Small system flow from STAR

Shengli Huang

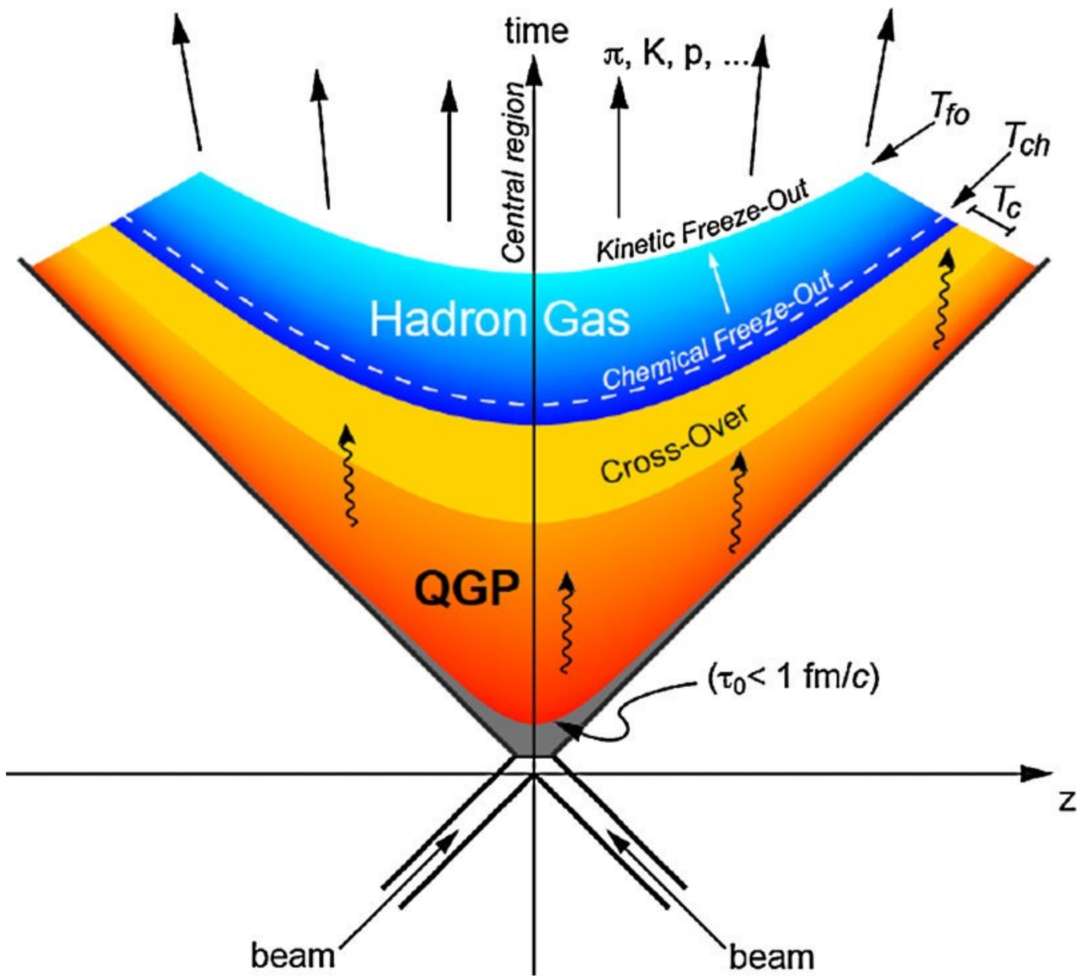
Outline:

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

Stony Brook University

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

System evolution in small system



p/d/^{3}He Au

- ❑ Different Initial Spatial Geometry: Nucleon Glauber vs. Sub-nucleon Glauber
- ❑ Hydro starts at τ ~ 0+; $V_n \propto \varepsilon_n$ is expected
- ❑ IP-Glasma+Hydro: Hydro starts at τ= 0.4fm/c; Large initial stage contribution (initial momentum correlation; pre-flow …)
- ❑ 3D Dynamical Glauber+Hydro: Hydro starts at different time for different regions

Nuclear Physics A 987 (2019) 144–201

Initial Geometry in Small-sized Systems

w/o gluon field fluctuation **With gluon field fluctuation**

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)

Model a: standard Glauber model *Phys. Rev. Lett. 113, 434 112301 (2014) ~ <ε_n>*

Model b: smooth gluon field sourced by nucleons *Phys. Rev. C 94, 024919 (2016) ~ε_n{2}*

Model c: smooth gluon field sourced by valence quark *Phys. Rev. C 94, 024919 (2016) ~ε_n{2}*

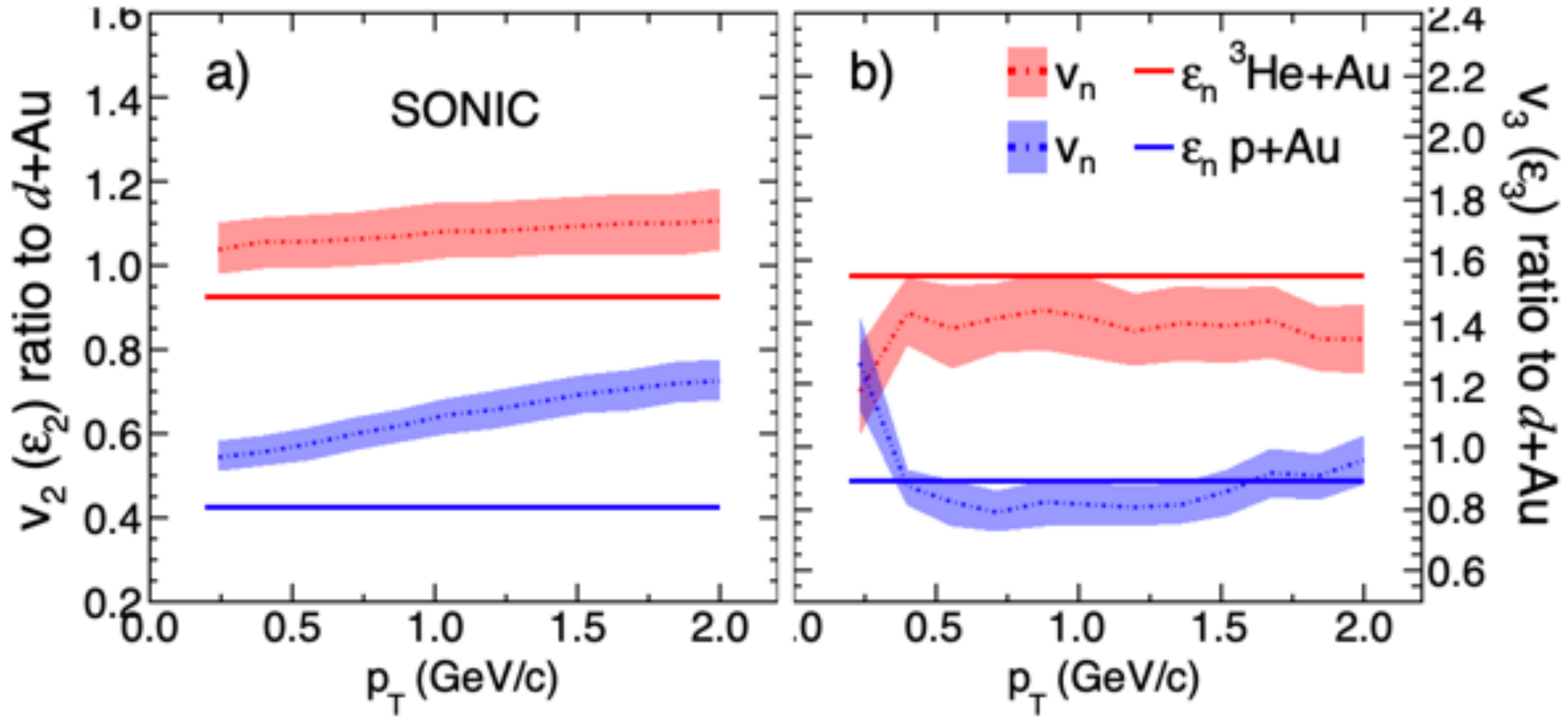
Model d: lumpy gluon field sourced by valence quark(IP-Glasma) *Phys. Rev. Lett. 108, 252301 ~ <ε_n>*

Sub-nucleon gluon field fluctuations: strong influence on the initial geometry eccentricity for small-sized system

Measuring flow in small-sized system can provide invaluable constraints for such effect

SONIC Hydro.

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

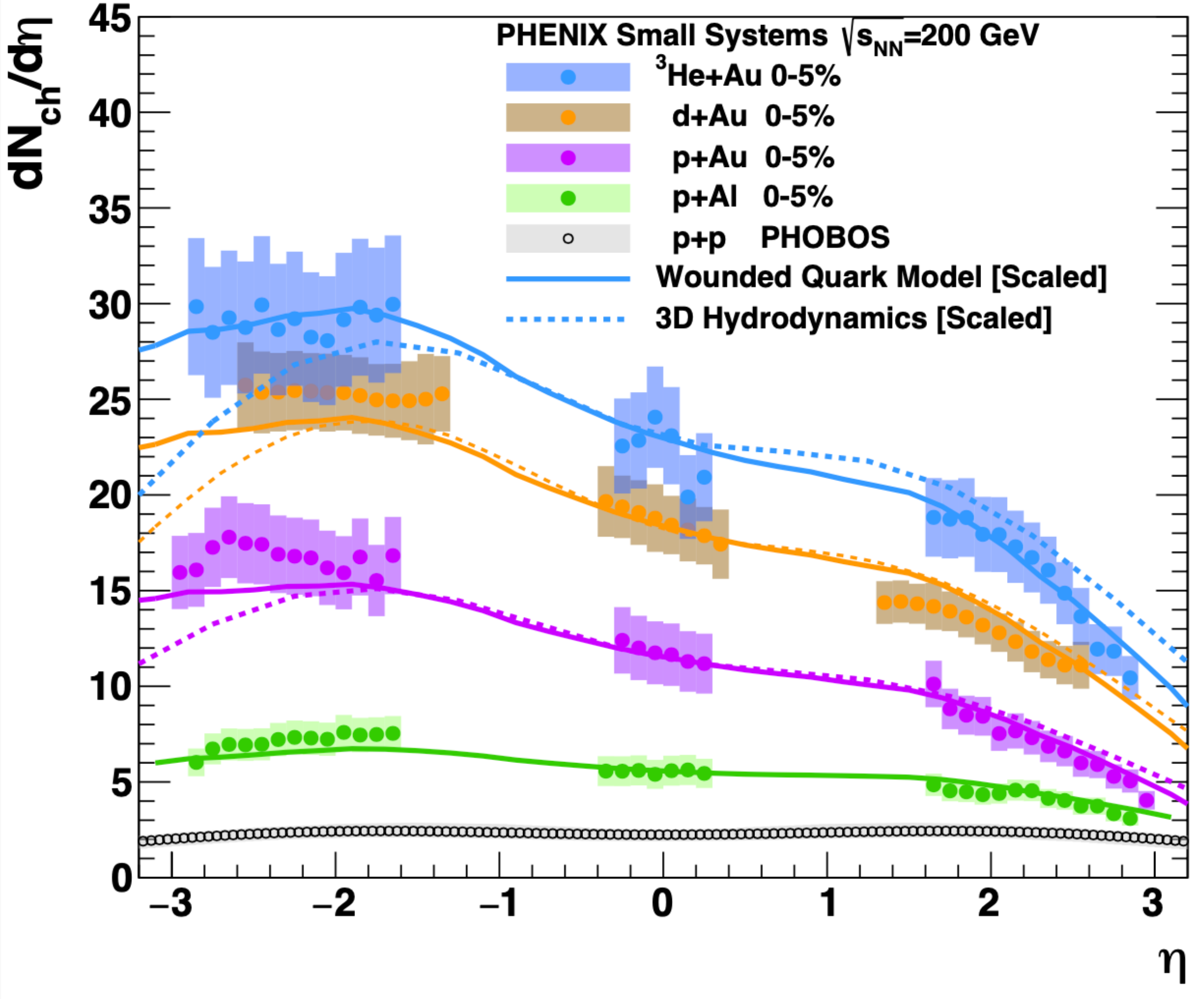


$V_n \propto \varepsilon_n$ roughly hold for v_3

v_2(pAu)/v_2(dAu) may be affected by different viscous correction function or others

Vn in p/d/^{3}He+Au and their ratio will be helpful to address the initial spatial geometry and pre-equilibrium dynamics in the initial stage

Middle-middle vs. backward-middle rapidity correlation?



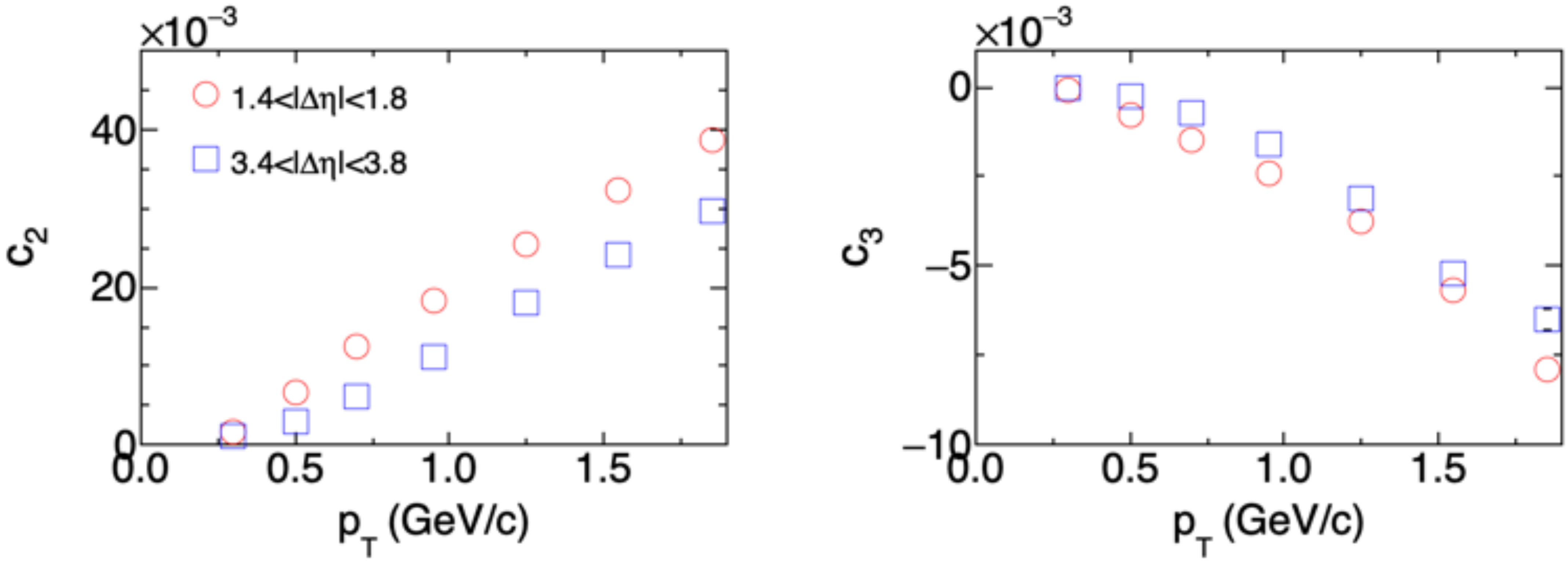
Multiplicity at backward rapidity in p/d/^{3}He+Au is significant different to that in pp

Estimating the nonflow will be difficult by using pp as reference for backward-middle rapidity correlation

Nonflow for middle-middle rapidity correlations in p/d/^{3}He+Au will be close to that in pp

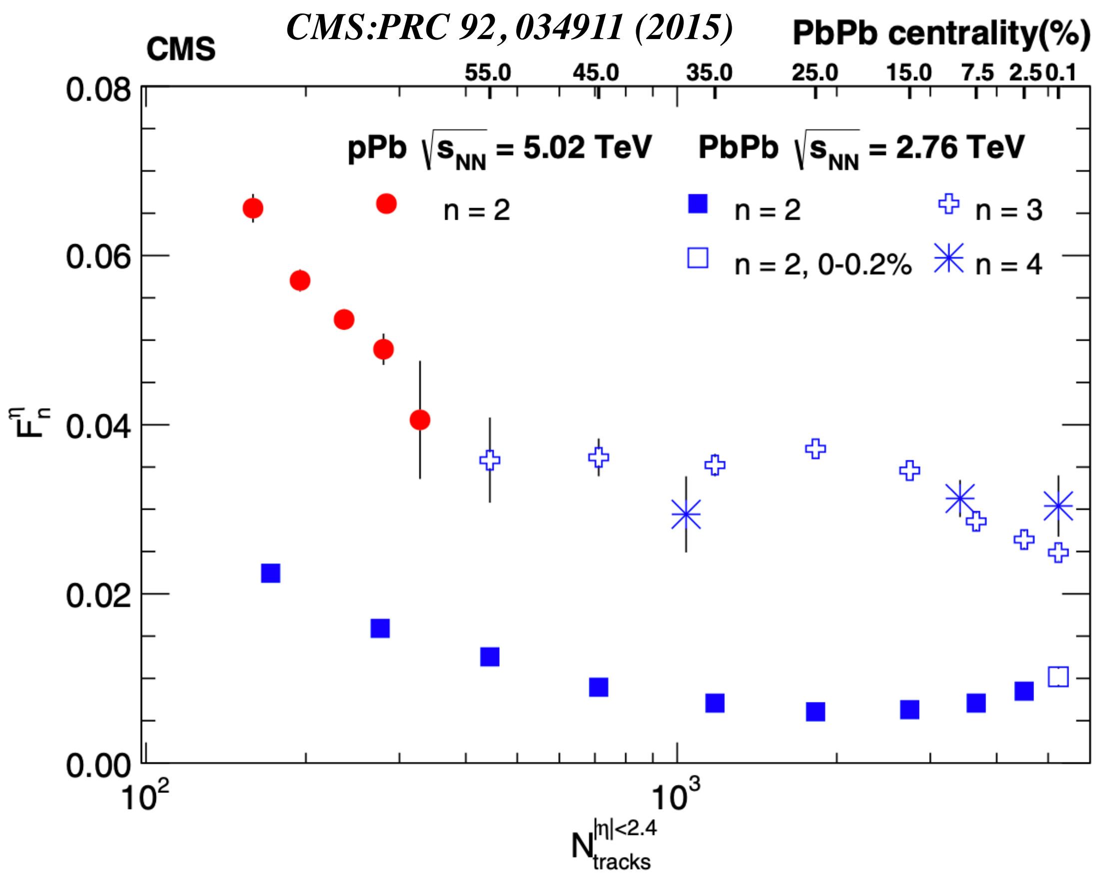
PHENIX:Phys. Rev. Lett. 121, 222301

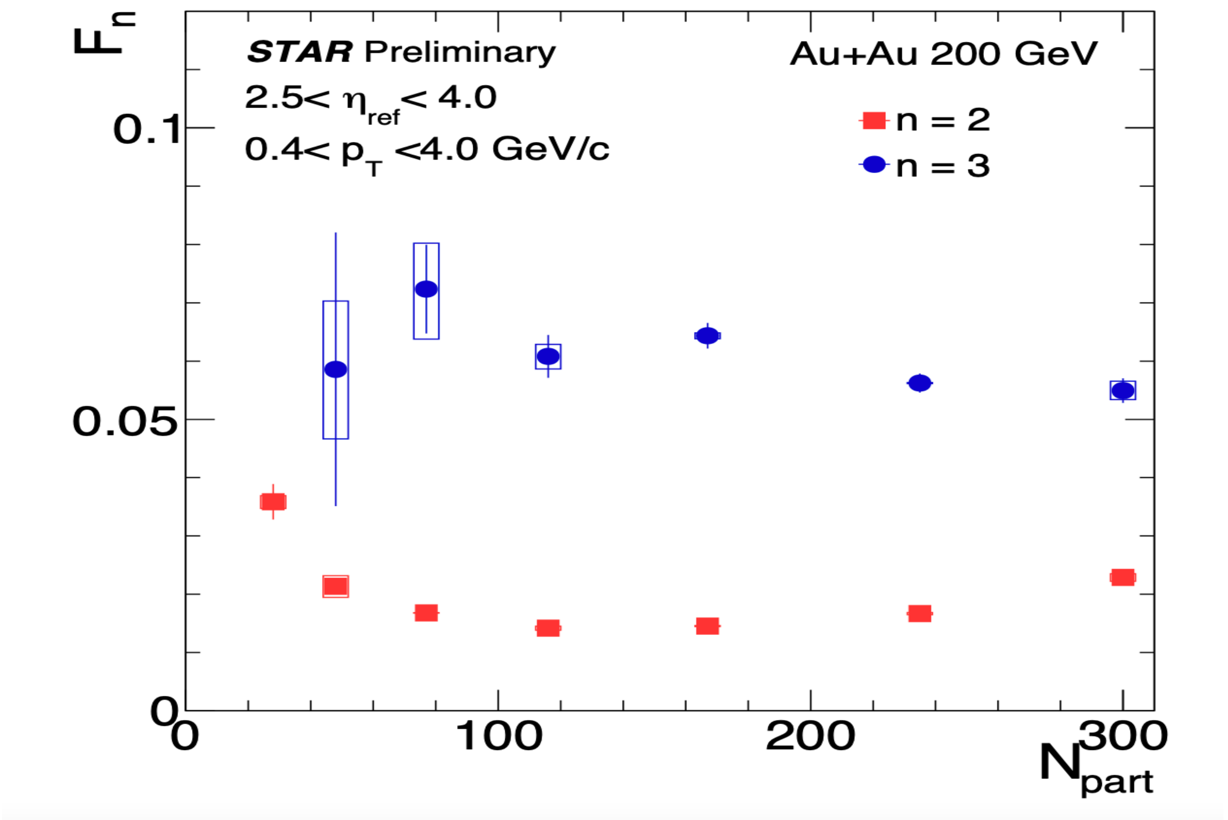
Nonflow vs. $\Delta\eta$ from pp@HIJING



Larger $\Delta\eta$ has only tiny effect to suppress the nonflow for v_3 measurements

Longitudinal Decorrelation



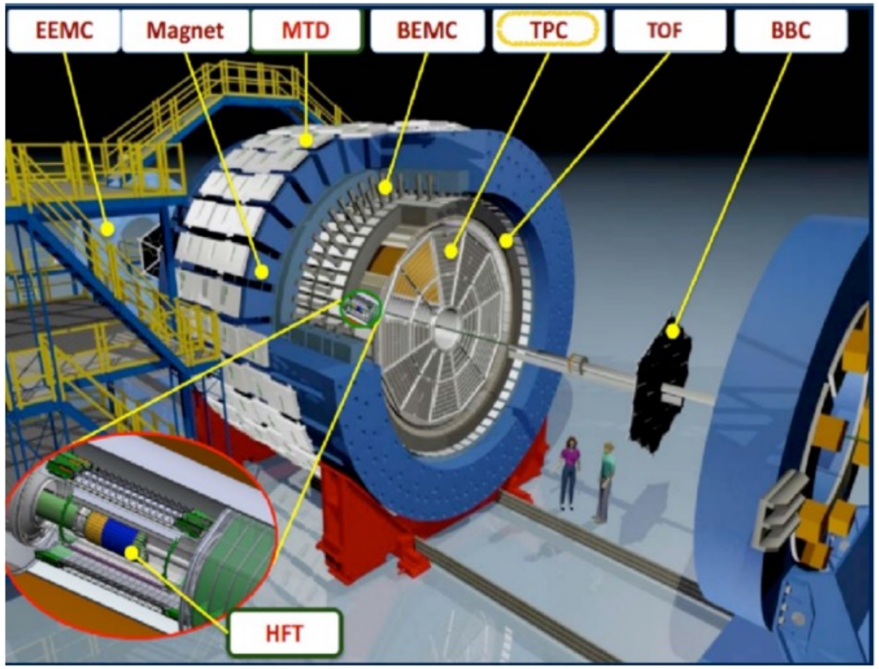


Large decorrelation at low multiplicity:

- pPb > PbPb
- AuAu@200GeV > PbPb@2.76TeV
- $v_3 > v_2$

Data Analyses

STAR Experiment at RHIC

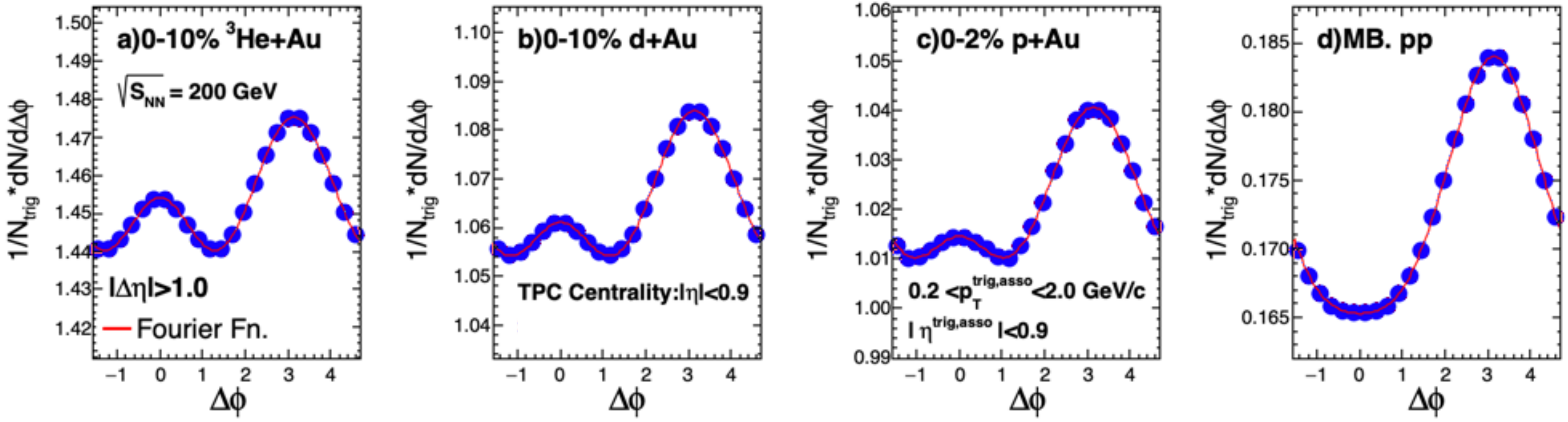


Measurements for p/d/^{3}He+Au collisions @ 200 GeV

- Centrality:
  - i) Number of tracks in TPC $0.2<p_T<3.0$ GeV/c, $|\eta|<0.9$
  - ii) BBC charge in Au-going direction $-5.0<\eta<-3.3$
- Two-particle correlation functions constructed for trigger and associated particles ***both at middle rapidity***
  - $0.2 < p_T < 2.0$ GeV/c
  - $|\eta|<0.9$
  - $|\Delta\eta| > 1.0$

✓ $v_2\{2\}(p_T)$, $v_3\{2\}(p_T)$ extracted from correlation functions following non-flow subtraction

Long-range two-particle correlators and v_n extraction (I)



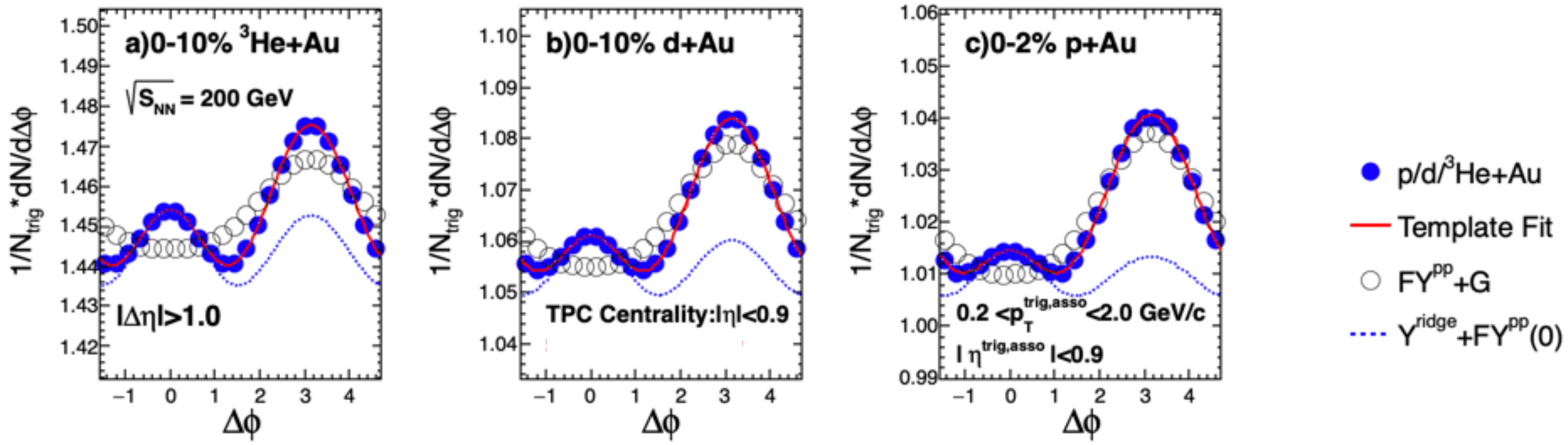
Four methods are employed for non-flow subtraction by using min-bias pp as a reference!

$$\frac{1}{N_{trig}} dN/d\Delta\phi = c_0(1 + 2\sum_{n=1}^{4} c_n \cos(n\phi))$$

- ✓ 1. via c_0: $c_{n,sub}^{sys.} = c_n^{sys.} - (c_0^{pp}/c_0^{sys.})c_n^{pp}$; n=2,3;
- ✓ 2. via near-side: $c_{n,sub}^{sys.} = c_n^{sys.} - (c_0^{pp}/c_0^{sys.})(Y_{NS}^{sys.}/Y_{NS}^{pp.})c_n^{pp}$; n=2,3
- ✓ 3. via c_1: $c_{n,sub}^{sys.} = c_n^{sys.} - (c_1^{sys}/c_1^{pp})c_n^{pp}$; n=2,3

$$v_{n,sub}^{sys.}(p_T) = c_{n,sub}^{sys.}(\text{pT,ref})/\sqrt{c_{n,sub}^{sys.}(ref)}$$

Long-range two-particle correlators and v_n extraction (II)



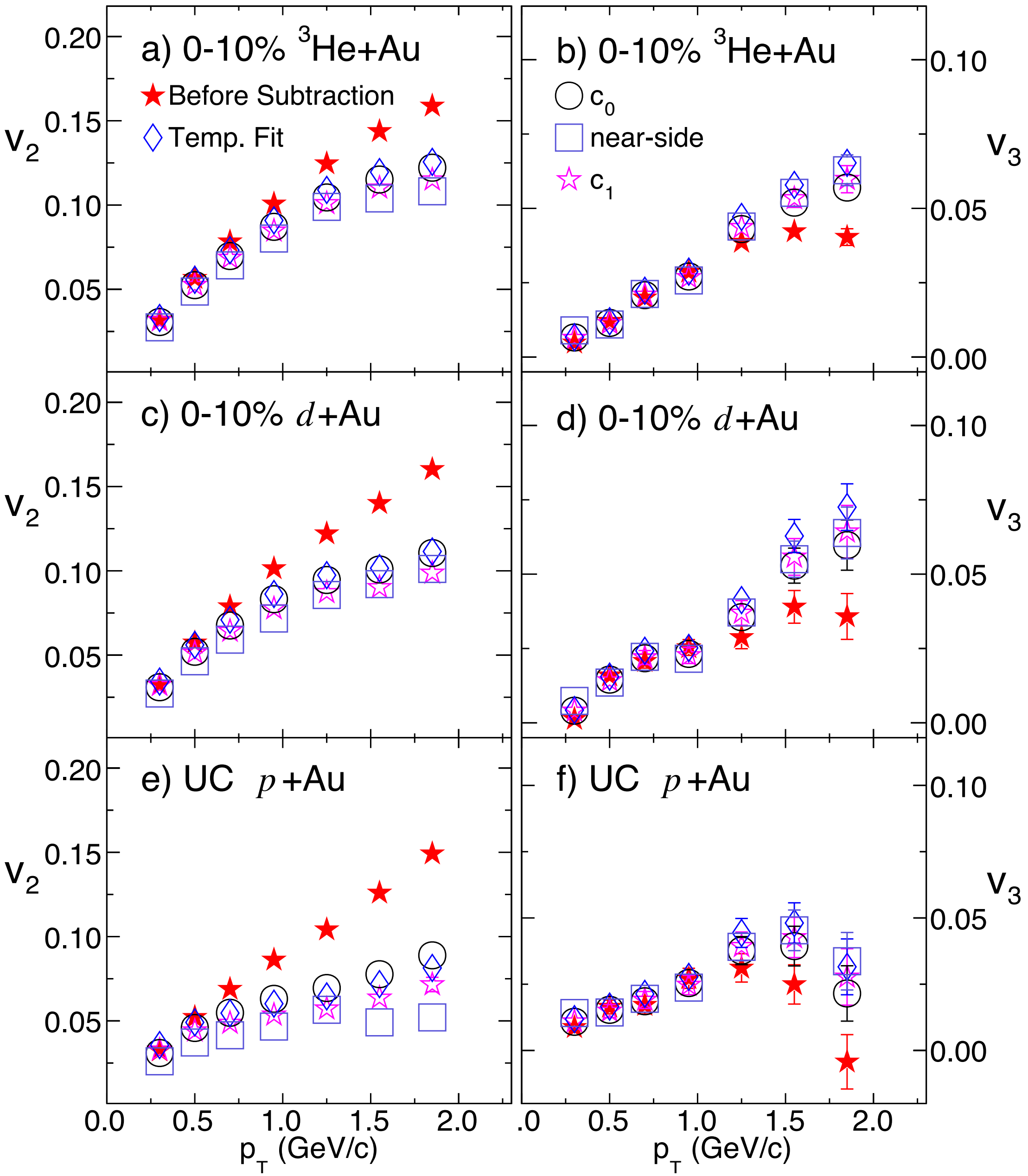
4. Template Fit *(ATLAS, PRL 116, 172301 (2016))*

$$Y_{templ.}(\Delta\phi) = Y_{ridge}(\Delta\phi) + F\, Y_{pp.}(\Delta\phi)$$

$$Y_{ridge}(\Delta\phi) = G(1 + 2\sum_{n=2}^{4} c_n^{sub}\cos(n\Delta\phi))$$

"F" represents the modification for the long-range away-side jet between **p/d/³He+Au and p+p**

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



STAR: 2210.11352

- **Non-flow subtracted v_2 and v_3 are method-independent**

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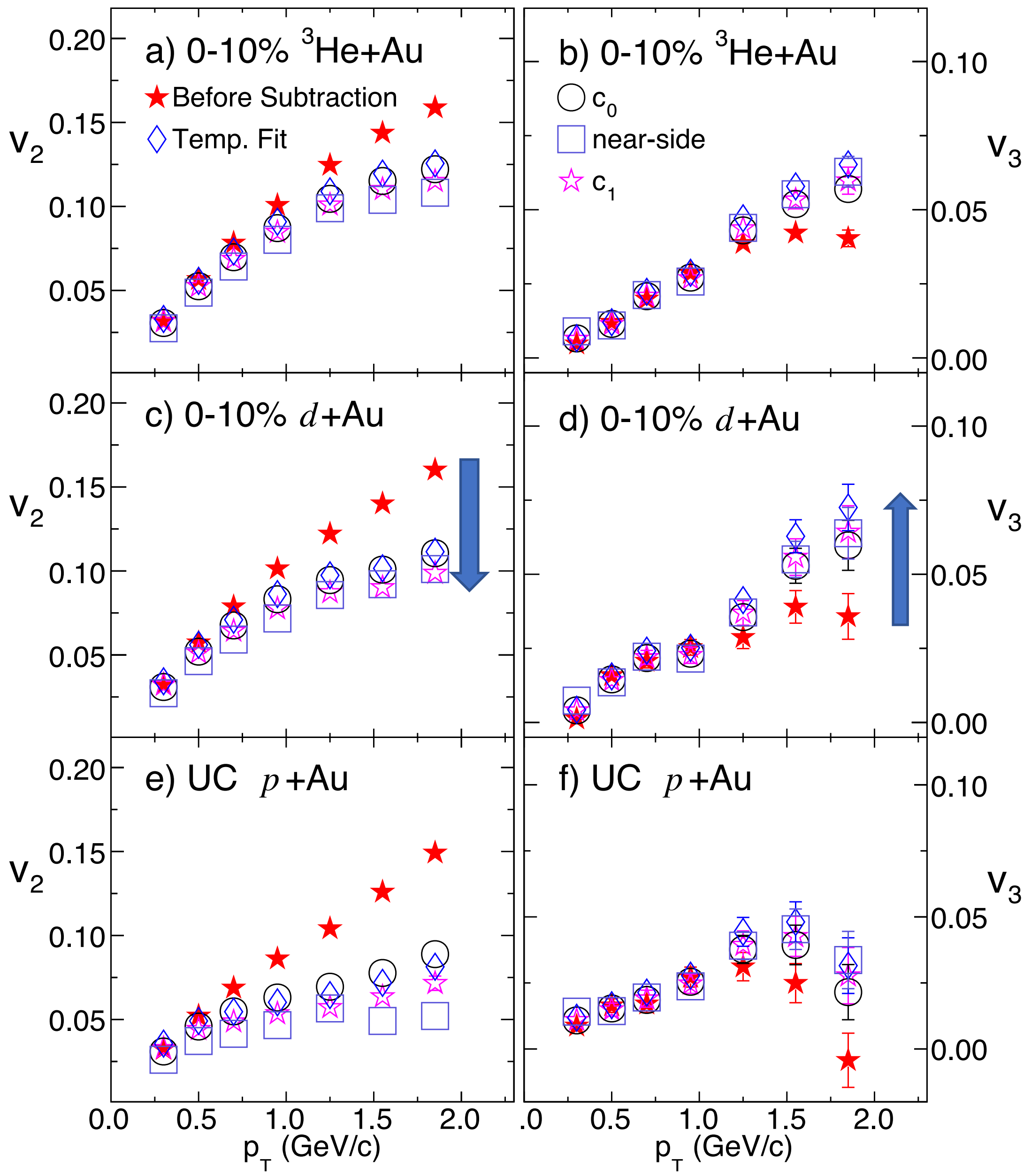
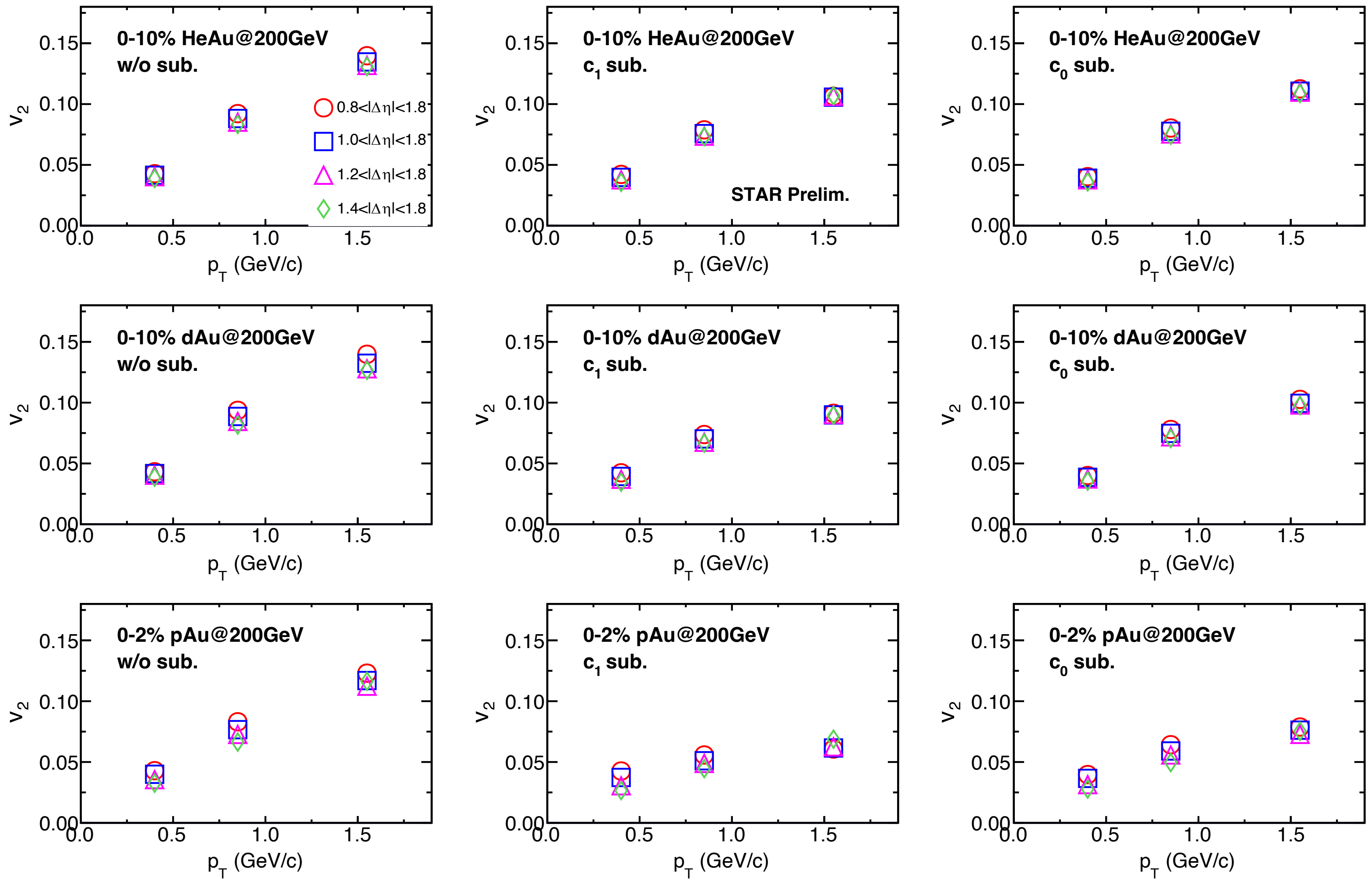


- **Non-flow subtracted v_2 and v_3 are method-independent**
- **Non-flow flow subtractions decrease v_2 and increase v_3**

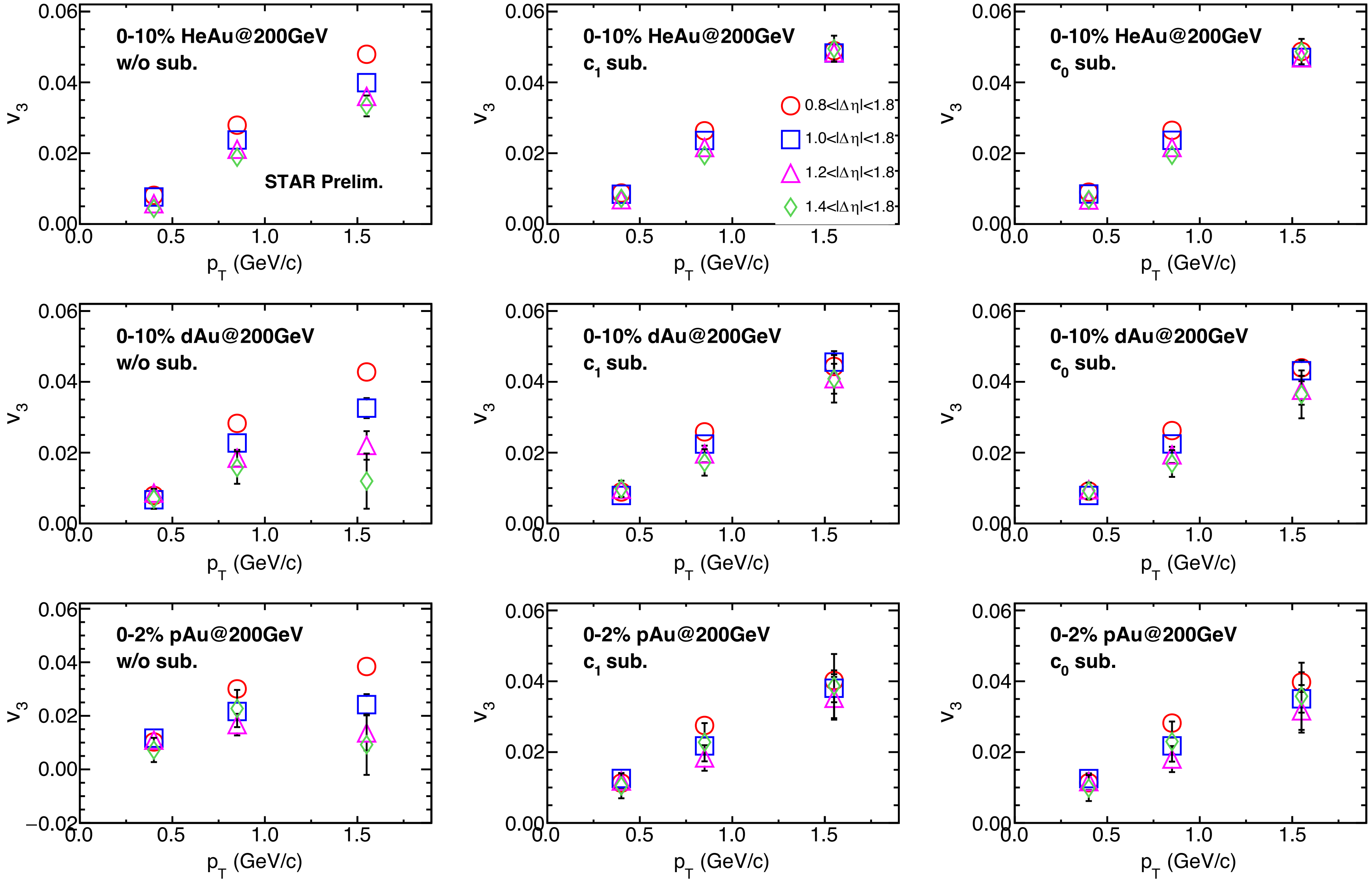
STAR: 2210.11352

v_2 with different $\Delta\eta$ cut



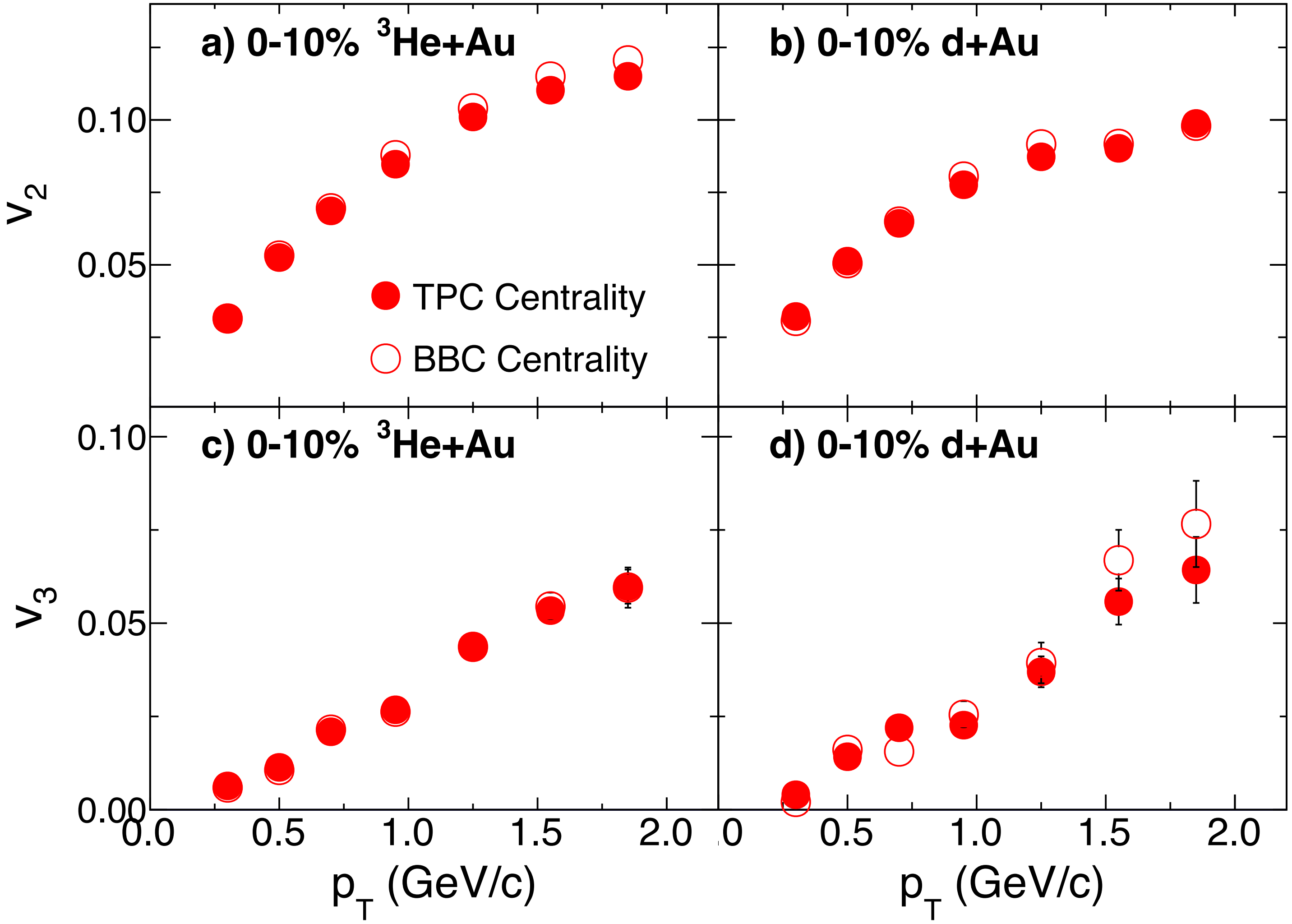
v_2 after nonflow subtraction is insensitive to $\Delta\eta$ cut and subtraction method

v_3 with different $\Delta\eta$ cut



v_3 after nonflow subtraction is also insensitive to $\Delta\eta$ cut and subtraction method

Differential v_2 and v_3 measurements for different centrality definitions

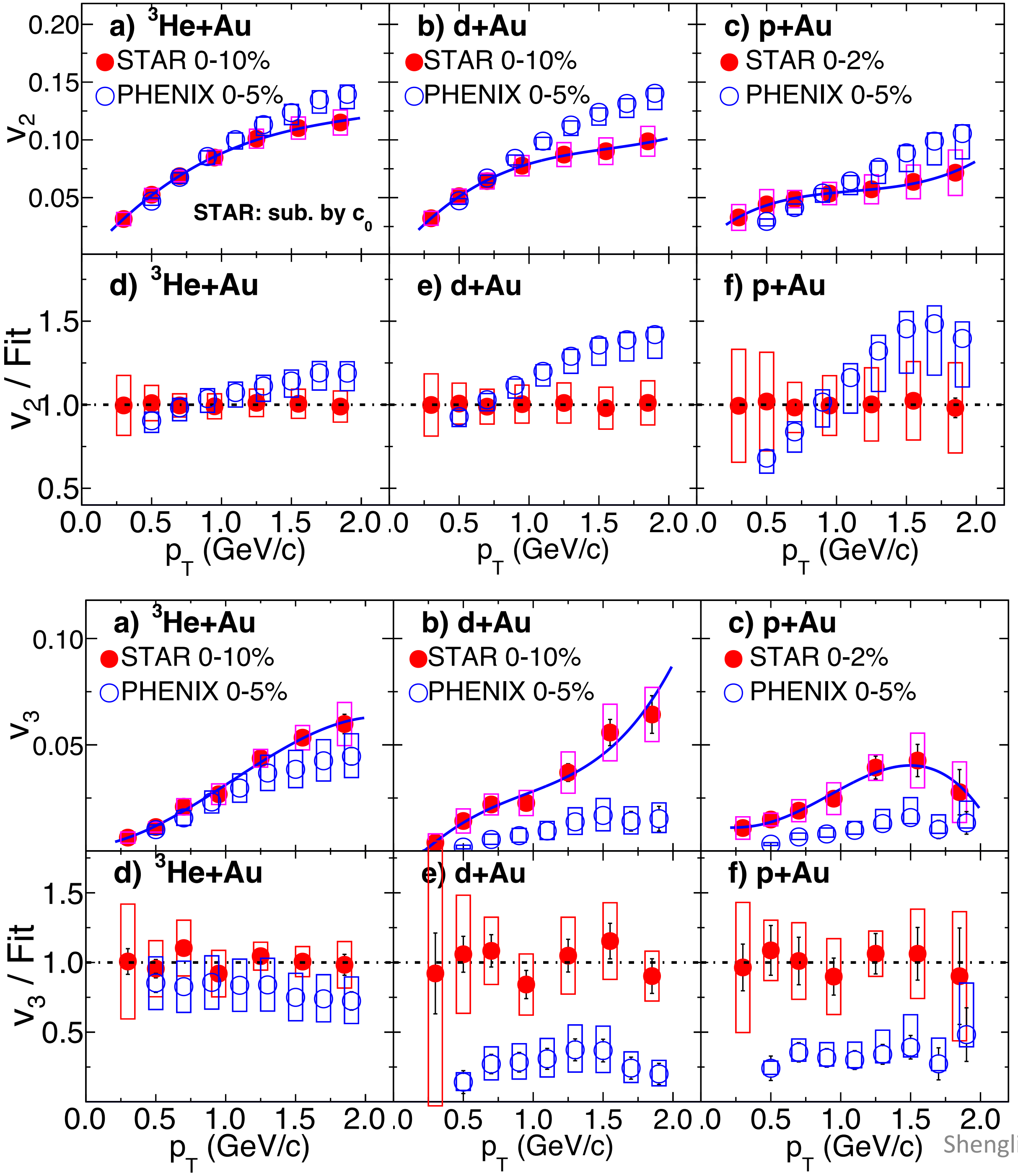


TPC centrality: Centrality and 2p correlation measured in same rapidity

BBC centrality: Centrality and 2p correlations measured in different rapidity, avoid auto-correlation

✓ **Results are consistent between two kinds of different centrality definitions with mid and backward rapidity regions**

Detail Comparisons to PHENIX



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

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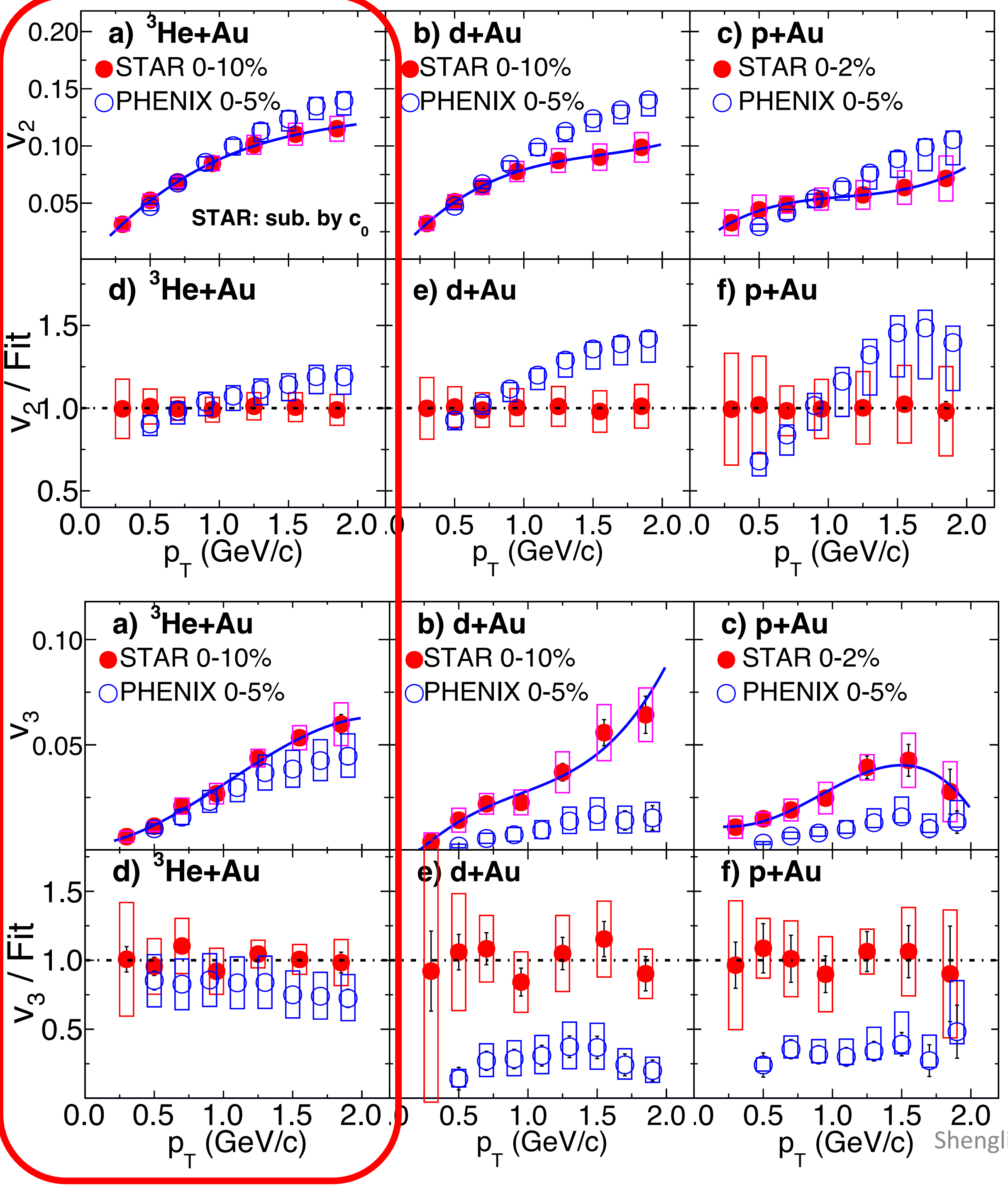

- The STAR and PHENIX v_2 and v_3 for ^{3}He+Au, show reasonable agreement

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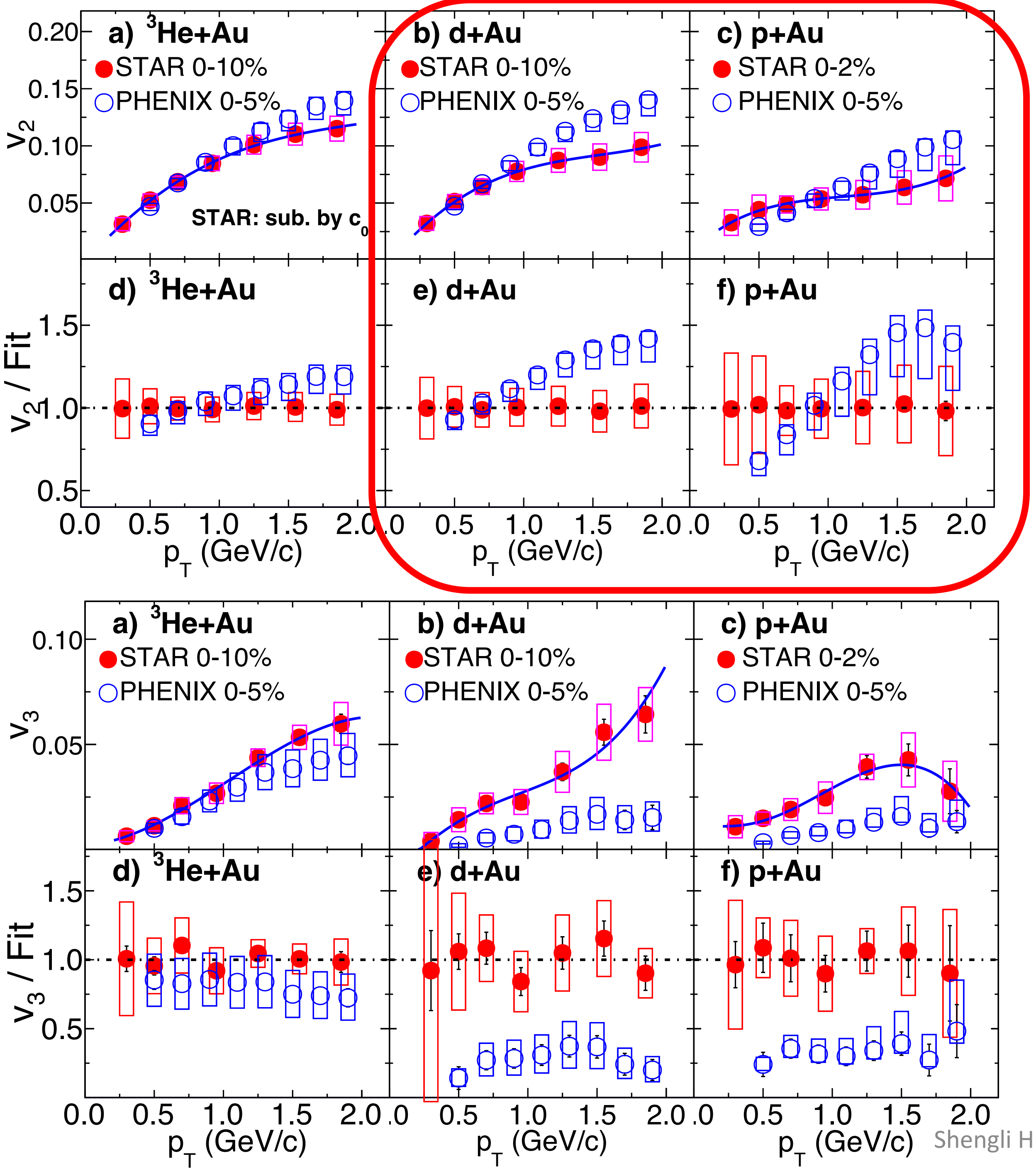

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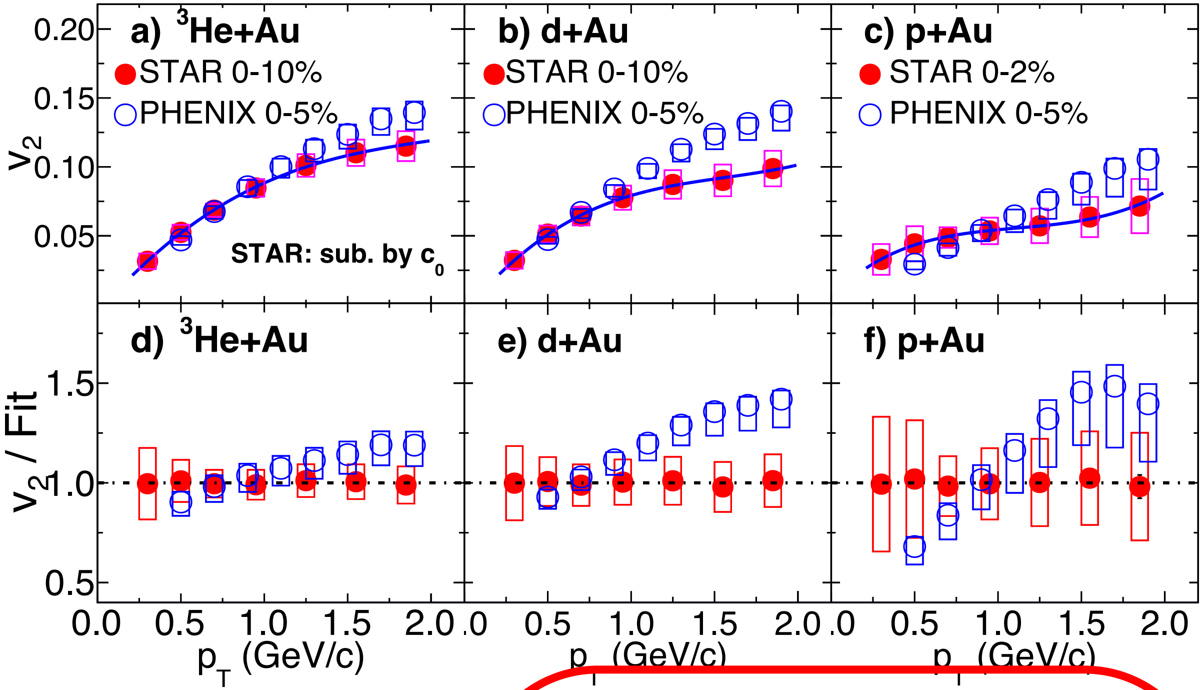

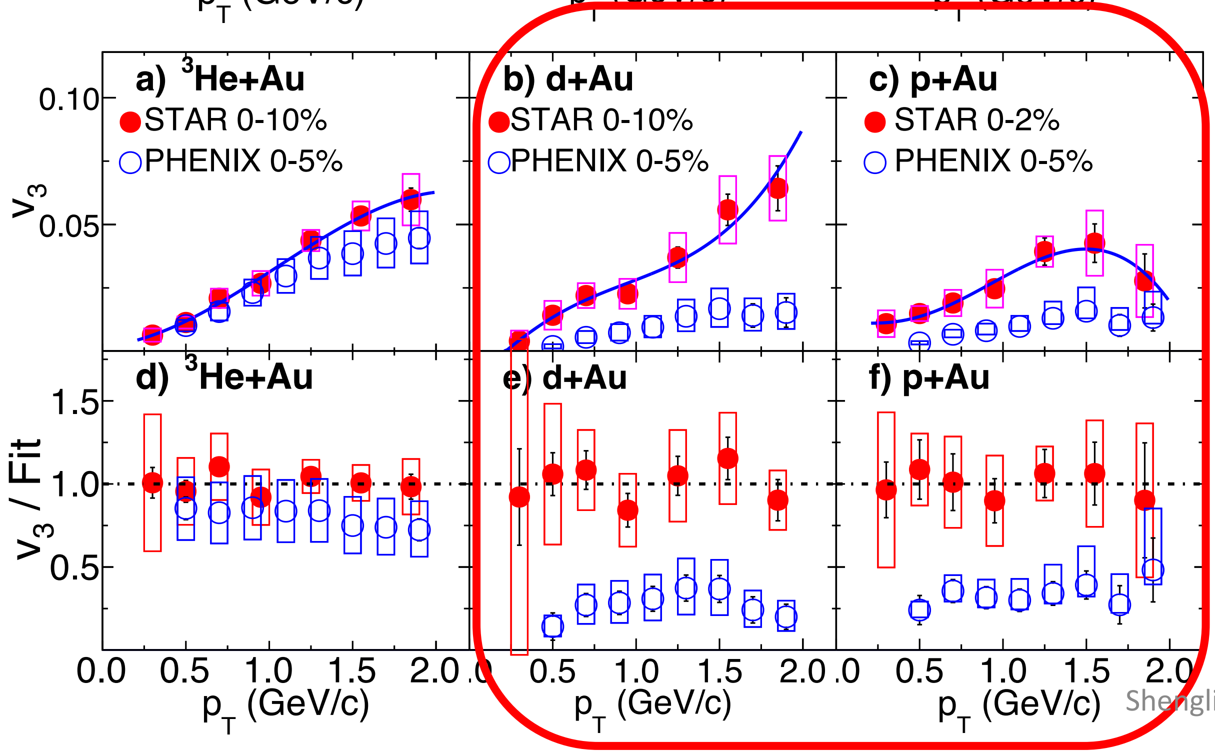

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- The STAR and PHENIX v_3 for p/d+Au, show similar p_T dependence
  - ✓ But magnitudes differ by a factor of 3
    - ✓ System-independent STAR v_3
    - ✓ System-dependent PHENIX v_3

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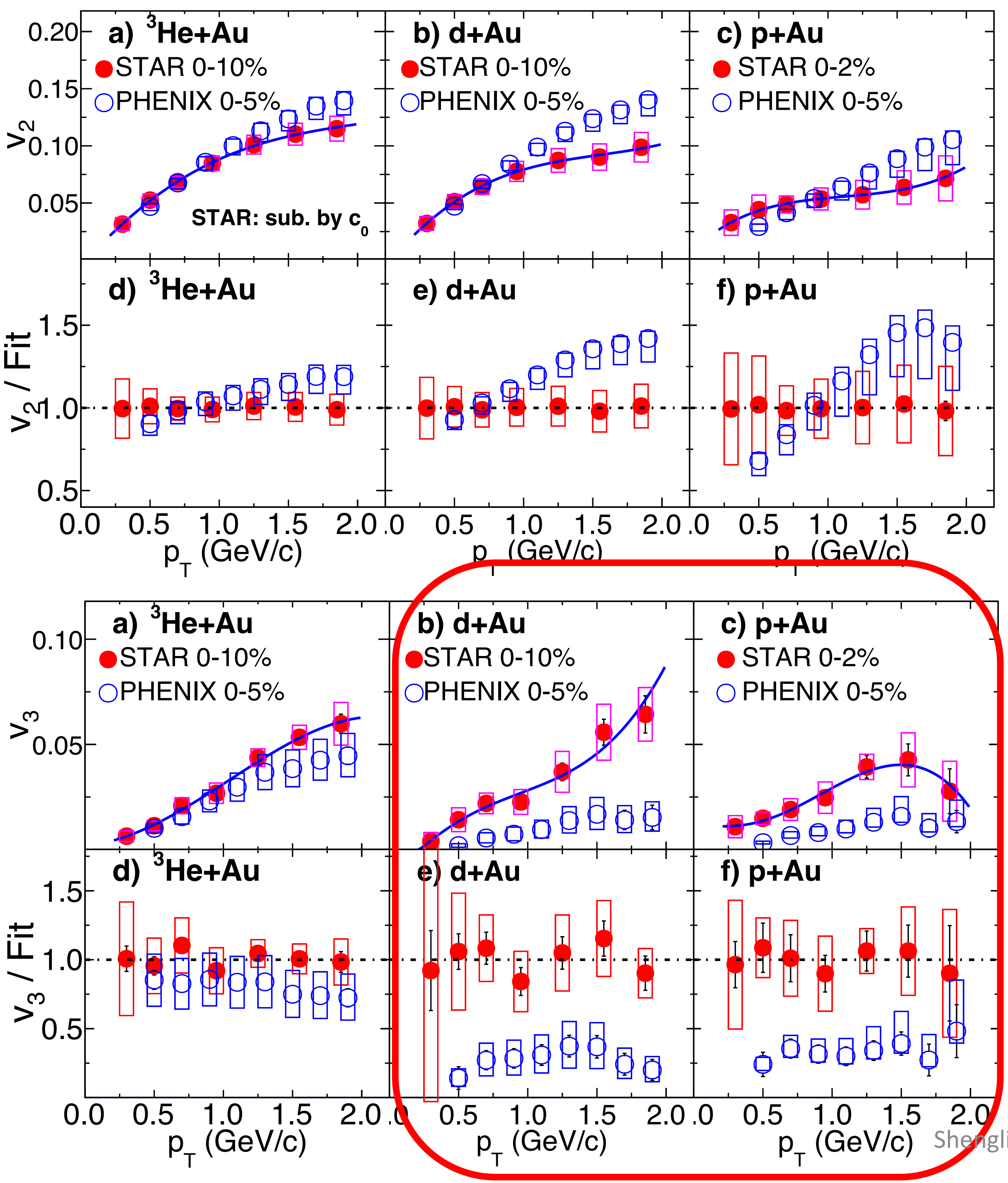

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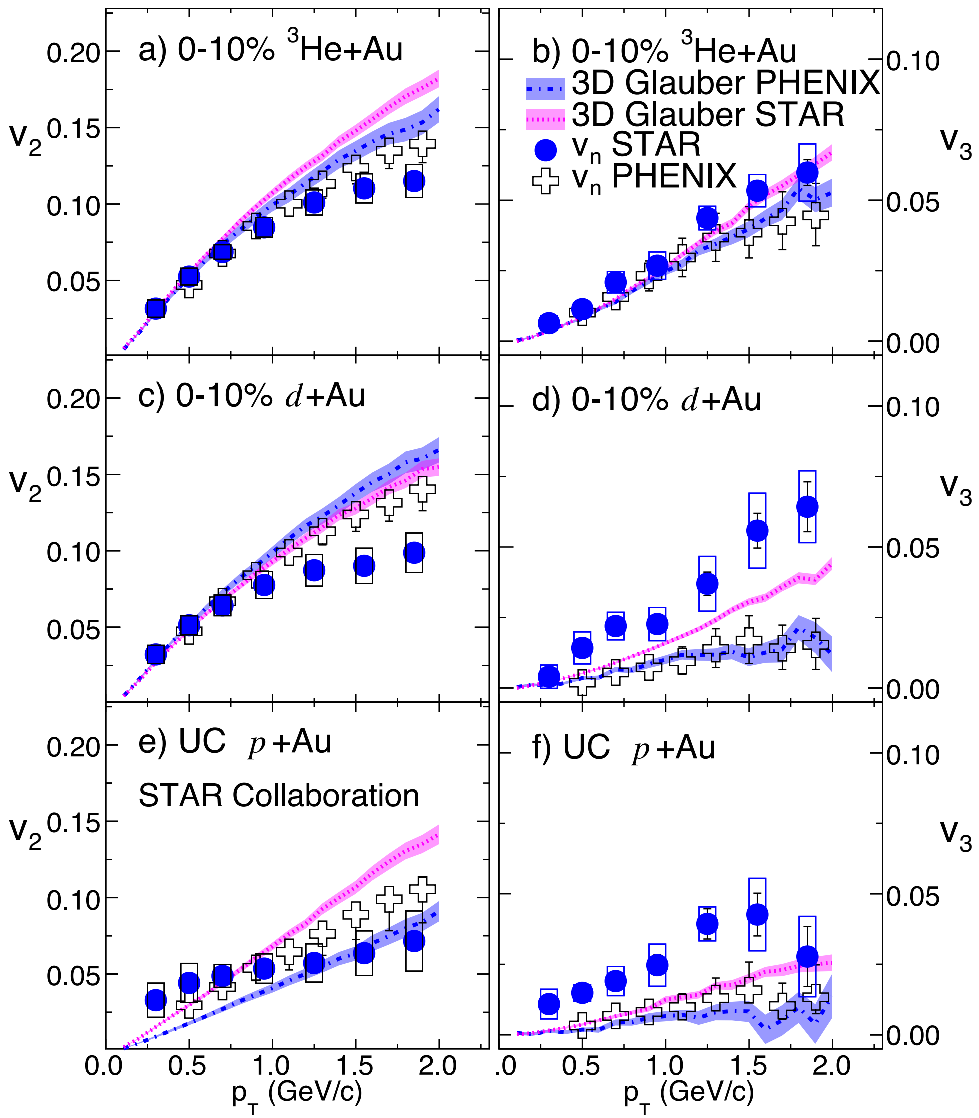
- ***Longitudinal decorrelation effect?***

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

Comparison to 3D-Glauber model

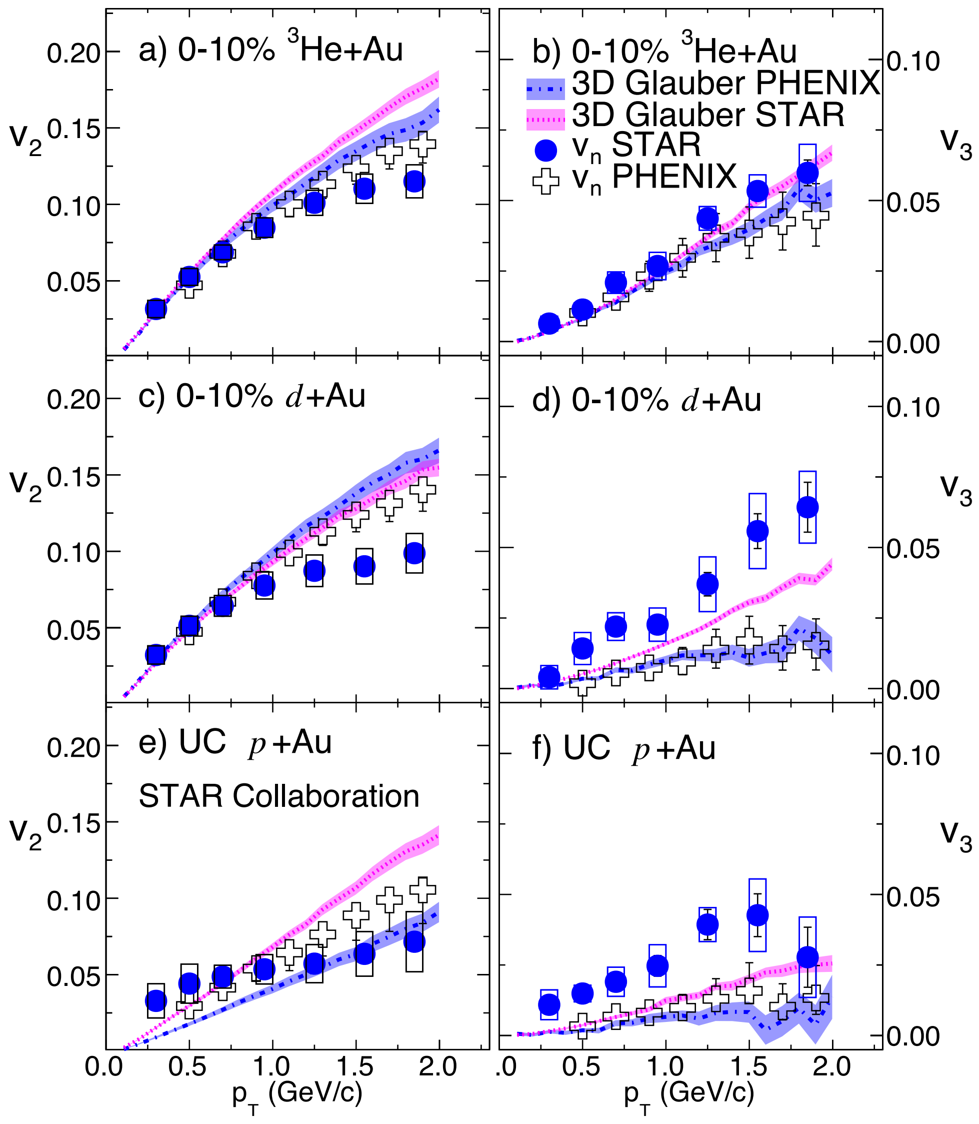


X. Zhao && C. Shen PRC.107.014904

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

Model still underestimates STAR measurements

Comparison to 3D-Glauber model



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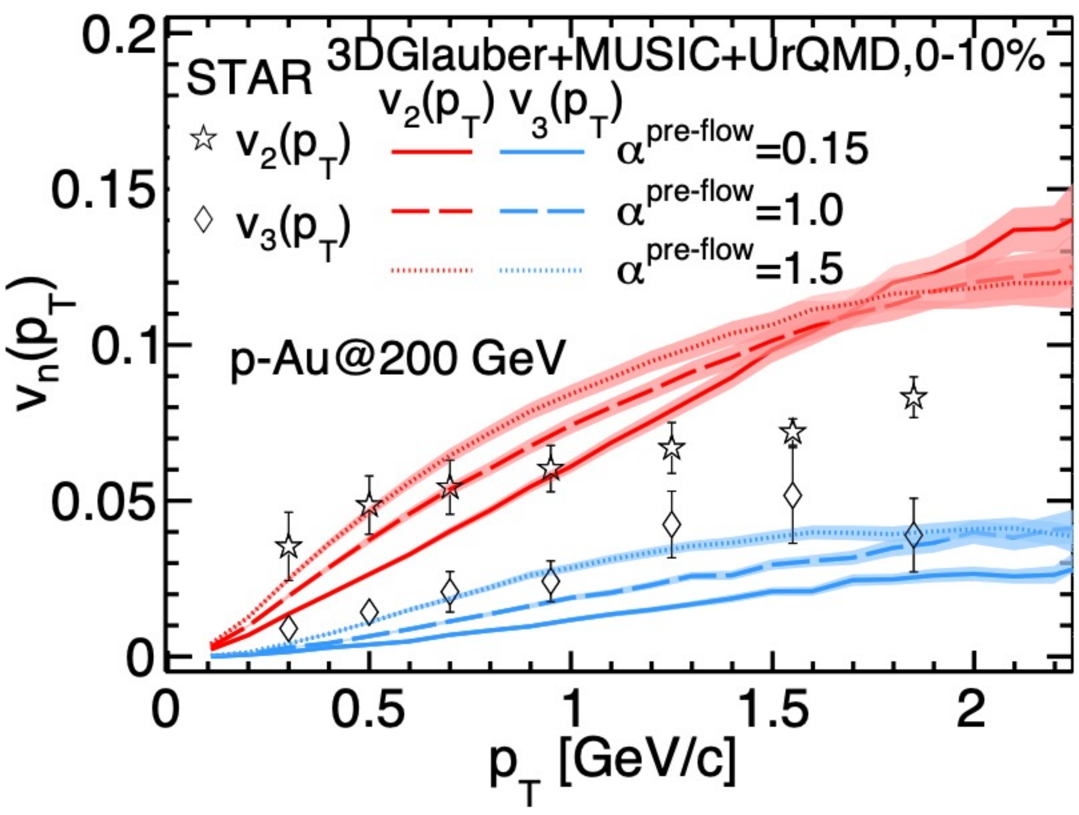

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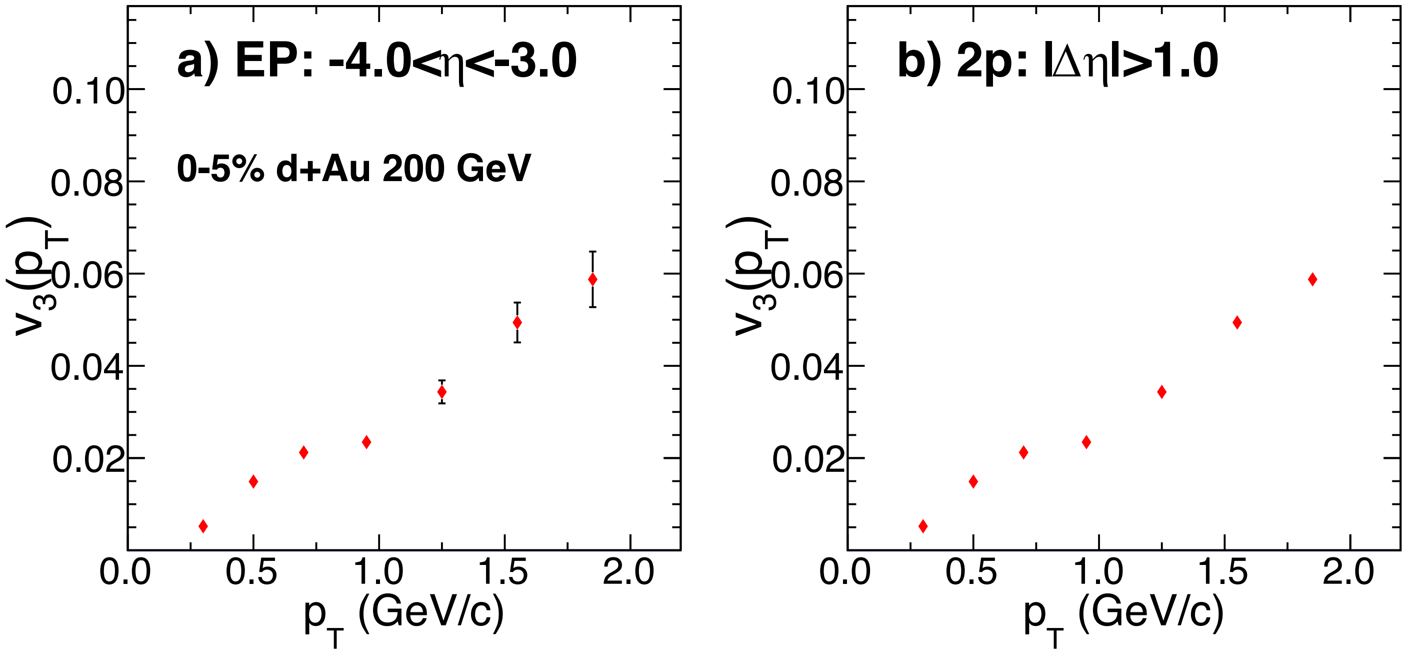
Model still underestimates STAR measurements

Pre-flow + nonflow in future calculations?

d+Au@RHIC 2021



Projection from 100M 0-5% d+Au@200GeV from Run21 with improved acceptance

Mean values are from current measurements

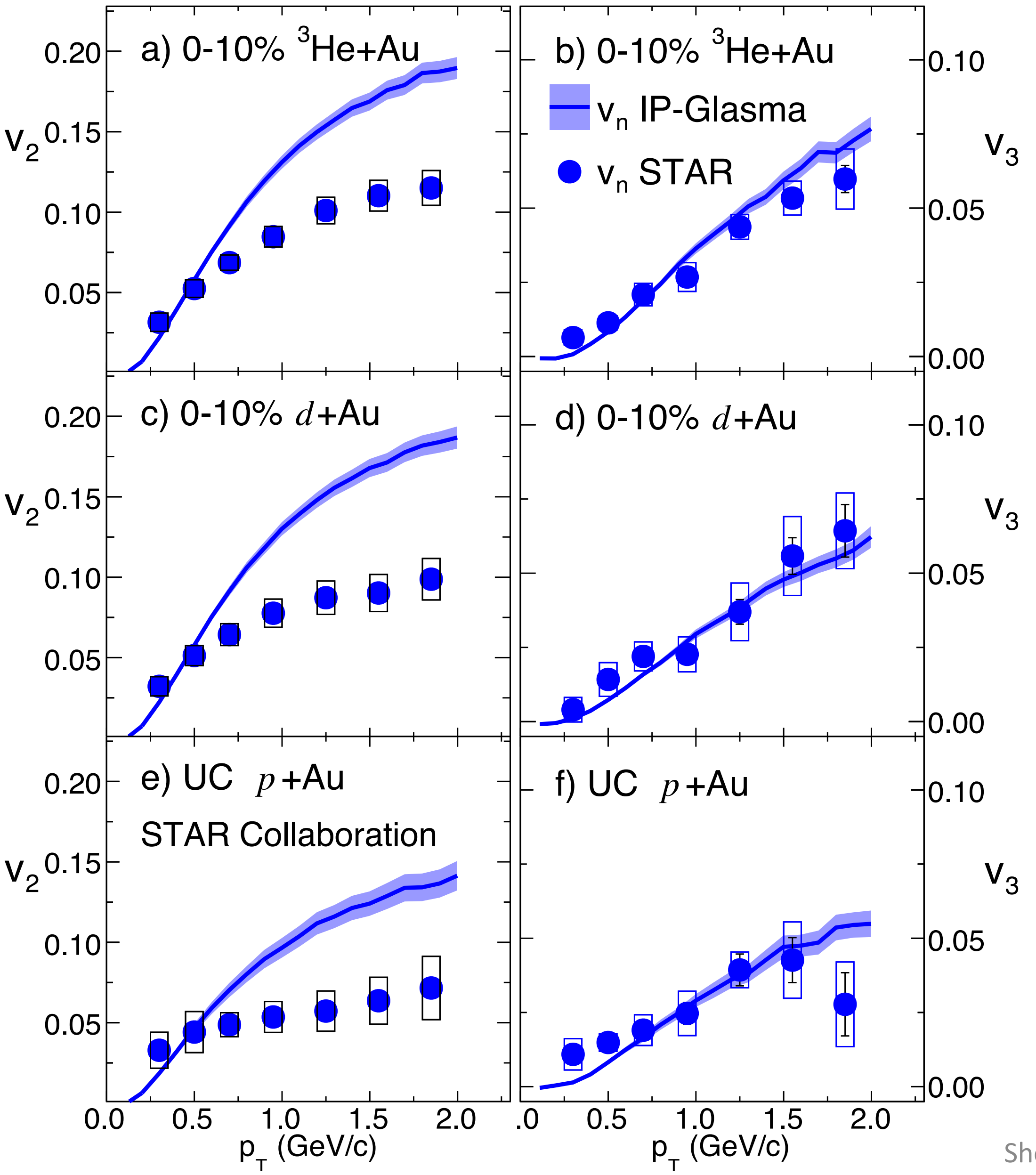
100M MB and 100M HM(0-5% selected by EPD) triggered events have been taken by STAR in 2021

Improved acceptance: iTPC (|η|<1.5) + EPD(2.1<|η|<5.1)

No Beam Cross Angle

Further investigate the longitudinal decorrelation in small-sized system

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 $\boldsymbol{\varepsilon}_2$ 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
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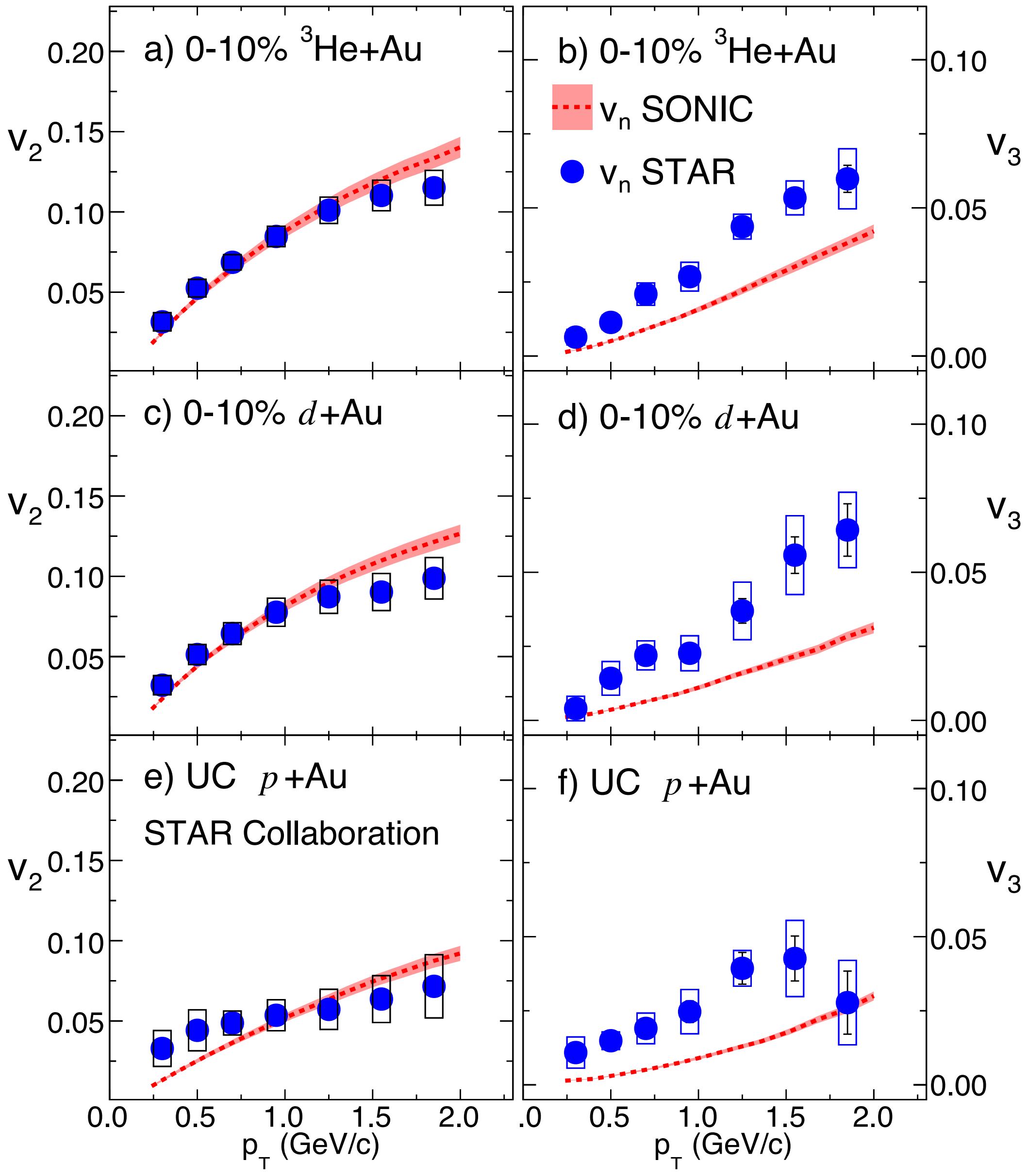
Comparison to SONIC



➢ ***SONIC model*** with initial geometry eccentricity without gluon field fluctuations under-predicts v_3 in all systems

Model	a	b	c	d
	$\varepsilon_2^a(\varepsilon_3^a)$	$\varepsilon_2^b(\varepsilon_3^b)$	$\varepsilon_2^c(\varepsilon_3^c)$	$\varepsilon_2^d(\varepsilon_3^d)$
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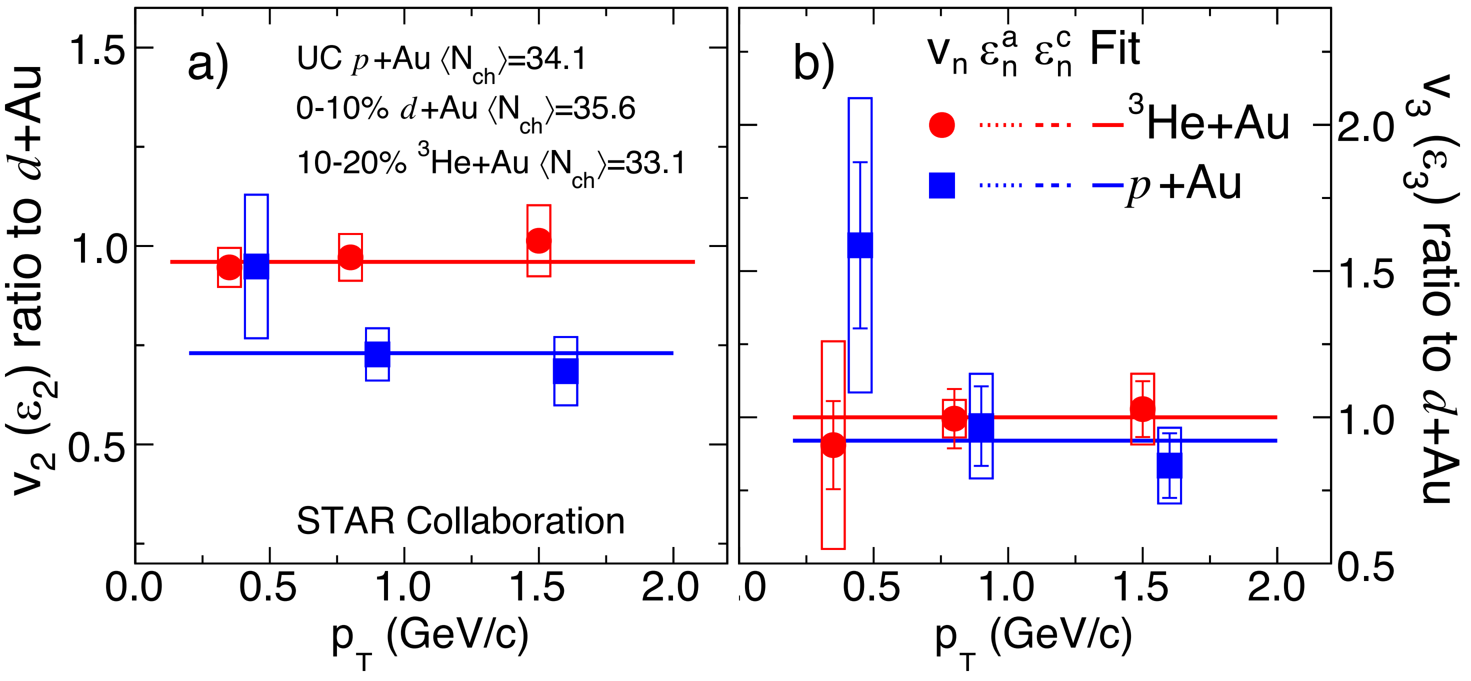
SONIC: P. Romatschke *Eur. Phys.J.C* **75**, 305 (2015)

The system dependence



Final state contribution is expected largely canceled out in v_n ratio due to similar multiplicity

It will be helpful to address the initial spatial geometry and contribution from initial stage

$V_2(^3HeAu) \approx v_2(dAu) > v_2(pAu)$
$V_3(^3HeAu) \approx v_3(dAu) \approx v_3(pAu)$

STAR: 2210.11352

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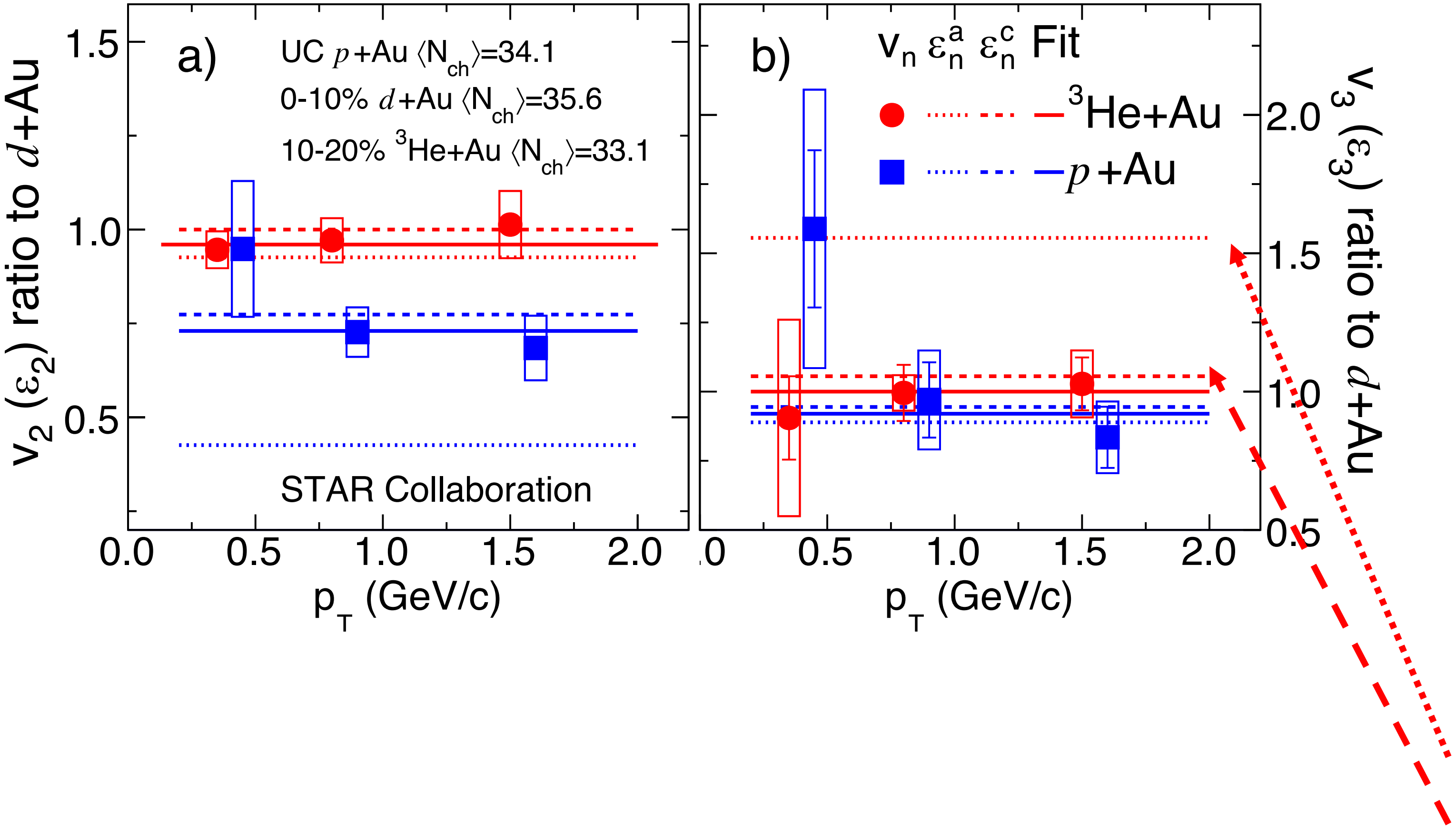

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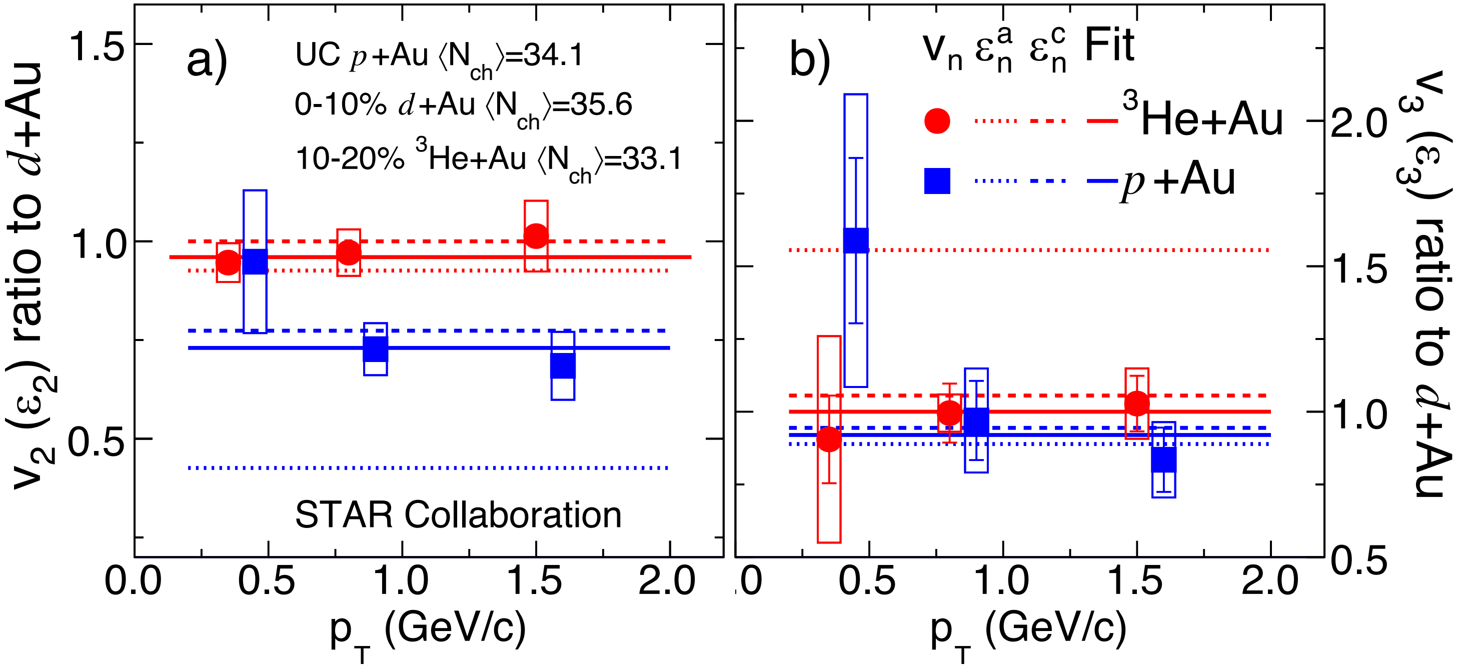
Two Base Lines:
Nucleon spatial Geometry
Sub-nucleon spatial Geometry

STAR: 2210.11352

The system dependence



Final state contribution is expected largely canceled out for similar multiplicity

Ratio will be helpful to address the initial spatial geometry and contribution from initial stage

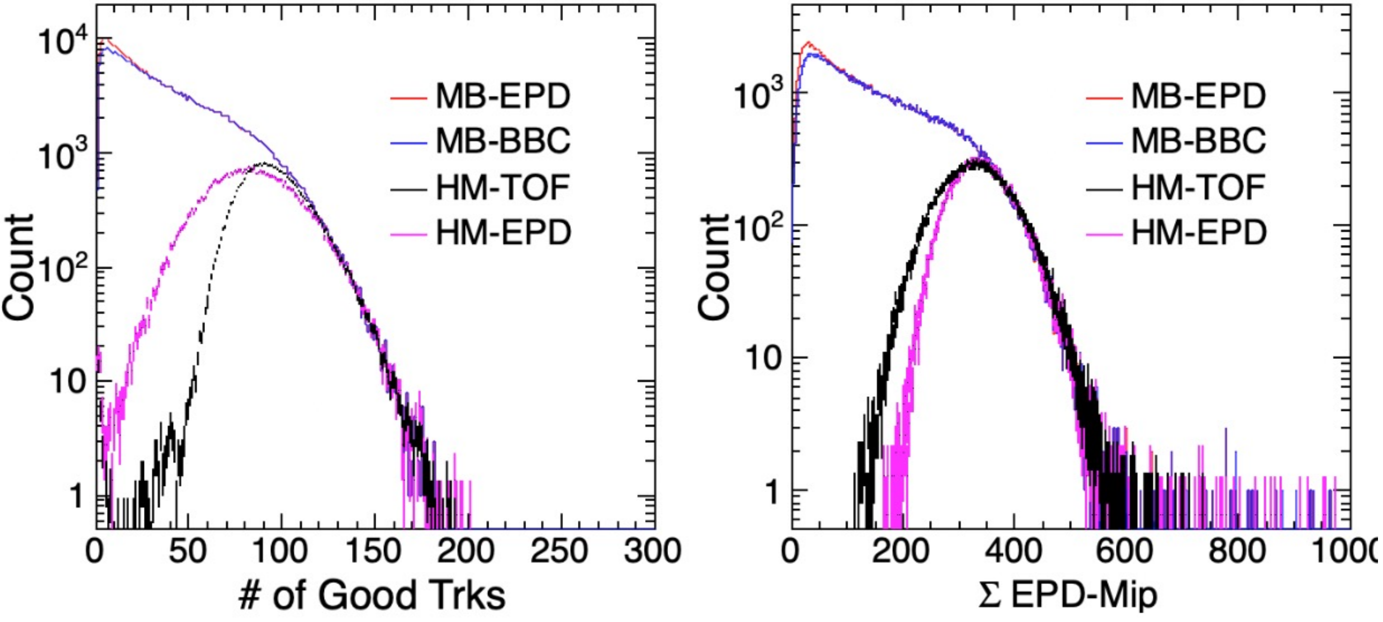
V_2(HeAu) ≈ v_2(dAu) > v_2(pAu)
V_3(HeAu) ≈ v_3(dAu) ≈ v_3(pAu)

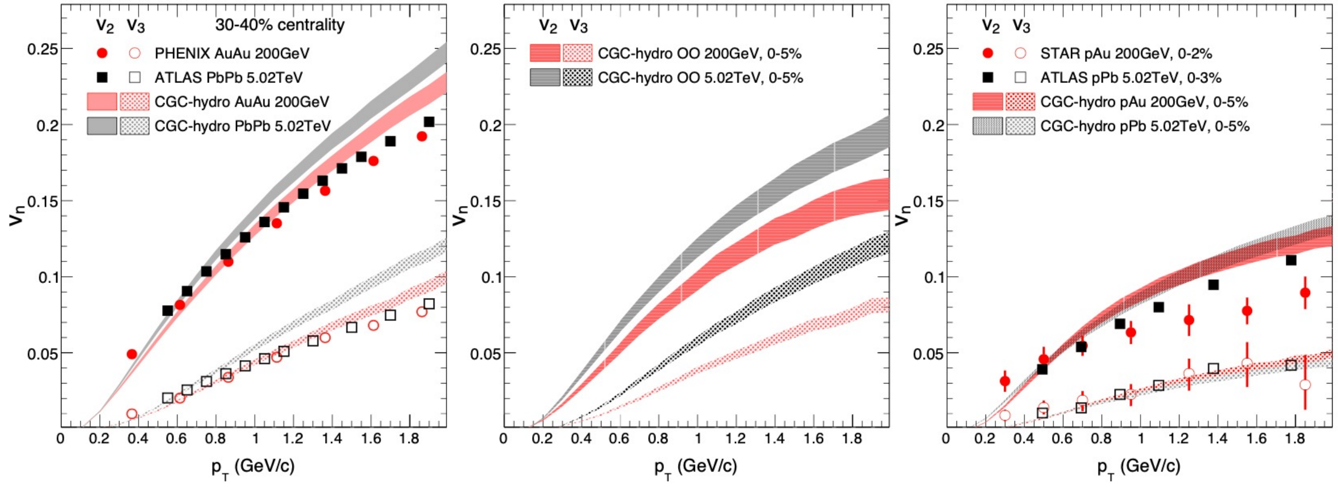
Two Base Lines:
Nucleon spatial Geometry
Sub-nucleon spatial Geometry

Sub-nucleon spatial Geometry + Hydro?
Or
large initial stage contribution?

STAR: 2210.11352

Outlook: O+O@RHIC 2021





STAR: BUR2020

- ***STAR has taken 400M MB and 200M HM O+O events in 2021***
  - ✓ Large rapidity coverage $|\eta|$<1.5 due to iTPC upgrade
  - ✓ Trigger HM event at both middle or forward rapidity

- **First** comparison between RHIC & LHC with ~identical Glauber geometry but different sub-nucleon fluctuation (Q_s) for a factor of 10 difference in energy

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

Summary

- STAR measured v_2 and v_3 as a function of p_T in central p/d/^{3}He+Au collisions. The extracted flow signals are found to be consistent among different non-flow subtraction methods

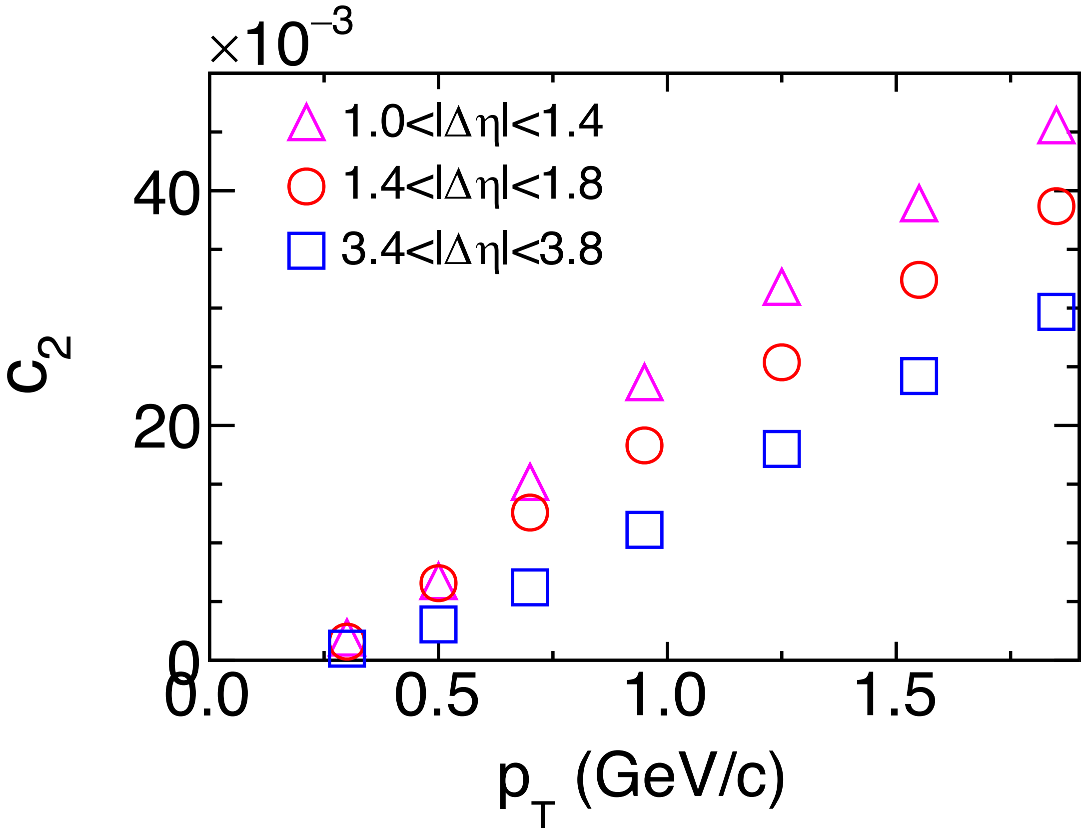
- A system independent v_3 has been found, indicating that sub-nucleon gluon field fluctuations have a strong influence on initial geometry for small-sized systems

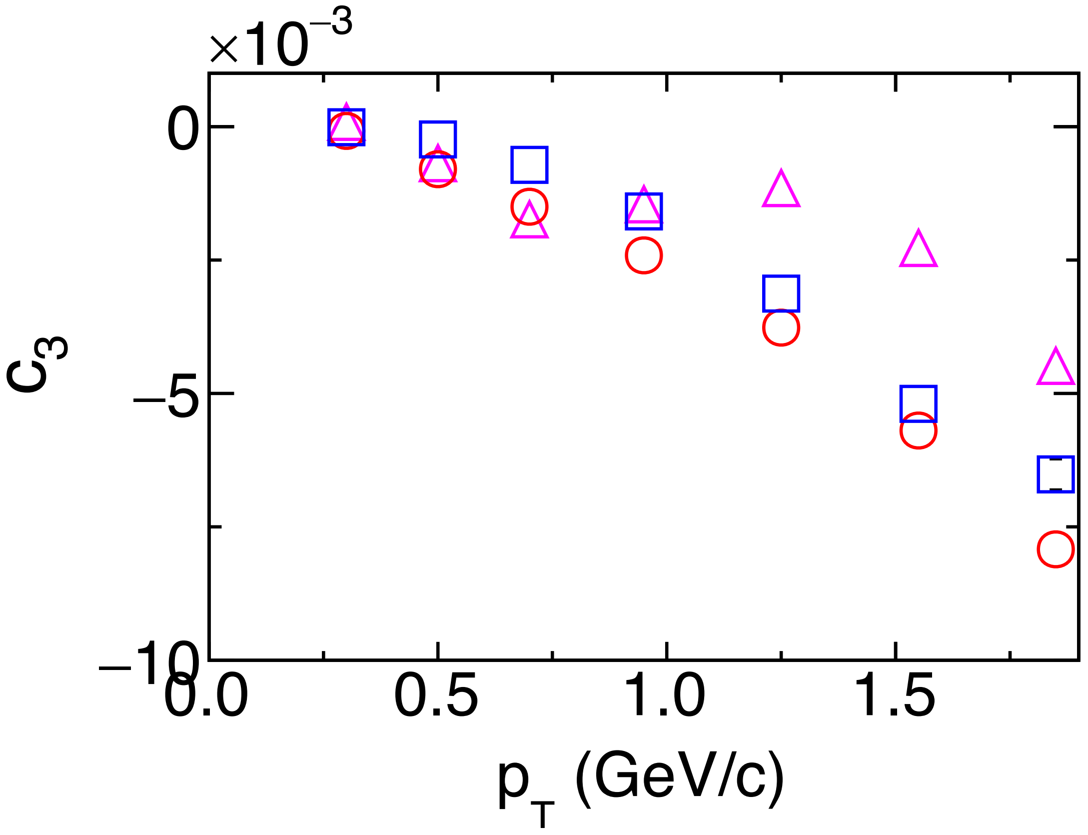
- In future, the new d+Au and O+O data will provide more information to study mini-QGP and sub-nucleon structure

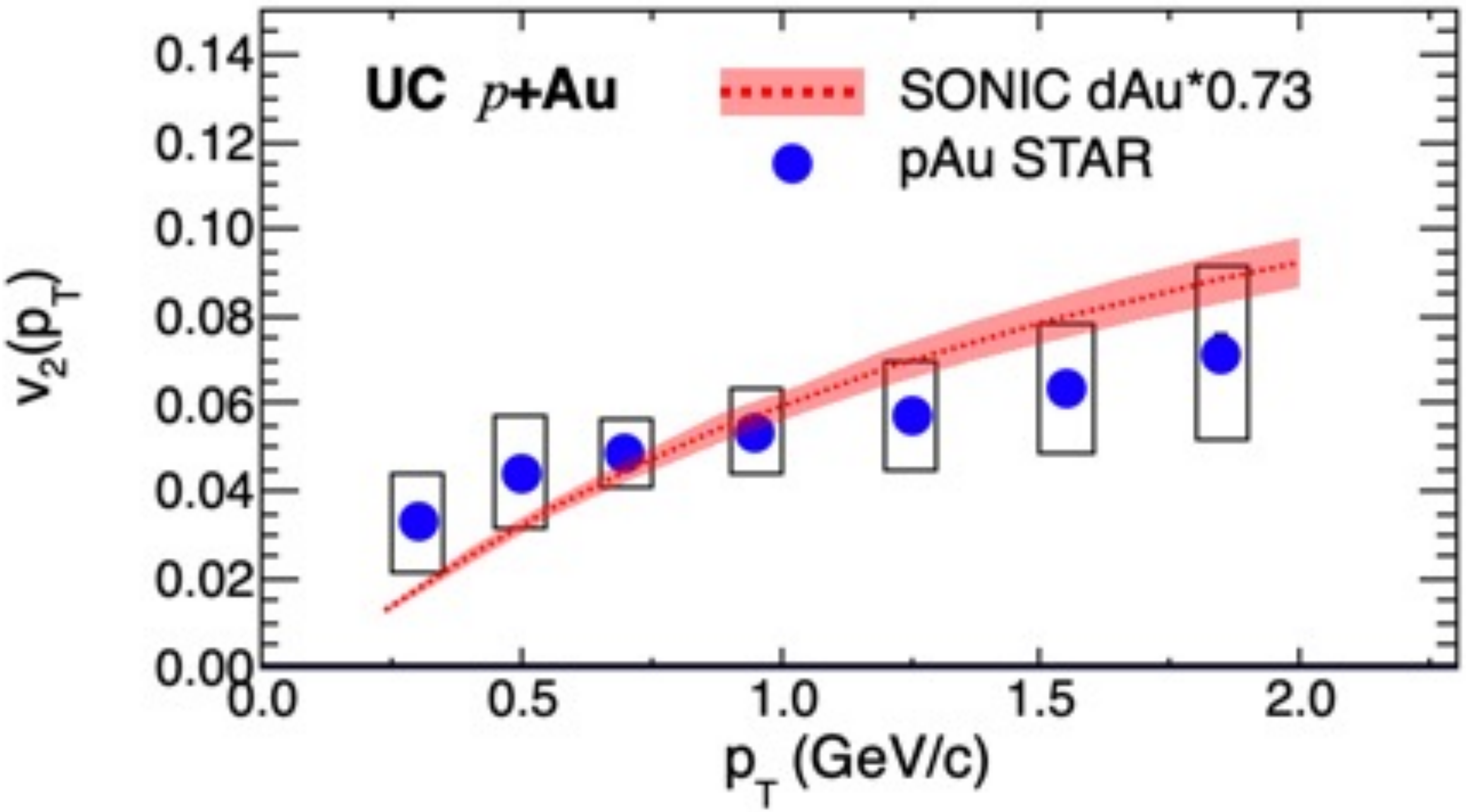
Thanks!

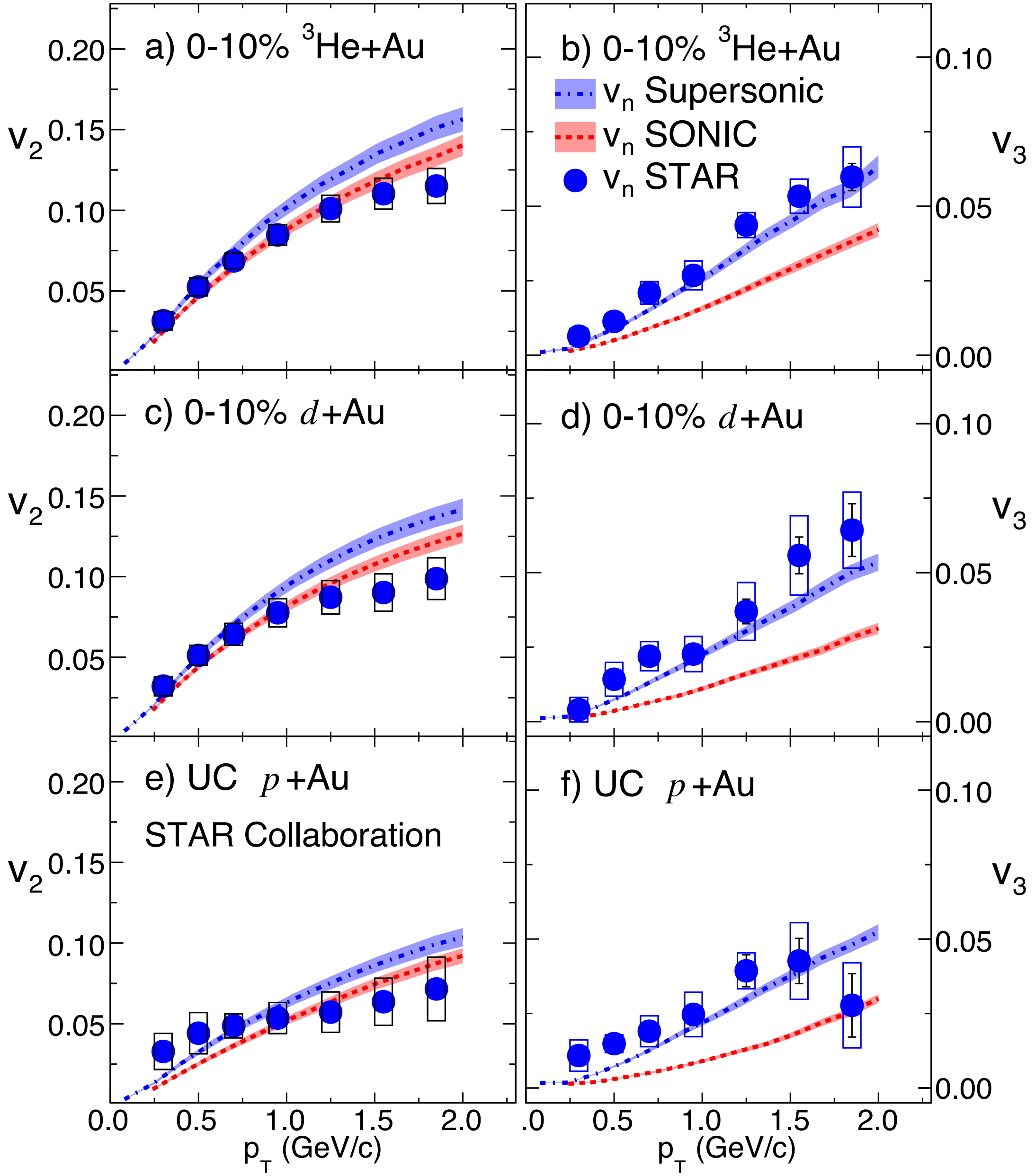
Backup

HIJING vs. η Gap






UC p+Au
SONIC dAu*0.73
pAu STAR
v2(pT)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.0
0.5
1.0
1.5
2.0
pT (GeV/c)



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