Anisotropic Flow of Identified Particles in Au + Au Collisions at $\sqrt{s_{NN}} = 3 - 19.6$ GeV

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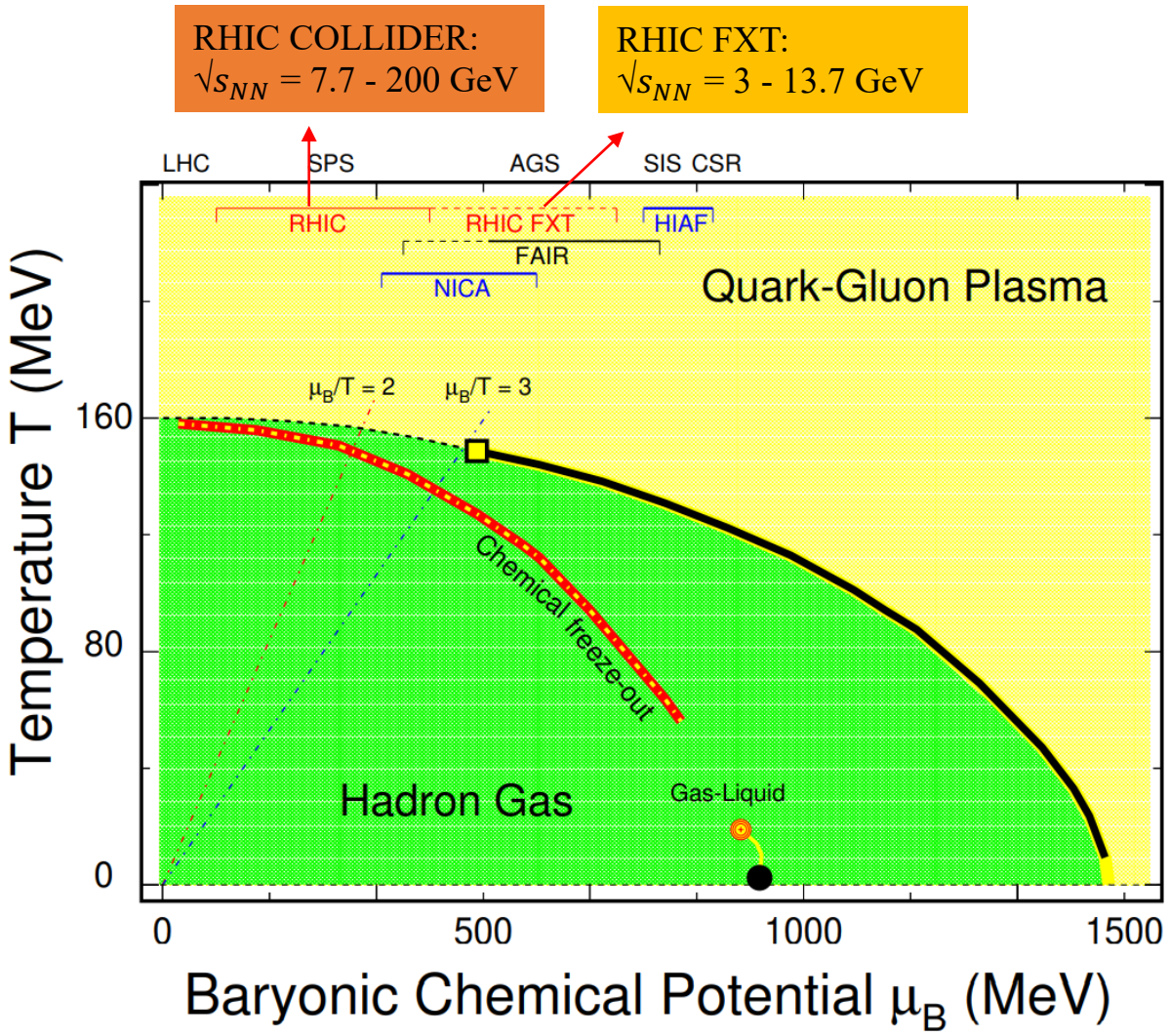
Supported in part by

U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

- Motivation
- Anti-flow of kaons
- Energy dependence of v_1, v_2
- NCQ scaling of v_2, v_3
- Summary

Beam Energy Scan

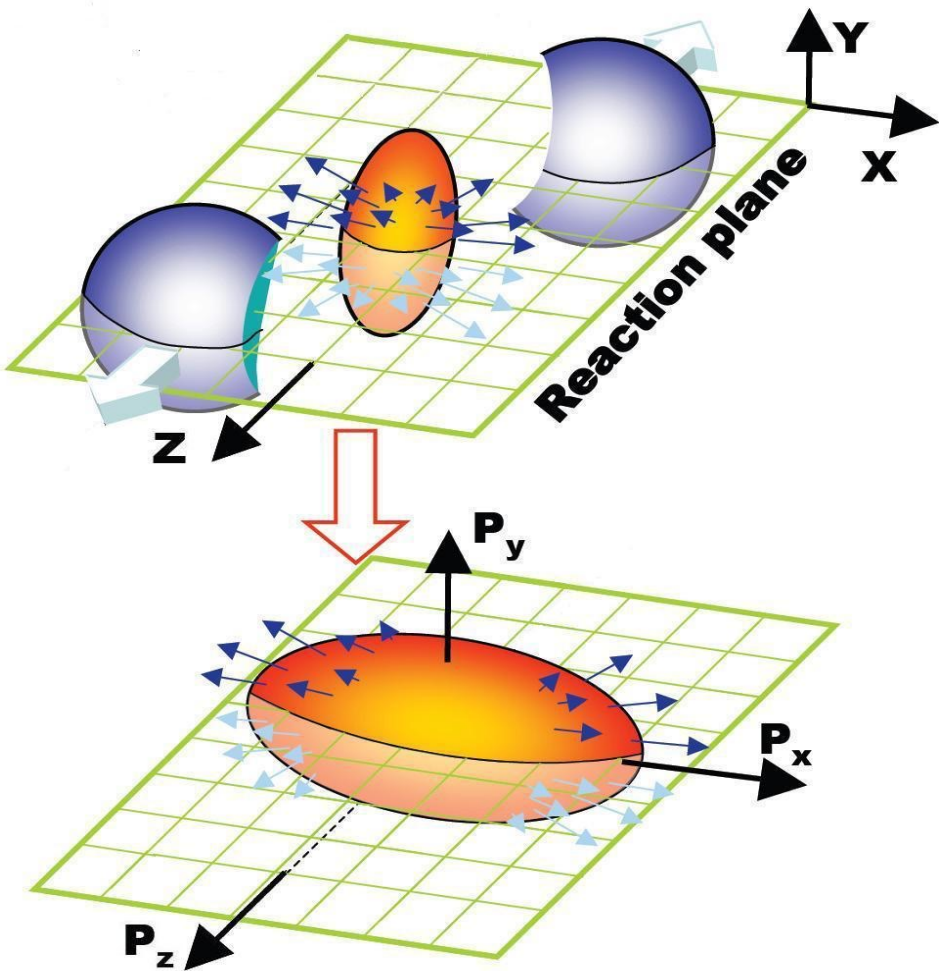


- RHIC Beam Energy Scan:
  - Collider mode: $\sqrt{s_{NN}}$ = 7.7 – 200 GeV
  - Fixed-target(FXT) mode: $\sqrt{s_{NN}}$ = 3 – 13.7 GeV

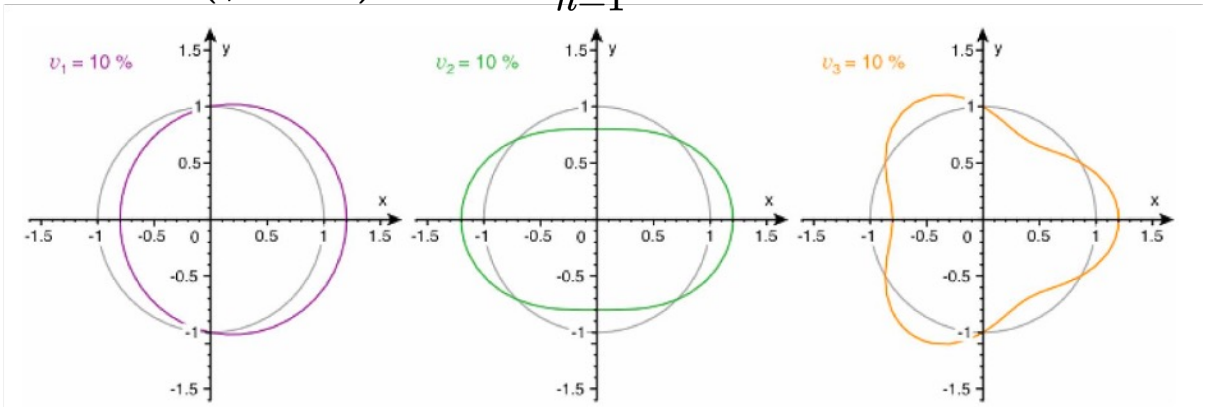
- Baryon density region: μ_B = 25 – 720 MeV
  - Study the properties of QGP.
  - Search for the critical point and locate the first-order phase boundaries.

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

Anisotropic Flow



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

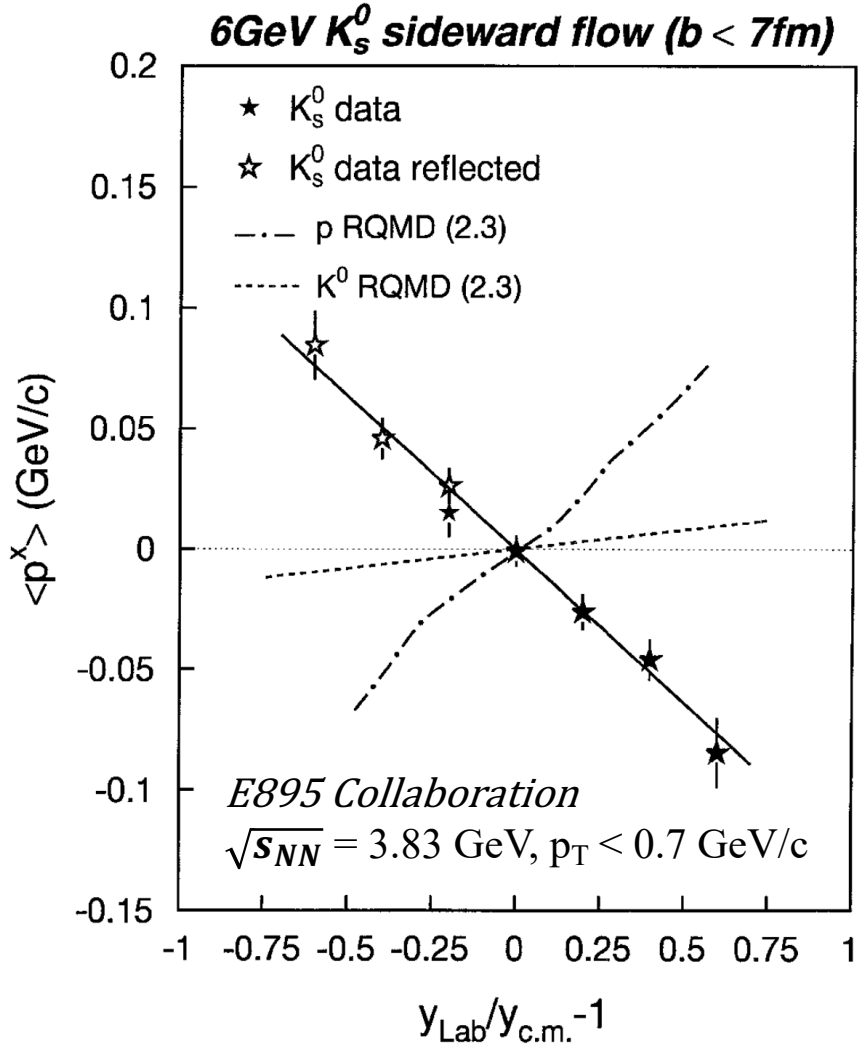


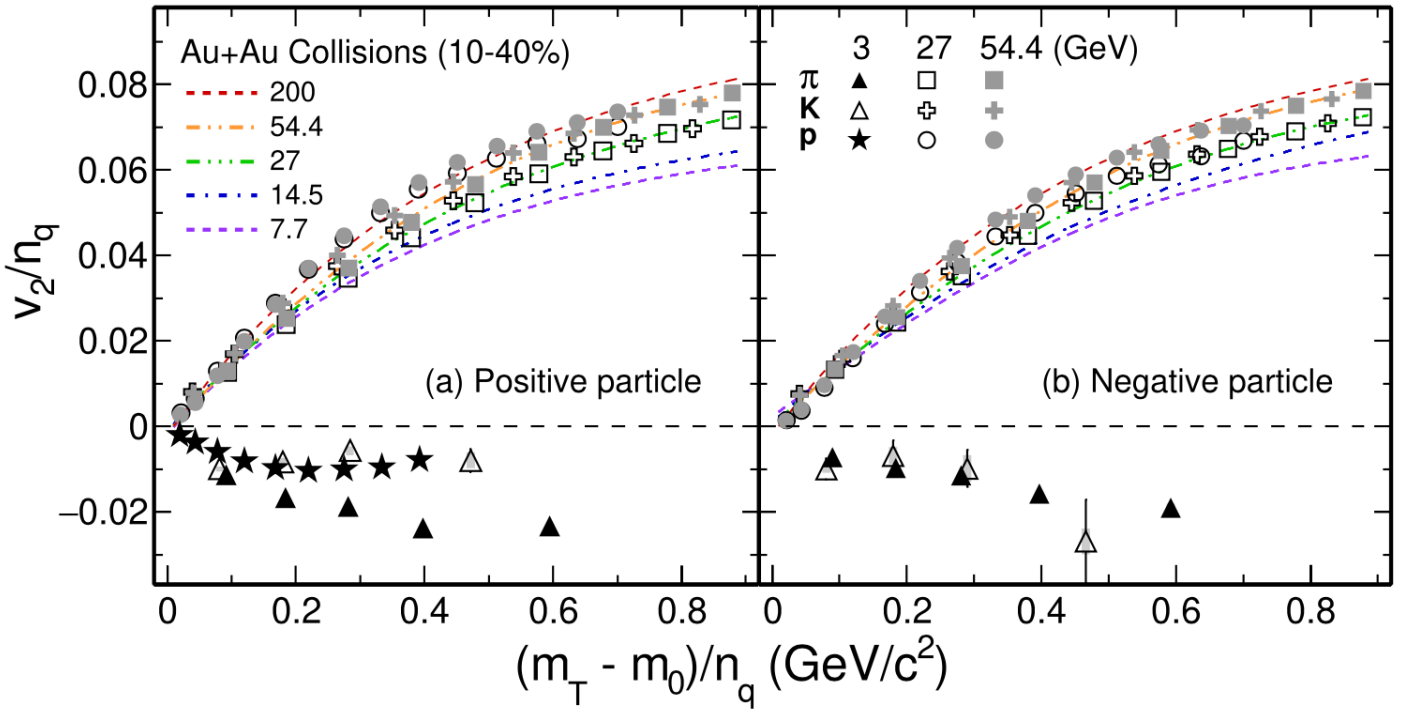
Directed flow(v_1) Elliptic flow(v_2) Triangular flow(v_3)

- v_1 reveals the interplay between initial compression and tilted expansion.
- v_2 and v_3 are sensitive to event-by-event fluctuations, and provide insight on the constituent interactions and degree of freedom.

B. Mohanty, N. Xu, Journal of Physics G 36, 064022 (2009); M. Nasim et al. Physical Review C 87, 014903 (2013)

Motivation

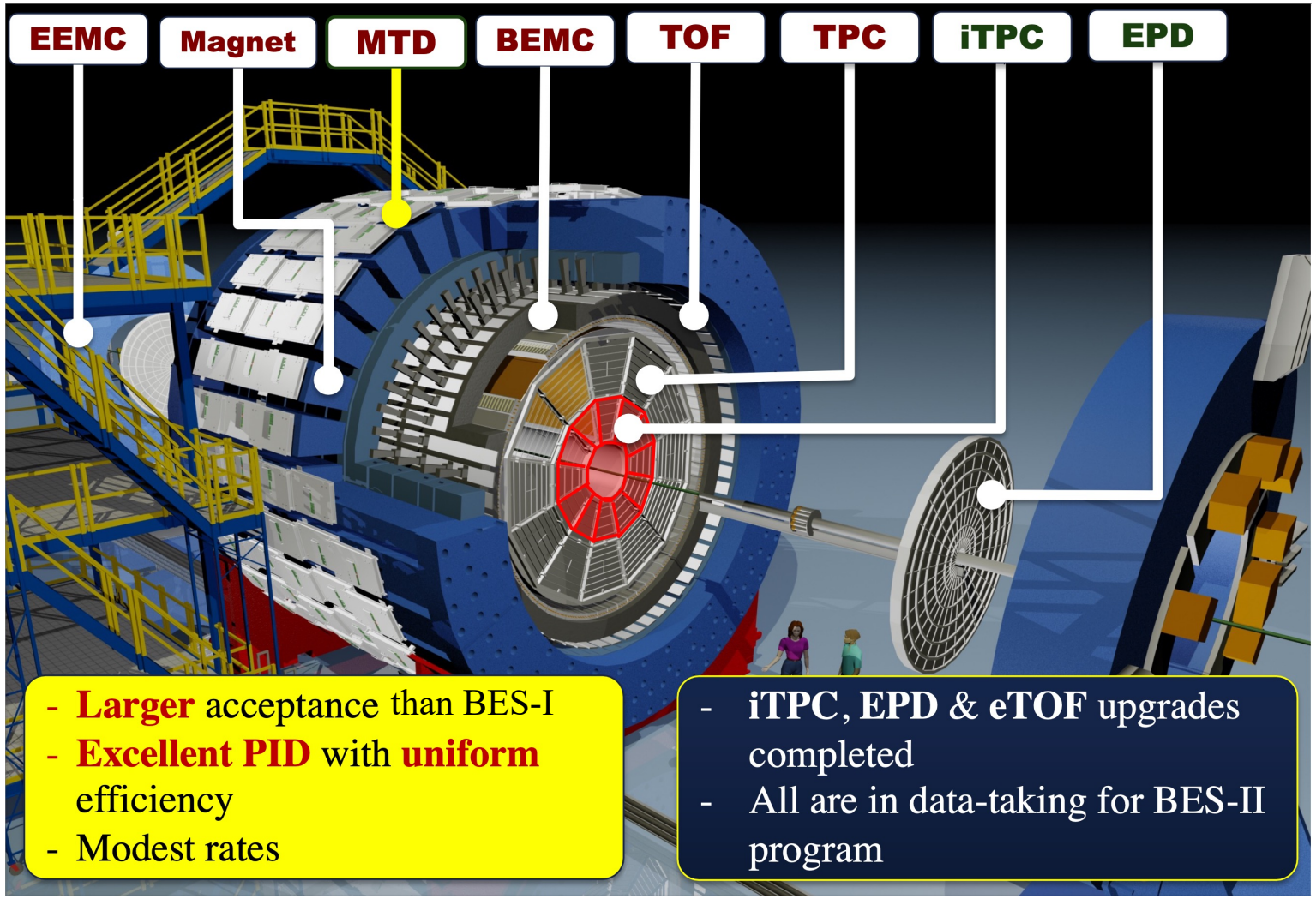




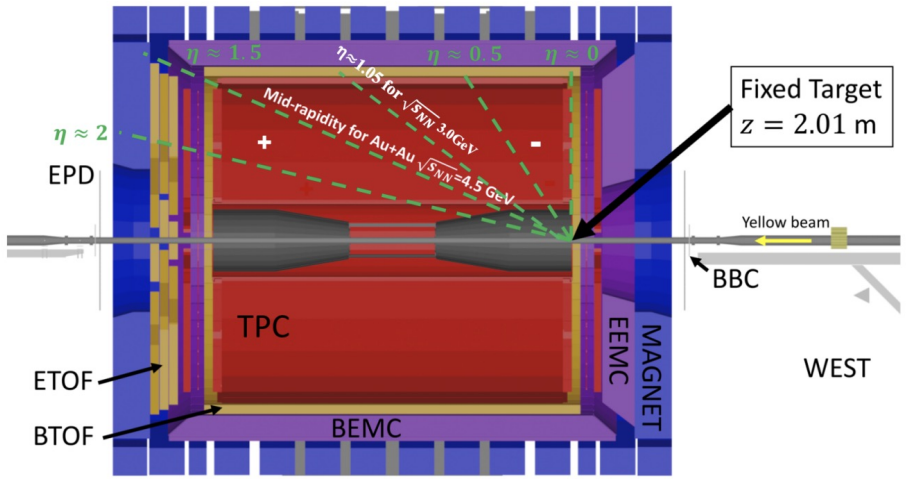
- E895: anti-flow of kaon at low p_T . → Kaon potential ?
- NCQ scaling violation at 3 GeV.
  Degree of freedom: partonic → hadronic ?

P. Chung et al. (E895 Collaboration), Phys. Rev. Lett. 85, 940(2000). M. S. Abdallah et al. (STAR Collaboration), Phys. Lett. B 827 (2022) 137003

STAR Detectors



FXT mode:



Tracking and particle identification:

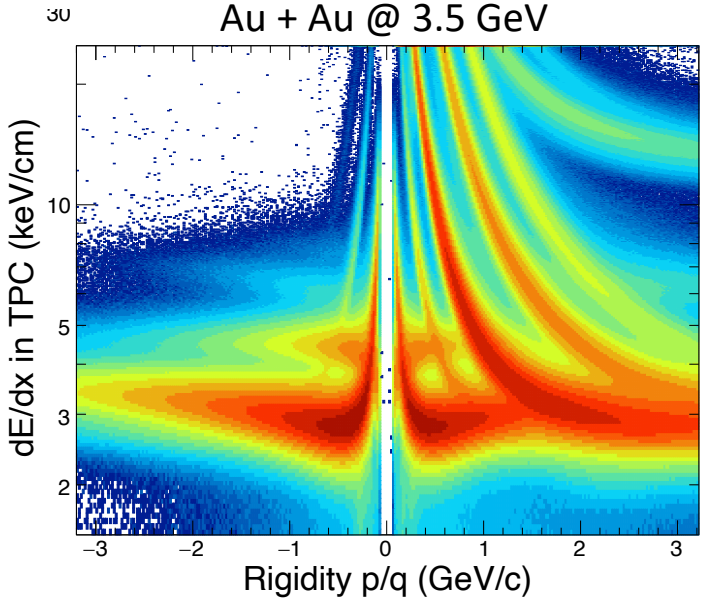
- Time Projection Chamber
  - Charged particle tracking
  - Particle identification
- Time Of Flight
  - Particle identification

Event plane determination:

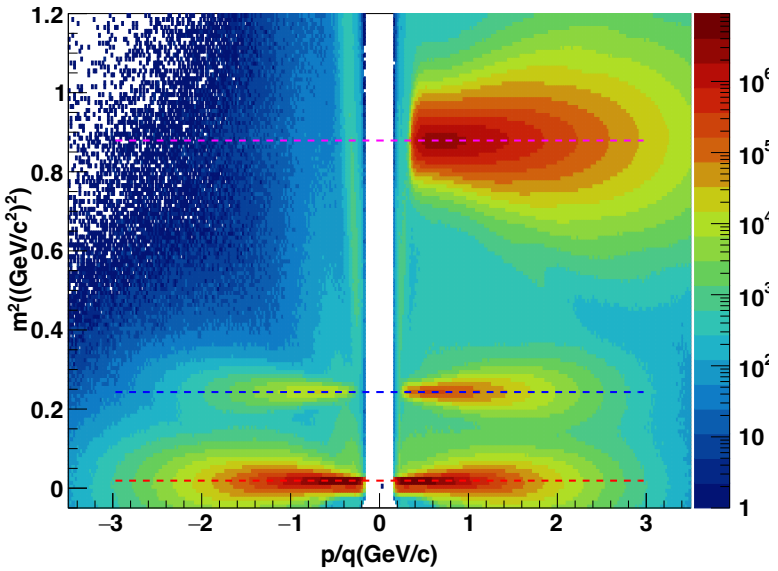
- Event Plane Detector
  - $2.1 < |\eta| < 5.1$

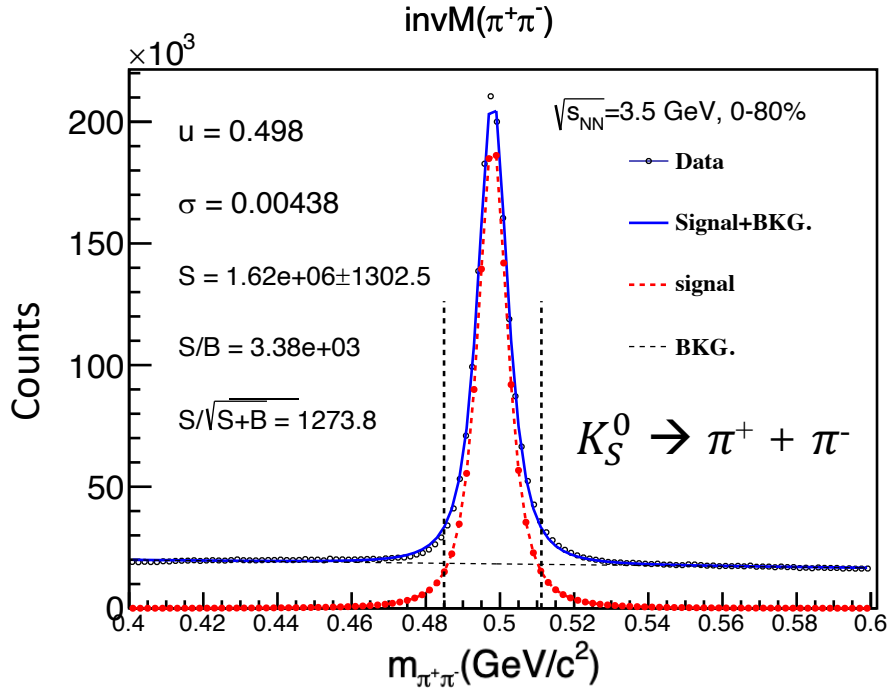
Particle Identification

TPC



TOF

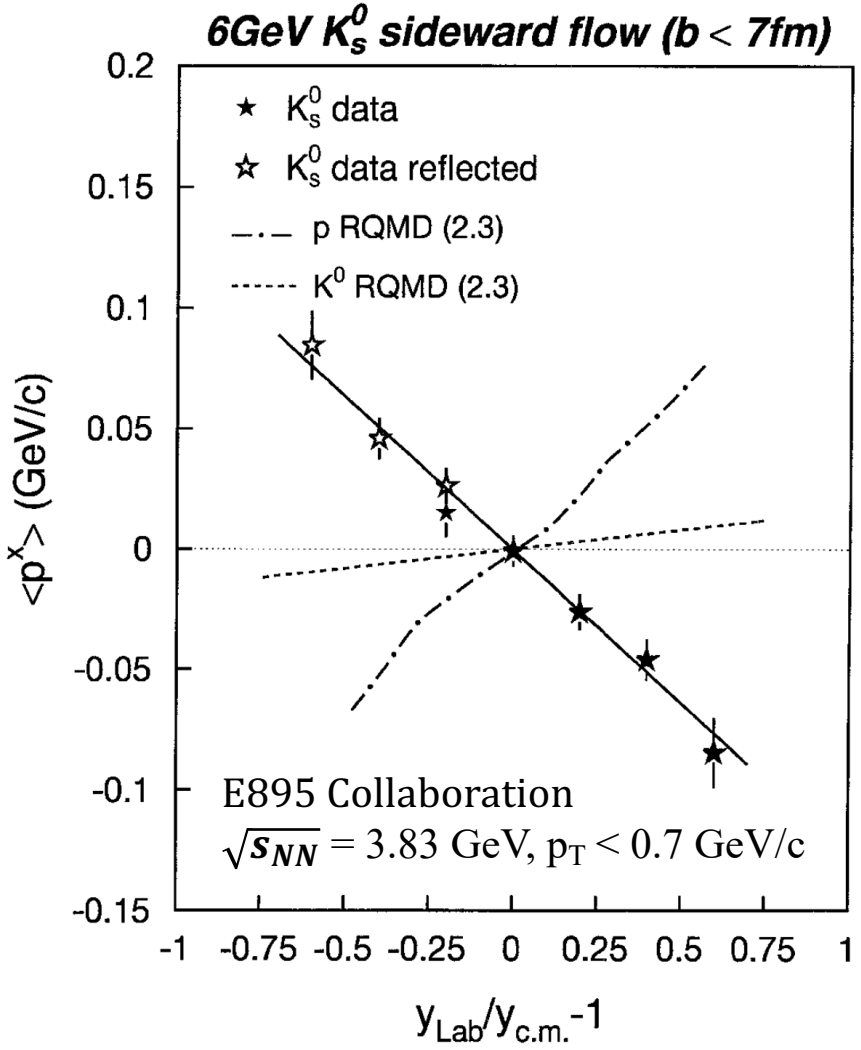


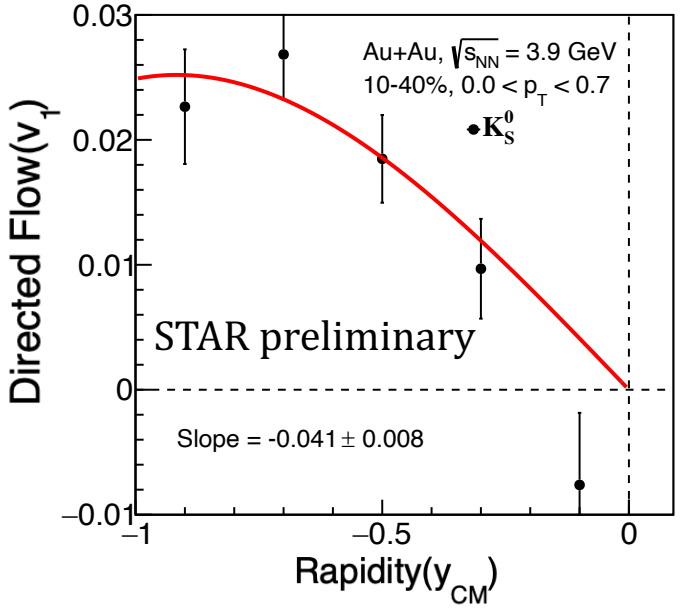


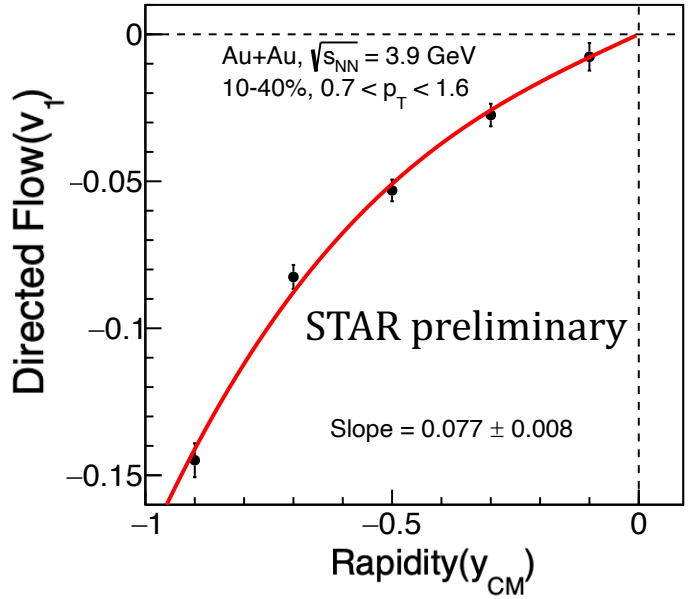
- Good particle identification capability based on TPC and TOF.
- Decayed particles are reconstructed by KF(Kalman Filter) particle package.

A. Banerjee, I. Kisel and M. Zyzak, Int. J. Mod. Phys. A 35, 2043003 (2020)

Anti-flow of Kaon





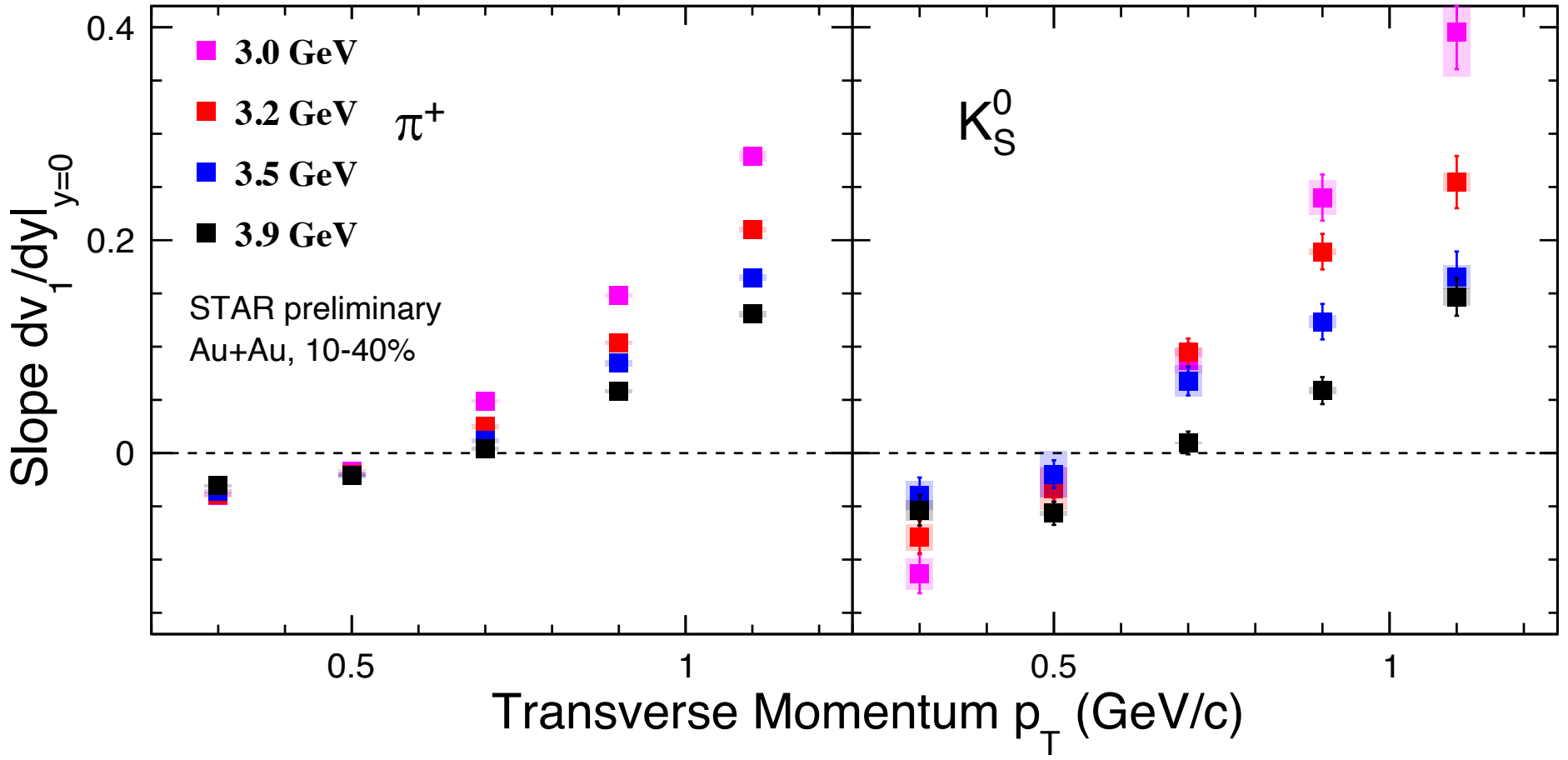


- 3.9 GeV: anti-flow observed for K^0_S at p_T < 0.7 GeV/c.
- Positive flow of K^0_S at p_T > 0.7 GeV/c.
  → Strong p_T dependence of K^0_S v_1 slope

Note: fitting function: $v_1 = p_0 * y + p_1 * y^3$
fitting range: $-1 < y_{CM} < 0$

P. Chung et al. (E895 Collaboration), Phys. Rev. Lett. 85, 940(2000).

Anti-flow of Mesons

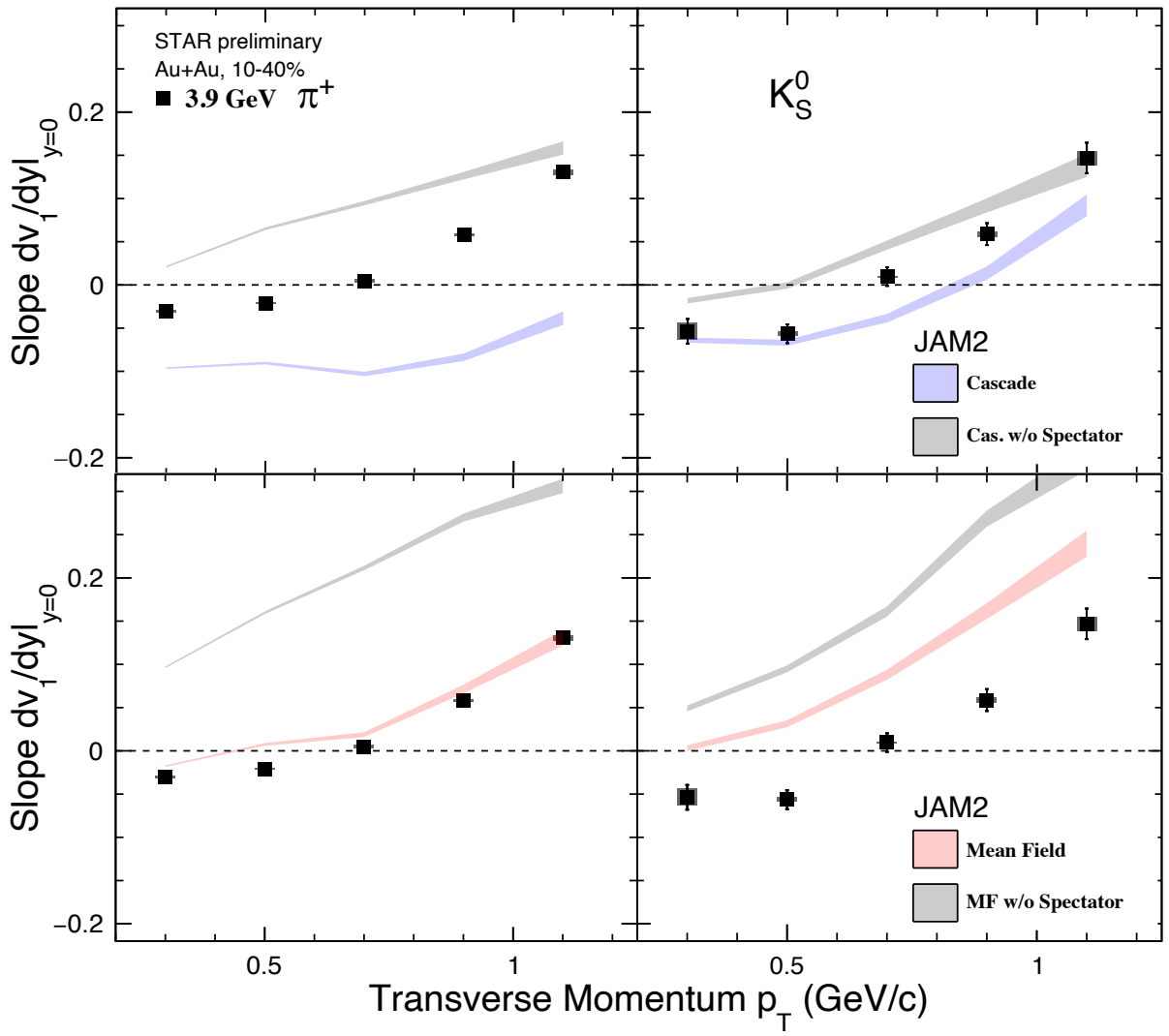


At low p_T :

- $\pi^+(u\bar{d})$ and $K^0_S(d\bar{s})$ show negative v_1 slope.
- Anti-flow observed at 3 – 3.9 GeV.

See also posters:
Xing Wu: #673
Guoping Wang: #551

Anti-flow of Mesons

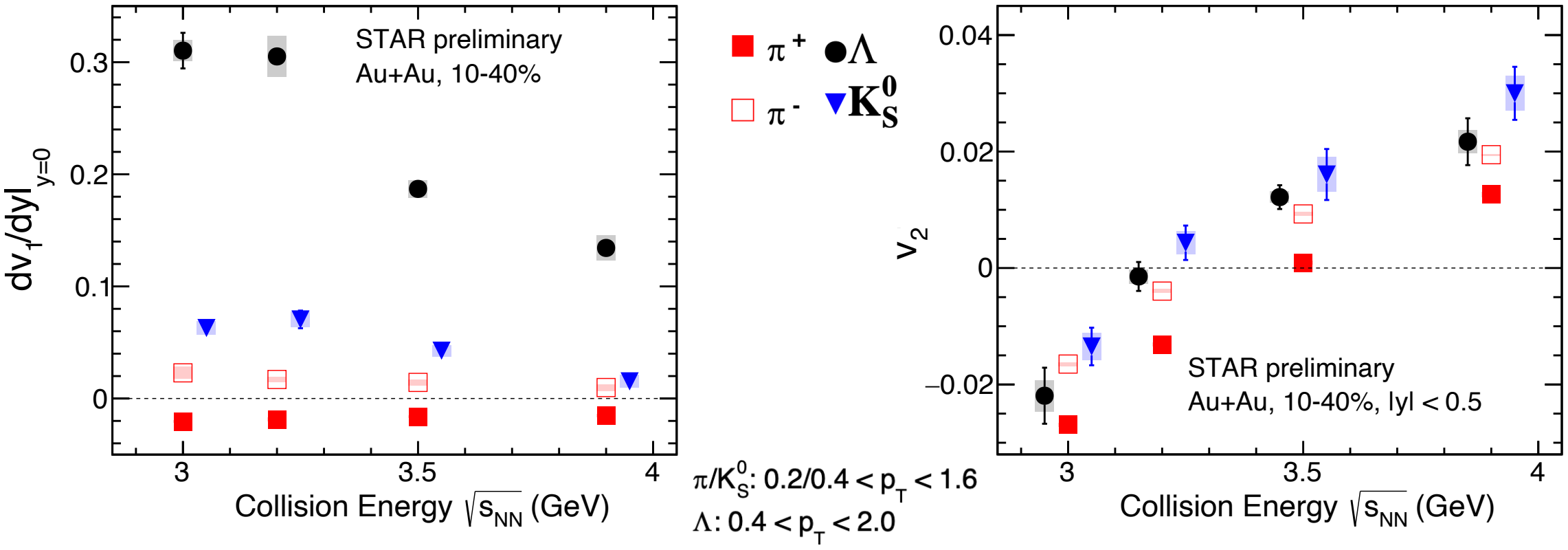


- 3.9 GeV: anti-flow of π^+ and K^0_S at low p_T .
- JAM reproduces anti-flow at low p_T without incorporating kaon potential.
- Anti-flow could be explained by shadowing effect from spectator.

Note:
Soft EoS in JAM baryonic mean field:
the nuclear incompressibility K = 210 MeV

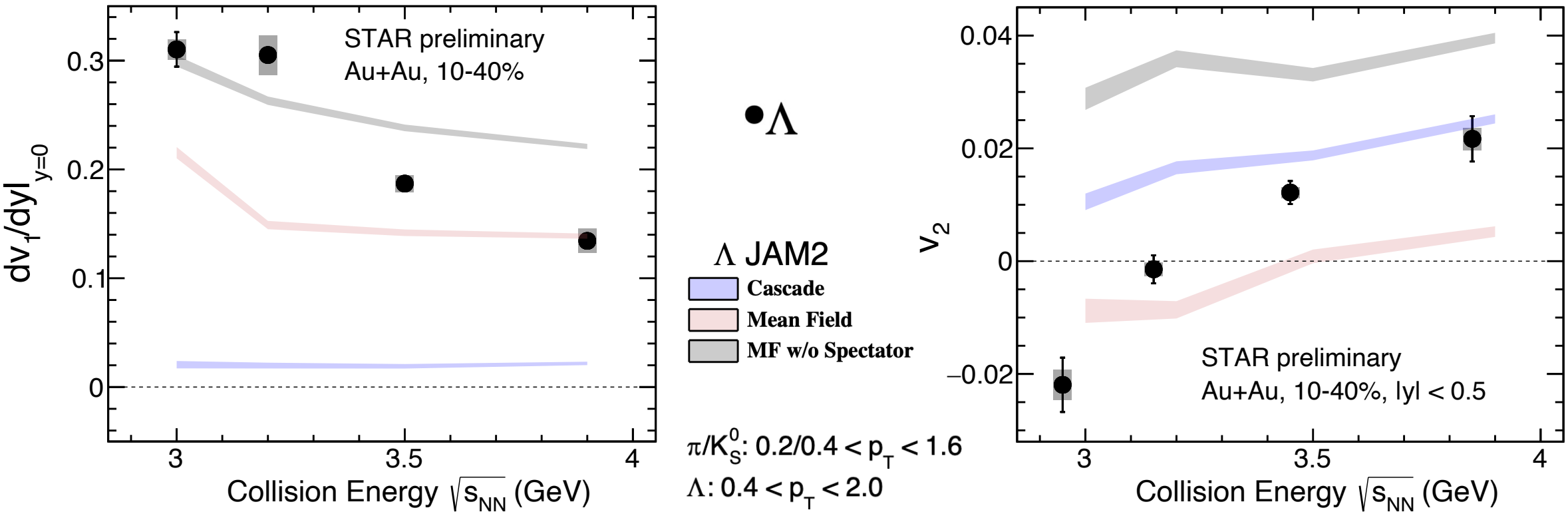
Yasushi Nara, Akira Ohnishi. Phys. Rev. C. 105, 014911(2022)

Energy Dependence of v_1, v_2



- v_1 slope decreases in magnitude as collider energy increases. → Stronger tilted expansion.
- Negative v_2 turns to positive:
  Out-of-plane flow (spectator effect) → in-plane flow

Energy Dependence of v_1, v_2



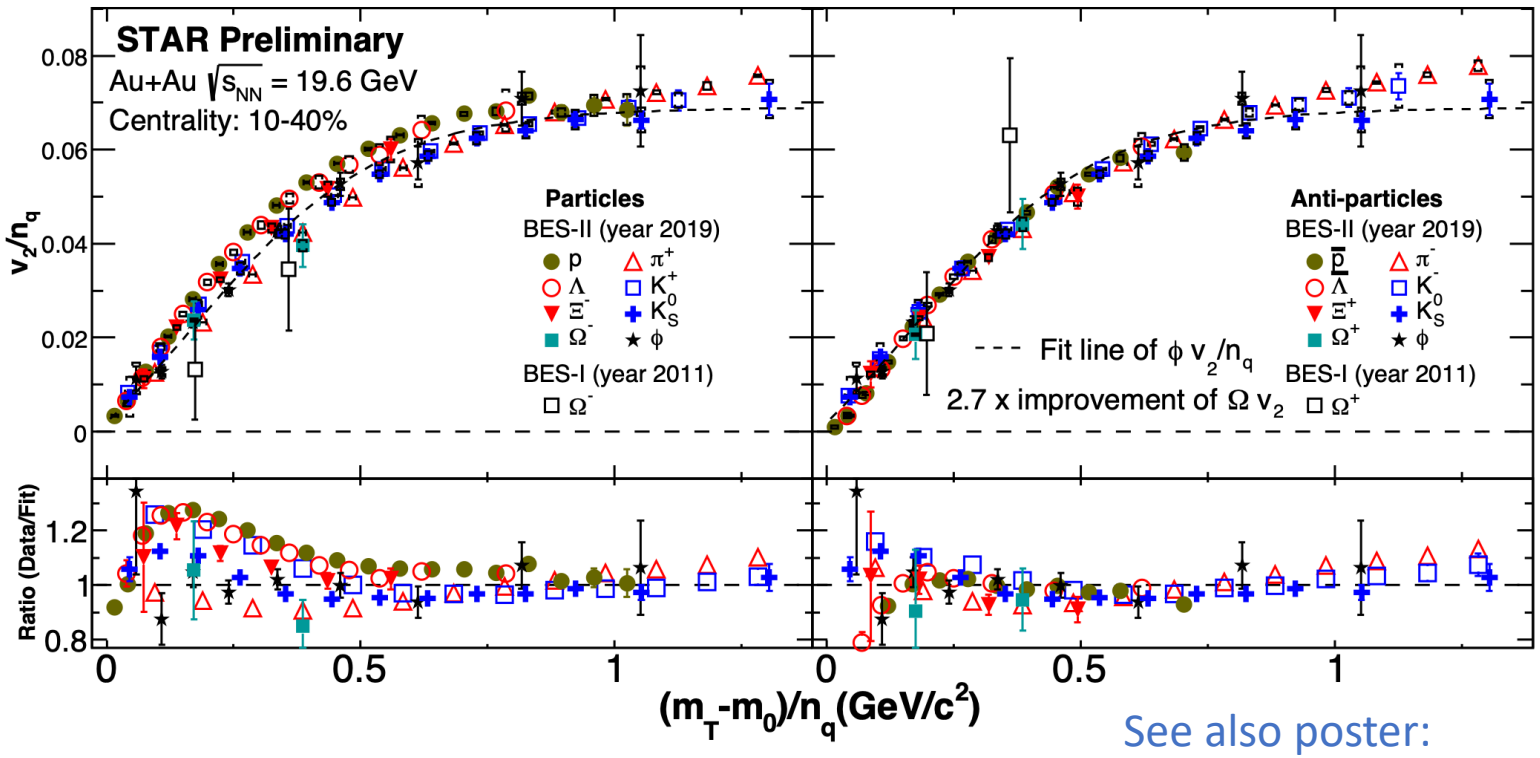
- Baryonic mean field enhances v_1 slope.
  → Strong mean field at high baryon density region.

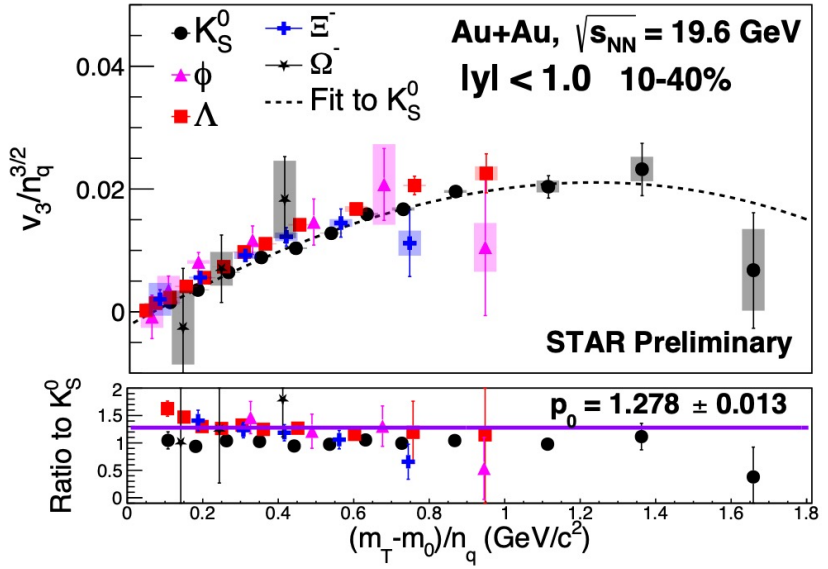
  Note:
  Soft EoS in JAM baryonic mean field:
  the nuclear incompressibility K = 210 MeV

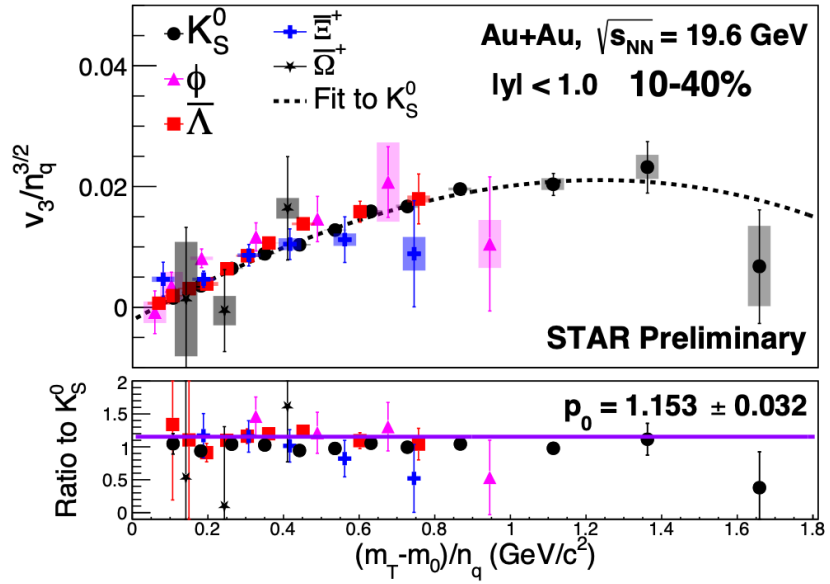
- Only baryonic mean-field with spectator shows sign change of v_2. → Mean-field and spectator shadowing play important roles.

Yasushi Nara, Akira Ohnishi. Phys. Rev. C. 105, 014911(2022)

NCQ Scaling of v_2, v_3 at 19.6 GeV



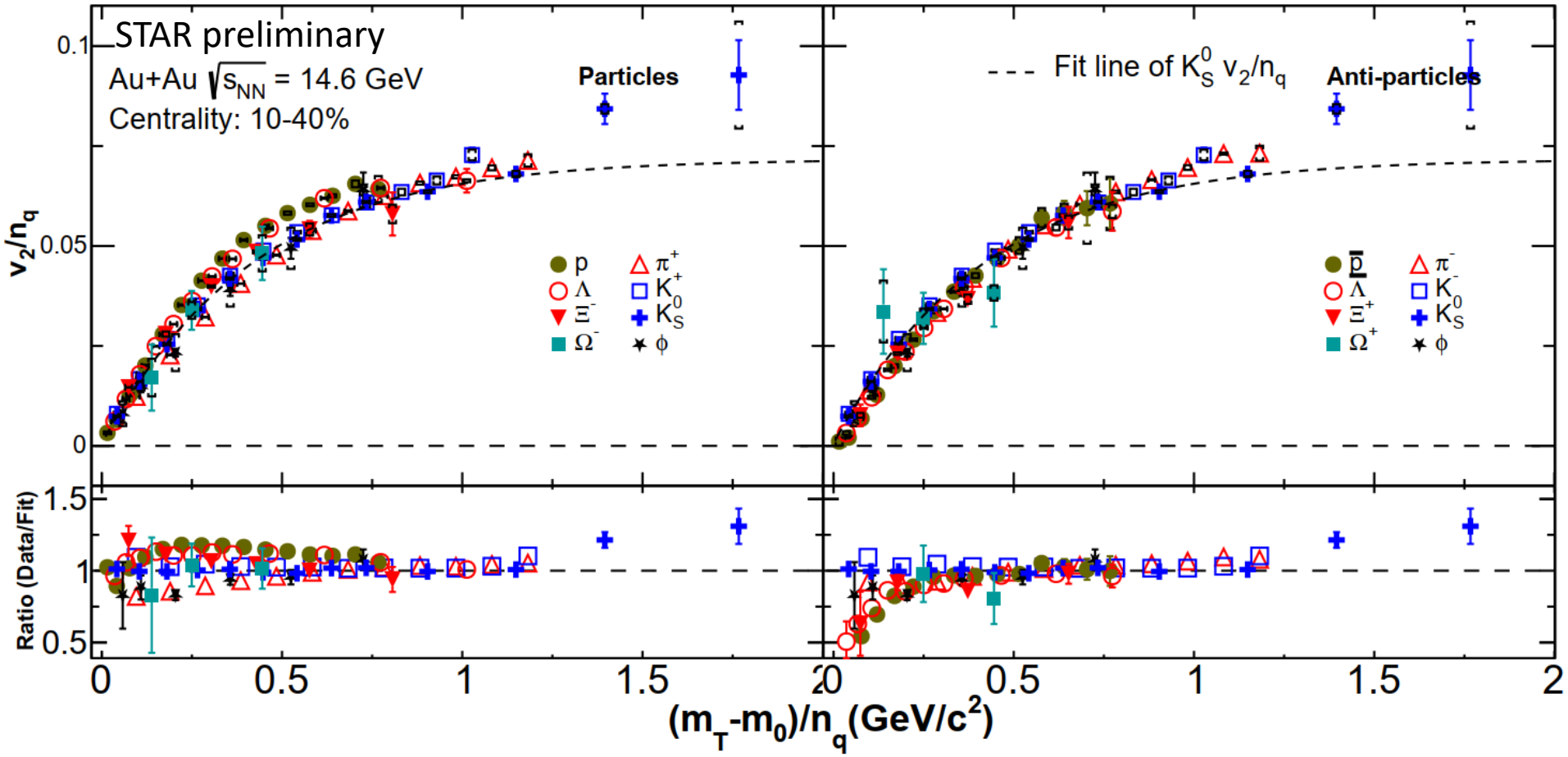




See also poster:
Li-ke Liu: #568

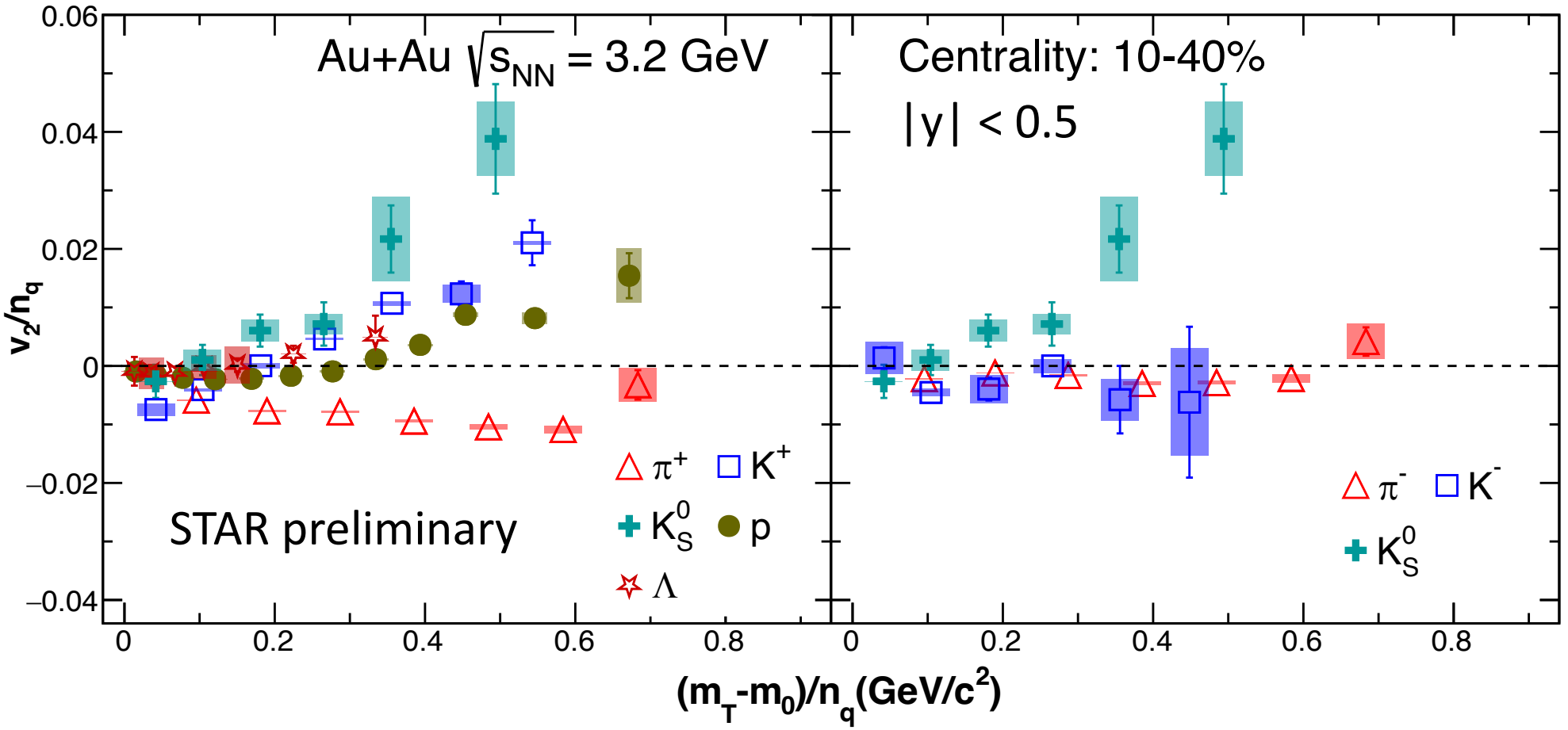
- Enhanced statistics from BES-II enable the test of NCQ scaling.
- NCQ scaling of v_2 (v_3) holds within 10(15)% for anti-particles, 20(30)% for particles.
  → Partonic interaction plays important role at 19.6 GeV.

NCQ Scaling of v_2 at 14.6 GeV



- NCQ scaling of v2 holds within 15% for anti-particles, 25% for particles.
  → Partonic interaction plays important role at 14.6 GeV.

NCQ Scaling of v_2 at 3.2 GeV



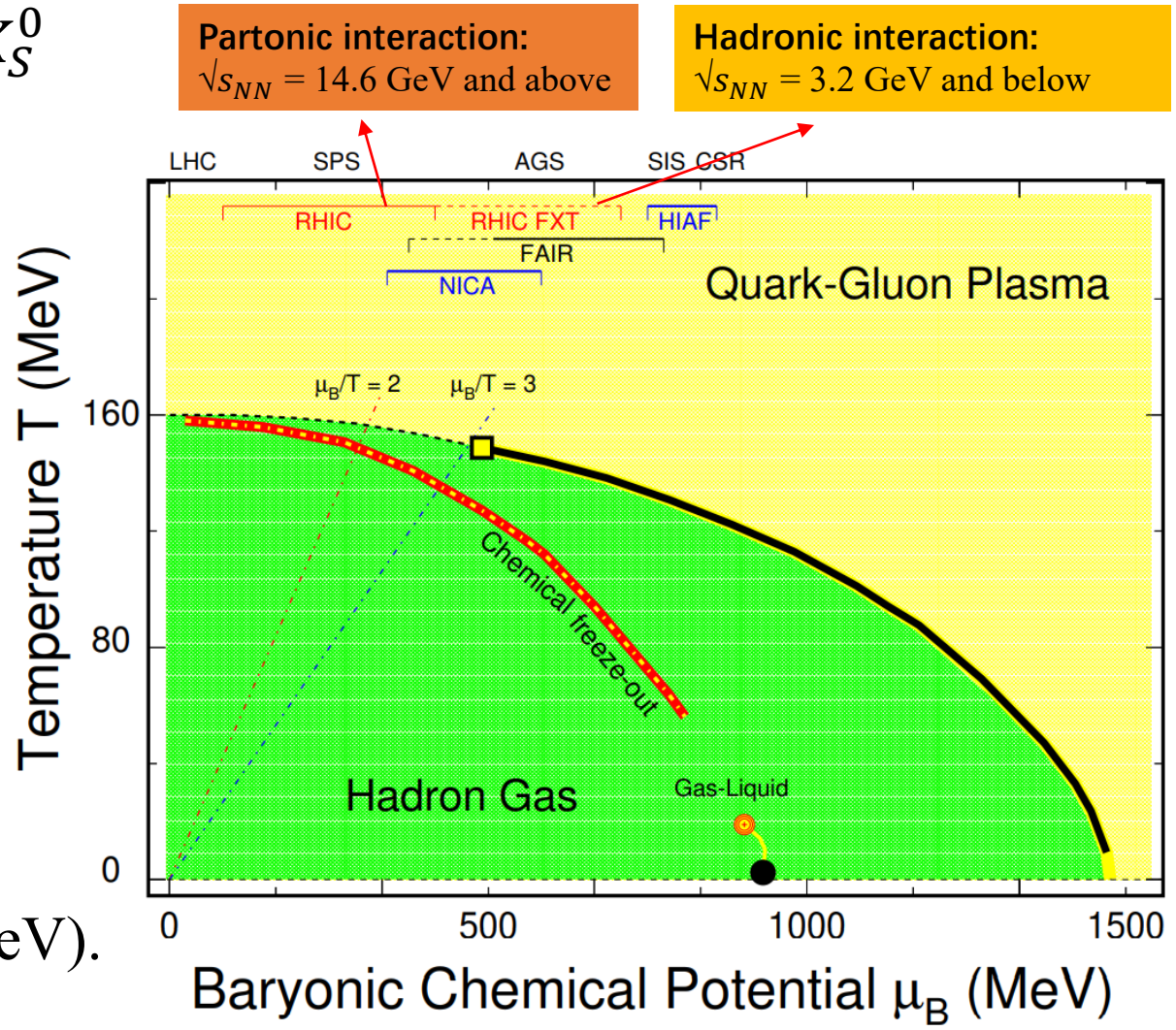
- NCQ scaling of v_2 breaks completely at 3.2 GeV.
  → Hadronic interaction dominates.

Summary

- 3 – 3.9 GeV: anti-flow observed for π^+ and K_S^0 at low p_T.
  → Shadowing effect from spectator could result in anti-flow.

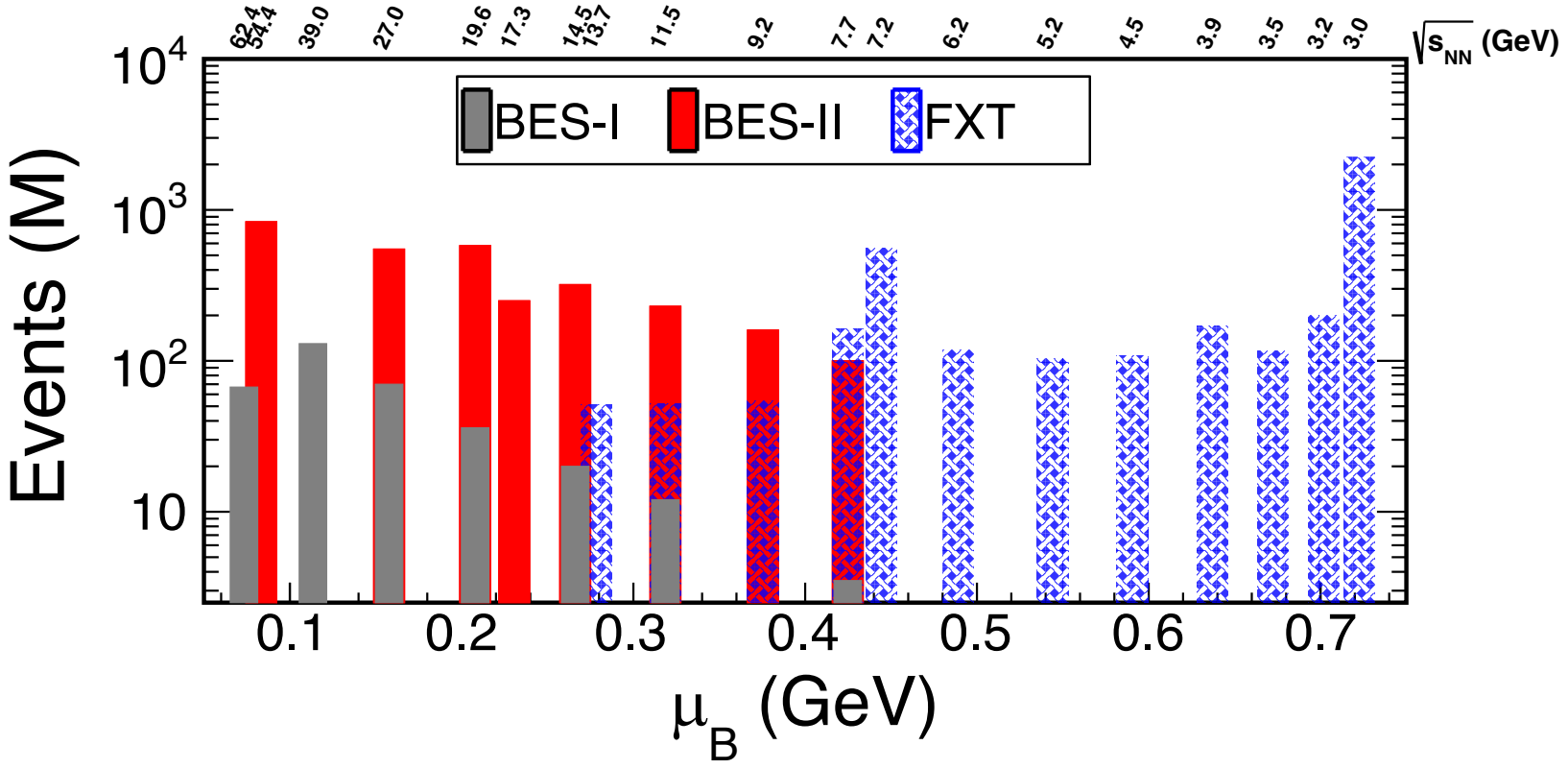
- Negative v_2 → positive v_2
  → The change of out-of-plane to in-plane expansion happens at 3 – 3.9 GeV.

- NCQ scaling of v_2, v_3 holds at 14.6 GeV and above, in contrast to violation at 3.2 GeV and below.
  →Partonic(> 14.6 GeV) to hadronic(< 3.2 GeV).



Outlook

STAR BES-II (2019-2021):
$\sqrt{s_{NN}}$ = 3 - 19.6 GeV



- Enhanced statistics, upgraded detectors from BES-II.
- Explore the QCD phase diagram with BES-II 3 - 19.6 GeV data.

Thank you for your attention!