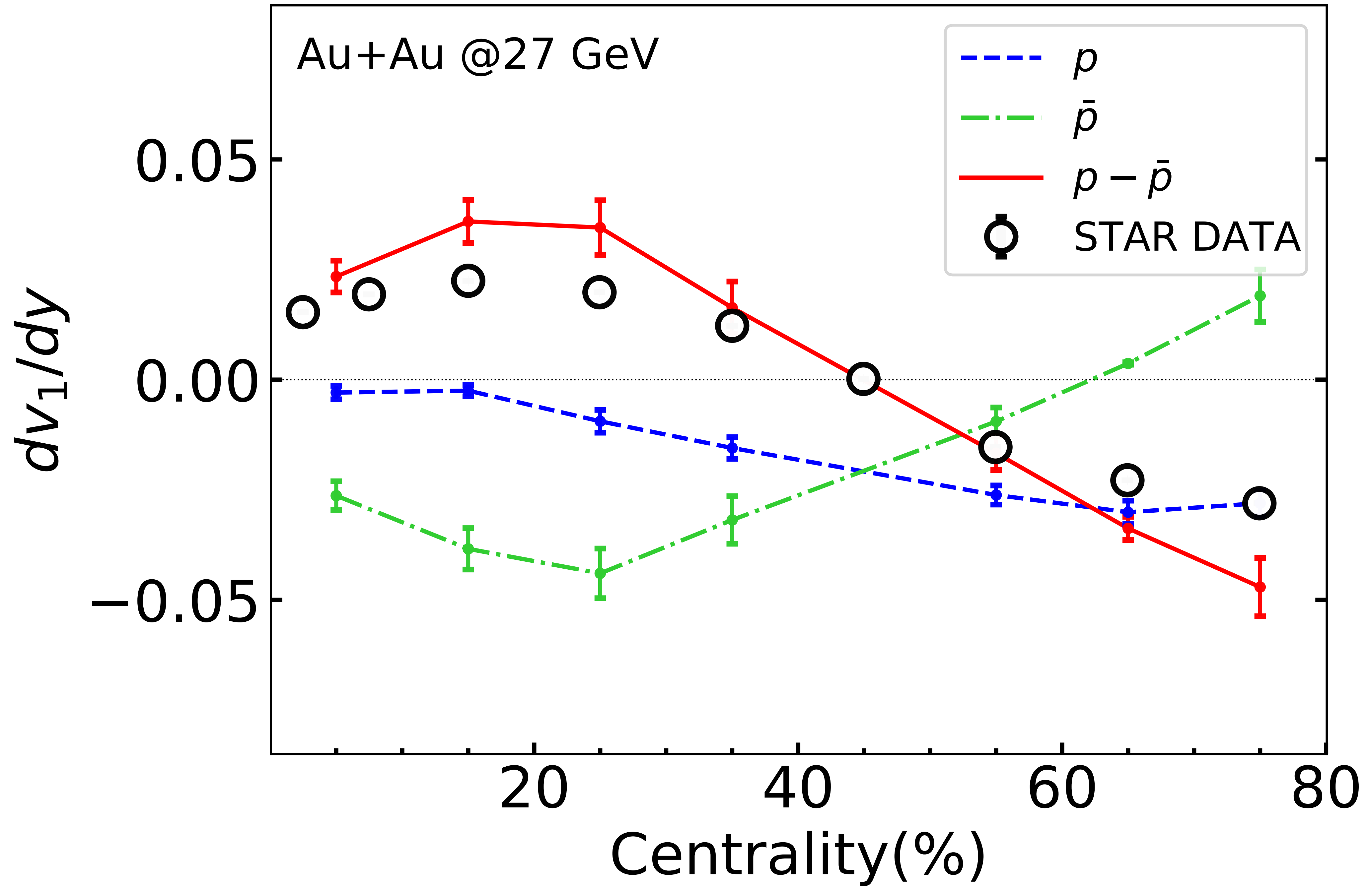
Combination of transport-free hadrons show splitting at various electric charge differences

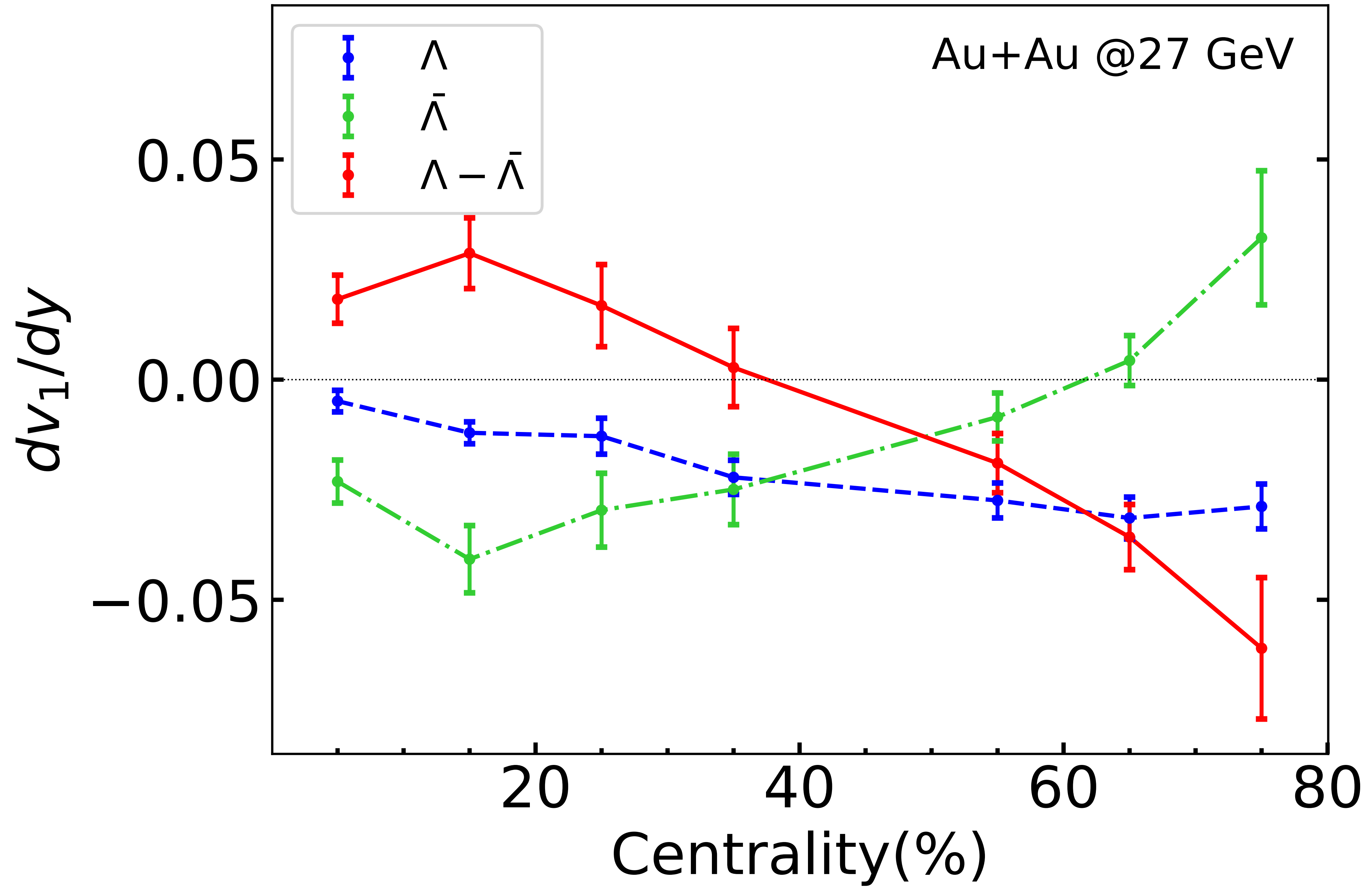




Splitting of charge dependent v_1 slope observed that cannot be explained by baryon transport

Possible background to EM field effects?





Large contribution from
baryon stopping

Summarising..

A new Glauber based model of initial baryon deposition proposed

Qualitative agreement across beam energies with data on yield, v_1

Helps in estimating background driven by baryon stopping across beam energies in signals of other physics like that of the EM field

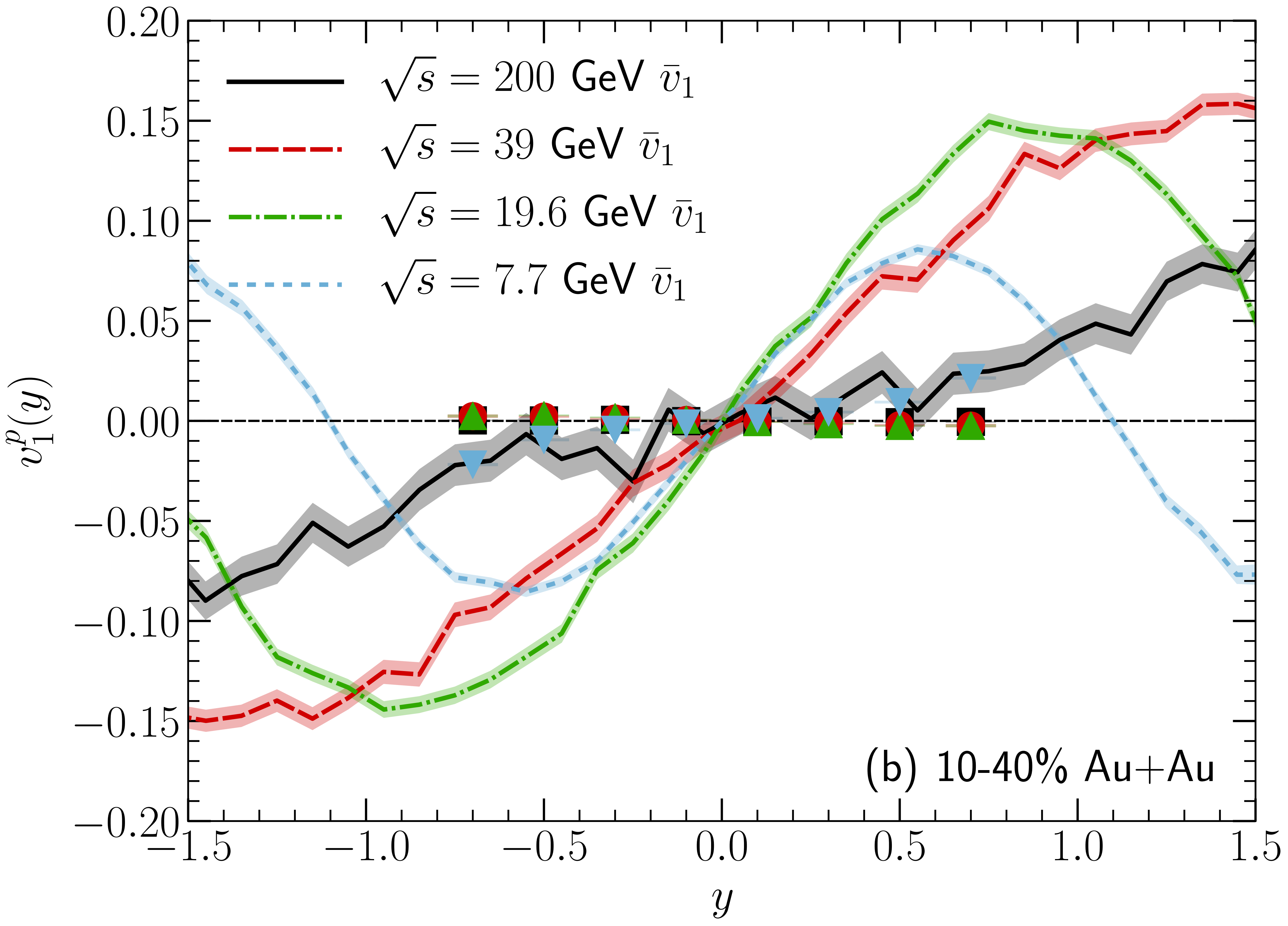
To be further constrained from baryon - anti baryon splits in other observables like that of polarisation etc

Baryon diffusion may be constrained by proper treatment of the systematics of the parameter space

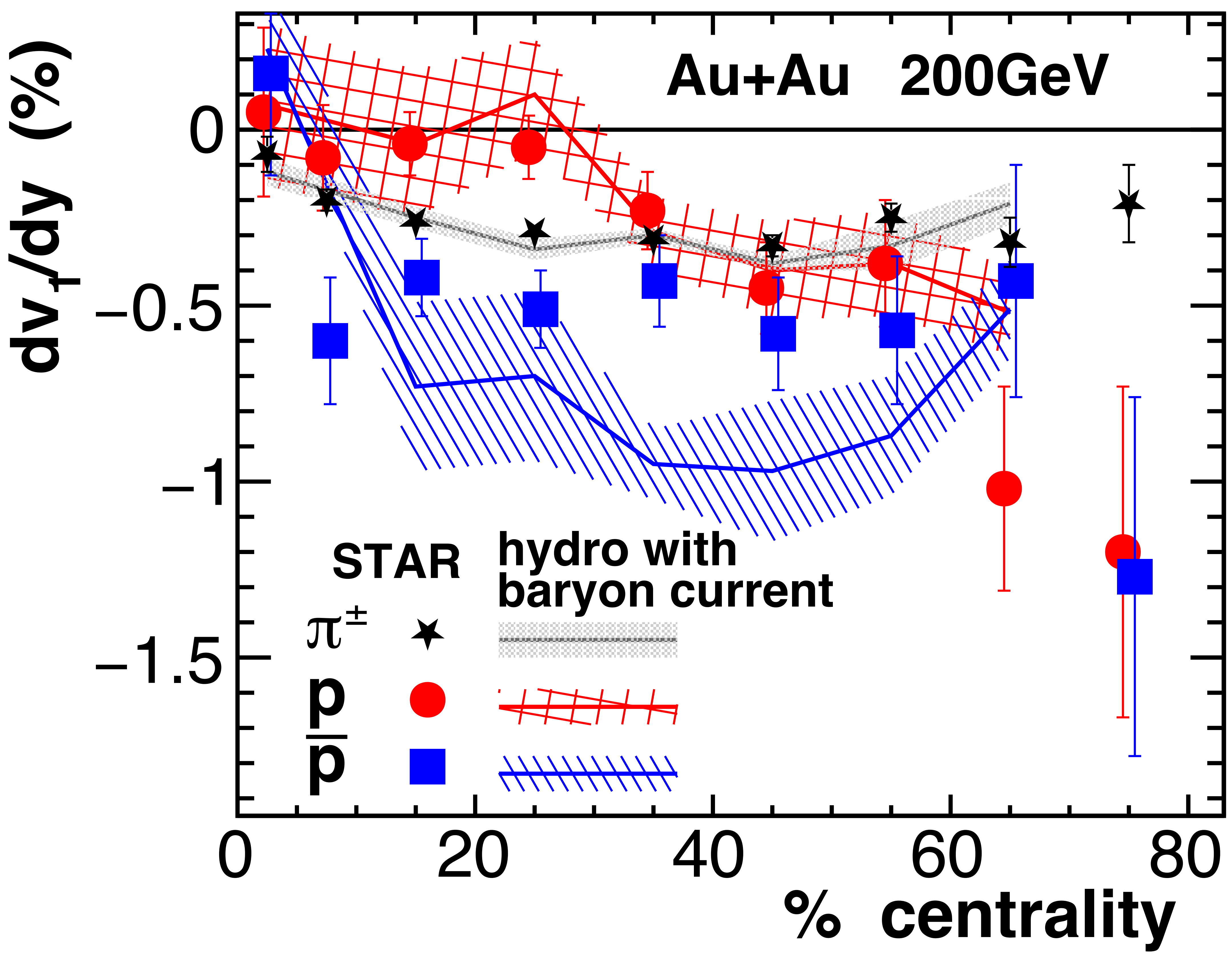
Independent Evolution of strangeness, electric charge seems important at $\sqrt{s_{NN}} \sim 10$ GeV.

Thank You

Other recent attempts



arXiv: 2003.05852



arXiv: 2207.04927