Energy dependence study of directed flow in Au+Au collisions using an improved coalescence in AMPT model

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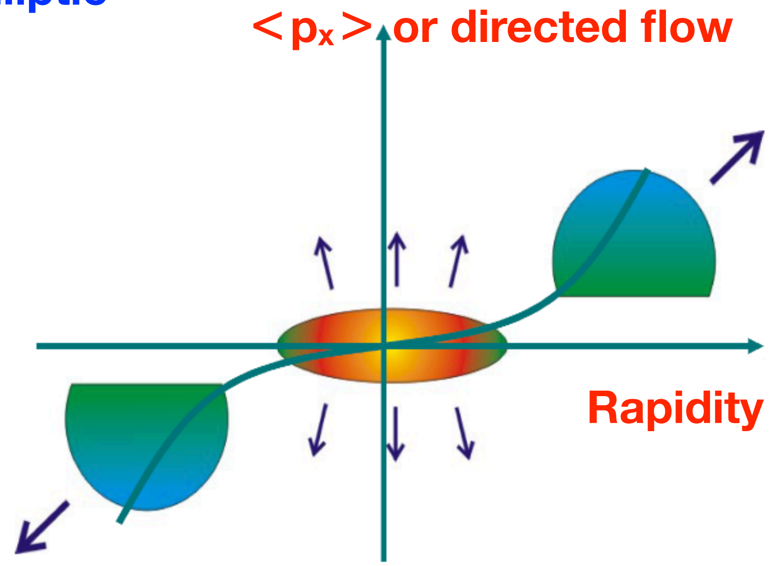
Outline

- ☑ **Introduction and motivation**
- ☑ **AMPT analysis details**
- ☑ **Results**
  - Directed flow (v_1) of identified hadrons
  - v_1 comparison with experimental data
  - Partons' v_1
- ☑ **Summary and outlook**

Introduction

Invariant yield, $E\frac{d^3N}{dp^3} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1 + 2\mathbf{v_1}\, cos(\phi - \psi_R) + 2\mathbf{v_2}\, cos2(\phi - \psi_R) + \ldots\right)$

Isotropic   Directed   Elliptic

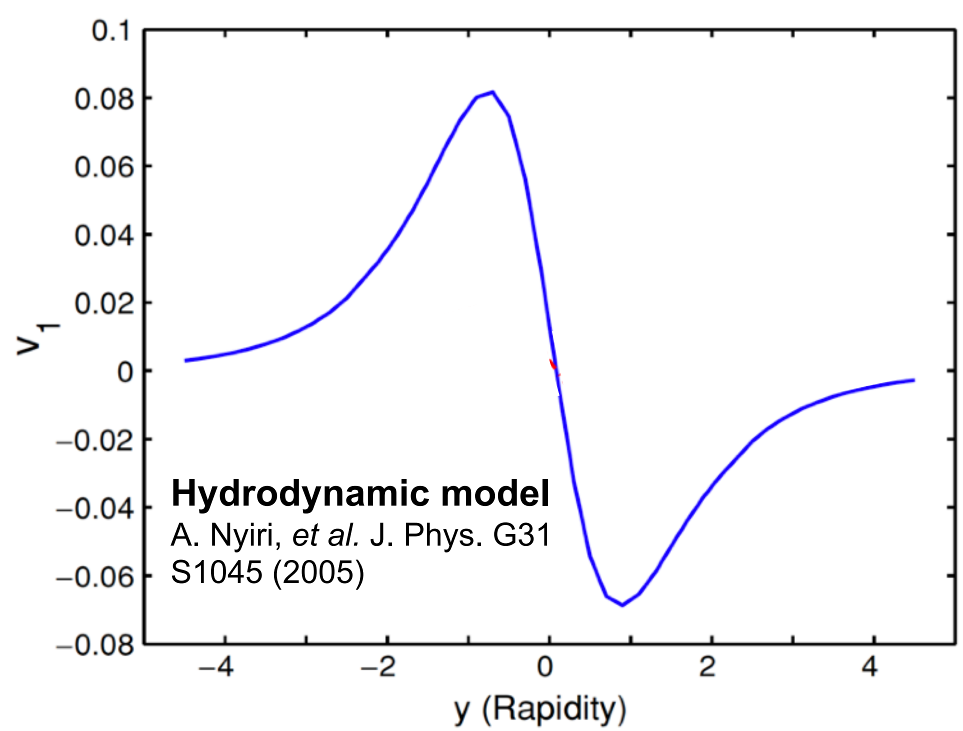


Directed flow (v_1) is quantified by the first harmonic v_1:

$$v_1 = \langle cos(\phi - \psi_R)\rangle \qquad \phi = tan^{-1}\left(\frac{p_y}{p_x}\right)$$

Directed flow, v_1:

- It is generated during the nuclear passage time ($2R/\gamma$~0.1 fm/*c*) and hence it probes the earliest stage of collision dynamics (Ref: arXiv:1407.5003)
- The spectators deflected from dense reaction zone are sensitive to the **pressure** and also have strong sensitivity towards the **EoS**
- It describes the sideward motion of the particles within the reaction plane



Motivation

An experimental approach of AMPT-SM model analysis with reference to STAR data paper:

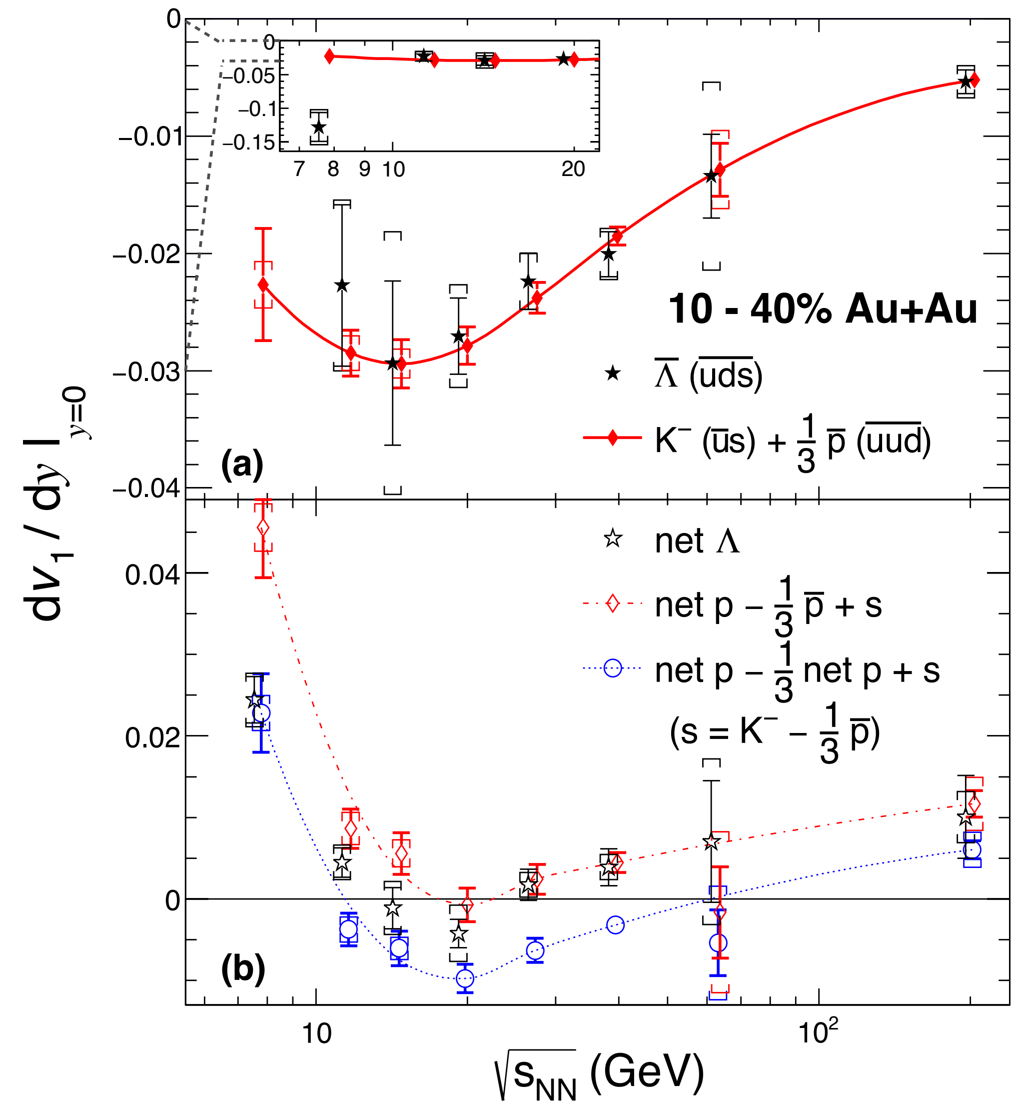
Coalescence sum rule: If deconfined quarks already acquired azimuthal anisotropy, then naive coalescence leads to to v_n of the resulting hadrons being the summed v_n of their constituent quarks

$$(v_n)_{(hadron)} = \sum (v_n)_{constituent\ quark}$$

(i) Coalescence sum rule for v_1:

$$\boxed{s = K^{-}(\bar{u}s) - \frac{1}{3}\bar{p}(\bar{u}\bar{u}\bar{d})}$$

It assumed $\bar{u}, \bar{d}$ quarks have same flow and so do s, $\bar{s}$ quarks



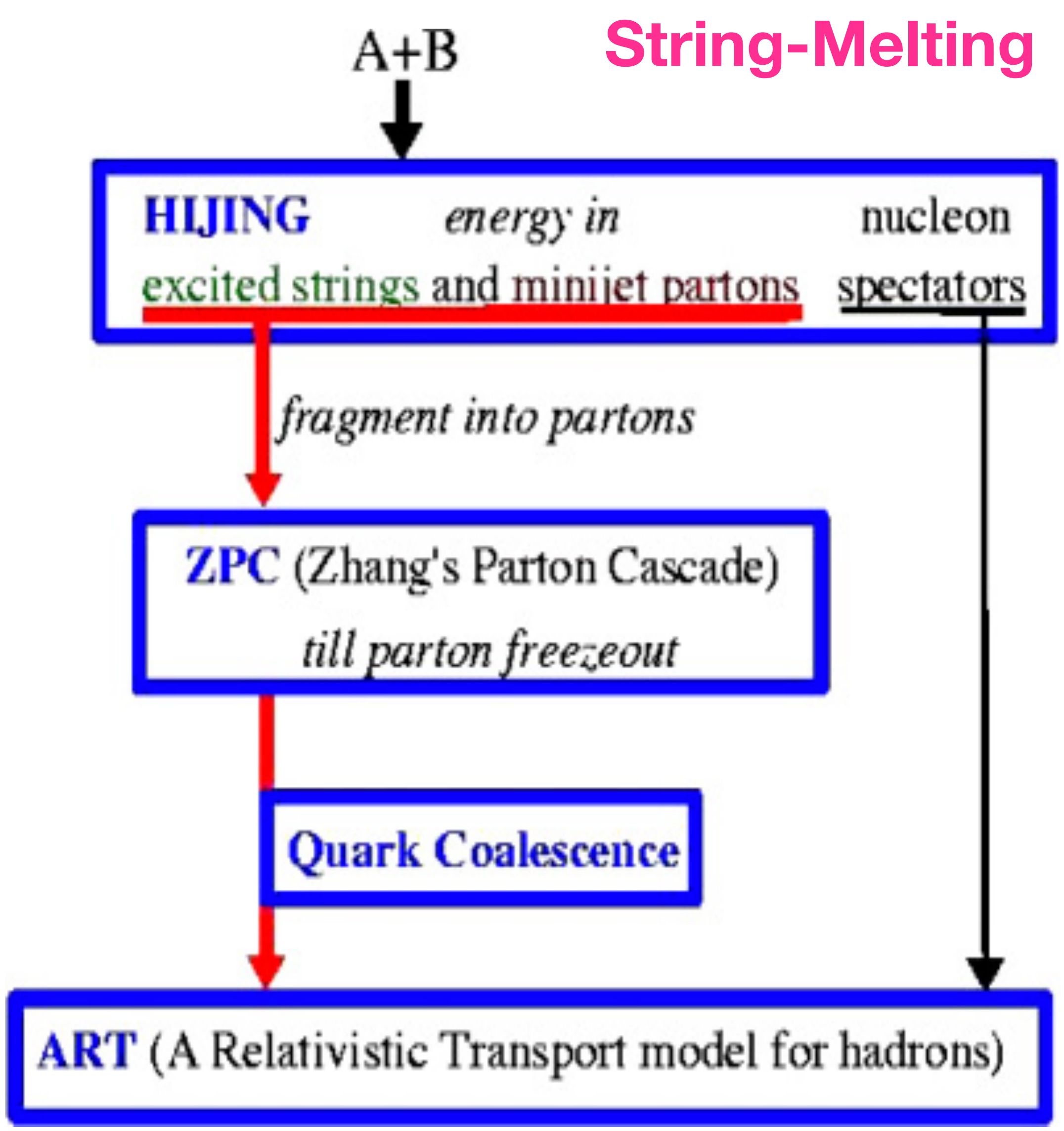
Phys. Rev. Lett. 120, 062301 (2018)
(STAR Collaboration)

(ii) Disentangle the effect of transported and produced quarks

$$\boxed{v_{1\ p} = r(y) v_{1\ \bar{p}} + \left[1 - r(y)\right] v_{1\ \mathrm{net\ p}}\ ; \quad r(y) = \bar{p}/p}$$

Essential for understanding the particle production mechanism at various energies

AMPT analysis details



- No. of events : **~1 million** for AMPT-String Melting
- AMPT-SM : parton cross section σ_p **=1.5 mb**,
  hadronic interaction time t_{max} **= 30 fm/c**
- Energy (GeV) : **7.7, 11.5, 14.5, 19.6, 27, 39, 54.4, 62.4, 200**
- Hadrons : $\pi^+, \pi^-, \mathbf{K}^+, \mathbf{K}^-, \mathbf{K}^0_S, \mathbf{p}, \bar{\mathbf{p}}, \Lambda, \bar{\Lambda}, \Xi^-, \Xi^+$
- Partons. : $\mathbf{u}, \bar{\mathbf{u}}, \mathbf{d}, \bar{\mathbf{d}}, \mathbf{s}, \bar{\mathbf{s}}$

Hadron	p_T cut (GeV/c)
$p, \bar{p}$	$0.2 < p_T < 2.0$
$\pi^{\pm}, K^{\pm}$	$p_T > 0.2$, $p < 1.6$
$\Lambda, \bar{\Lambda}, K^0_S, \Xi, \bar{\Xi}$	$0.2 < p_T < 5.0$
ϕ	$0.15 < p_T < 10.0$

All the particles and anti-particles are identified via their corresponding Pythia-ID (PID)

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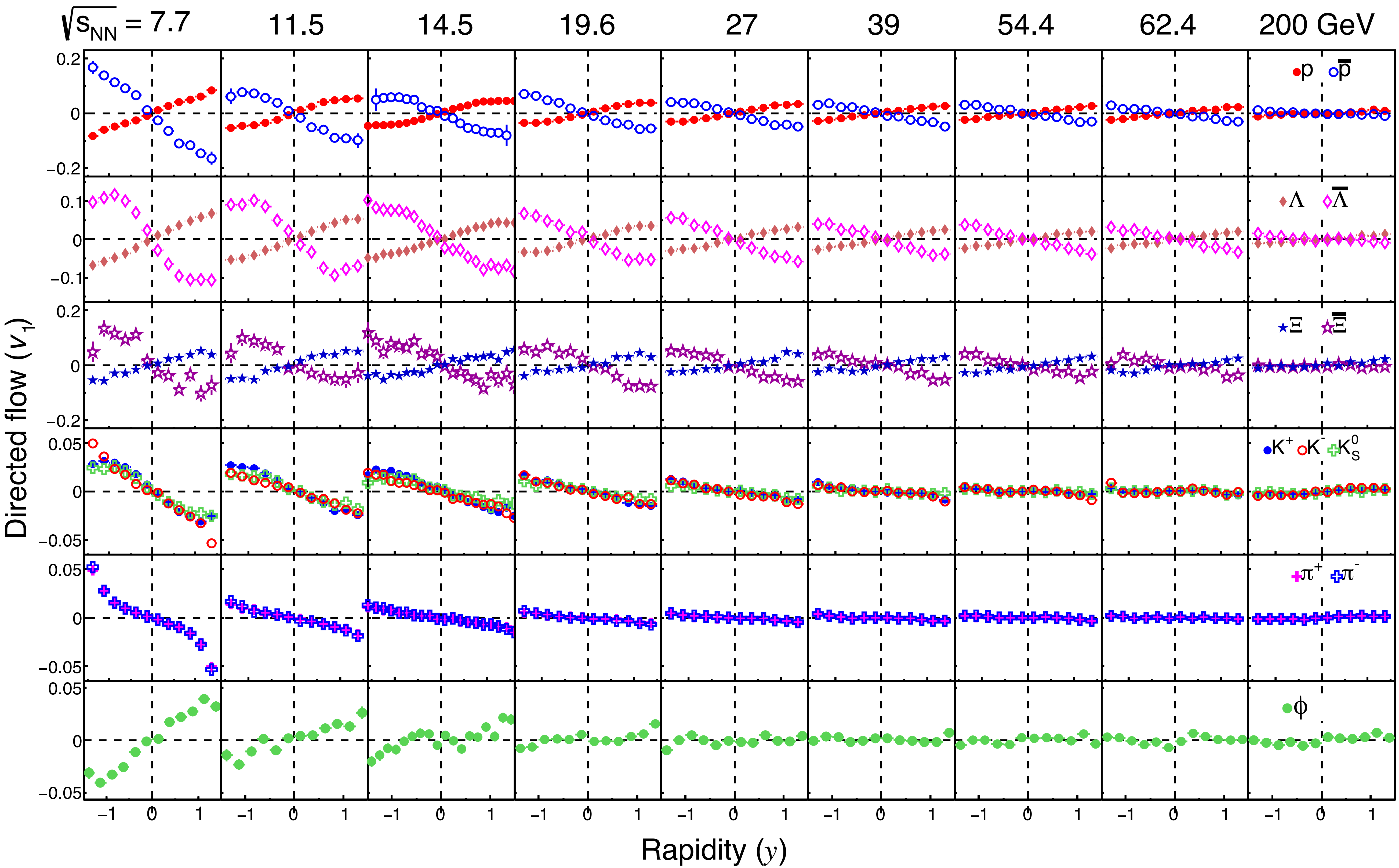
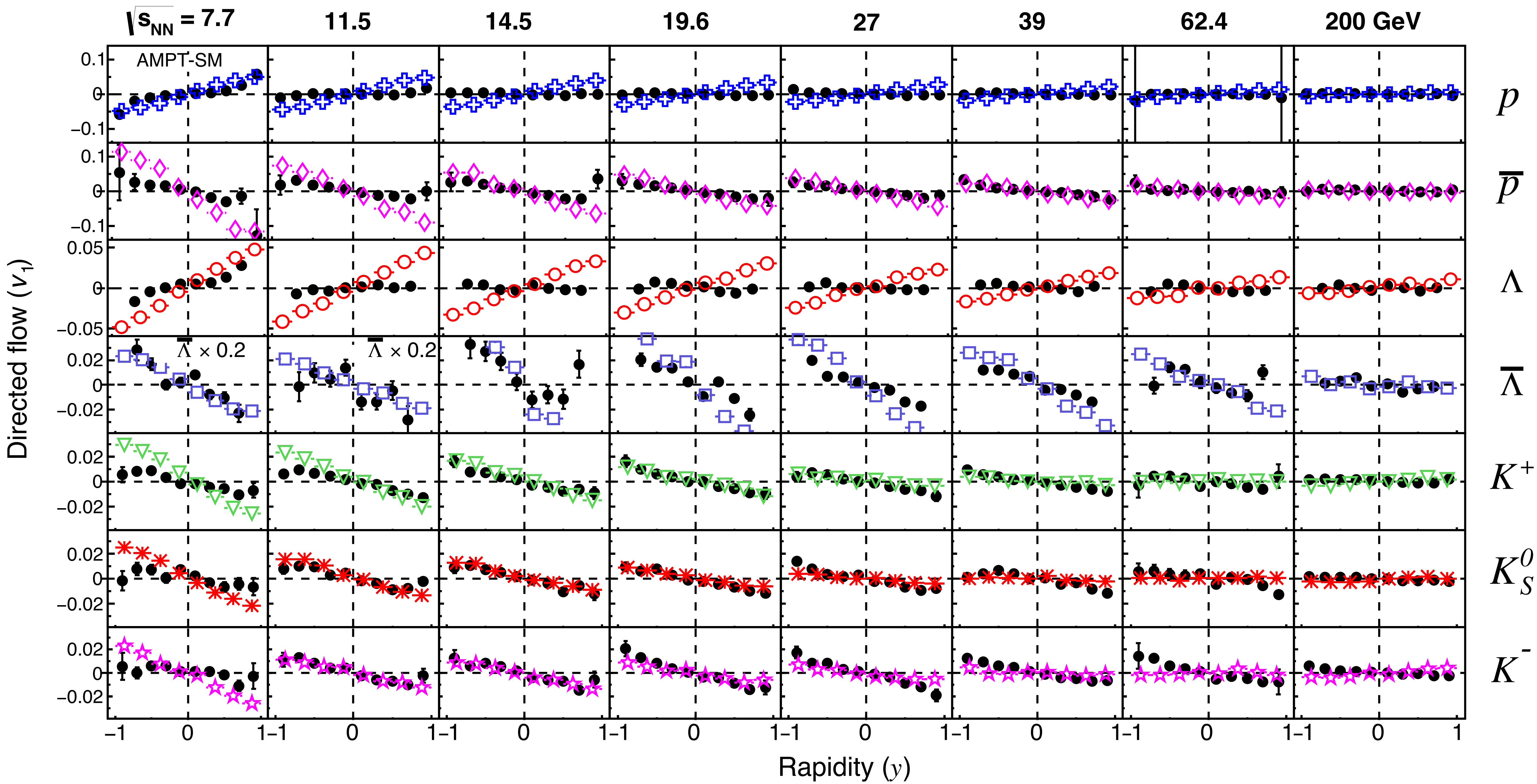
AMPT-SM: v_1 vs y [10-40%]



Compared with data: v_1 vs y [10-40%]



Black solid circles are experimental data and color markers are AMPT-SM

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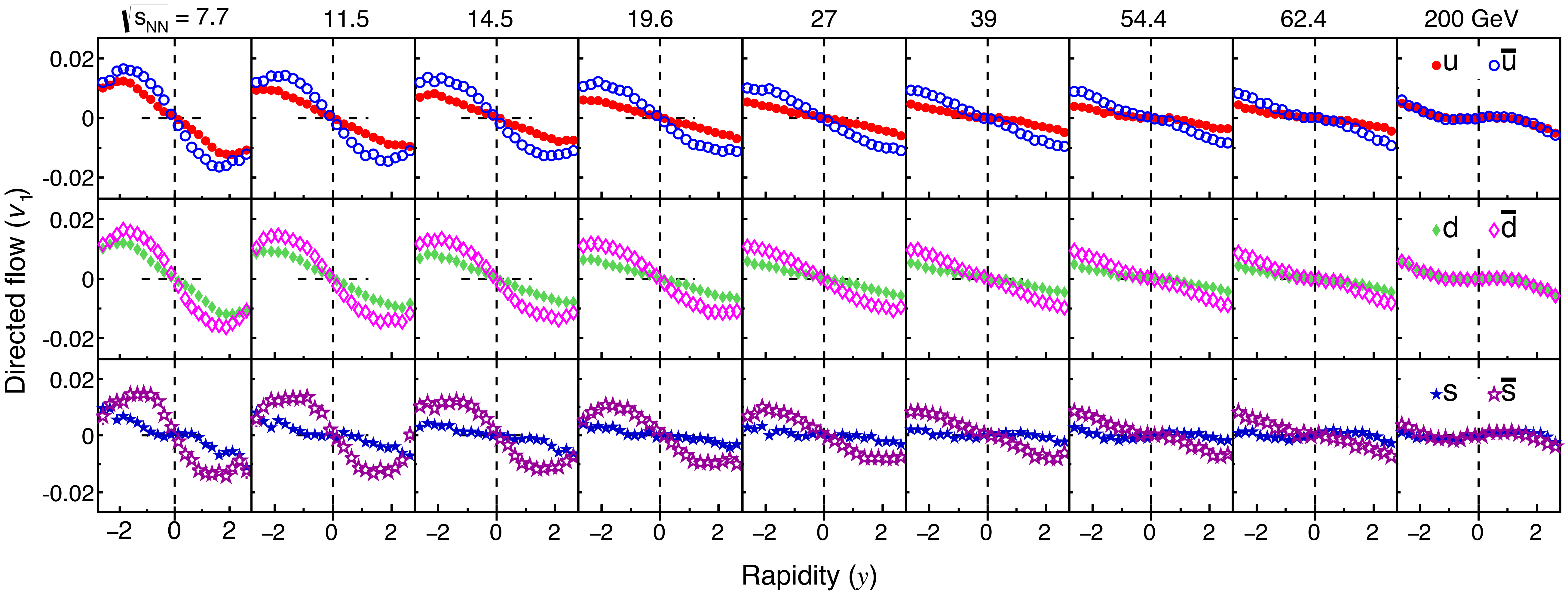
AMPT-SM: Partons' v_1



✓ Strong rapidity and energy dependence of quarks and anti-quarks

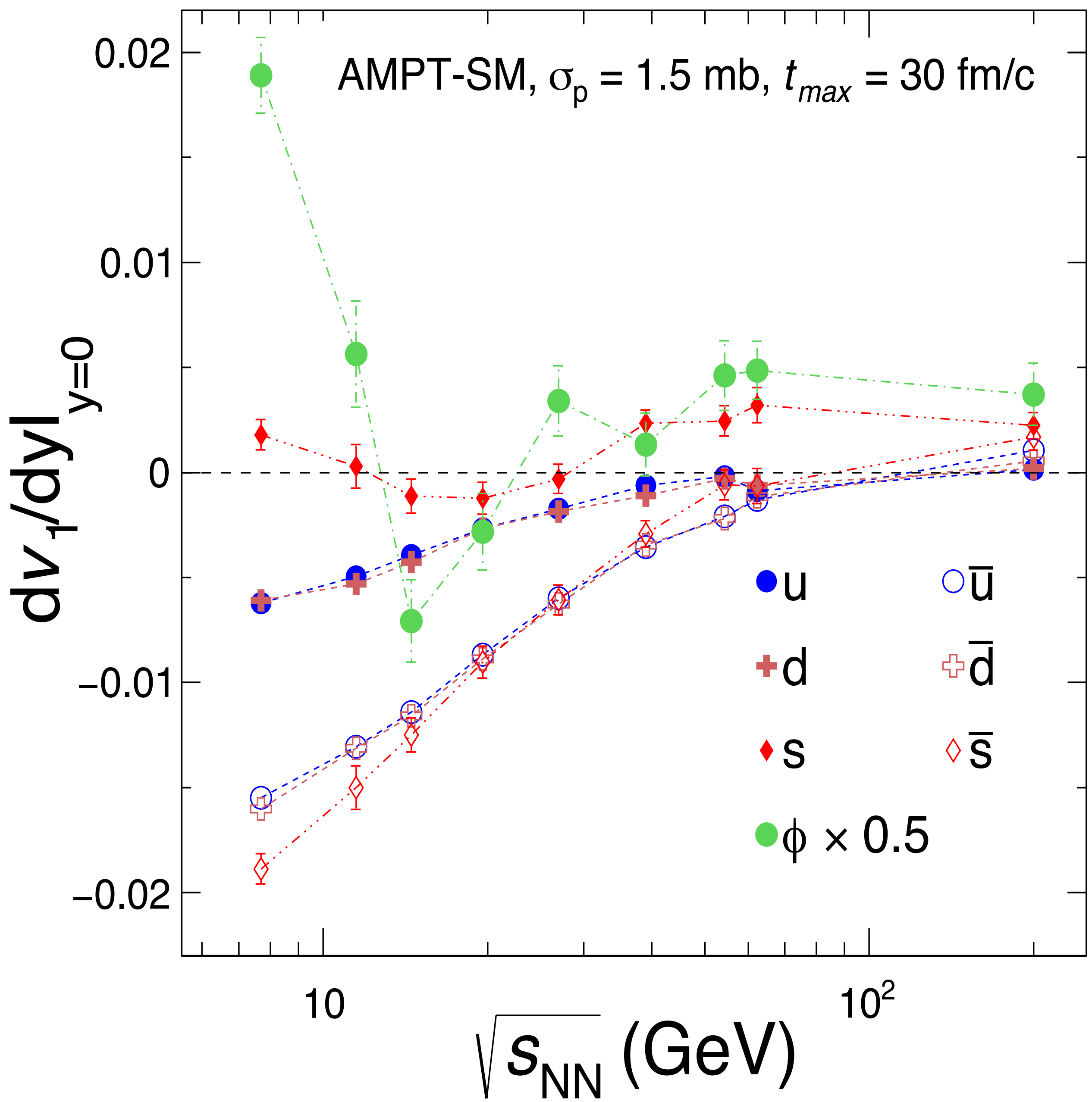
✓ Difference between quark and anti-quark v_1 value increases with decrease in energy

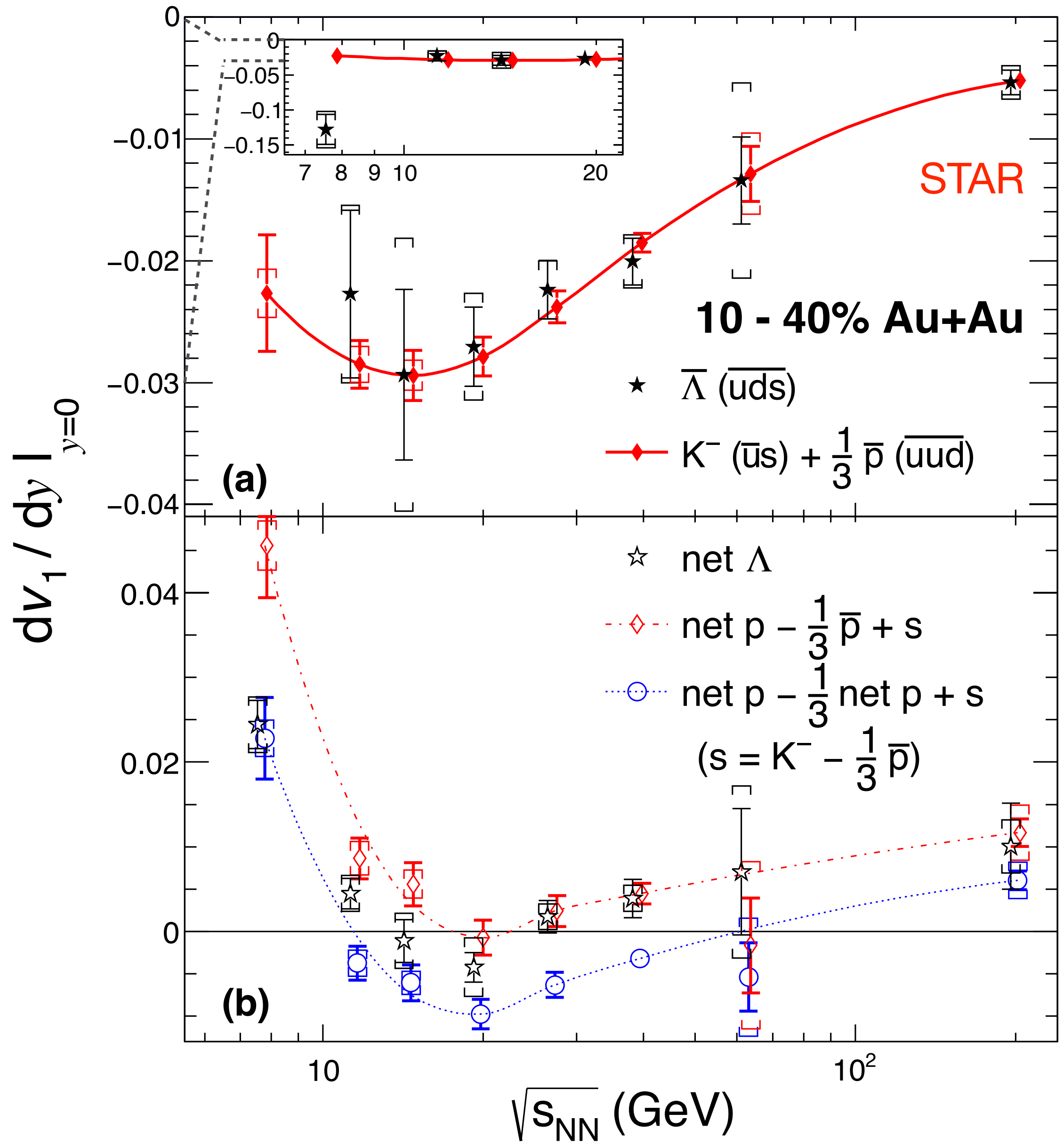
➡ Similar v_1 values for quark and anti-quark at 200 GeV unlike 7.7 GeV

$$v_1(y) = Fy + F_3 y^3$$

Slope (dv_1/dy) Fluctuation

Produced partons slope *vs* $\sqrt{s_{NN}}$





✓ Difference between quark and anti-quark v_1 value increases with decrease in energy

✓ Similar v_1 values for **u** and **d** quarks unlike **s** quark

✓ v_1 values of quarks and anti-quarks are less negative (& can become positive) with increase in energy

➡ At 200 GeV all quarks and anti-quarks have positive v_1 values unlike 7.7 GeV

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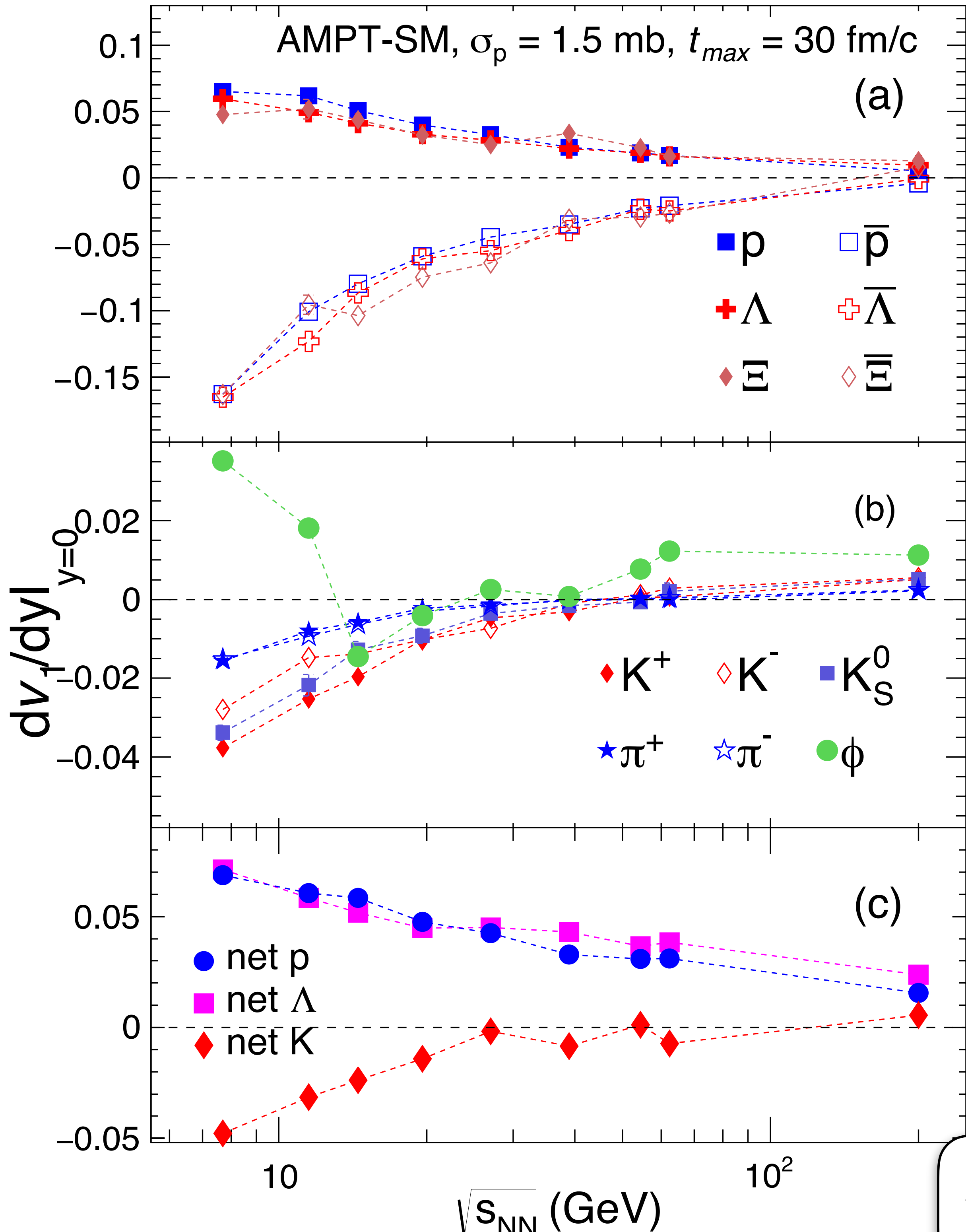
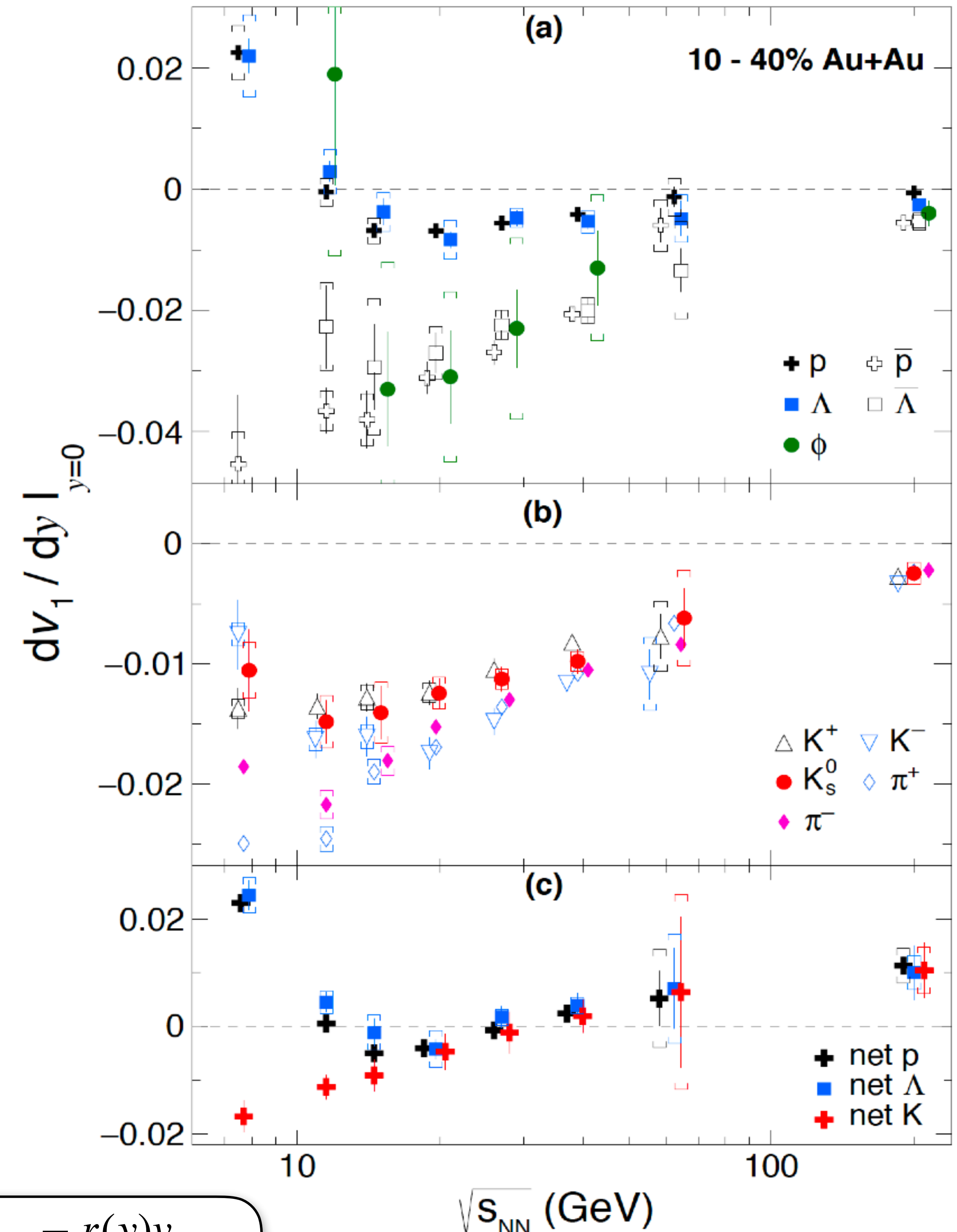
AMPT-SM: slope *vs* $\sqrt{s_{NN}}$ [10-40%]

STAR





$$v_{1\ net\ p} = \frac{v_{1\ p} - r(y) v_{1\bar{p}}}{1 - r(y)}$$

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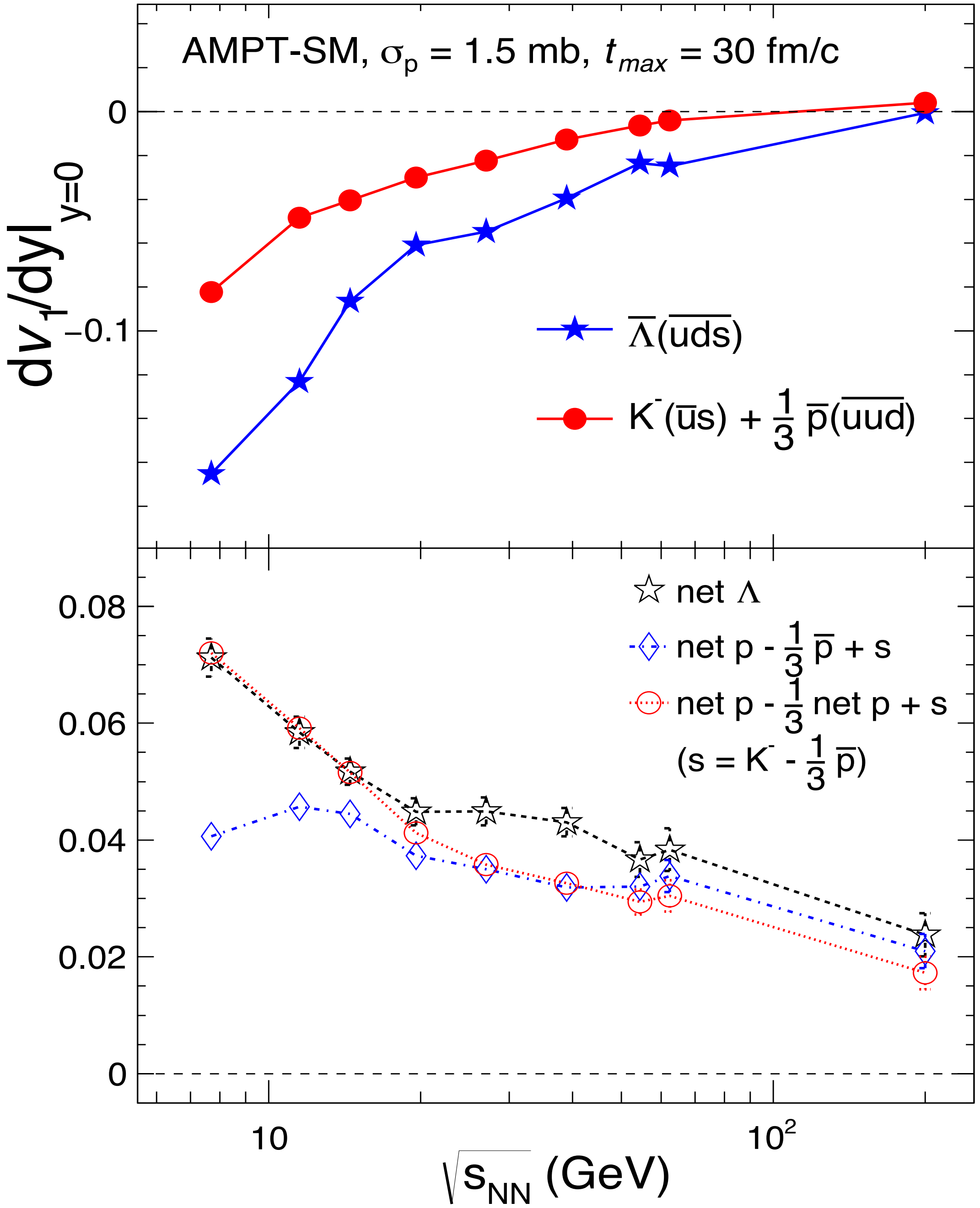
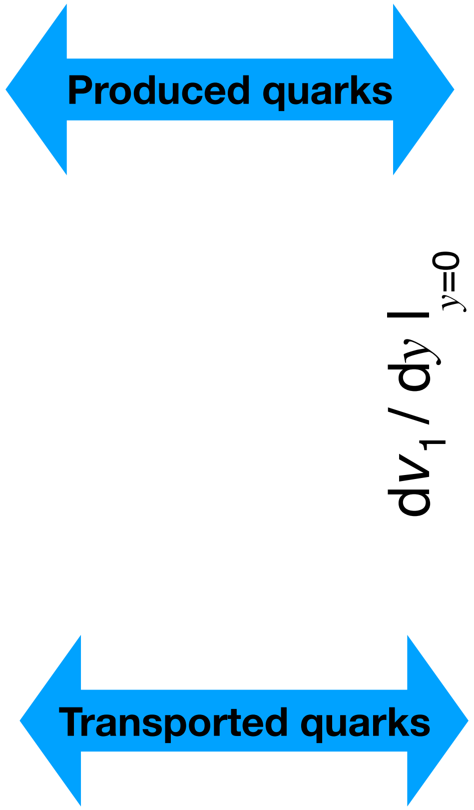
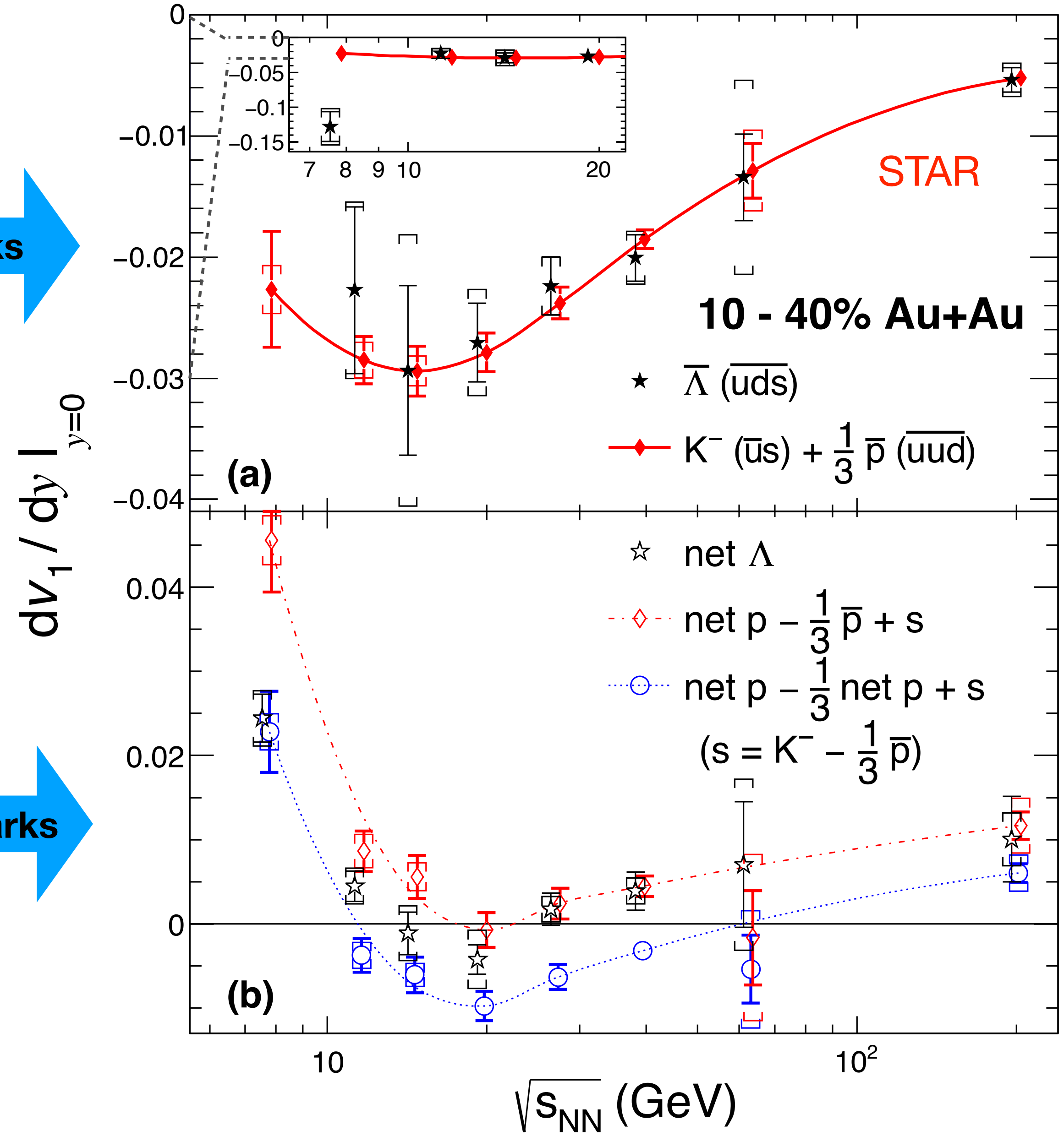
✓ Qualitative similarity between net K and data unlike net p, net Λ where data show a sign change but AMPT doesn't

AMPT-SM: slope *vs* $\sqrt{s_{NN}}$ [10-40%]







- ✓ A produced u quark is removed by keeping the term $\left[\text{net p} - \dfrac{1}{3}\bar{p}\right]$
- ✓ Transported quarks dominant at lower energies (< 14.5 GeV) and more produced quarks at high energy

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Summary

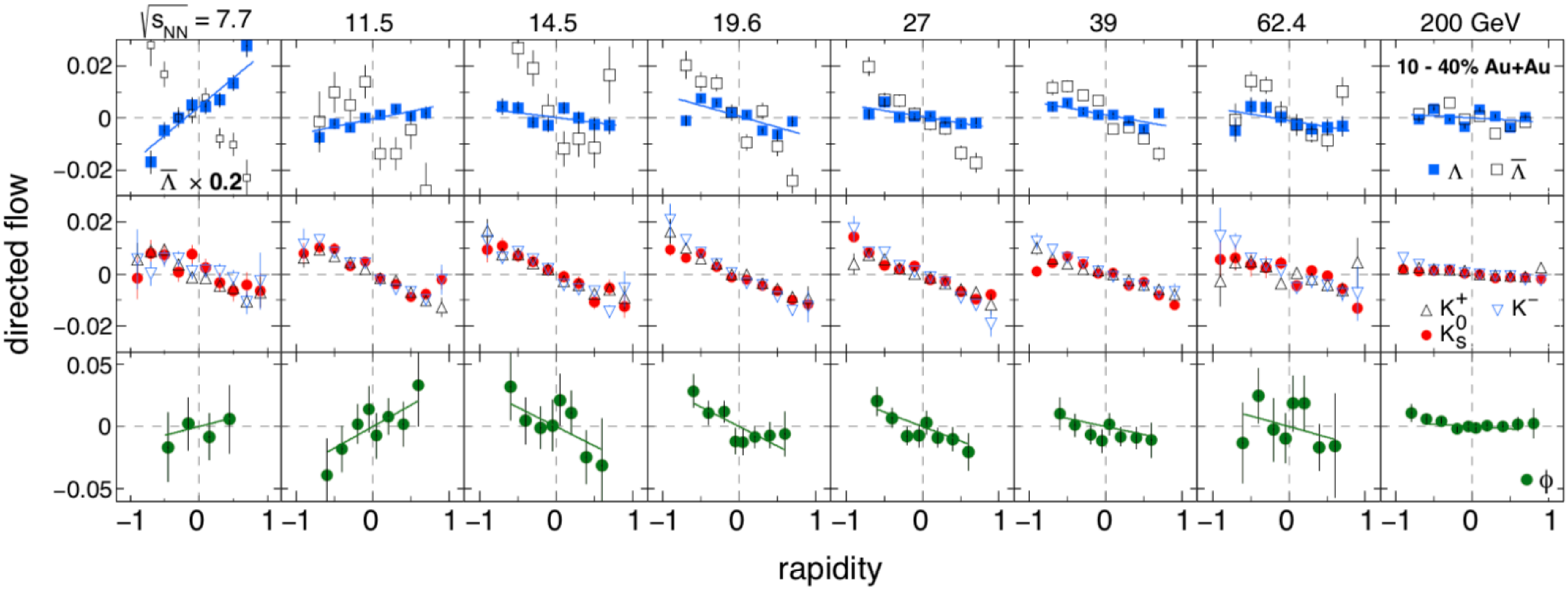
- A significant species dependence of rapidity odd component of directed flow from lower (7.7 GeV) to higher energy (200 GeV) in AMPT-SM similar to experimental data is observed
- Higher value of net p, net Λ and net K v_1 at 7.7 GeV compared to 200 GeV suggests that the contribution of transported quarks at lower energy is more compared to higher energy
- *Transported and produced quarks have different v_1 values*
- *Strange and anti-strange quark don't have the same flow over all energies*
- ***Particle production via quark coalescence seems better at higher energies***

Outlook

- Relations between final state hadrons' v_1 and partons' v_1 are under investigation

Thank you!

STAR: Directed flow (v_1):



$$v_1(y) = Fy + F_3 y^3$$

Slope (dv_1/dy)

Fluctuation