RHIC-STAR能量扫描II中直接流的实验研究进展

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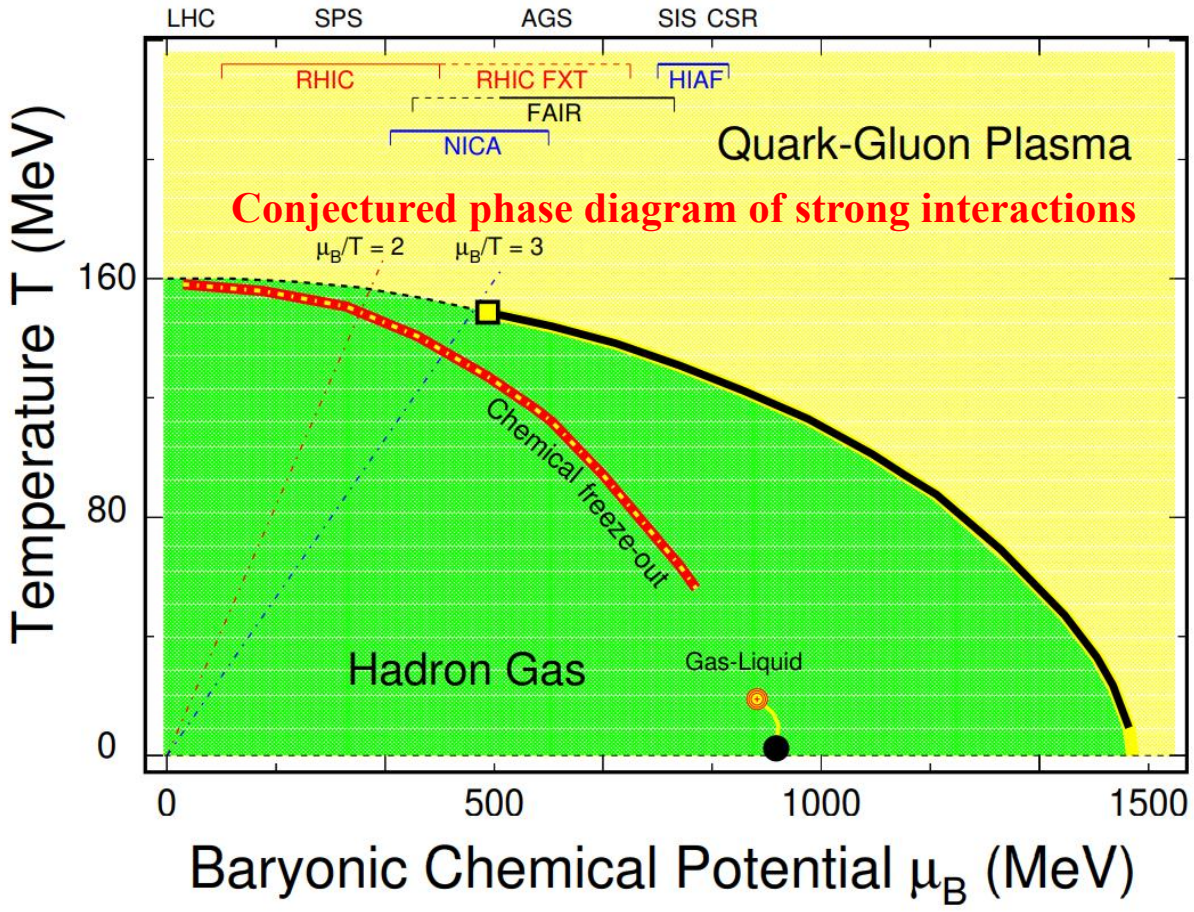
OutLine

- **Motivation**
- **Experimental Setup**
- **Analysis Method**
- **Results and discussions**
- **Summary and Outlook**

Motivation



- Colliding mode: $\sqrt{s_{NN}}$ = 7.7-200GeV
- Fixed-target mode: $\sqrt{s_{NN}}$ = 3-7.7GeV

X.Luo, S.Shi, Nu Xu et al. Particle 3, 278 (2020)

- **High energy heavy ion collisions:**
  Study the properties of QGP
- **Beam Energy Scan**
  Critical End Point
  1st order phase boundary

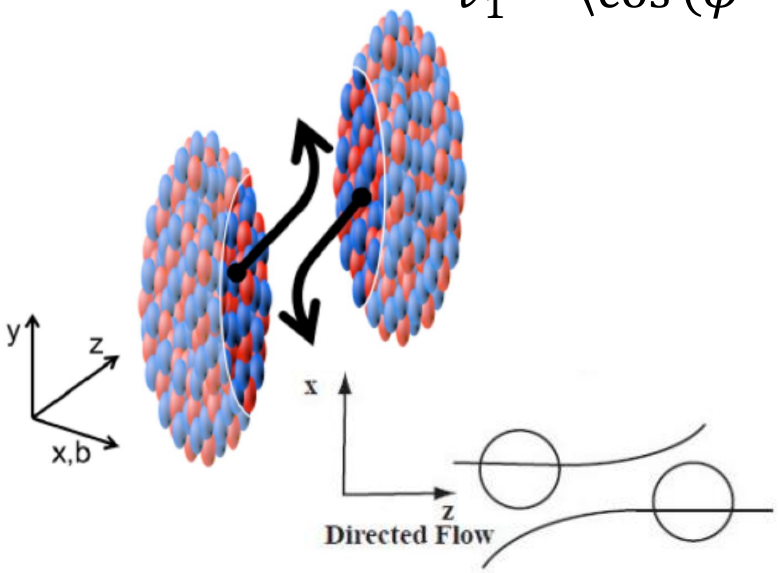
$\sqrt{s_{NN}}$(GeV)	μ_B(MeV)	Events	Date collected
19.6	206	478 M	2019
14.6	262	324 M	2019
11.5	316	235 M	2020
9.2	373	162 M	2020
7.7	422	101M+163 M	2021
6.2	487	118 M	2020
5.2	541	103 M	2020
4.5	589	108 M	2020
3.9	632	170 M	2020
3.5	666	116 M	2020
3.2	697	201 M	2019
3.0	721	2361 M	2021

BES-II data taking has been finished

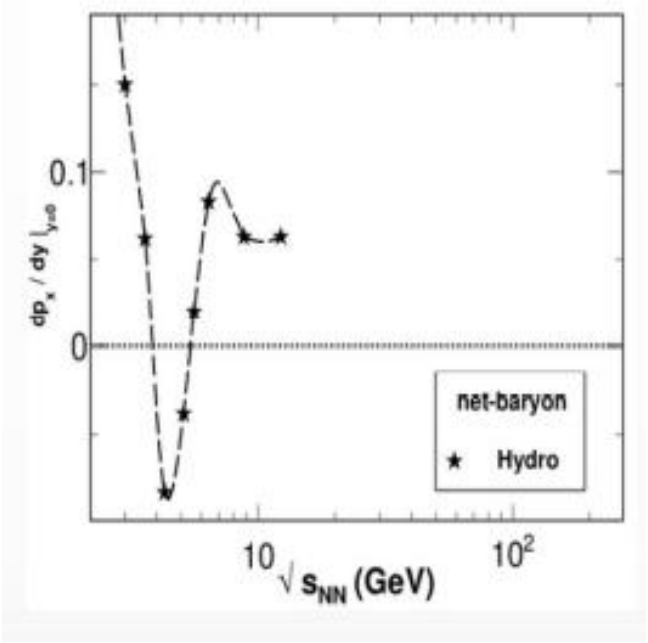
Motivation

$$\frac{dN}{d(\phi-\Psi)} \sim 1+\sum_{n=1}^{\infty} 2v_n \cos(n(\phi-\Psi))$$

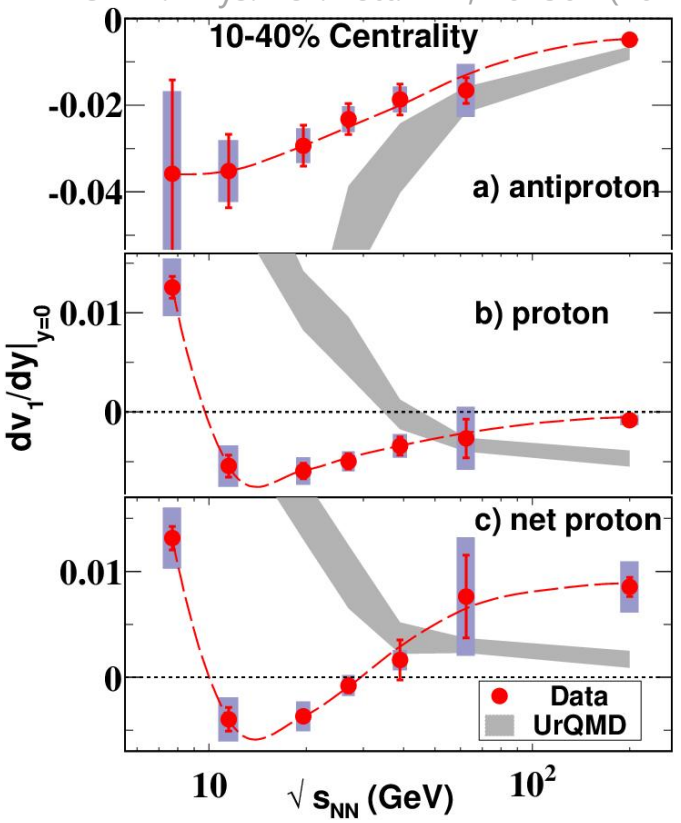
$$v_1 = \langle \cos(\phi - \Psi_{RP}) \rangle$$



H. Stoecker, Nucl. Phys. A 750, 121 (2005)

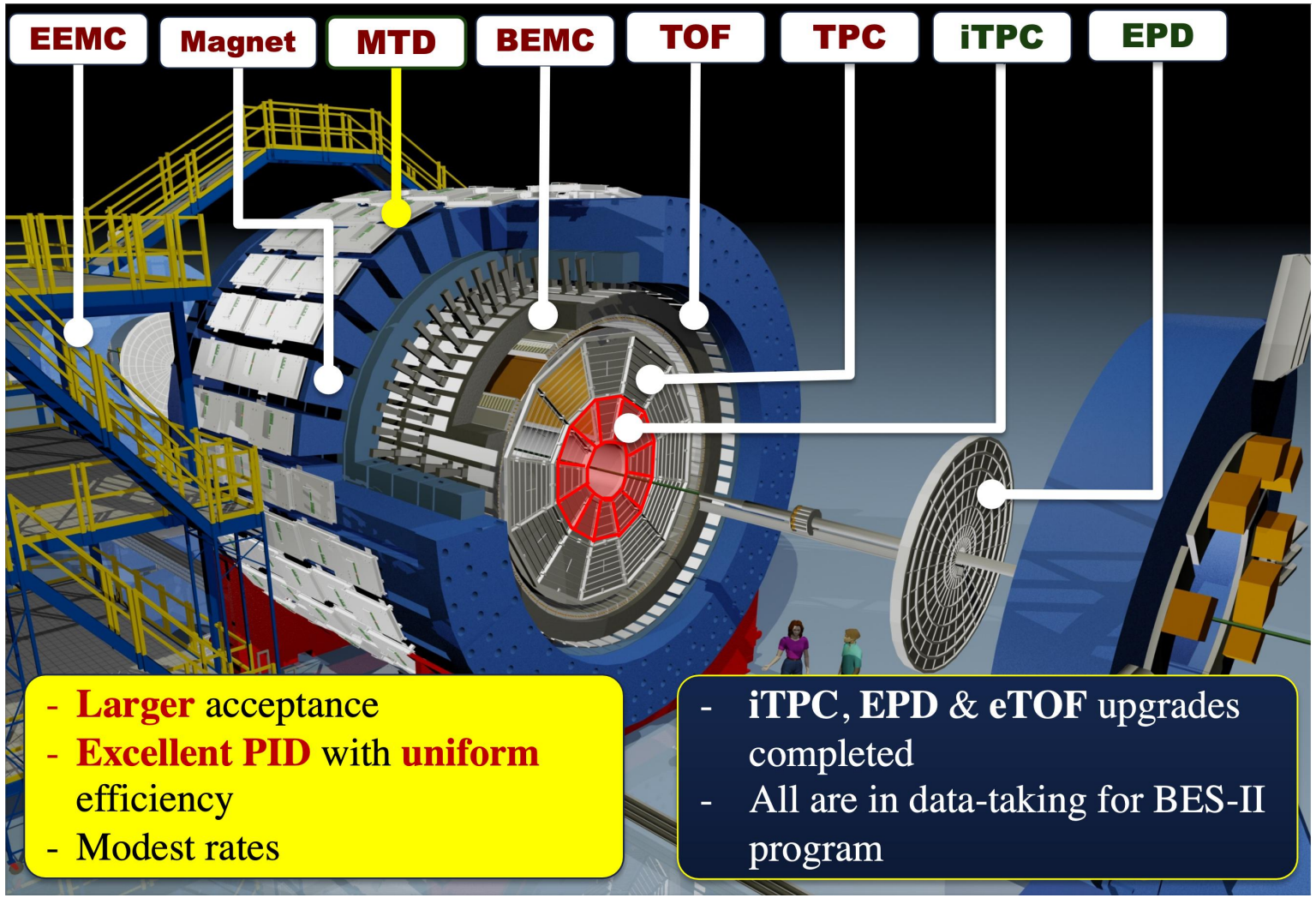


STAR: Phys. Rev. Lett. 112, 162301 (2014)

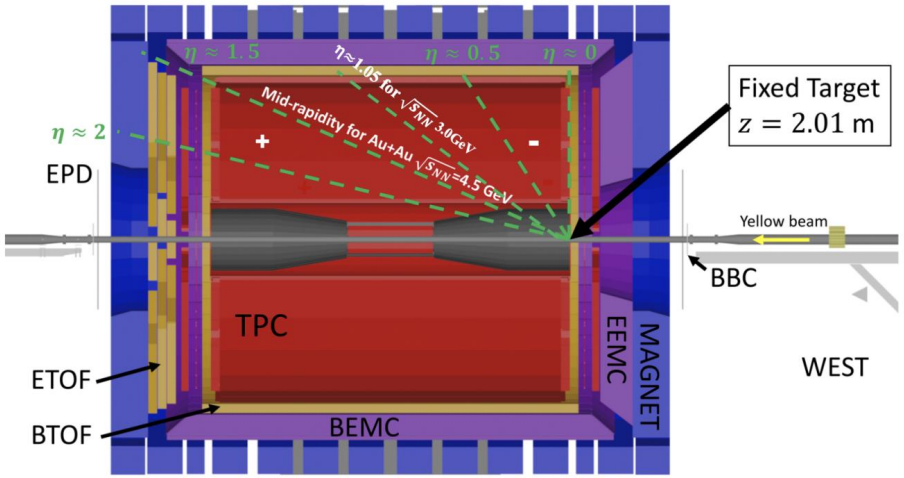


- Directed flow (v_1) describes sideward collective motion of produced particles with respected to the reaction plane
- Hydrodynamic calculation with the 1st order phase transition predicts a minimum of slope of directed flow as a function of collision energy
- The net-proton shows non-monotonic slope (dv_1/dy) as function of collision energy

Experimental Setup



STAR Fixed Target Setup:

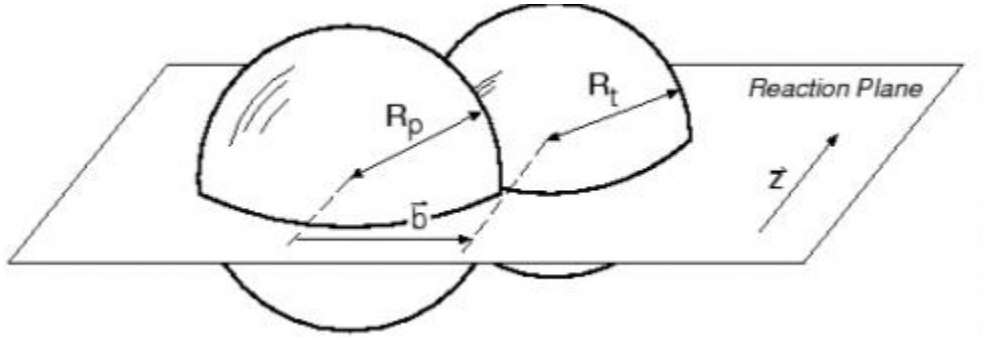


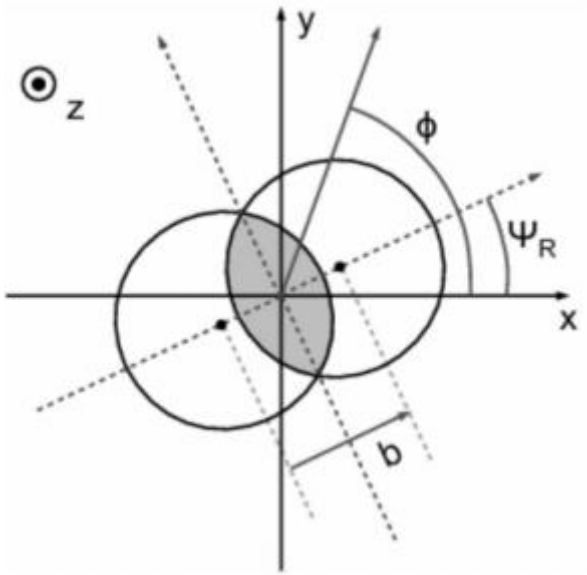
- **Explore the high baryon density region**
- **Good coverage at mid-rapidity**

Conventions: beam-going direction is the positive direction (Yellow beam)

Analysis Method

Event Plane Method





$$v_1 = \frac{\langle \cos(\phi - \Psi_1) \rangle}{\langle \cos(\Psi_{1,EP} - \Psi_{RP}) \rangle} = \frac{v_1^{obs}}{R_1}$$

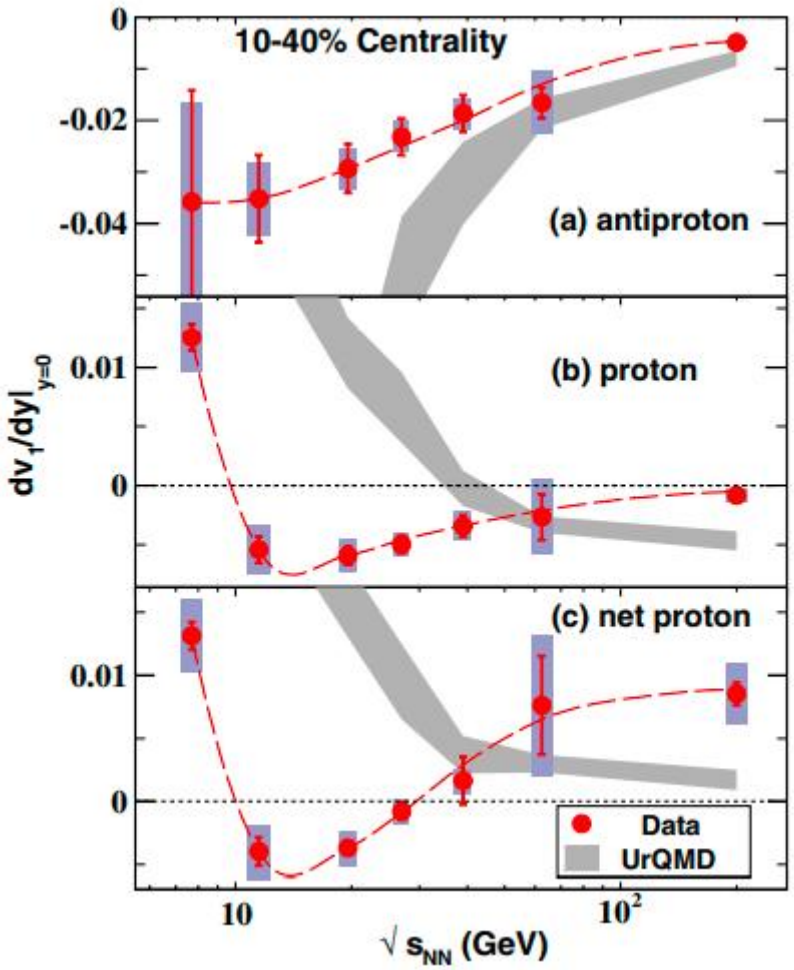
$$\Psi_1 = \tan^{-1} \frac{\sum_i w_i \sin(\phi_i)}{\sum_i w_i \cos(\phi_i)}$$

- Reaction plane is defined by impact parameter and beam going direction
- The event plane is an estimate of reaction plane

Poskanzer, A. M. and Voloshin, S. A.. "Methods for analyzing anisotropic flow in relativistic nuclear collisions." Phys. Rev. C 58.3 (1998): 1671--1678.

Results: BES-I

Net-proton v_1 slope v.s. beam energy



- The proton and net-proton slope show a minimum between 11.5 and 19.6 GeV. In addition, the net-proton slope changes sign twice between 7.7 and 39 GeV.
  → a possible signature of a first-order phase transition between hadronic matter and a deconfined phase
- The UrQMD model can not reproduce the data.
- BES II: centrality dependence.

"Net particle" represents the excess yield of a particle species over its antiparticle.

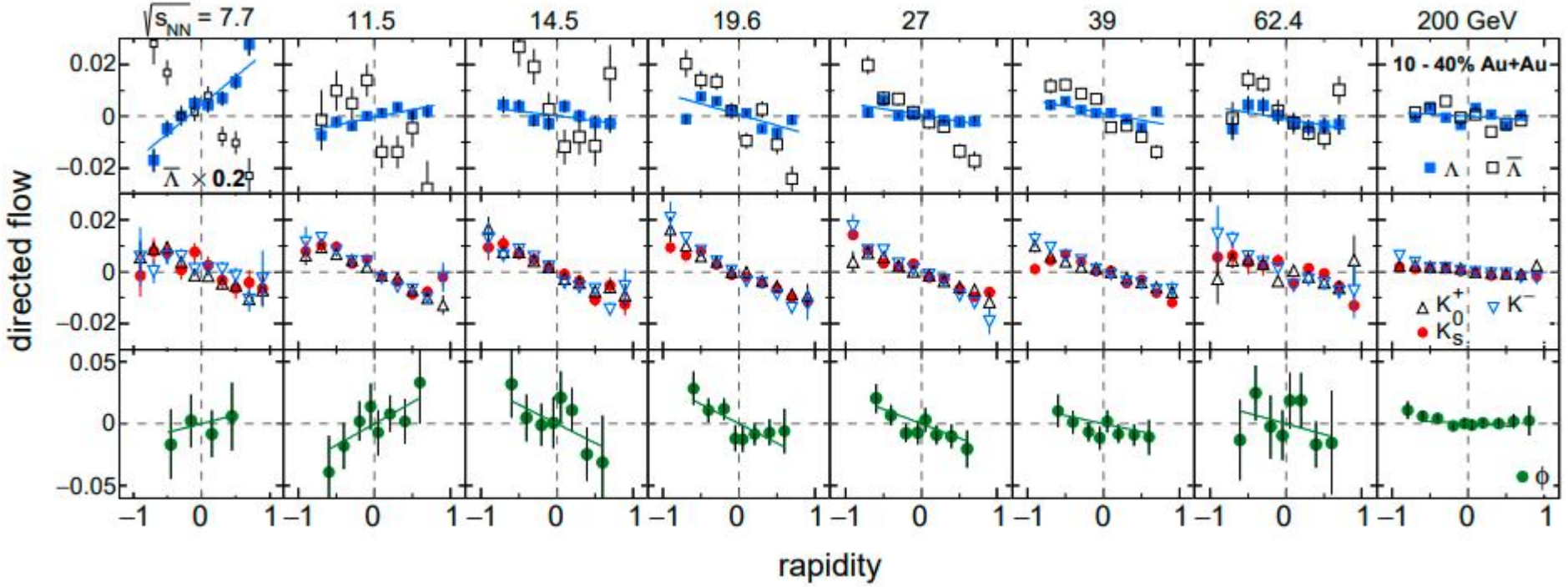
The slope of net-p is based on expressing the y dependence of v1 for all protons as:

$$[v_1(y)]_p = r(y)[v_1(y)]_{\bar{p}} + [1 - r(y)][v_1(y)]_{\text{net-}p}$$

r: the ratio of anti-p to p.

STAR: Phys. Rev. Lett. 112, 162301 (2014)

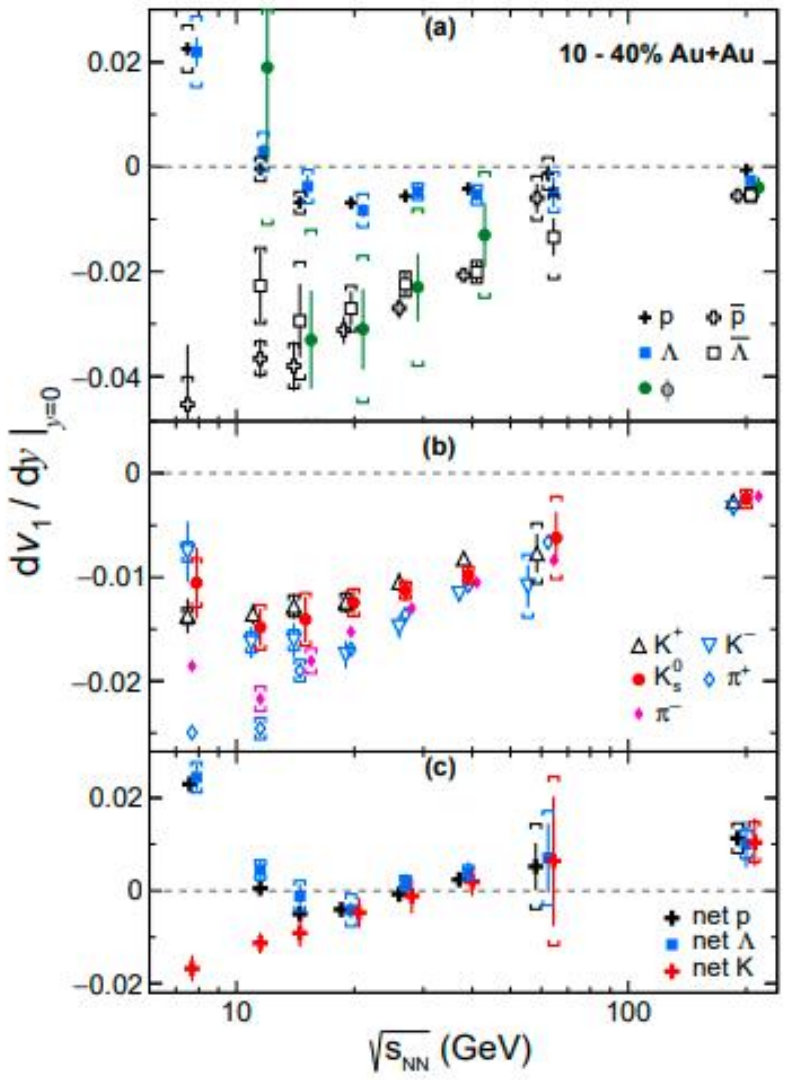
v_1 of ϕ mesons



- ϕ meson v_1 slope have the same trend as Λ at low energy
- Mesons and all anti-baryons show negative slope except ϕ mesons when $\sqrt{s_{NN}}$ < 14.5 GeV
  → Change of medium property? High precision data needed: BES-II

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

v_1 slope v.s. beam energy

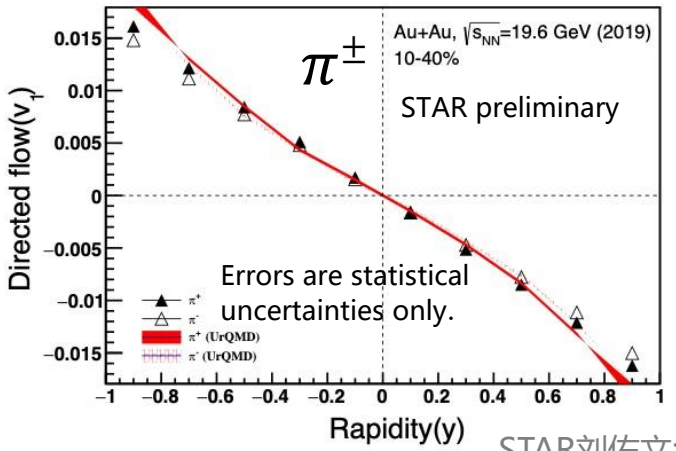


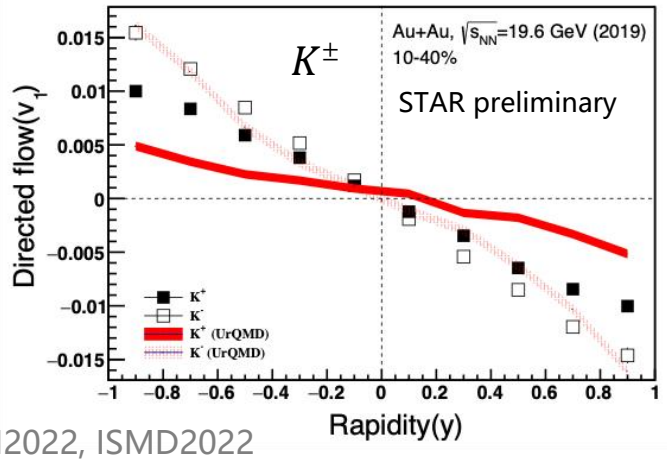
- dv_1/dy for protons and Λs change sign near 11.5 GeV
- Antiprotons, $\bar{\Lambda}$s, and mesons have negative dv_1/dy throughout the studied energy range
- Net-particle dv_1/dy for p, Λ and K agree $\sqrt{s_{NN}}$ >= 14.5 GeV, but net-Kaons increasingly diverge at 11.5 and 7.7 GeV

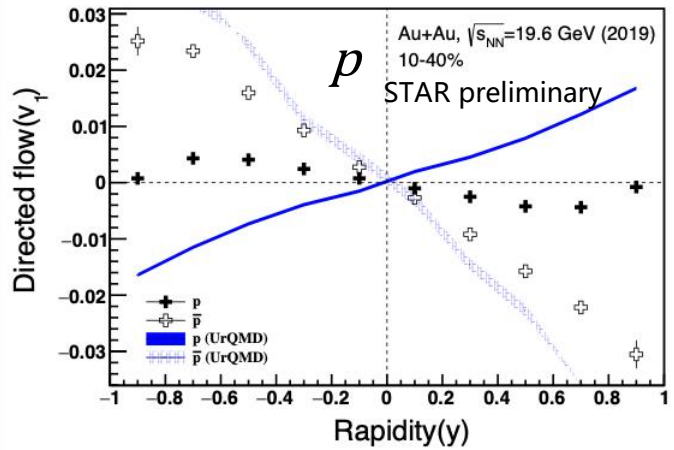
STAR: Phys. Rev. Lett. 120, 062301(2018)

Results: BES-II

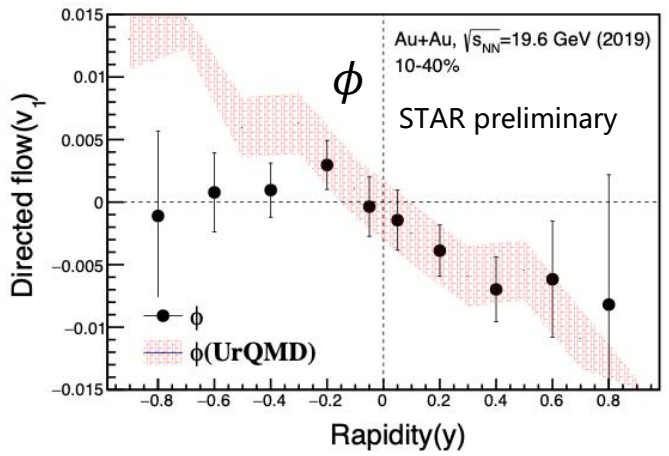
Rapidity Dependence: 19.6GeV

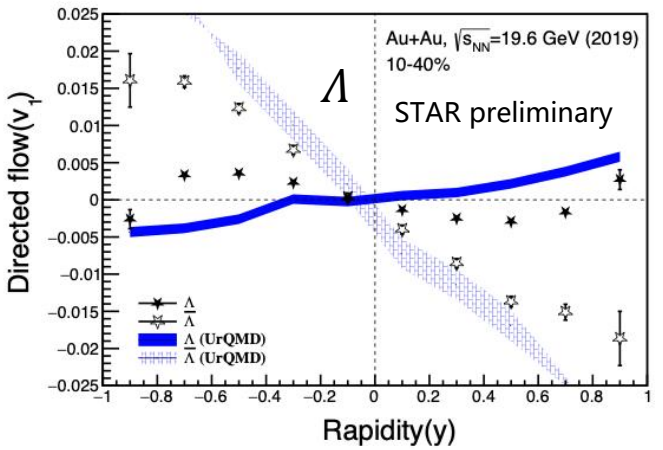






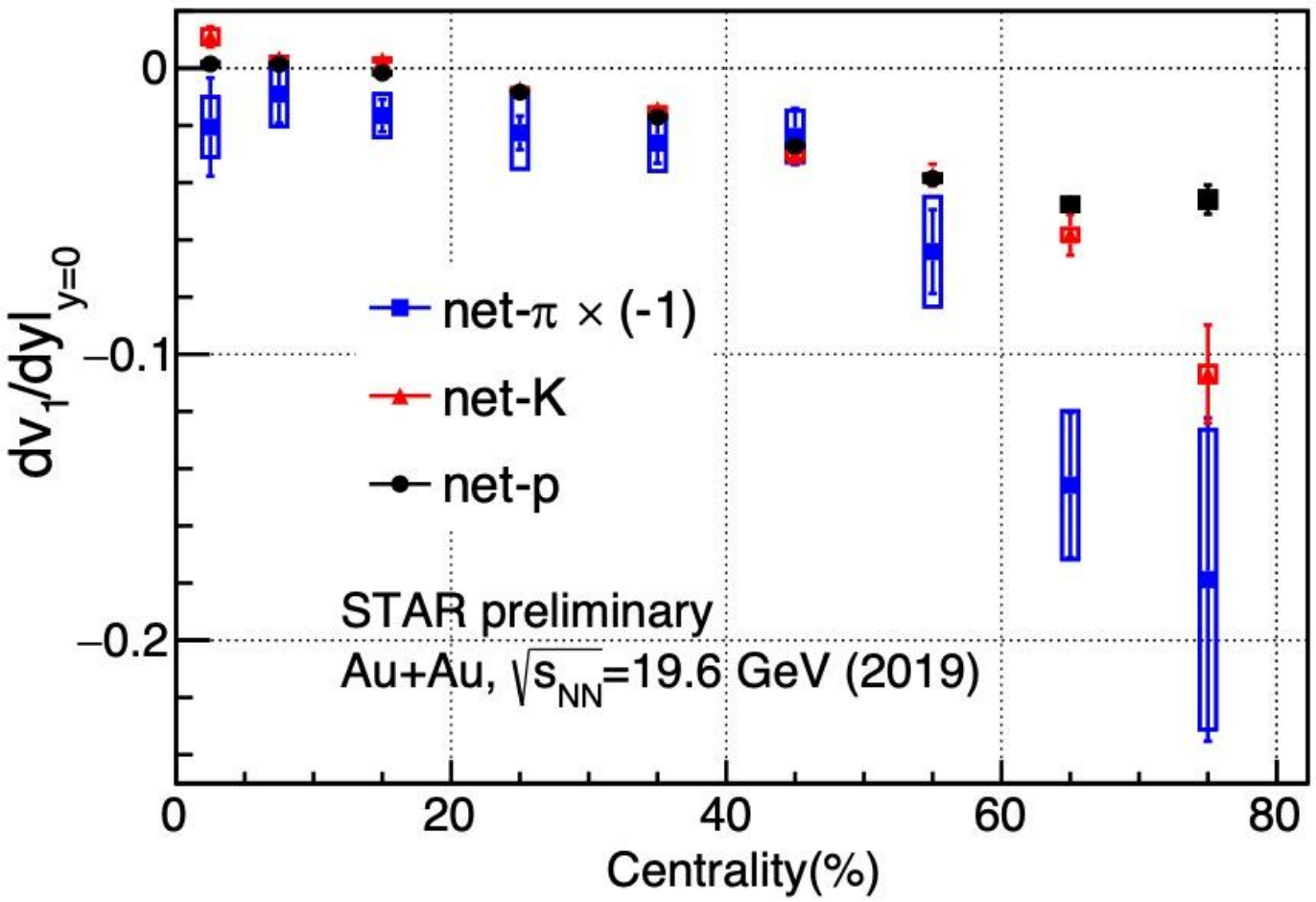
STAR刘佐文: SQM2022, ISMD2022





- Pions, Kaons, protons, ϕ and Λs have negative v_1 slope at mid-rapidity
- UrQMD shows opposite trend of proton and Λ v_1

Centrality Dependence : 19.6GeV

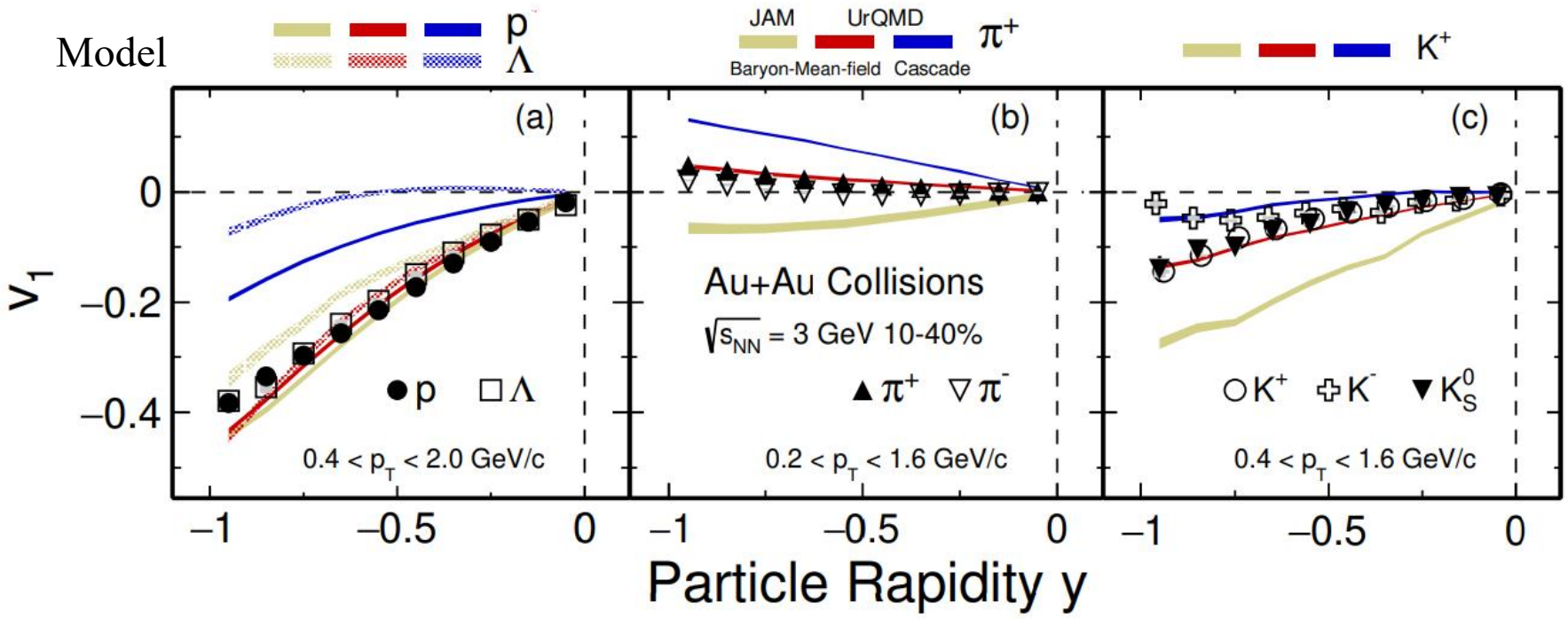


- v_1 slope of net-particle is larger in magnitude for more peripheral collisions
  - → More transported quarks in the peripheral collisions

- v_1 slopes of net-proton and net-Kaon are similar in central and mid-central collisions

Net-pion dv_1/dy is positive at all centralities. To facilitate plotting in the figure opposite, net-pion dv_1/dy is shown with reversed sign.

Rapidity Dependence : 3 GeV

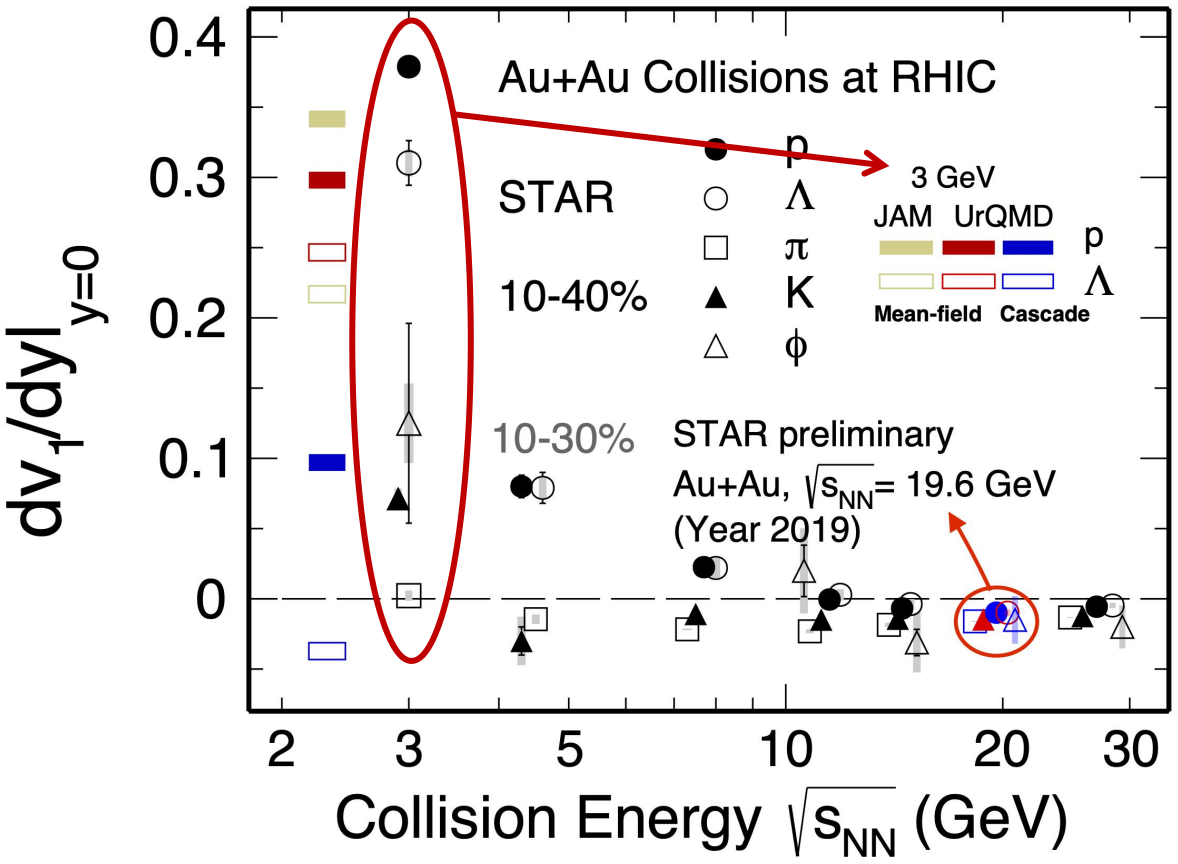


- The slope of v_1 for baryon is larger than that of mesons
  → The strength of v_1 is proportional to the hadron mass

- The results from UrQMD with baryonic mean-field potential qualitatively describe data

STAR, Phys. Lett. B 827, 137003 (2022)

Beam Energy Dependence of dv_1/dy



- All particles show negative slope at 19.6 GeV, but positive slope at 3 GeV

- The calculations of JAM and UrQMD with baryonic mean-field quantitatively reproduce data in 3 GeV
  → Unlike at 19.6 GeV, the dominant degrees of freedom at 3 GeV are hadrons,

- Further study with other BES-II energies could offer more information on the change of equation of state and possible phase transition

STAR, Phys. Lett. B 827, 137003 (2022)

Summary and Outlook

- BES-I:
  - The net-proton slope shows no-monotonic behavior
    a possible signature of a first-order phase transition
  - ϕ meson v_1 slope seems changing sign between 11.5 and 14.5 GeV
    change of medium property?

- BES-II:
  - 19.6 GeV :
    measurements of centrality dependence done
  - 3 GeV :
    The dominant degrees freedom at 3 GeV are hadrons, unlike higher energies

Outlook
- Explore the QCD phase diagram with more energies from BES-II

Thank you for your attention!