Measurements of v_2,v_3 at mid-rapidity in p+Au, d+Au and ^{3}He+Au collisions at 200 GeV

Shengli Huang

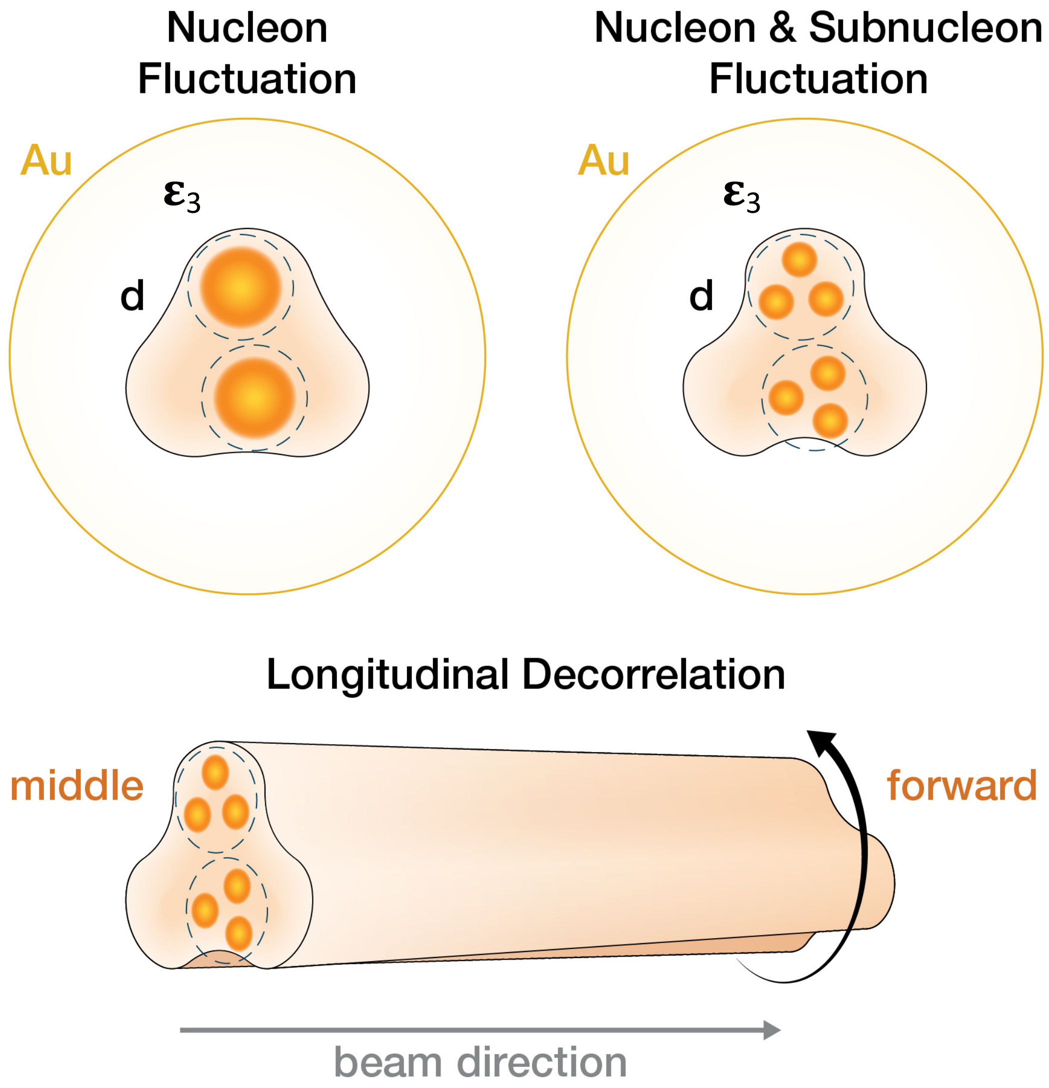
Outline:

- Introductions and Motivations
- Two-particle correlations at mid-rapidity
- Model Comparison and Discussion
- Summary

Stony Brook University

In part supported by U.S. DEPARTMENT OF ENERGY Office of Science

Initial Geometry in small system



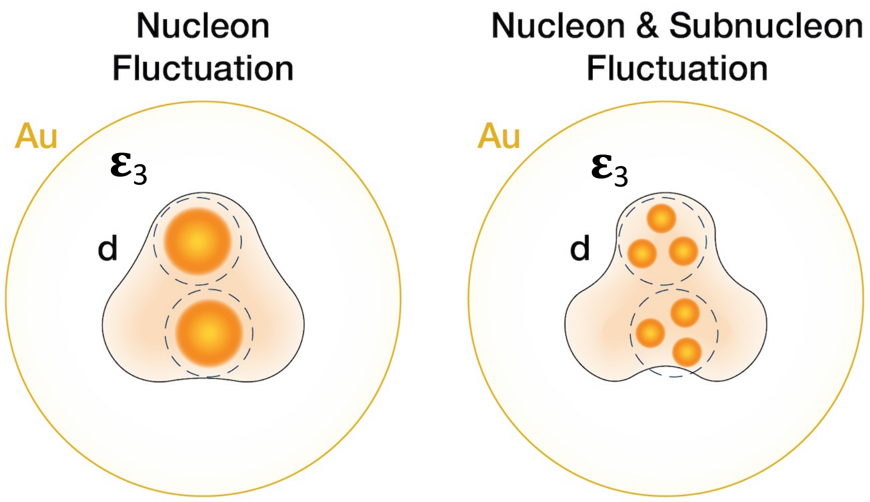
Interplay between three possible sources:

1) Fluctuations in nucleon position

2) Fluctuations in nucleon position and its quark and gluon constituents

3) Fluctuation of overlap geometry along the beam direction

Nucleon vs. sub-nucleon fluctuation



	Nucleon Glauber $\varepsilon_2(\varepsilon_3)$	Sub-Nucleon Glauber $\varepsilon_2(\varepsilon_3)$
0-5% pAu	0.23(0.16)	0.38(0.30)
0-5% dAu	0.54(0.18)	0.51(0.31)
0-5% ^{3}He+Au	0.50(0.28)	0.52(0.35)

Nucleon Glauber: J. L. Nagle, PRL 113, 112301 331 (2014).
Sub-Nucleon: K. Welsh, J. Singer, and U. Heinz, PRC 94, 334 024919 (2016).

Nucleon Fluctuations:

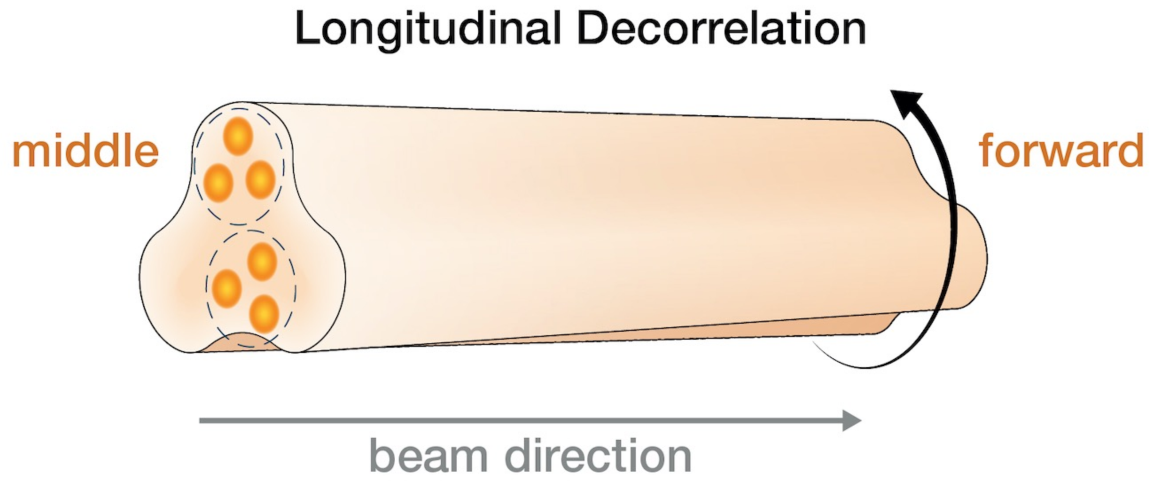
$$\epsilon_2^{p+Au} \ll \epsilon_2^{d+Au} \approx \epsilon_2^{^3He+Au}$$
$$\epsilon_3^{p+Au} \approx \epsilon_3^{d+Au} < \epsilon_3^{^3He+Au}$$

Nucleon + Subnucleon Fluctuations:

$$\epsilon_2^{p+Au} < \epsilon_2^{d+Au} \approx \epsilon_2^{^3He+Au}$$
$$\epsilon_3^{p+Au} \approx \epsilon_3^{d+Au} \approx \epsilon_3^{^3He+Au}$$

The eccentricity hierarchy is smeared by sub-nucleon fluctuation

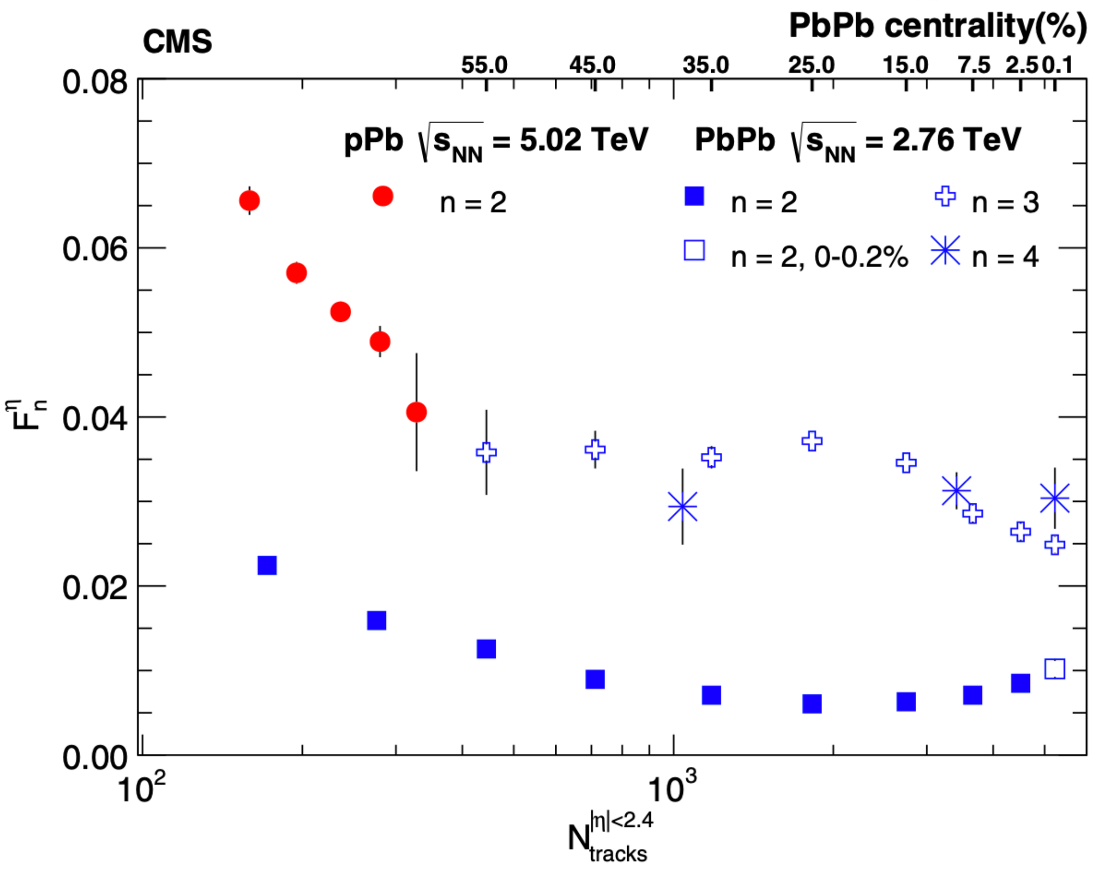
Longitudinal Decorrelation



The longitudinal decorrelation from mid to forward rapidity complicates the inference of the true initial geometry

Decorrelation is stronger for asymmetric systems (pPb > PbPb) and higher order anisotropy coefficients (for v_3 > for v_2)

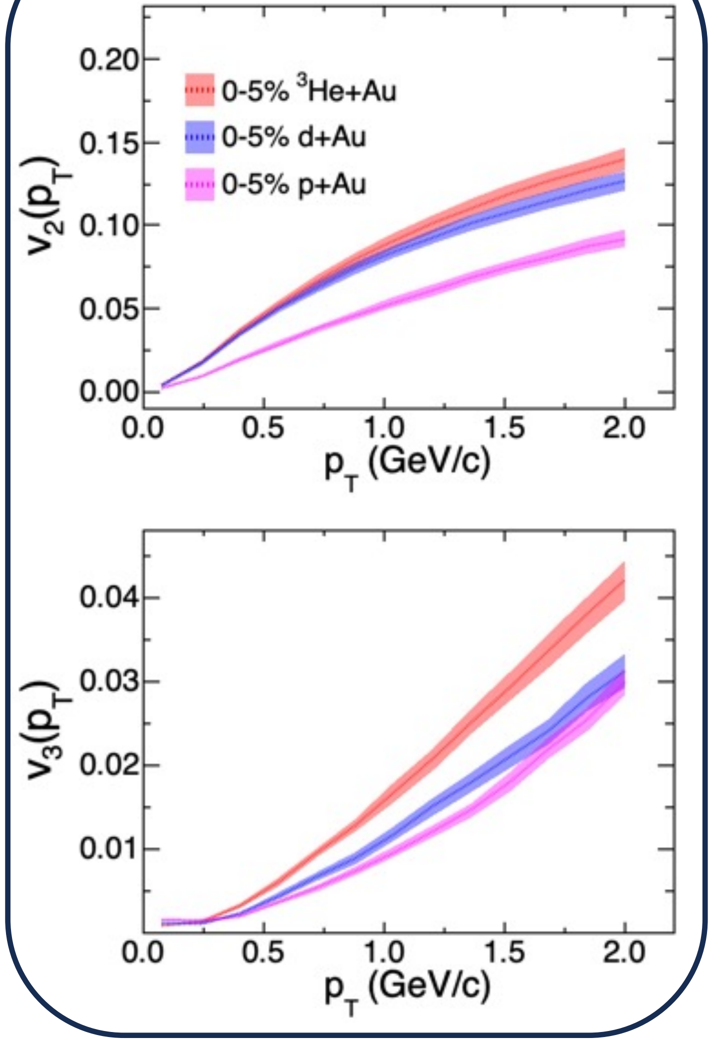
CMS:PRC 92, 034911 (2015)



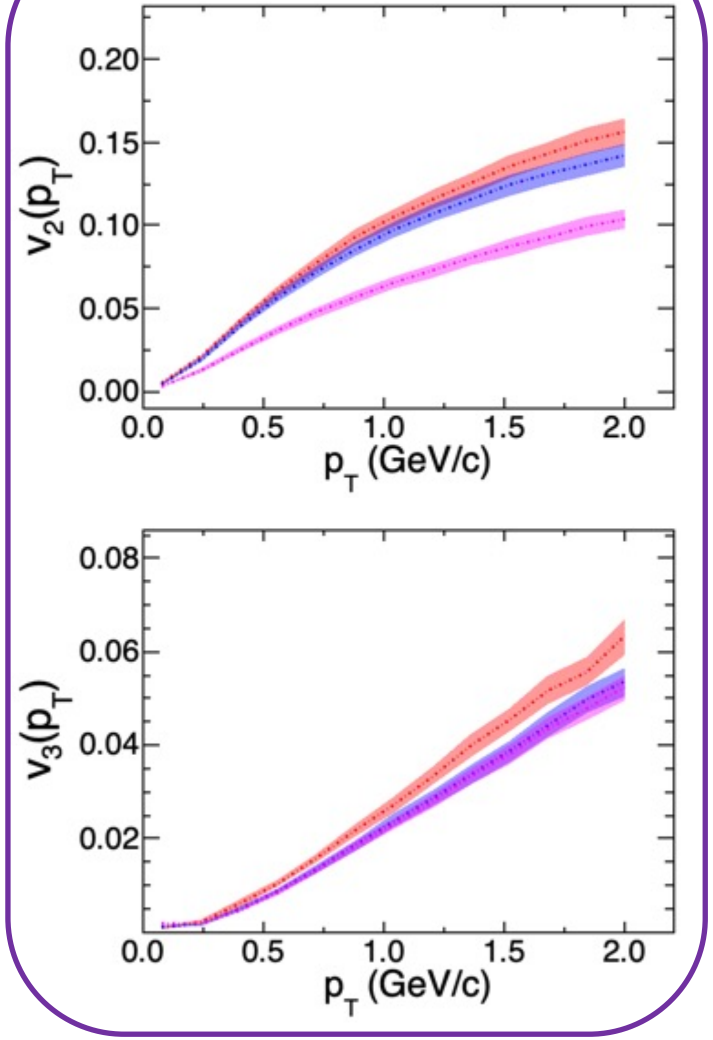
Decorrelation poses challenges for all boost-invariant hydro model-to-data comparisons

Pre-Flow Effect

SONIC



superSONIC



SONIC: Nucleon Fluctuation

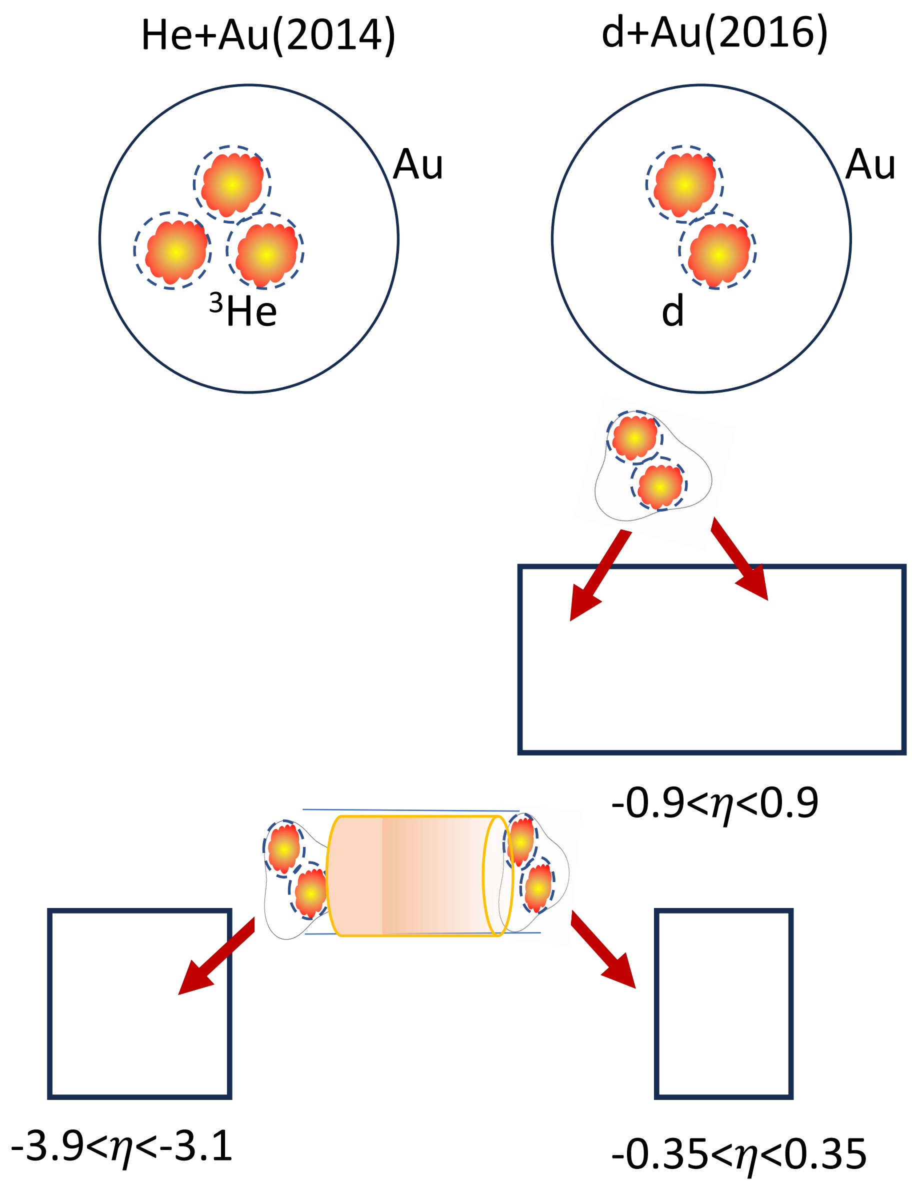
superSONIC: Nucleon Fluctuation + Pre-Flow

SONIC: $v_3^{p+Au} \approx v_3^{d+Au} < v_3^{^3He+Au}$

superSONIC: $v_3^{p+Au} \approx v_3^{d+Au} \approx v_3^{^3He+Au}$

Pre-Flow effect will change the v_3 magnitude and dilute system hierarchy

Differences in STAR-PHENIX Measurement



STAR

Phys. Rev. Lett. 130, 242301

PHENIX

Nature Phys. 15, 214 (2019)

STAR: Mid-mid rapidity correlation

PHENIX: Mid-backward rapidity correlation

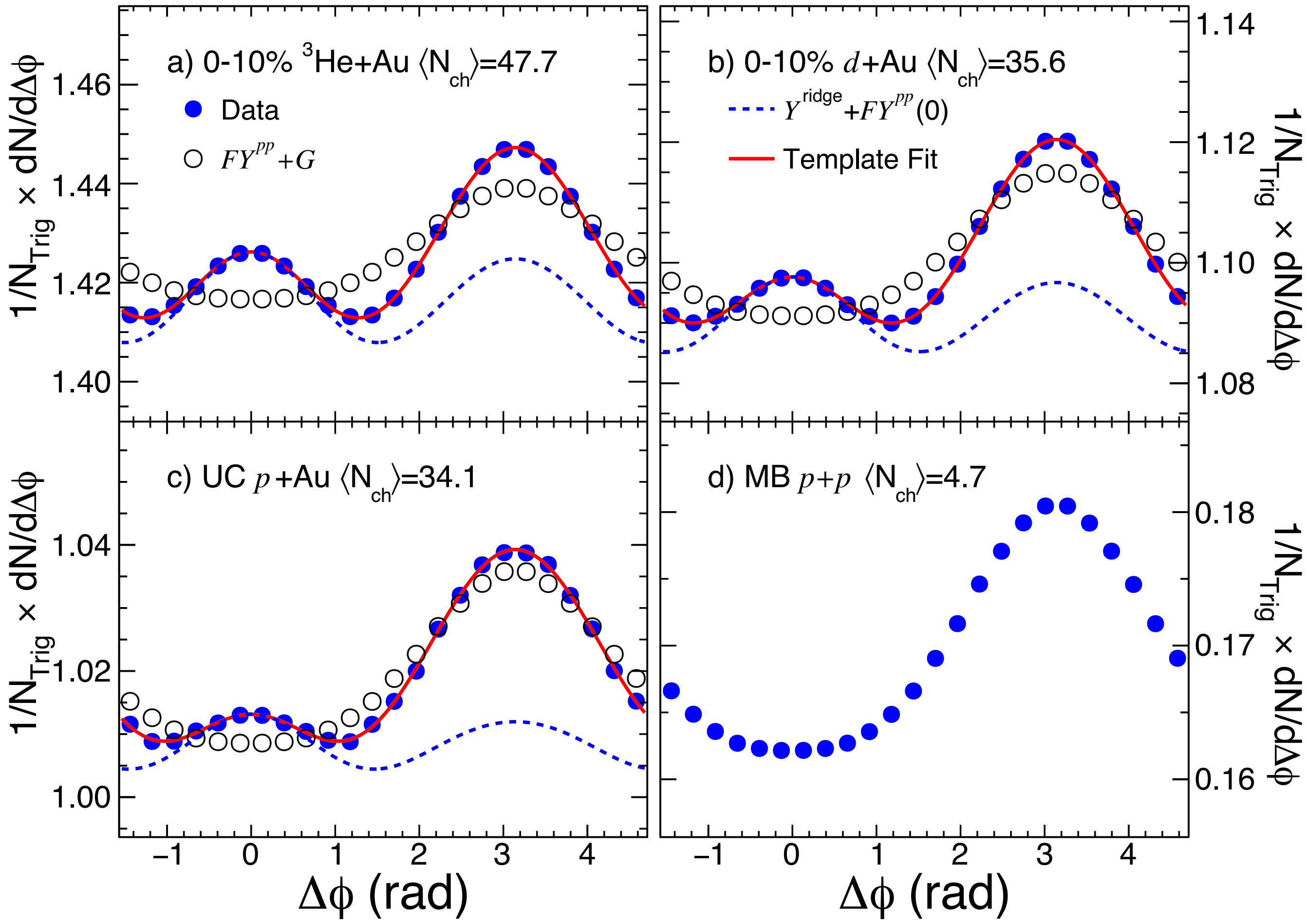
❑ **STAR:**

1. $|\Delta\eta|$ > 1.0 to suppress the near-side nonflow
2. Small longitudinal decorrelation is expected, boost invariant models can be directly compared
3. Four types of nonflow subtraction methods implemented
4. Centrlity:Two types of selections, activity in $|\eta|$<0.9 or -5.0<η<-3.3

❑ **PHENIX:**

1. $|\Delta\eta|$ > 2.75 to suppress the near-side nonflow
2. Large longitudinal decorrelation is expected
3. Nonflow estimated using multiplicity scaling of p+p v_n
4. Centrality: activity in -3.9<η<-3.1

Correlation Function and Away-side Nonflow Subtraction



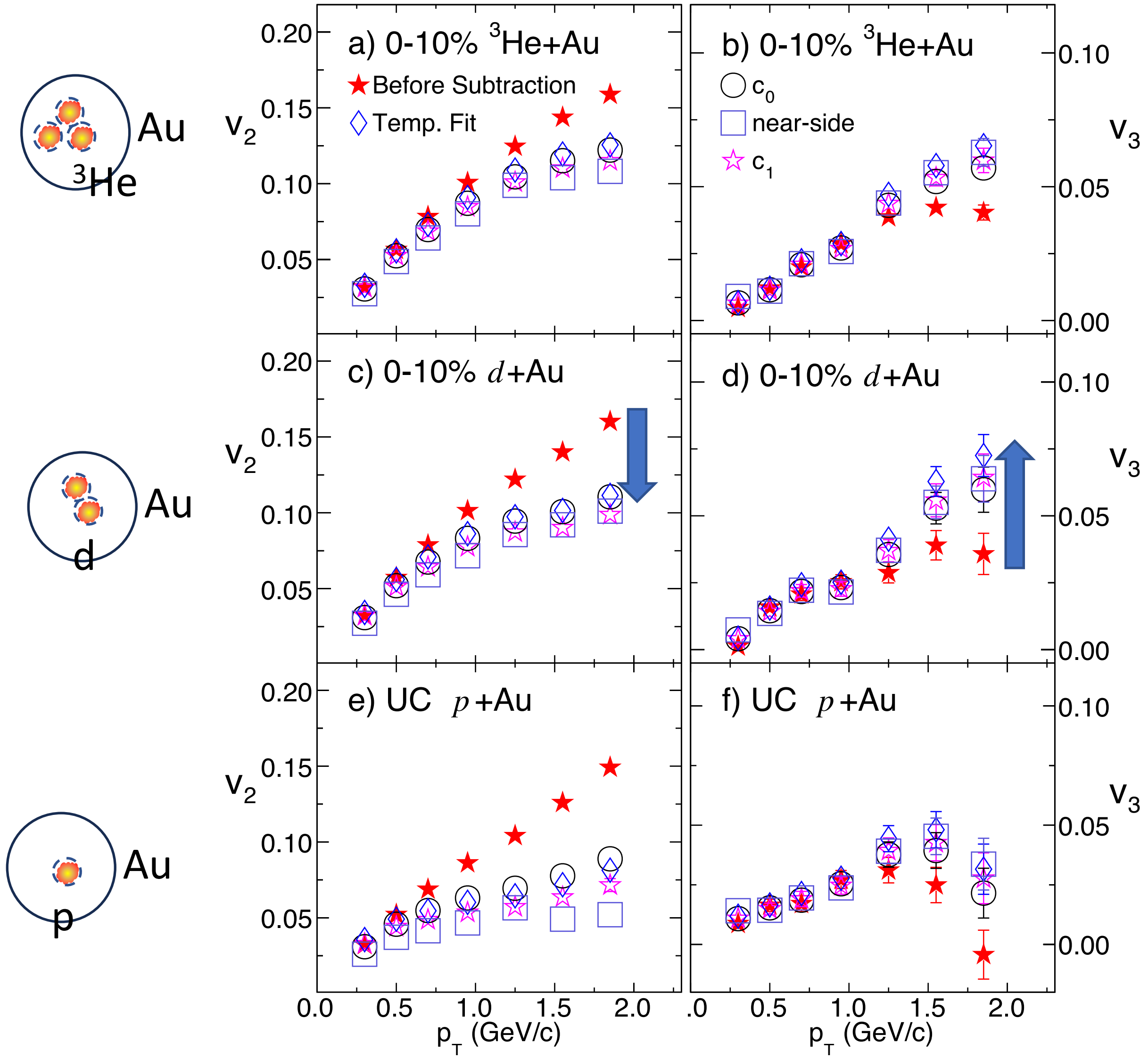
STAR, Phys. Rev. Lett. 130, 242301

Correlation function in p+p indicates nonflow is dominated by the away-side jet-like correlation

Four nonflow subtraction methods have been employed using p+p as reference

1. c_0 method: scaled with per trigger yield
2. Near-side method: scaled with near-side jet yield
3. c_1 method: scaled by v_1 from momentum conservation
4. Template Fit method: scaled with away-side jet

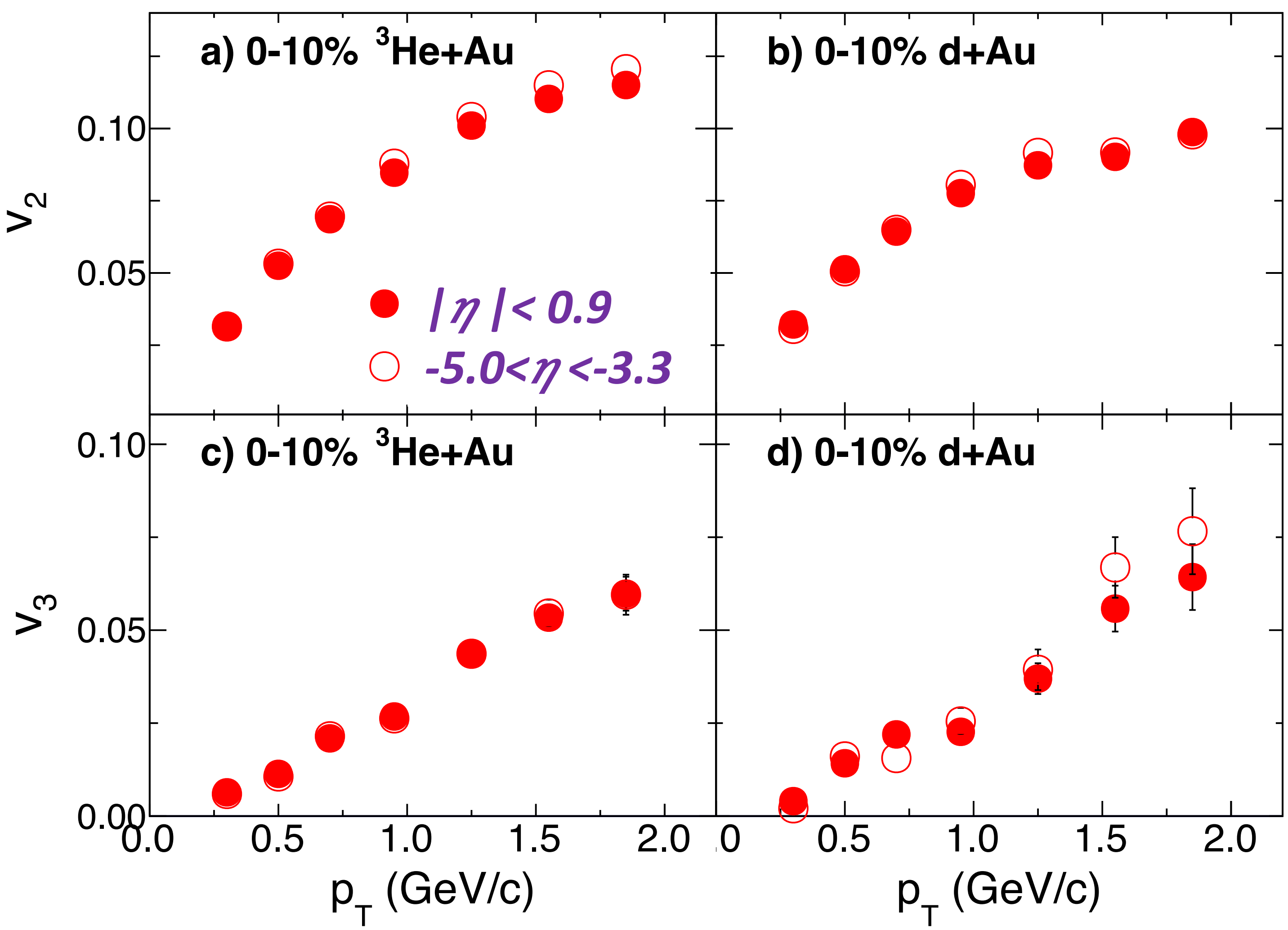
STAR differential v_n measurements for p/d/3He+Au



- **Non-flow subtraction will only decrease v_2 and increase v_3**
- **Non-flow subtracted v_2 and v_3 show minimal method dependence**

STAR, Phys. Rev. Lett. 130, 242301

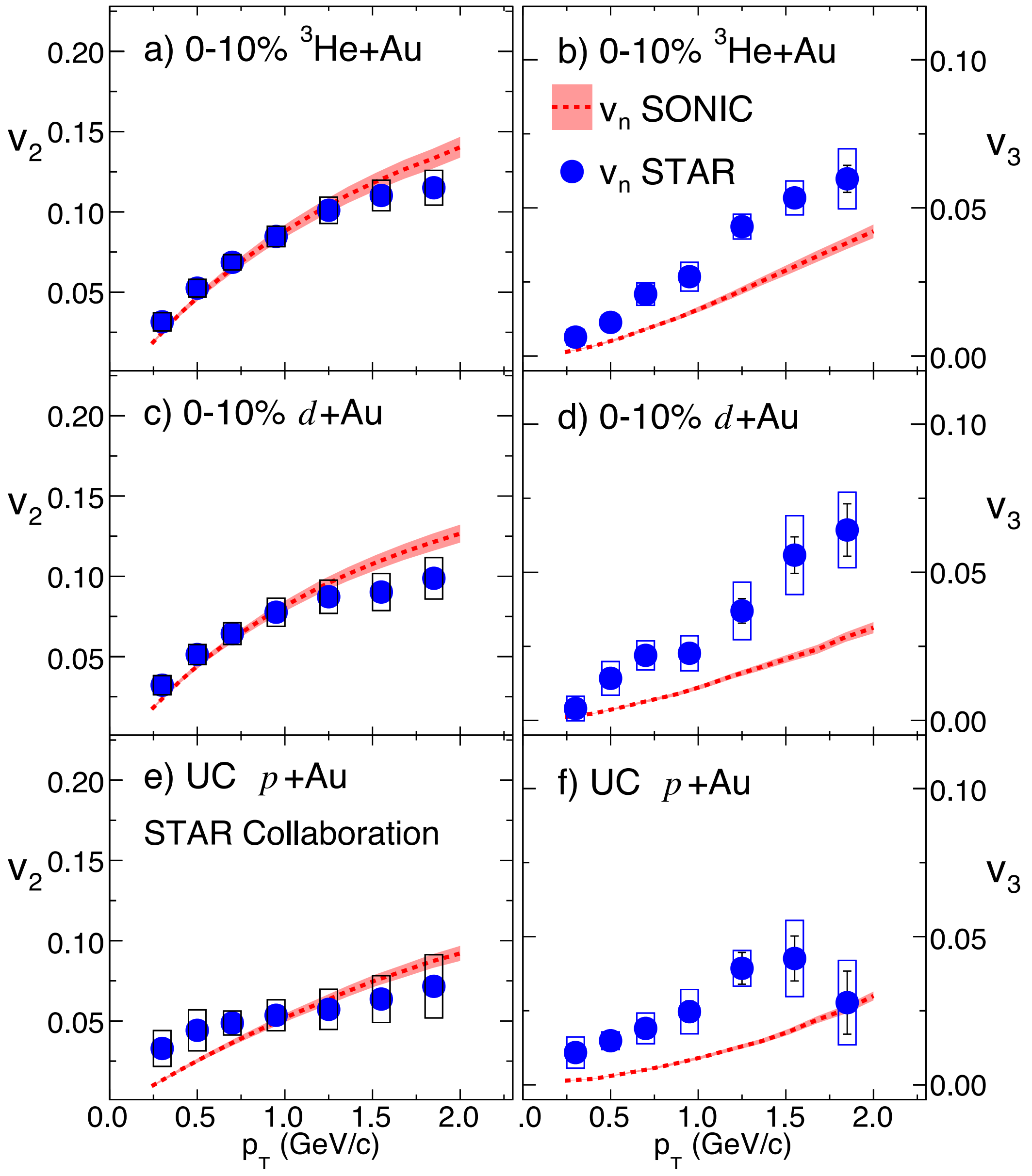
Vn for Different Centrality Selection



(c_1 subtraction)

✓ **Results agree well for both centrality definitions using activity from mid and backward rapidity regions**

Role of Pre-Flow



- ***SONIC model*** , which incorporates initial geometry eccentricity from nucleon position but does not consider sub-nucleon fluctuations, under-predicts the observed v_3 in all systems.

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0-5% pAu	0.23(0.16)	0.38(0.30)
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(super)SONIC: P. Romatschke *Eur. Phys.J.C* **75**, 305 (2015)

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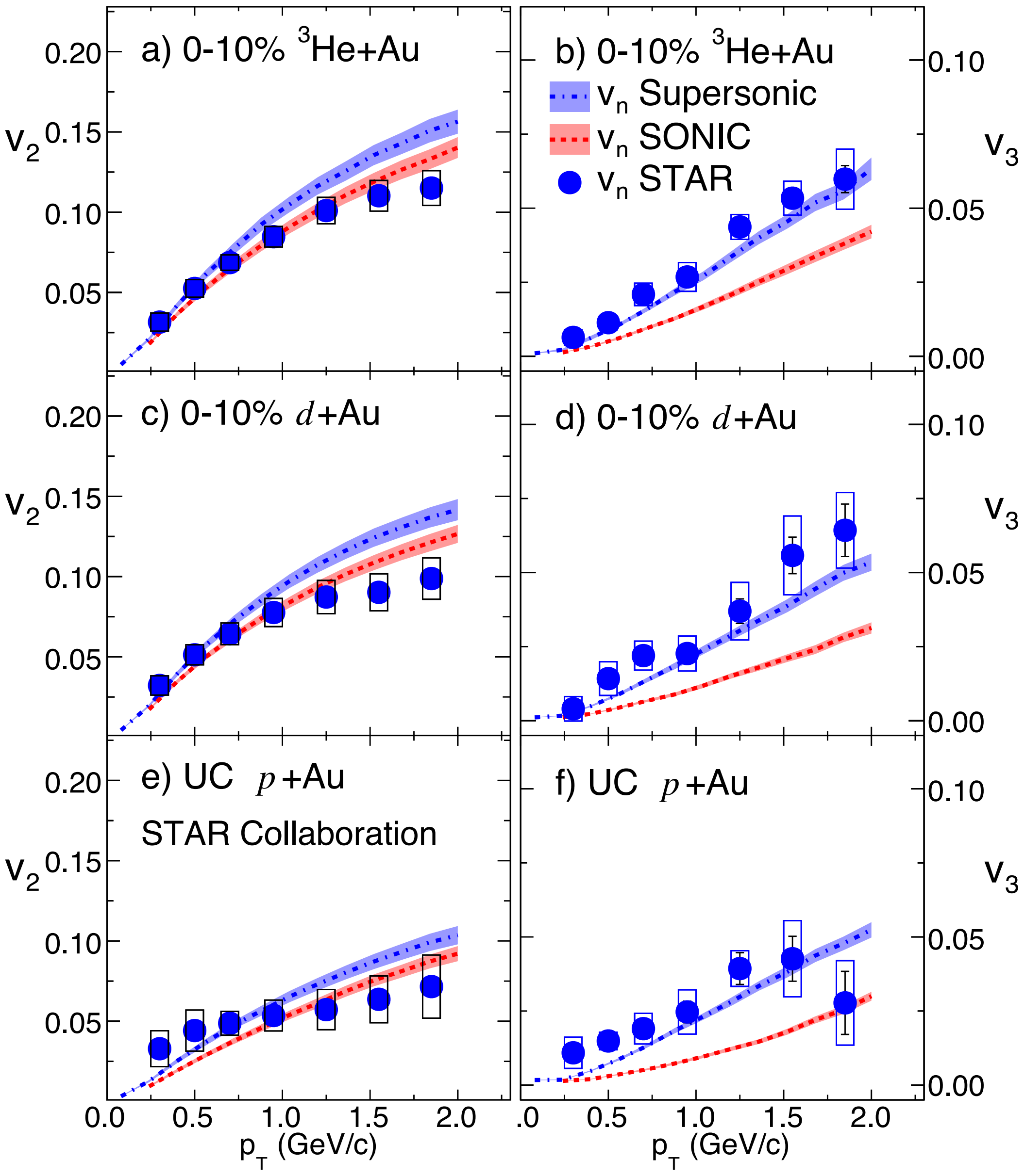

- ***SONIC model*** , which incorporates initial geometry eccentricity from nucleon position but does not consider sub-nucleon fluctuations, under-predicts the observed v_3 in all systems.

- ***SuperSONIC mode***, which include initial geometry eccentricity from nucleon position and the "pre-flow" can provide better description of v_3

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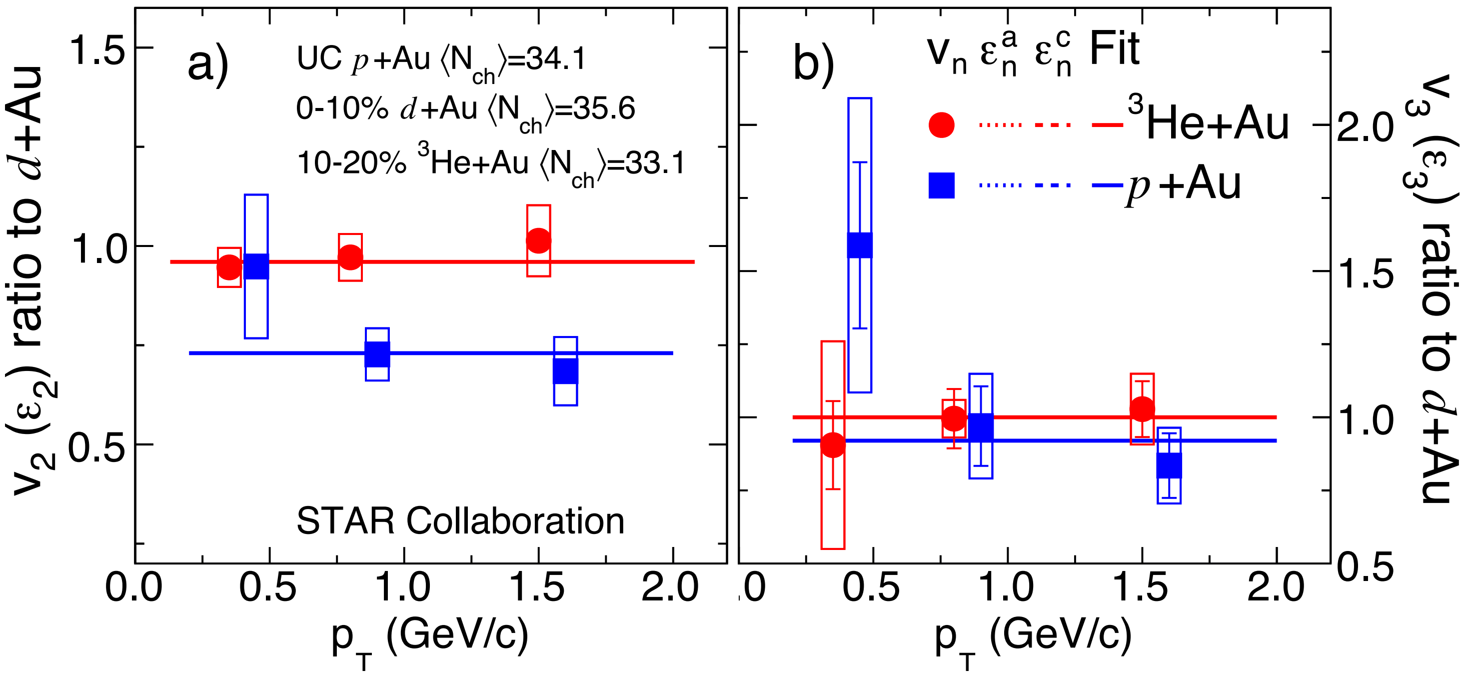
The system dependence



The final state contributions are expected to be largely canceled out when comparing similar multiplicity events

Studying the ratios of flow will be helpful to understand the initial spatial geometry and the contribution from the preflow

$V_2(HeAu) \approx v_2(dAu) > v_2(pAu)$
$V_3(HeAu) \approx v_3(dAu) \approx v_3(pAu)$

STAR, Phys. Rev. Lett. 130, 242301

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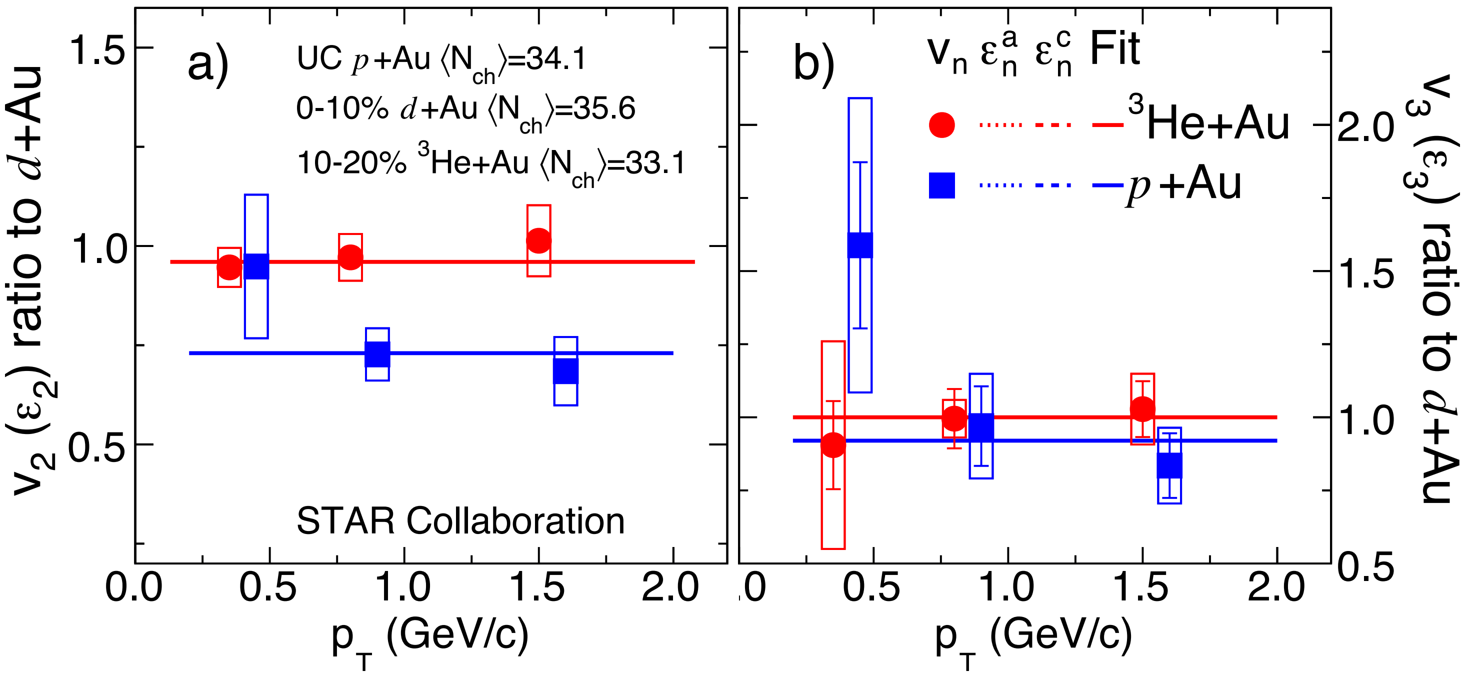

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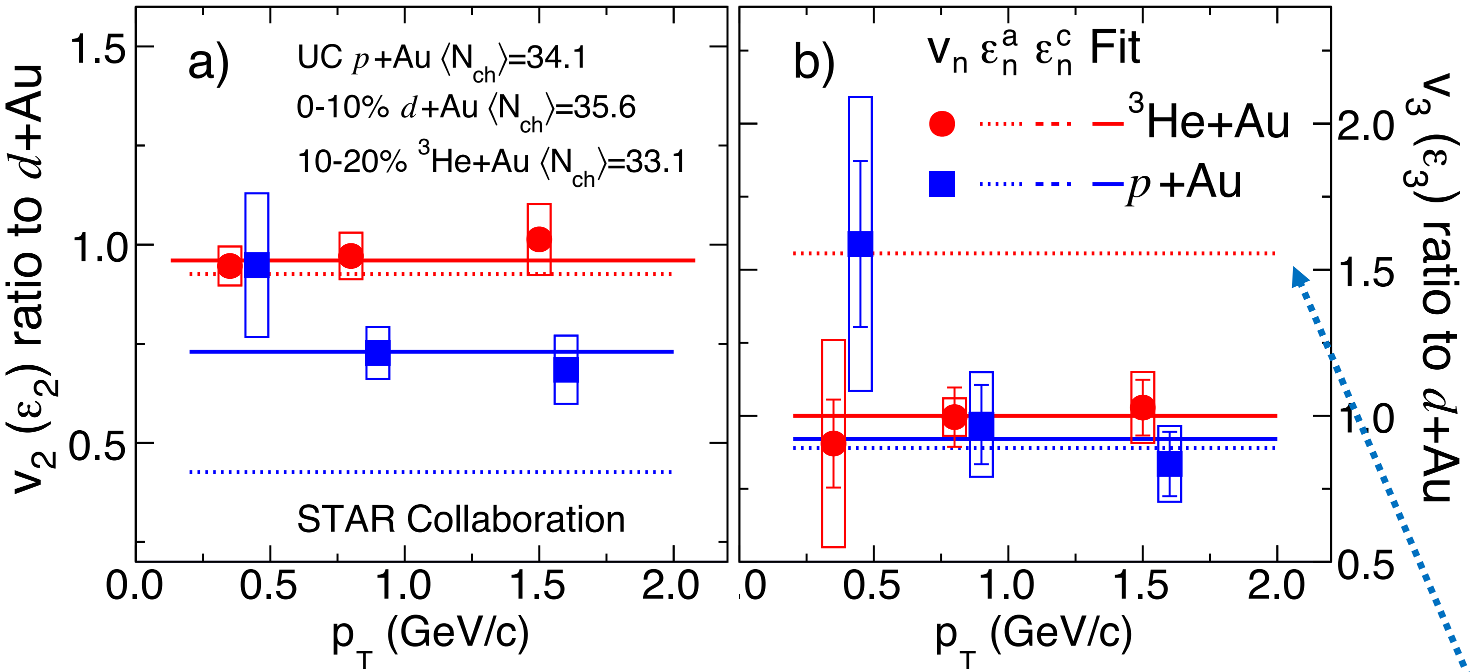
V_2(HeAu) ≈ v_2(dAu) > v_2(pAu)
V_3(HeAu) ≈ v_3(dAu) ≈ v_3(pAu)

Midrapidity v_3 implies no difference in triangular fluid shape between systems

STAR, Phys. Rev. Lett. 130, 242301

The system dependence



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Two Base Lines: eccentricity ratios
Eccentricity with nucleon fluctuation

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STAR, Phys. Rev. Lett. 130, 242301

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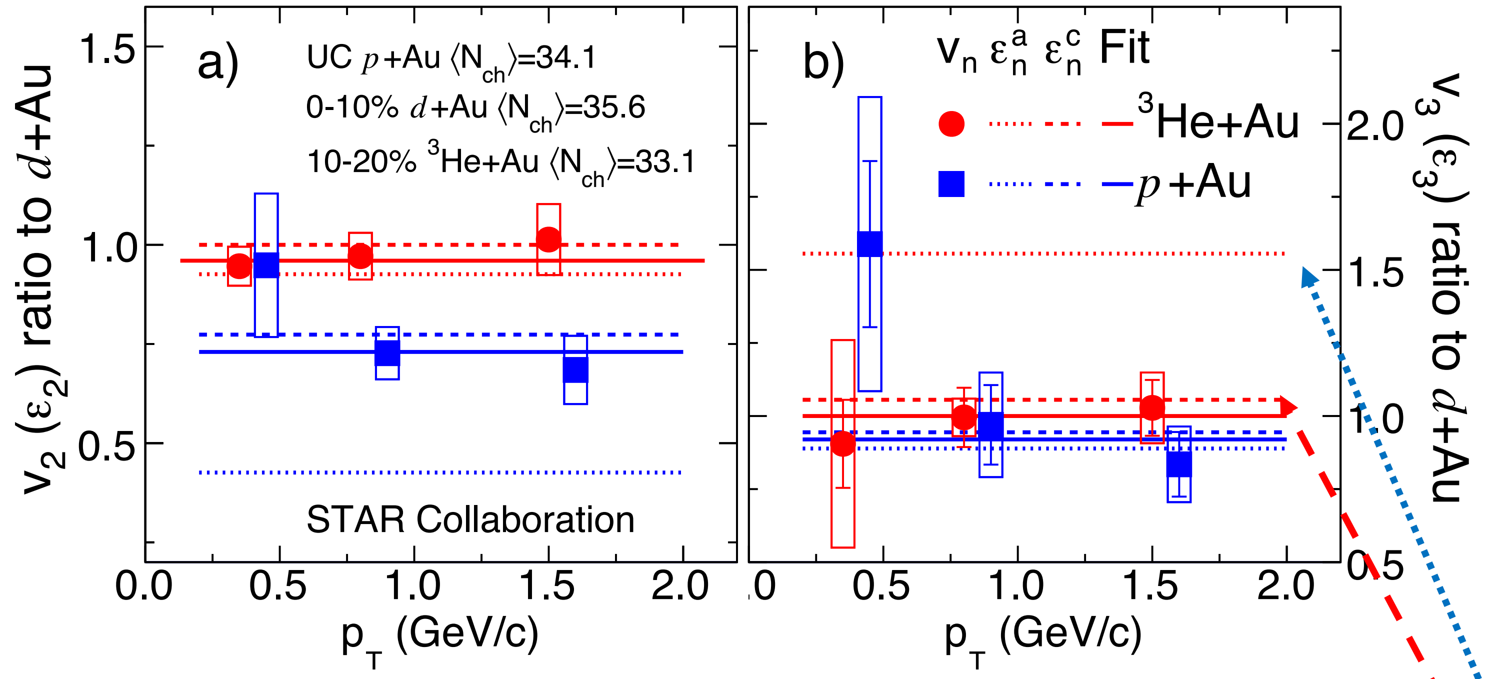

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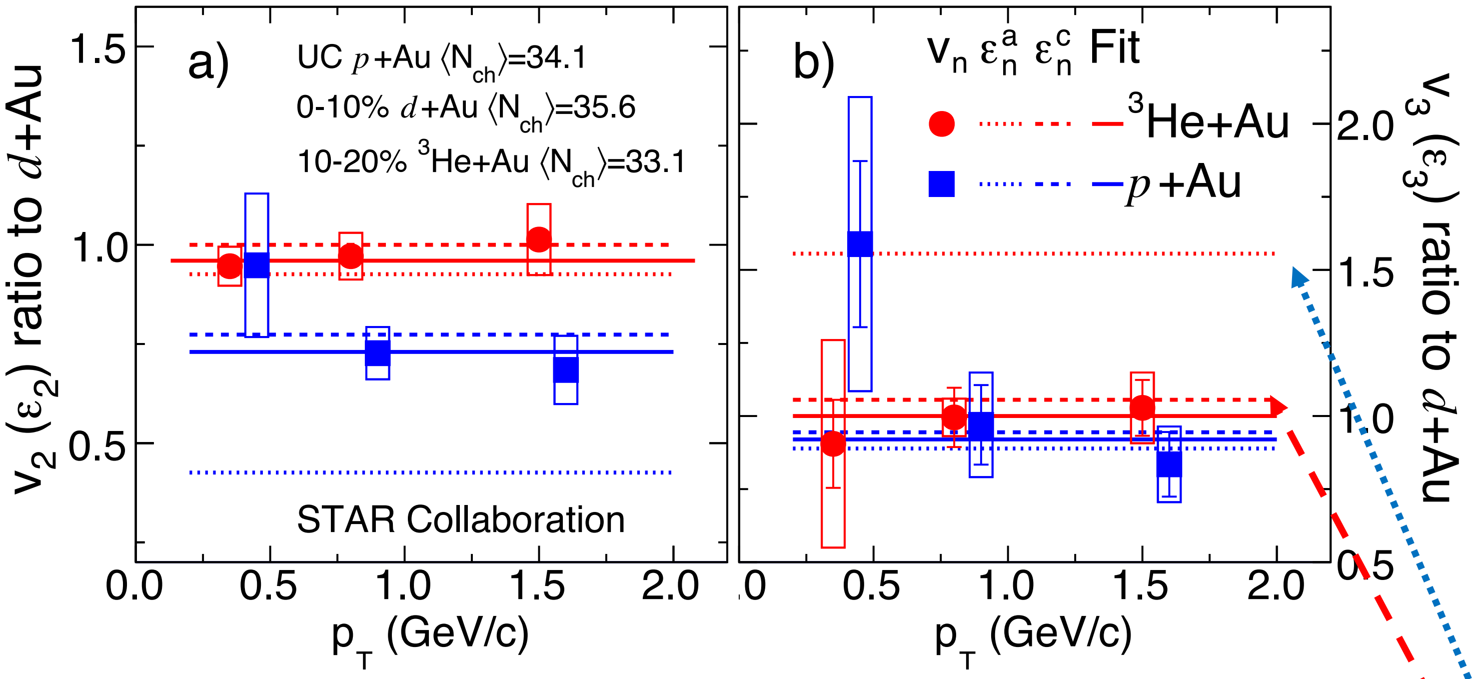
Two Base Lines: eccentricity ratios

Eccentricity with nucleon fluctuation

Eccentricity with nucleon+sub-nucleon

STAR, Phys. Rev. Lett. 130, 242301

The system dependence



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Two Base Lines: eccentricity ratios

Eccentricity with nucleon fluctuation

Eccentricity with nucleon+sub-nucleon

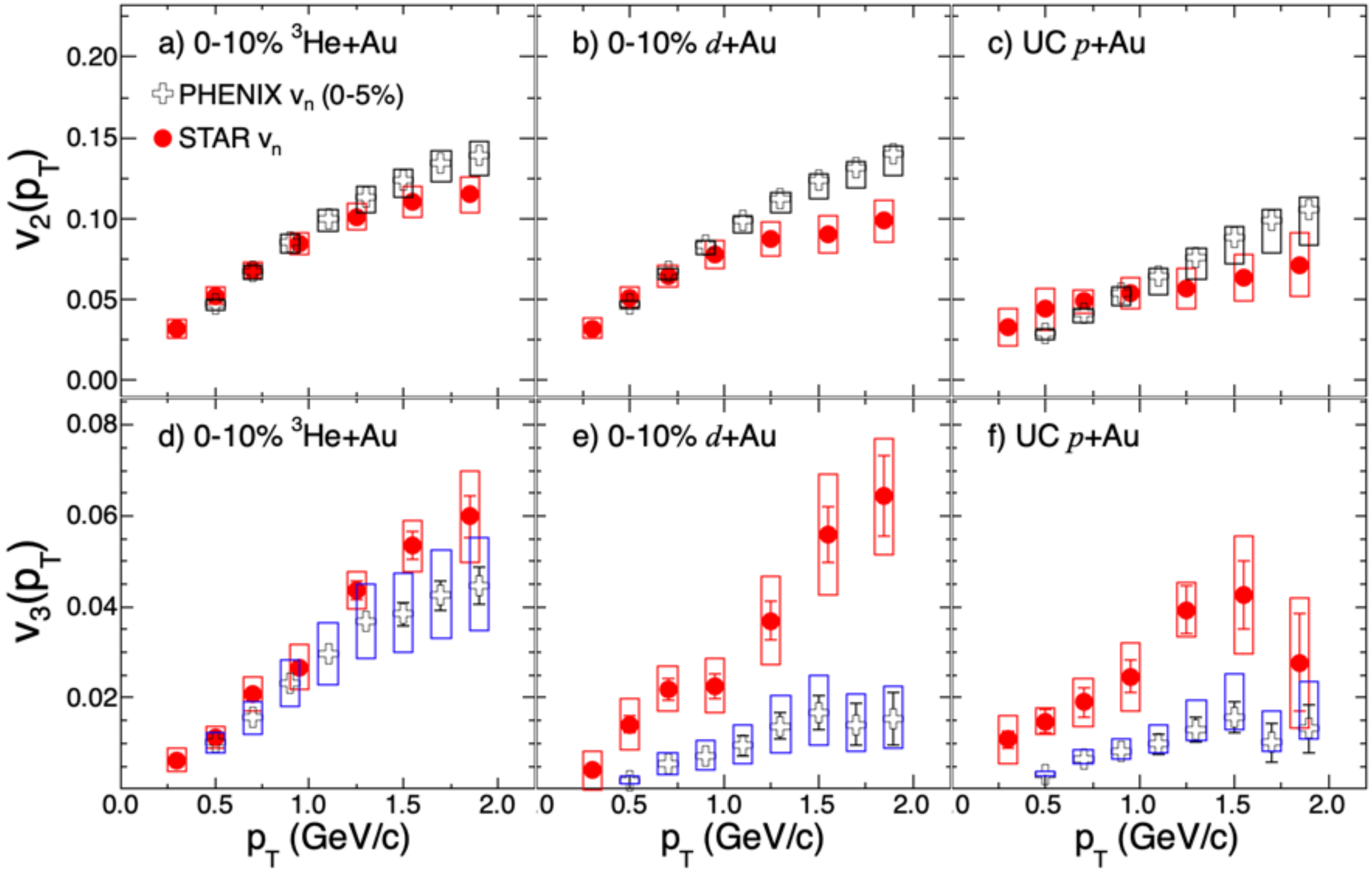
Sub-nucleon fluctuation?

or

Pre-flow?

STAR, Phys. Rev. Lett. 130, 242301

Role of longitudinal decorrelation: 3D-Glauber model

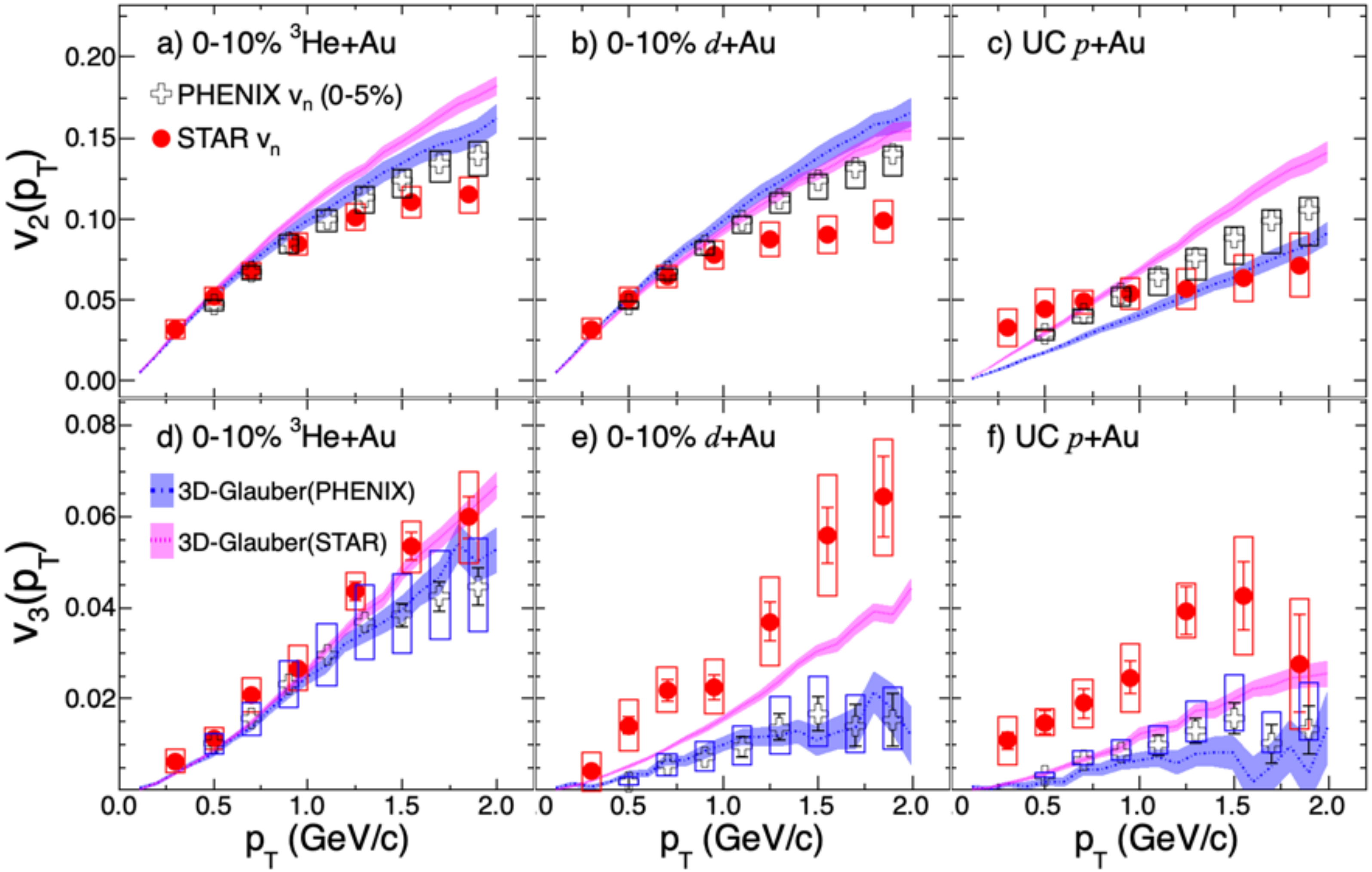


The STAR and PHENIX v_3 for p/d+Au, show similar p_T dependence

- ✓ But magnitudes differ by a large factor
  - ✓ System-independent STAR v_3
  - ✓ System-dependent PHENIX v_3

X. Zhao && C. Shen PRC.107.014904

Role of longitudinal decorrelation: 3D-Glauber+MUSIC



The STAR and PHENIX v_3 for p/d+Au, show similar p_T dependence

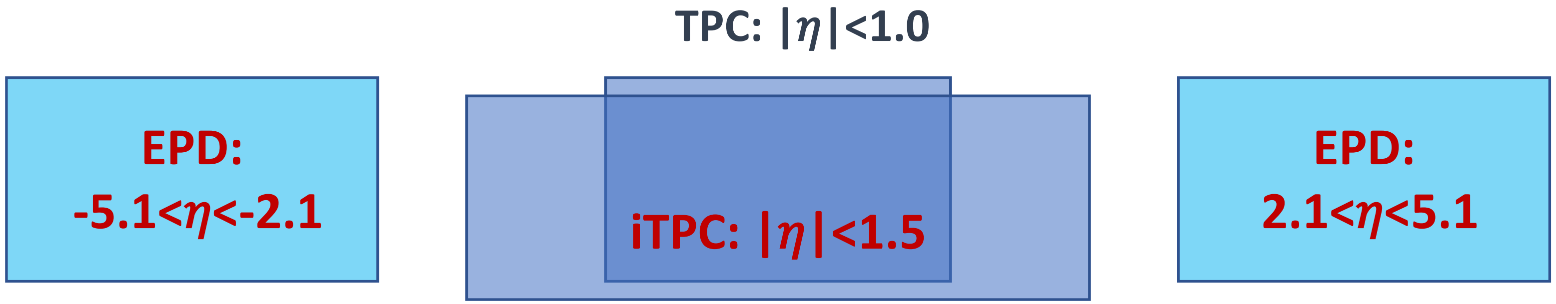
- ✓ But magnitudes differ by a large factor
  - ✓ System-independent STAR v_3
  - ✓ System-dependent PHENIX v_3

3D Glauber + MUISC indicates there are significant de-correlations in PHENIX v_3 measurements

Model underestimates STAR and PHENIX v_3 measurements in p+Au

X. Zhao && C. Shen PRC.107.014904

New d+Au Data 2021



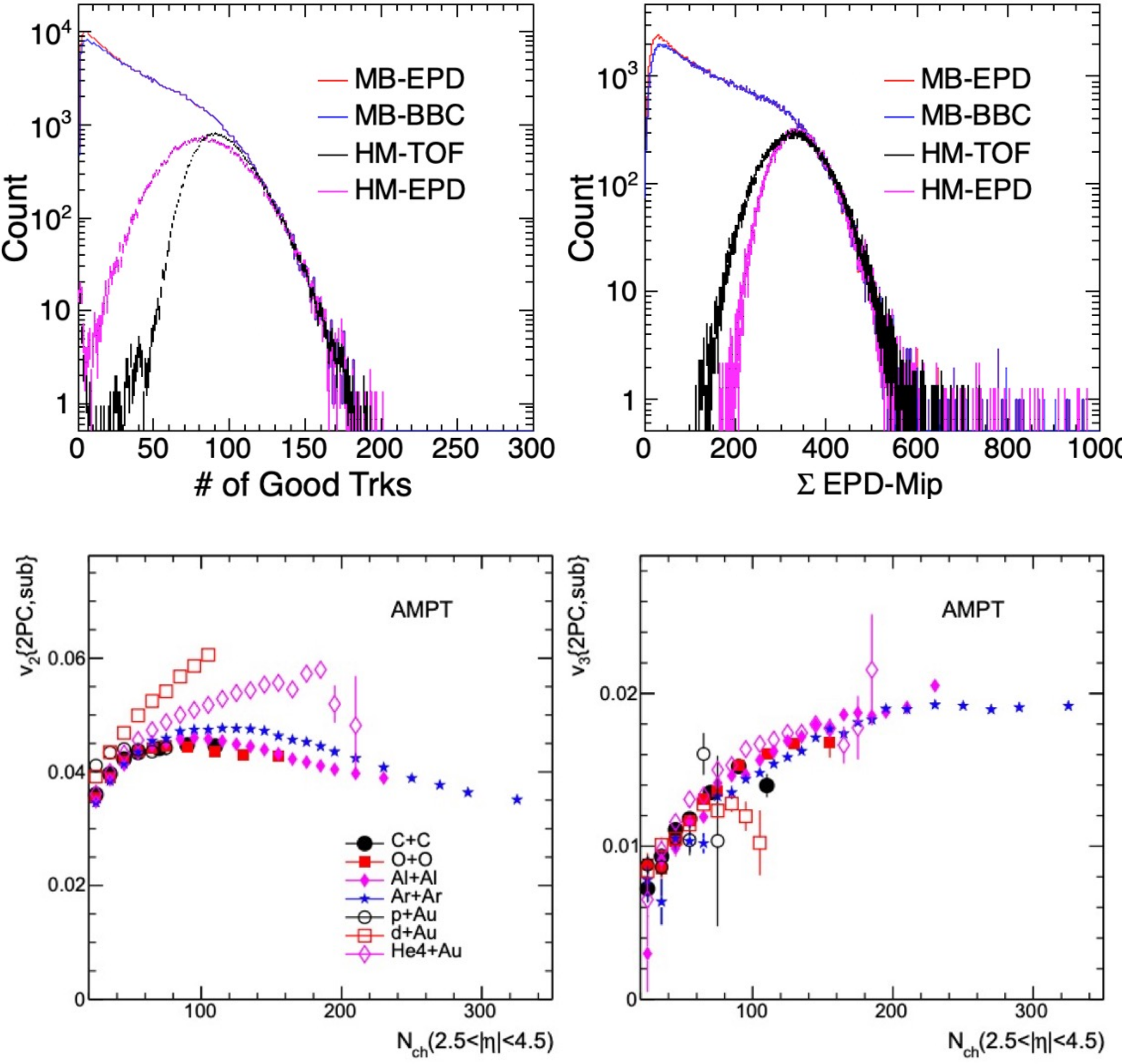
100M MB and 100M HM(0-5% selected by EPD) triggered events have been taken by STAR in 2021

Improved acceptance: iTPC ($|\eta|<1.5$) + EPD($2.1<|\eta|<5.1$)

Simultaneously measuring the mid-mid and mid-backward rapidity correlations

Further investigate the longitudinal decorrelation in small-sized system

O+O@RHIC 2021



- ➢ ***STAR has taken 600M MB and 200M HM O+O events in 2021***
  - ✓ Large rapidity coverage due to iTPC $|\eta|<1.5$ and EPD($2.1<|\eta|<5.0$)
  - ✓ Trigger on HM event at both middle and forward rapidity regions
- ➢ ***Different flow behaviors between symmetric and asymmetric collision systems***
- ➢ ***Disentangle the impact of the subnucleon fluctuations from the nuclear shape***

S.Huang , Z. Chen, J. Jia, W. Li: PhysRevC.101.021901

Summary

- The STAR experiment conducted measurements of v_2 and v_3 as a function of p_T in central p+Au, d+Au and ^{3}He+Au collisions. The extracted flow signals were found to be consistent across four different non-flow subtraction methods.

- The observed v_3 is system independent, suggesting a significant influence of sub-nucleon gluon field fluctuations on the initial geometry of small-sized systems. Although, longitudinal decorrelation and pre-flow effects need to be further investigated

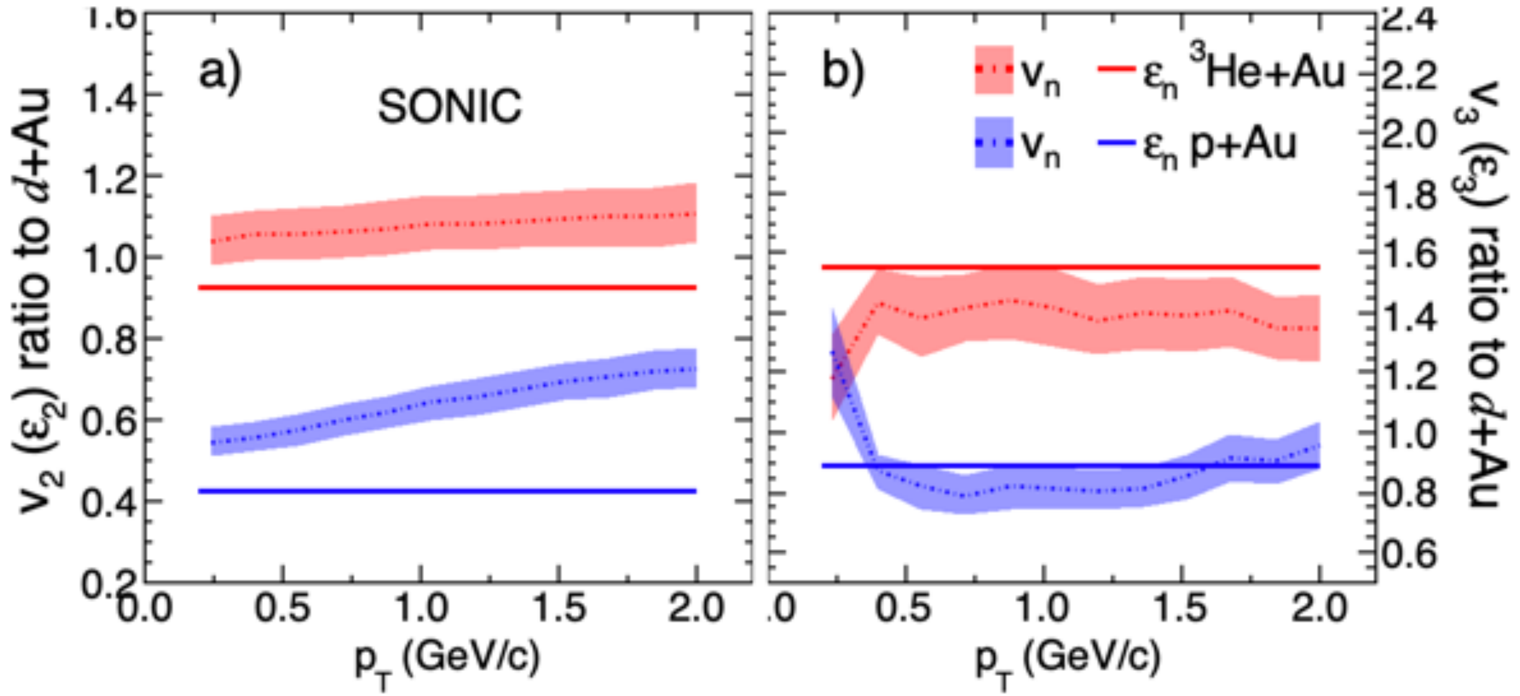
- In the future, the availability of new d+Au and O+O data will provide additional information for studying the sub-nucleon structure, pre-flow and longitudinal decorrelations.

Thanks!

Backup

SONIC Hydro.

SONIC: P. Romatschke *Eur. Phys.J.C* **75**, 305 (2015)

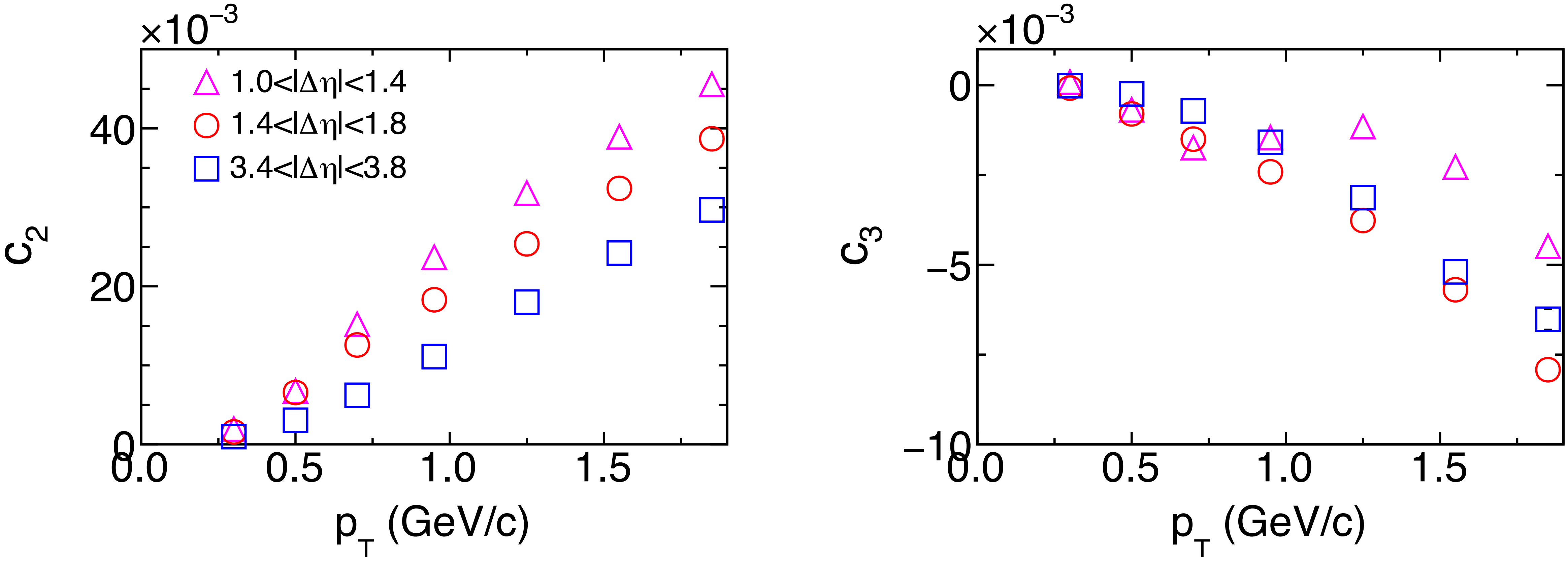


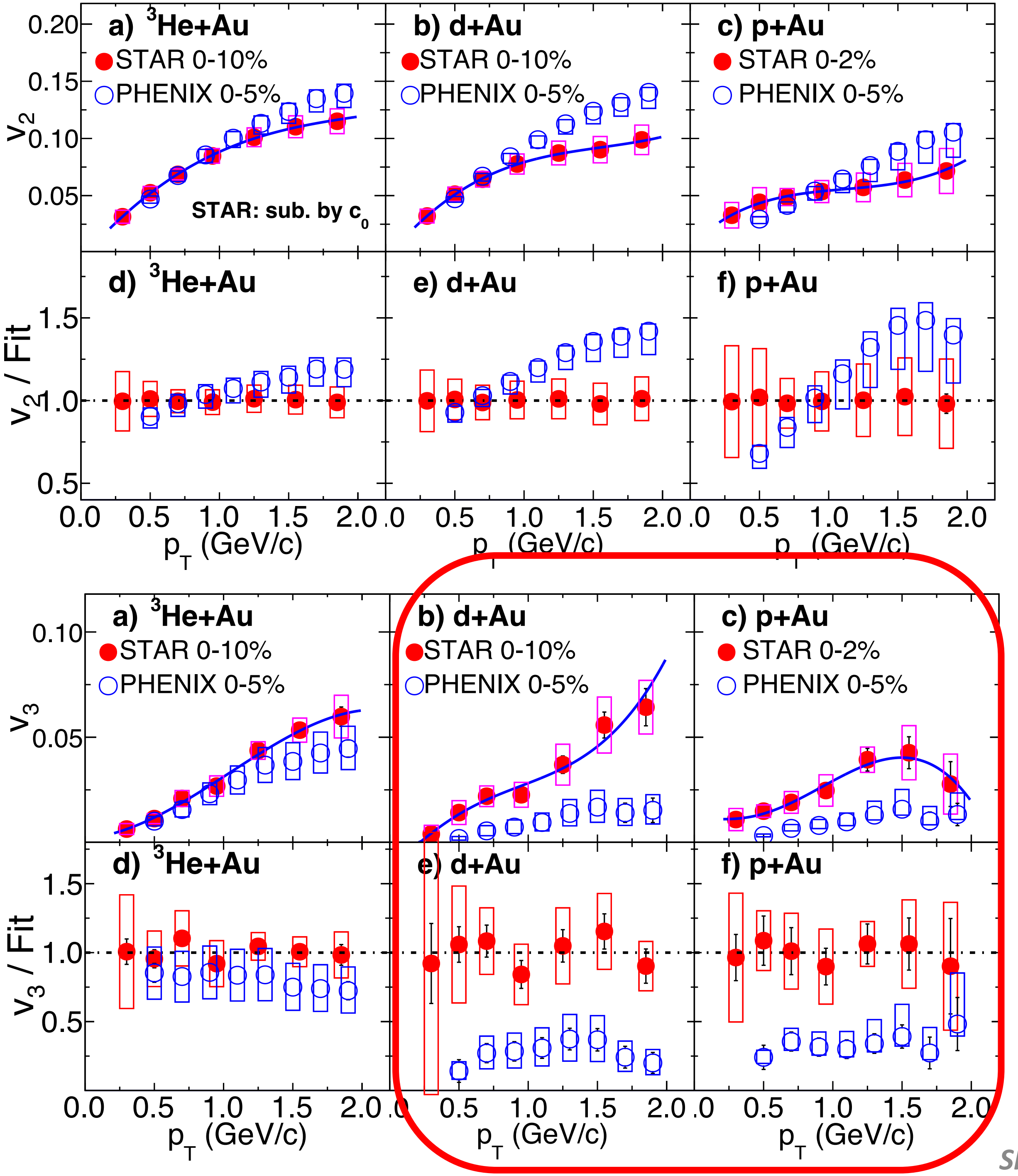
$V_n \propto \varepsilon_n$ approximately holds for v_3

On the other hand, the ratio v_2(pAu)/v_2(dAu) may be affected by different viscous correction functions or other dynamical effects

Studying v_n in p/d/^{3}He+Au collisions and their ratios can provide valuable insights into the initial spatial geometry and pre-equilibrium dynamics during the initial stage of the collision

HIJING pp vs. η Gap





Detail Comparisons to PHENIX

- The STAR and PHENIX v_2 and v_3 for ^{3}He+Au, show reasonable agreement

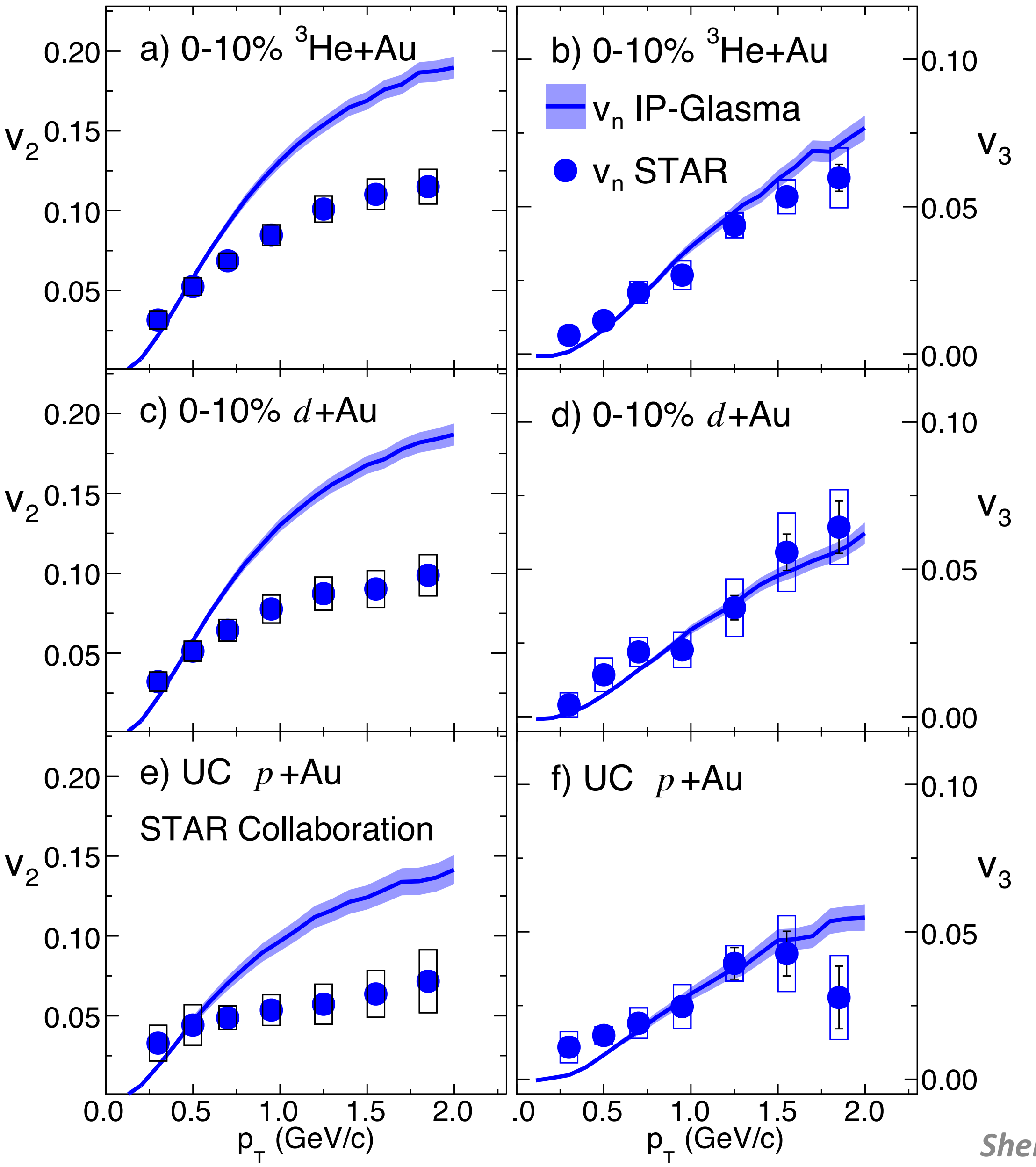
- The STAR and PHENIX measurements for v_2 are also in reasonable agreement for p/d+Au
  - ✓ Some difference(~25%) for p_T>1 GeV/c in d+Au and p_T<1 GeV/c in p+Au

- The STAR and PHENIX v_3 for p/d+Au, show similar p_T dependence
  - ✓ But magnitudes differ by a factor of 3
    - ✓ System-independent STAR v_3
    - ✓ System-dependent PHENIX v_3

- ***Longitudinal decorrelation effect?***

PHENIX: Nature Phys. 15, 214 (2019)
STAR: 2210.11352

Comparison to IP-Glasma

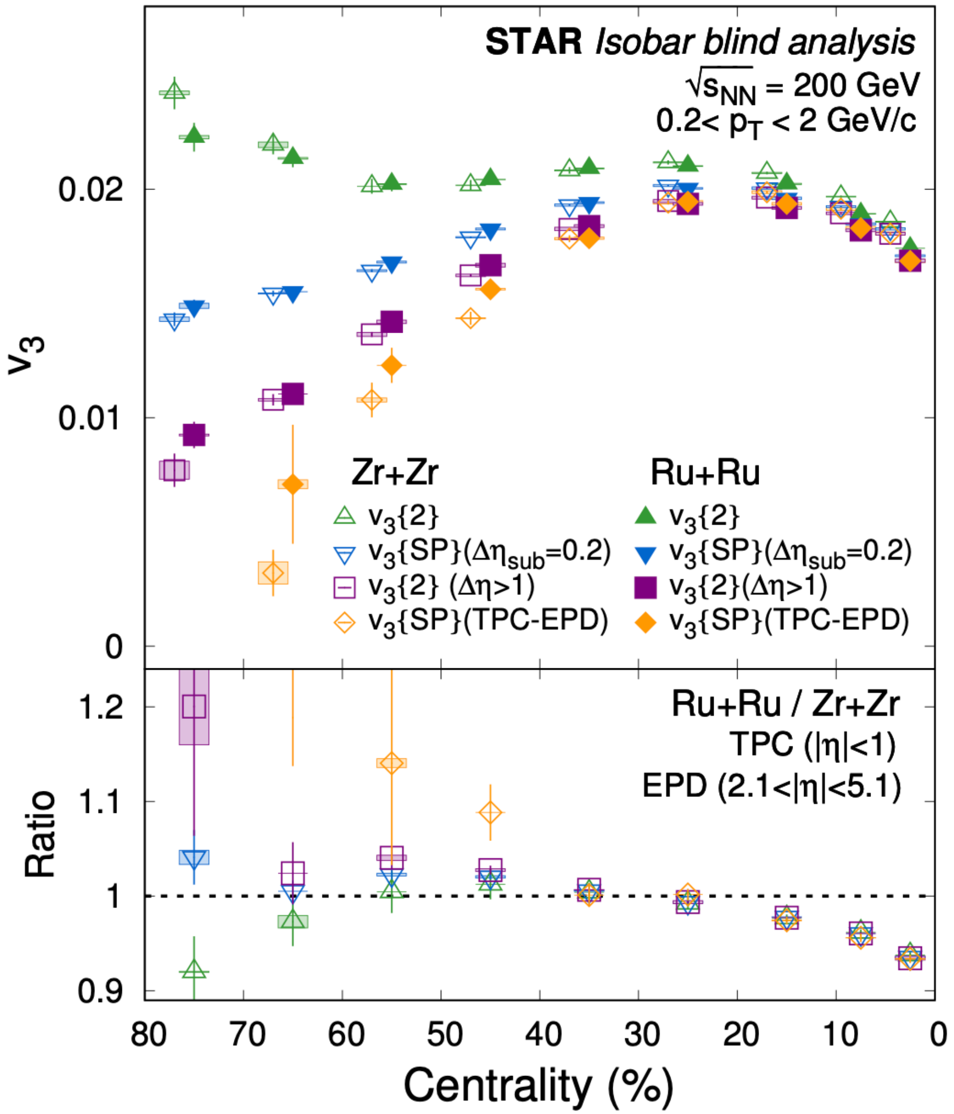


- ***IP-Glasma+Hydro*** includes sub-nucleonic gluon field fluctuations + initial momentum correlation + pre-flow.
- It is tuned to describe the data for large-sized systems and then extrapolated to small-sized systems
- It overpredicts v_2 but reproduces v_3 . Larger ε_2 or strong pre-flow from IP-Glasma model ?
- STAR measurements provide useful constraints on model tuning in future

IP-Glasma+Hydro: Phys. Lett. B 803, 135322 (2020)

Model	a	b	c	d
	$\varepsilon_2^a(\varepsilon_3^a)$	$\varepsilon_2^b(\varepsilon_3^b)$	$\varepsilon_2^c(\varepsilon_3^c)$	$\varepsilon_2^d(\varepsilon_3^d)$
^{3}He+Au	0.50(0.28)	0.52(0.35)	0.53(0.38)	0.64(0.46)
d+Au	0.54(0.18)	0.51(0.32)	0.53(0.36)	0.73(0.40)
p+Au	0.23(0.16)	0.34(0.27)	0.41(0.34)	0.50(0.32)

Isobar Vn



STAR Isobar blind analysis
$\sqrt{s_{NN}}$ = 200 GeV
0.2< p_T < 2 GeV/c
v_3
0.02
0.01
0
Zr+Zr
$v_3\{2\}$
$v_3\{SP\}(\Delta\eta_{sub}=0.2)$
$v_3\{2\}$ ($\Delta\eta$>1)
$v_3\{SP\}$(TPC-EPD)
Ru+Ru
$v_3\{2\}$
$v_3\{SP\}(\Delta\eta_{sub}=0.2)$
$v_3\{2\}(\Delta\eta$>1)
$v_3\{SP\}$(TPC-EPD)
Ratio
1.2
1.1
1
0.9
Ru+Ru / Zr+Zr
TPC (|η|<1)
EPD (2.1<|η|<5.1)
80
70
60
50
40
30
20
10
0
Centrality (%)