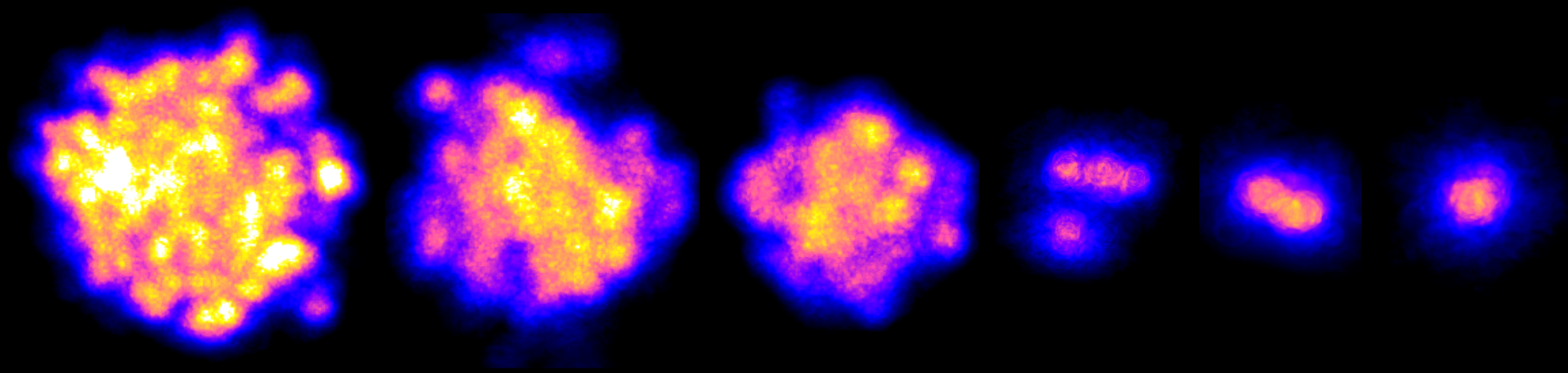


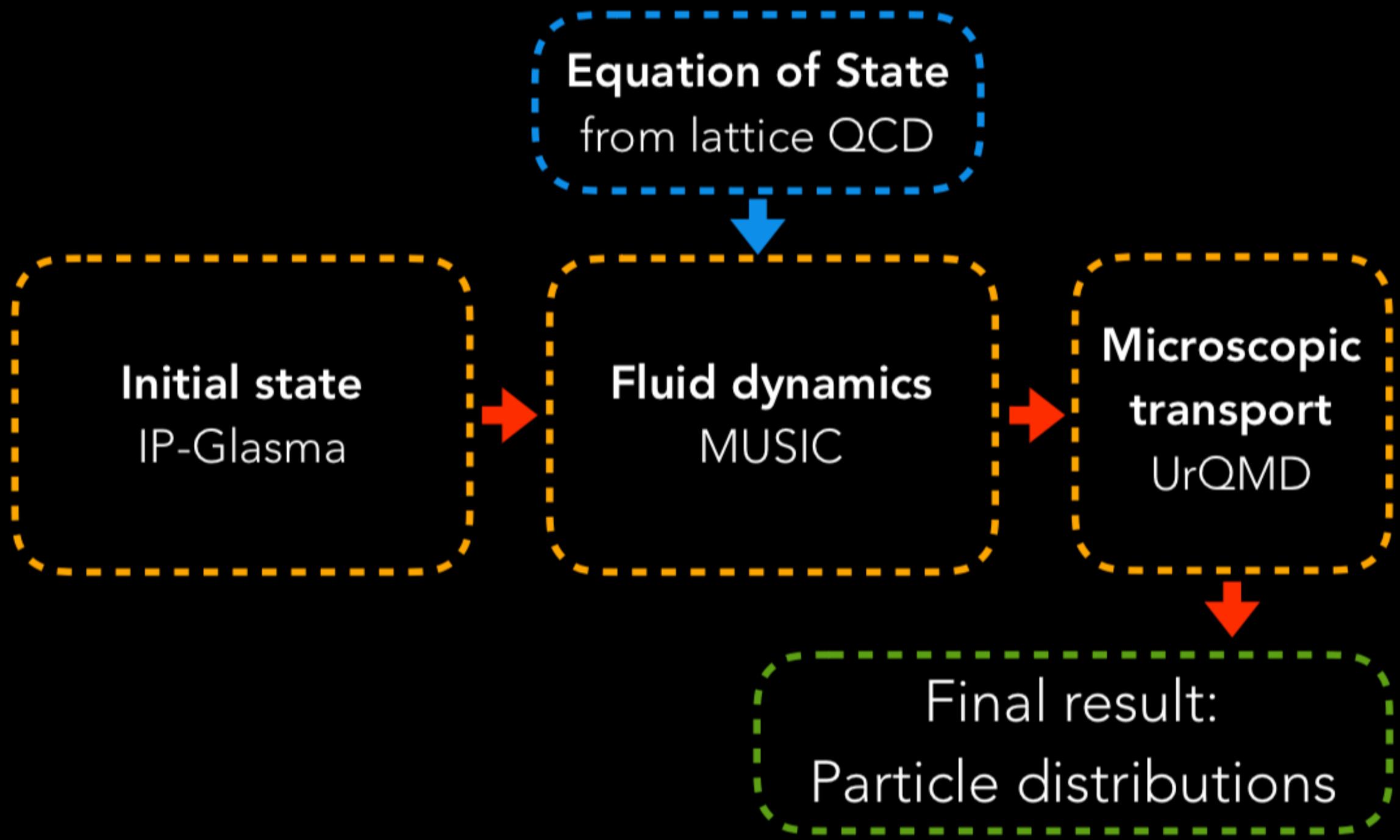
BJÖRN SCHENKE, CHUN SHEN, PRITHWISH TRIBEDY

DYNAMICAL MODELING OF SMALL SYSTEMS

Mar. 14, 2019 Rice University

Small Systems workshop

The hybrid theoretical Framework



Matching to fluid dynamics

Passing the system's full energy momentum tensor,

$$T^{\mu\nu}_{\mathrm{CYM}} = T^{\mu\nu}_{\mathrm{hydro}}$$

In the hydro phase, the energy momentum tensor can be decomposed as,

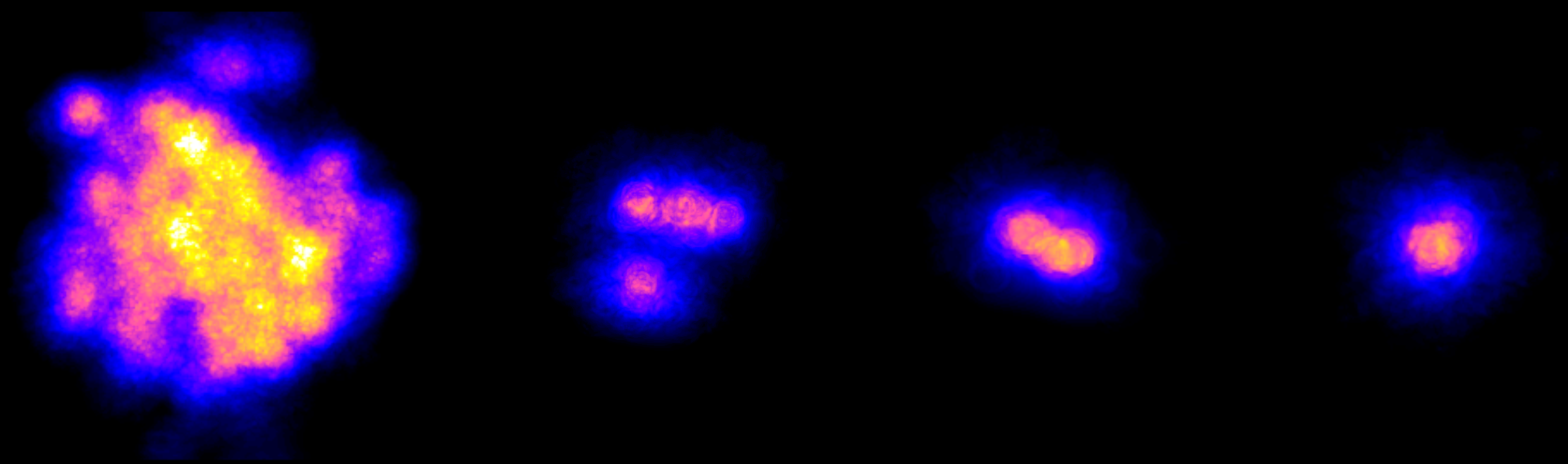
Landau Matching $$u_\mu T^{\mu\nu}_{\mathrm{hydro}} = e u^\nu$$

Shear $$\pi^{\mu\nu} = T^{\mu\nu}_{\mathrm{CYM}} - \frac{4}{3} e u^\mu u^\nu + \frac{e}{3} g^{\mu\nu}$$

Bulk $$\Pi = \frac{e}{3} - P(e)$$

Lattice EoS

Extrapolate from AA to pA



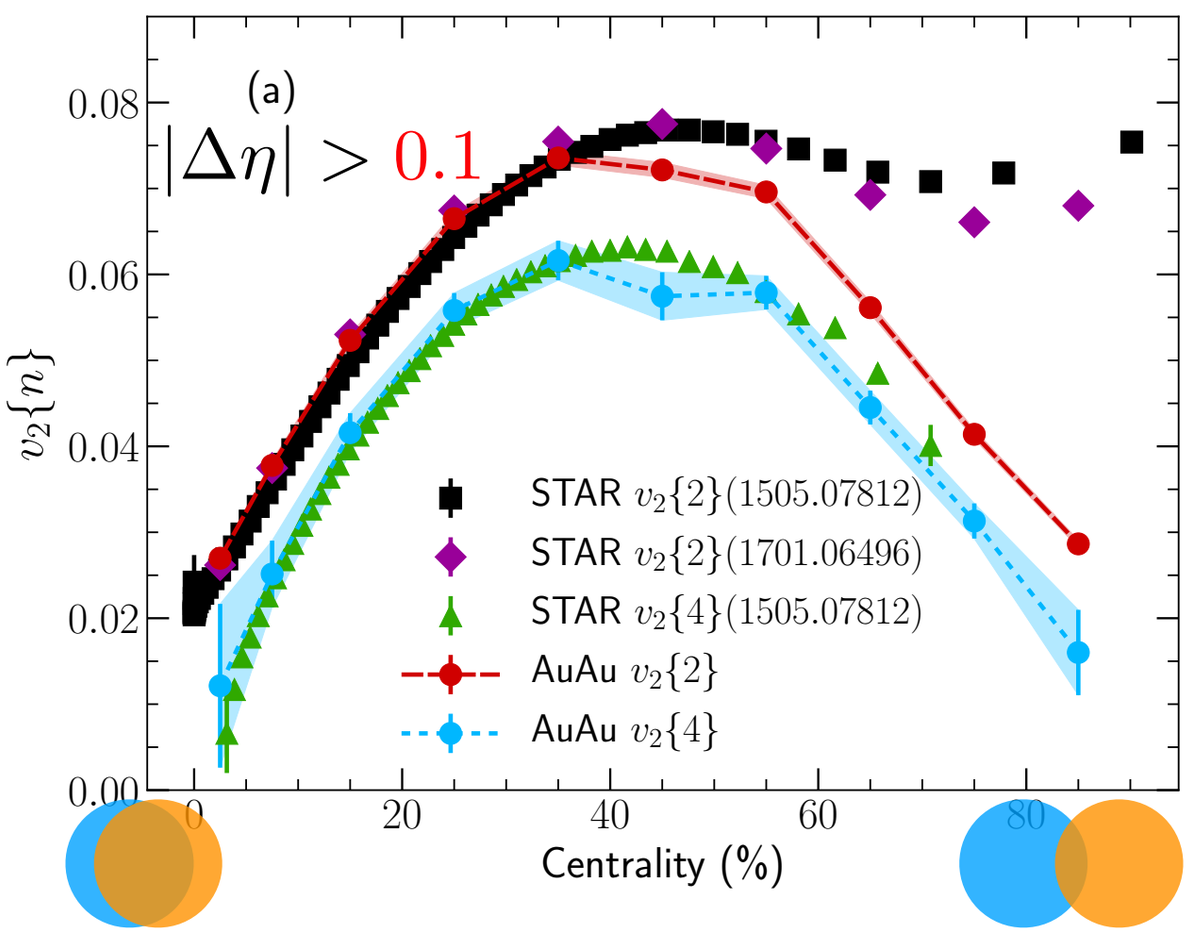
Au+Au ^{3}He+Au d+Au p+Au

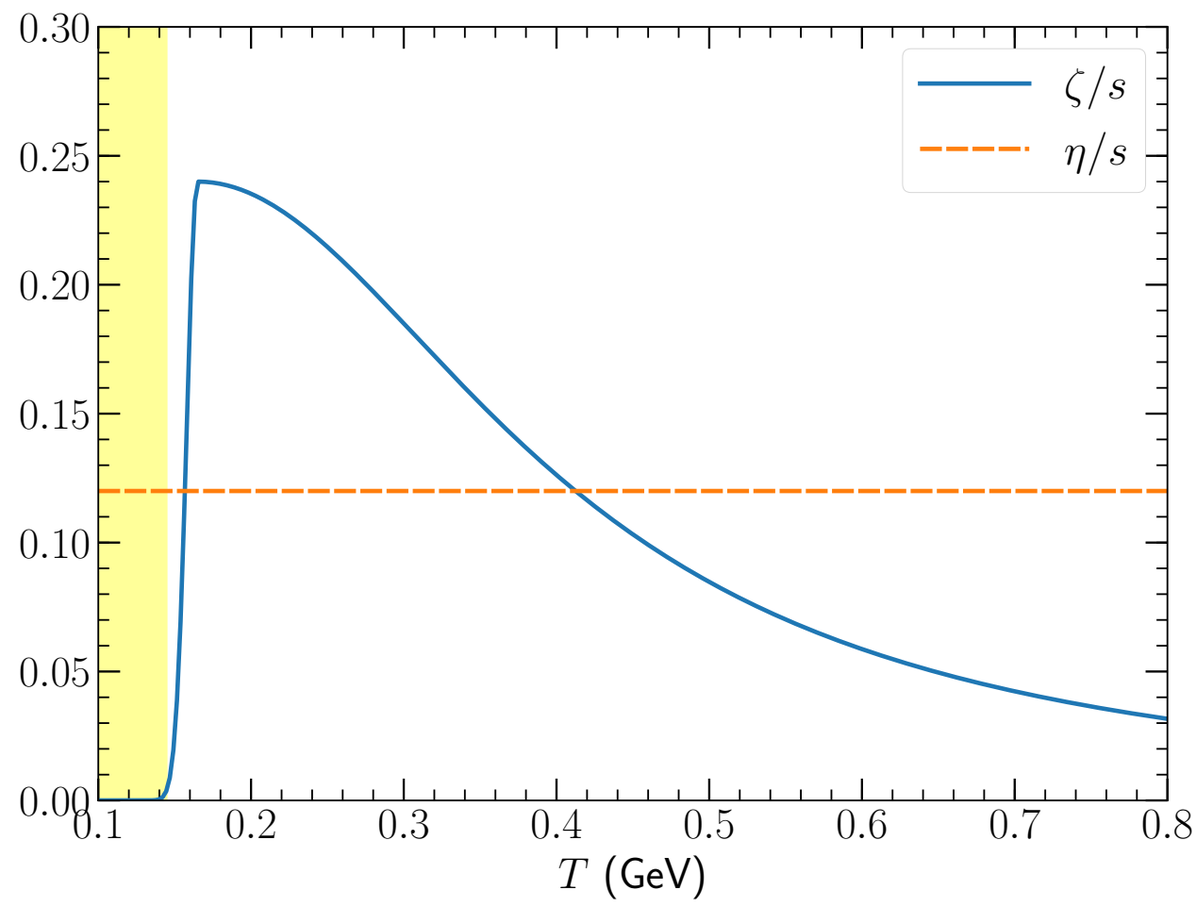
elucidate initial state vs. final state interactions

Anisotropic flow coefficients

Au+Au

B. Schenke, C. Shen, and P. Tribedy, arXiv: 1901.04378

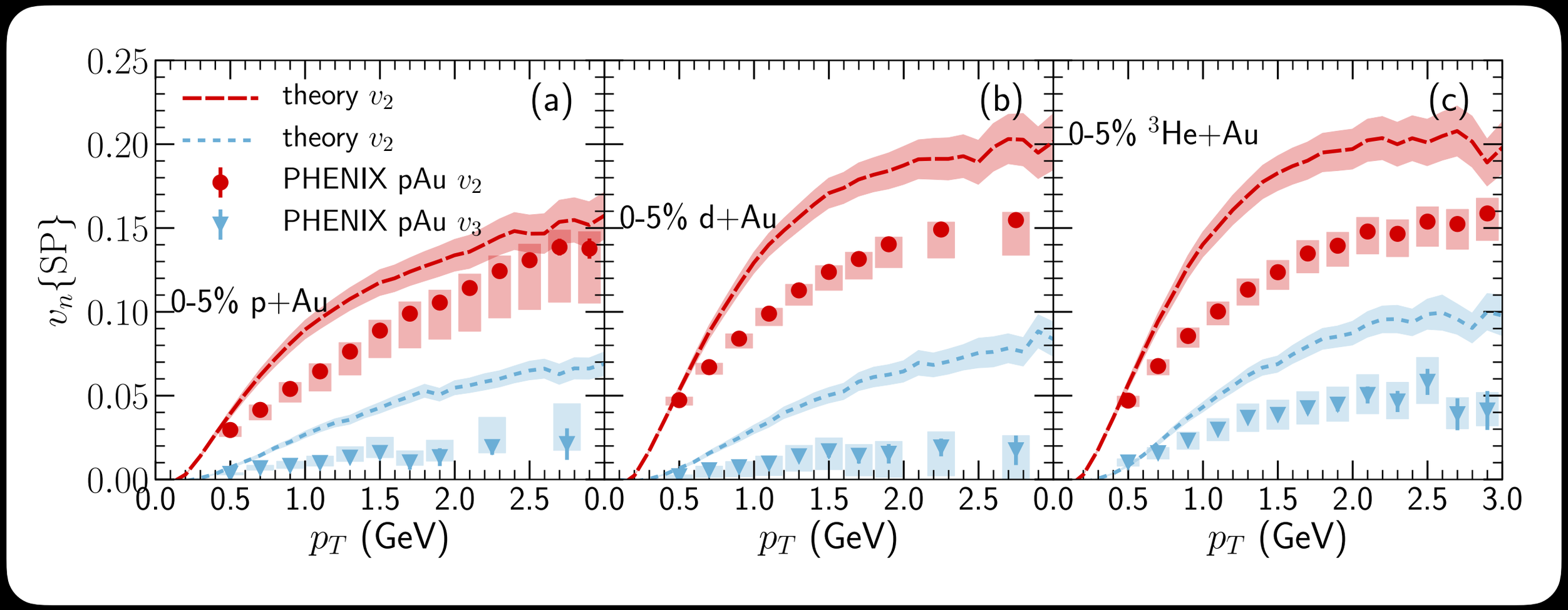




- Good agreement with $v_2\{4\}$ suggests sizable non-flow contribution in peripheral $v_2\{2\}$ measurements

v_n in central pAu, dAu, and ^{3}HeAu

B. Schenke, C. Shen, and P. Tribedy, in preparation

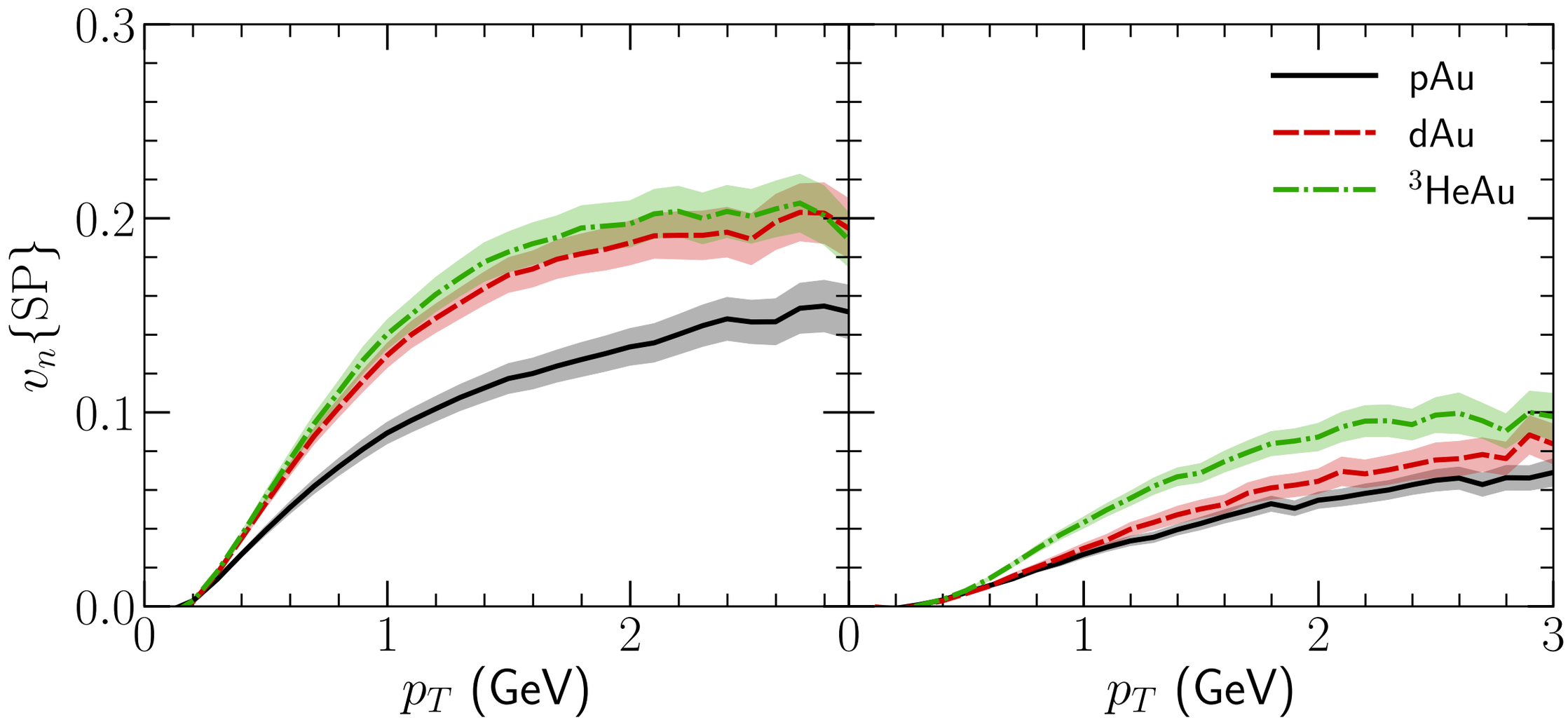


- IPGlasma + MUSIC + UrQMD over predicts v_2 and v_3 in small collision systems

open the box and understand the theory systematics

v_n in central pAu, dAu, and ^{3}HeAu

B. Schenke, C. Shen, and P. Tribedy, in preparation

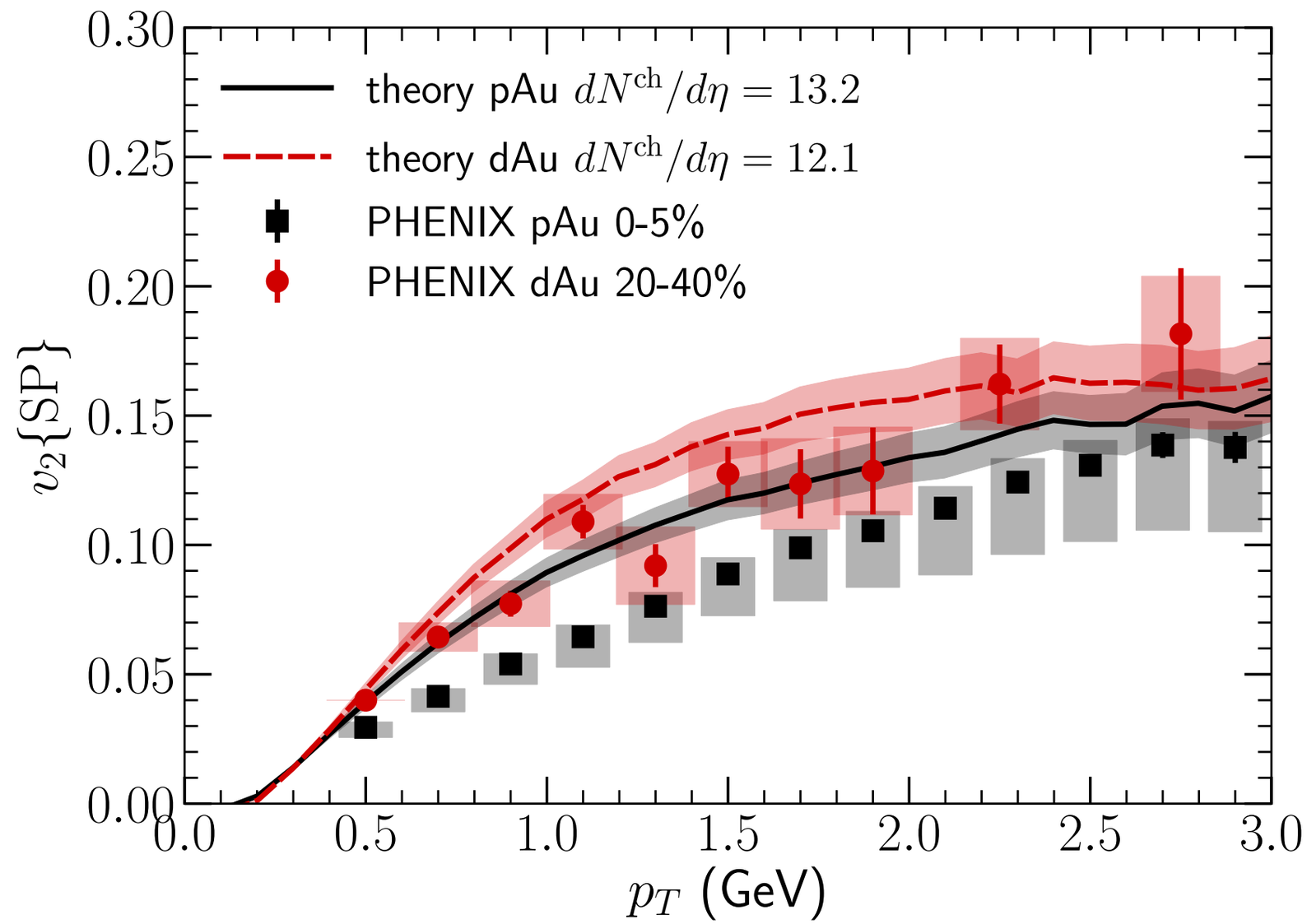


- System size hierarchy : ^{3}HeAu > dAu > pAu

Lifetime in the hydrodynamic phase

v_n of pAu vs dAu at same N_{ch}

B. Schenke, C. Shen, and P. Tribedy, in preparation

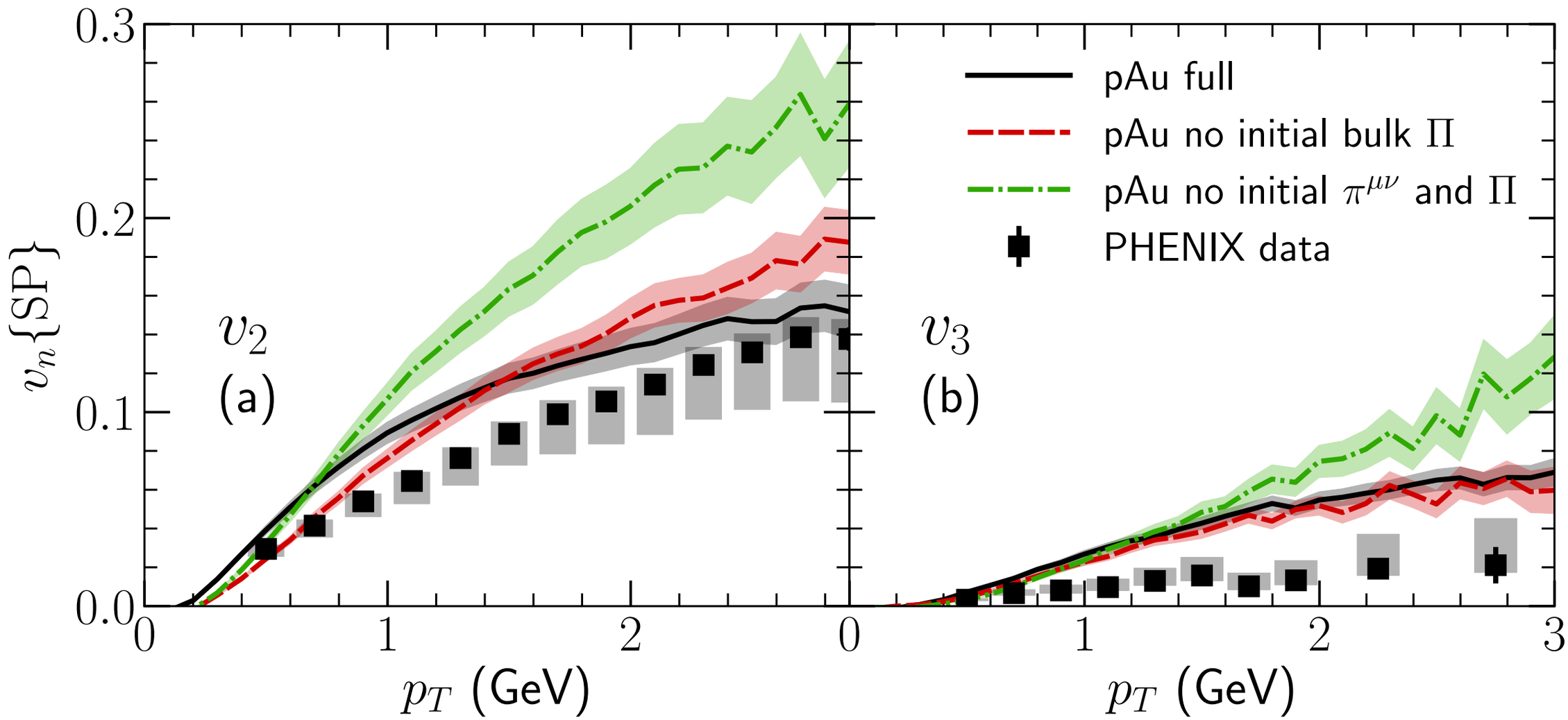


Data from PHENIX Collaboration, arXiv:1805.02973

- The difference between dAu and pAu v_2 is similar to the PHENIX measurement

Effects from initial $\pi^{\mu\nu}$ and Π

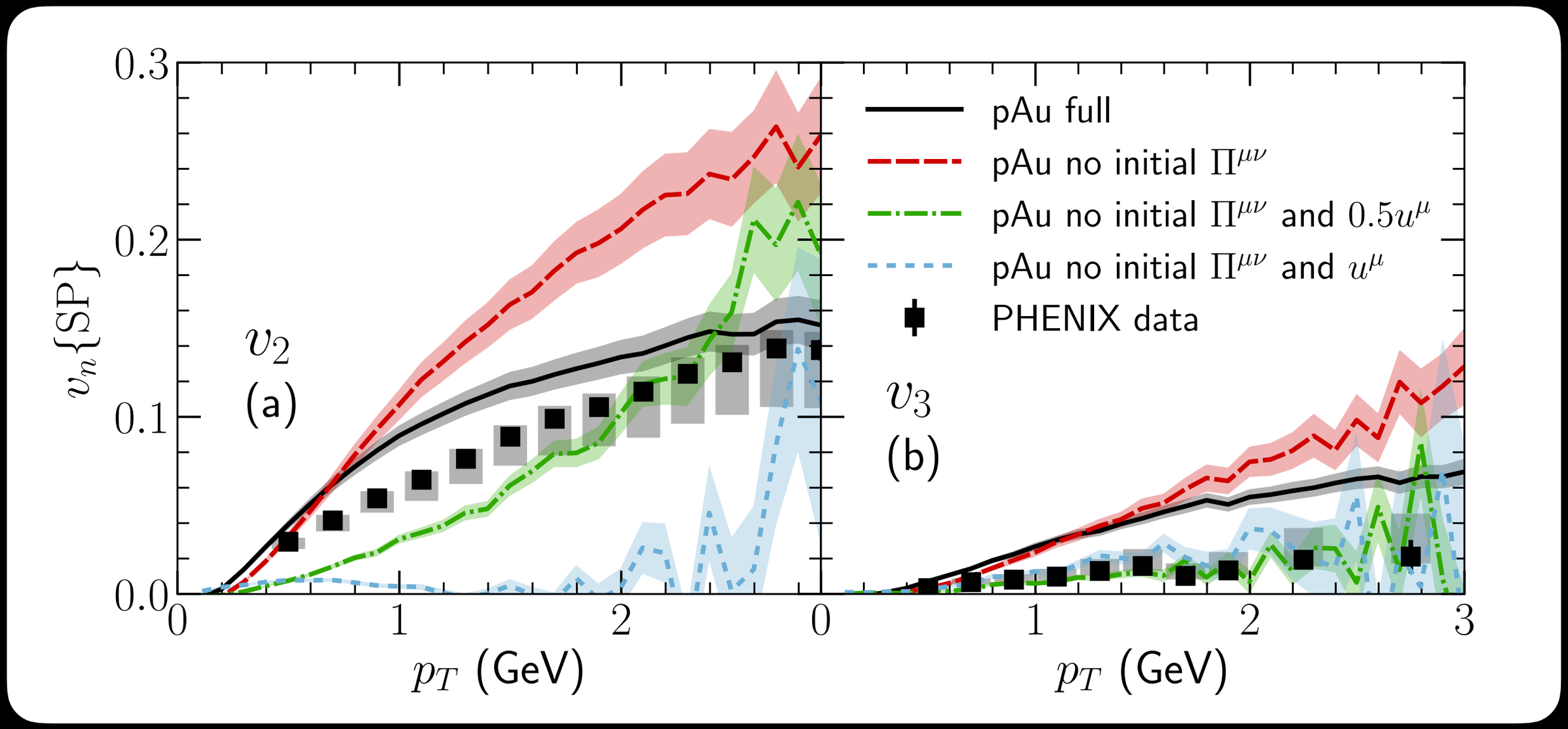
B. Schenke, C. Shen, and P. Tribedy, in preparation



- pAu v_n shows large sensitivity to pre-equilibrium evolution

Effects from initial $\Pi^{\mu\nu}$ and u^{μ}

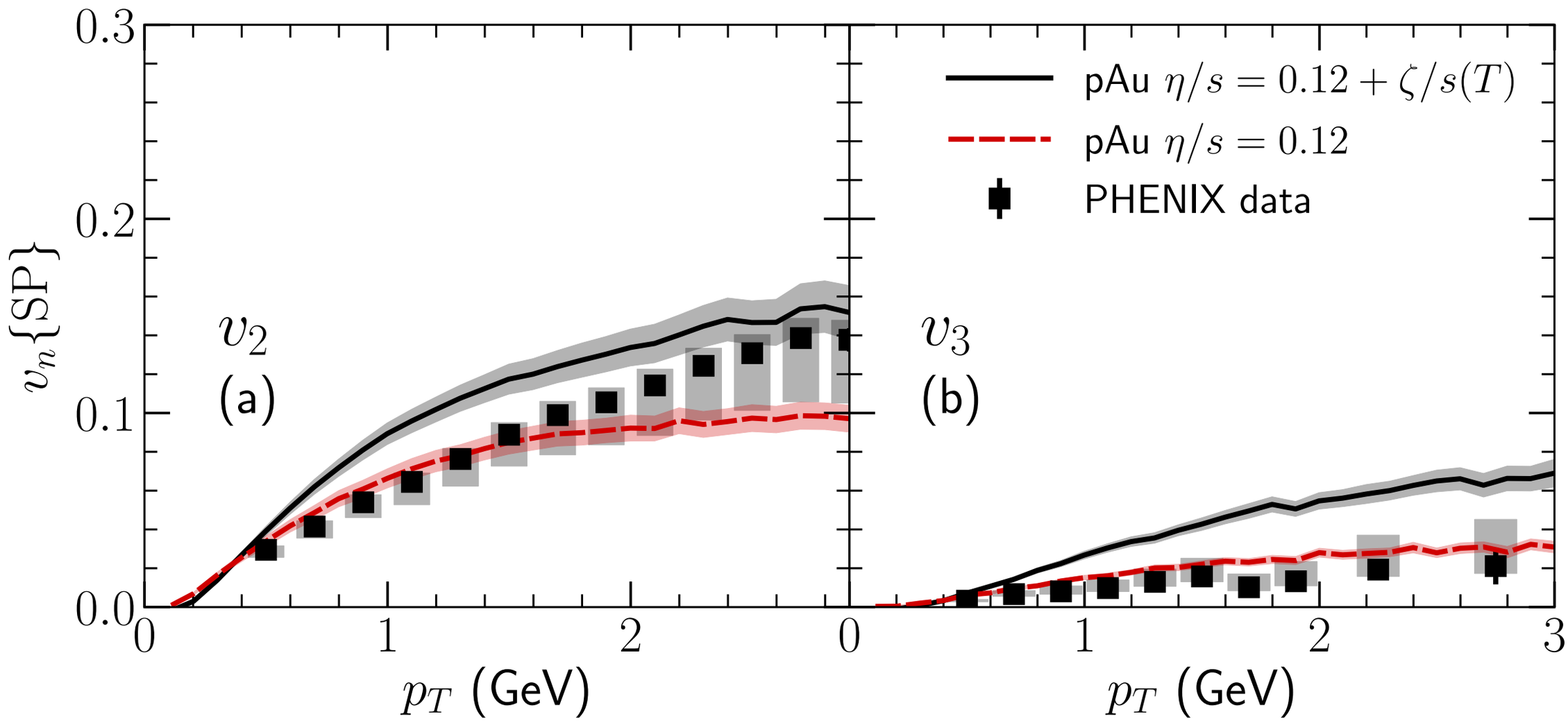
B. Schenke, C. Shen, and P. Tribedy, in preparation



- pAu v_n shows large sensitivity to pre-equilibrium evolution

Effects of bulk viscosity

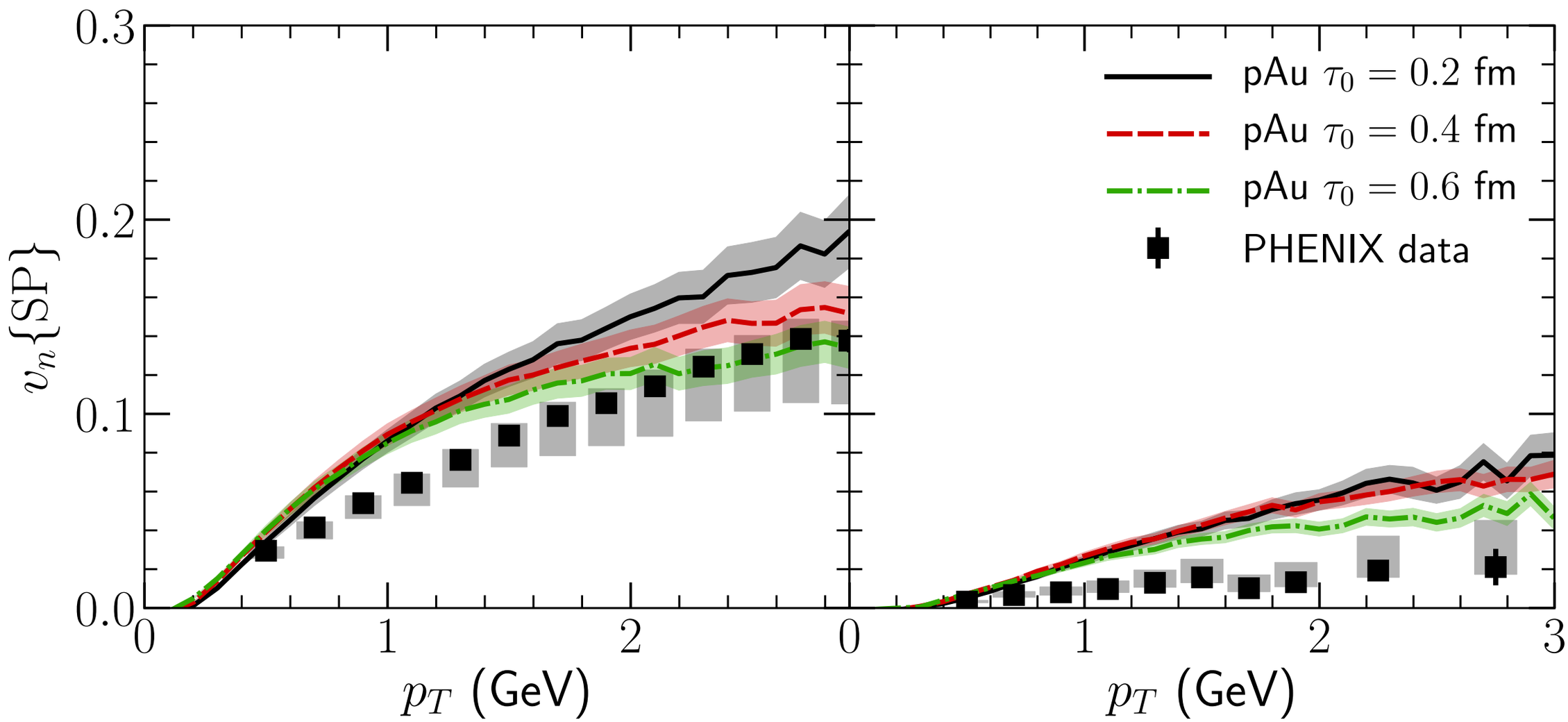
B. Schenke, C. Shen, and P. Tribedy, in preparation



	Shear + Bulk	Shear only
$\langle p_T \rangle$ (GeV)	0.628	0.902
v_2	0.051	0.050
v_3	0.013	0.011

Sensitivity to hydro starting time τ_0

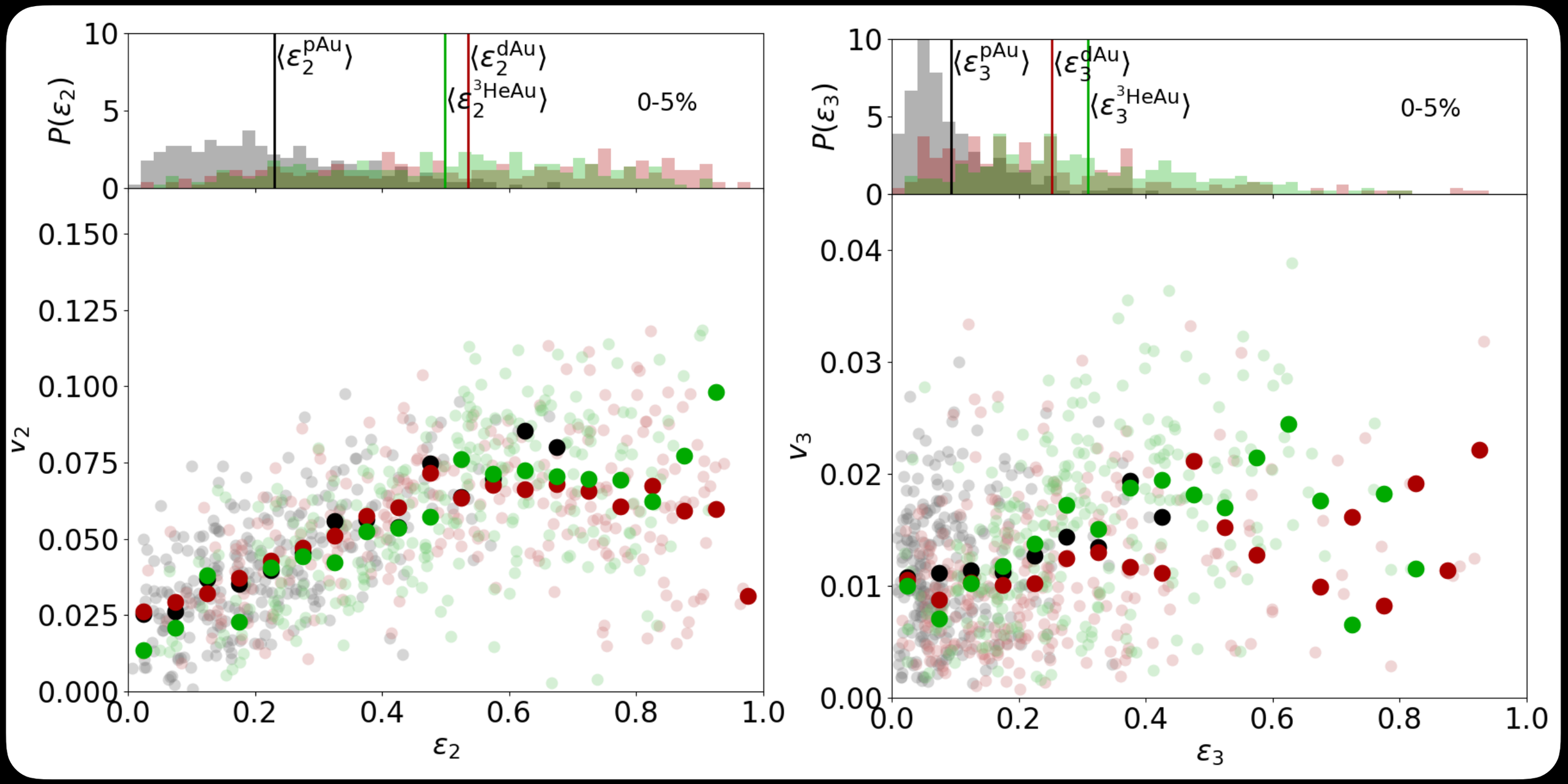
B. Schenke, C. Shen, and P. Tribedy, in preparation



- With matching the full $T^{\mu\nu}$ tensor, flow coefficients show little dependence on τ_0

Geometry driven flow?

B. Schenke, C. Shen, and P. Tribedy, in preparation



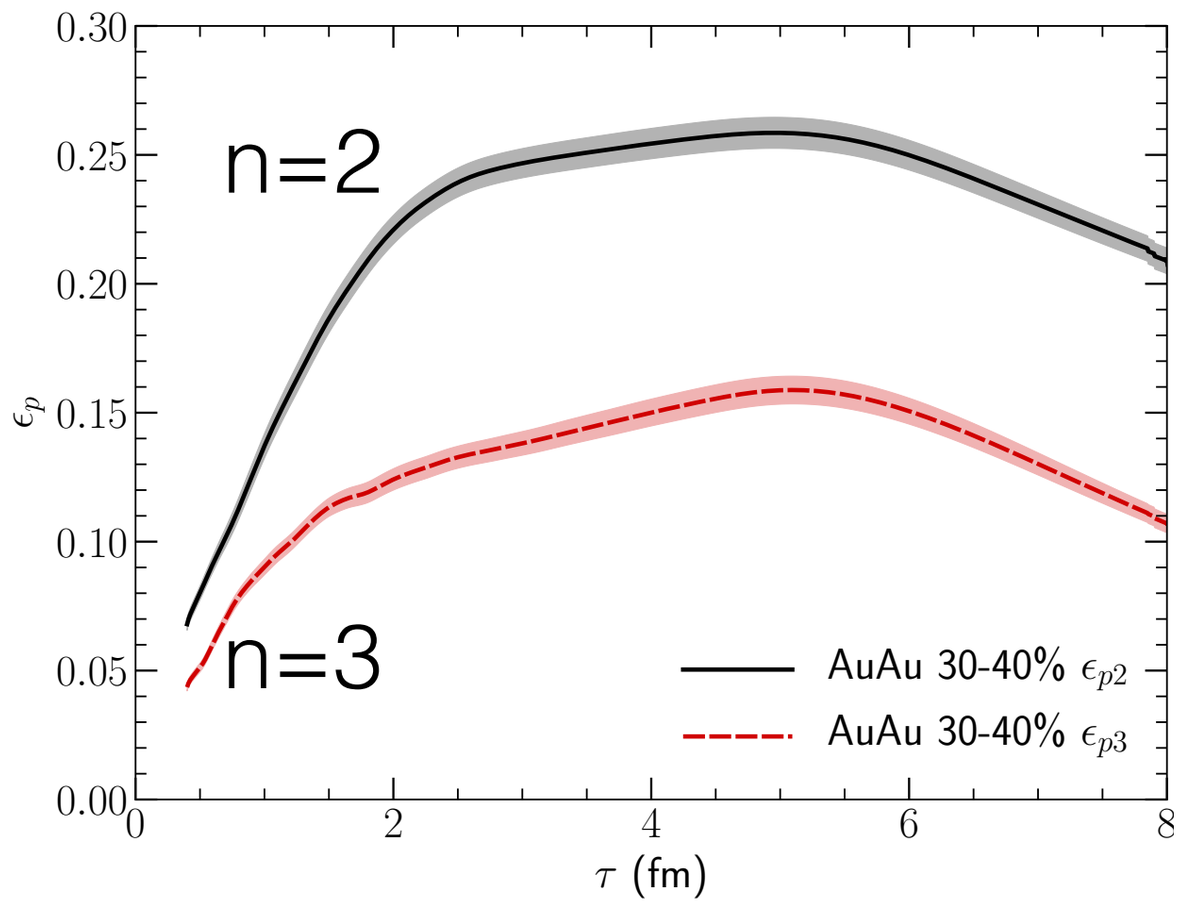
$v_2 \propto \epsilon_2$

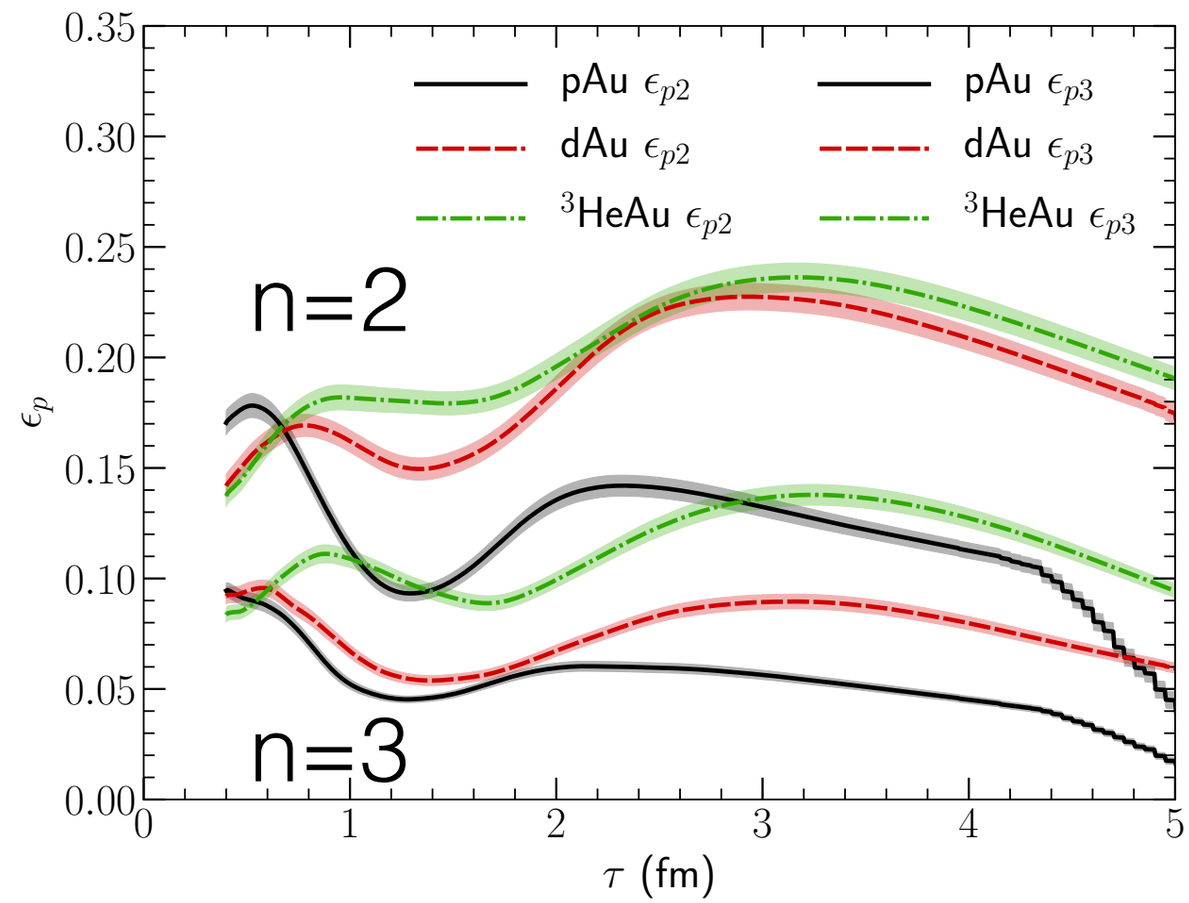
$v_3 \propto \epsilon_3$?

What drives v_3 in small systems?

Evolution of momentum anisotropy

B. Schenke, C. Shen, and P. Tribedy, in preparation



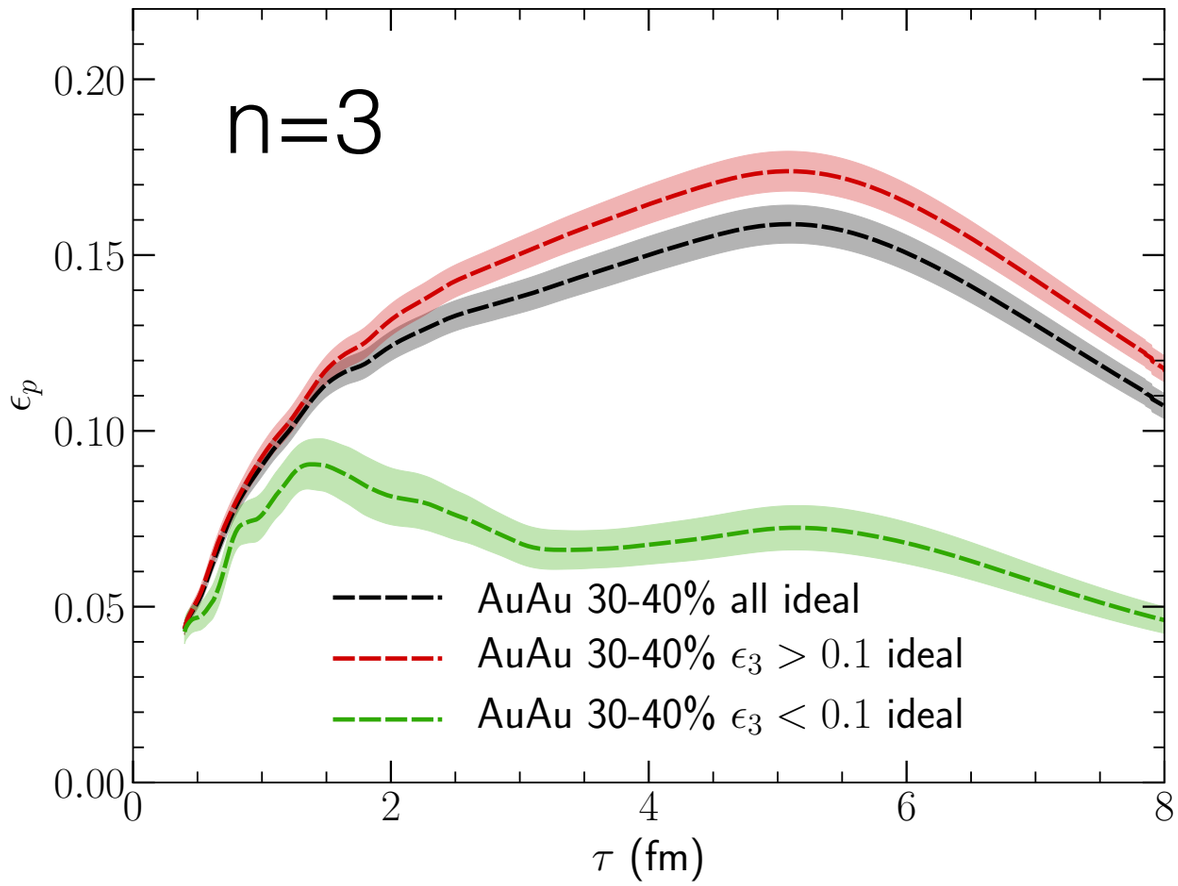


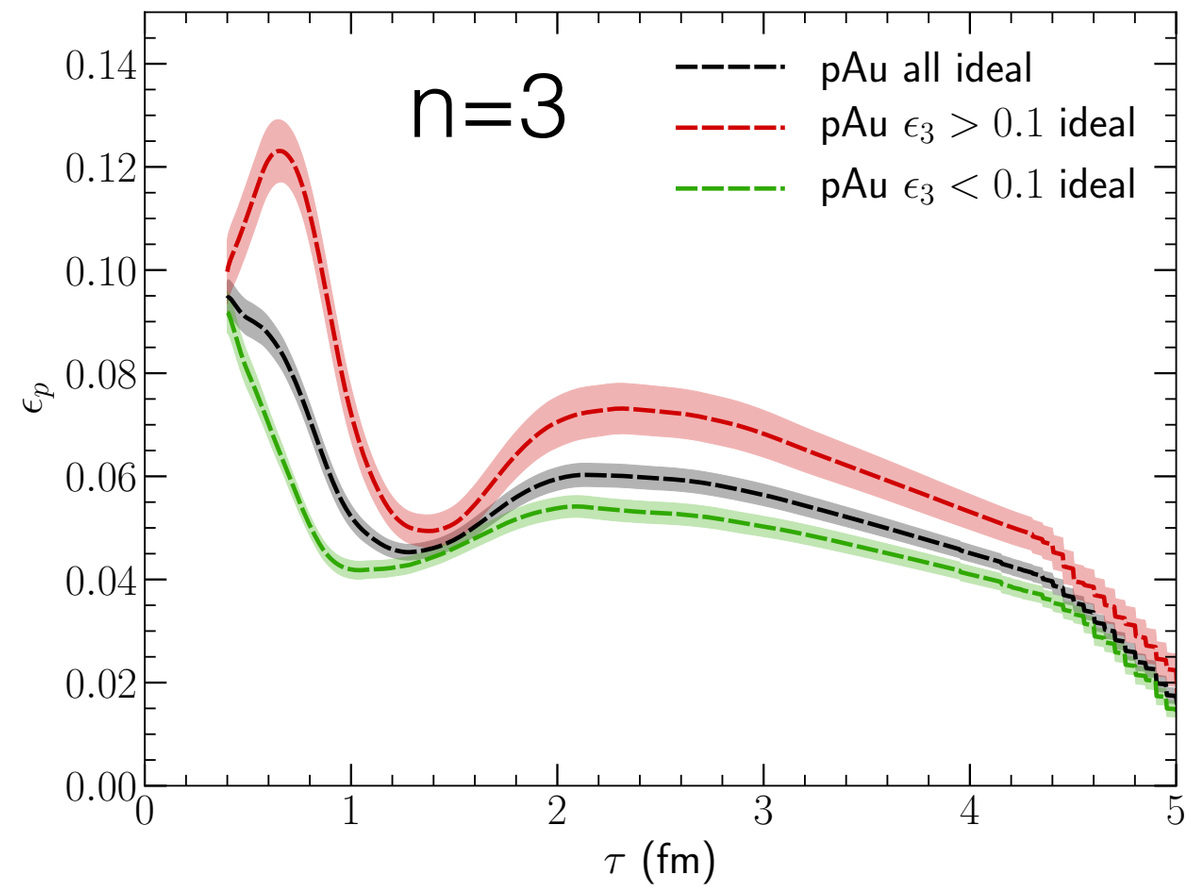
- In the IP-Glasma phase ε_{pn}: pAu > dAu > ^{3}HeAu > AuAu

$$\epsilon'_{pn} = \sqrt{\frac{\langle T^{0r} cos(n\phi_u)\rangle^2 + \langle T^{0r} sin(n\phi_u)\rangle^2}{\langle T^{0r}\rangle^2}}$$

Evolution of momentum anisotropy

B. Schenke, C. Shen, and P. Tribedy, in preparation





- In the IP-Glasma phase ε_{pn}: pAu > dAu > ^{3}HeAu > AuAu
- Hydrodynamic response to geometry develops around $\tau \sim 2$ fm/c in AuAu collisions

Conclusions

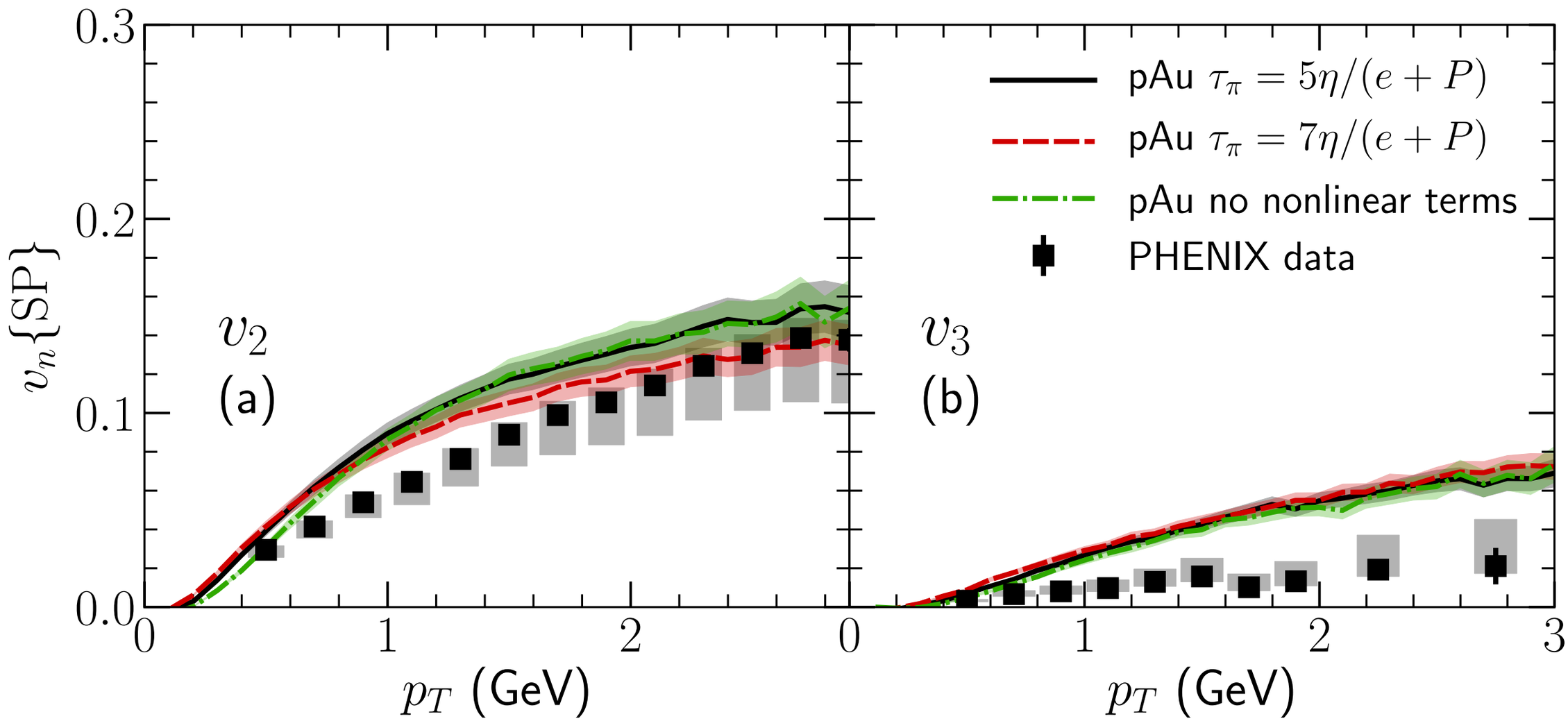
- The anisotropic flow coefficients v_n in small systems show *large* sensitivity to the pre-equilibrium evolution

Initial flow u^μ and $\Pi^{\mu\nu}$

- In pAu, the correlation between ε_3 and v_3 is very weak

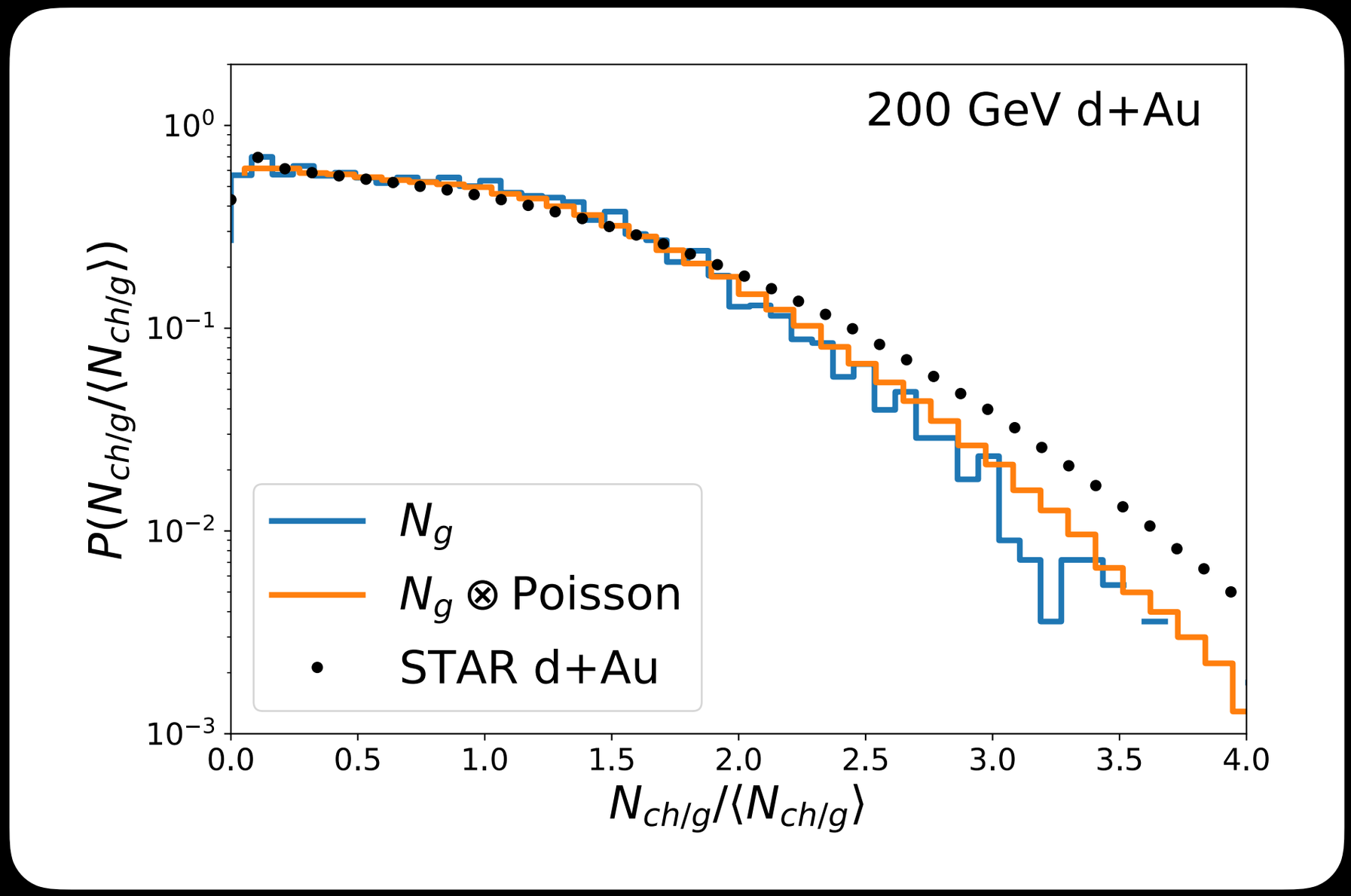
Effects from shear relaxation time

B. Schenke, C. Shen, and P. Tribedy, in preparation



RHIC system scan

B. Schenke, C. Shen, P. Tribedy, in preparation

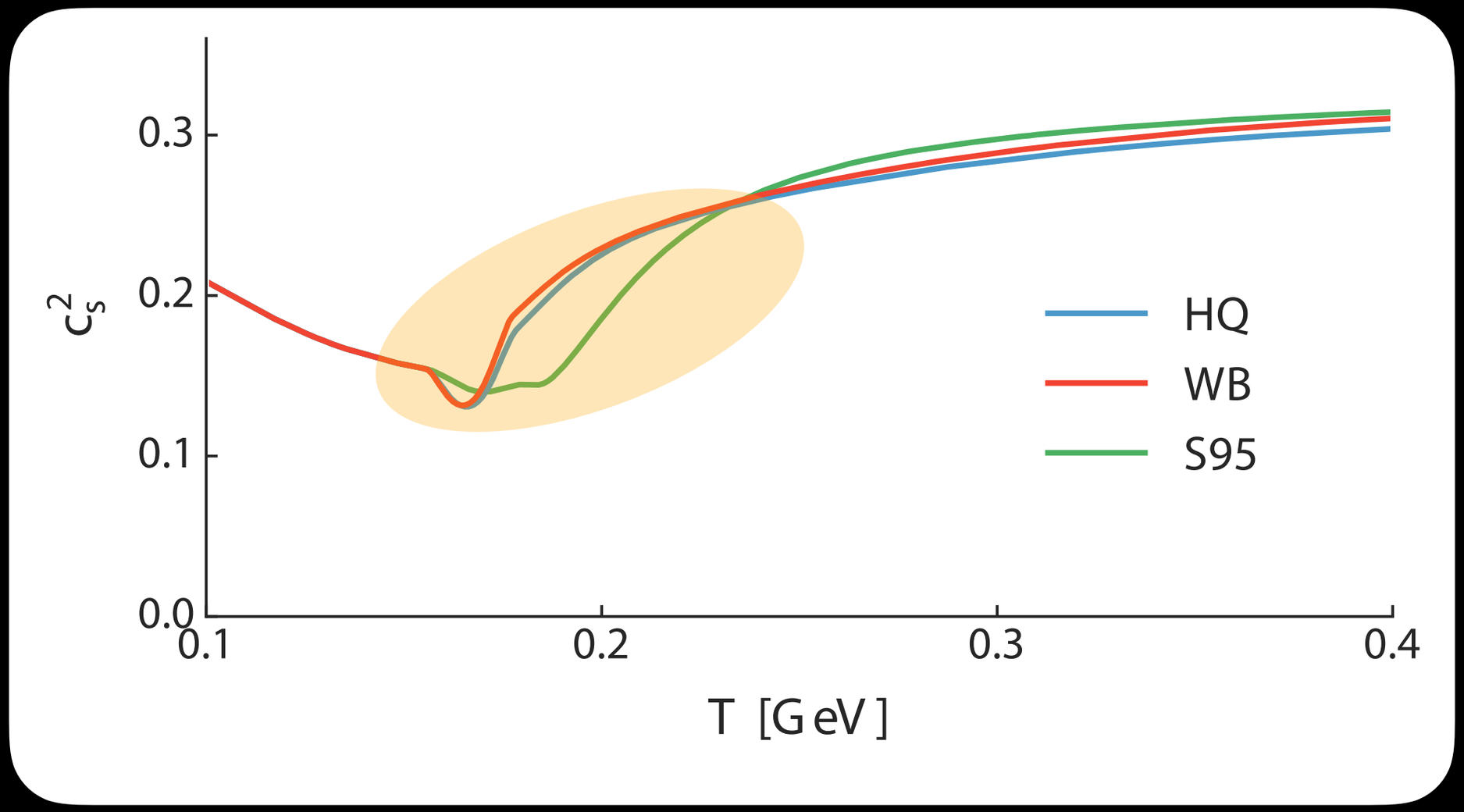


Multiplicity distribution: d+Au 200 GeV

Equation of State

Use the latest EoS constructed from (HotQCD) LQCD data

Larger speed of sound compared to s95p leads to more flow



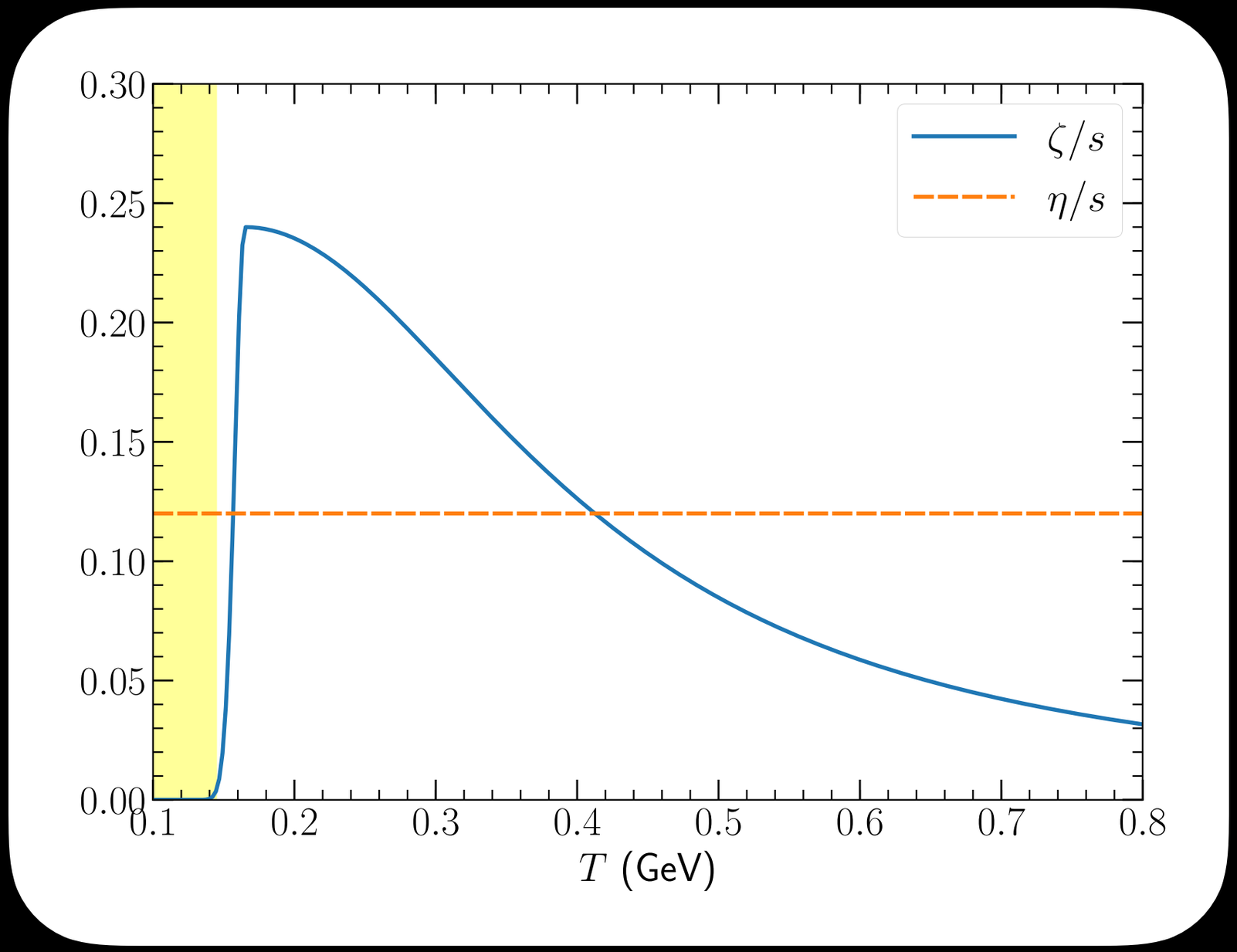
Affects extraction of viscosities: v_n change by 10% η/s needs to change by ~50%

Figure from J.S. Moreland, R.A. Soltz, Phys.Rev. C93, 044913 (2016), also see P. Alba et al. arXiv:1711.05207

Shear and bulk viscosities

$(\eta/s)_{eff}$=0.12

(up from 0.095 used earlier because of changes in EoS)



Bulk viscosity

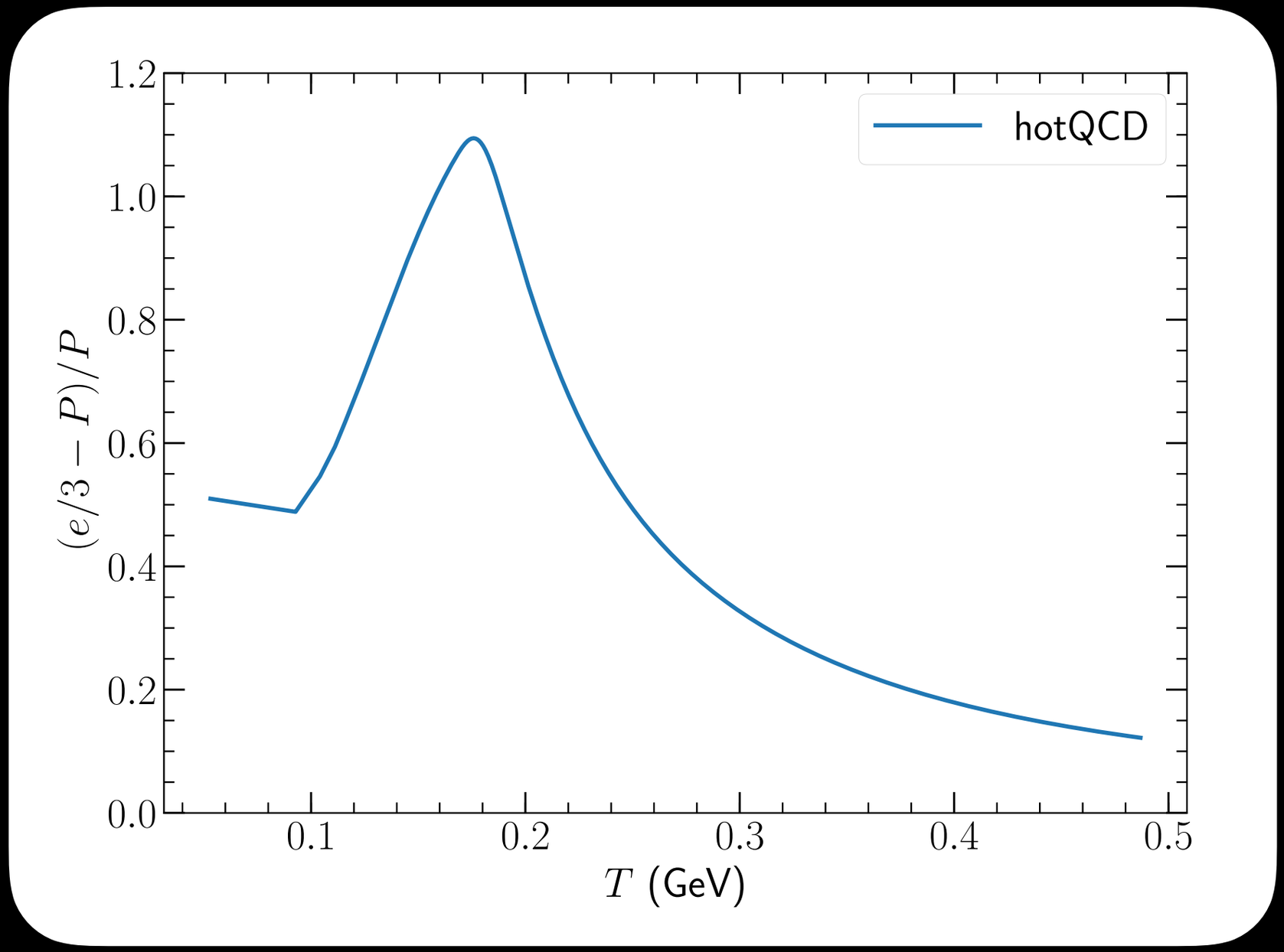
Peaks at 165 MeV

A wide peak as a function temperature

Yellow region is simulated microscopically by UrQMD

Initial bulk viscous pressure

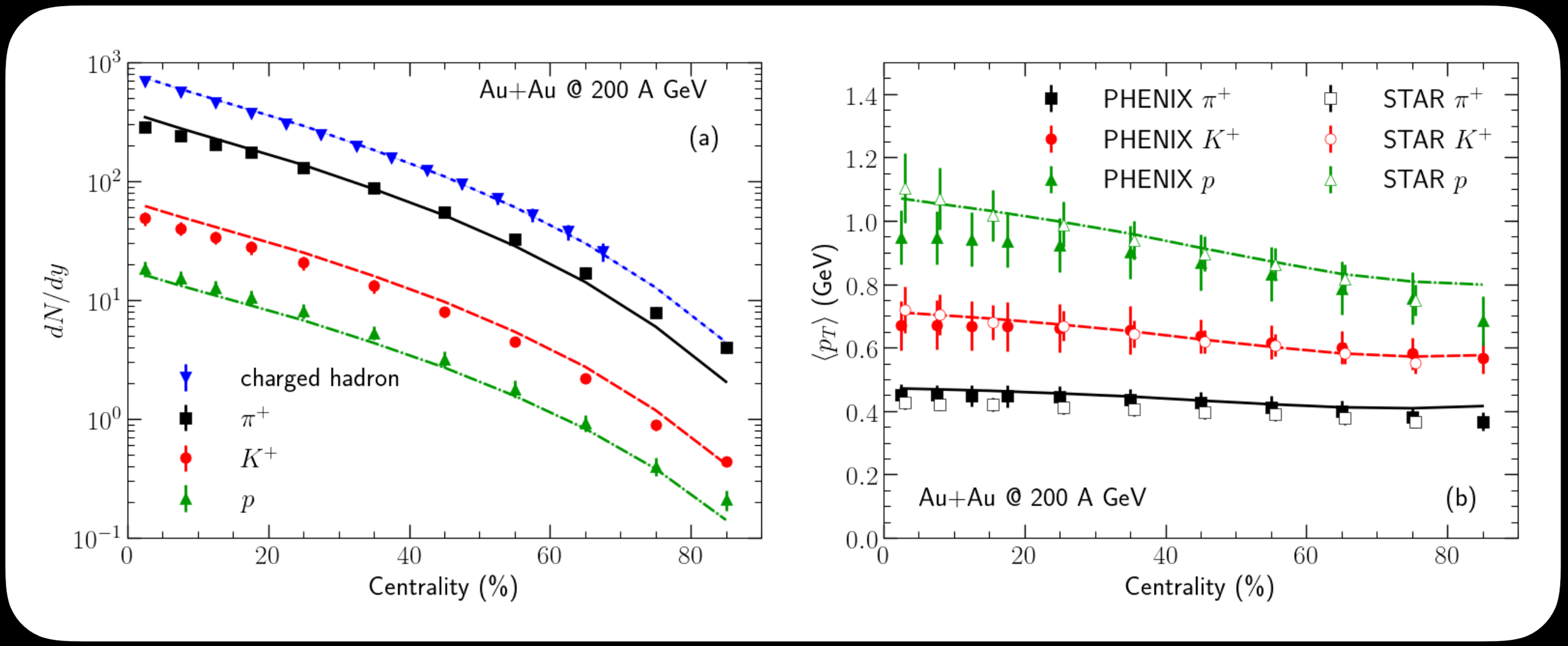
- In our model, the initial bulk viscous pressure is caused by the abrupt change of EoS between CYM and hydrodynamics



- Initial Π is positive and large compared to thermal pressure

Particle yields and mean p_T

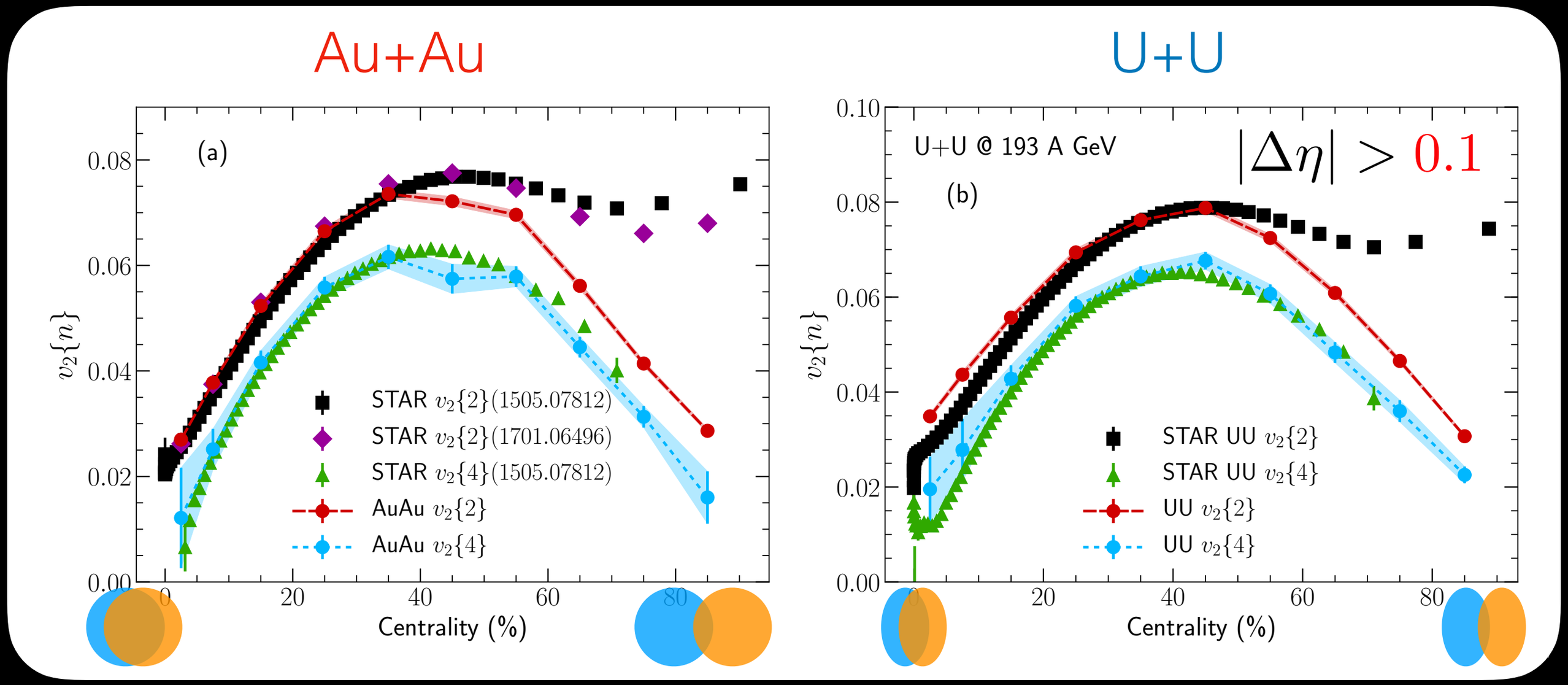
B. Schenke, C. Shen, and P. Tribedy, arXiv: 1901.04378



- The temperature dependence of bulk viscosity can reproduce particle mean p_T measurements from RHIC to LHC

Anisotropic flow coefficients

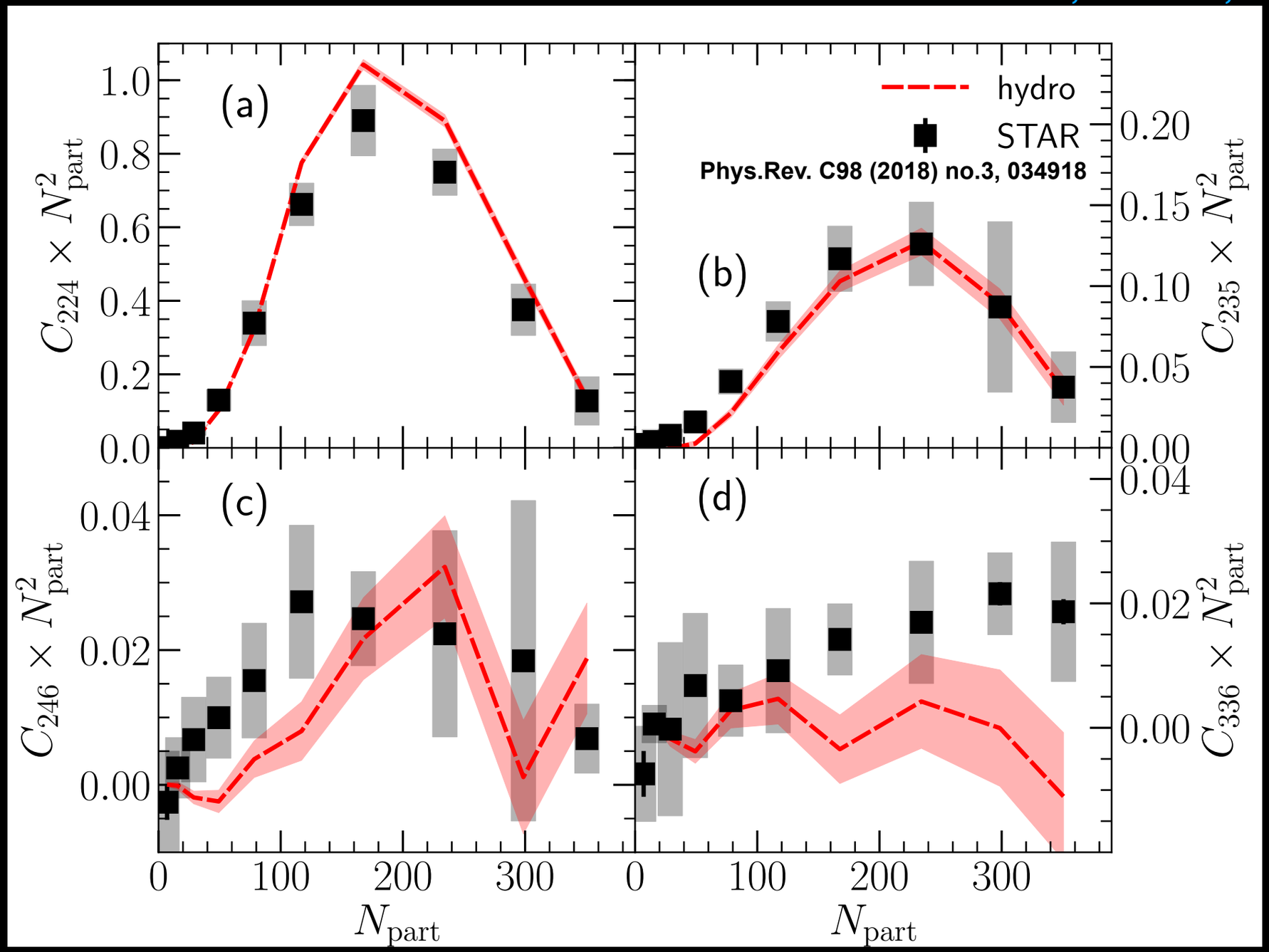
B. Schenke, C. Shen, and P. Tribedy, arXiv: 1901.04378



- Good agreement with $v_2\{4\}$ suggests sizable non-flow contribution in peripheral $v_2\{2\}$ measurements

Three-particle correlations

B. Schenke, C. Shen, and P. Tribedy, arXiv: 1901.04378



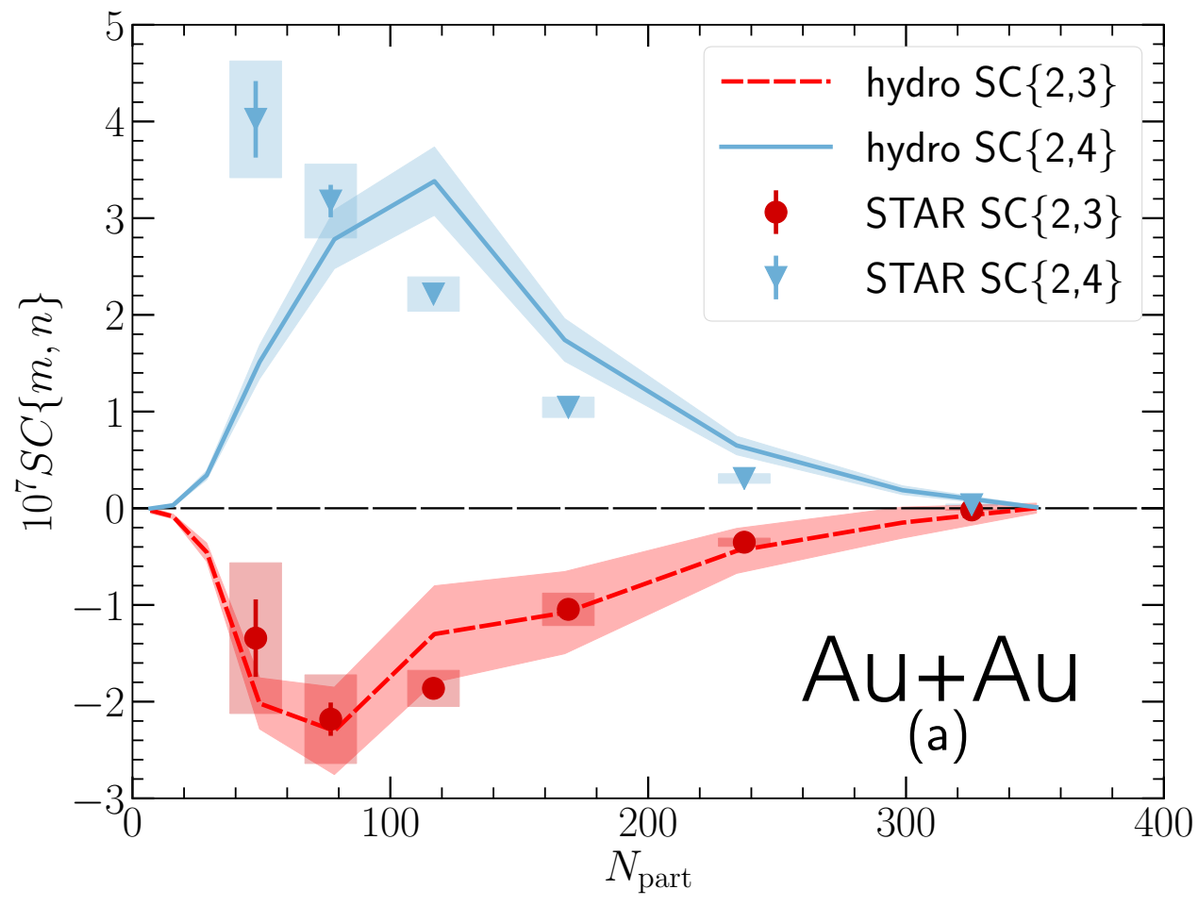
$$C_{nmk} \propto \langle V_n V_m V_k^* \rangle$$

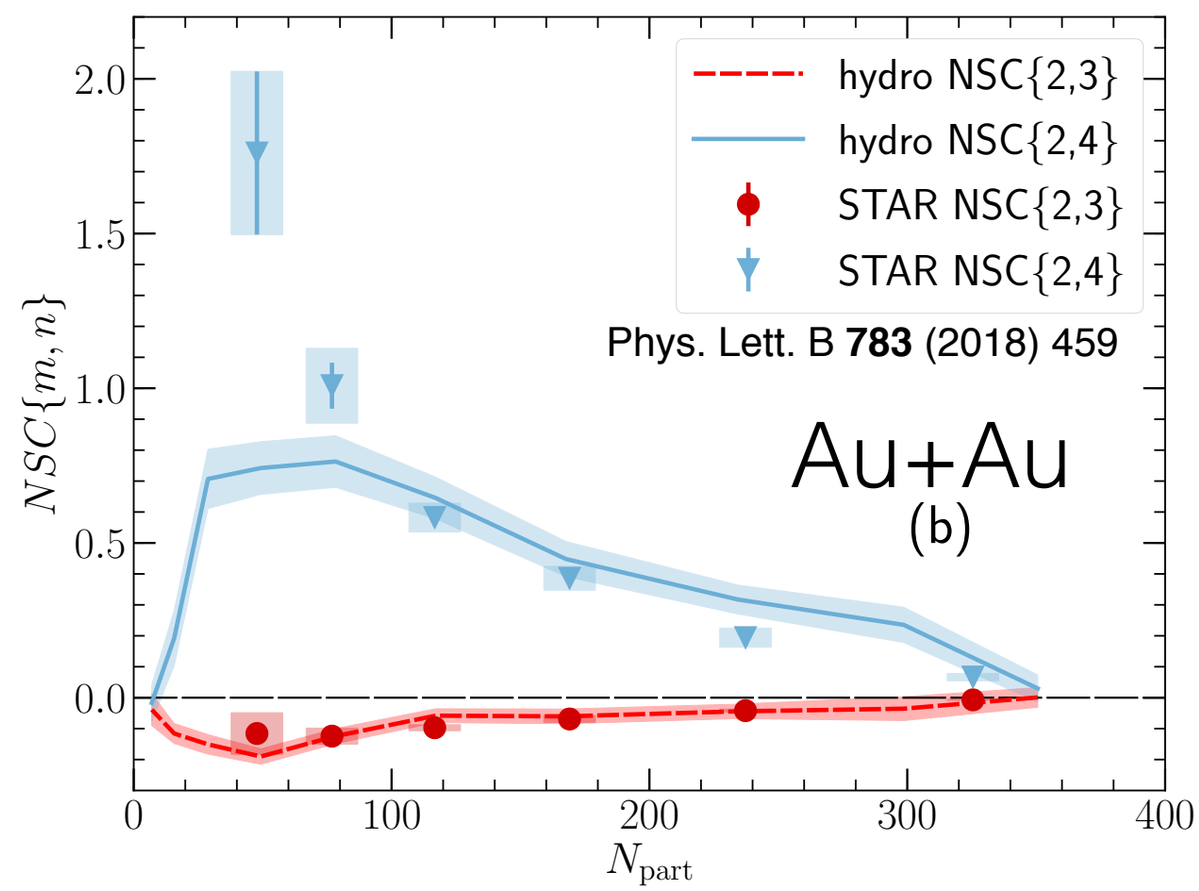
$$k = m + n$$

- Hydrodynamics captures correlations between different v_n coefficients

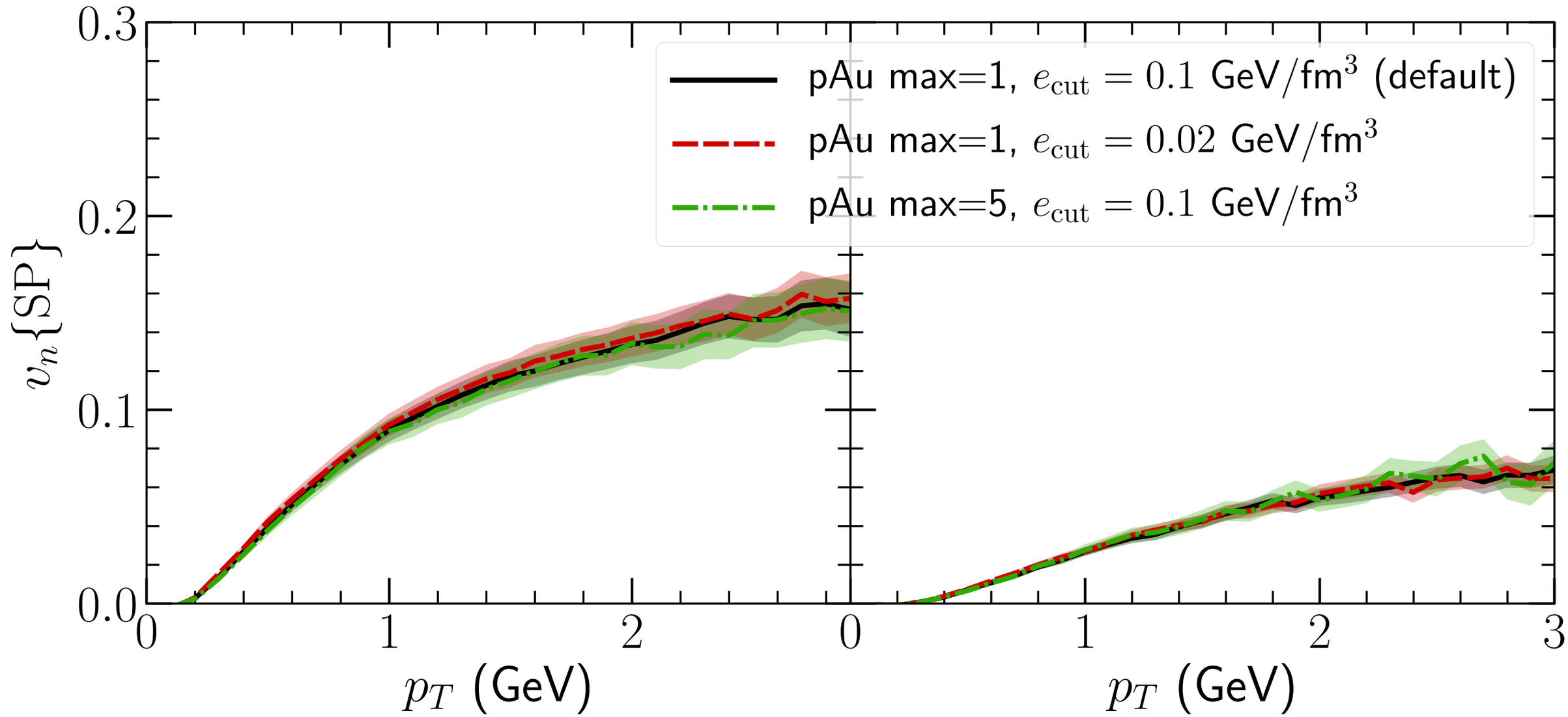
Four-particle correlation

B. Schenke, C. Shen, and P. Tribedy, arXiv: 1901.04378





$$SC\{m,n\} = \langle V_n V_n^* V_m V_m^* \rangle - \langle V_n V_n^* \rangle \langle V_m V_m^* \rangle; \; NSC\{m,n\} = \frac{SC\{m,n\}}{\langle V_n V_n^* \rangle \langle V_m V_m^* \rangle}$$

- Hydrodynamics captures fluctuations and correlations between different v_n coefficients

Test for regulation strength