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Overview of STAR Small System Correlations Results

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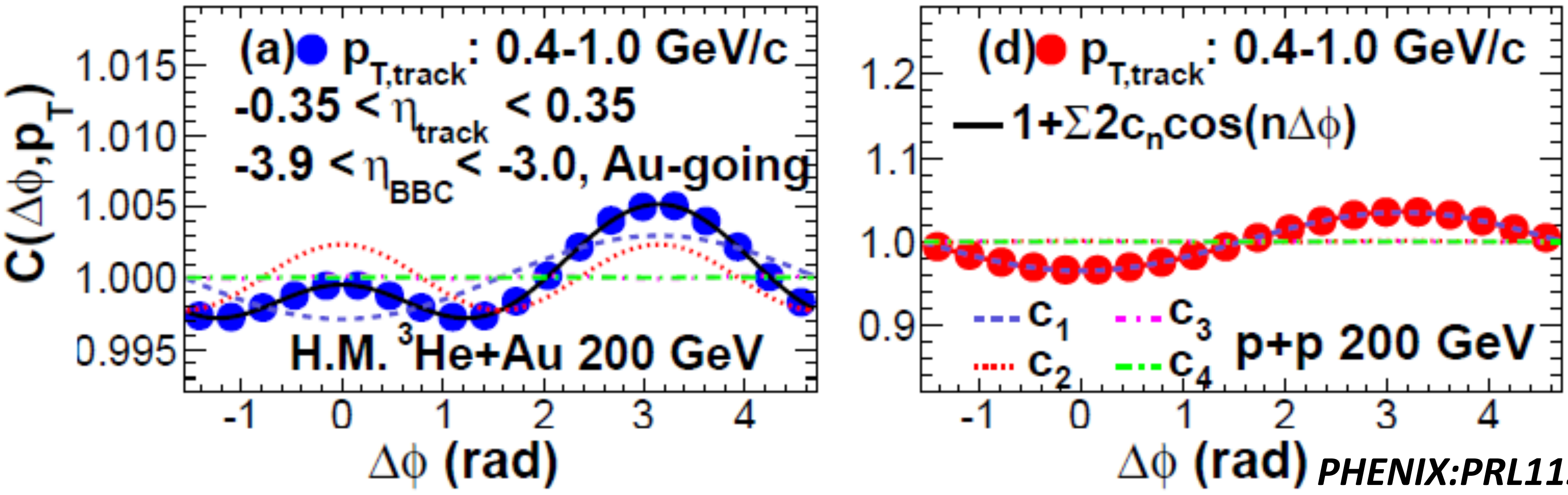
Outline

- ❑ Motivation and Analysis Methods
- ❑ Physics Results
- ✓ The v_2 in different small systems at different collision energies
- ✓ Model study for nonflow subtraction with AMPT
- ✓ The $c_2\{4\}$ in d+Au collisions at different collision energies
- ❑ Summary

What is the Origin of Ridge?



PHENIX:PRL115(2015)142301

- **Ridge (a long-range near-side correlation) is observed in small systems at RHIC:**
  Creation of a small QGP droplet or other mechanisms?

- **If a small QGP droplet is indeed created:**
  How does the system evolve in a small QGP droplet?
  How about the dependence of multiplicity and collision energy for the flow?

Participant nucleon vs. parton Glauber model

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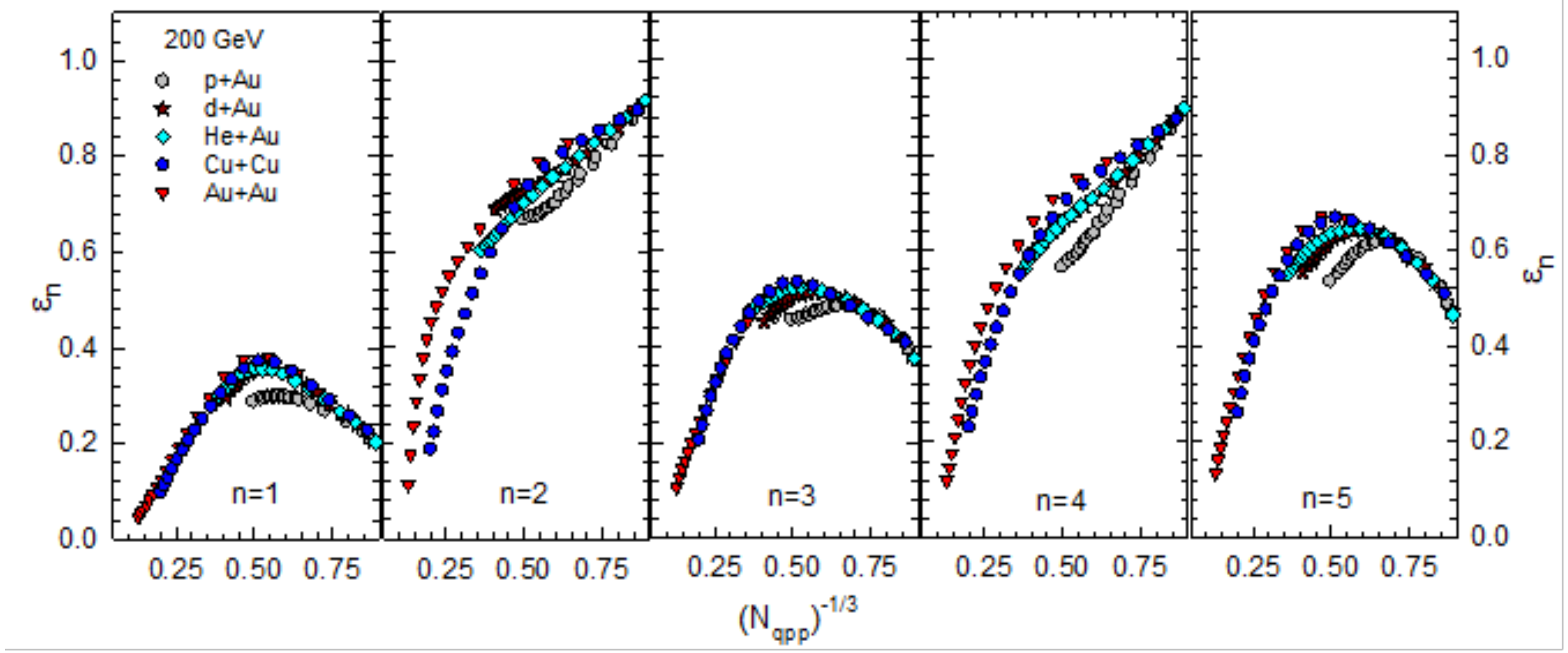
Participant nucleon

	0-5% p+Au	0-5% d+Au	0-5% He+Au
ε_2	0.23	0.54	0.50
ε_3	0.16	0.19	0.28

J. L. Nagle ***PRL113(2014)112301***

- Different initial geometry in small systems such as p/d/^{3}He+Au

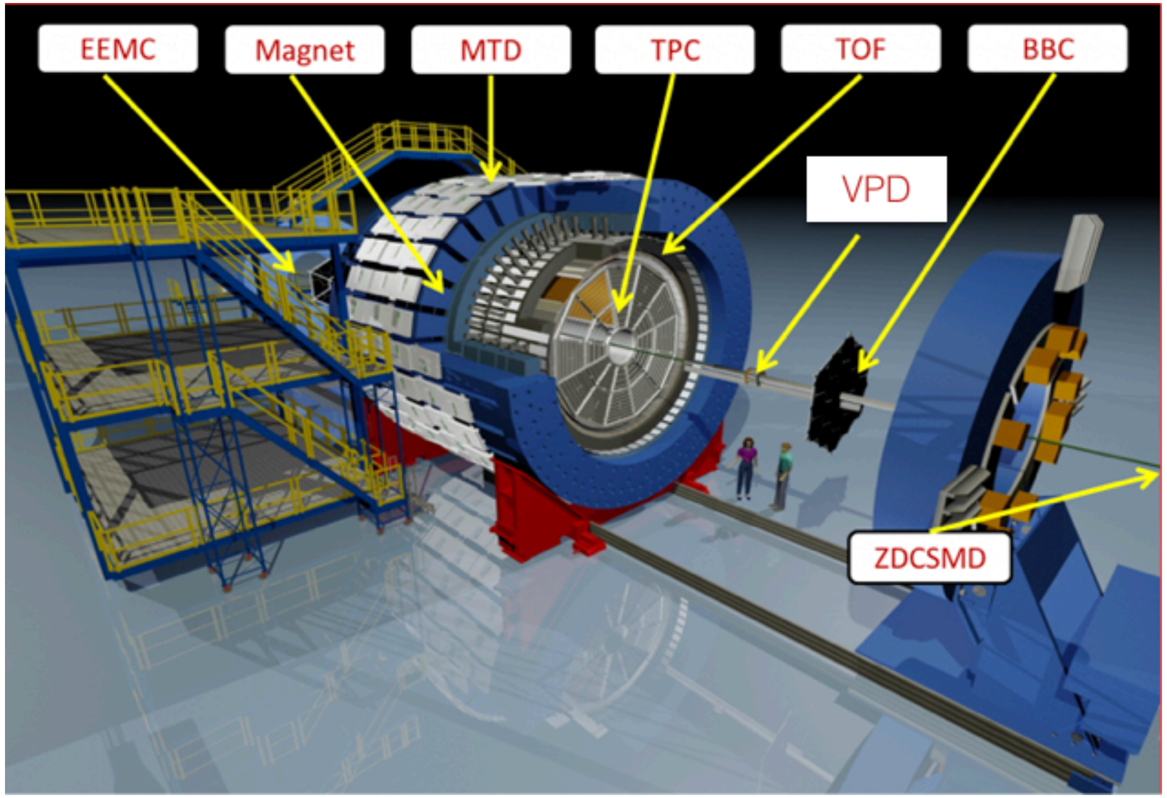
Participant parton

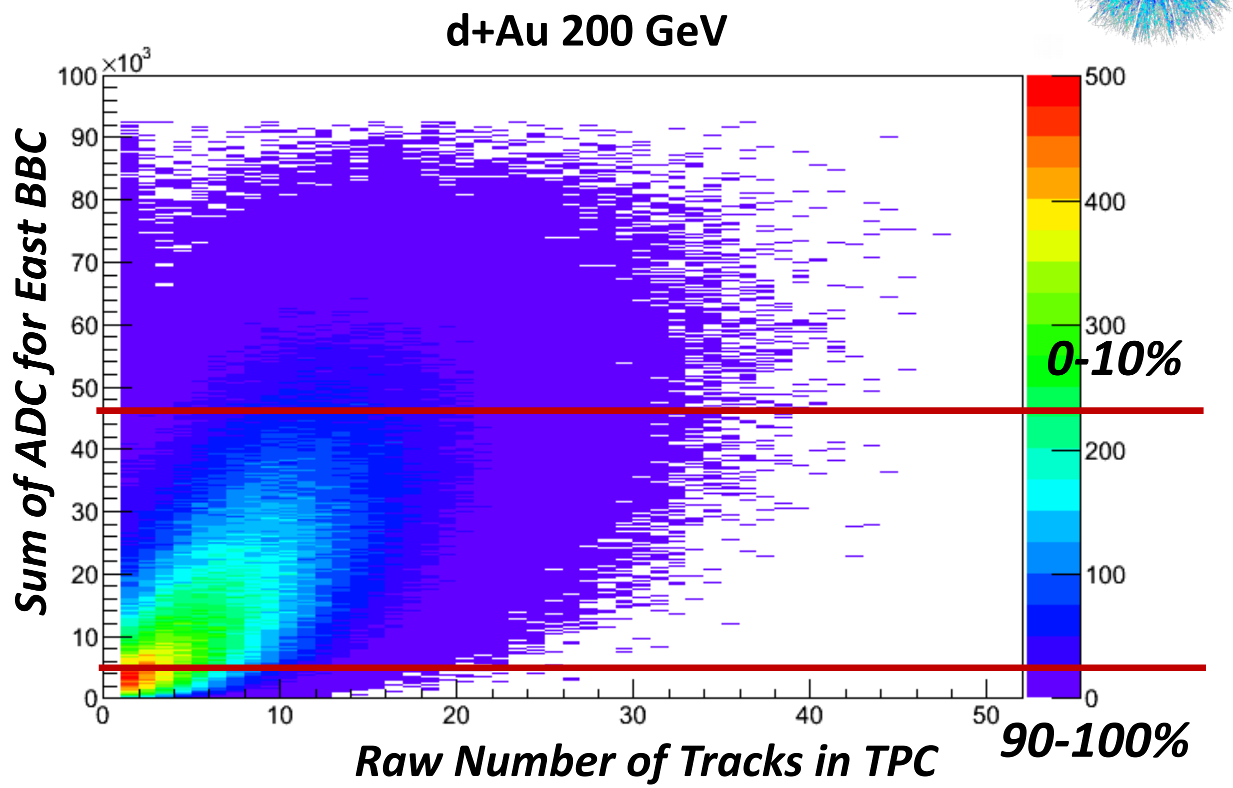


P. Liu arXiv:1804.04618

- **Similar eccentricity patterns for small and large systems in peripheral collisions.**
  - ✓ **Trivial shape dependence for similar geometric size in central and mid-central collisions**
  - ✓ **Fluctuations important for small systems**

Event Activity



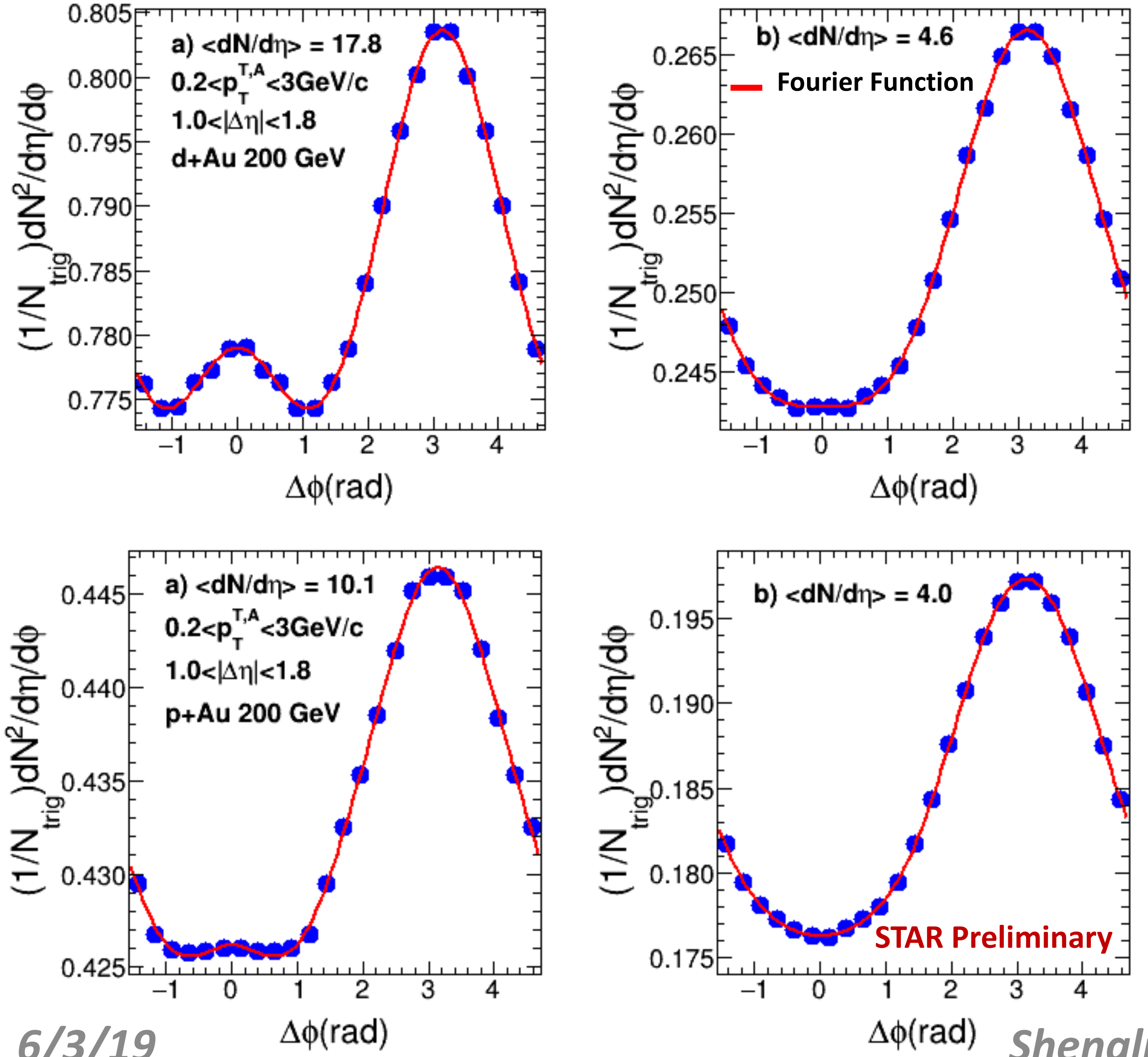


- Event classes with different activity are selected by using BBC east in the Au-going direction ($-5.0<\eta<-3.3$)
- Long-range two-particle correlations are measured in TPC($|\eta|<0.9$)

- Correlation between multiplicity at backward and mid-rapidity
- 10 event classes with different TPC $<dN/d\eta>$ are selected by sum ADC of BBC east in d+Au collisions at 200 GeV

Long-range Two-particle Correlations

High Multiplicity (HM) **Low Multiplicity (LM)**



d+Au 200 GeV

p+Au 200 GeV

- ❑ A near-side ridge is observed in the HM d+Au ($\langle dN/d\eta \rangle$=17.8) and p+Au ($\langle dN/d\eta \rangle$=10.1) collisions
- ❑ A Fourier function is employed to extract the $V_{n,n}$

$$dN/d\Delta\phi \sim 1 + \sum_{n=1}^{4} 2V_{n,n} \times \cos(n\Delta\phi))$$

Integral $v_n = \mathrm{sqrt}(V_{n,n})$; $v_n(p_T) = V_{n,n}(p_T)/v_n$

Two Jet Subtraction Methods

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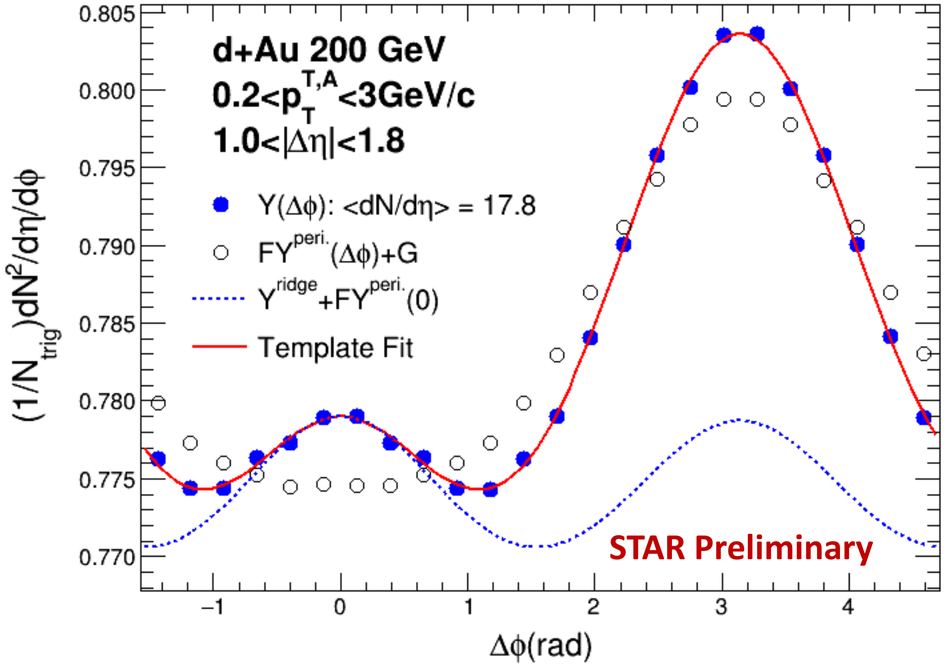
1.Low multiplicity subtraction scaled by short-range ($|\Delta\eta|$<0.5) near-side jet yield

$$V_{n,n}^{HM}(subtracted) = V_{n,n}^{HM} - V_{n,n}^{LM} \times \frac{N_{asso.}^{LM}}{N_{asso.}^{HM}} \times \frac{Y_{jet,near-side}^{HM}}{Y_{jet,near-side}^{LM}}$$

ATLAS:PRC90(2014)044906
CMS:PLB765(2017)193
STAR: PLB743(2015)333

✓ ***Assumption: short-range near-side jet modification = long-range away-side jet modification***

2.Template Fit



✓ **A new developed method to subtract away-side jet contribution by ATLAS:**

$$Y_{templ.}(\Delta\phi) = F \times Y_{LM}(\Delta\phi) + Y_{ridge}(\Delta\phi)$$

where

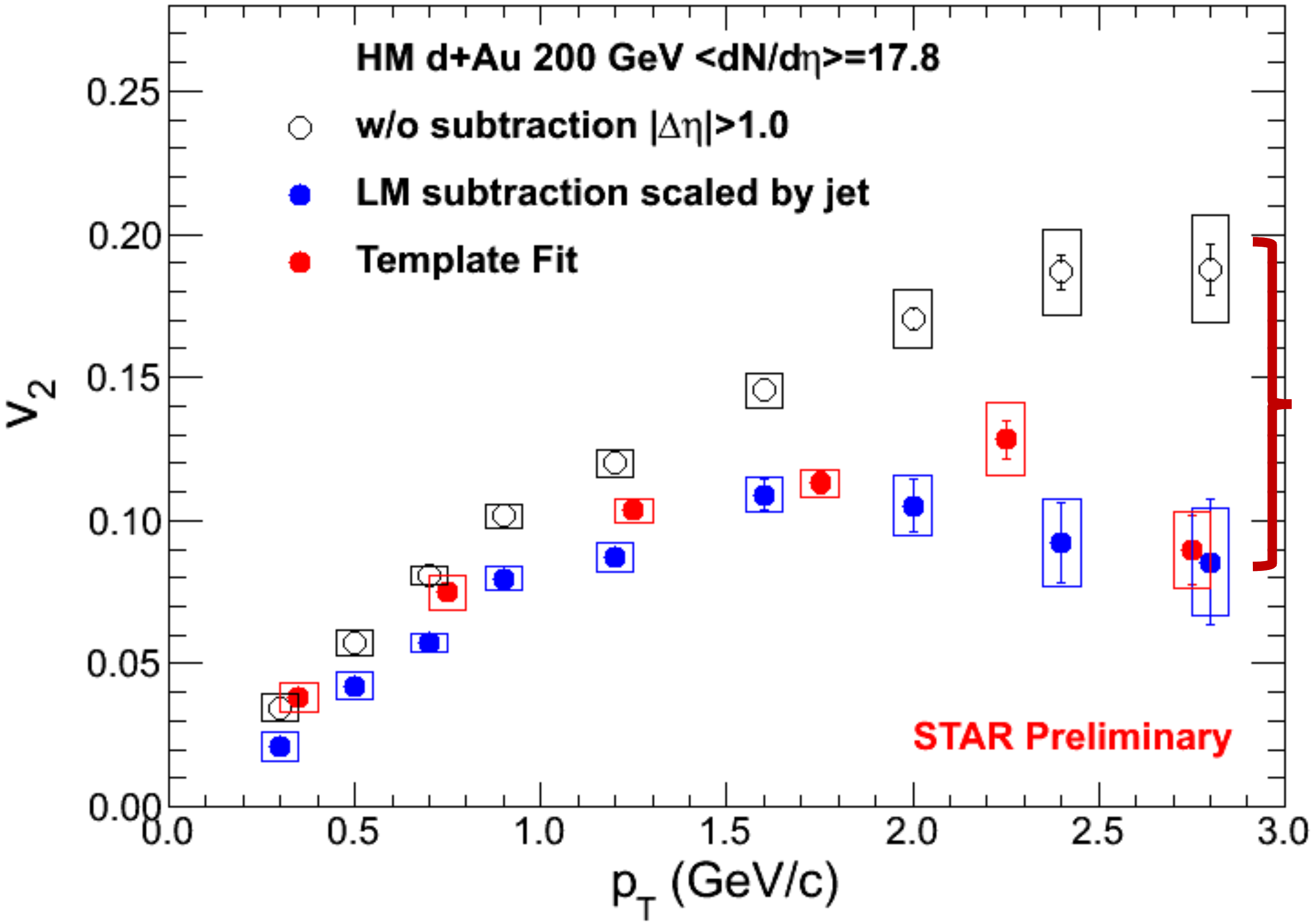
$$Y_{ridge}(\Delta\phi) = G\times(1 + 2\times \sum_{n=2}^{4} V_{n,n}\times\cos(n\Delta\phi))$$

ATLAS:PRL(116)172301

✓ **Assumption: away-side jet shape can be measured in LM events and scaled by fit parameter "F" due to jet modification**

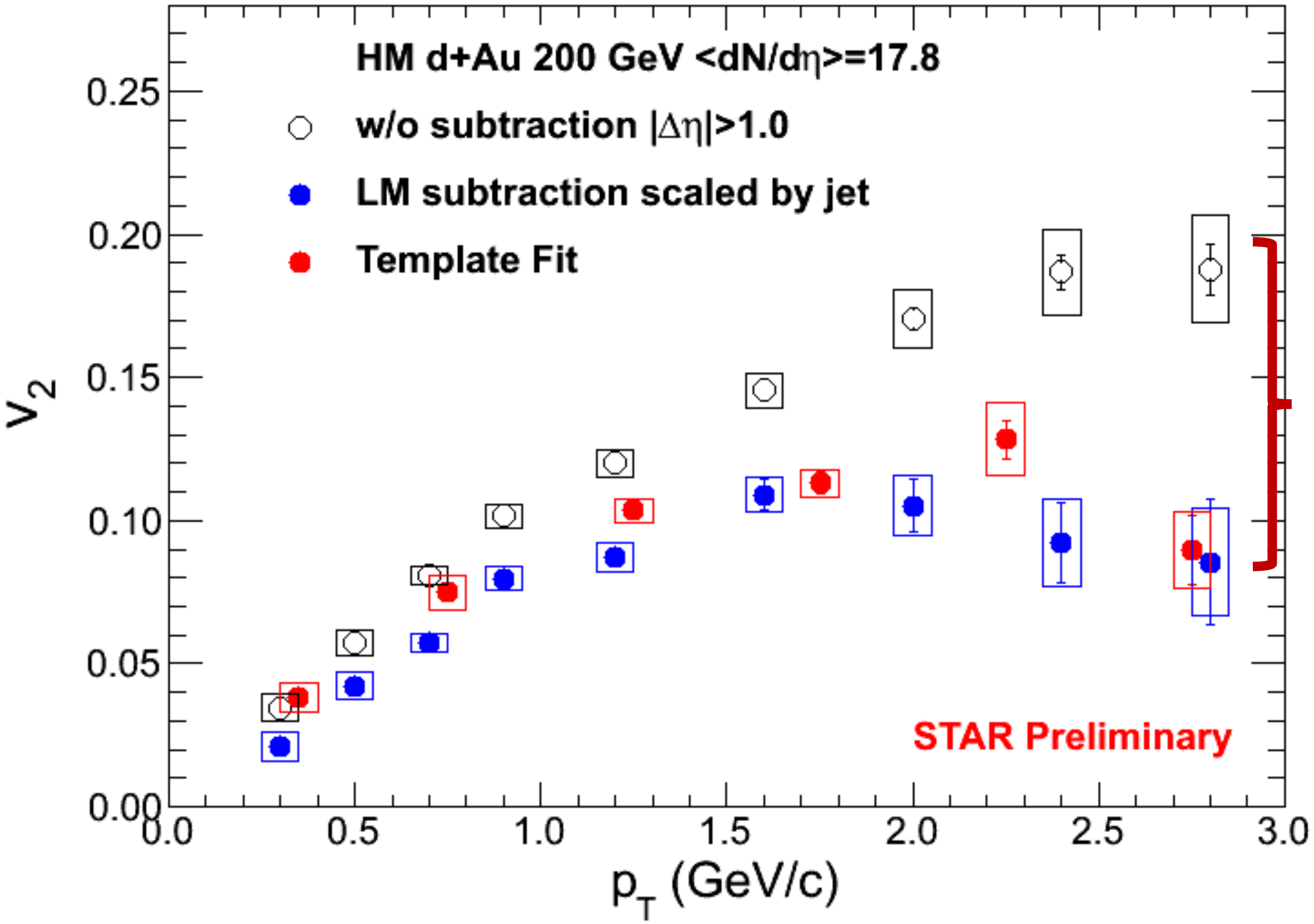
It will cause a bias if assumptions are not correct

v_2 in HM d+Au (0-10%) at 200 GeV



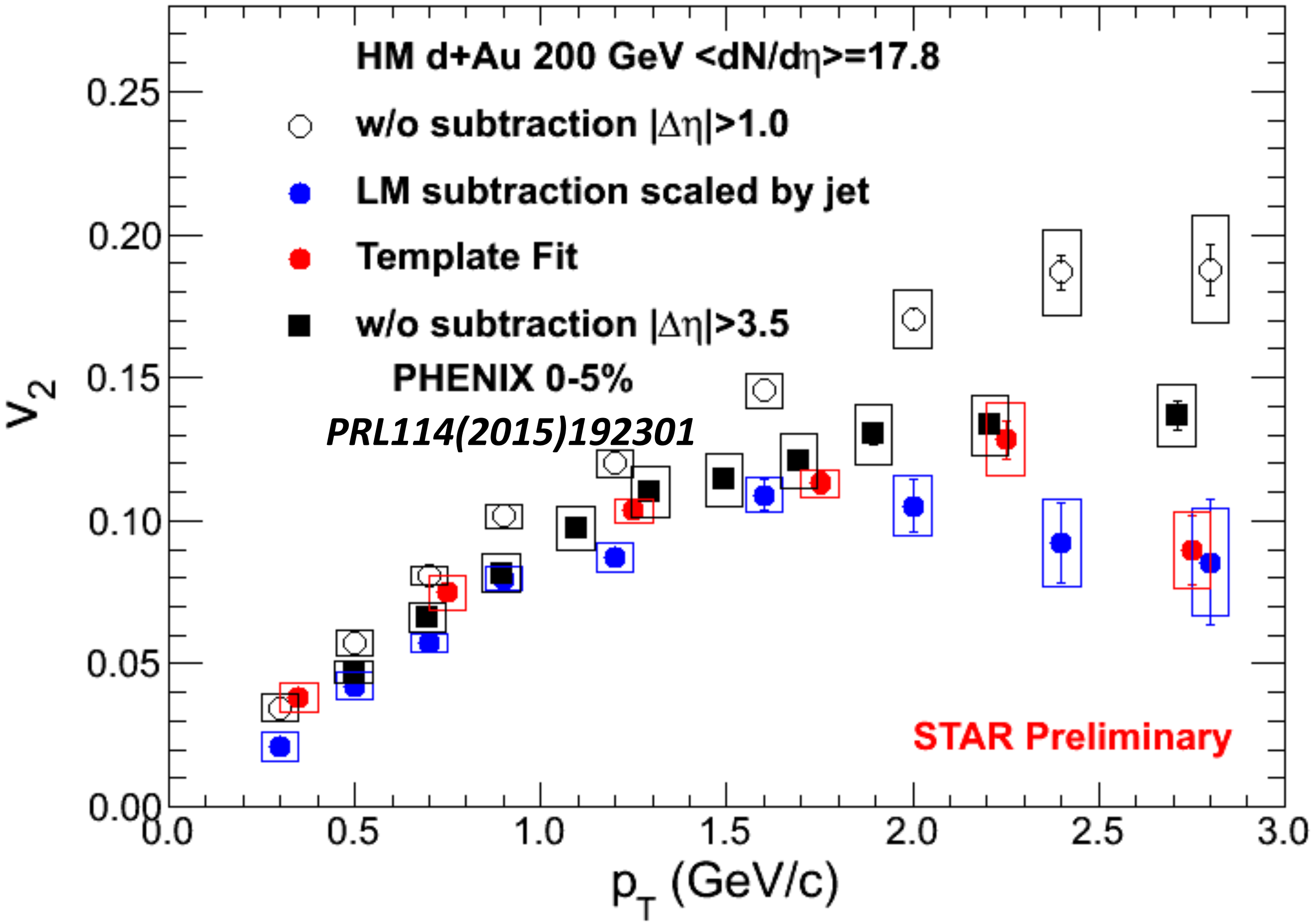
- v_2 without subtraction is larger than that with subtraction for both methods. ***The subtraction of non-flow is crucial in small system!***

v_2 in HM d+Au (0-10%) at 200 GeV



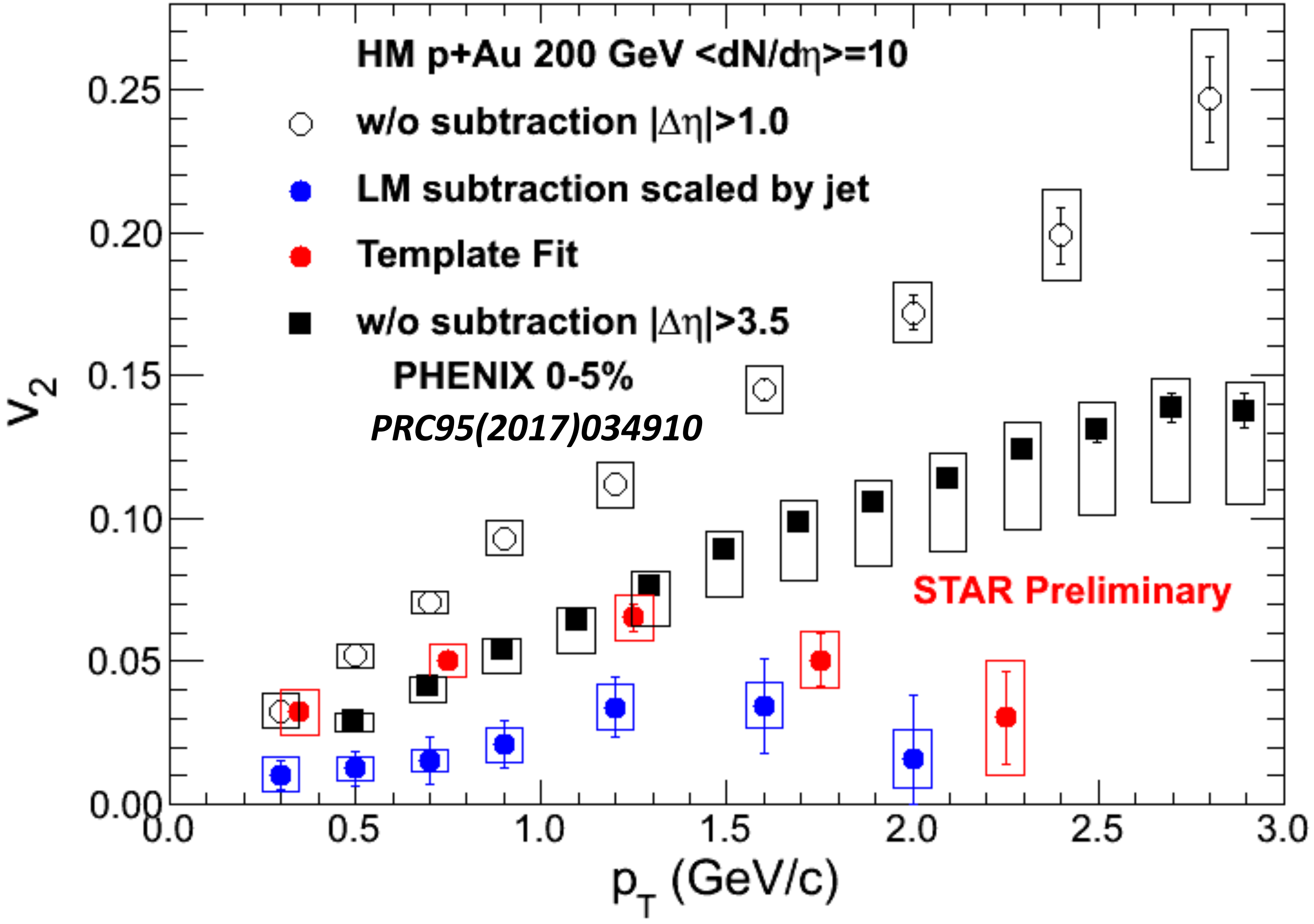
- v_2 without subtraction is larger than that with subtraction for both methods. ***The subtraction of non-flow is crucial in small system!***
- At lower p_T, the v_2 from LM subtraction is around 35% lower than that from template fit, while they are quite similar at intermediate p_T

v_2 in HM d+Au (0-10%) at 200 GeV



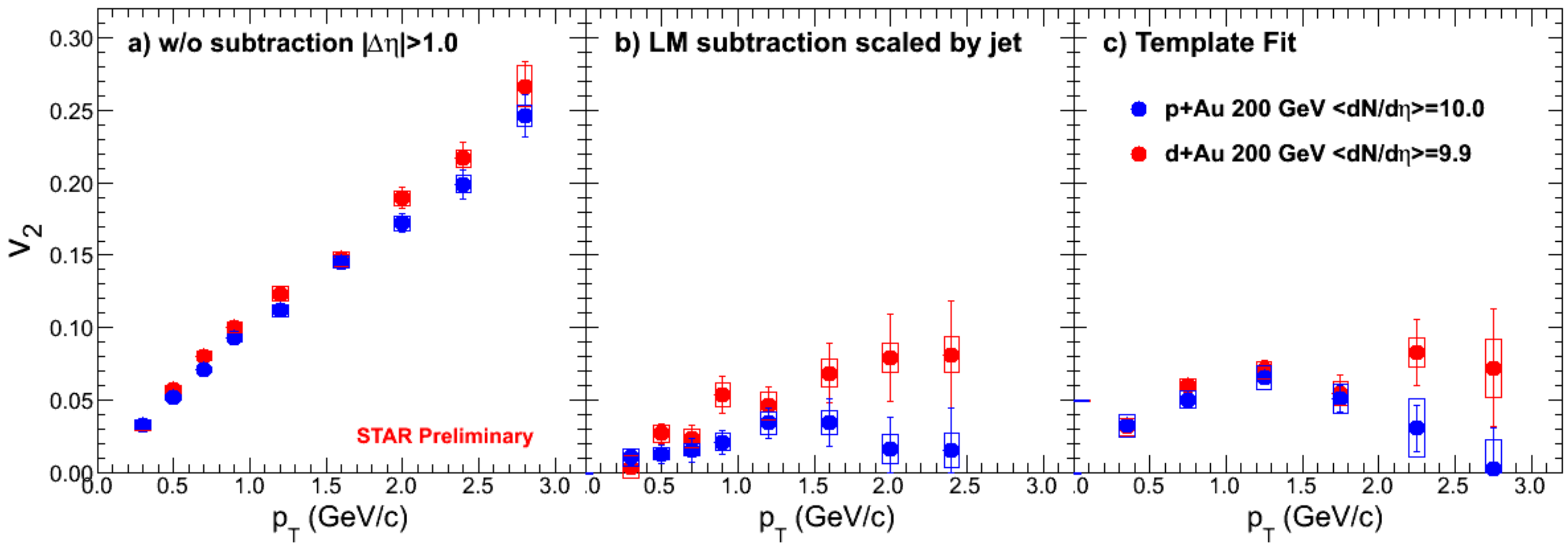
- v_2 without subtraction is larger than that with subtraction for both methods. ***The subtraction of non-flow is crucial in small system!***
- At lower p_T, the v_2 from LM subtraction is around 35% lower than that from template fit. While they are quite similar at intermediate p_T
- The subtracted v_2 measured by STAR is similar to PHENIX measurement, which has at least 10% non-flow

v_2 in HM p+Au (0-10%) at 200 GeV



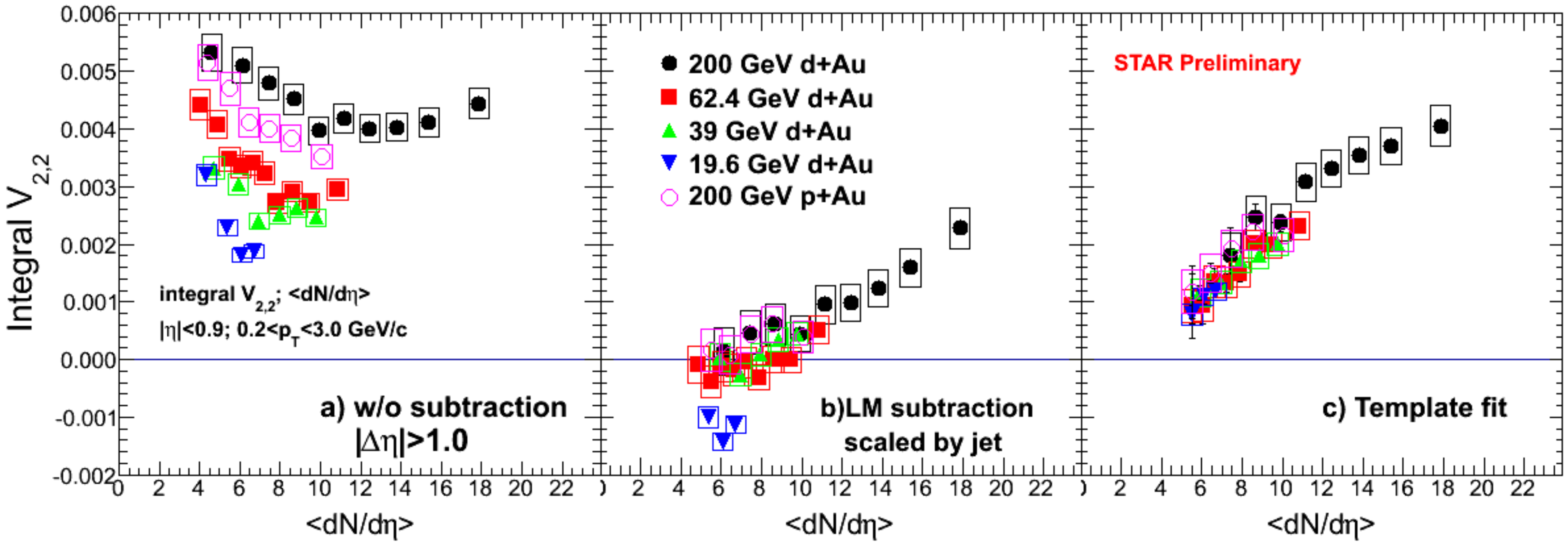
- Compared to d+Au results, v_2 in p+Au without subtraction is much larger than that with subtraction for two methods
- In p+Au collision, the v_2 from LM subtraction is much lower than that from template fit.
- v_2 from template fit method is similar to PHENIX measurement at low p_T

p/d+Au v_2 with same <dN/dη>



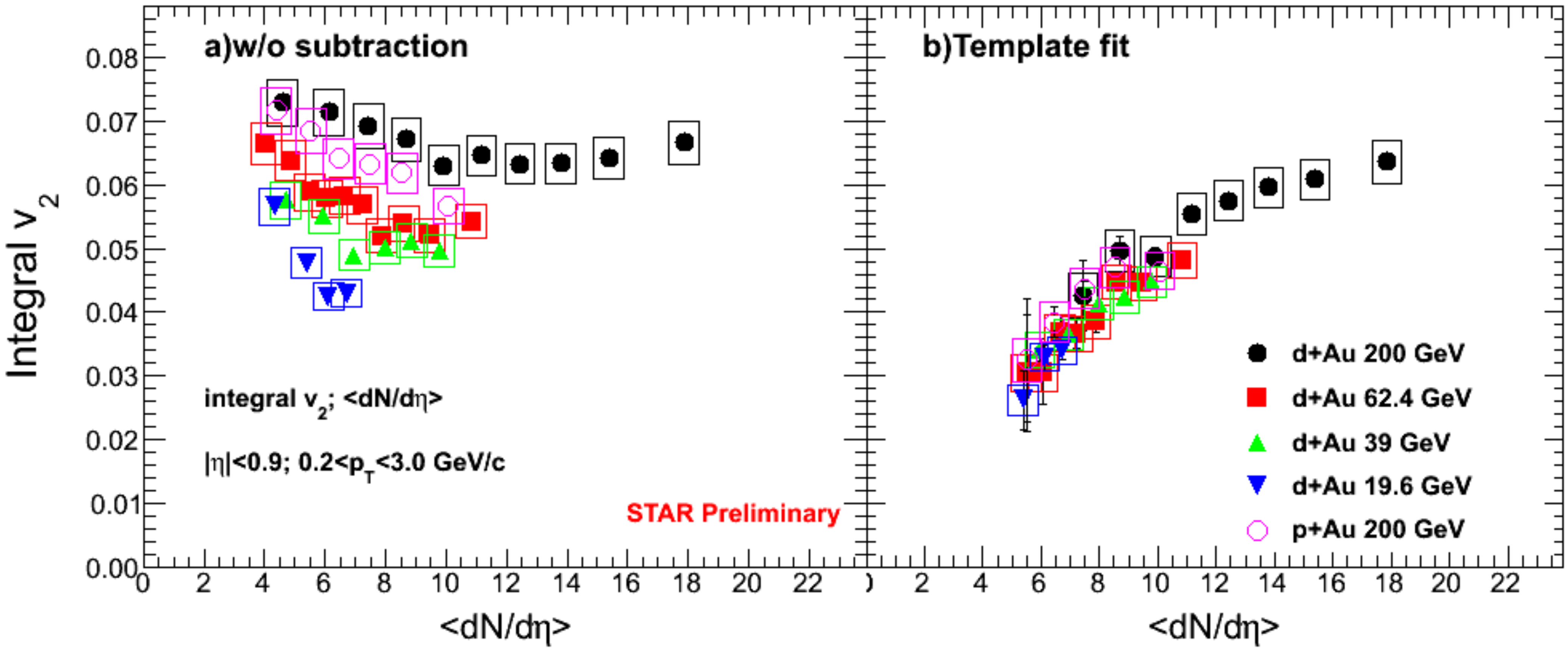
- By LM subtraction method, v_2 in d+Au is a little bit larger than that of p+Au collisions
- v_2 between p+Au and d+Au collisions from template fit is similar, while the initial eccentricities are different by a factor of two

Integral $V_{2,2}$ vs. <dN/dη>



- ❑ There is large difference between two methods
- ❑ LM subtraction leads to a negative $V_{2,2}$ at low energy
  - ✓ Different kinematics between near- and away-side jet-like correlations?
- ❑ $V_{2,2}$ from template fit increases as a function of <dN/dη>

Integral v_2 from Template Fit



- The unsubtracted integral v_2 as a function of <dN/dη> is different in different systems at different collision energies
- The integral v_2 from template fit shows a universal trend as a function of <dN/dη>

Modified Template Fit

Template Fit:

$Y_{templ.}(\Delta\phi) = F \times Y_{peri.}(\Delta\phi) + Y_{ridge}(\Delta\phi)$

where

$Y_{ridge}(\Delta\phi) = G\times(1 + 2\times\sum_{n=2}^{4} V_{n,n}^{templ.}\times\cos(n\Delta\phi))$

Modified Template Fit

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Template Fit:

$$Y_{templ.}(\Delta\phi) = F \times Y_{peri.}(\Delta\phi) + Y_{ridge}(\Delta\phi)$$

where

$$Y_{ridge}(\Delta\phi) = G\times(1 + 2\times\sum_{n=2}^{4} V_{n,n}^{templ.}\times\cos(n\Delta\phi))$$

The associate particles under the pedestal can also evolve into the flow

The yield of such part of particles will be $2\pi FY_{peri.}(0)$

It will give large contribution if G is not much larger than $FY_{peri.}(0)$

Modified Template Fit

STAR

Template Fit:

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

where

$$Y_{ridge}(\Delta\phi) = \mathrm{G}\times(1 + 2\times\sum_{n=2}^{4} V_{n,n}^{templ.}\times\cos(n\Delta\phi))$$

The associate particles under the pedestal can also evolve into the flow

The yield of such part of particles will be $2\pi F Y_{peri.}(0)$

It will give large contribution if G is not much larger than $FY_{peri.}(0)$

$$Y_{ridge}(\Delta\phi) = \boldsymbol{G}\times(\mathbf{1} + \mathbf{2}\times\sum_{n=2}^{4} \boldsymbol{V}_{n,n}^{templ.}\times\boldsymbol{cos}(\boldsymbol{n\Delta\phi})) + \boldsymbol{F}\times\boldsymbol{Y}_{peri.}(\boldsymbol{0})$$

Modified Template Fit

Template Fit:

$$Y_{templ.}(\Delta\phi) = F \times Y_{peri.}(\Delta\phi) + Y_{ridge}(\Delta\phi)$$

where

$$Y_{ridge}(\Delta\phi) = G\times(1 + 2\times\sum_{n=2}^{4} V_{n,n}^{templ.}\times\cos(n\Delta\phi))$$

The associate particles under the pedestal can also evolve into the flow

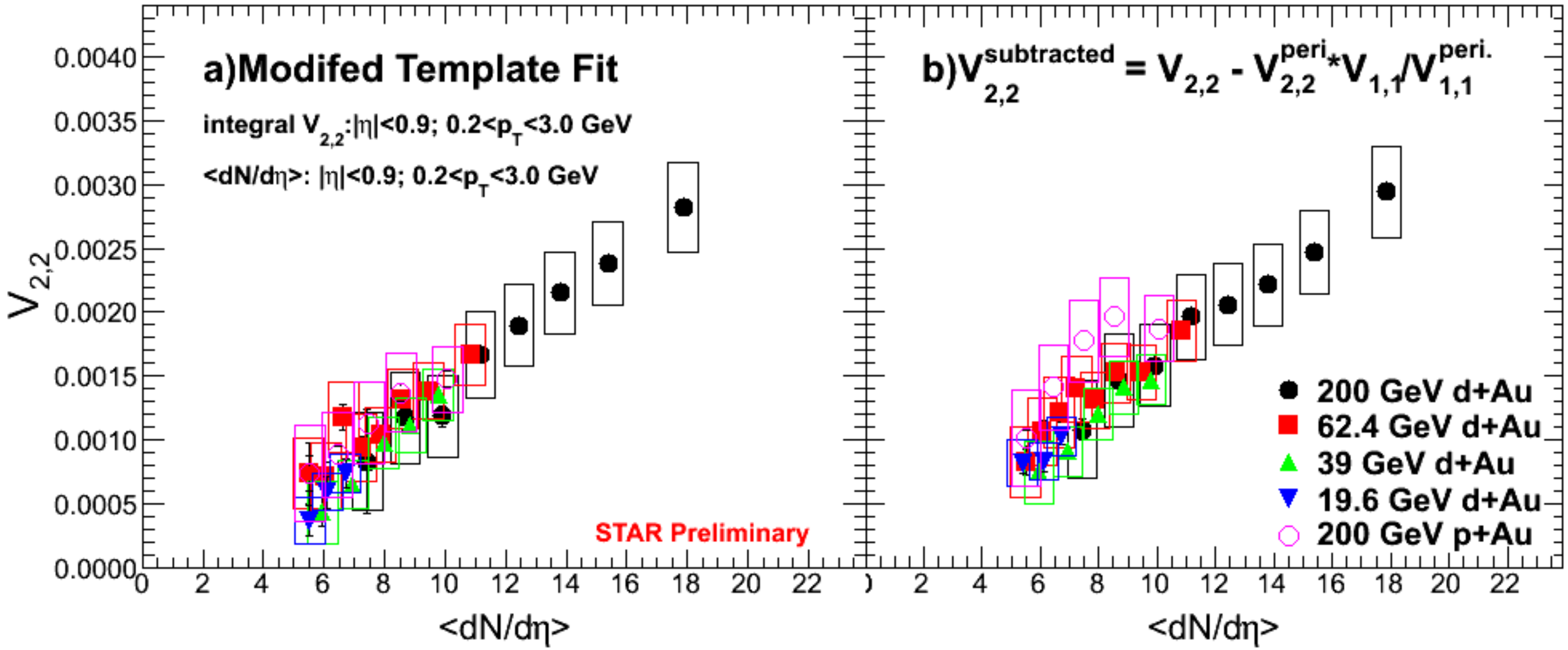
The yield of such part of particles will be $2\pi F Y_{peri.}(0)$

It will give large contribution if G is not much larger than $F Y_{peri.}(0)$

$$Y_{ridge}(\Delta\phi) = G\times(1 + 2\times\sum_{n=2}^{4} V_{n,n}^{templ.}\times\cos(n\Delta\phi)) + F\times Y_{peri.}(0)$$

$$V_{22}^{Modified} = V_{22}^{templ.}\times G/(G + F Y_{peri.}(0))$$

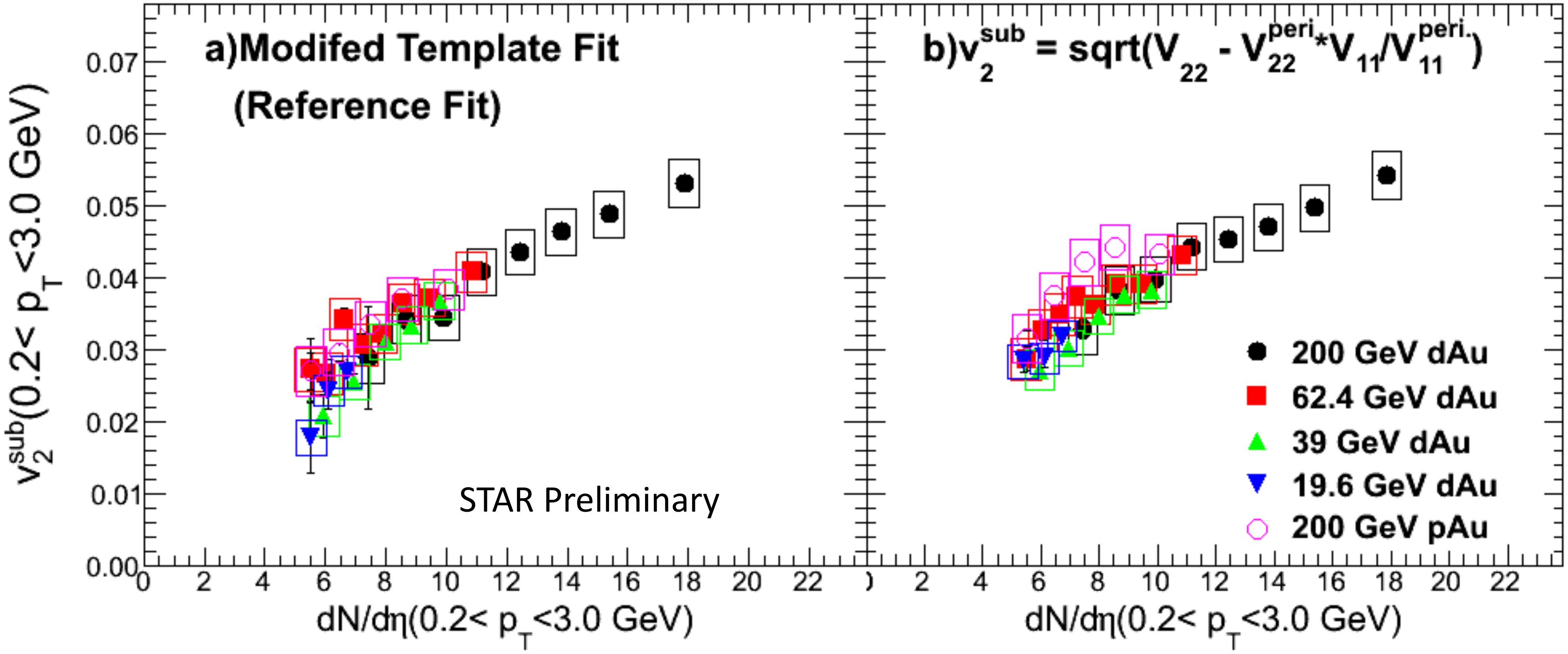
Modified Template Fit



- Using the modified template fit, $V_{2,2}$ shows a universal linear trend as a function of <dN/dη> for different systems and collision energies

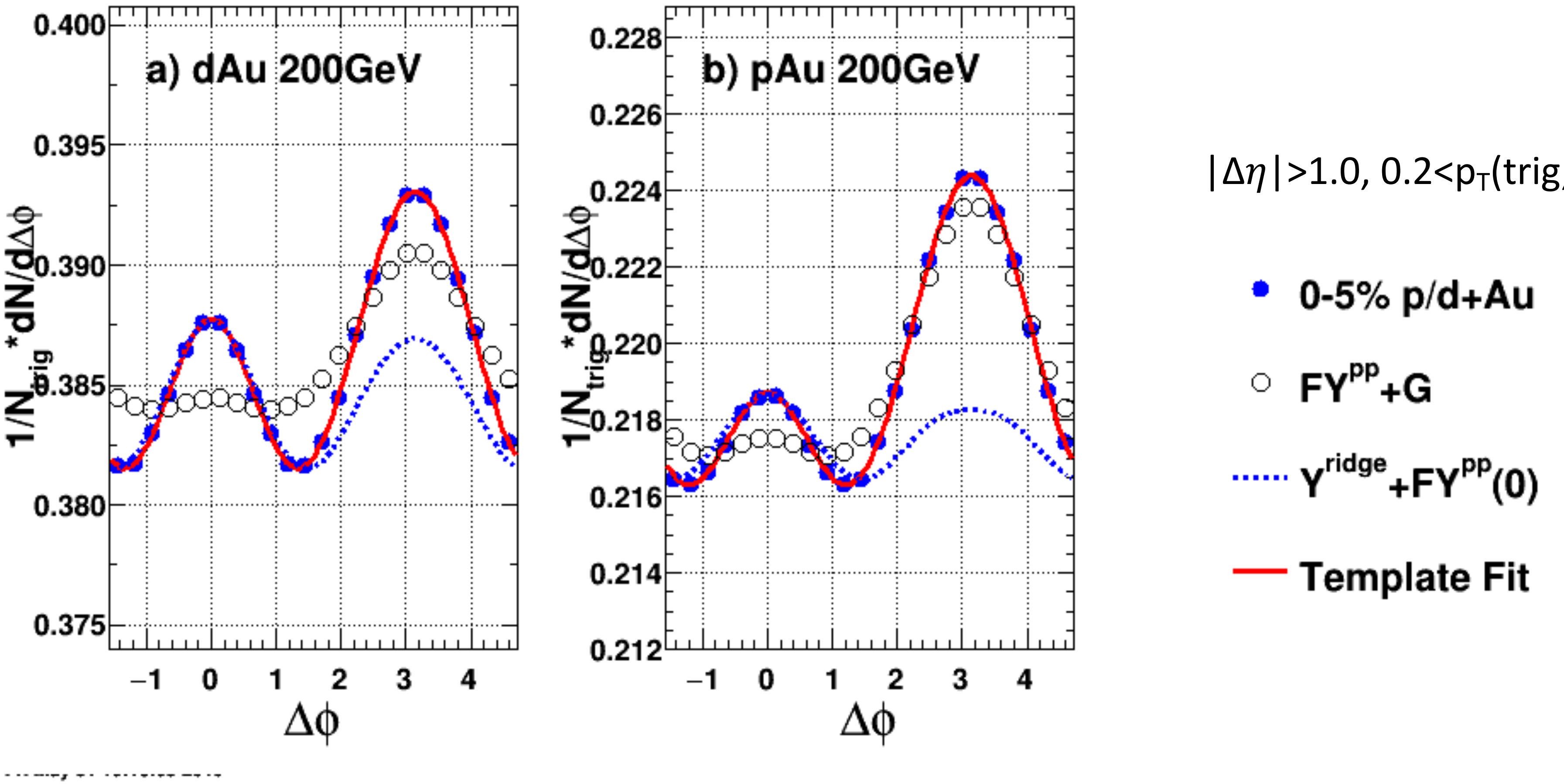
- The results are similar to the $V_{2,2}$ after peripheral subtraction scaled by the $V_{1,1}$

Integral v_2 from modified template fit



- The integral v_2 from two subtraction methods show a universal trend as a function of <dN/dη>

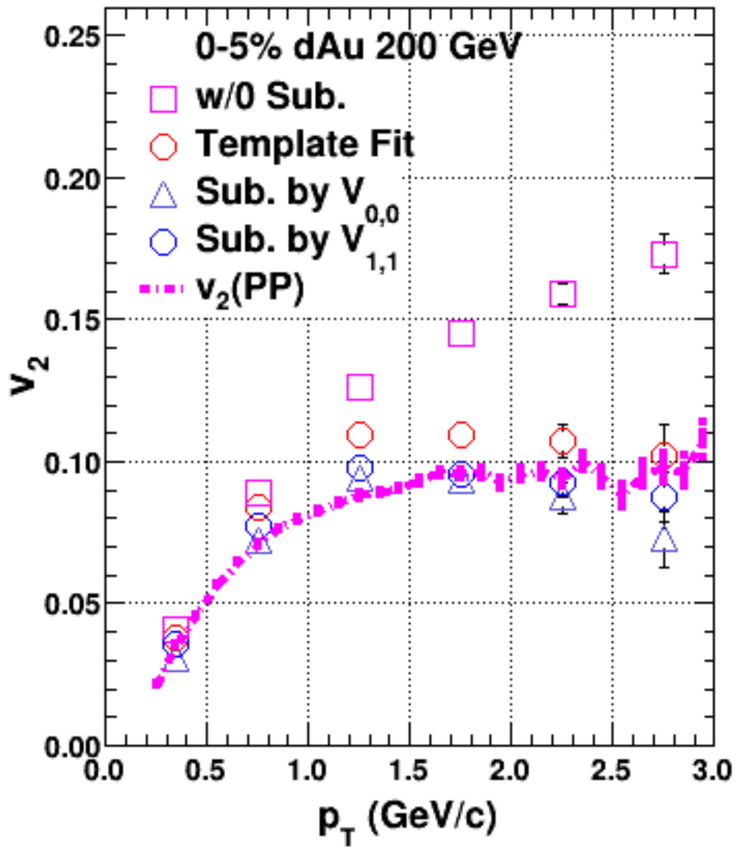
Nonflow subtraction in AMPT

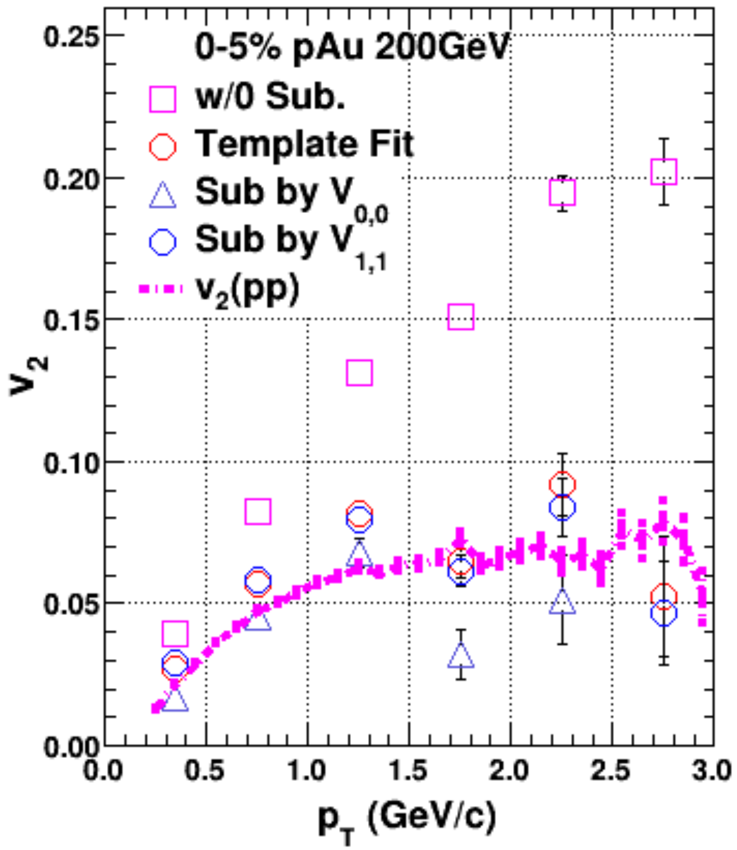


pp as reference, a near side peak is shown even $|\Delta\eta|>1.0$

0-5% centrality is selected with particles $-5.0<\eta<-3.0$

$v_2(p_T)$ in 0-5% pAu, dAu at 200GeV





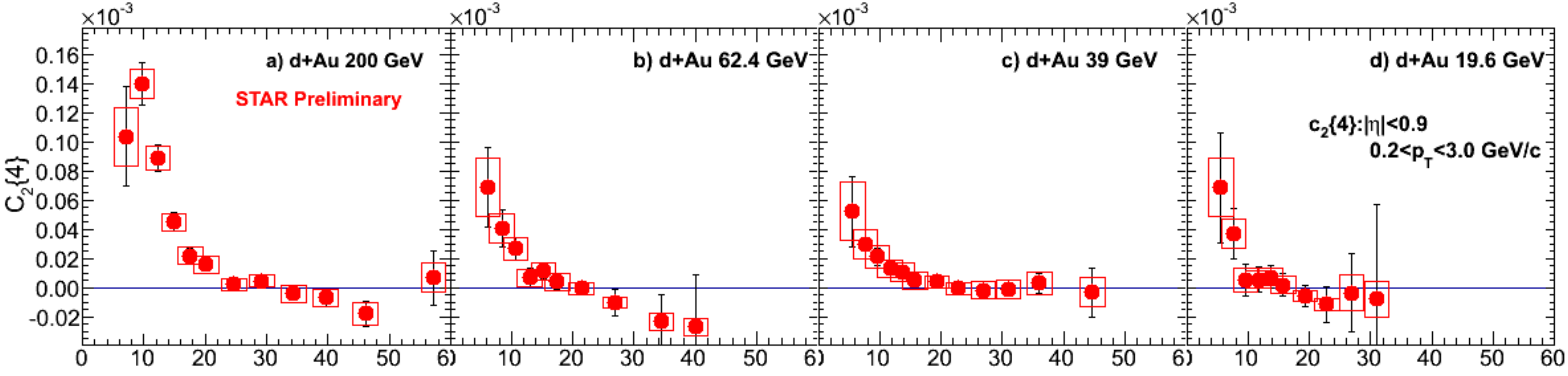
$V_2(pp) = \langle\cos 2(\phi-\psi_{PP})\rangle/F$

$$F=\sqrt{\frac{\langle\cos 2(\psi_{PP}-\psi_{EP,A})\rangle/\langle\cos 2(\psi_{pp}-\psi_{EP,B})\rangle}{\langle\cos 2(\psi_{EP,A}-\psi_{EP,B})\rangle}}$$

ψ_{PP}: participant plane
$\psi_{EP,A}$:event plant from particles $-4.5<\eta<-2.5$
$\psi_{EP,B}$:event plant from particles $0<\eta<2.5$

Results from different subtraction are similar
The subtracted $v_2(p_T)$ have same trend as v_2(PP) as a function of p_T
The subtraction methods works well even with $|\Delta\eta|>1.0$

$c_2\{4\}$ vs. <dN/dη>



Four-Particle Cumulant

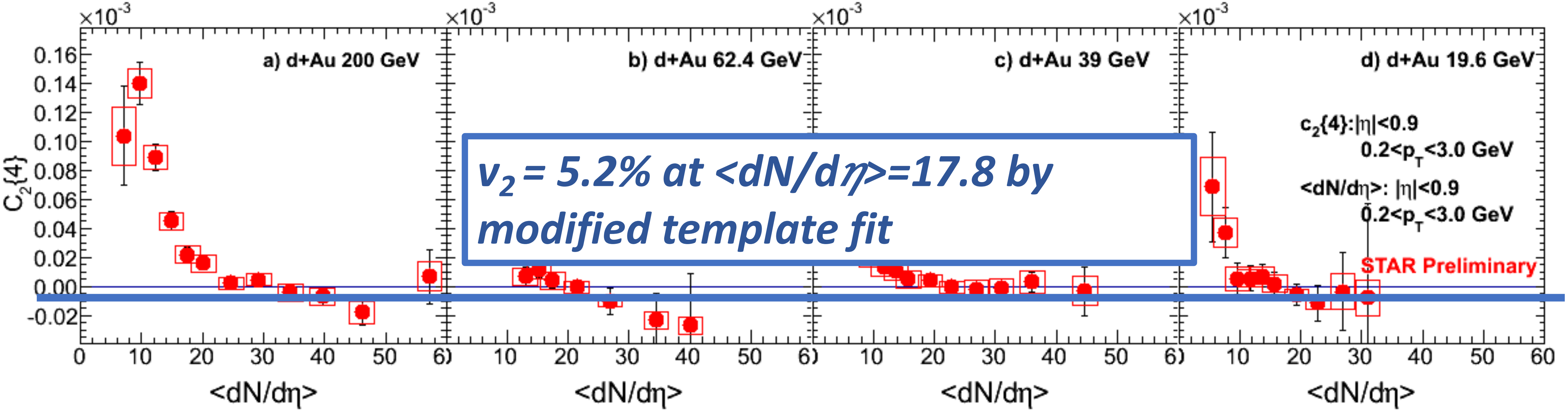
$$c_2\{4\} = \langle\langle e^{-i2(\phi_i+\phi_j-\phi_k-\phi_l)}\rangle\rangle - 2\langle\langle e^{-i2(\phi_i-\phi_j)}\rangle\rangle$$

$\phi_i, \phi_j, \phi_k, \phi_l$ are the azimuthal angles of four different particles in an event ; 《》 represents the average over all particles from all events within a given multiplicity range

$$v_2\{4\} = \sqrt[4]{-c_2\{4\}}$$

An indication that $c_2\{4\}$ is negative for high multiplicity d+Au collisions at 200 and 62.4 GeV, while the statistical uncertainties are large

$c_2\{4\}$ vs $<dN/d\eta>$



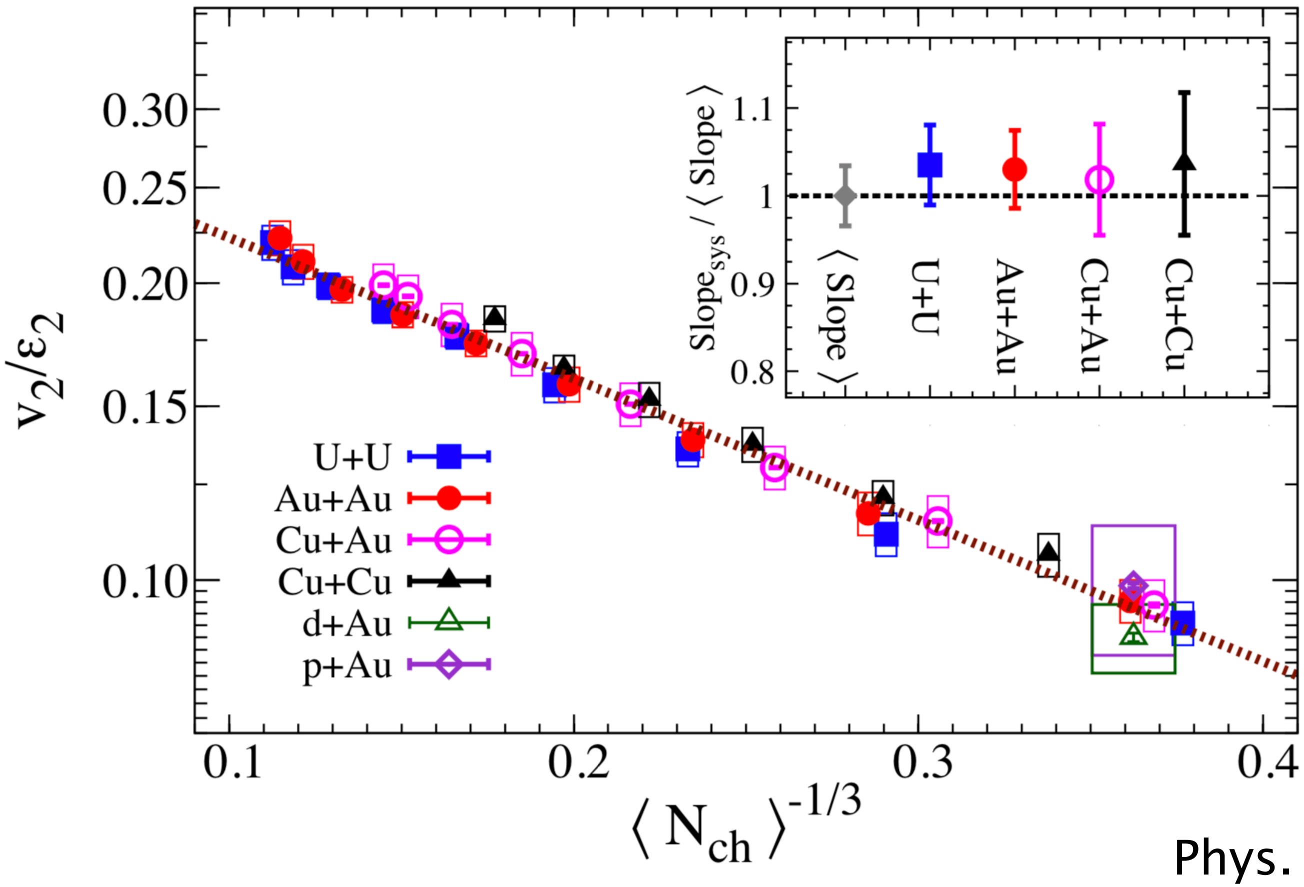
$$c_2\{4\} = \langle\langle e^{-i2(\phi_i+\phi_j-\phi_k-\phi_l)}\rangle\rangle - 2\langle\langle e^{-i2(\phi_i-\phi_j)}\rangle\rangle$$

$\phi_i, \phi_j, \phi_k, \phi_l$ are the azimuthal angles of four different particles in an event ; 《》 represents the average over all particles from all events within a given multiplicity range

$$v_2\{4\} = \sqrt[1/4]{-c_2\{4\}}$$

An indication that $c_2\{4\}$ is negative for high multiplicity in d+Au collisions at 200 and 62.4 GeV

From large to small system



Phys. Rev. Lett. **122** (2019) 172301

A universal scaling from large to small system. Driven by same physics?

Summary

We see similar v_2 between p/d+Au collisions for same multiplicity.

- ✓ v_2 is not only driven by initial geometry

The integral v_2 extracted by template fit shows a universal trend as a function of <dN/dη> for different small systems at different energies. v_2 in large and small systems follow an universal trend

- ✓ Multiplicity plays an important role for the flow in small systems!

$c_2\{4\}$ is negative at high multiplicity at 62.4 and 200 GeV, but the measurements are limited by statistics.

Comparison of v_2 between two and four particles correlation, and testing of nonflow subtraction in AMPT, both indicate that nonflow is well controlled in STAR