# Anti-flow of Kaons in the High Baryon Density Region

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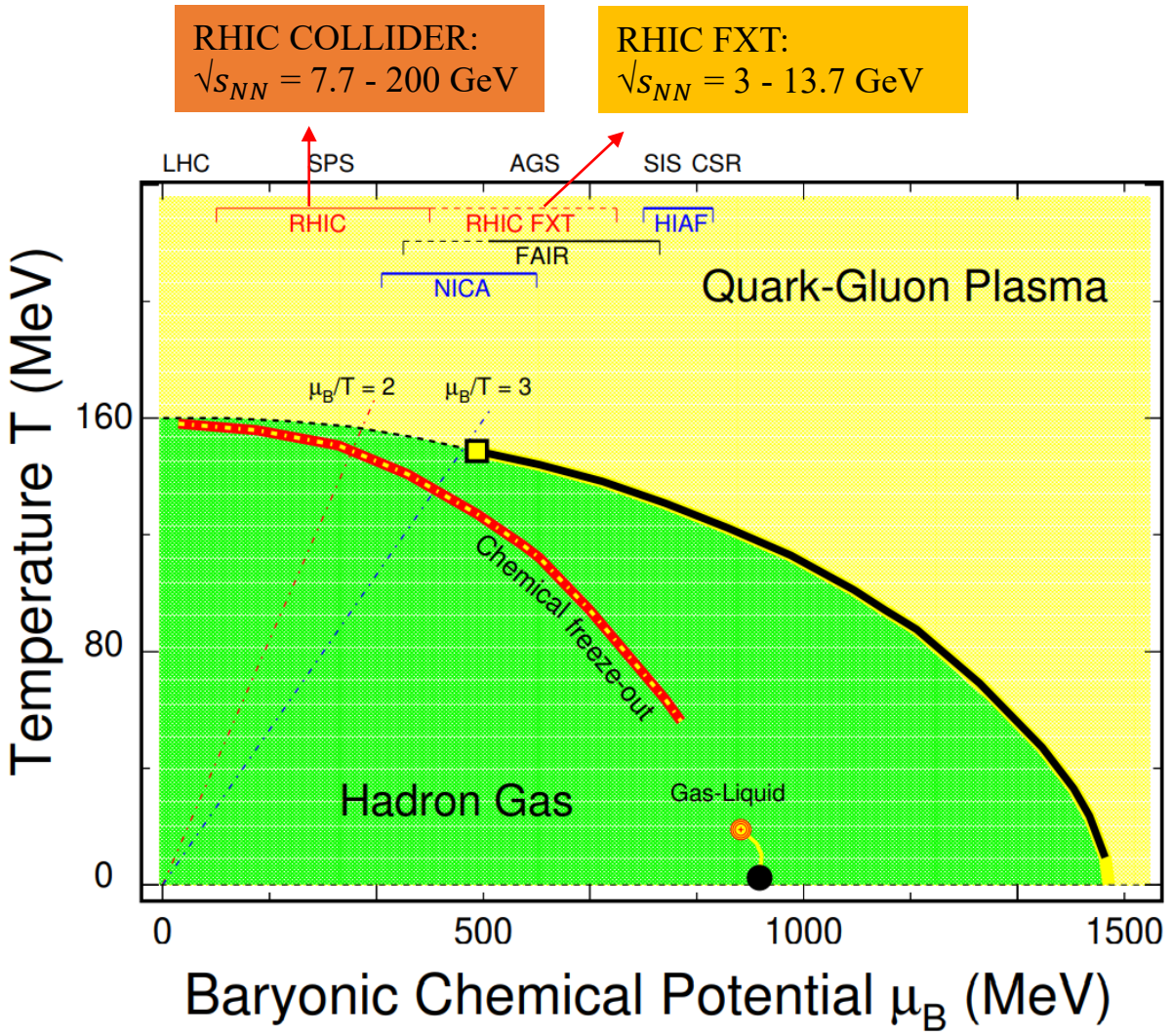
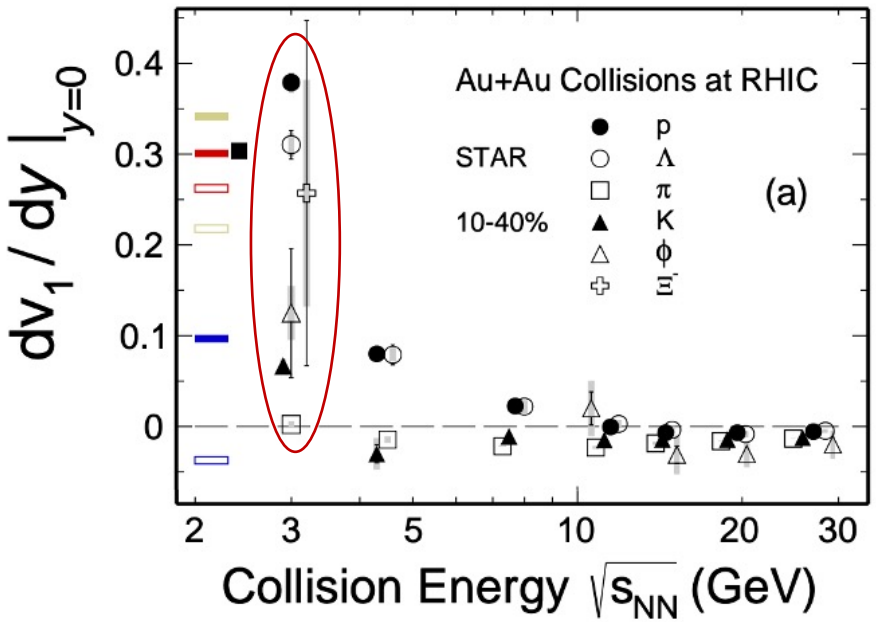
# Outline

- Motivation
- Results
  - JAM calculations: $p_T$, centrality, time evolution
  - STAR results: $p_T$, centrality, comparison to JAM
- Summary

# Beam Energy Scan

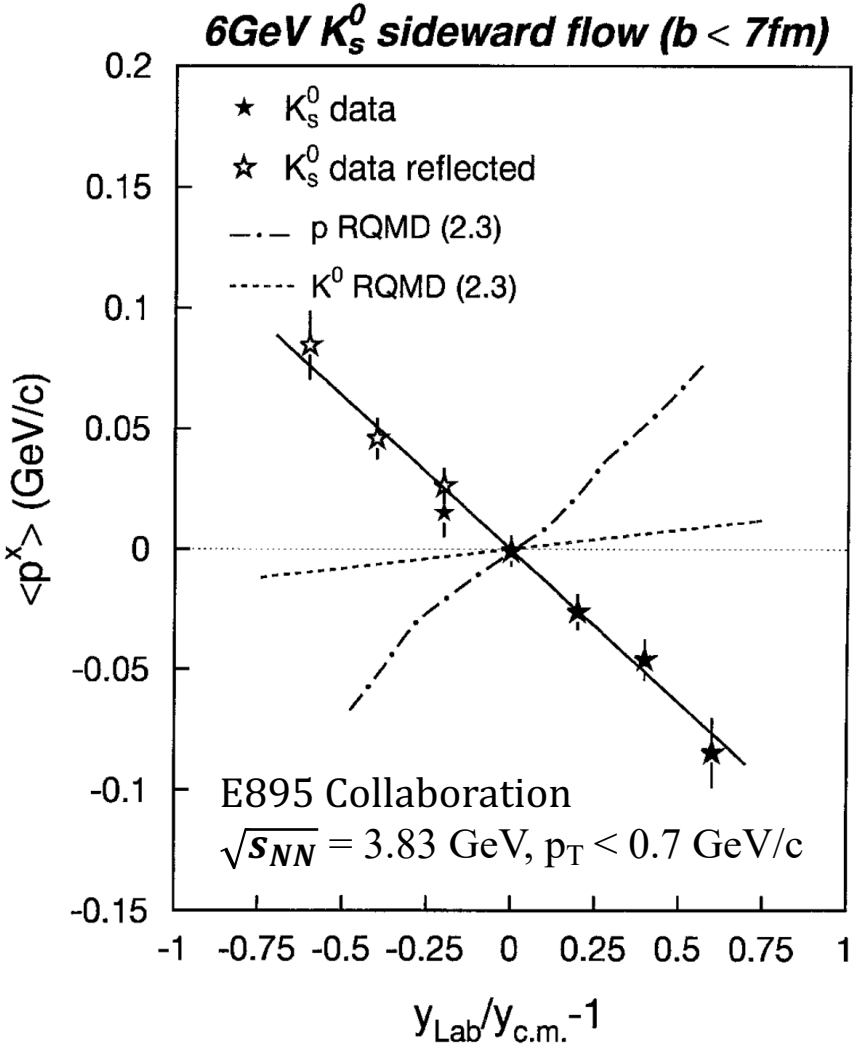


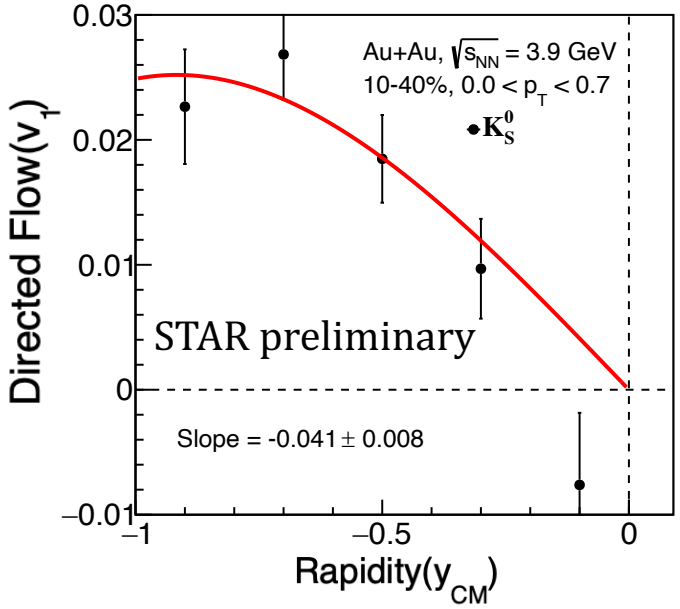

- Fixed-target mode extends the baryon density region up to $\mu_B \approx 720$ MeV.
- Hadronic interaction dominates at high baryon density, e.g. N + N → K + Λ + N.
- All particles show positive $v_1$ slopes at 3.0 GeV.

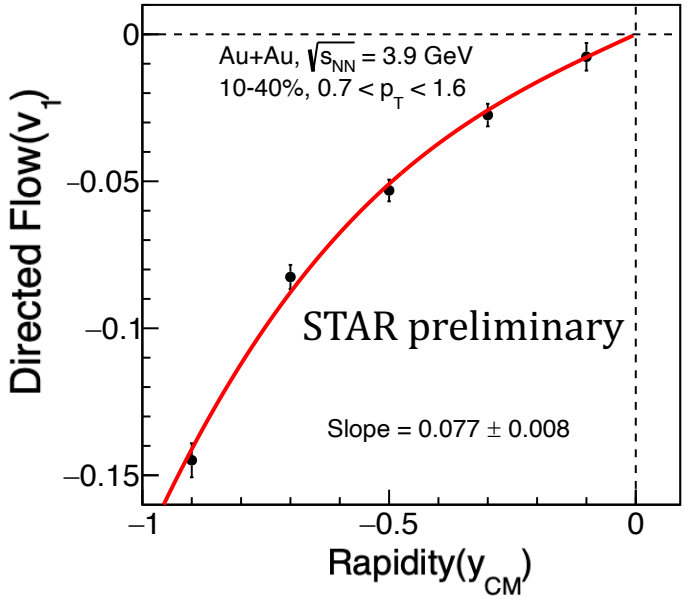



X.Luo, S.Shi, Nu Xu et al. Particle 3, 278 (2020); ); Phys. Lett. B 827, 137003 (2022)

# Motivation



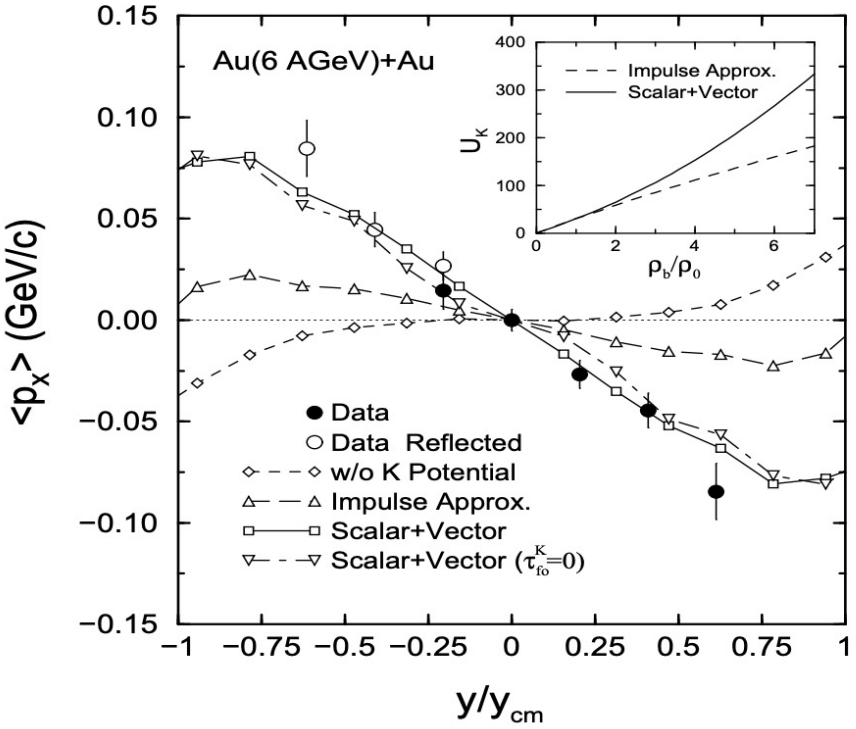

- E895: anti-flow of kaon at low $p_T$ . → Kaon potential ?
- 3.9 GeV: anti-flow observed for $K_S^0$ at $p_T$ < 0.7 GeV/c.
- Positive flow of $K_S^0$ at $p_T$ > 0.7 GeV/c.
  → Strong $p_T$ dependence of $K_S^0$ $v_1$ slope

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

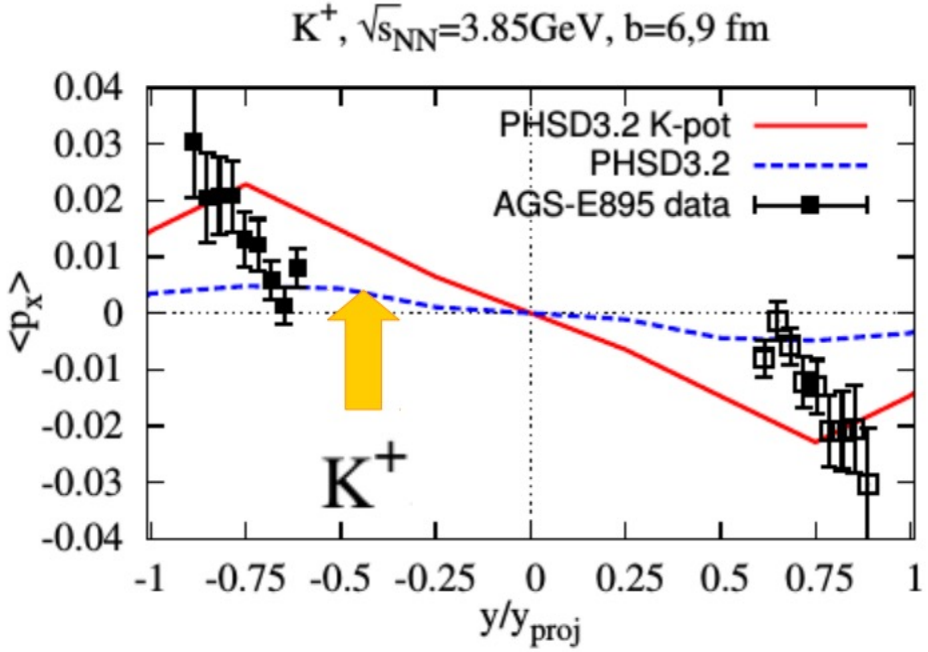
P. Chung et al. (E895 Collaboration), Phys. Rev. Lett. 85, 940(2000)

# Kaon potential?

ART model calculation Phys. Rev. C 62, 061903 (2000)

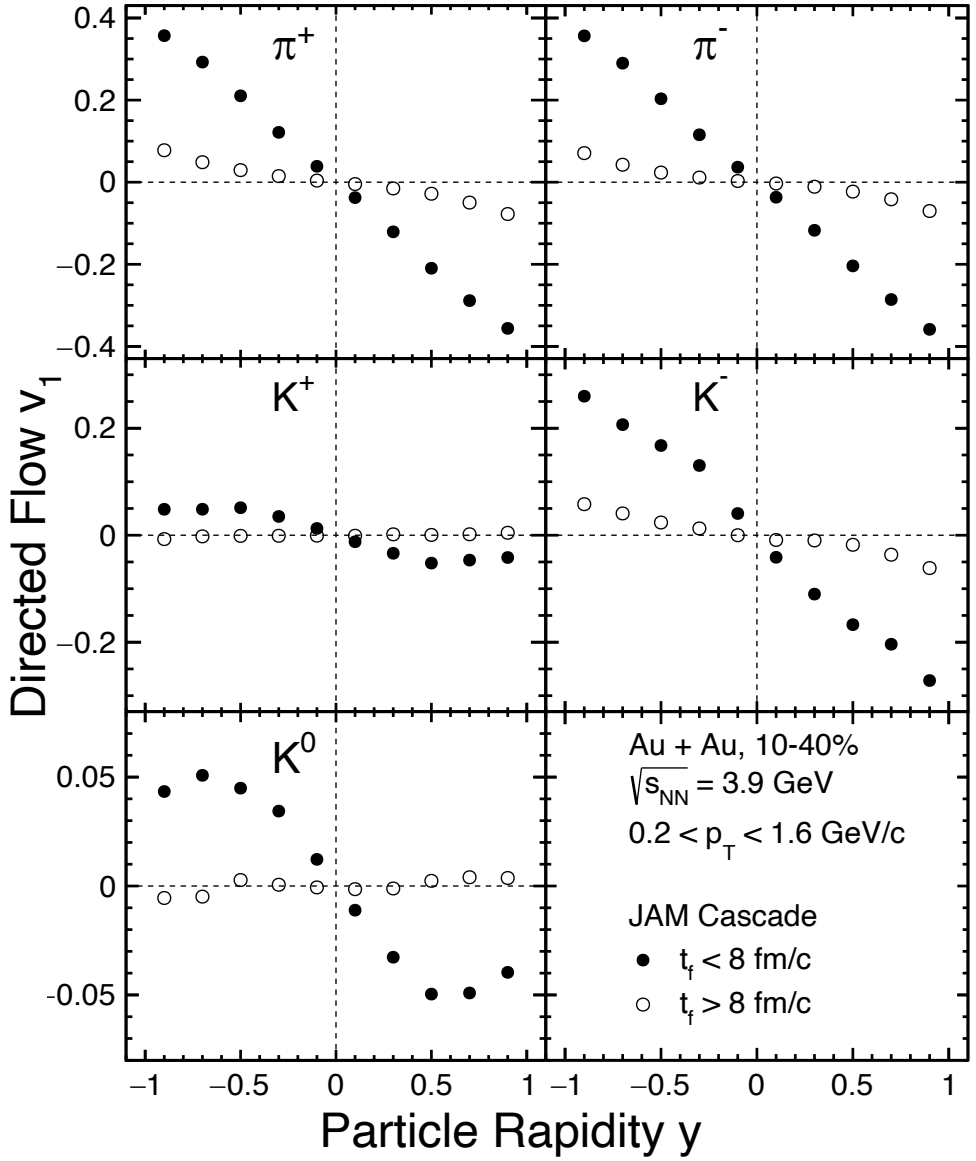


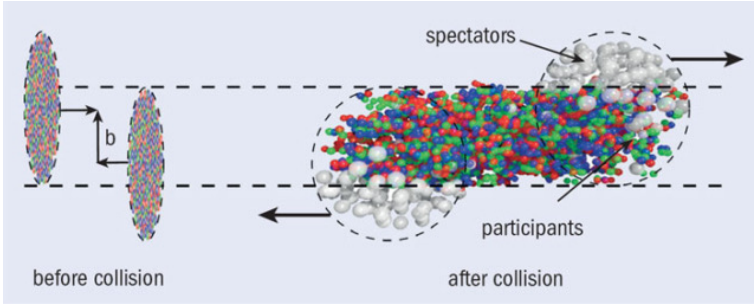

PHSD calculation SQM2015, Alessia Palmese




**Theory prediction of kaon potential**: PRL 74, 235(1995). PLB 175, 57(1986), PRC 43, 1881(1991). PLB 379, 34(1996). PRC 53, 1416(1996)…

# JAM: time evolution dependence



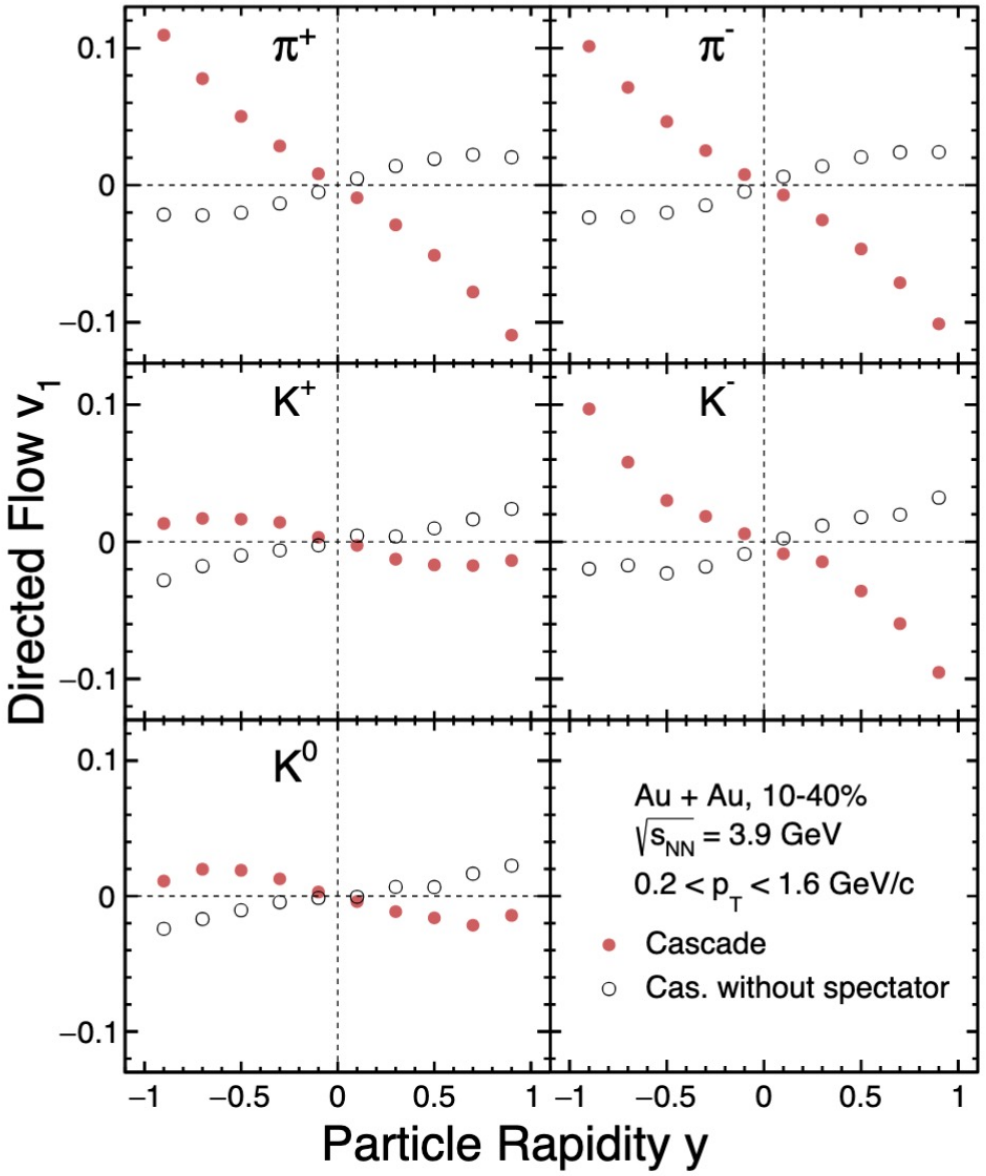

| $\sqrt{s_{NN}}$ (GeV) | $y$ | $\beta$ ($c$) | $t_p$ (fm/$c$) | $t_m$ (fm/$c$) | $t_p/t_m$ |
|---|---|---|---|---|---|
| 3.0 | 1.06 | 0.79 | 11.00 | 16.99 | 0.65 |
| 3.2 | 1.13 | 0.81 | 10.07 | 16.68 | 0.60 |
| 3.5 | 1.25 | 0.85 | 8.72 | 16.34 | 0.53 |
| 3.9 | 1.37 | 0.88 | 7.59 | 16.01 | 0.47 |

$t_p$: the spectator passing time
$t_m$: the hadron freeze-out mean time

- A well-defined anti-flow at mid-rapidity is formed before spectators passing the participant bulk.

Phys. Rev. C 110, 034903 (2024)

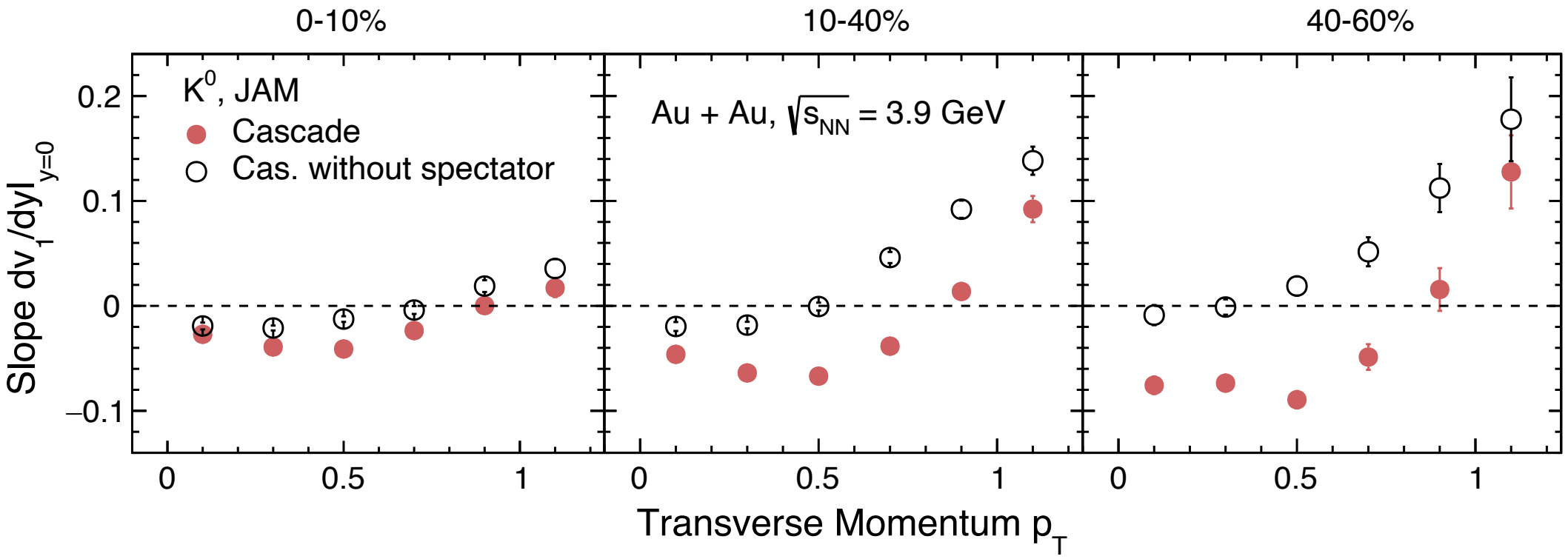
# JAM: rapidity dependence




- Negative $v_1$ slopes with spectators, in contrast to positive $v_1$ slopes w/o spectators.
- The anti-flow at mid-rapidity may arise from spectator shadowing effect.

Phys. Rev. C 110, 034903 (2024)

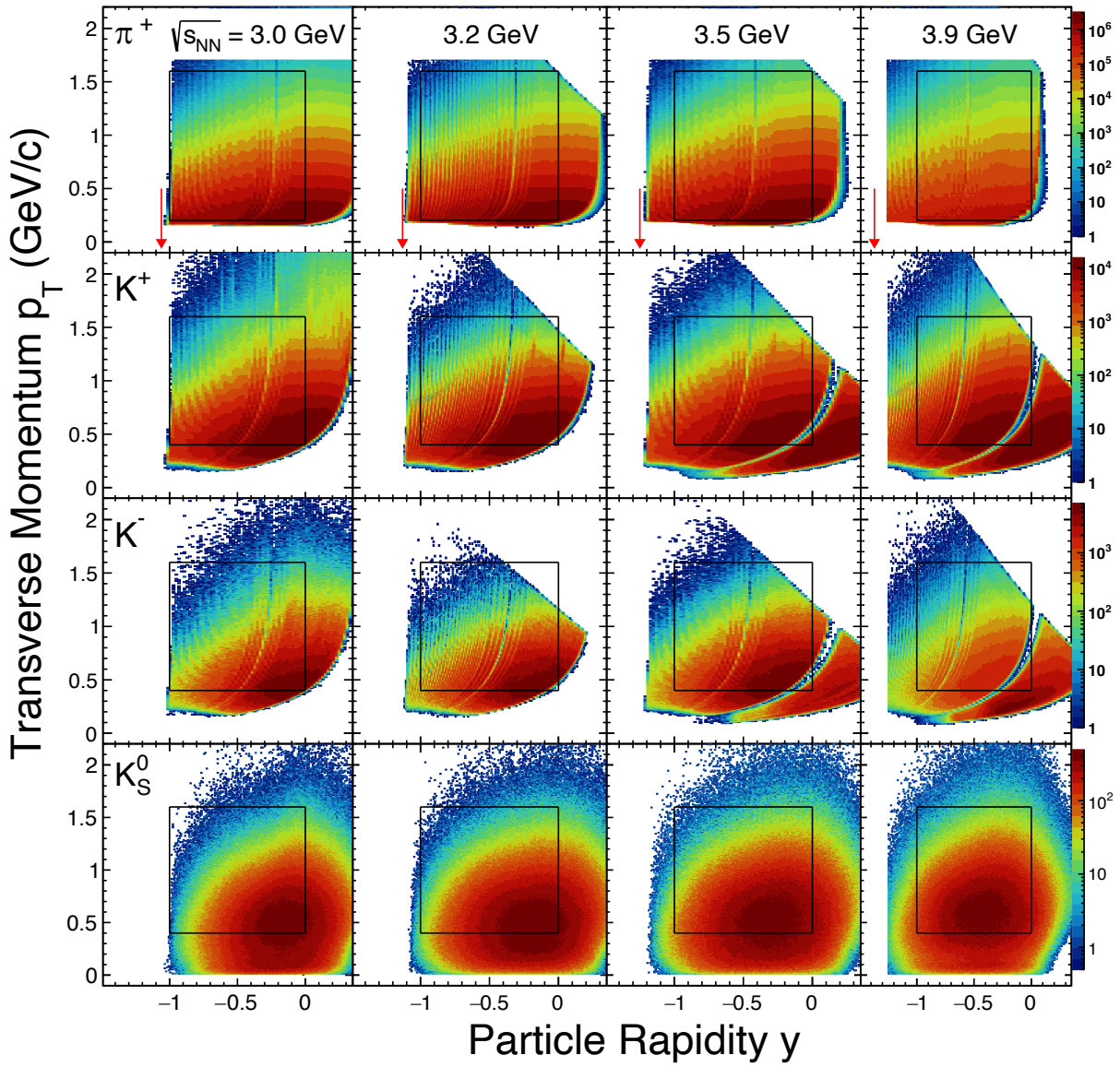
# JAM: $p_T$ and centrality dependence




- **Strong $p_T$ dependence**: negative $v_1$ slopes at low $p_T$, in contrast to positive ones at high $p_T$.
- **Centrality dependence**: $v_1$ slopes are more negative in more peripheral collisions.
- The spectator shadowing effect shifts the $v_1$ slopes in the negative direction.

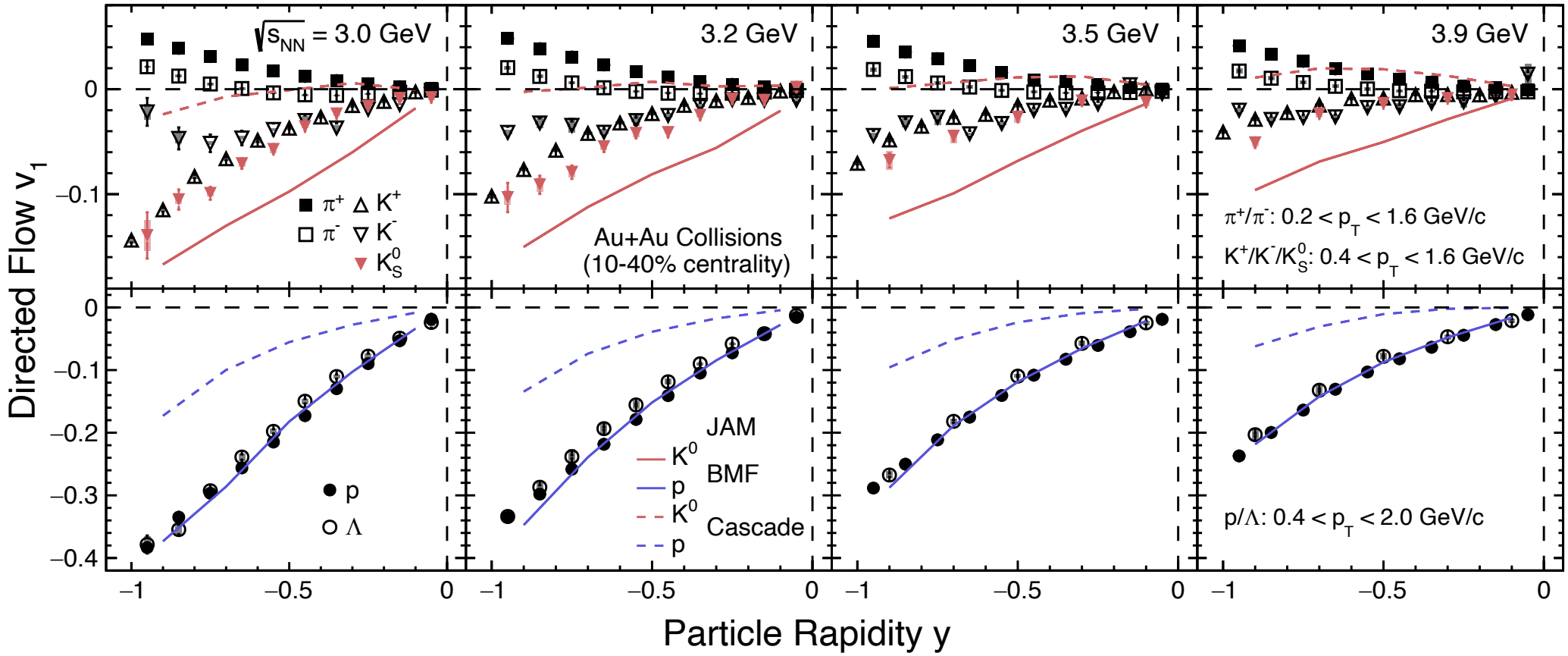
Phys. Rev. C 110, 034903 (2024)

# STAR: acceptance



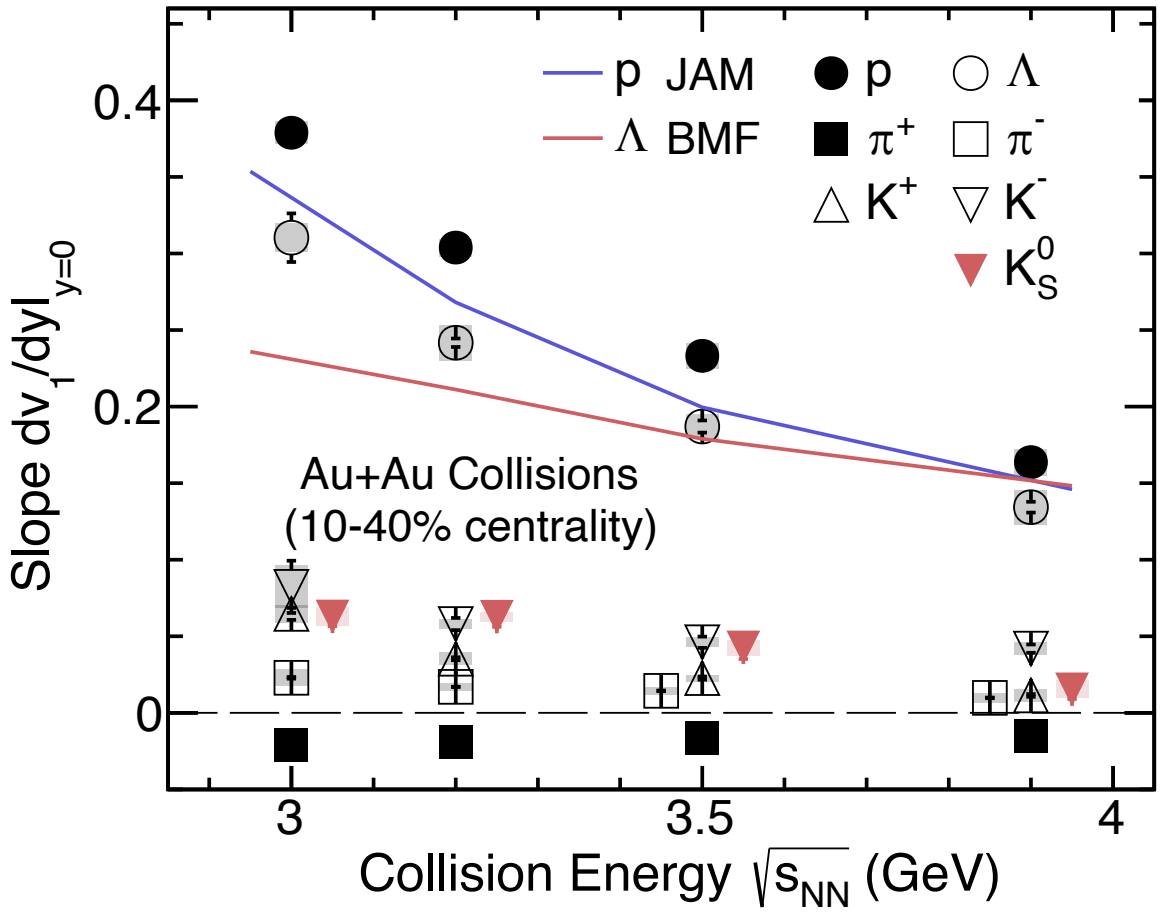

- Uniform acceptance at $\sqrt{s_{NN}}$ = 3.0, 3.2, 3.5, and 3.9 GeV with updated iTPC and eTOF.
- Beam rapidity is close to the rapidity of emitted particles.

# STAR: rapidity dependence




- Positive $v_1$ slopes of kaons in the wide $p_T$ interval.
- Good description for protons and lambdas with baryonic mean field in JAM.

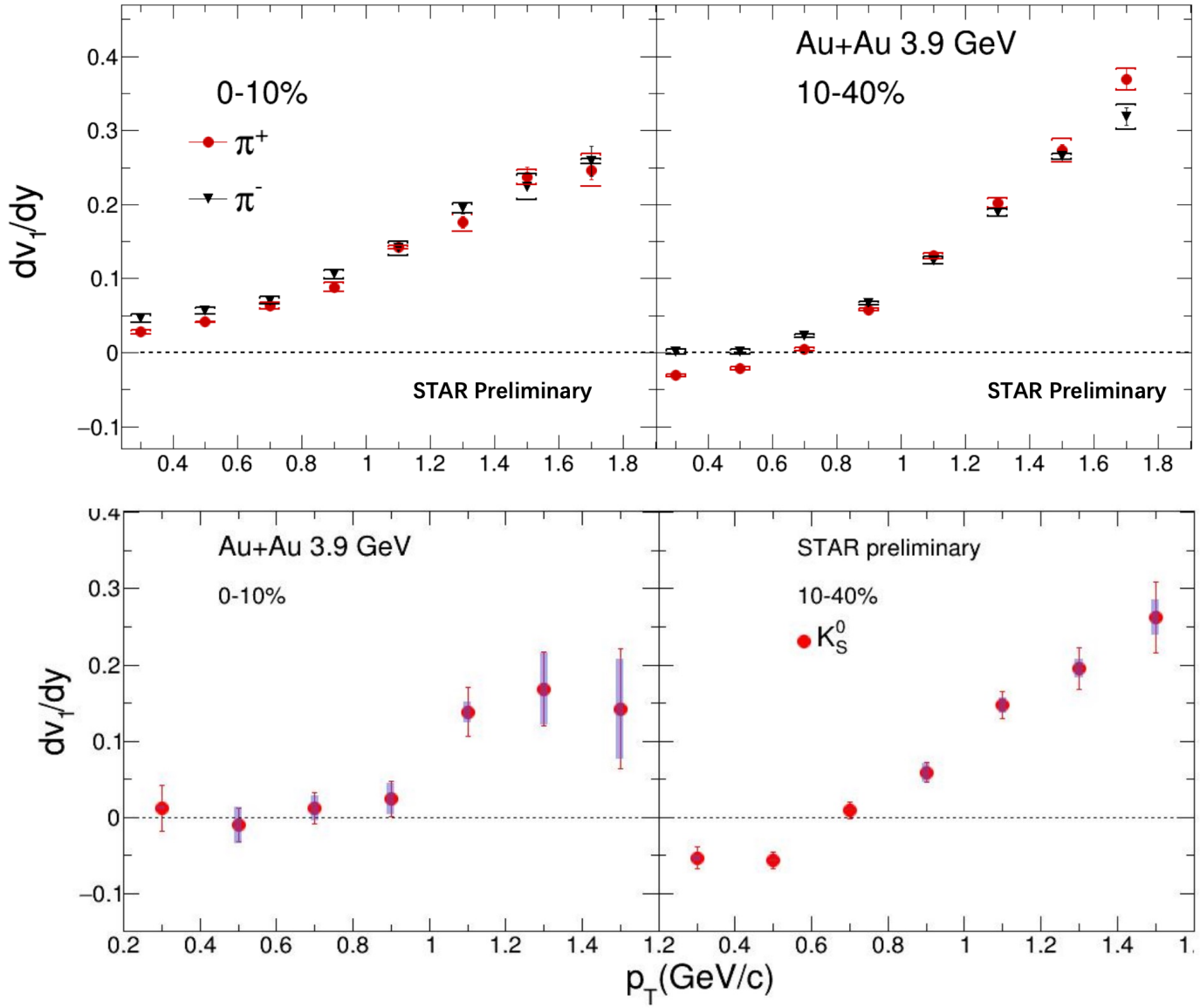
# $dv_1/dy$ vs. $\sqrt{s_{NN}}$




- Good description for protons and lambdas with baryonic mean field in JAM.
- The $v_1$ slope difference of mesons: Coulomb effect?

Note: without the mean field option, the predicted $v_1$ slopes are about a factor of four smaller for protons and lambdas.

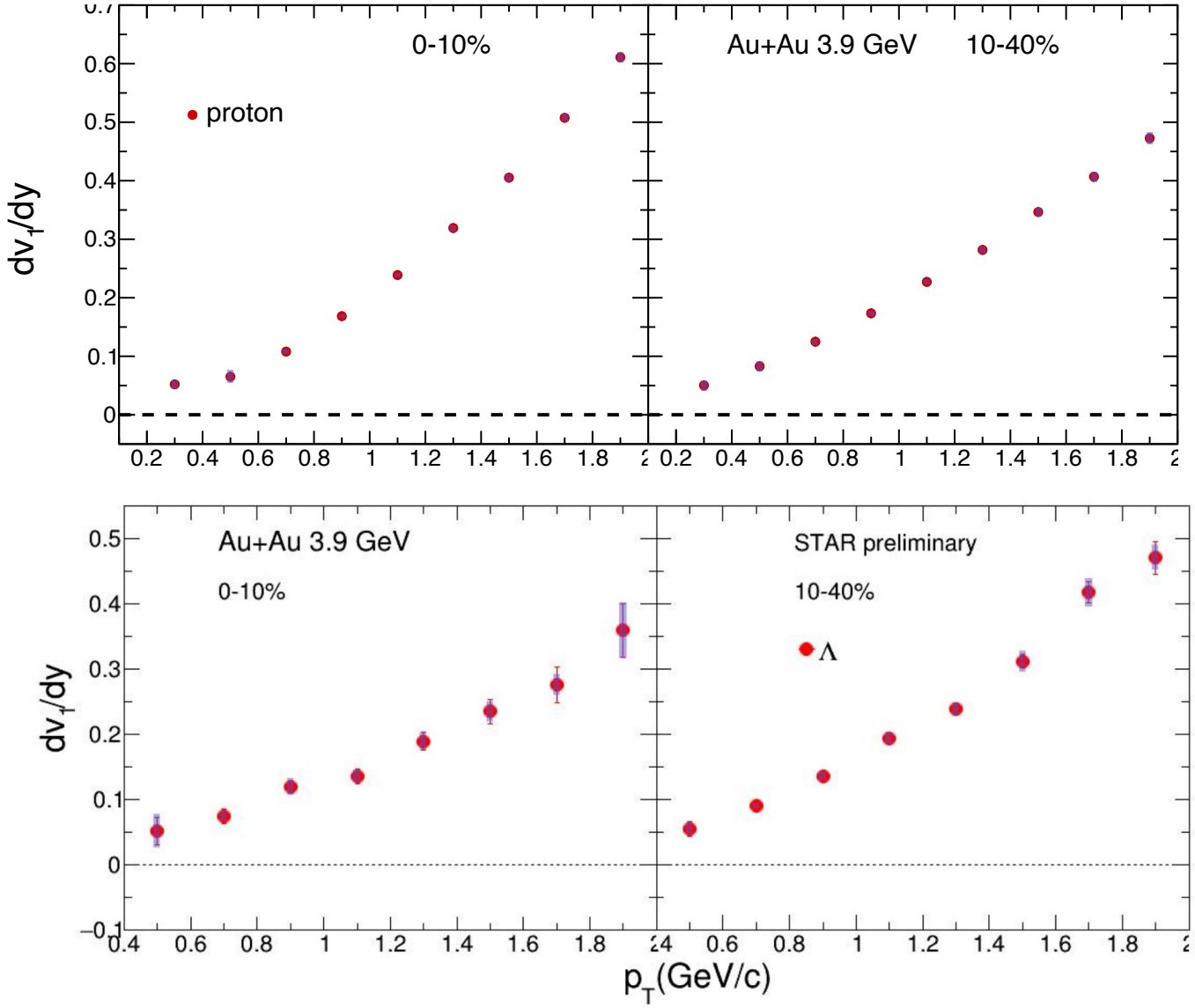
# Mesons: $dv_1/dy$ vs. $p_T$




- **Strong $p_T$ dependence**: negative $v_1$ slopes at low $p_T$, in contrast to positive ones at high $p_T$.
- **Centrality dependence**: positive $v_1$ slopes in very-central collisions, negative in mid-central collisions.

QM23 posters, Xing Wu and Guoping Wang

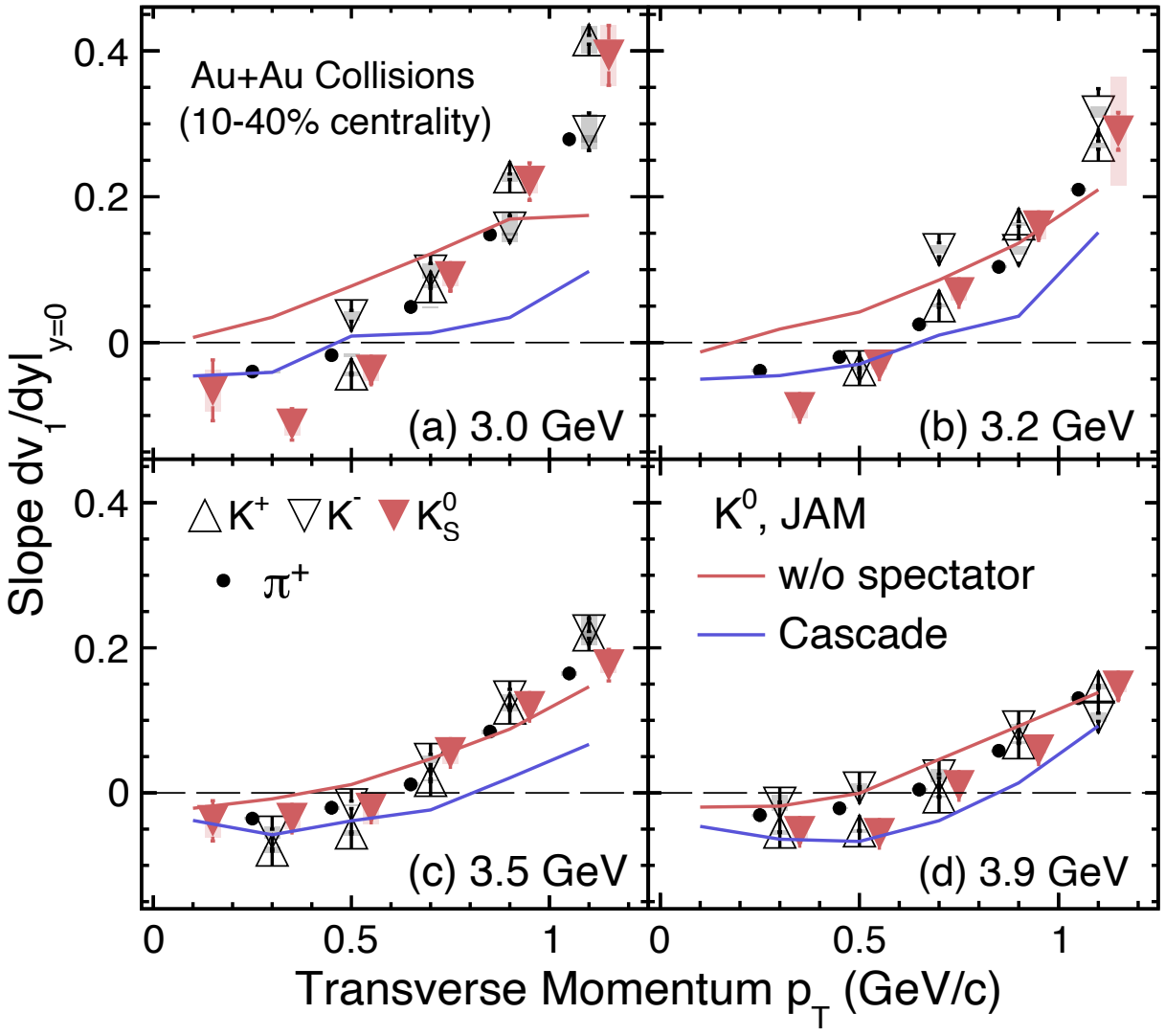
# Baryons: $dv_1/dy$ vs. $p_T$




- $v_1$ slopes for protons and lambdas are positive.

QM23 posters, Xing Wu and Guoping Wang

# $dv_1/dy$ vs. $p_T$




- Strong $p_T$ dependence: anti-flow at low $p_T$ ($p_T < 0.6$ GeV).
- JAM: the spectator shadowing effect shifts the $v_1$ slopes in the negative direction.

# Summary

$v_1$ measurements of $\pi^{\pm}$, $K^{\pm}$, $K_S^0$, p, and $\Lambda$ in Au + Au collisions at $\sqrt{s_{NN}}$ = 3.0-3.9 GeV.

- The dependences on $p_T$, centrality, particle type, time evolution, and the presence of the spectator.
  - → Shadowing effect plays an important role on kaon anti-flow.
  - → Kaon potential is not unique.

- The comparison of baryon $v_1$ to model calculations.
  - → A strong baryon mean field in the high baryon density region.

***Thank you for your attention!***