Systematic Study of Anisotropy Flow in p/d/^{3}He+Au Collisions

Shengli Huang

For STAR Collaboration

Outline:

- Physics Motivations
- Analysis Results
- Comparison to prior measurements
- Comparison to model calculations
- Summary

Stony Brook University

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

Initial Geometry in Small-sized Systems

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

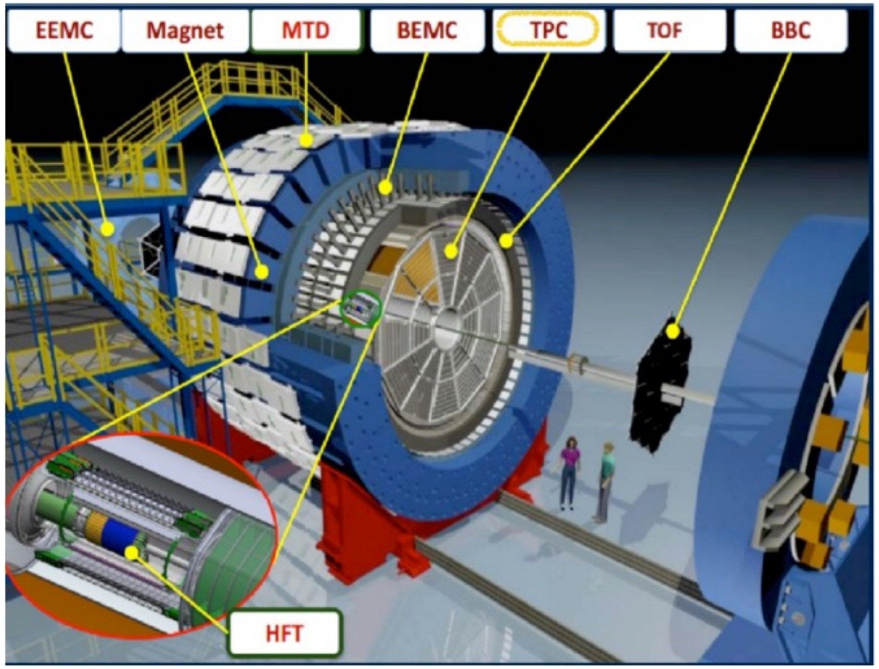
Model	a $\varepsilon_2^a(\varepsilon_3^a)$	b $\varepsilon_2^b(\varepsilon_3^b)$	c $\varepsilon_2^c(\varepsilon_3^c)$	d $\varepsilon_2^d(\varepsilon_3^d)$
^{3}He+Au	0.50(0.28)	0.52(0.35)	0.53(0.38)	0.64(0.46)
d+Au	0.54(0.18)	0.51(0.32)	0.53(0.36)	0.73(0.40)
p+Au	0.23(0.16)	0.34(0.27)	0.41(0.34)	0.50(0.32)

Model a: standard Glauber model ***Phys. Rev. Lett. 113, 434 112301 (2014)***
Model b: smooth gluon field sourced by nucleons ***Phys. Rev. C 94, 024919 (2016)***
Model c: smooth gluon field sourced by valence quark ***Phys. Rev. C 94, 024919 (2016)***
Model d: lumpy gluon field soueced by valence quark(IP-Glasma) ***Phys. Rev. 436 Lett. 108, 252301***

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

Data Analyses

STAR Experiment at RHIC



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

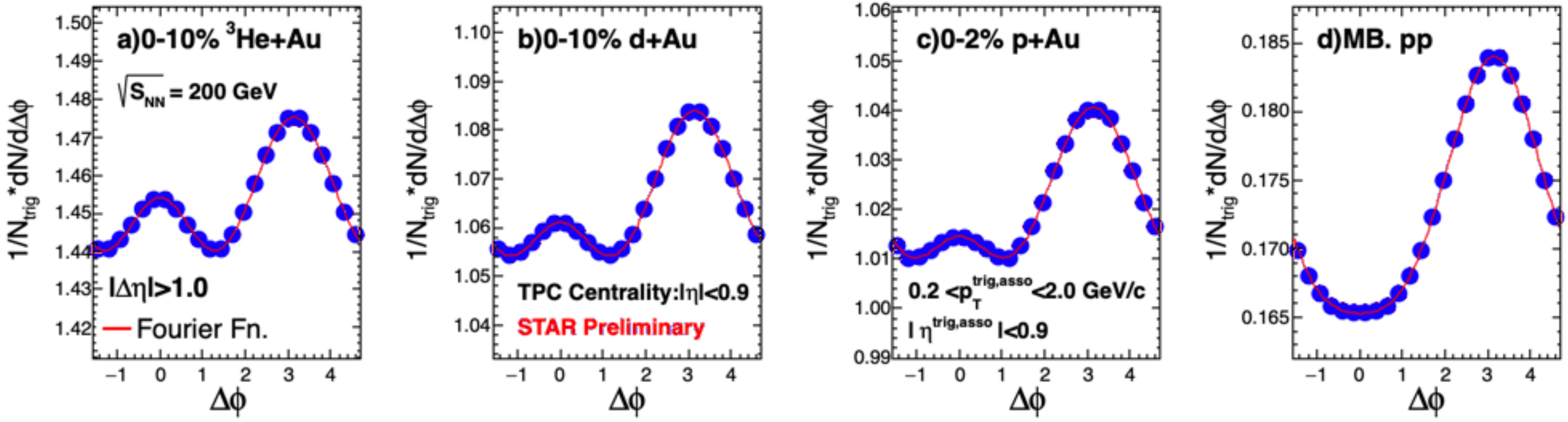
- Centrality:
  - i) Number of tracks in TPC $0.2<p_T<3.0$ GeV/c, $|\eta|<0.9$
  - ii) BBC charge in Au-going direction $-5.0<\eta<-3.3$

- Two-particle correlation functions constructed for trigger and associated particles with $0.2 < p_T < 2.0$ GeV/c $|\eta|<0.9$ and $|\Delta\eta| > 1.0$

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

✓ Comparison to $v_2\{4\}$

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



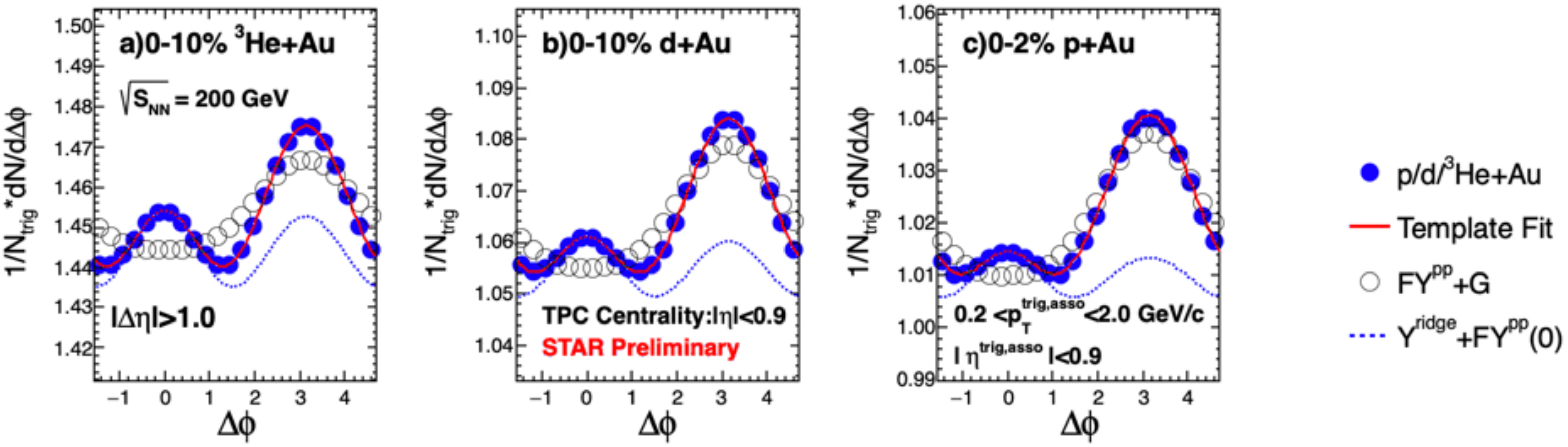
Three methods are employed for non-flow subtraction by using min-bias pp as a reference!

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

- ✓ 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 c_1: $c_{n,sub}^{sys.} = c_n^{sys.} - (c_1^{sys}/c_1^{pp})c_n^{pp}$; n=2,3

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

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



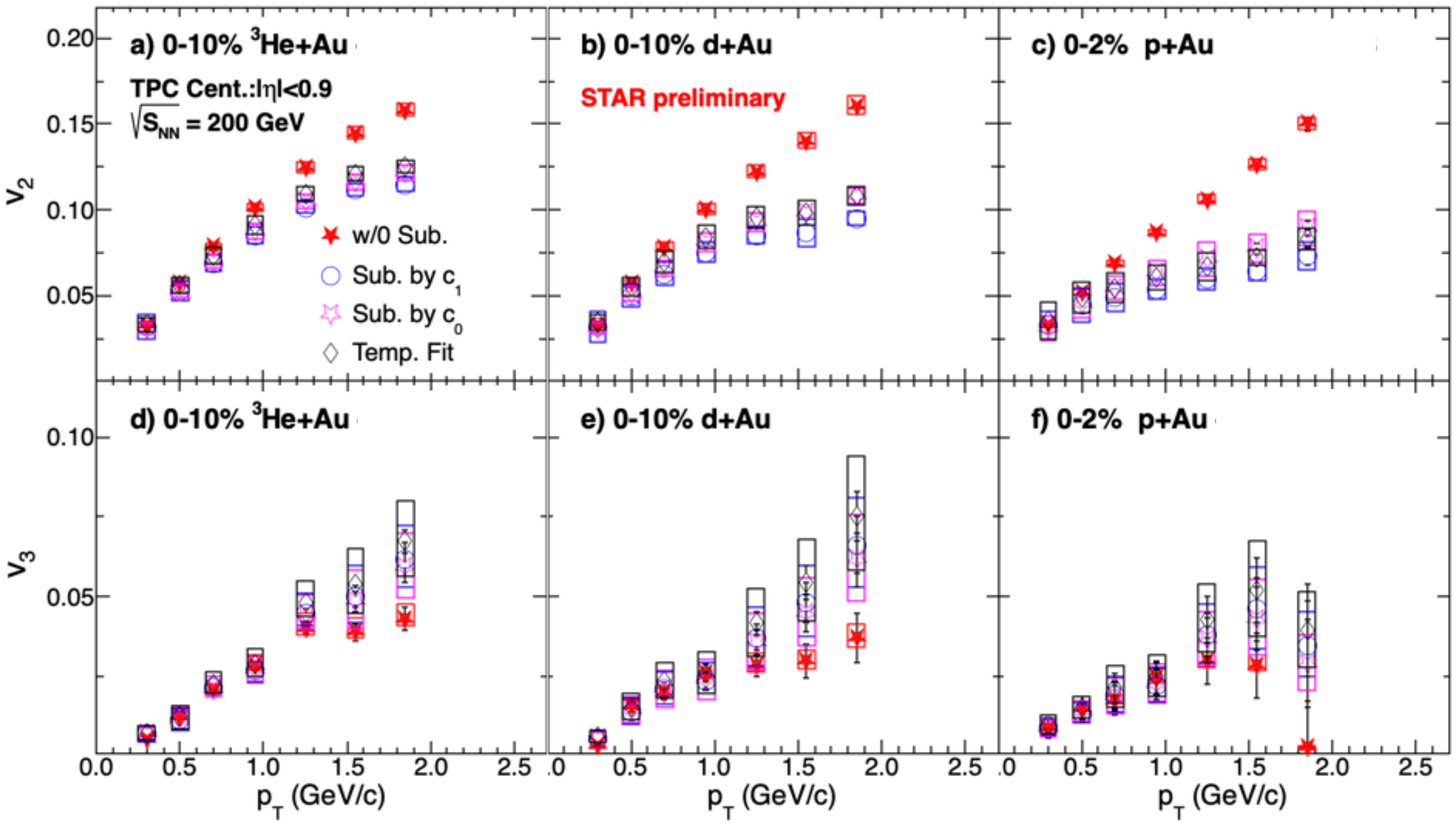
3. Template Fit *(ATLAS, PRL 116, 172301 (2016))*

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

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

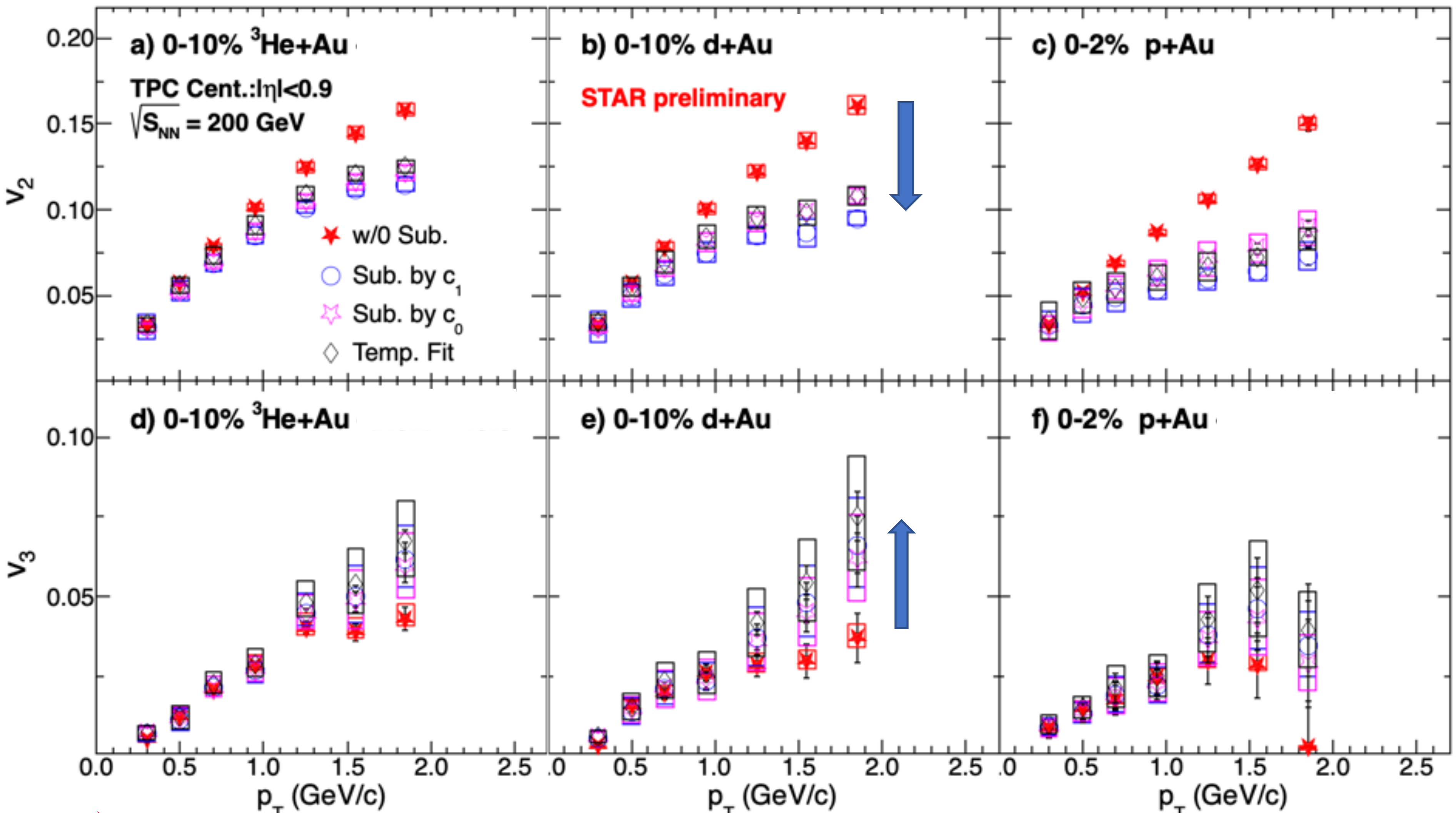
"F" represents the modification for the long-range away-side jet between **p/d/³He+Au and p+p**

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



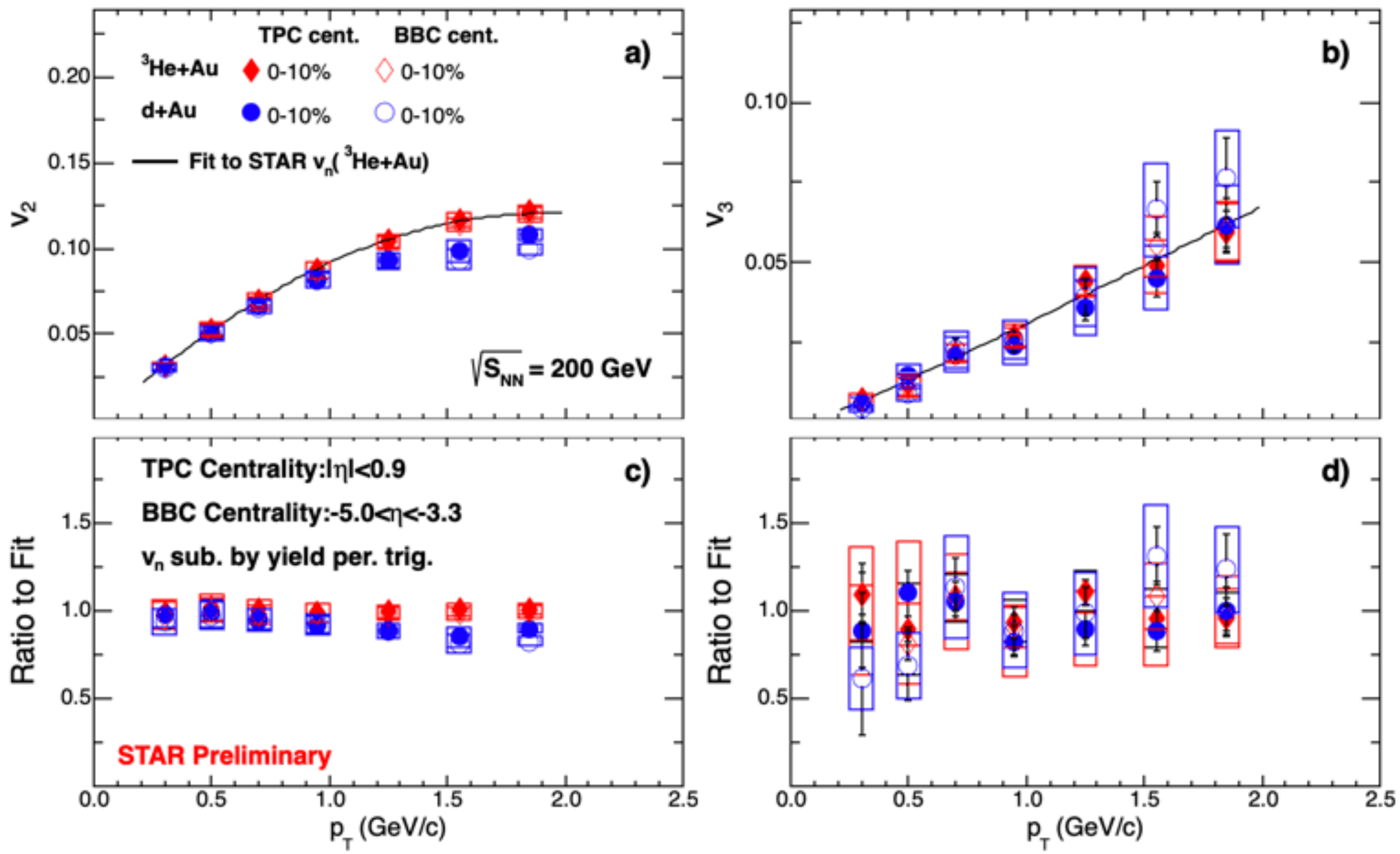
- Non-flow subtracted v_2 and v_3 are method-independent

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



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

Differential v_2 and v_3 measurements for different centrality definitions

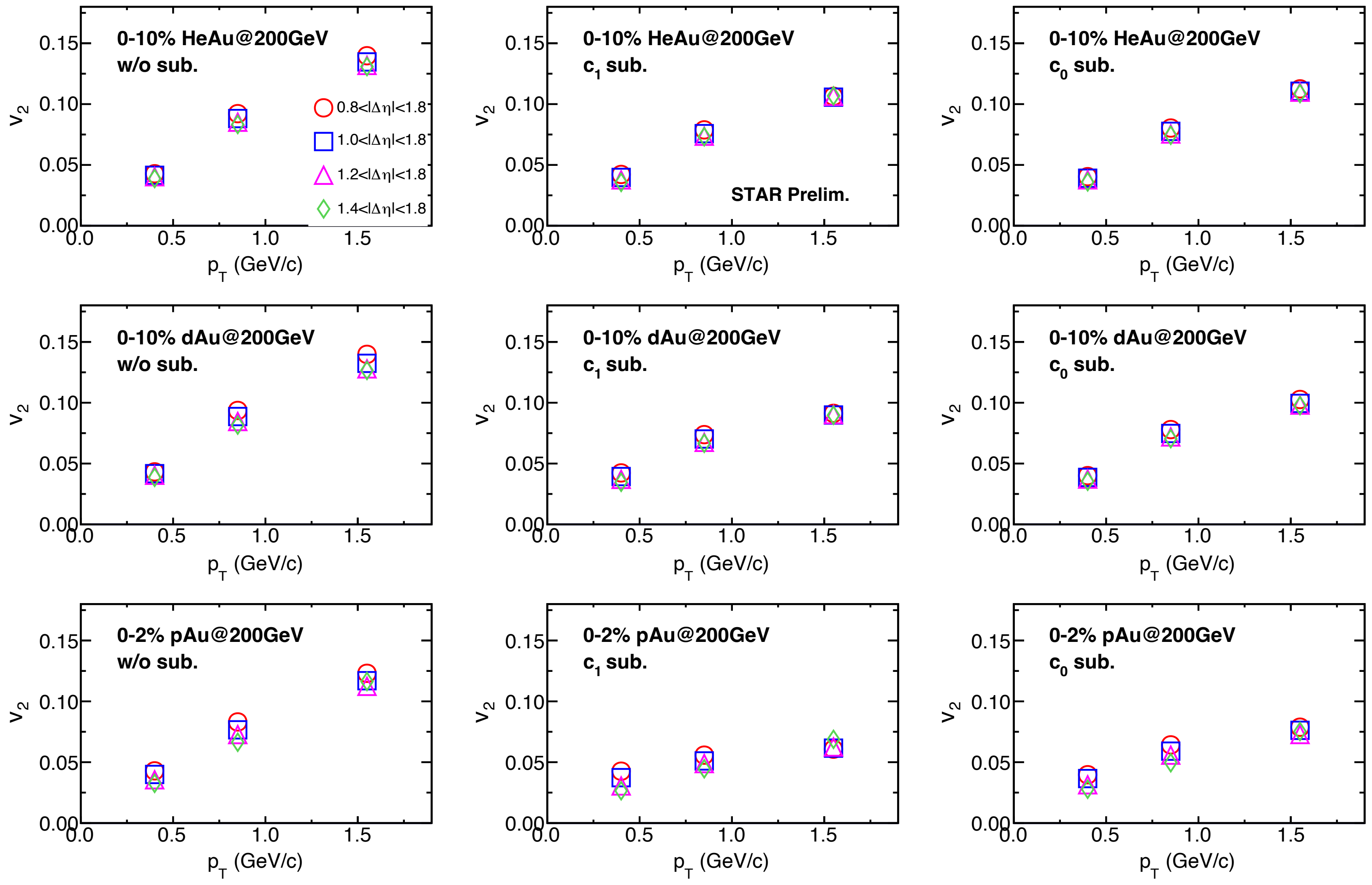


TPC centrality: Centrality and 2p correlation measured in same rapidity

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

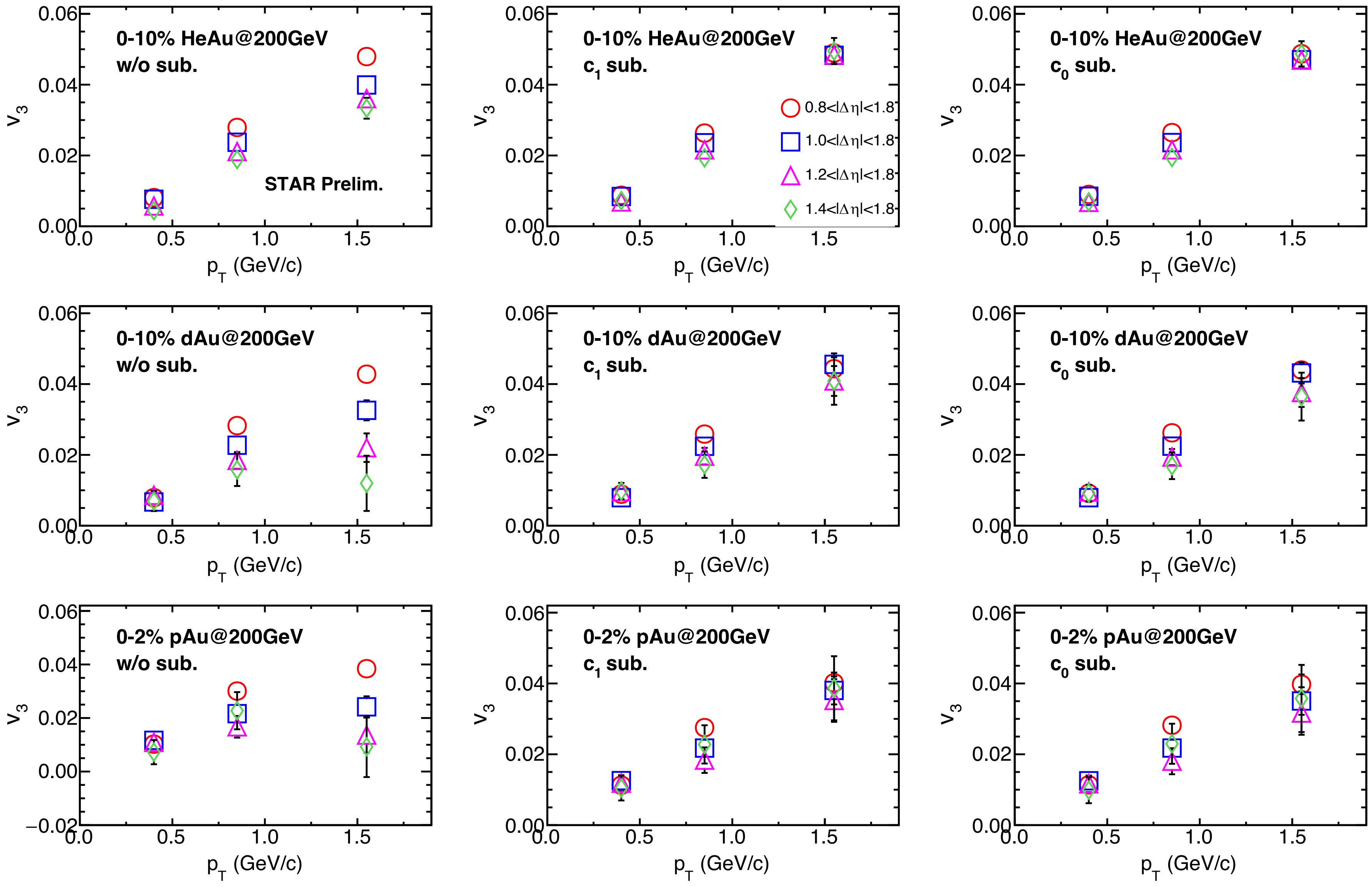
✓ **Results are consistent between two kinds of different centrality definitions with mid and backward rapidity regions**

v_2 with different $\Delta\eta$ cut



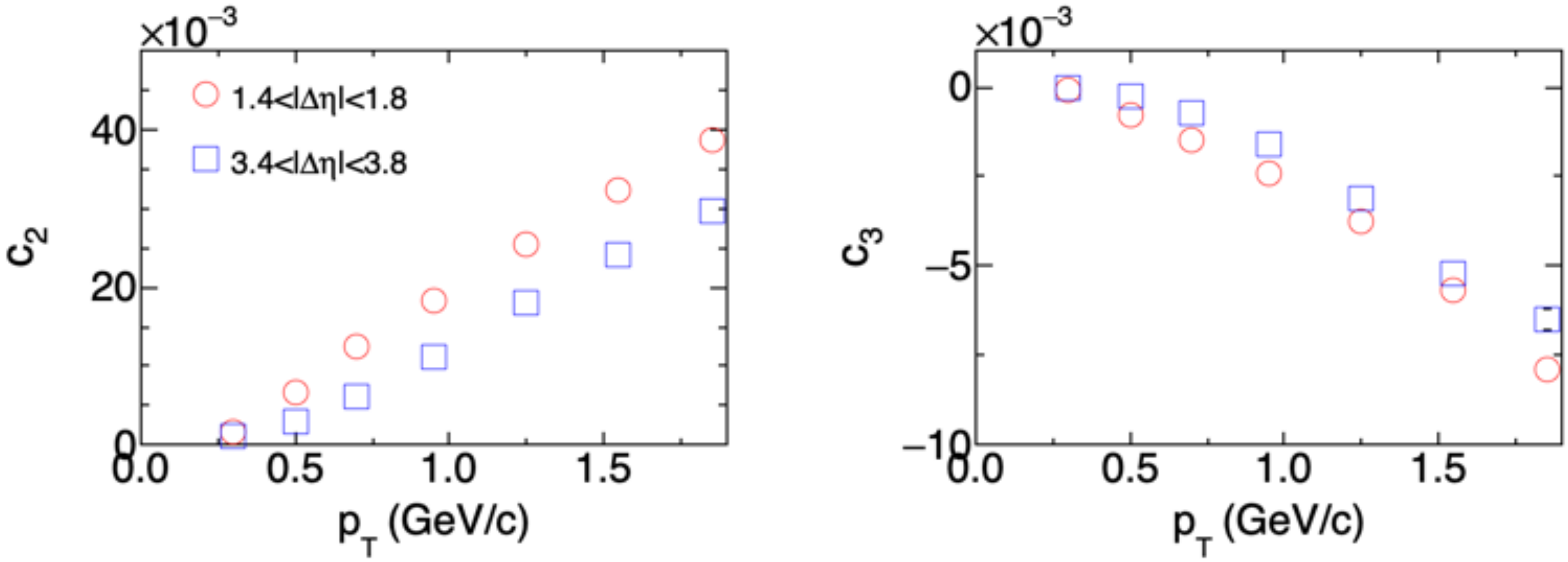
v_2 after nonflow subtraction is insensitive to $\Delta\eta$ cut and subtraction method

v_3 with different $\Delta\eta$ cut



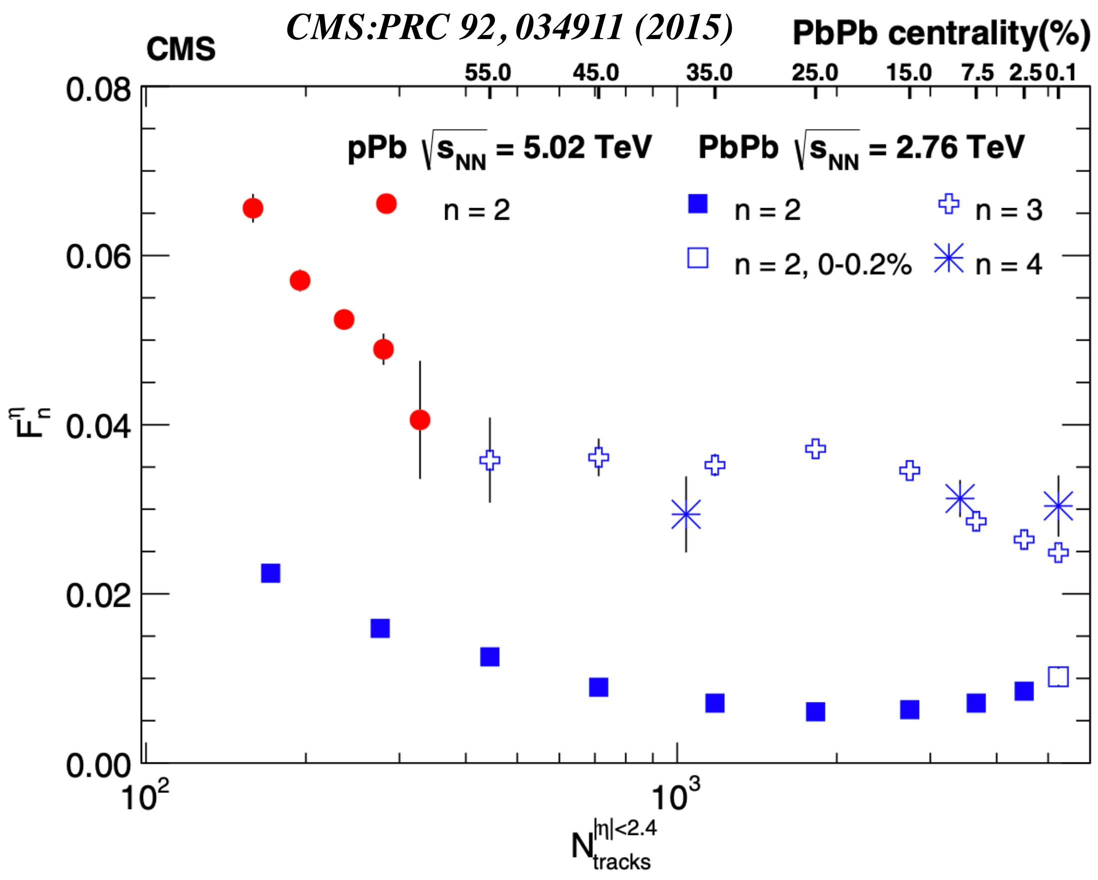
v_3 after nonflow subtraction is also insensitive to $\Delta\eta$ cut and subtraction method

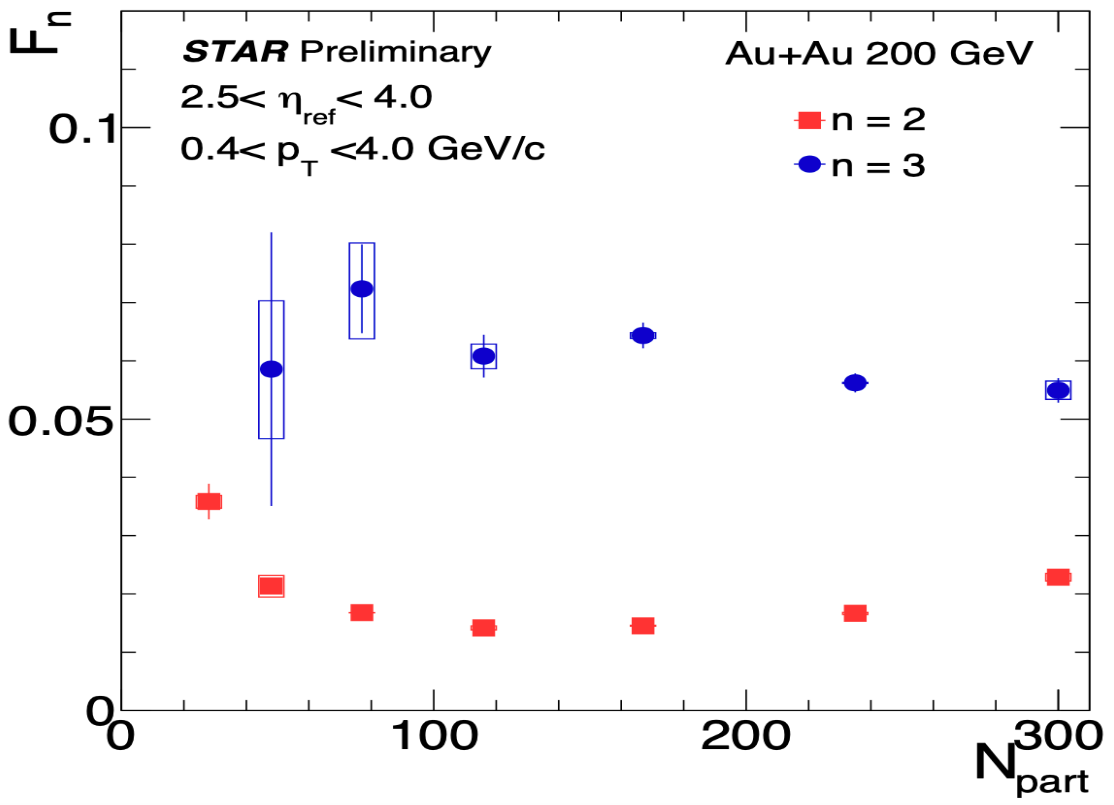
Nonflow vs. $\Delta\eta$ from pp@HIJING



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

Longitudinal Decorrelation

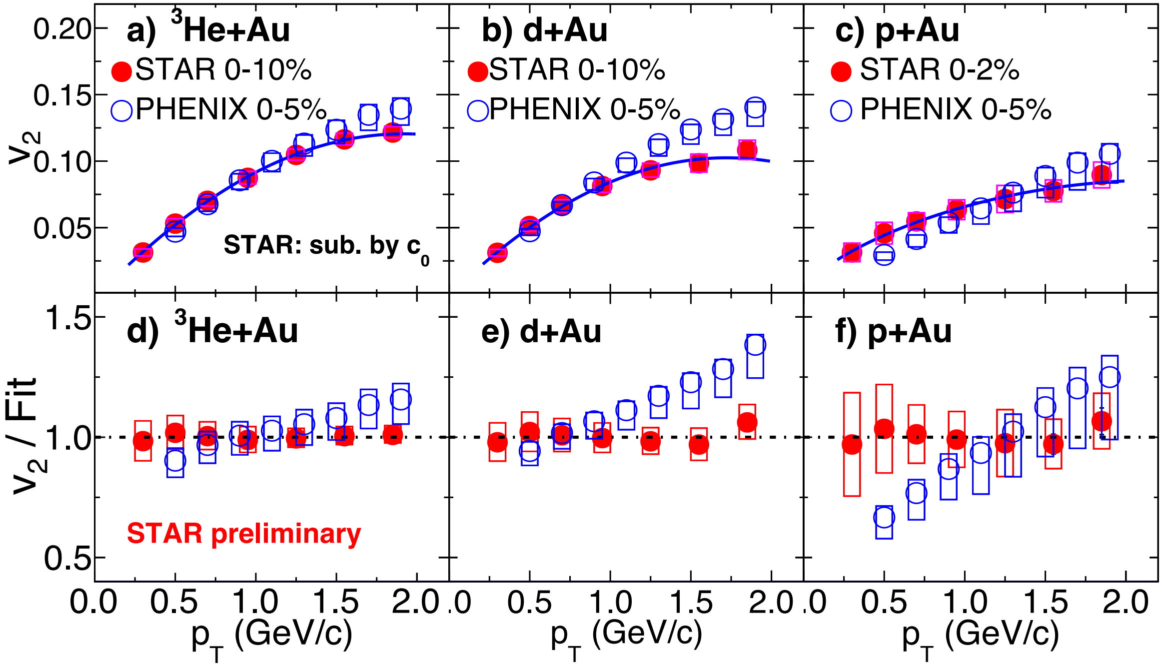


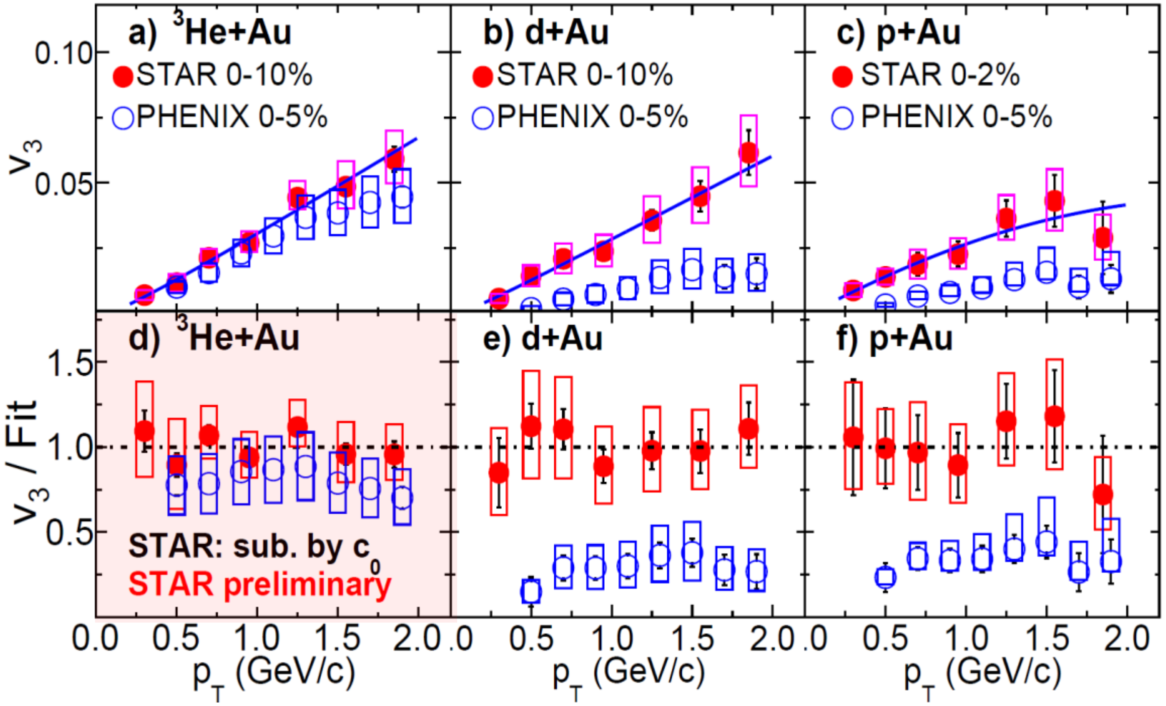


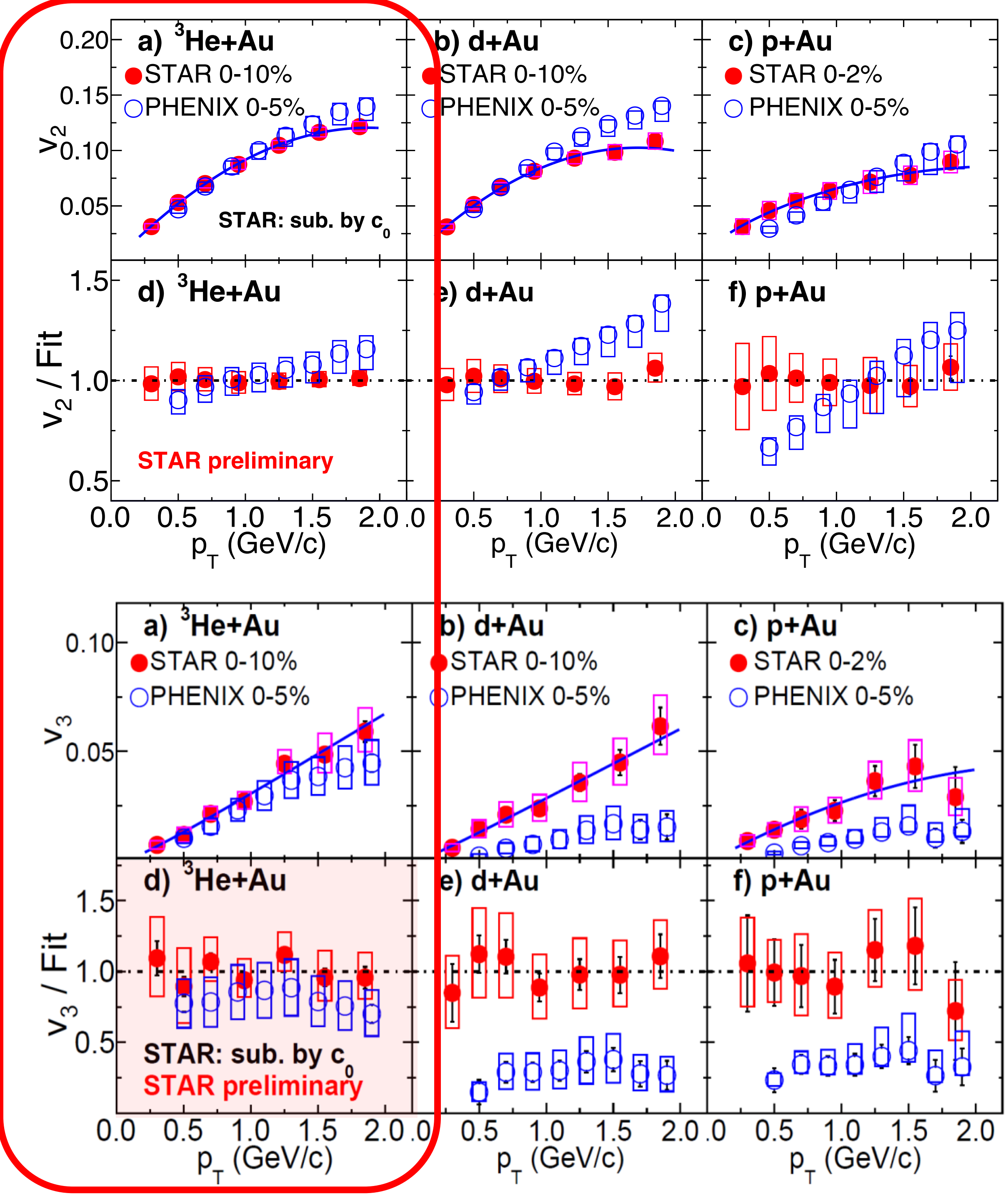
Large decorrelation at low multiplicity:

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

Detail Comparisons to PHENIX

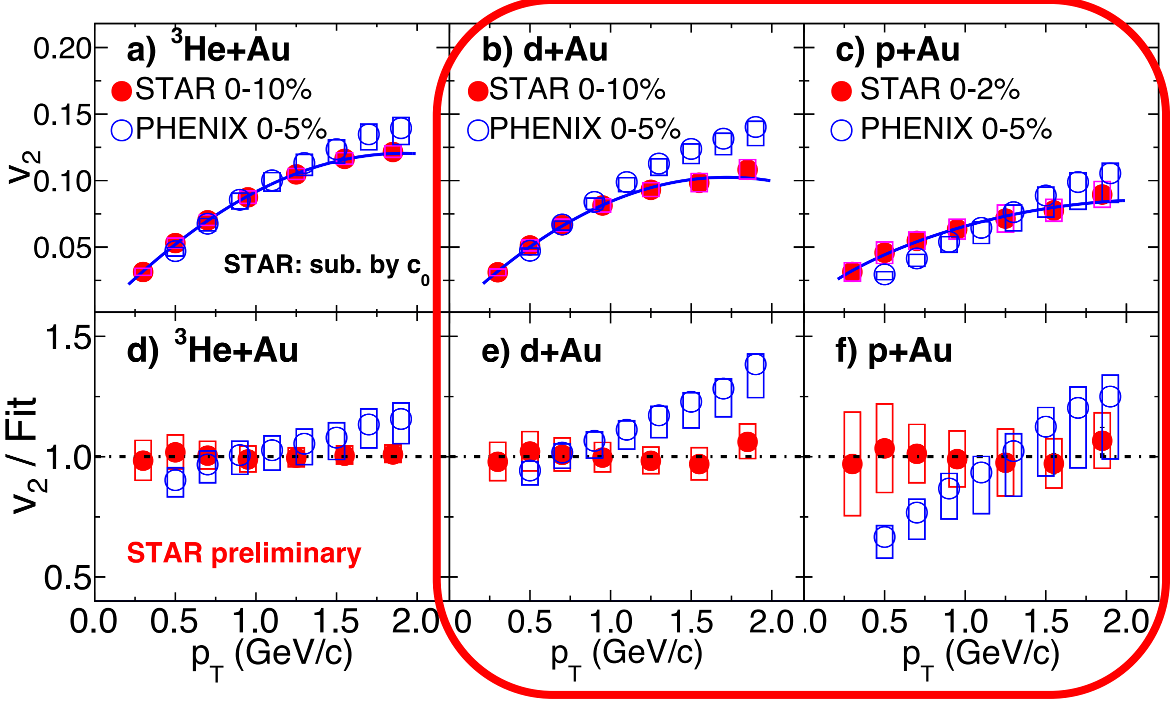


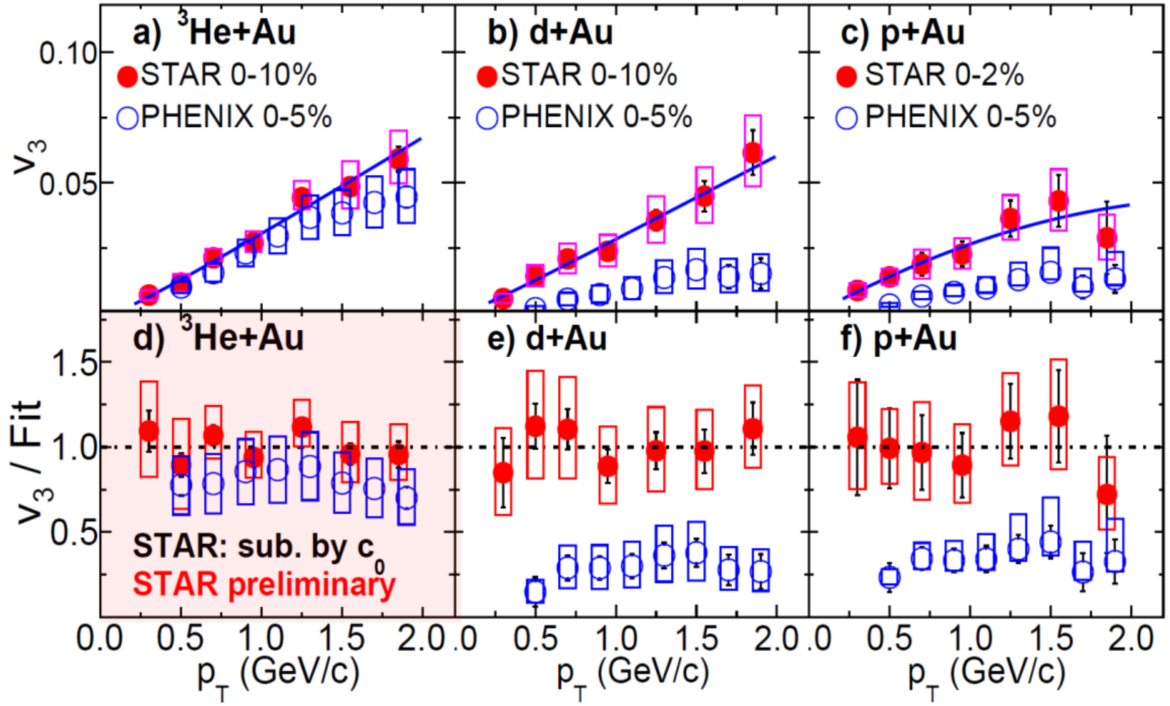




Detail Comparisons to PHENIX

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



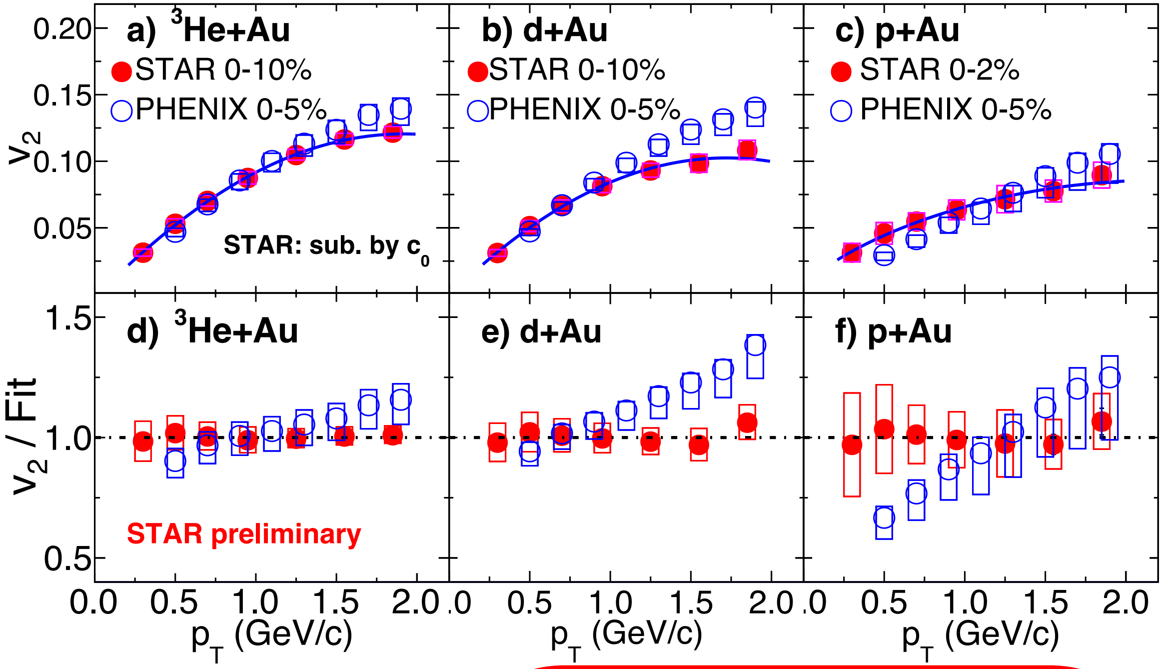


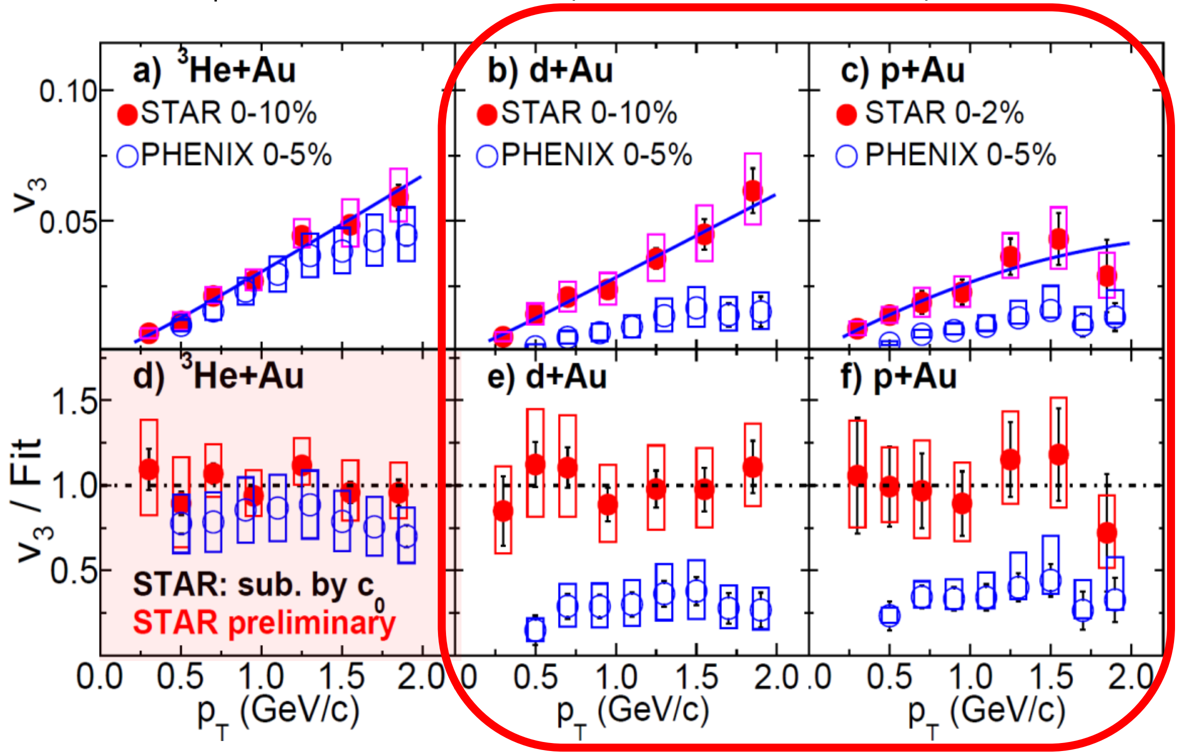
Detail Comparisons to PHENIX

- 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

Detail Comparisons to PHENIX





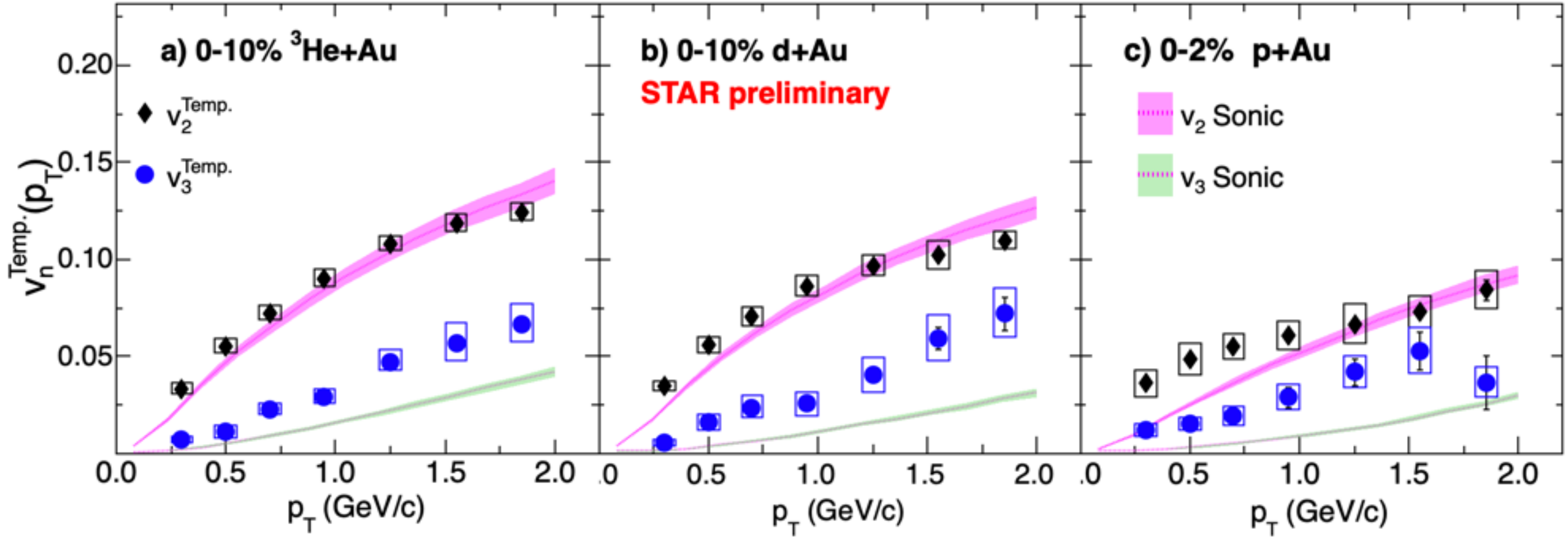
- The STAR and PHENIX v_2 and v_3 for ^{3}He+Au, show reasonable agreement

- 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?***

Comparison to model

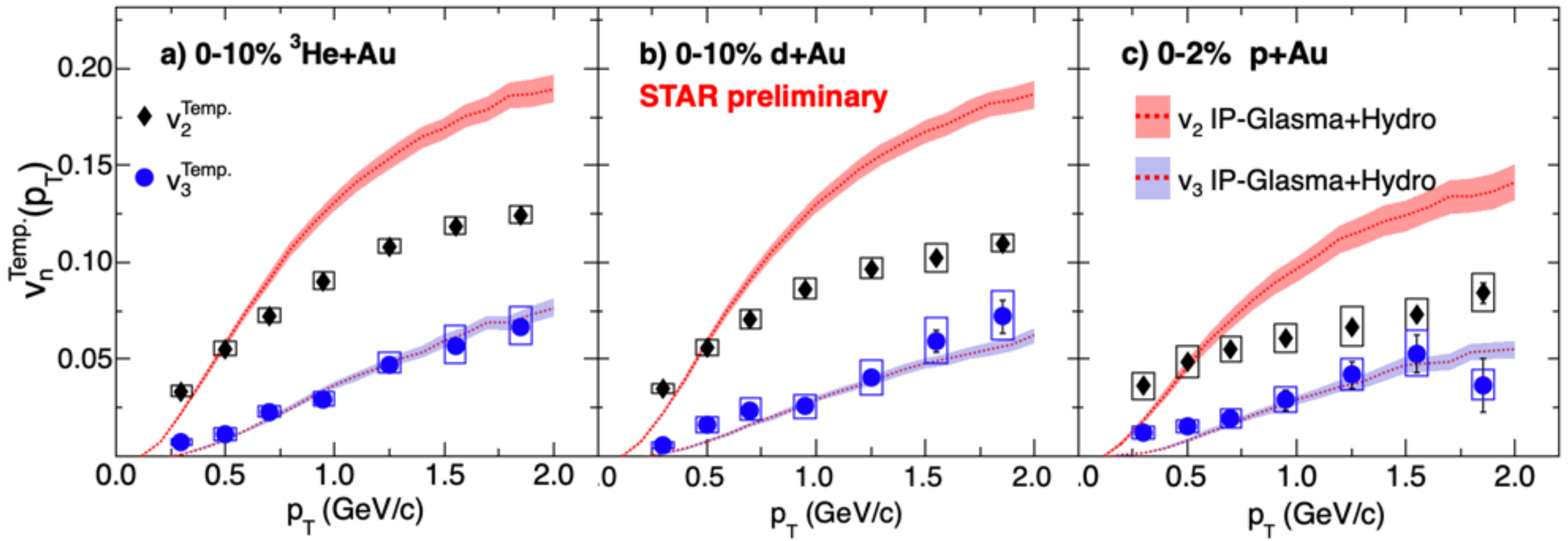


Sonic: P. Romatschke, arXiv:1502.04745 [nucl-th].

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

Model	a $\varepsilon_2^a(\varepsilon_3^a)$	b $\varepsilon_2^b(\varepsilon_3^b)$	c $\varepsilon_2^c(\varepsilon_3^c)$	d $\varepsilon_2^d(\varepsilon_3^d)$
^{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)

Comparison to model

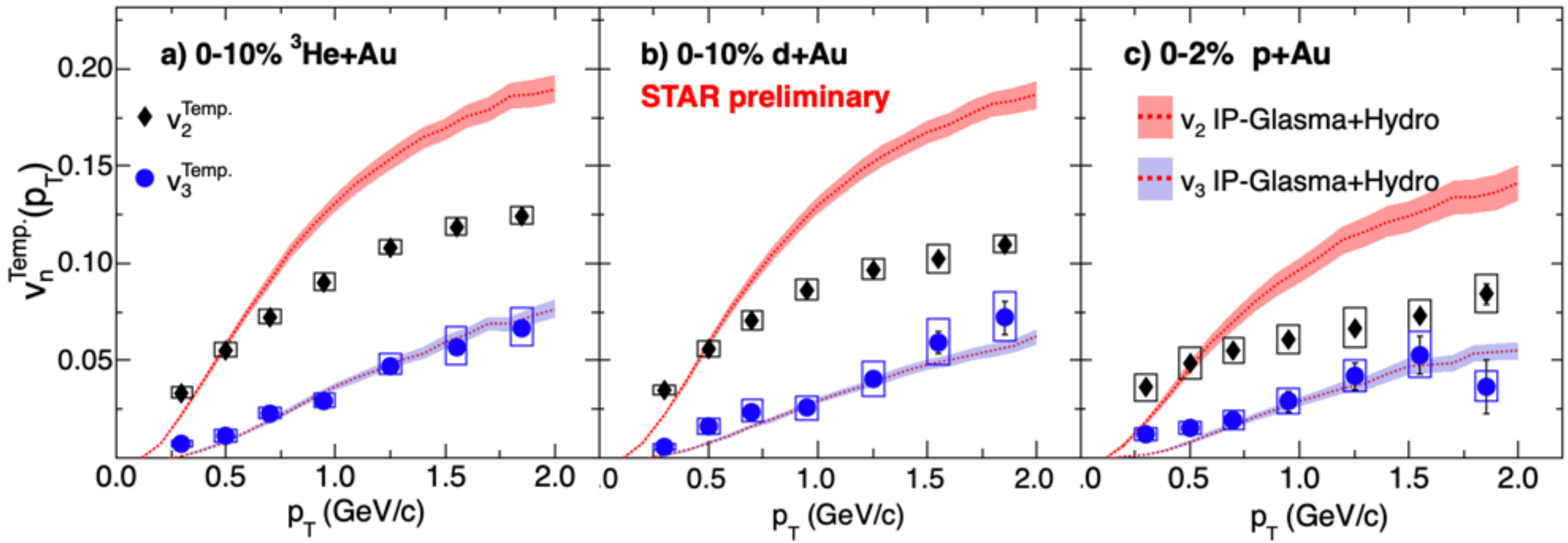


- ***IP-Glasma+Hydro*** that includes sub-nucleonic gluon field fluctuations + initial momentum correlation. It is tuned to describe the data for large-sized systems and then extrapolated to small-sized systems
- It overpredicts v_2 but reproduces v_3. Larger ε_2 from IP-Glasma model or initial momentum correlations?
- 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)

Comparison to model

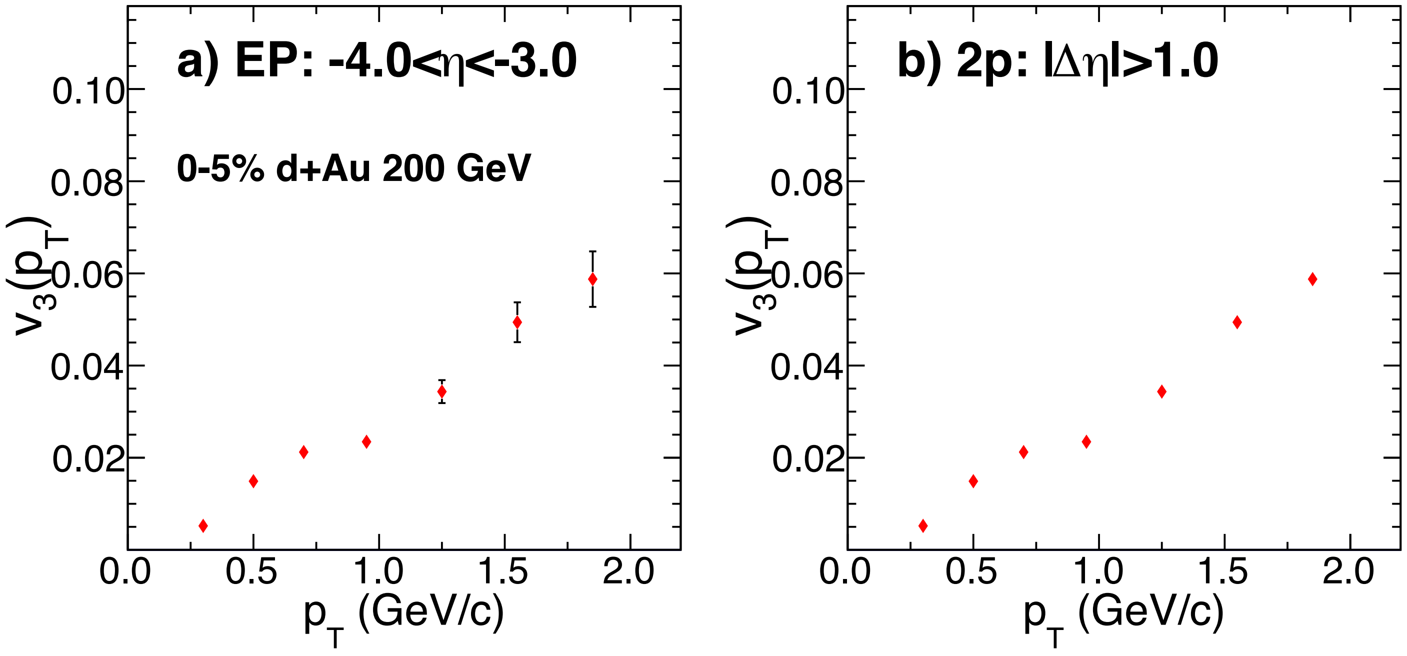


- *IP-Glasma+Hydro* that includes sub-nucleonic fluctuations + initial momentum correlation. It is tuned to describe the data for large-sized systems and then extrapolated to small-sized systems
- It over predicts v_2 but reproduces v_3. Larger ε_2 from IP-Glasma model or initial momentum correlations?
- STAR measurements provide useful constraints for model tuning in future
- ***Hydro with eccentricity from model b or c could describe the data better***

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)

Outlook: d+Au@RHIC 2021



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

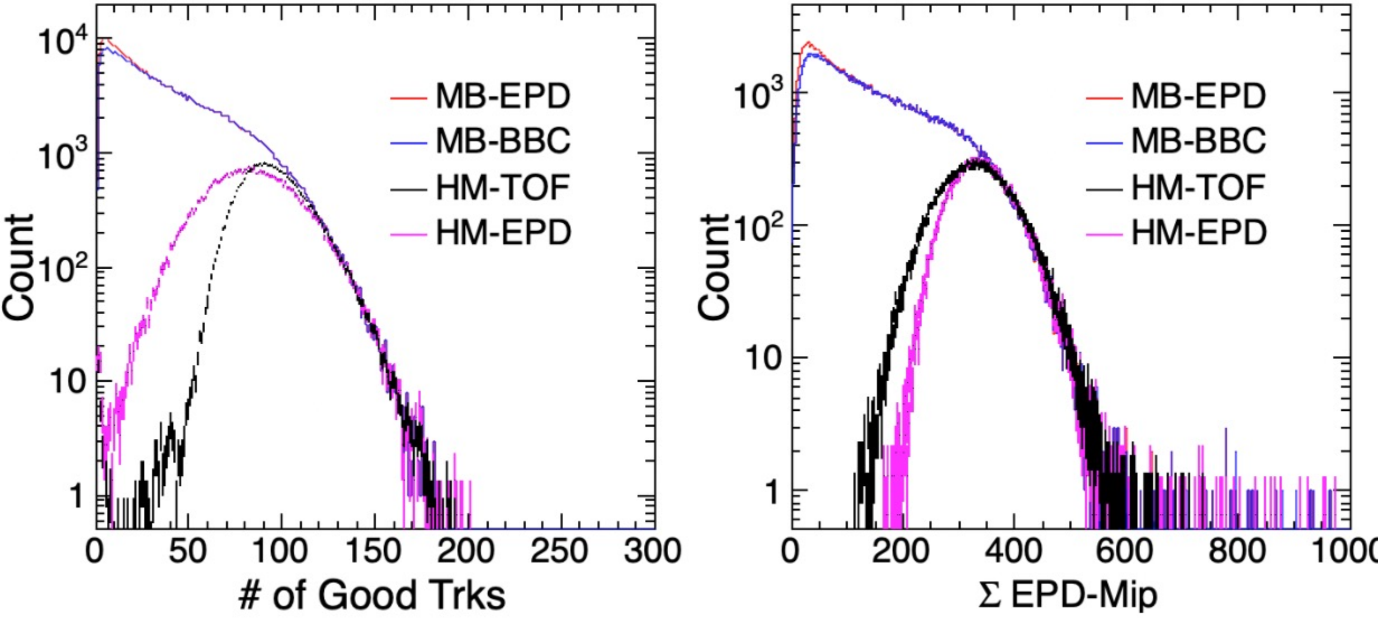
Mean values are from current measurements

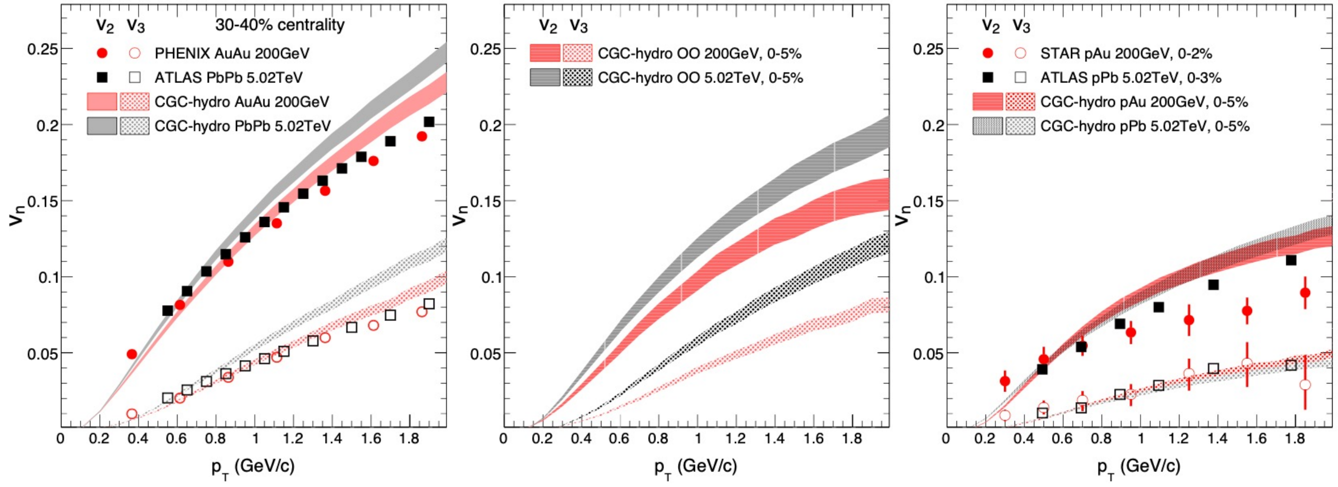
100M MB and 100M HM(0-5% selected by EPD) triggered events have been taken by STAR in 2021

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

Further investigate the sub-nucleon fluctuations and longitudinal decorrelation in small-sized system

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

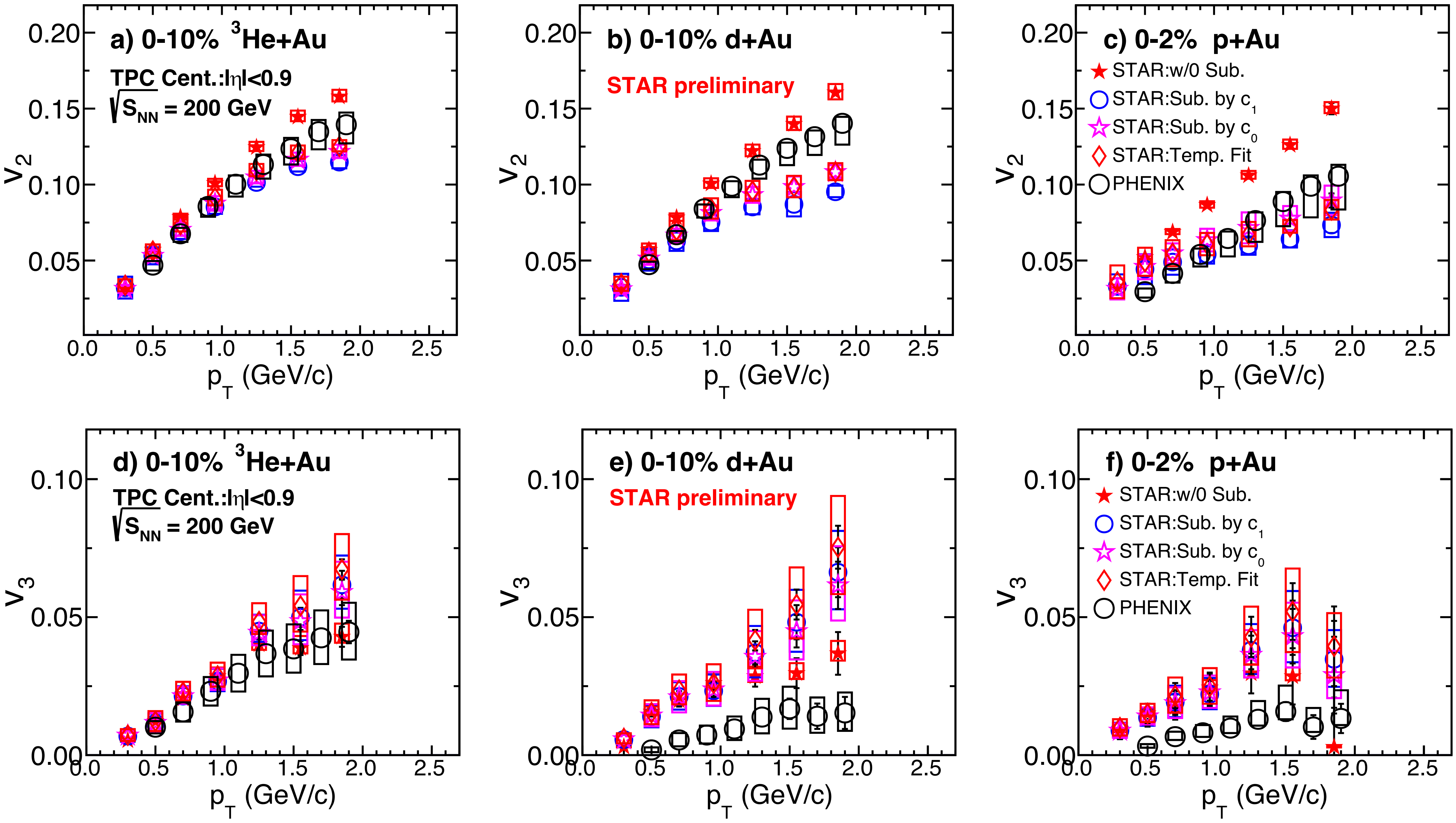
- A system independent v_3 has been found, indicating that sub-nucleon gluon field fluctuations have a strong influence on initial geometry for small-sized systems

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

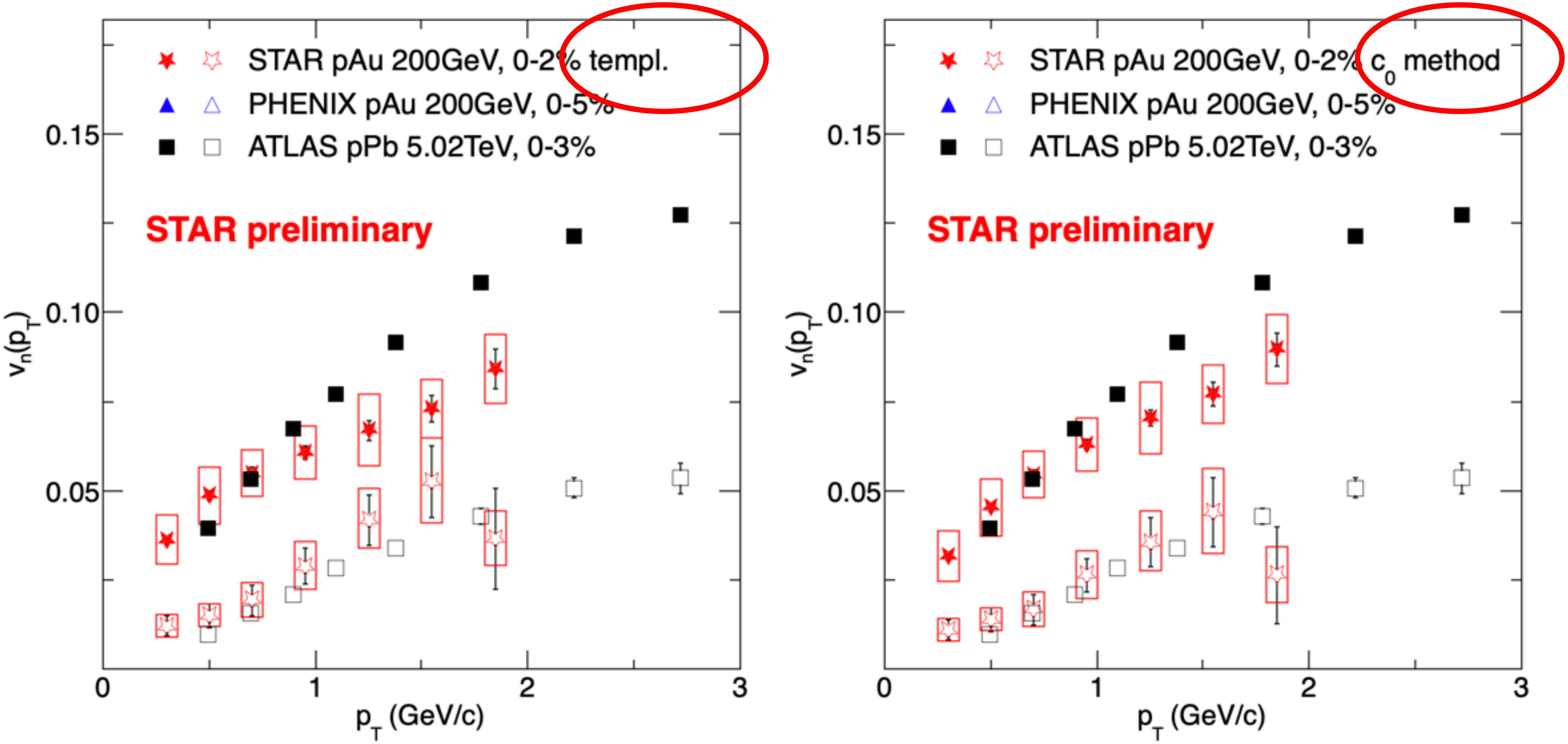
Thanks!

Backup

Backup


a) 0-10% 3He+Au
TPC Cent.:|η|<0.9
√SNN = 200 GeV
b) 0-10% d+Au
STAR preliminary
c) 0-2% p+Au
STAR:w/0 Sub.
STAR:Sub. by c1
STAR:Sub. by c0
STAR:Temp. Fit
PHENIX
d) 0-10% 3He+Au
e) 0-10% d+Au
f) 0-2% p+Au
v2
v3
pT (GeV/c)

Backup



STAR pAu 200GeV, 0-2% templ.
PHENIX pAu 200GeV, 0-5%
ATLAS pPb 5.02TeV, 0-3%
STAR preliminary
$v_n(p_T)$
0.15
0.10
0.05
0
1
2
3
p_T (GeV/c)
STAR pAu 200GeV, 0-2% c_0 method
PHENIX pAu 200GeV, 0-5%
ATLAS pPb 5.02TeV, 0-3%
STAR preliminary
$v_n(p_T)$
0.15
0.10
0.05
0
1
2
3
p_T (GeV/c)