Measurements of v_2 and v_3 in p/d/^{3}He+Au Collisions

Shengli Huang

For STAR Collaboration

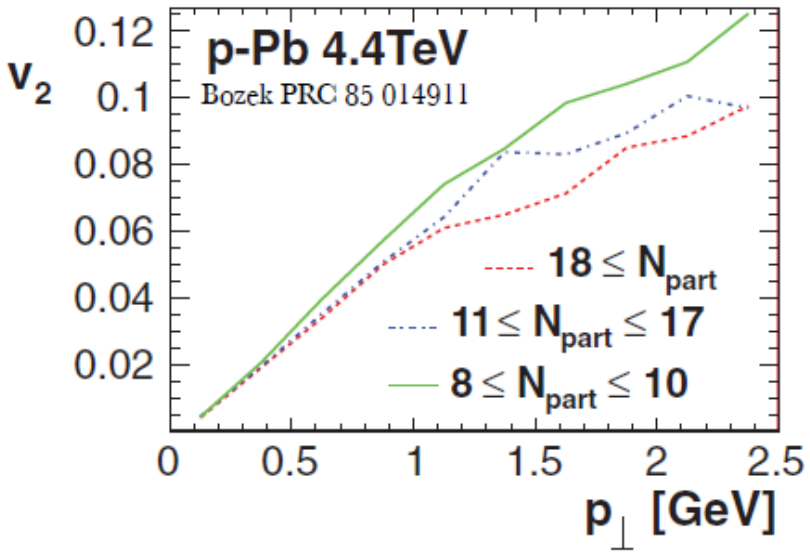
Outline:

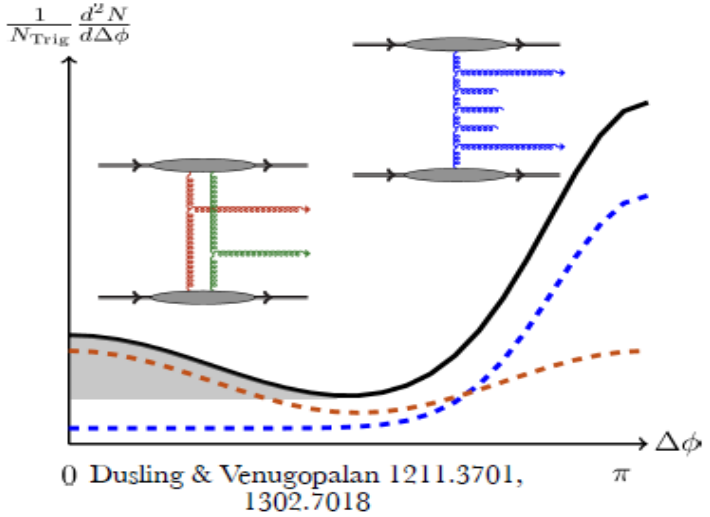
- Physical Motivations
- Analysis Results
- Comparison to models and other measurements
- Summary

Stony Brook University

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

Anisotropy in small system





Dusling & Venugopalan 1211.3701, 1302.7018

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  - ✓ Final state interaction: Hydrodynamics?
  - ✓ Initial momentum correlation: CGC?

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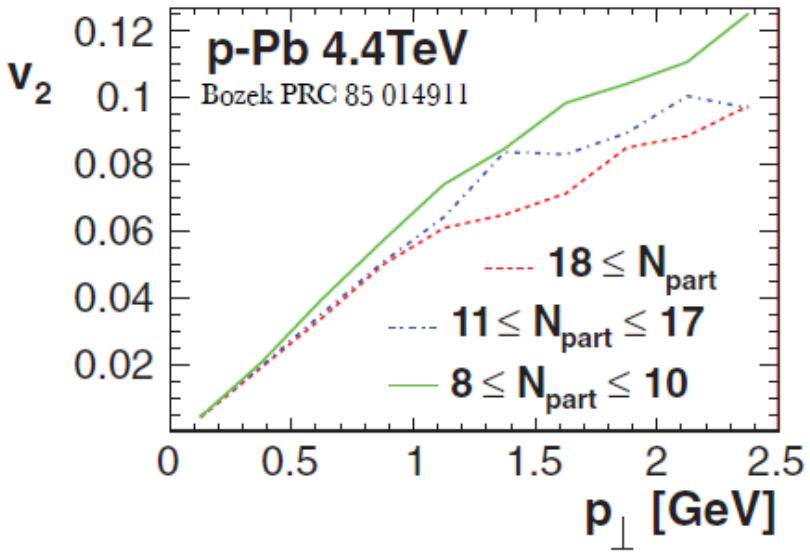

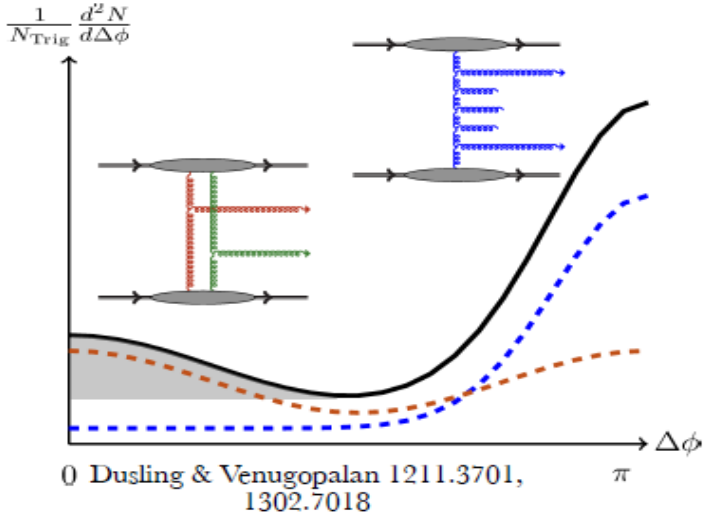

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- **Initial geometry in small system**
  - ✓ Nucleonic vs Sub-Nucleonic fluctuations

	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).
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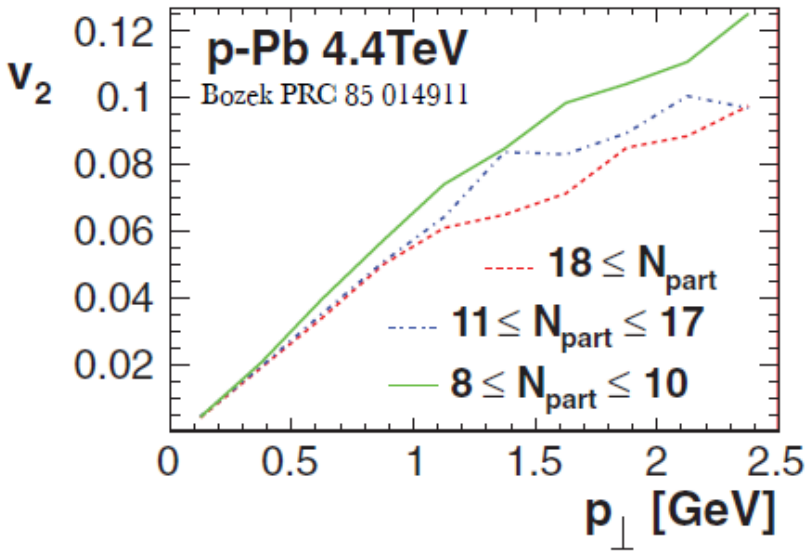

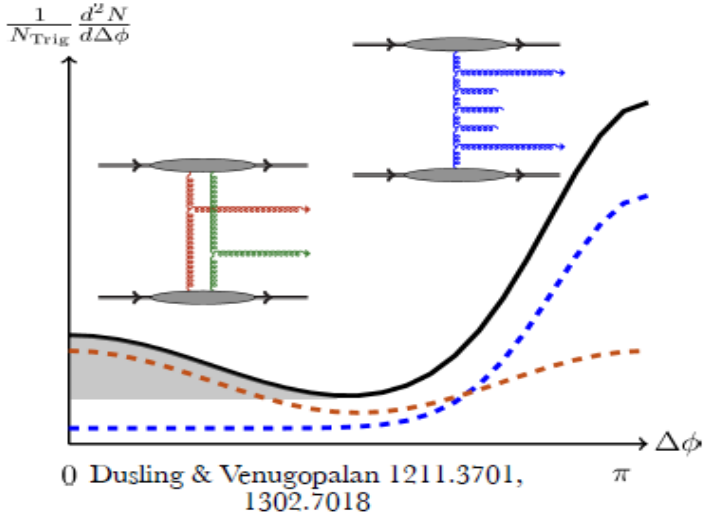

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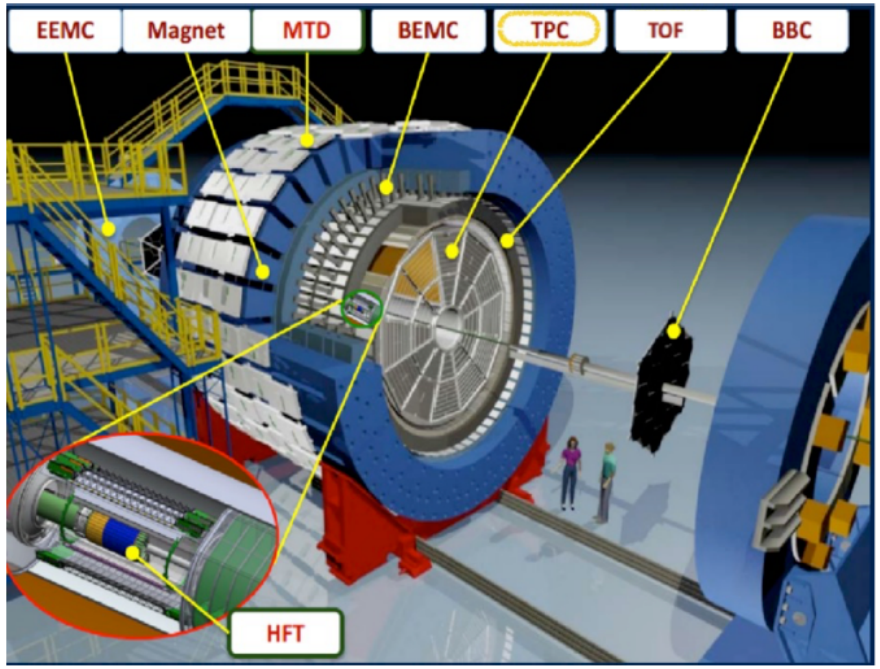
STAR Experiment at RHIC



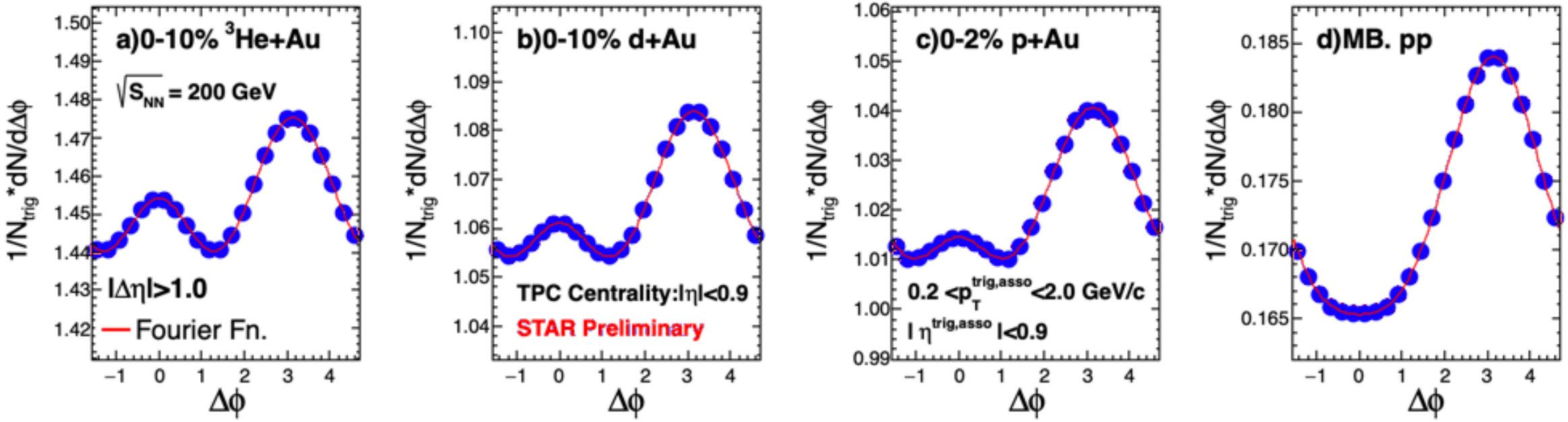
Measurements for p/d/^{3}He+Au collisions @ 200 GeV

- 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)



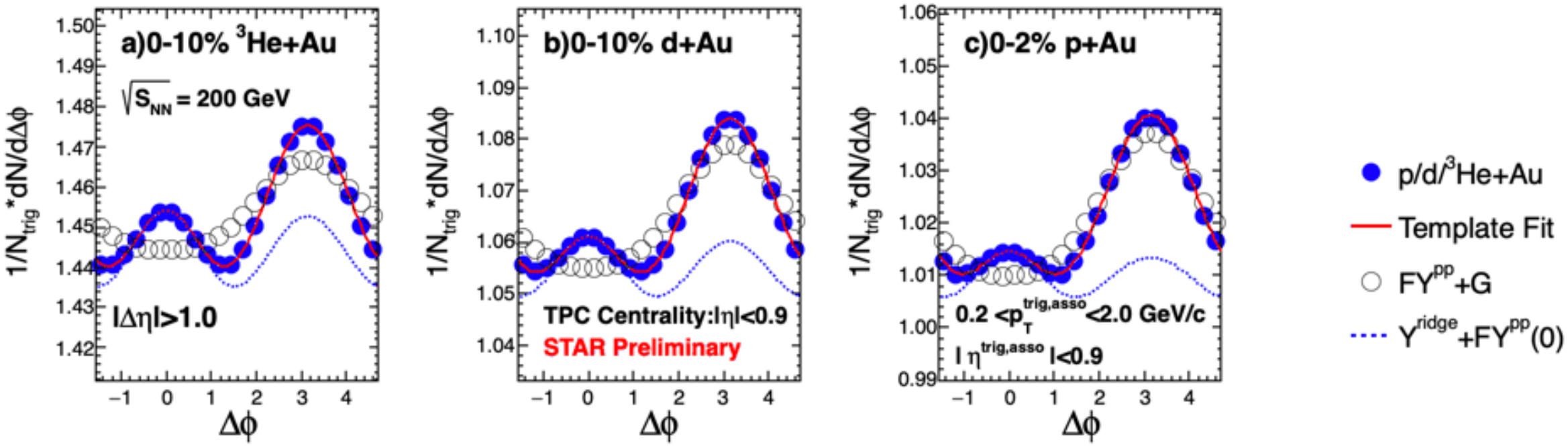
Three methods are employed for non-flow subtraction by using min-bias pp as a reference!

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

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

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

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



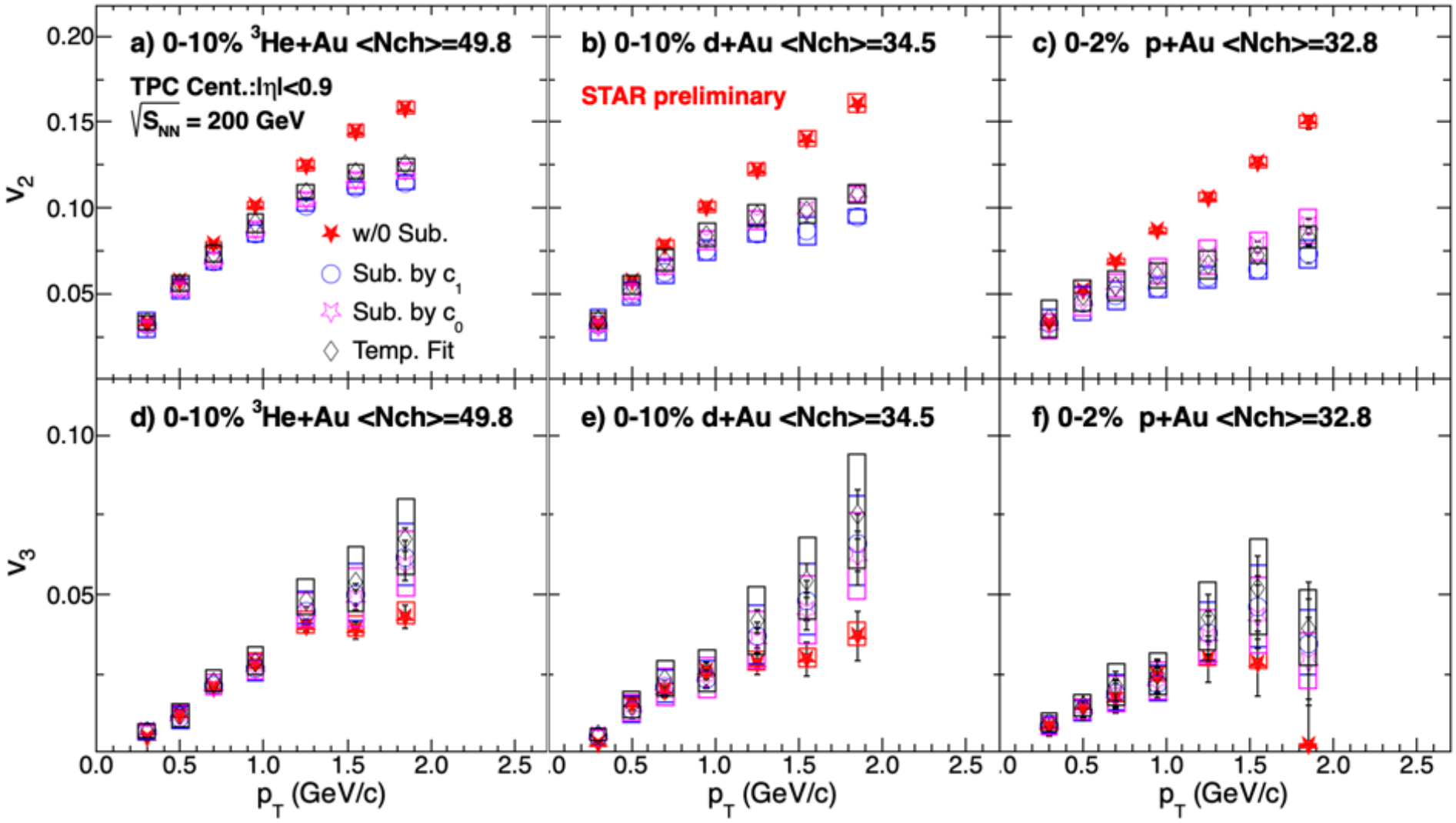
3. Template Fit *(ATLAS, PRL 116, 172301 (2016))*

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

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

"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



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

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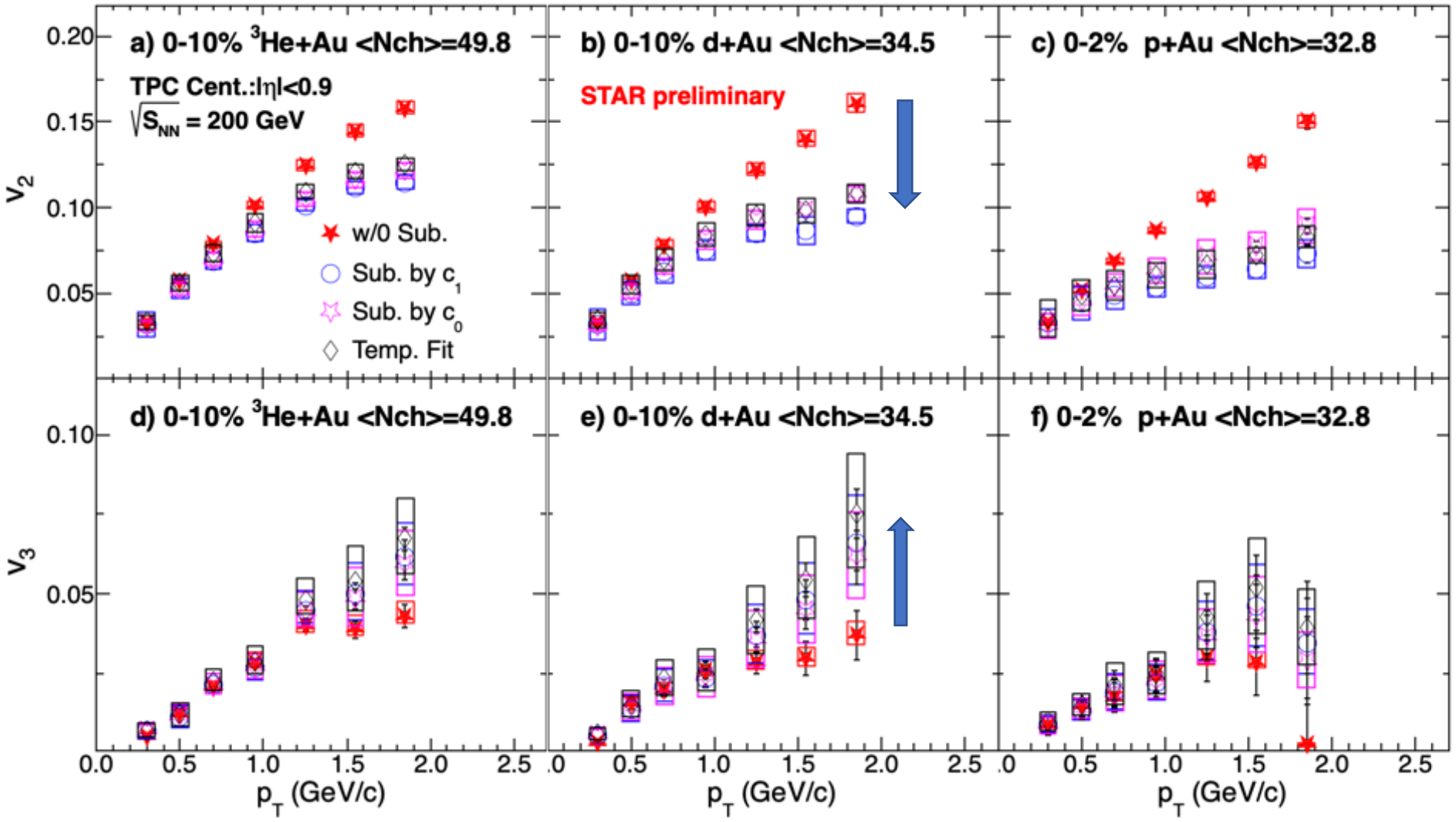
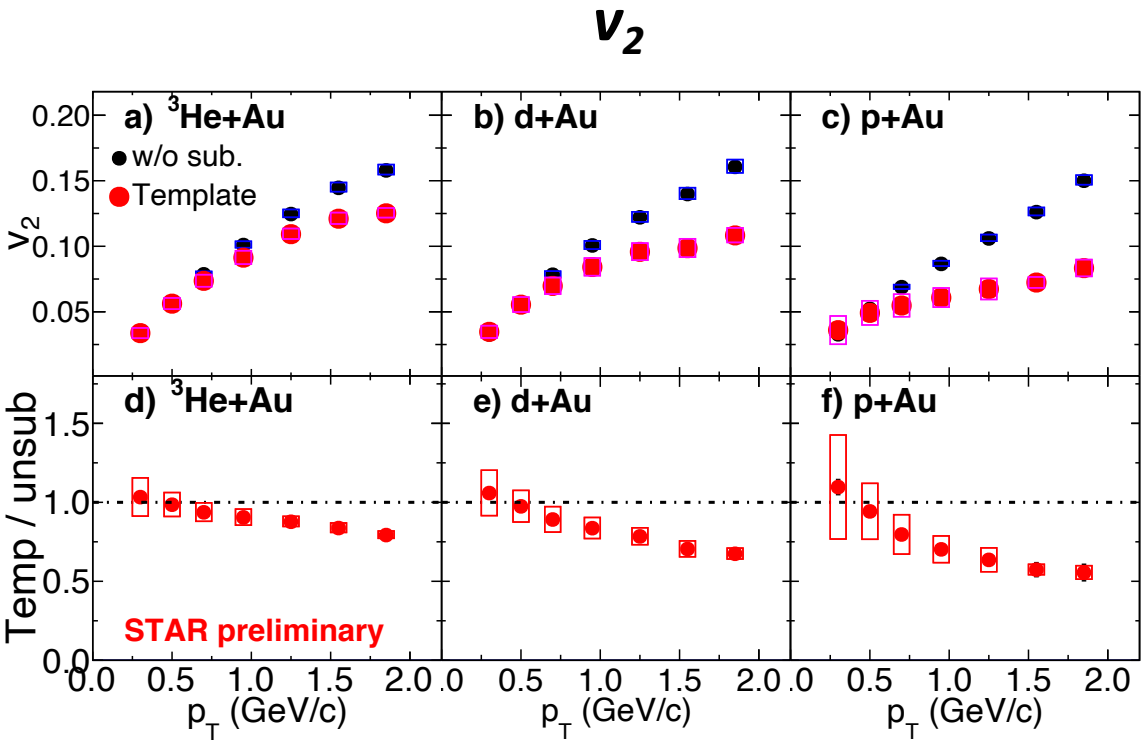
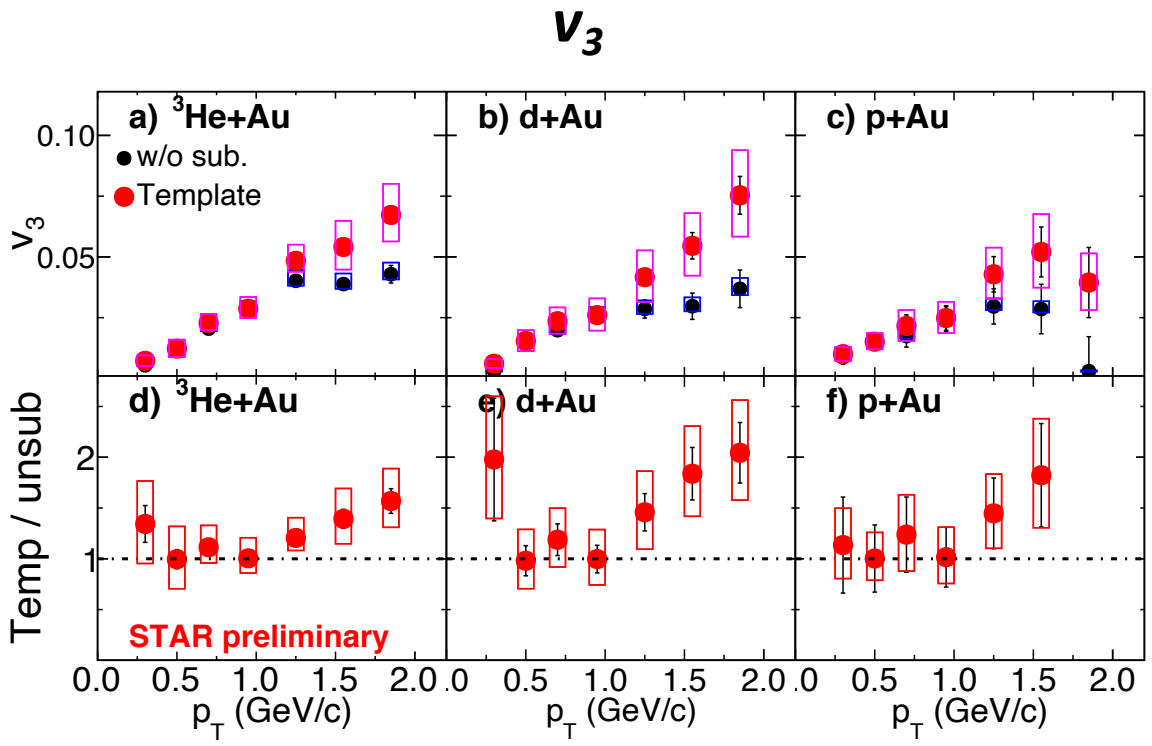


- Non-flow subtracted v_2 and v_3 are method-independent
- Non-flow flow subtractions decrease v_2 and increase v_3

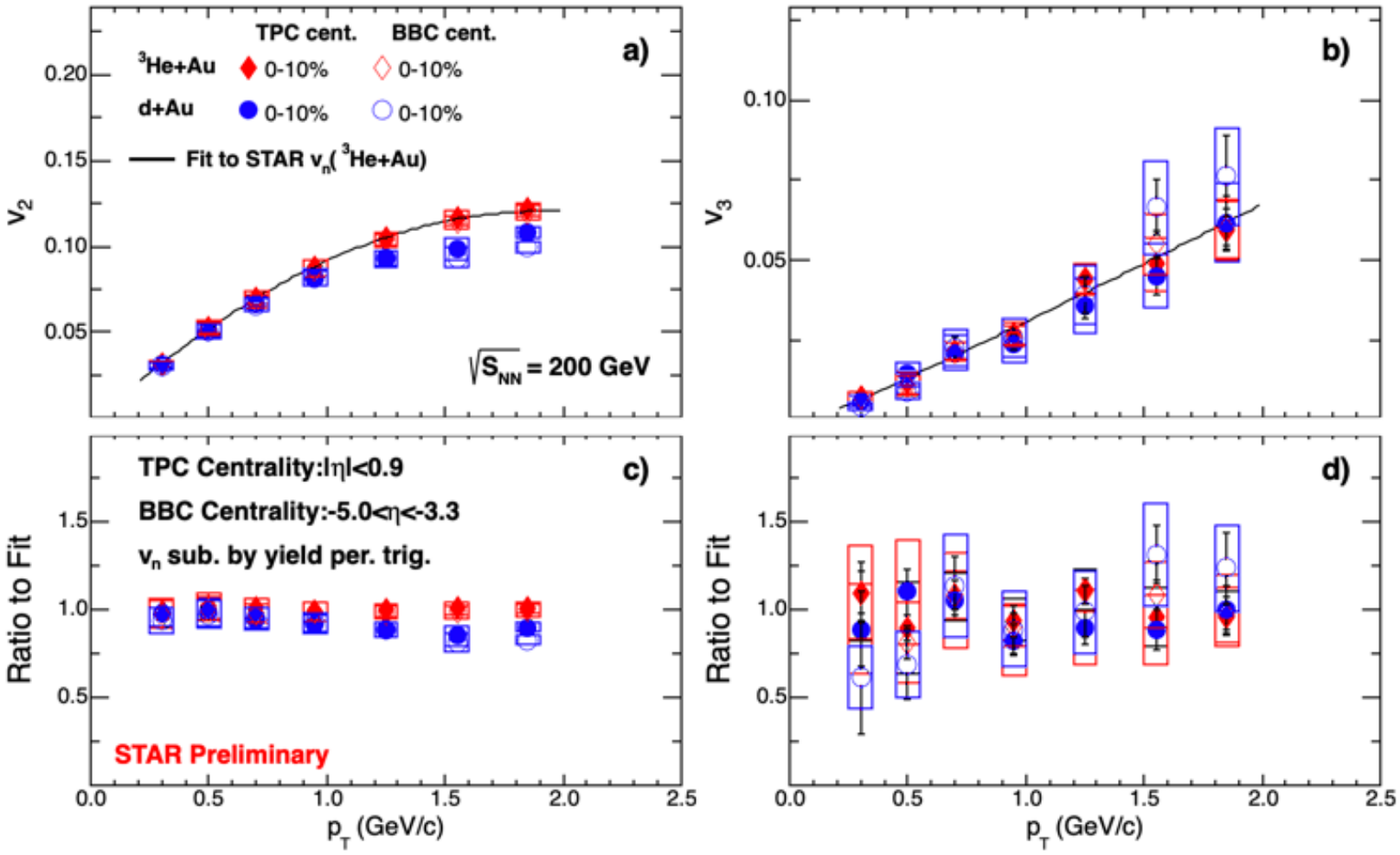
Non-flow in STAR





- Non-flow contributions in both v_2 and v_3 increase with p_T
- The away-side jet or dipole gives a positive contributions on v_2 while negative contributions on v_3

Differential v_2 and v_3 measurements for different centrality definitions

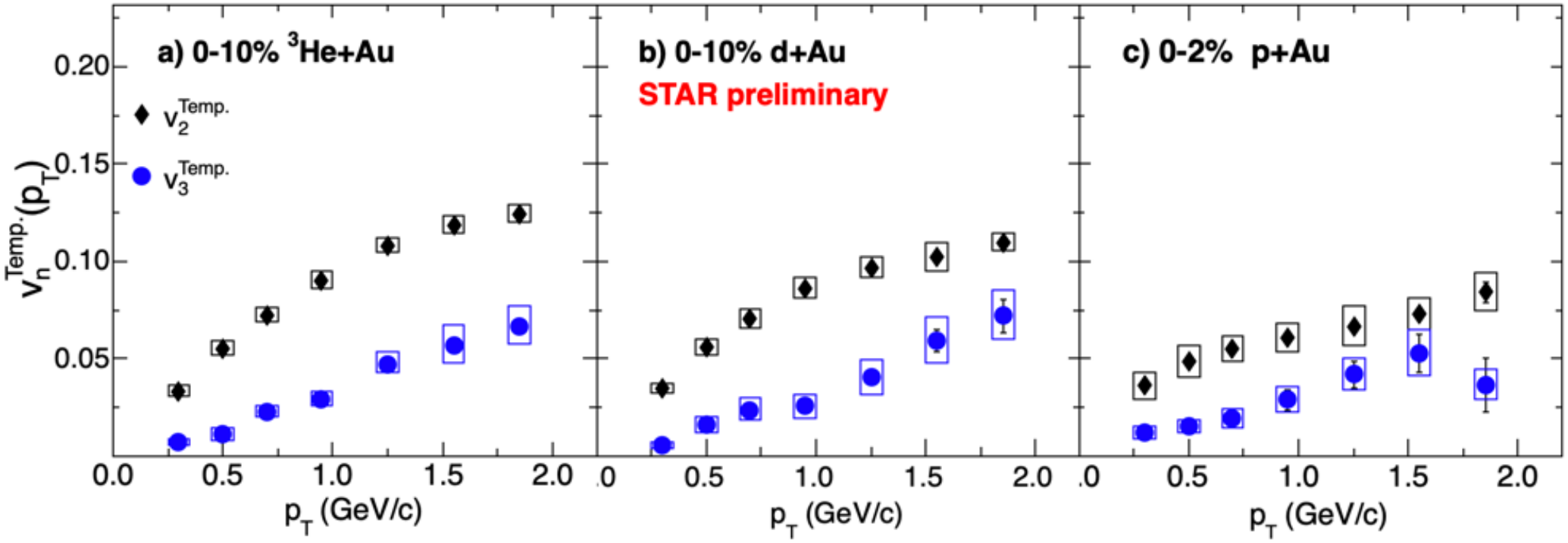


TPC centrality: Centrality and 2p correlation measured in same rapidity

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**

Comparison to model



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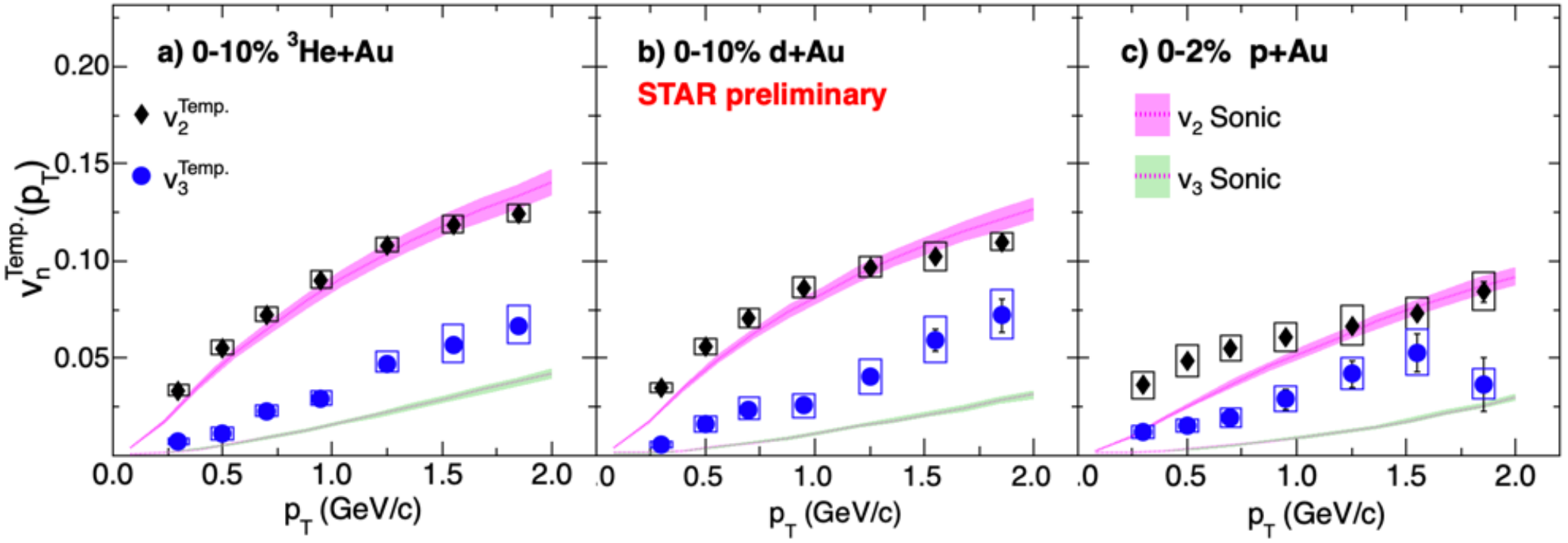

(Super)Sonic: P. Romatschke, arXiv:1502.04745 [nucl-th].
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- ***Sonic model*** with initial geometry eccentricity from ***Nucleon Glauber*** under-predicts v_3 in all systems
  - ✓ ***How about Sub-nucleonic Glauber?***

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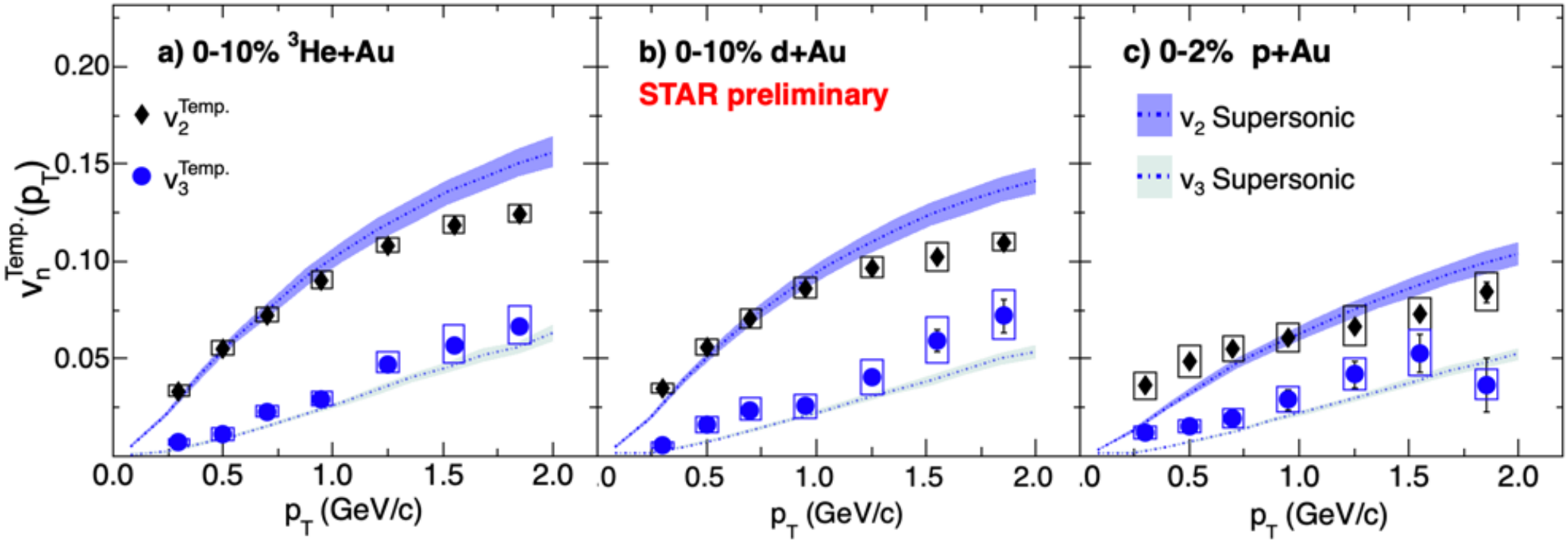

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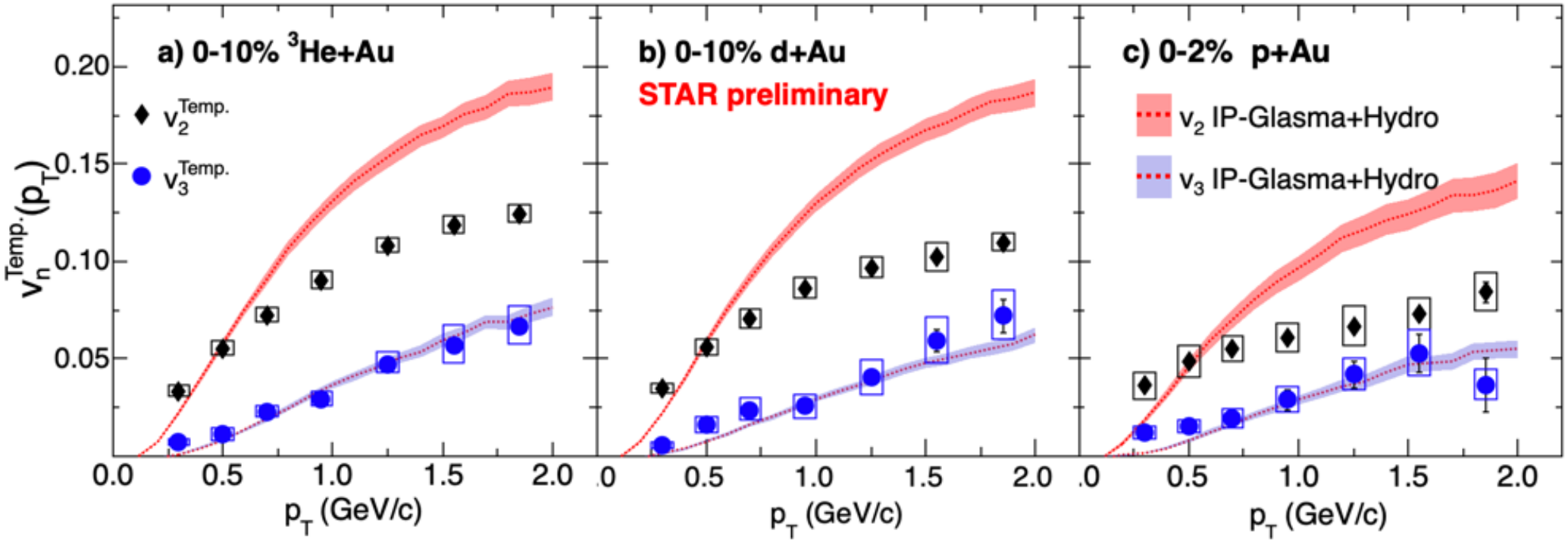

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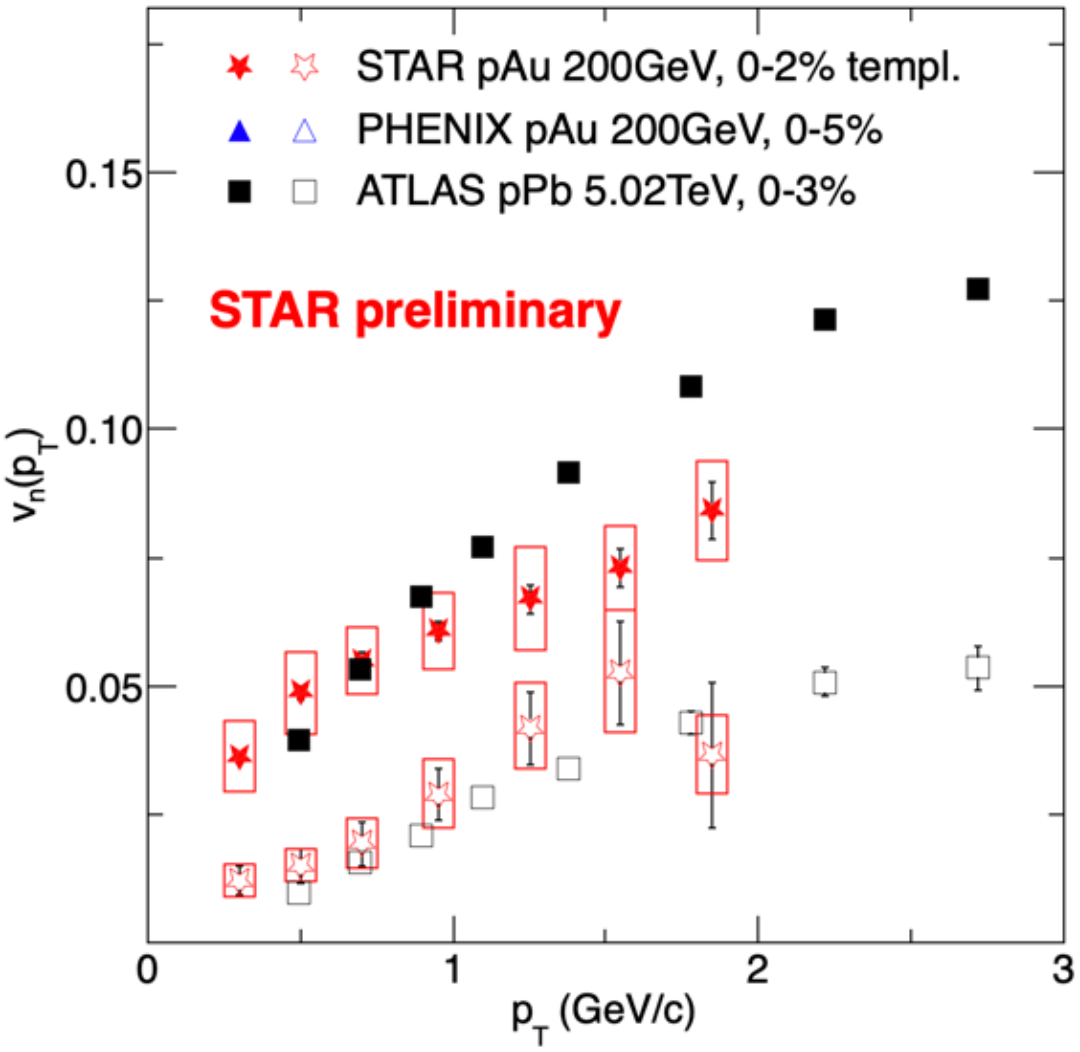
  - ✓ ***How about Sub-nucleonic Glauber?***
- ***Supersonic model*** can match the v_2 and v_3 better by including the "***pre-flow***"
- ***IP-Glasma+Hydro*** that includes sub-nucleonic fluctuations + initial momentum correlation over predicts v_2 but reproduces v_3

Comparisons to LHC



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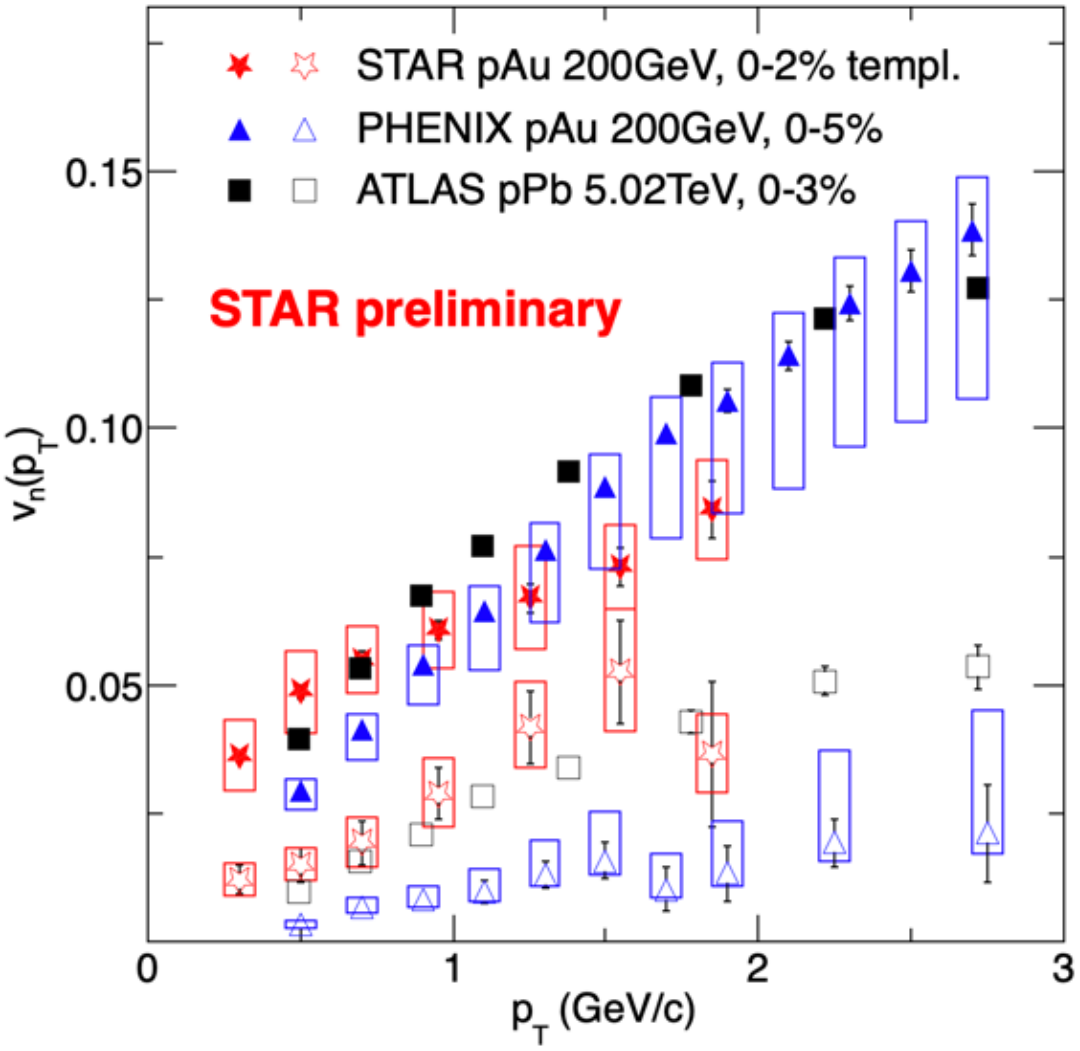

- Measurements of both v_2 and v_3 from STAR are similar with that from LHC
- Significant difference between STAR and PHENIX for v_3

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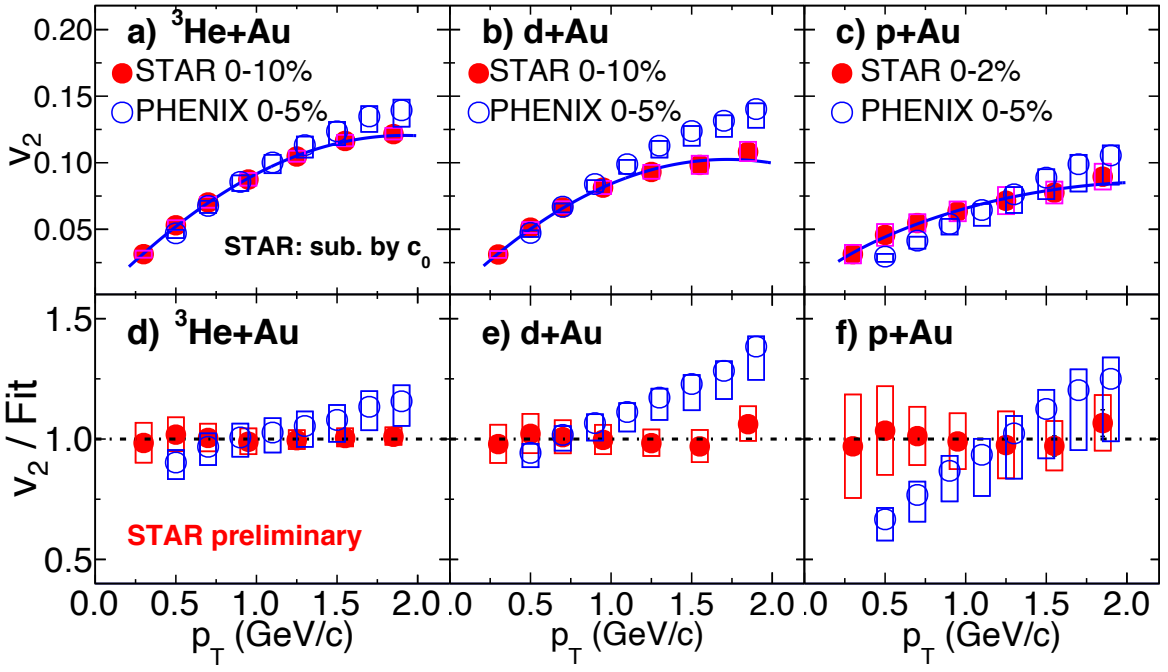
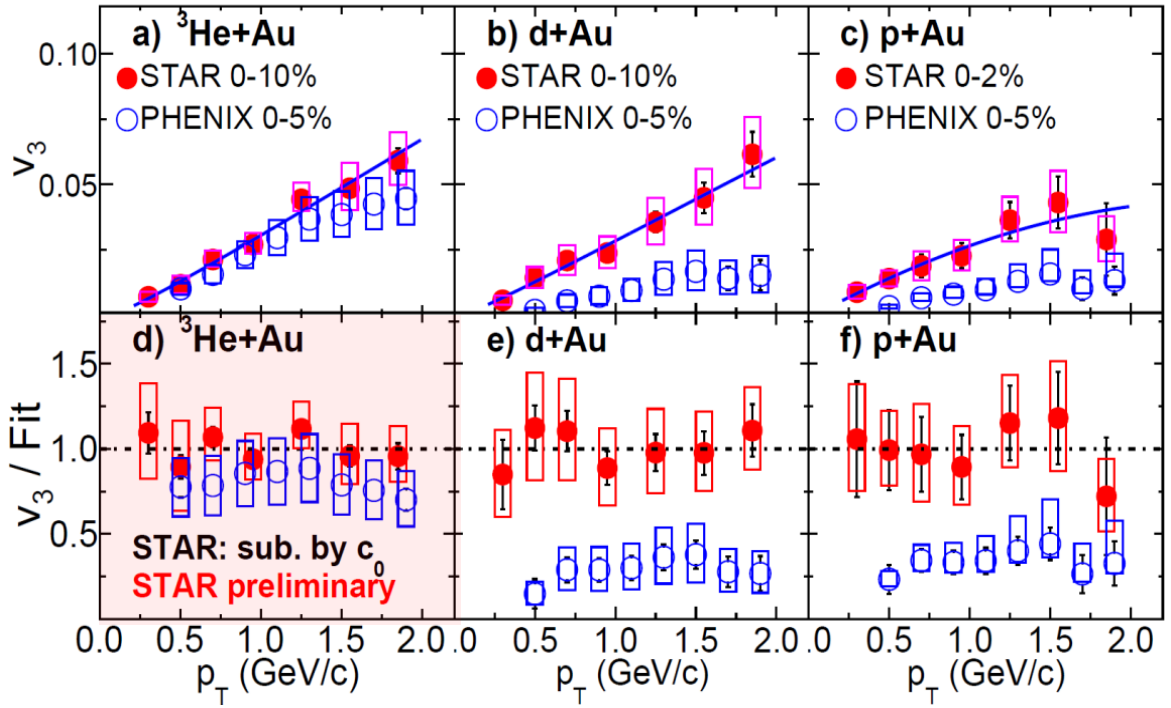
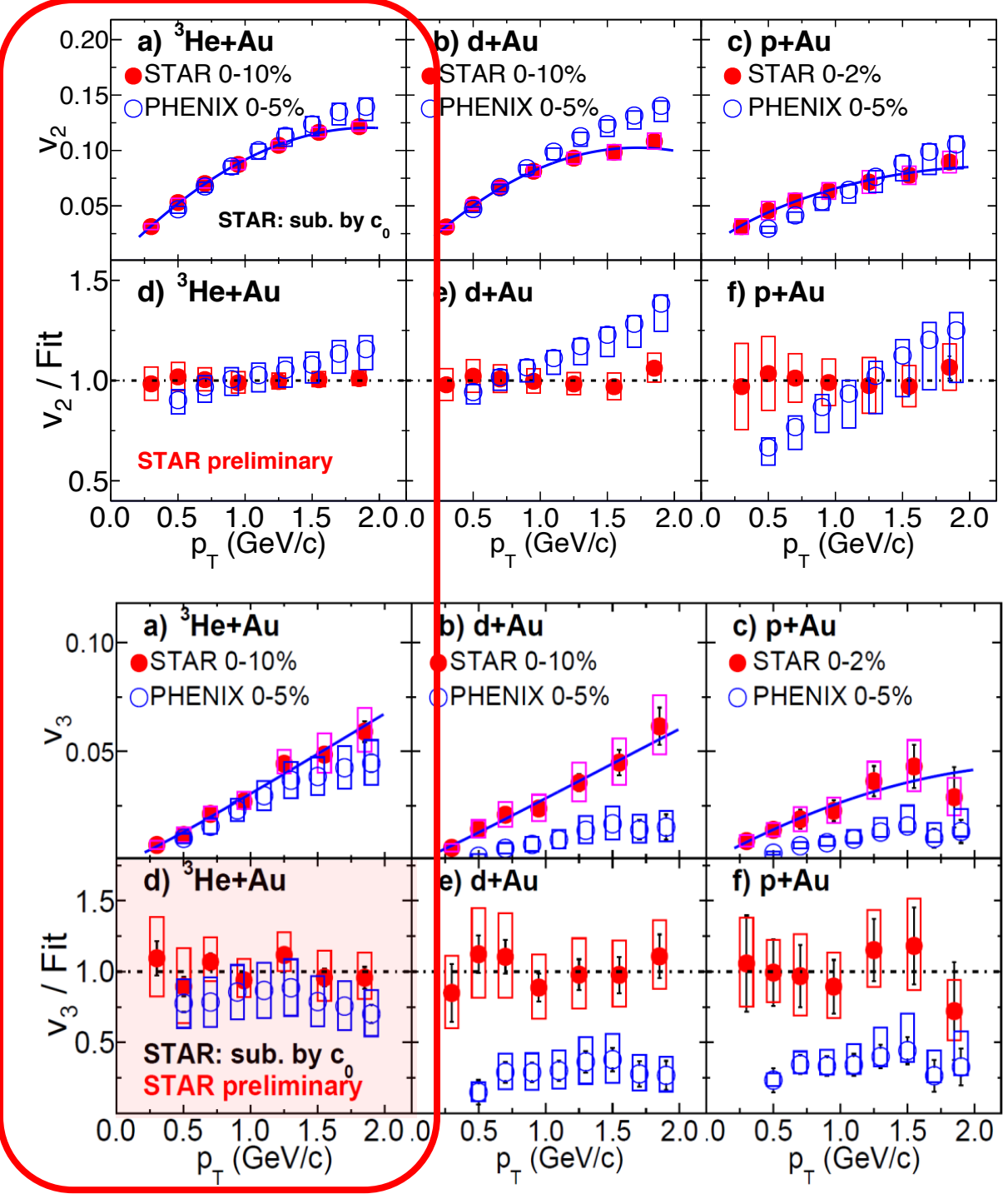
Detail Comparisons to PHENIX







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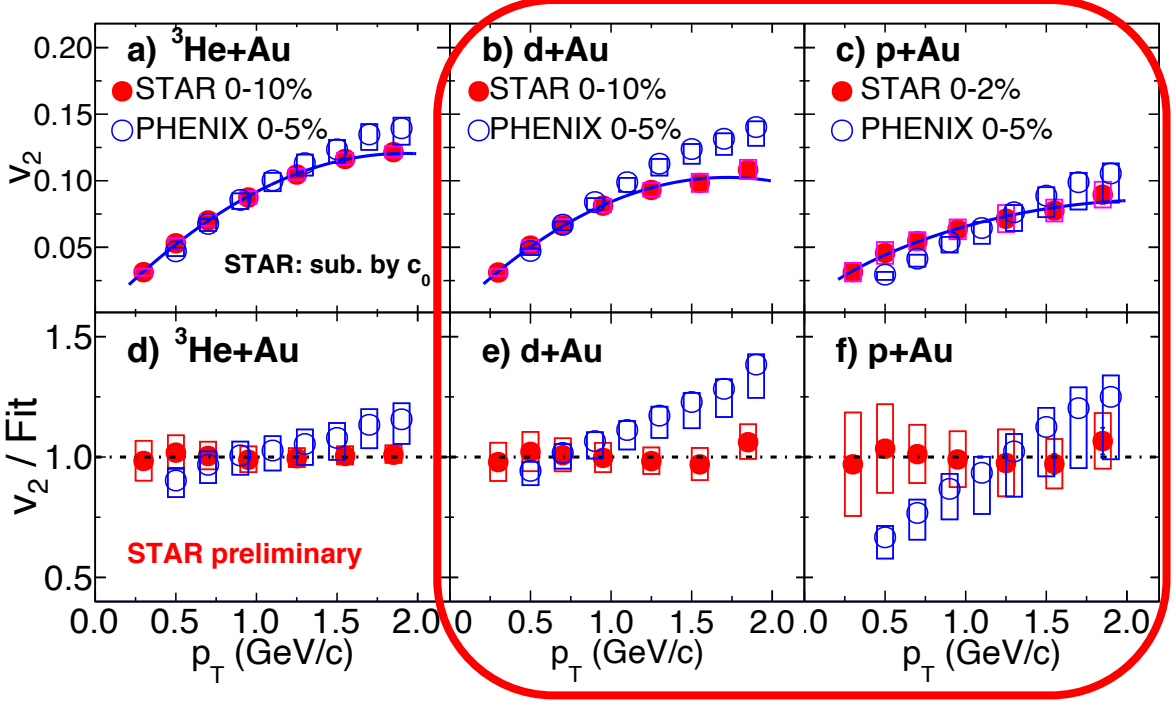

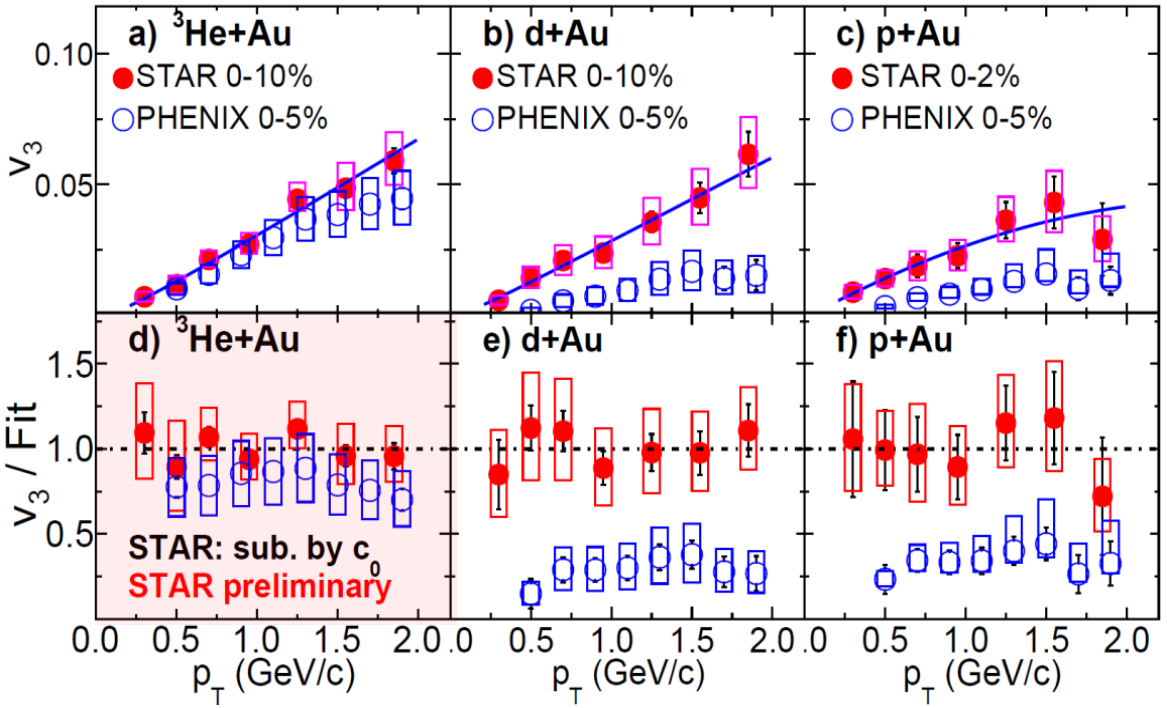

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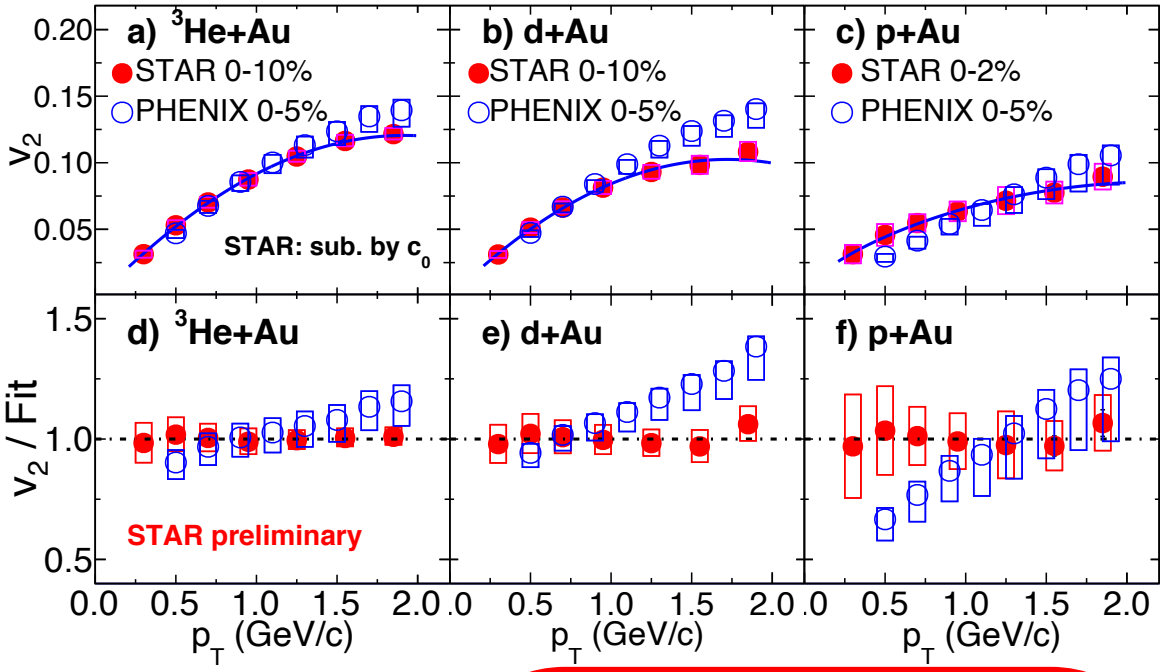

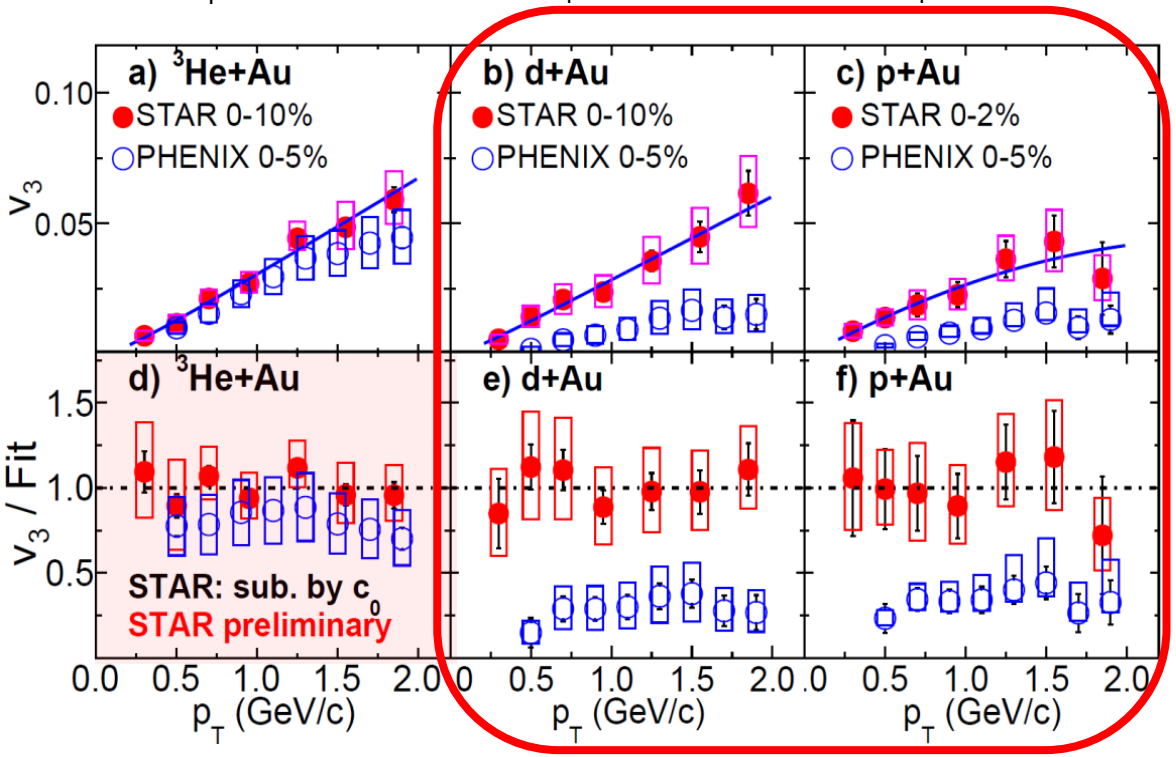

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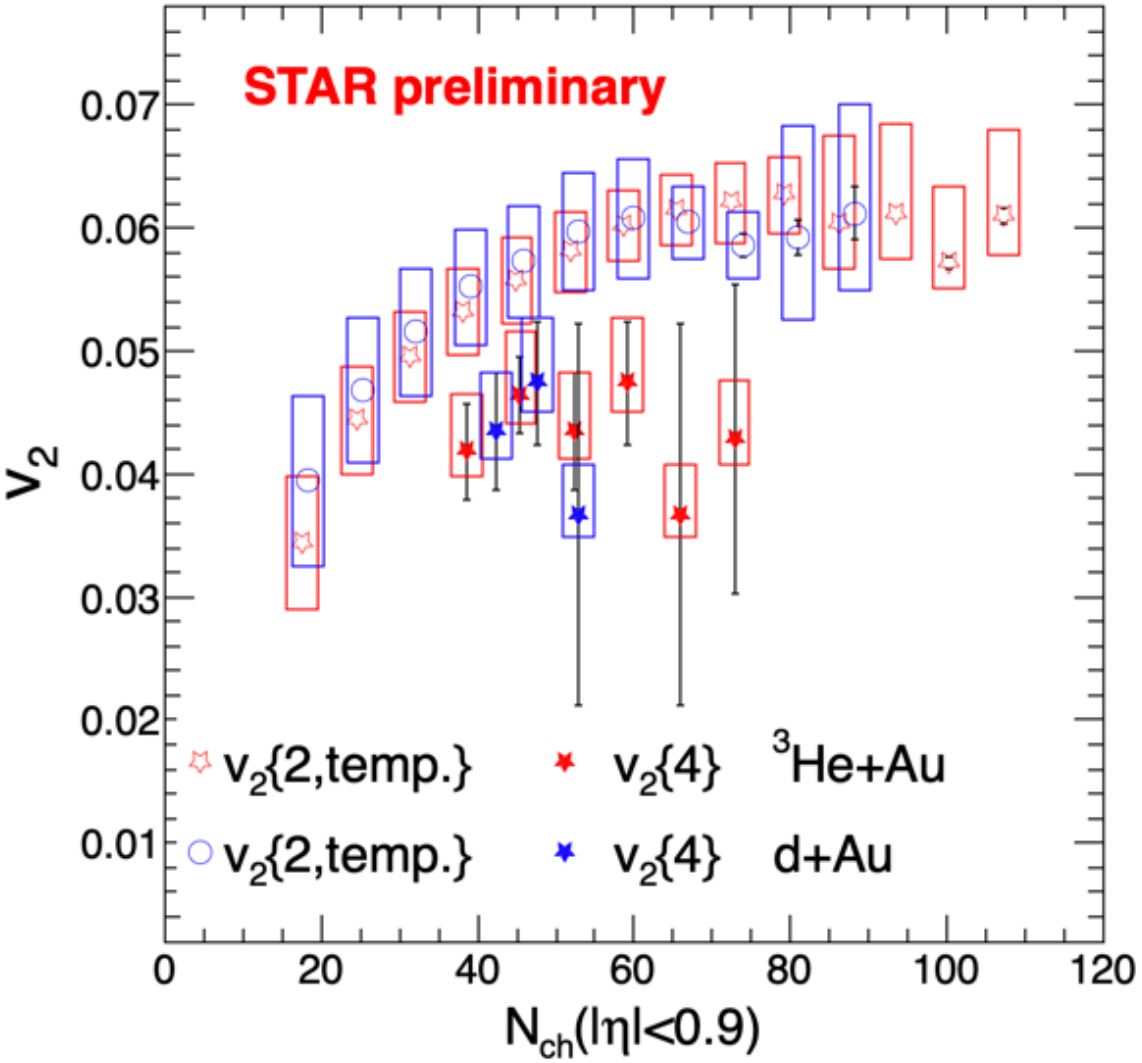
- The STAR and PHENIX v_3 for p/d+Au, show similar pT-dependence
  - ✓ But magnitudes differ by a factor of 3
    - ✓ System-independent STAR v_3
    - ✓ System-dependent PHENIX v_3

Cross Checks done by STAR

Checks		Consistent results (within uncertainties)		Difference between measurements
Different techniques for flow extraction	✓	Good agreement between different methods		
Flow extraction with different centrality definition	✓	Good agreement between measurements with different centrality definition		
Independent analyses of v_n for d+Au	✓	Good agreement between measurements from independent groups		
Peripheral subtraction vs. pp subtraction			✗	Peripheral subtraction is an underestimate

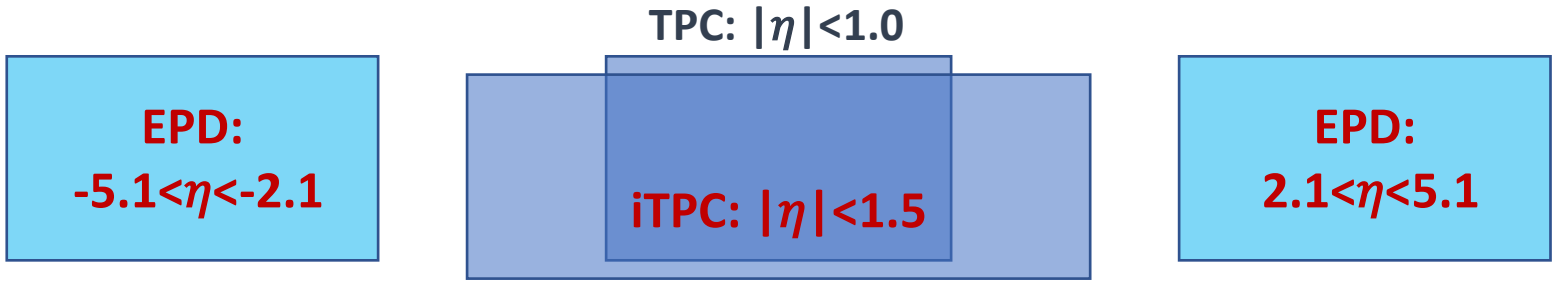
"A cross-experiment Small systems Advisory Committee" has been formed by BNL managements recently to understand the difference between STAR and PHENIX

$V_2\{2\}$ vs. $v_2\{4\}$



- A positive $v_2\{4\}$ is first observed at mid-rapidity by STAR in d+Au and ^{3}He+Au collisions
- The $v_2\{2\}$ from template fit are larger than $v_2\{4\}$ due to fluctuations

Outlook: O+O@RHIC 2021



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  - ✓ Large rapidity coverage due to new upgrade
  - ✓ Trigger HM event at both middle or forward rapidity

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TPC: $|\eta|<1.0$

EPD: $-5.1<\eta<-2.1$

iTPC: $|\eta|<1.5$

EPD: $2.1<\eta<5.1$

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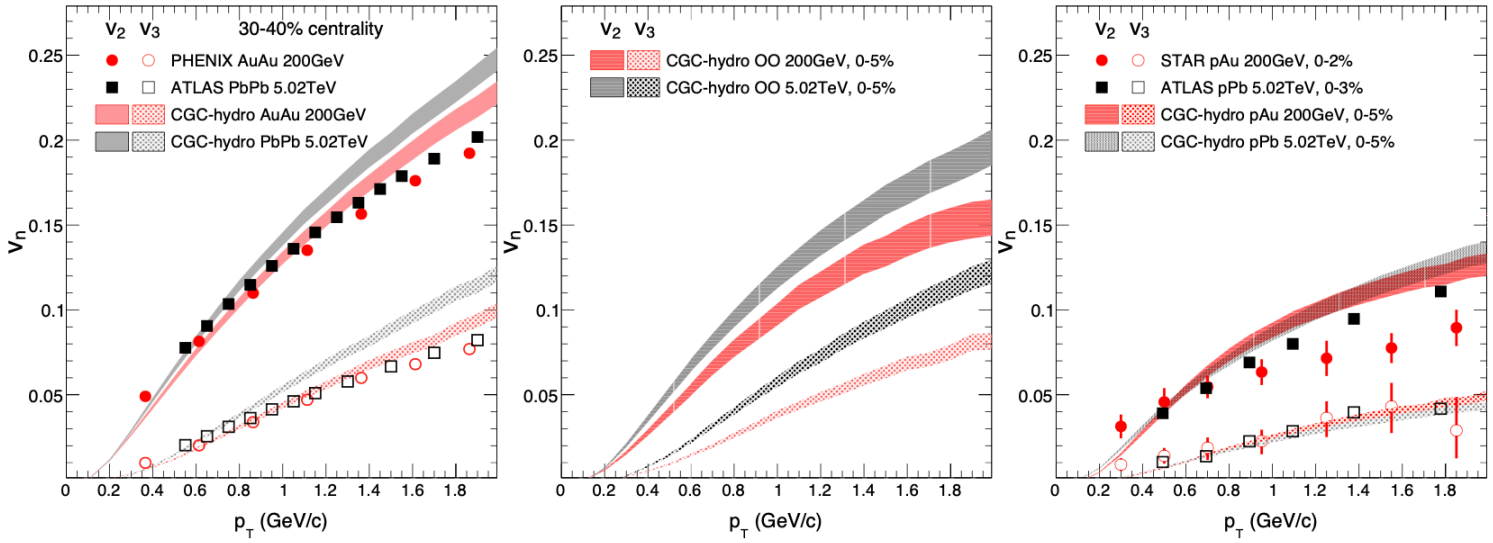

- ➢ **First** comparison between RHIC & LHC with ~identical Glauber geometry but different sub-nucleon fluctuation (Q_s) for a factor of 10 difference in energy

STAR: BUR2020

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

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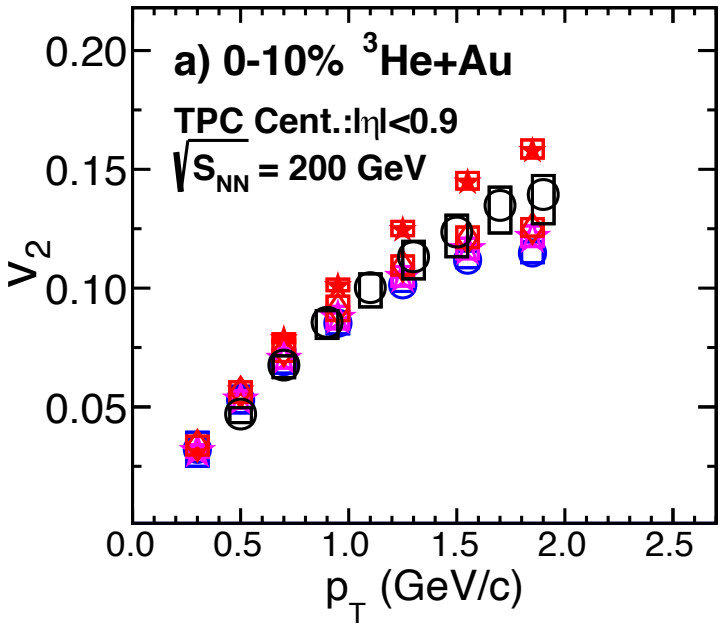
Backup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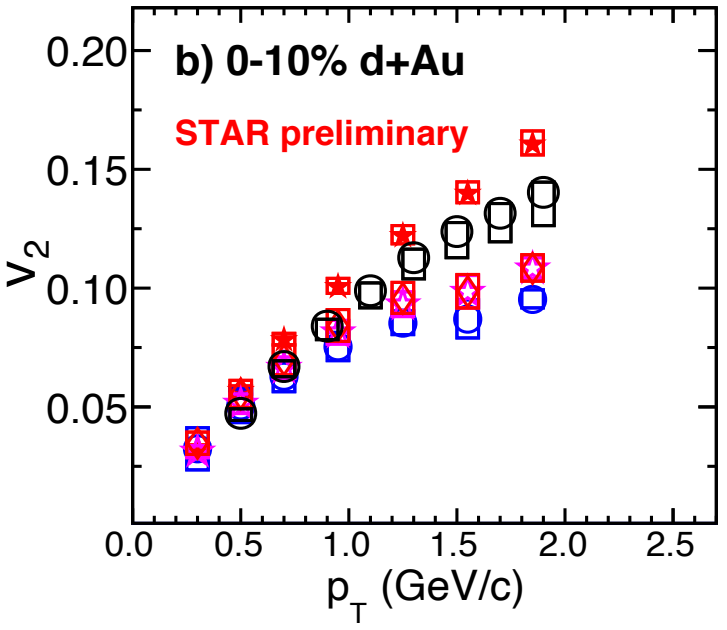
v_2
p_T (GeV/c)


b) 0-10% d+Au
STAR preliminary
v_2
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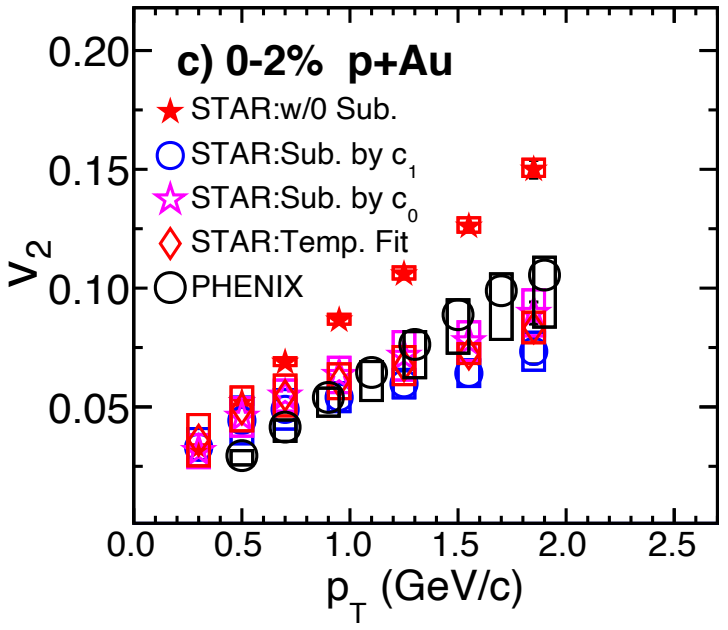
c) 0-2% p+Au
STAR:w/0 Sub.
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STAR:Temp. Fit
PHENIX
v_2
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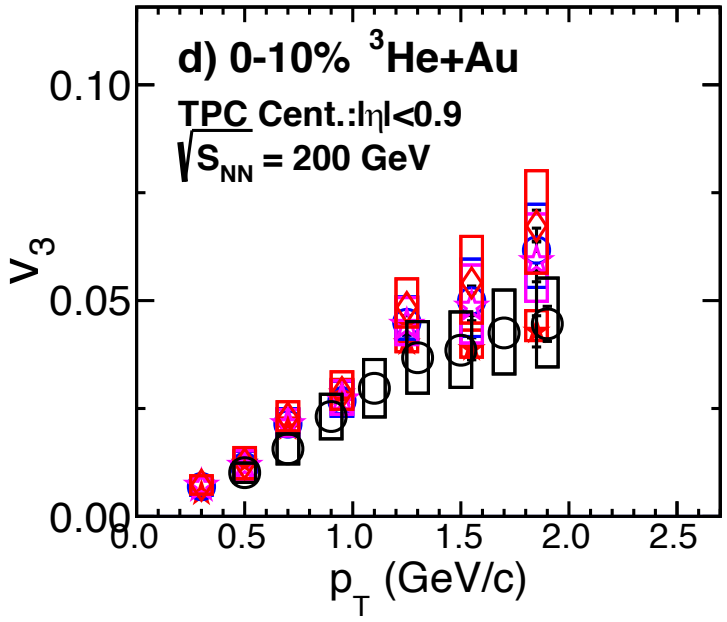
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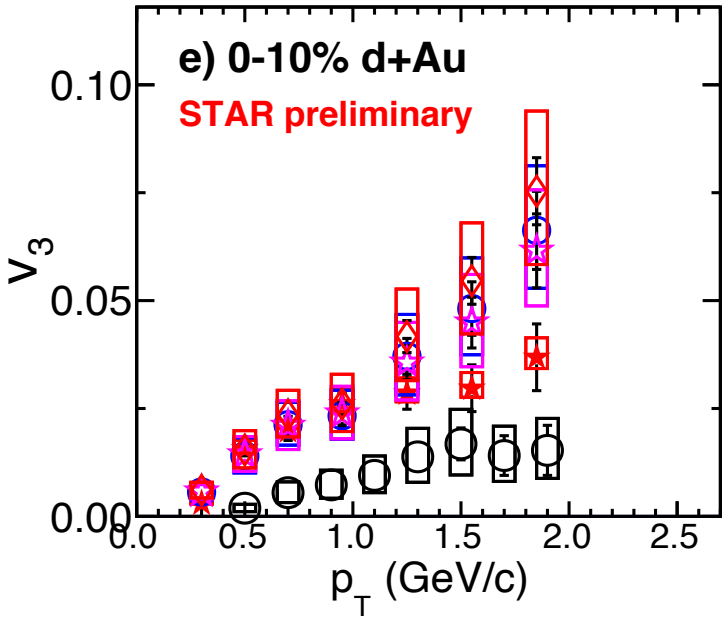
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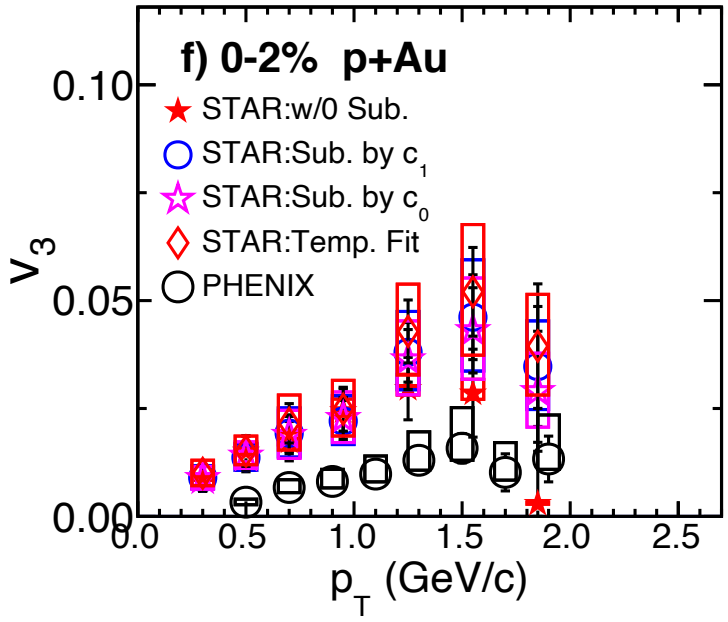
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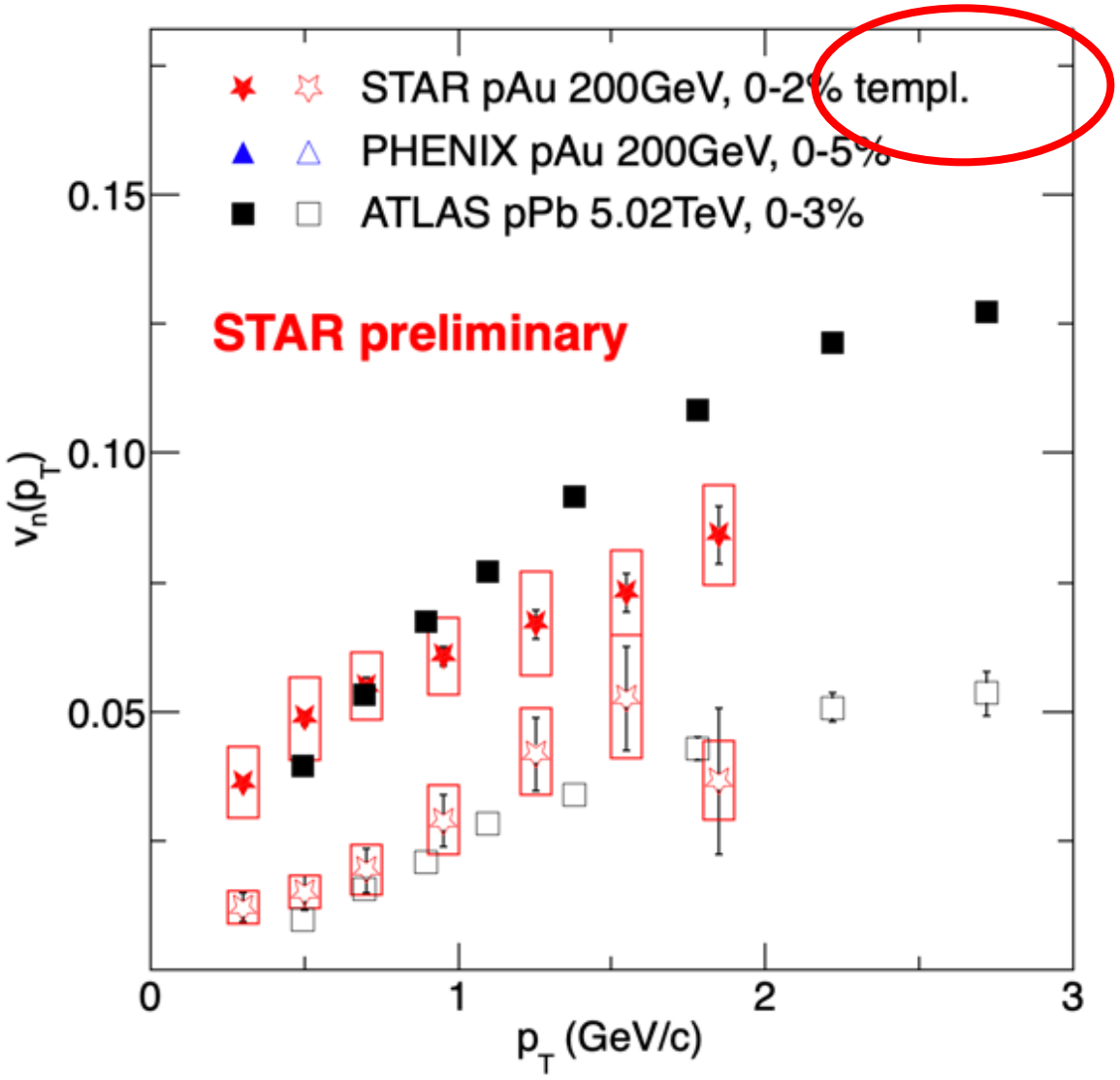
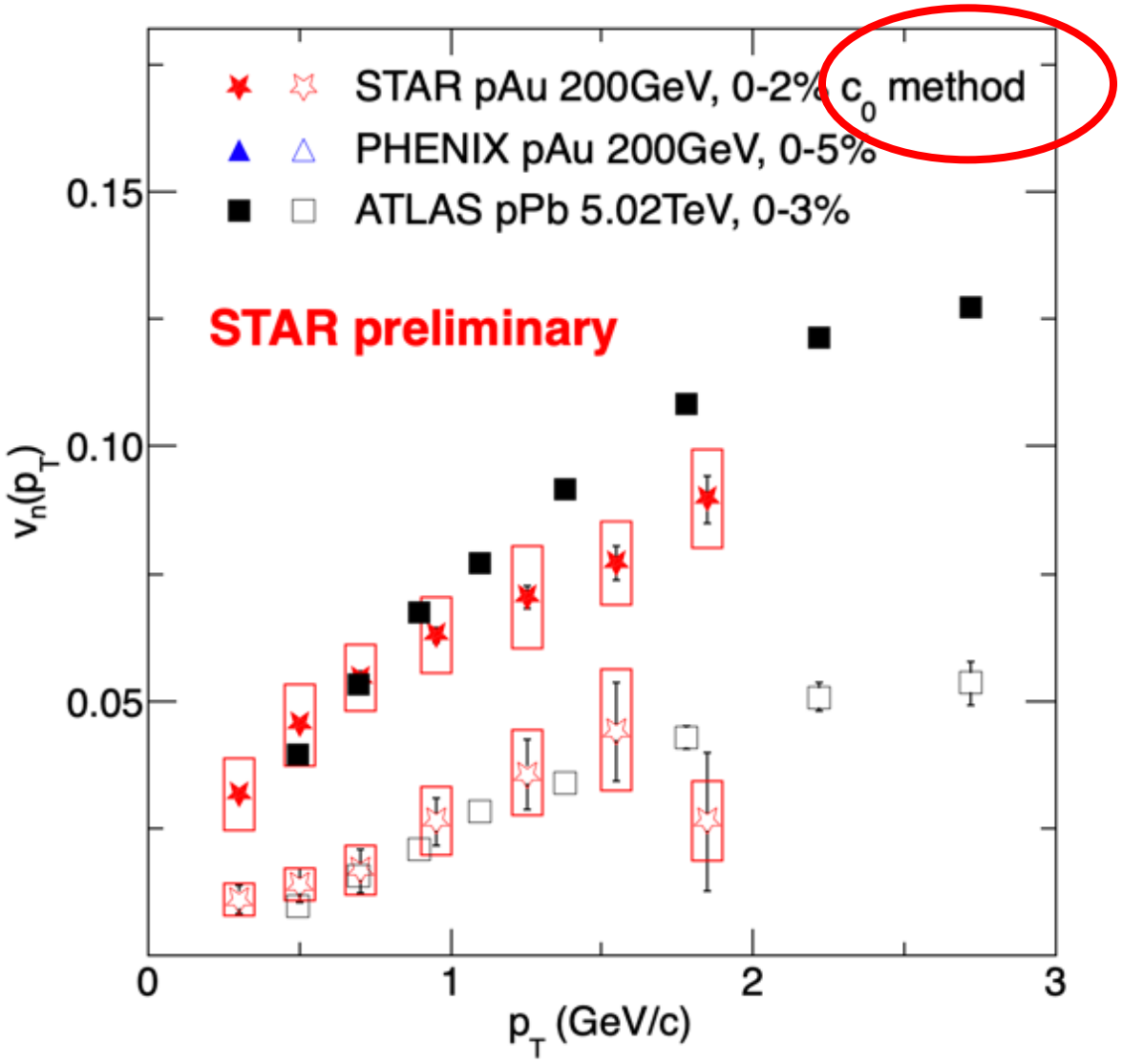
p_T (GeV/c)

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)