



Radial Flow Fluctuations of Identified Hadrons in Heavy-Ion Collisions at RHIC–STAR

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Outline

- Motivation
- STAR Detector
- Observable $v_0(p_T)$
- Results
 - ◆ $v_0(p_T)$ of Identified Hadrons
 - ◆ NCQ scaling test
 - ◆ Model Comparison
 - ◆ Energy dependence
- Summary



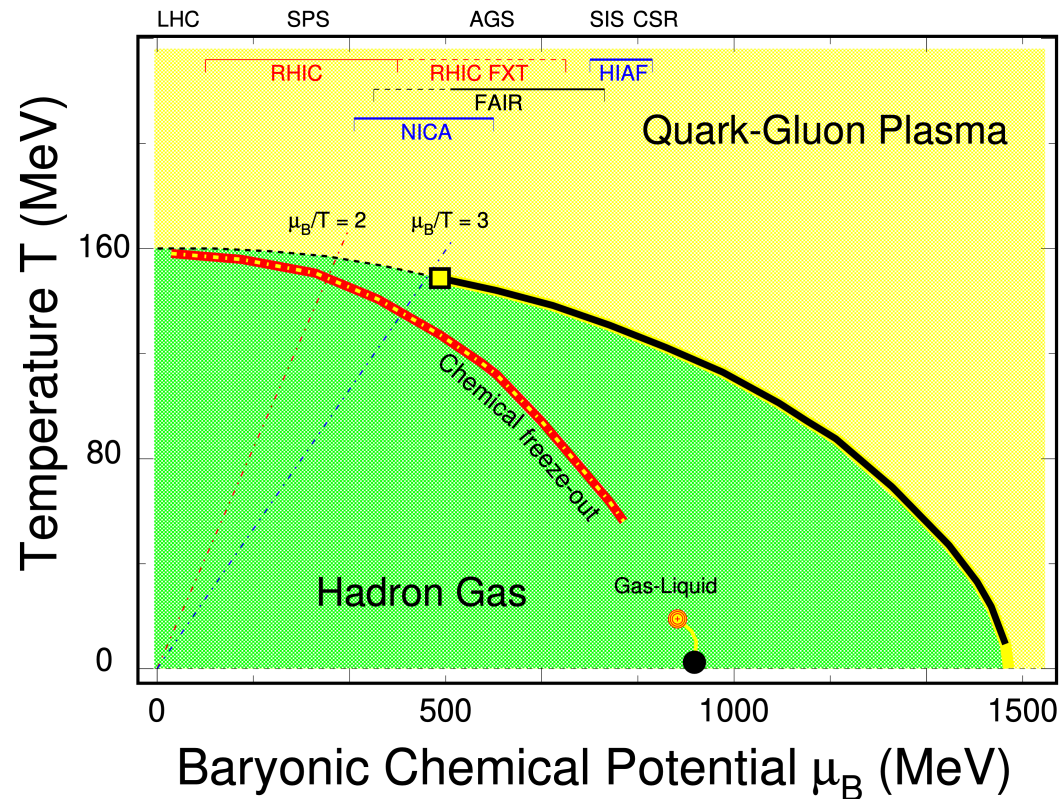
Motivation– QCD Phase Diagram

BES-I:

$$\sqrt{s_{NN}} = 7.7 - 200 \text{ GeV (COL)}$$

BES-II:

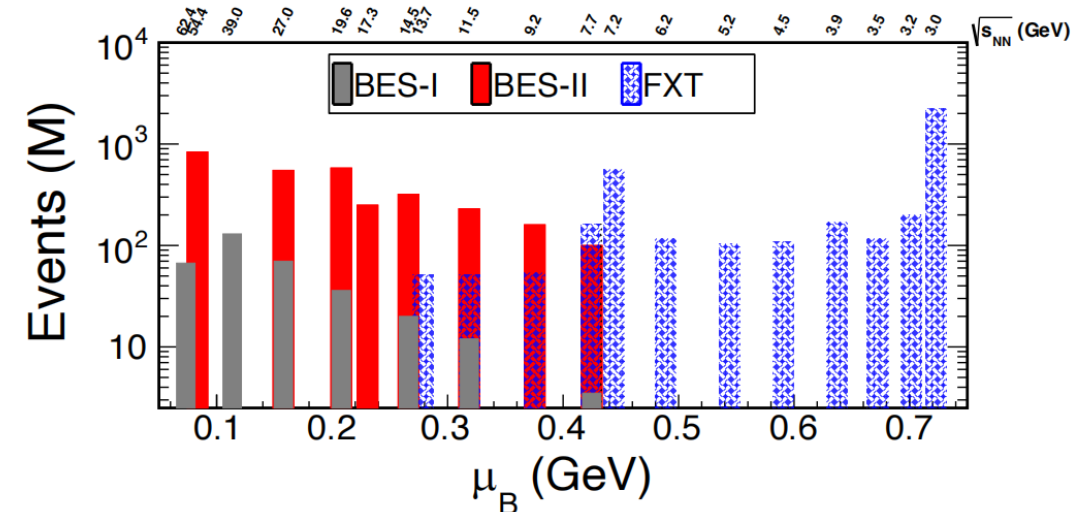
$$\begin{aligned} \sqrt{s_{NN}} &= 7.7 - 54.4 \text{ GeV (COL)} \\ &+ \\ \sqrt{s_{NN}} &= 3.0 - 13.7 \text{ GeV (FXT)} \end{aligned}$$



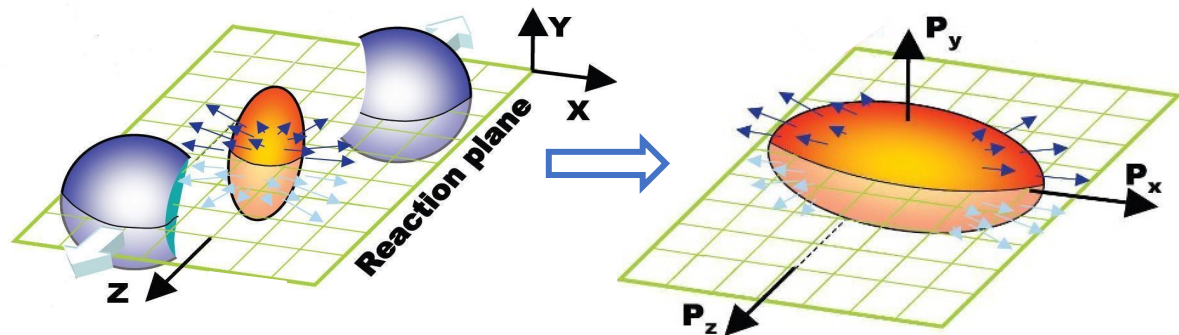
X.Luo, S.Shi, Nu Xu et al. Particle 3, 278 (2020)

RHIC Beam Energy Scan(BES) Program:

- Study the properties of QGP
- Critical End Point
- First-order phase boundary



Motivation



$$\frac{d^2N}{d\phi dp_T} = N(p_T) \left(1 + 2 \sum_{n \geq 1} v_n \cos(n(\phi - \psi_n)) \right)$$

Radial flow
 $\delta[p_T] \propto -\delta R$

Anisotropic flow v_n
 $v_n \propto \varepsilon_n$

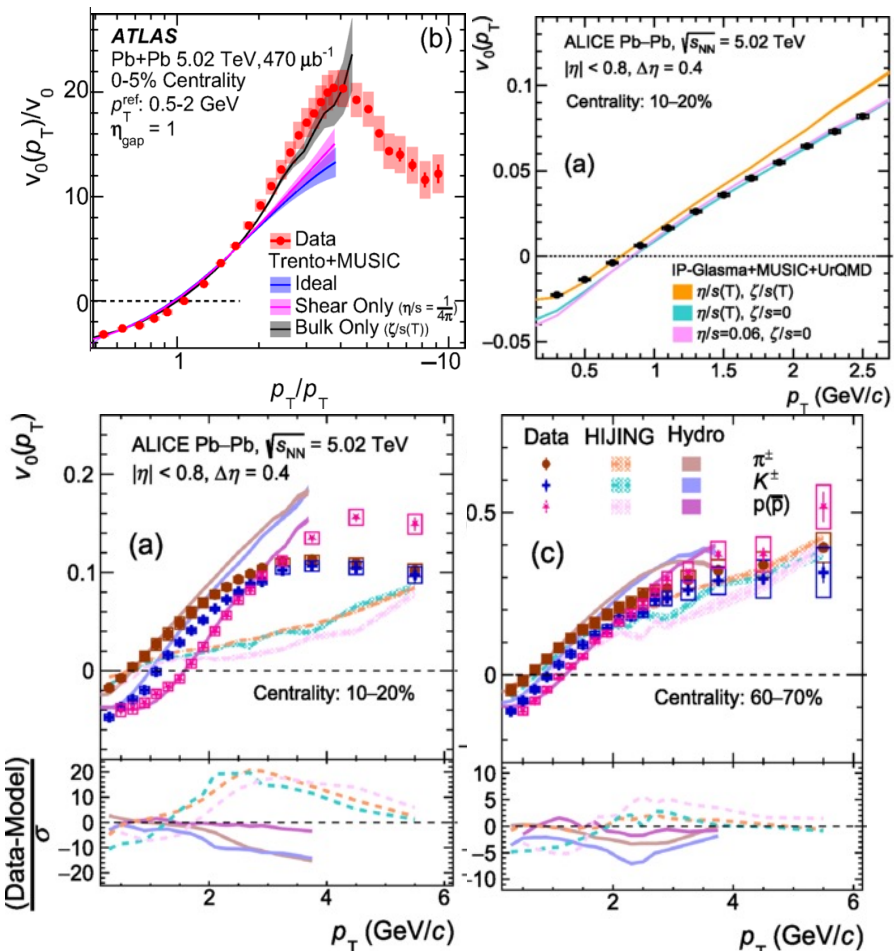
New observable $v_0(p_T) \rightarrow$ capture radial flow fluctuation

Sensitive to Initial Conditions

- ❑ Shape fluctuations of the overlap region control anisotropic flow.
- ❑ Radial flow fluctuations originate from its size fluctuations.

Sensitive to QGP transport properties

- ❑ Anisotropic flow: sensitive to shear (η/s) and bulk (ζ/s) viscosities.
- ❑ Radial flow: more sensitive to bulk (ζ/s) viscosities.
- ❑ Both are sensitive to Equation-of-State.

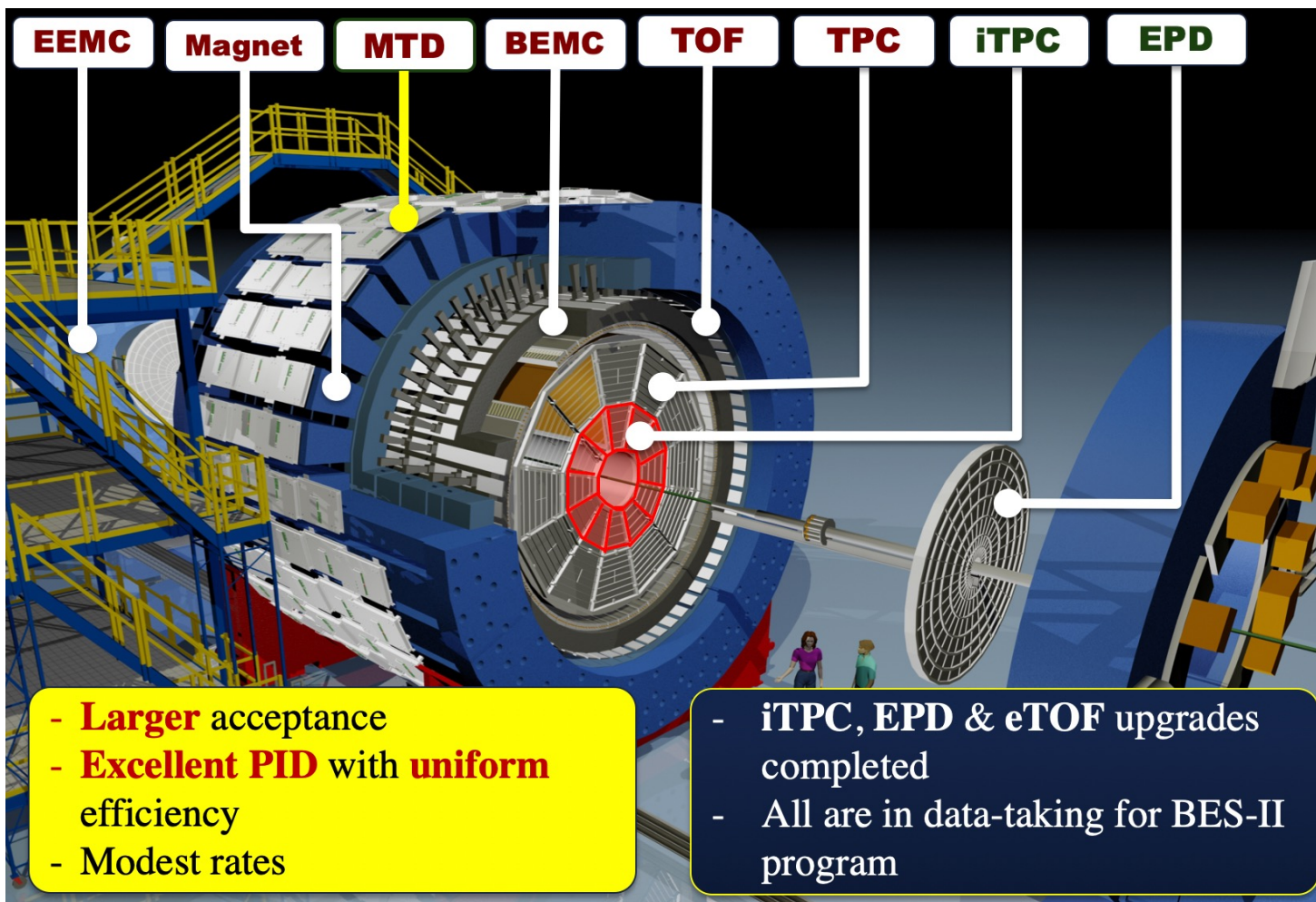


ATLAS Phys. Rev. Lett. 136, 032301 (2026)
ALICE Phys. Rev. Lett. 136, 032302 (2026)

STAR provides:

- ◆ Different collision system
- ◆ More particle species
- ◆ Energy dependence

STAR Detectors



- **Track Projection Chamber (TPC):**
 - ◆ Particle identification - Ionization energy loss (dE/dx)
 - ◆ Momenta measurement $p \in (0.1, 30) \text{ GeV}/c$
- **Time Of Flight (TOF):**
 - ◆ Time of flight
 - ◆ Particle identification
- **iTPC upgrade :**
 - ◆ Improves capability of PID
 - ◆ Extends η coverage from 1.0 to 1.5



Observable $v_0(p_T)$ -Definition

- Correlations between the **E-by-E local p_T -differential yield $n(p_T)$** and the **E-by-E global mean transverse momentum $[p_T]$** .

$$v_0(p_T) \equiv \frac{\langle \delta n_A(p_T) \delta [p_T]_B \rangle}{\langle n_A(p_T) \rangle \sigma_{p_T}}$$

A

B

η
 $-1.0 \quad -0.05 \quad 0.05 \quad 1.0$

$$n_A(p_T) = \frac{N_A(p_T)}{\int N_A(p_T) dp_T} \quad \delta n_A(p_T) = n_A(p_T) - \langle n_A(p_T) \rangle$$

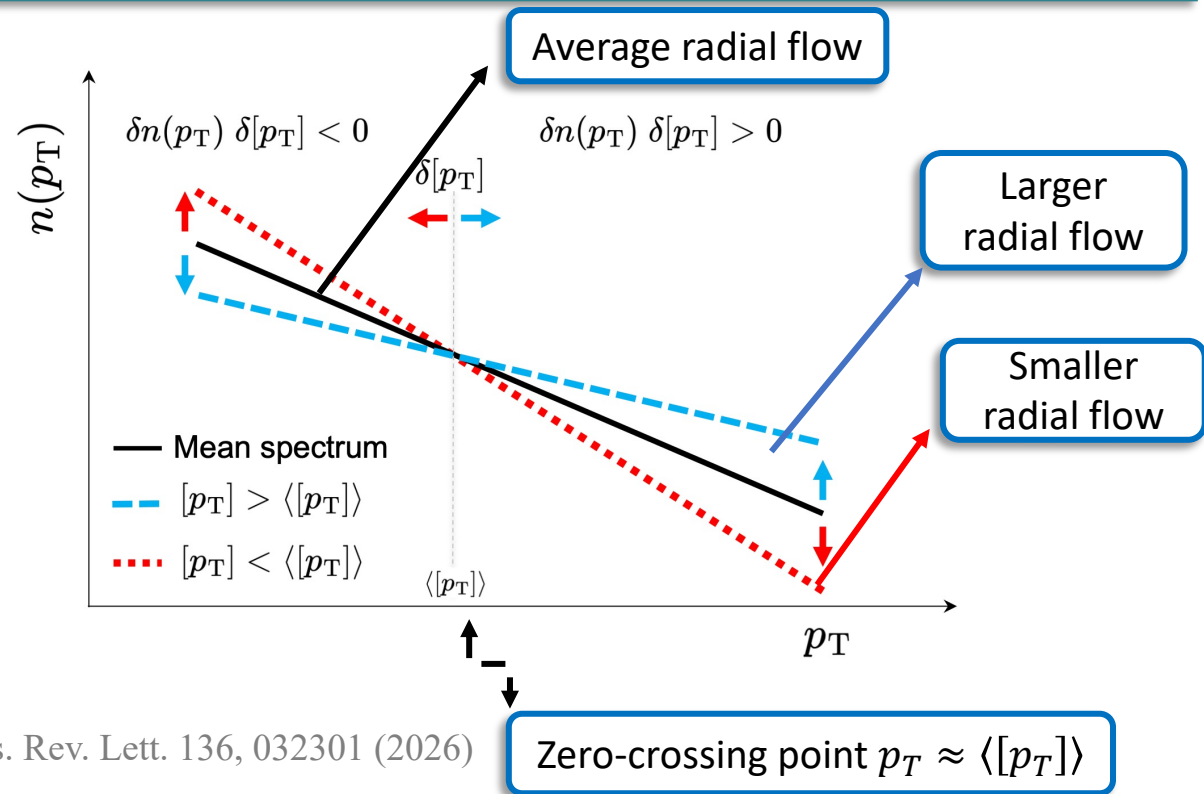
$$[p_T]_{A/B} = \langle [p_T] \rangle_{A/B} + \delta [p_T]_{A/B}$$

$$\delta [p_T]_{A/B} = [p_T]_{A/B} - \langle [p_T] \rangle_{A/B}$$

$$\sigma_{p_T}^2 = \langle \delta [p_T]_A \delta [p_T]_B \rangle$$

σ_{p_T} : standard deviation of the event-wise mean p_T .

Phys. Lett. B 857, 138985(2024)

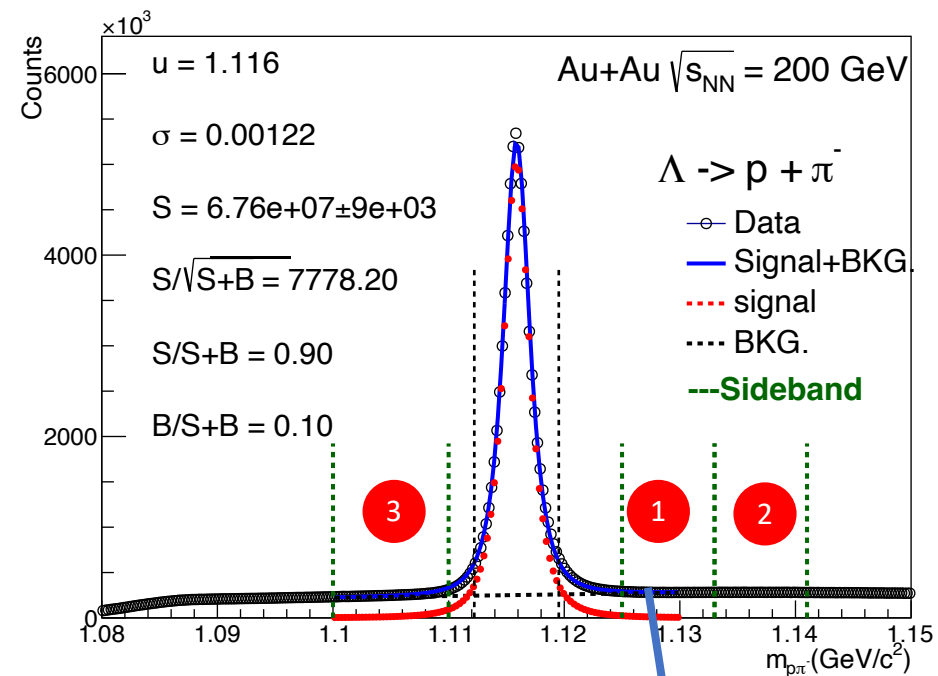
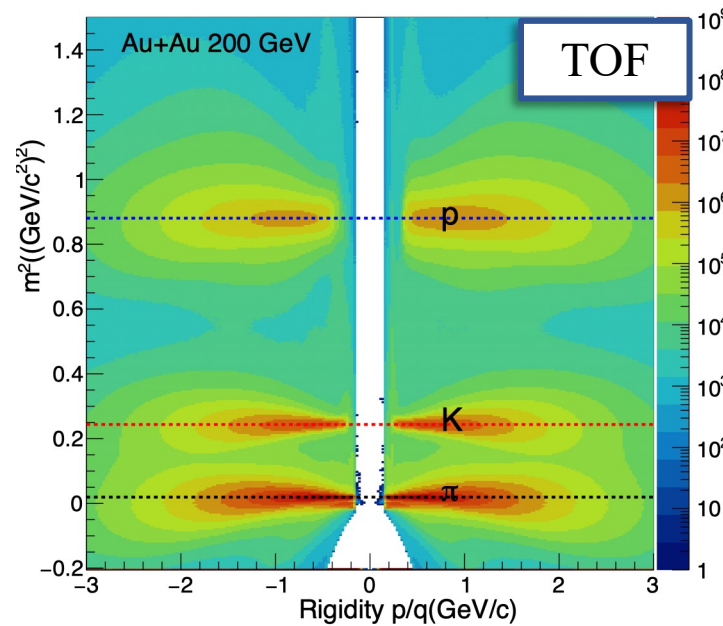
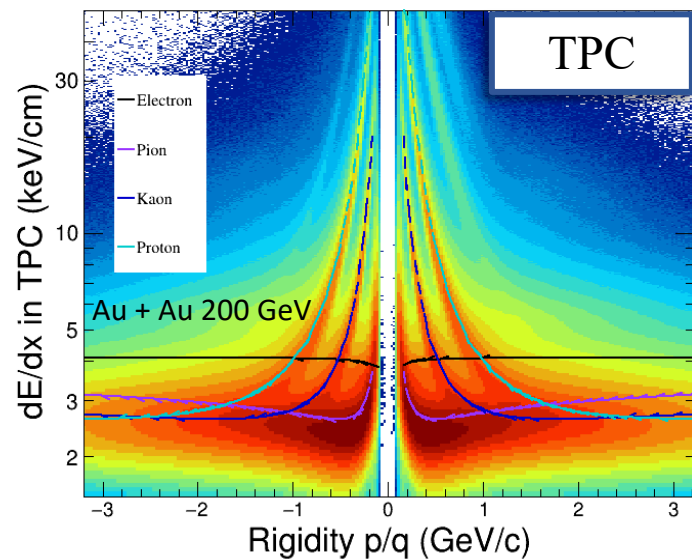


- Larger radial flow ($\delta [p_T] > 0$) $\rightarrow$ Flatter distribution of $n(p_T)$ $\rightarrow$ Higher $[p_T]$
- Smaller radial flow ($\delta [p_T] < 0$) $\rightarrow$ Steeper distribution of $n(p_T)$ $\rightarrow$ lower $[p_T]$



positive covariance ($\langle \delta n_A(p_T) \delta [p_T]_B \rangle > 0$) at $p_T \geq \langle [p_T] \rangle$.
negative covariance ($\langle \delta n_A(p_T) \delta [p_T]_B \rangle < 0$) at $p_T \leq \langle [p_T] \rangle$.

Particle Identification and Reconstruction



Side-band used to estimate the BG v_0

- Good capability of particle identification (PID)

based on TPC and TOF

- Extend the phase space coverage by TOF

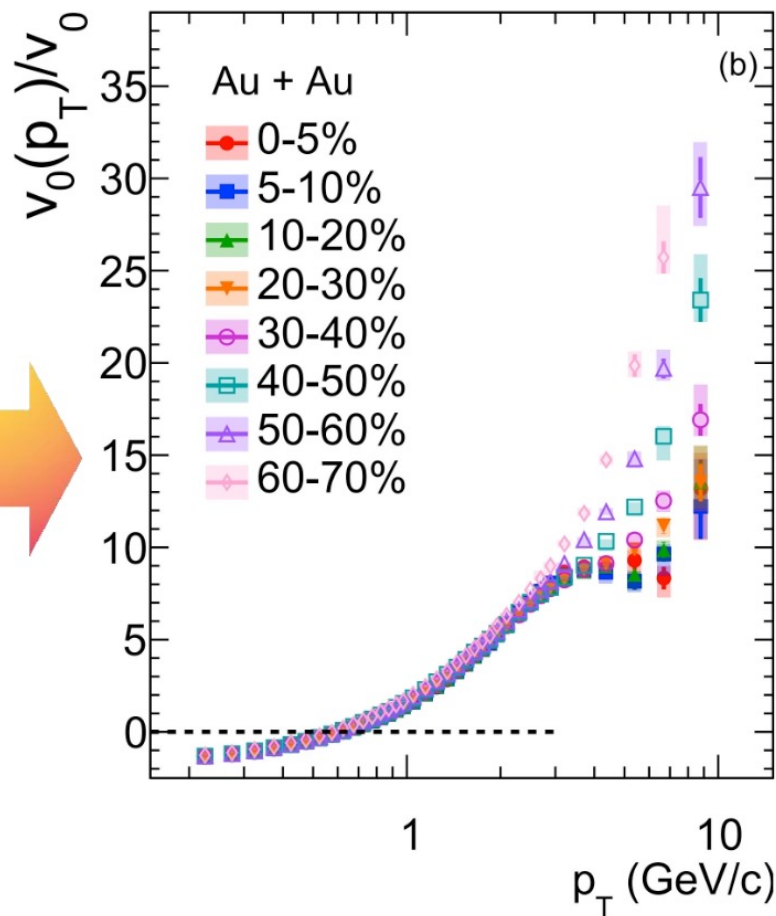
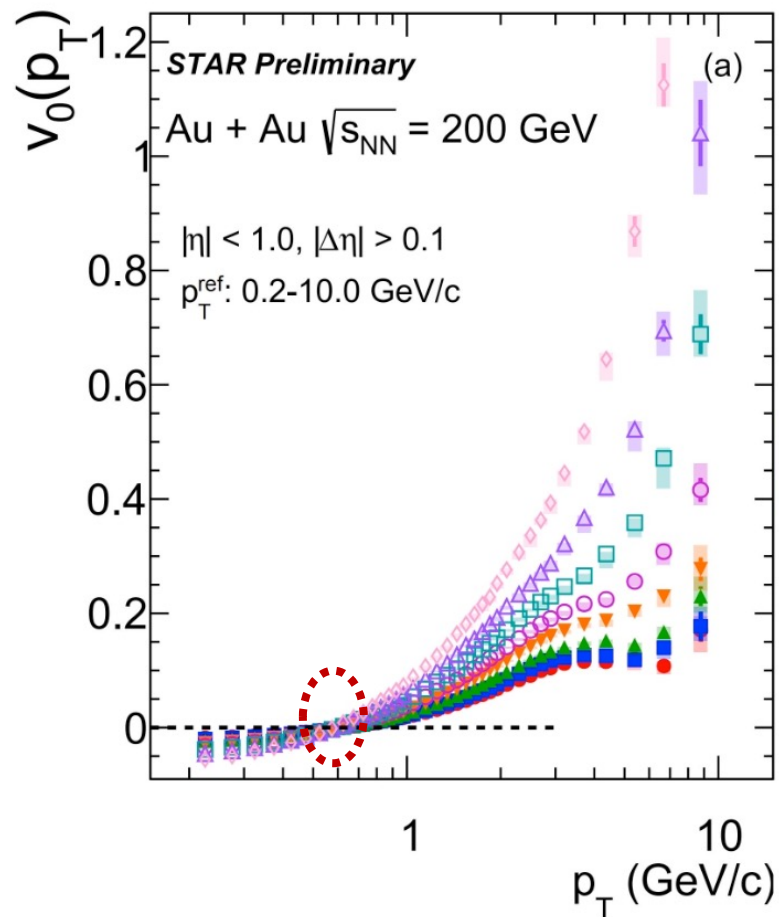
- Decayed particles are reconstructed

by KF(Kalman Filter) particle package

- Estimate of background contribution on v_0 :
use side-band to estimate the BG contribution
on the signal peak range.

$$v_0^{S+B}(p_T) = v_0^S(p_T) \frac{S}{S+B} + v_0^B(p_T) \frac{B}{S+B}$$

Observable $v_0(p_T)$ & $v_0(p_T)/v_0$



Zaining, SQM2026

$$v_0(p_T) = \kappa_0(p_T) \left(-\frac{\delta R}{R} \right)$$

$$v_0 = \kappa_0 \left(-\frac{\delta R}{R} \right)$$

$$\frac{v_0(p_T)}{v_0} = \frac{\kappa_0(p_T)}{\kappa_0}$$

κ_0 is hydrodynamic response coefficient
 $\frac{\delta R}{R}$ is initial-state fluctuation

Strong centrality-dependence:

size-driven radial flow fluctuations

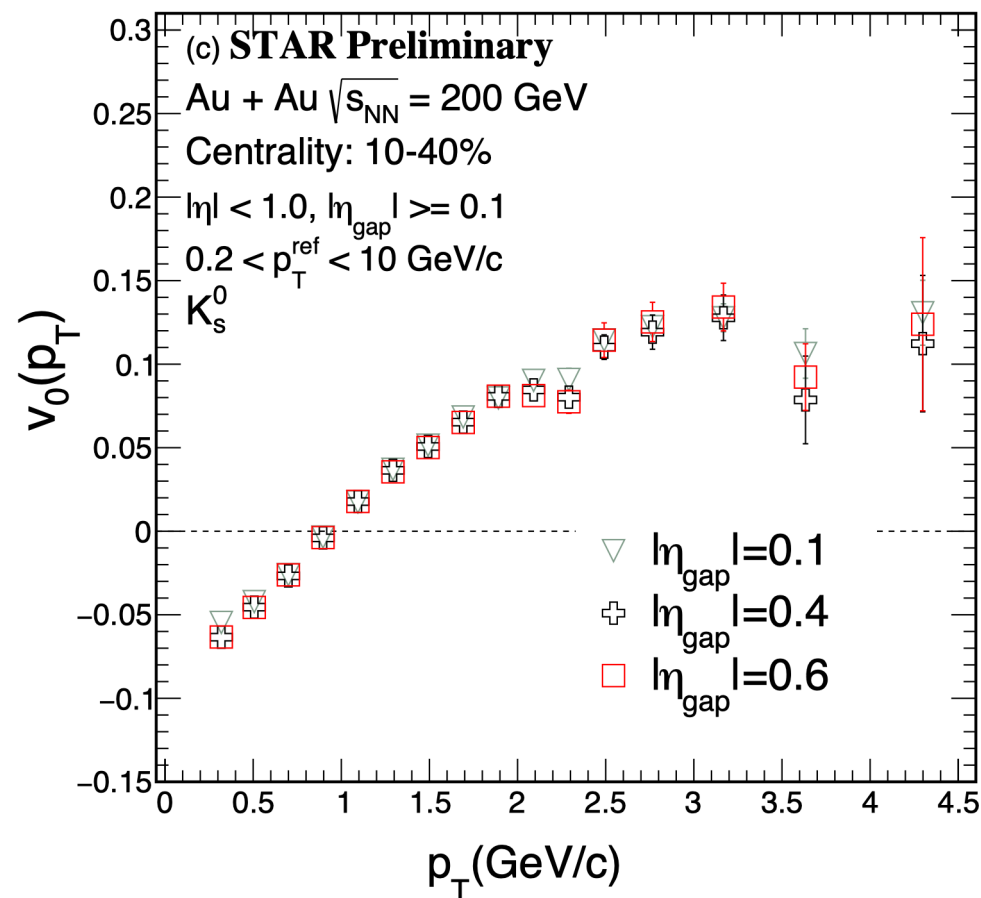
Zero crossing point (set by $\langle [p_T] \rangle$ by definition).

Factorization $v_0(p_T)/v_0$:

No centrality dependence at low p_T (hydrodynamic response)

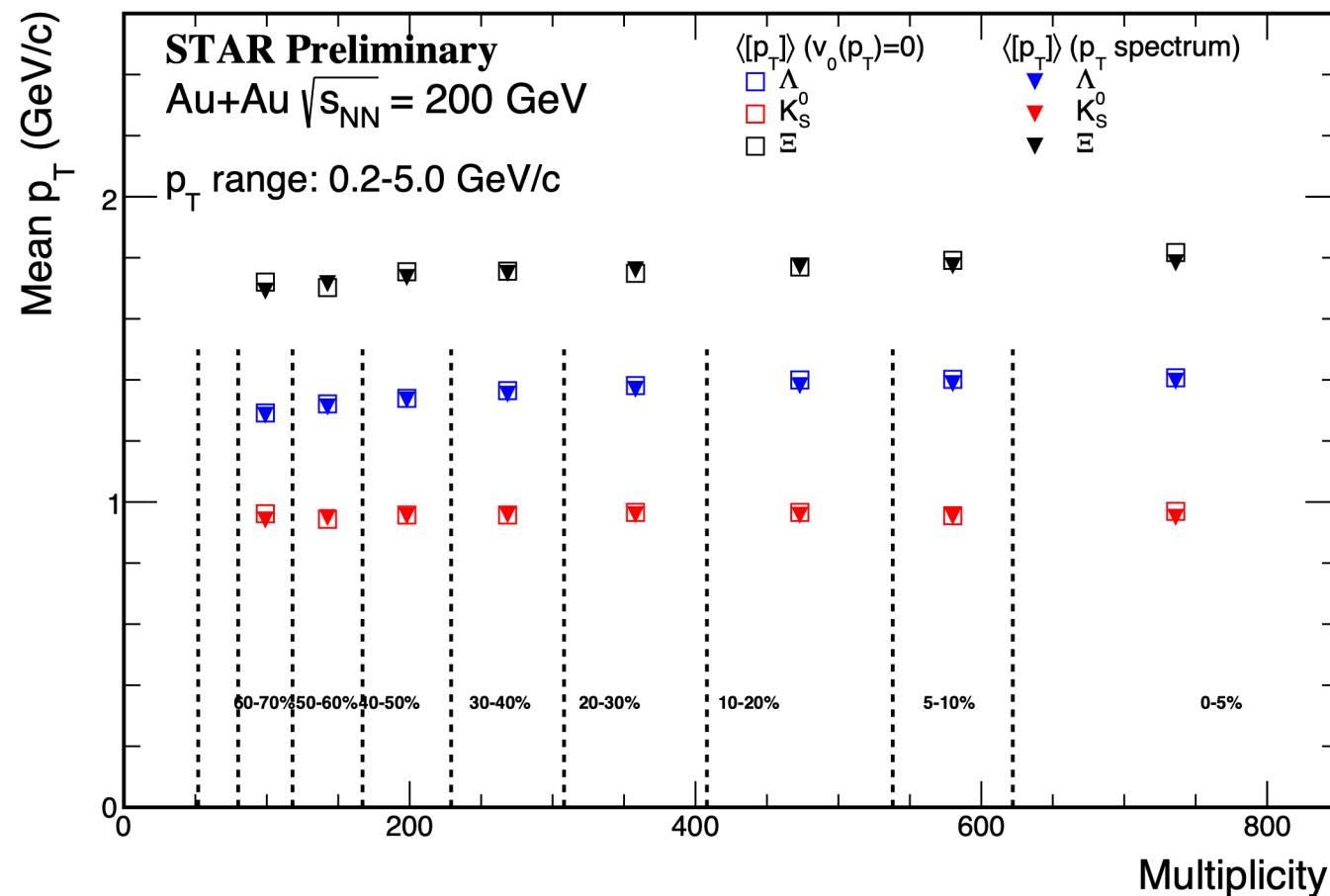


Observable $v_0(p_T)$



Long-range behavior:

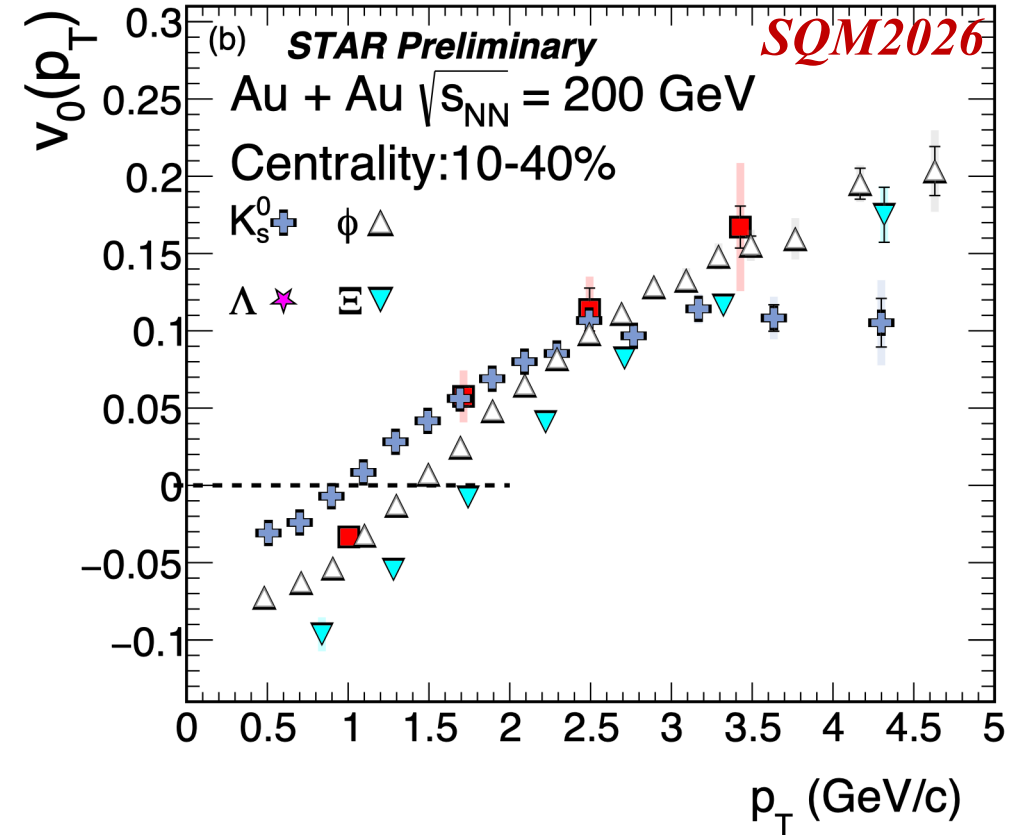
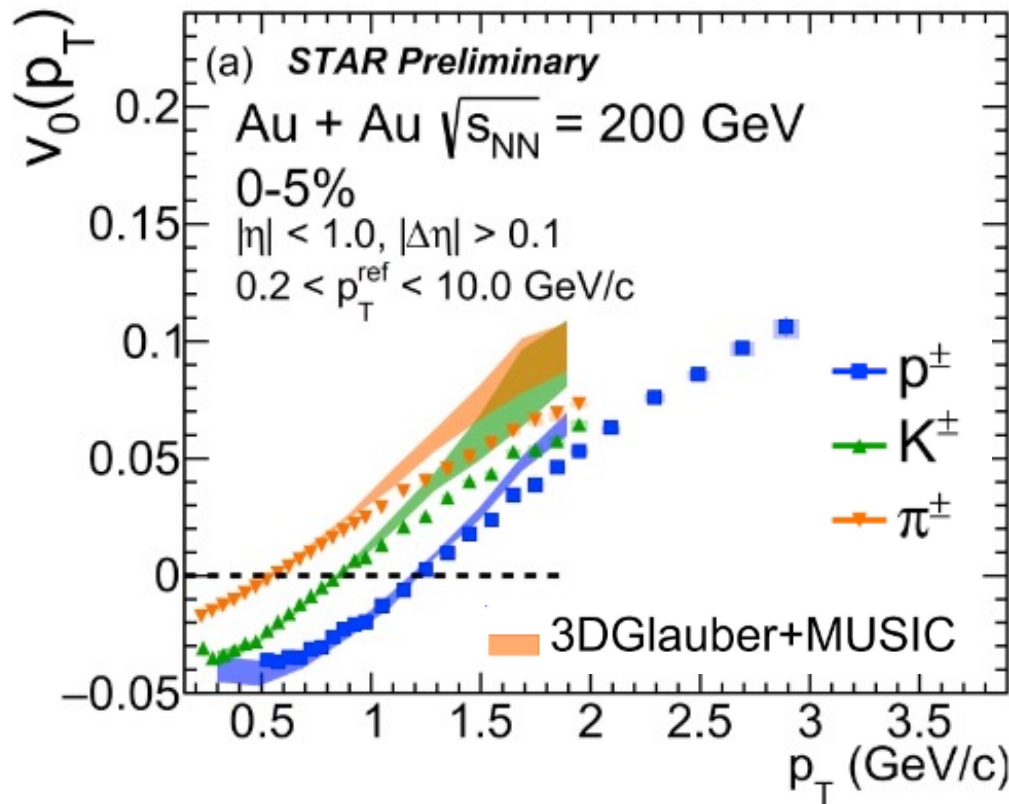
$v_0(p_T)$ weakly depends η_{gap} .



Zero crossing point:

$v_0(p_T)$ crosses zero at $p_T \approx \langle [p_T] \rangle$ of the particle spectra.

Mass ordering

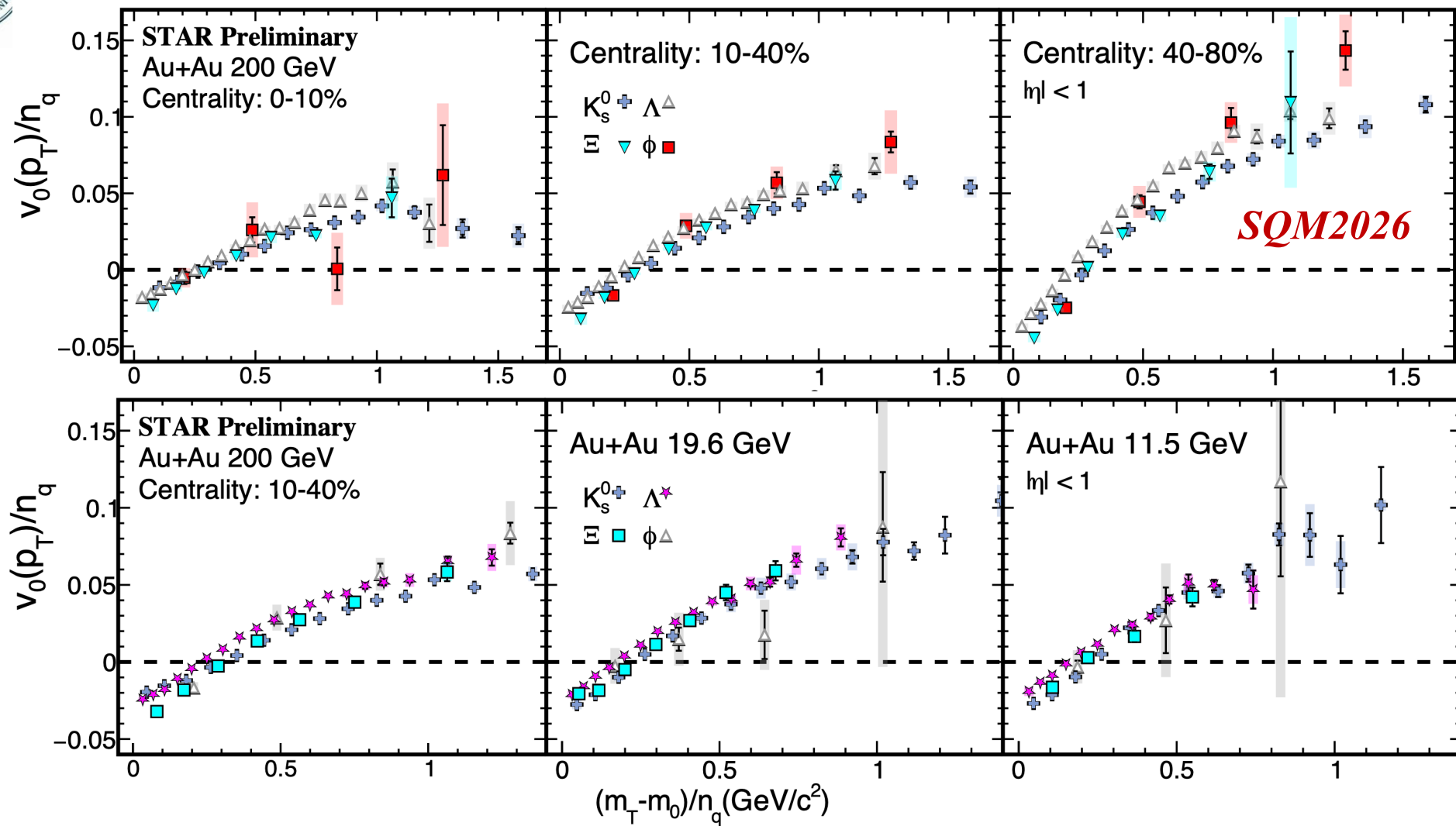


S. A. Jahan, H. Roch, C. Shen, Phys. Rev. C 113, 024919 (2026).

- Mass ordering observed at low p_T (< 2.5 GeV/c). where hadrons of different masses respond differently to the same collective radial velocity field.
- Baryon-meson splitting between baryons (Λ , Ξ) and mesons (K_S^0) at 200 GeV.

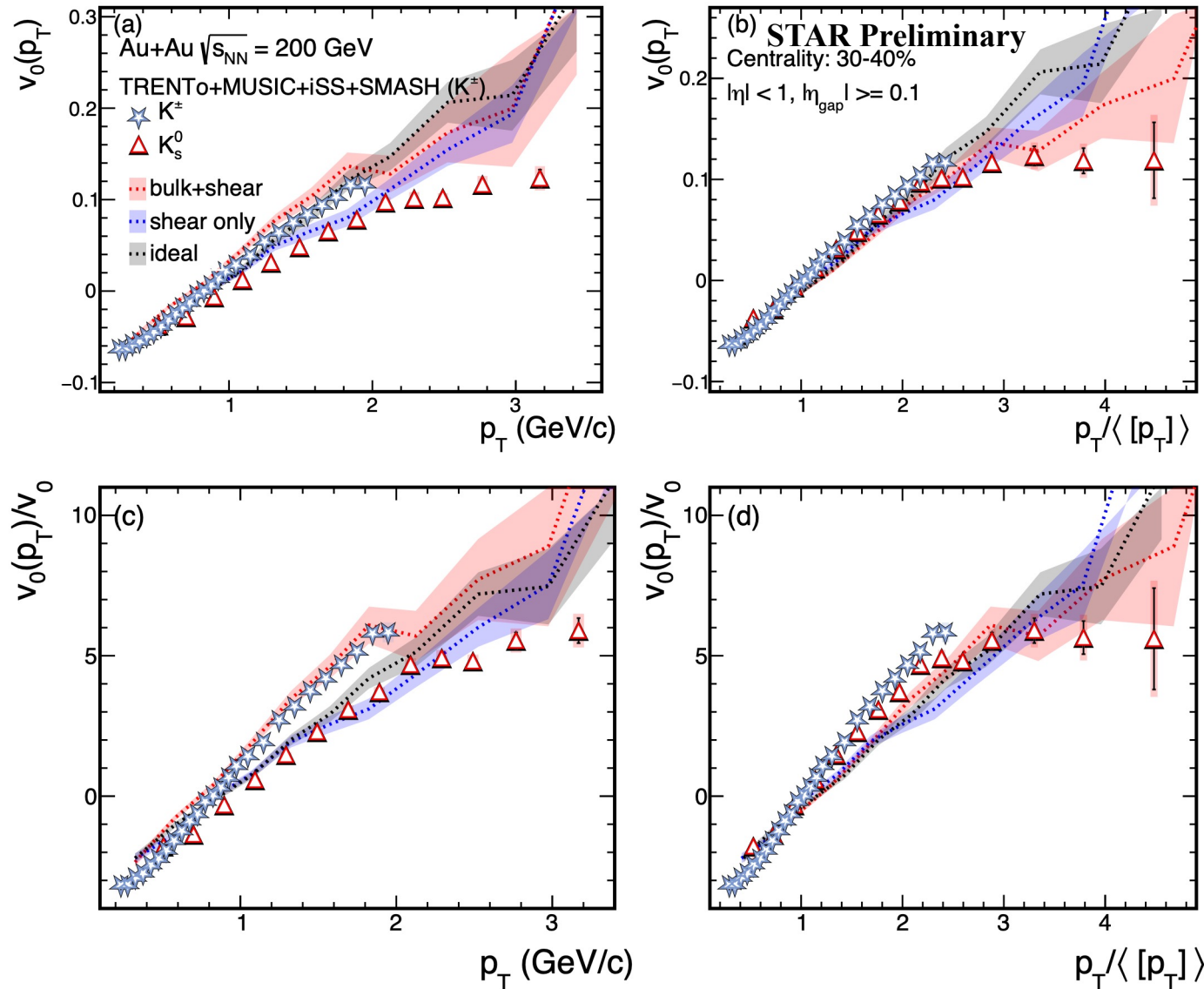


NCQ scaling test



■ NCQ scaling: better in more central collisions

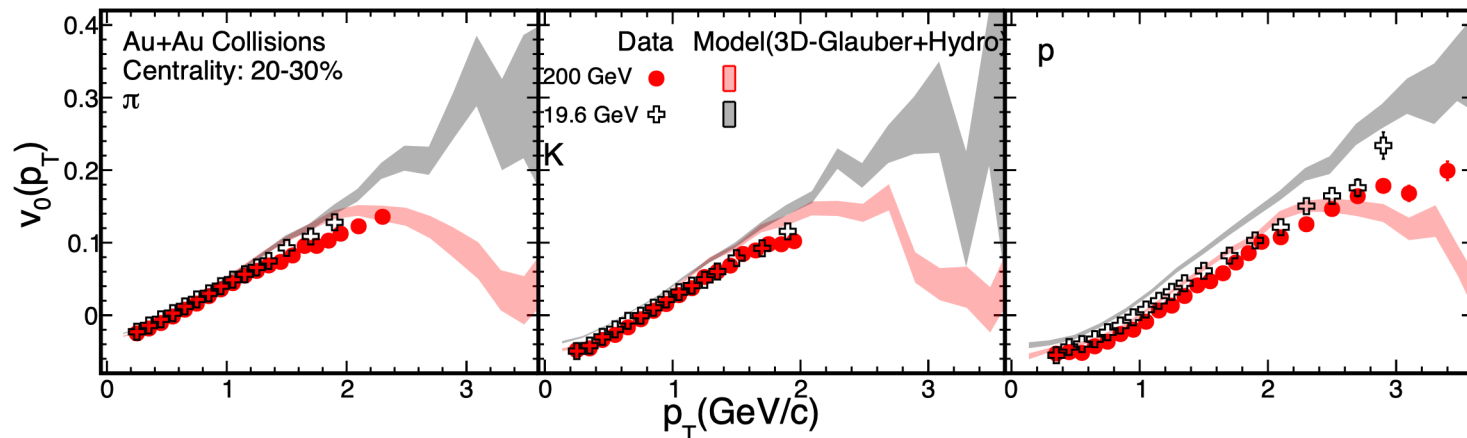
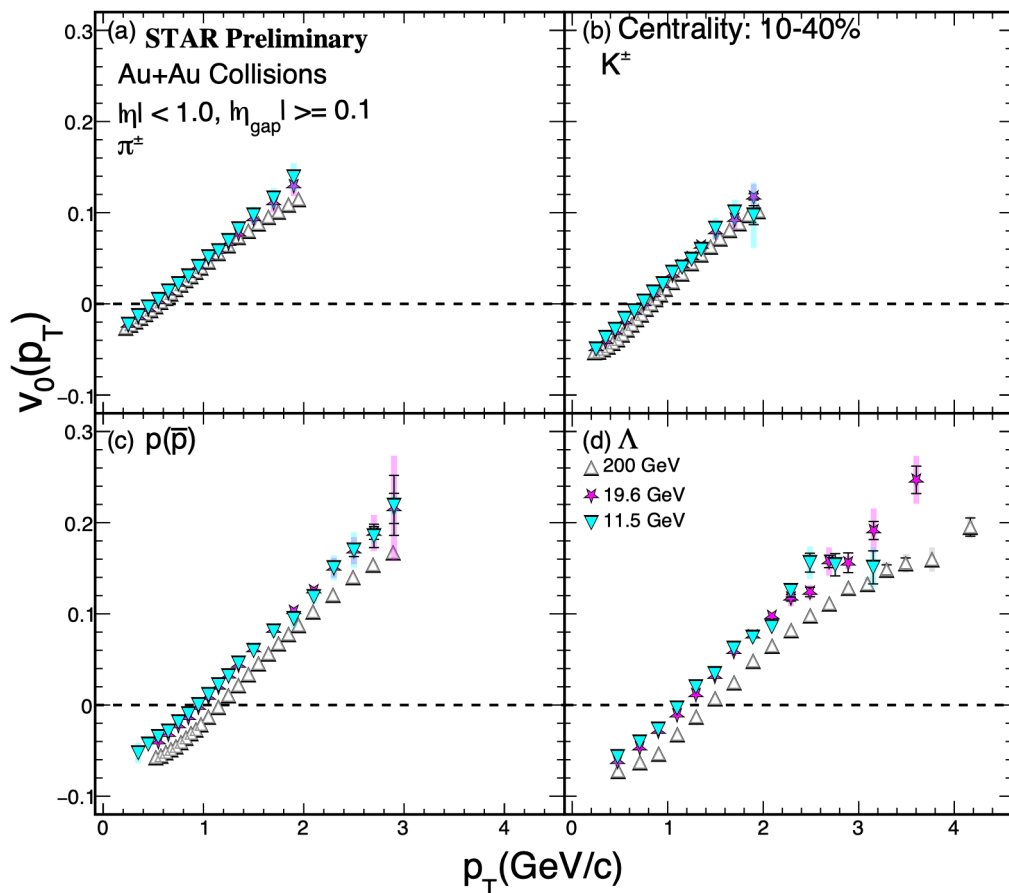
Model Comparison



- $v_0(p_T)/v_0$ cancels the impact from initial state.
- $p_T/\langle [p_T] \rangle$ reduces the momentum-scale difference.
- Kaon and K_S^0 : shows unique sensitivity to bulk viscosity.

L. Du, Phys. Rev. C 113, 014901 (2026).

Energy Dependence



S. A. Jahan, H. Roch, C. Shen, Phys. Rev. C 113, 024919 (2026).

- ❑ Weak energy dependence
- ❑ As the collision energy increases, the systems develop larger hydrodynamic radial flow (higher $\langle p_T \rangle$) and the zero-crossing point of $v_0(p_T)$ shifts to higher p_T values.



Summary and Outlook

Summary :

- ❑ First measurements of p_T -differential radial flow fluctuations observable $v_0(p_T)$ at RHIC.
- ❑ Properties of $v_0(p_T)$
 - ◆ Long-range global correlation
 - ◆ Mass ordering observed at low p_T .
 - ◆ Better NCQ scaling in central collisions
 - ◆ Weak energy dependence.
- ❑ Model comparison
 - ◆ Radial flow is sensitive to bulk (ζ/s) viscosities.

Outlook :

- ❑ Scanning the energy of BES II
- ❑ Studying more collision systems



Thank you for your attention!