BES Scan in Small System

Shengli Huang
Stony Brook University

Outline

1. Motivation

2. The Results from Geometry Scan:

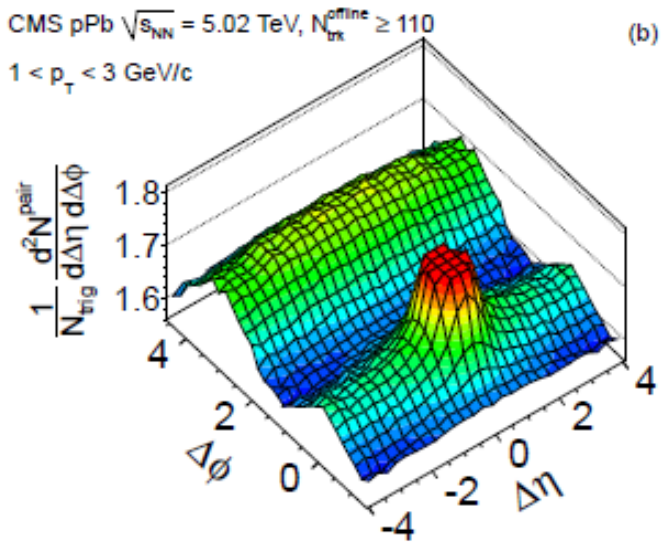
1) V_n in p/d/^{3}He+Au collisions
2) Four particles cumulant results
3) Identified particle v_2

3. The Results from Energy Scan

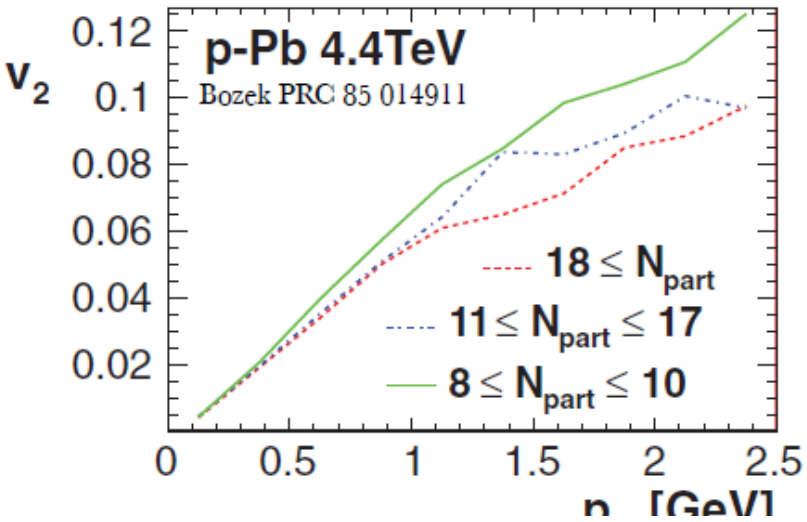
1) The v_2(EP) in d+Au collisions at 19.6, 39, 62.4 and 200 GeV
2) The v_2 as a function of η vs collision energy
3) $v_2(4)$ vs collision energy

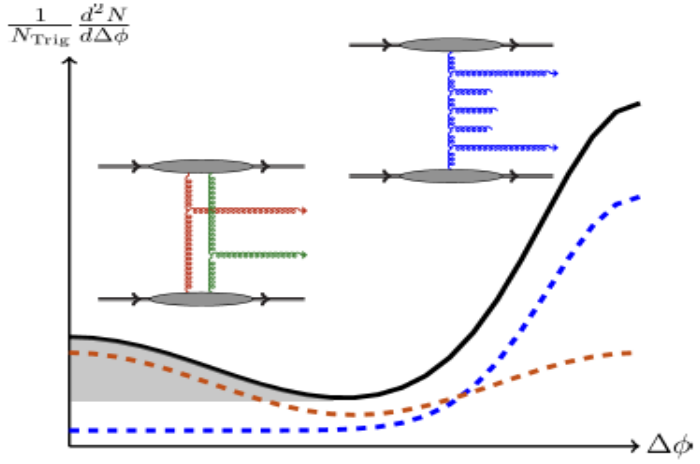
4. Summary

What is the origin of the ridge in small system?



CMS: Phys. Lett. B 7198(2013)

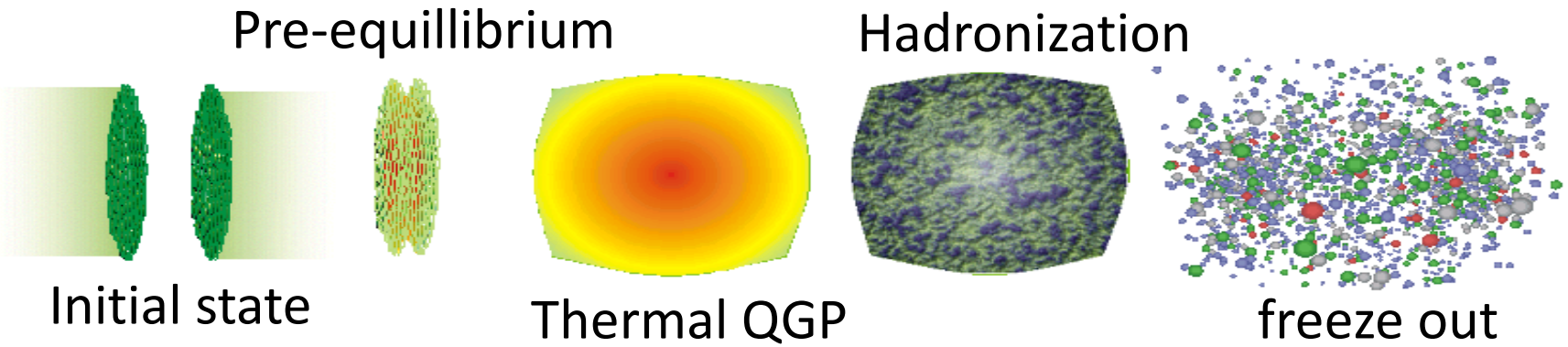




Dusling & Venugopalan 1211.3701, 1302.7018

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

What can we learn from the small QGP drop?

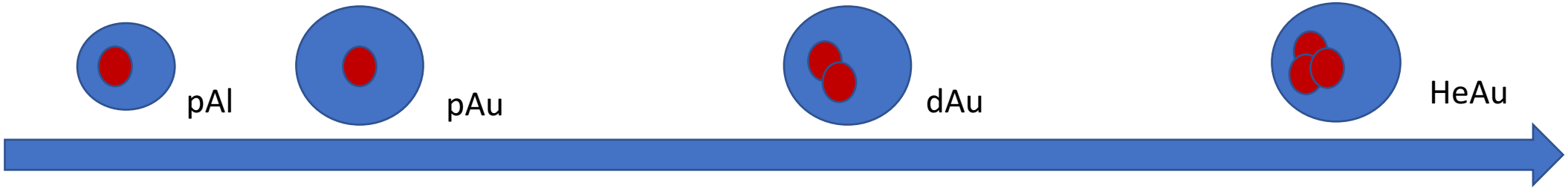


1. What is the effect of initial geometry and its fluctuation?

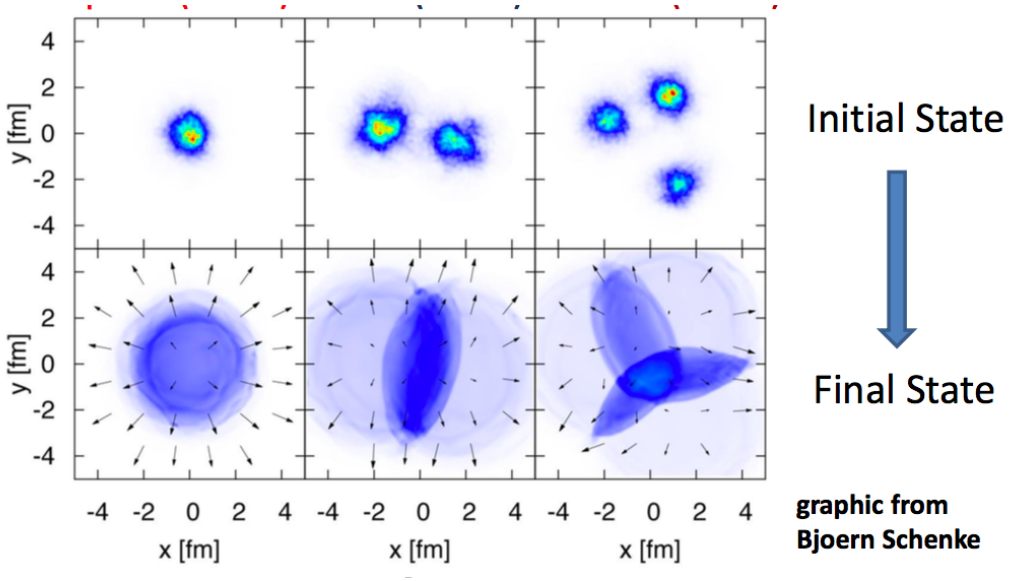
2. What is the contribution from pre-equilibrium and hadronic stages?

3. How small can the QGP drop be?

Small system program at RHIC



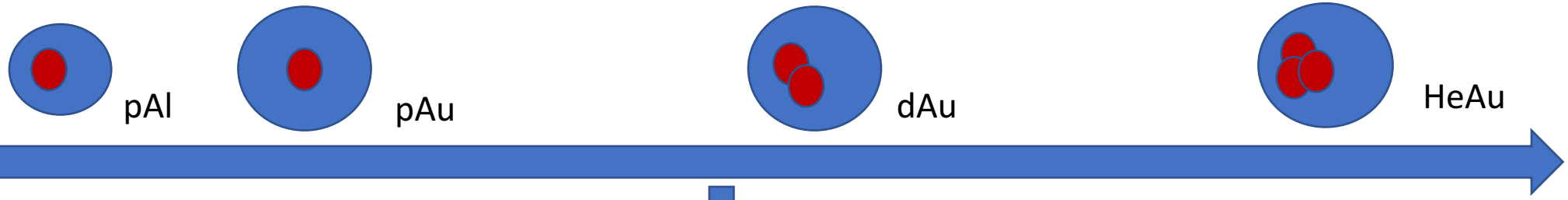
Geometry Scan



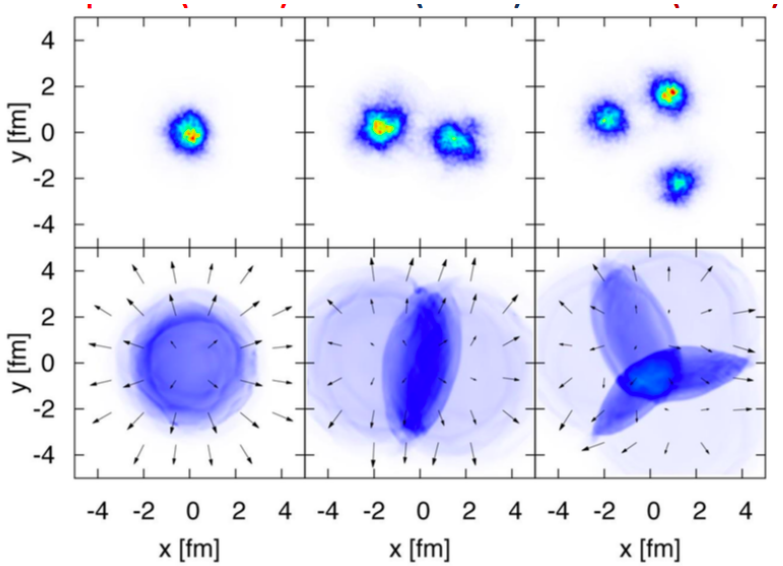
graphic from Bjoern Schenke

	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

Small system program at RHIC



Geometry Scan



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	0-5% p+Au	0-5% d+Au	0-5% He+Au
ε_2	0.23	0.54	0.50
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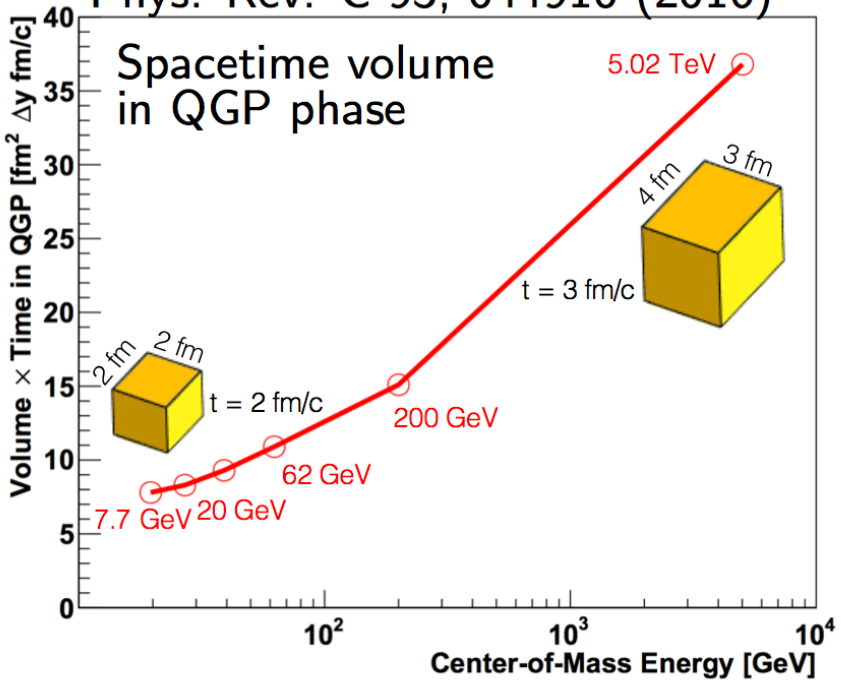
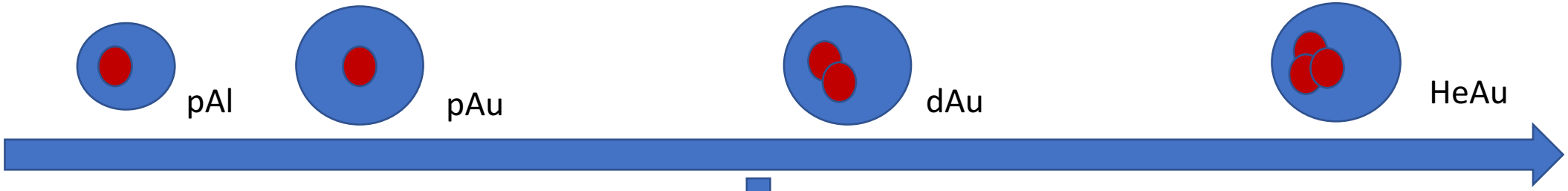
Energy Scan

- **dAu 200GeV**
- **dAu 39GeV**
- **dAu 62.4GeV**
- **dAu 19.6GeV**

J.D. Orjuela Koop et al
Phys. Rev. C 93, 044910 (2016)



Small system program at RHIC



Geometry Scan

PHENIX

	MB Event	Cental Events
p+Au	0.8 B	1.4 B
He+Au	600 M	400 M

d+Au collision energy	total events analyzed	central events analyzed
200 GeV	636 million	585 million
62.4 GeV	131 million	76 million
39 GeV	137 million	49 million
19.6 GeV	15 million	3 million

Energy Scan

dAu 200GeV

dAu 39GeV

dAu 62.4GeV

dAu 19.6GeV

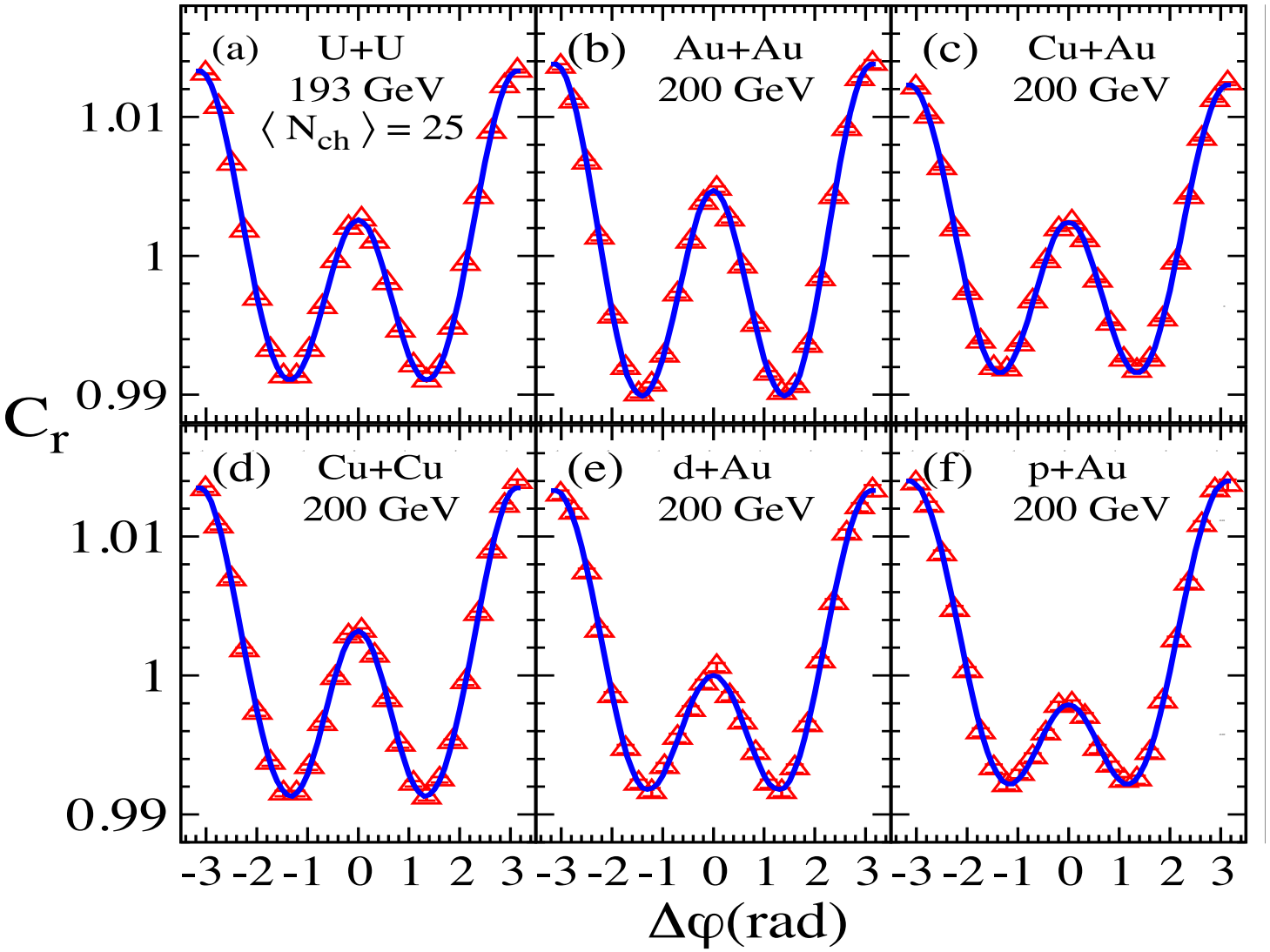
STAR

	MB Events
p+Au	400 M
He+Au	300 M

d+Au	Total Events
200 GeV	280 M
62.4 GeV	200 M
39 GeV	383 M
19.6 GeV	50 M

I. The Geometry Scan

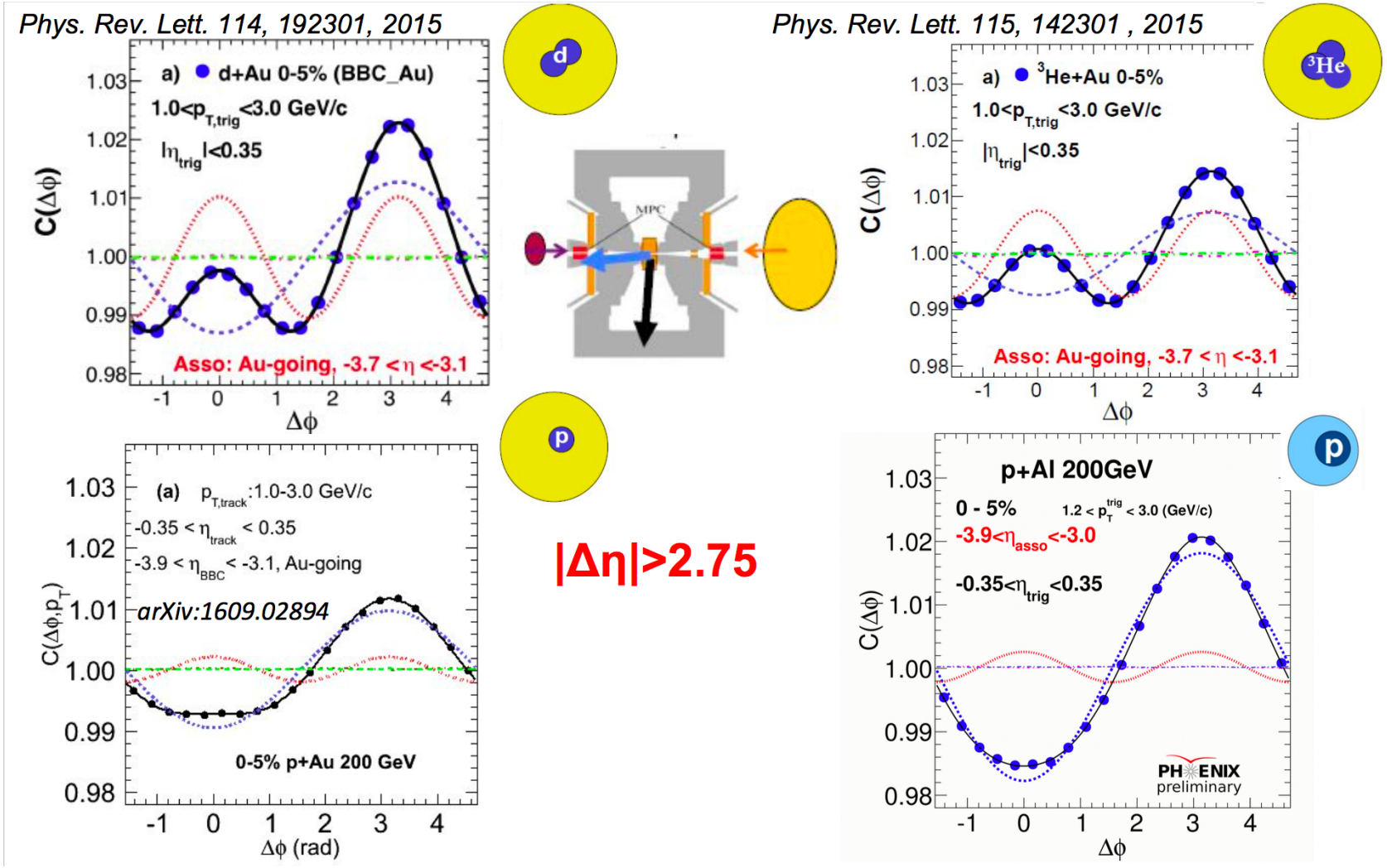
Ridge from large to small system(STAR)



$|\Delta\eta|>0.7$, $0.2< p_T< 4.0$ GeV

At a fixed <Nch>=25, the ridge is observed from large(UU, AuAu …) to small system(dAu, pAu)

Ridge in small systems (PHENIX)

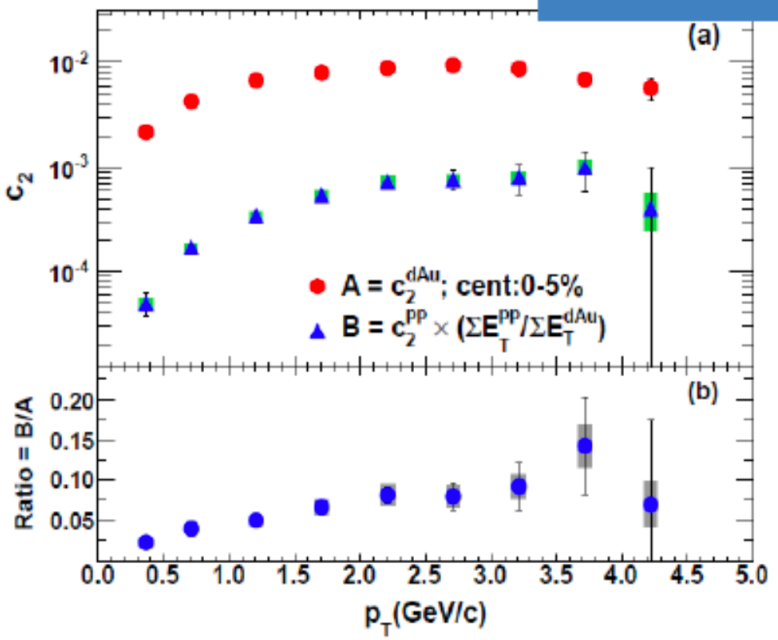


The near side long-range angular correlation("ridge") is observed in small system for high multiplicity d/^{3}He+Au collisions

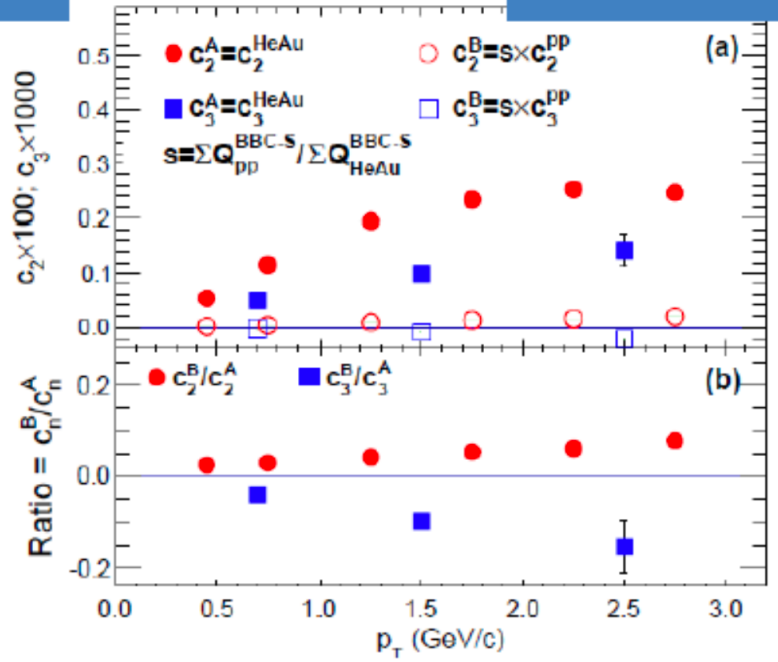
Non-flow estimation in PHENIX

Phys. Rev. Lett. 114, 192301

Central d+Au



PHENIX ^{3}HeAu and Central ^{3}He+Au



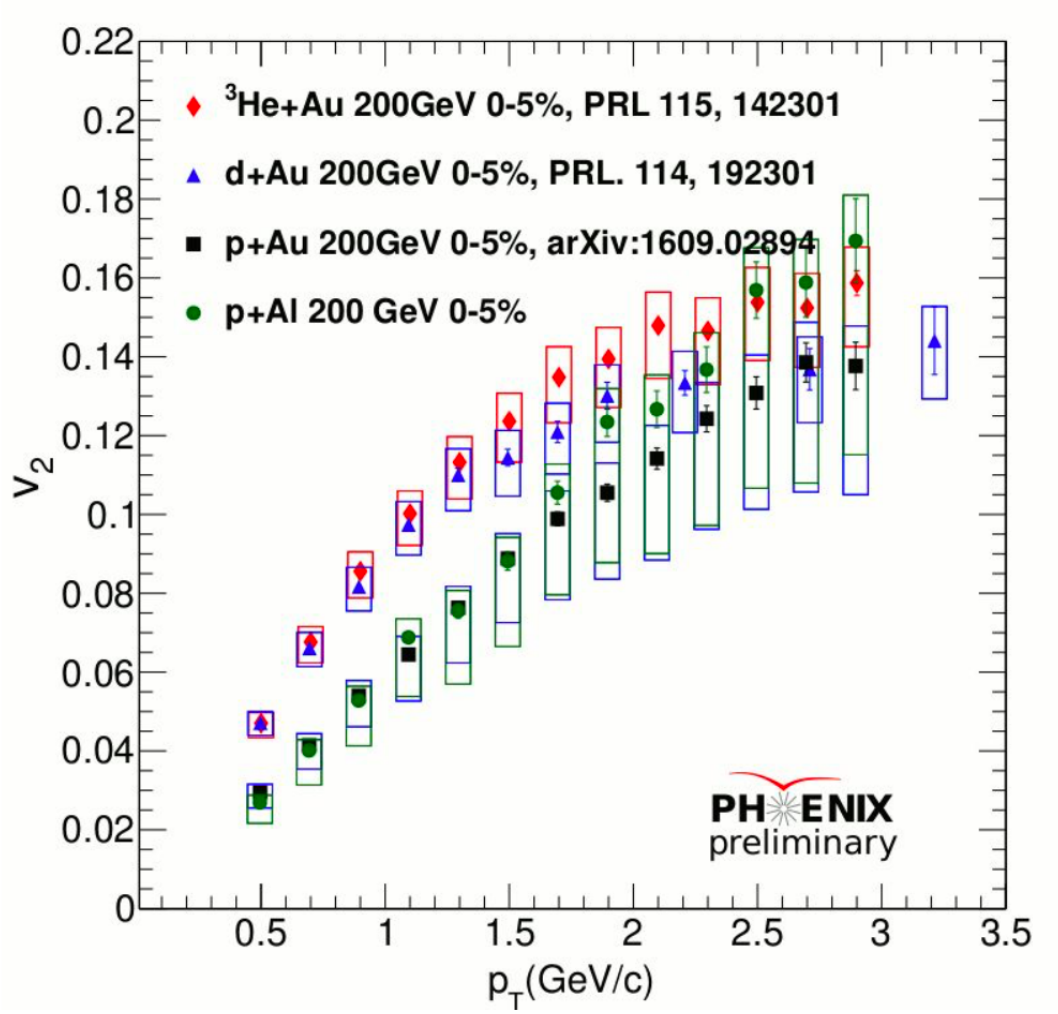
Phys. Rev. Lett. 115, 142301

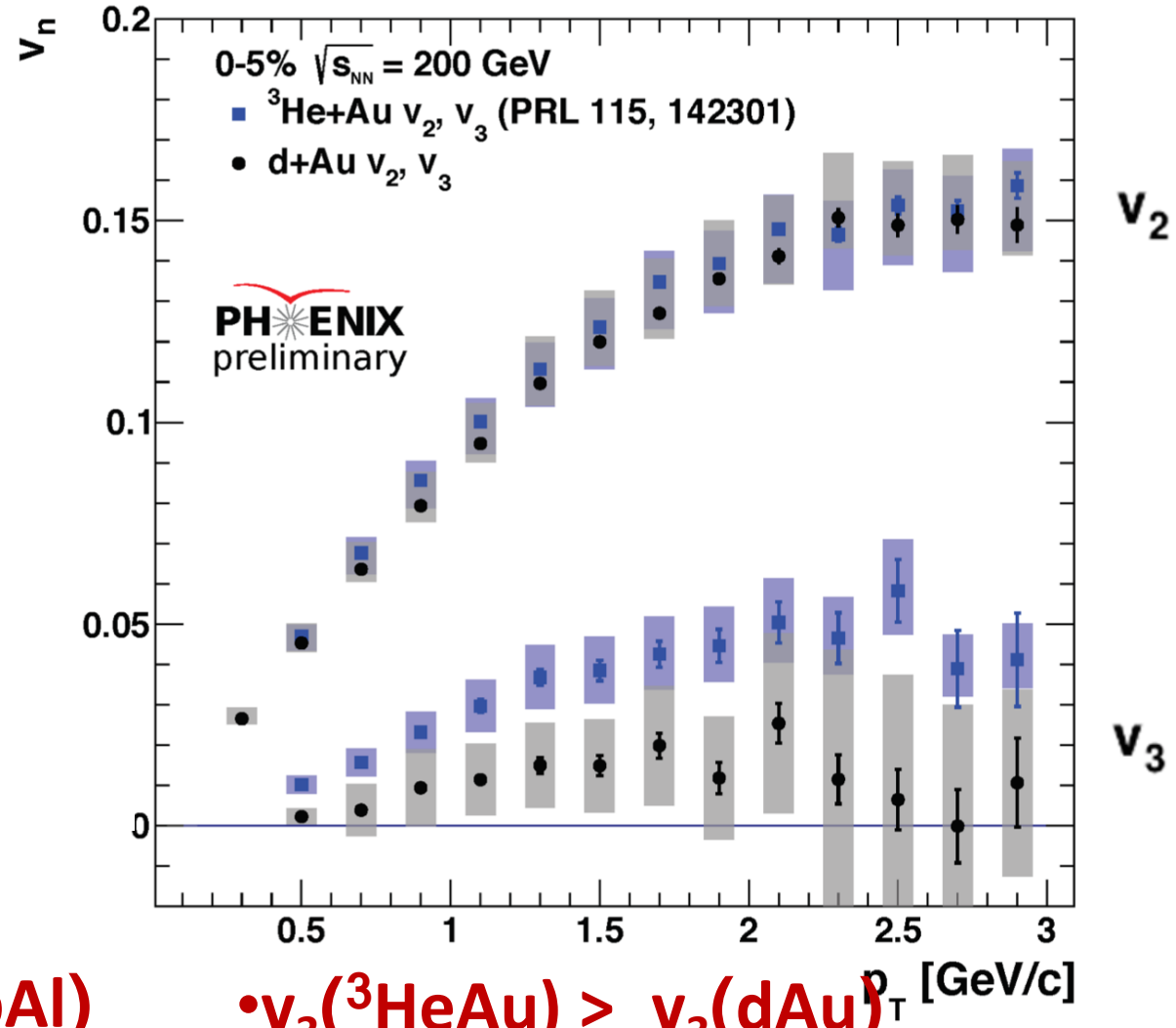
$$c_2^{dAu}(p_T) = c_2^{\text{Non-elem.}}(p_T) + c_2^{\text{Elem.}}(p_T)$$
$$\approx c_2^{\text{Non-elem.}}(p_T) + c_2^{pp}(p_T)\frac{\Sigma E_T^{pp}}{\Sigma E_T^{dAu}}$$

For c_2, the non-flow contribution estimated using p+p correlation is <10% in 0-5% d/^{3}He+Au collisions

In 0-5% ^{3}He+Au collisions, the non-flow contribution is <15% for c_3

Vn in small systems

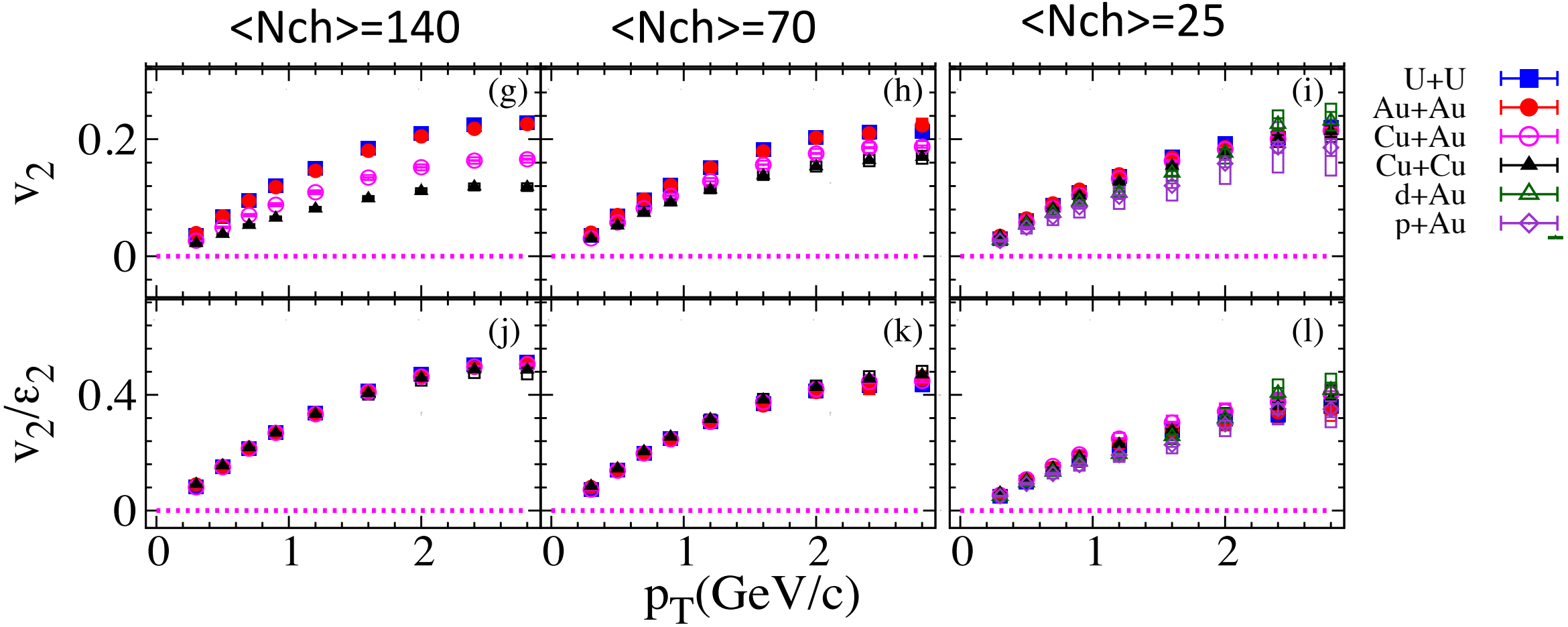




- $v_2(^3HeAu) \sim v_2(dAu) > v_2(pAu) \sim v_2(pAl)$
- $v_3(^3HeAu) > v_3(dAu)$

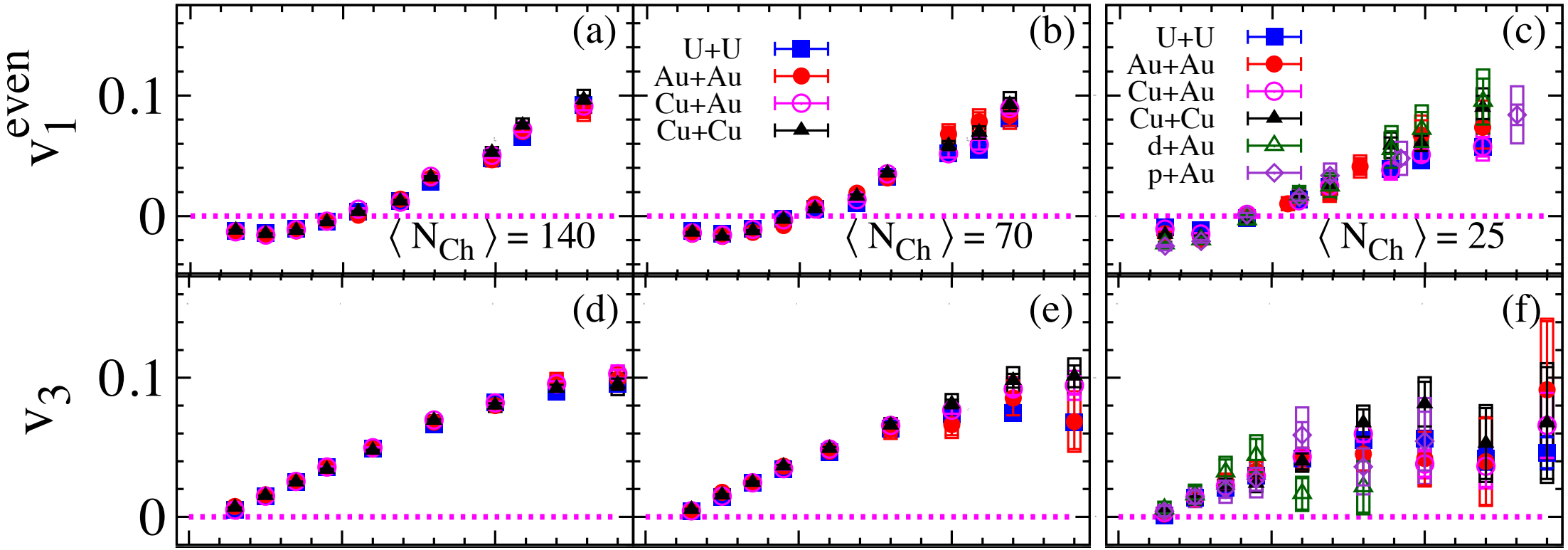
Initial geometry plays a role; Important to rule out the multiplicity difference

v_2 for a fixed <Nch>



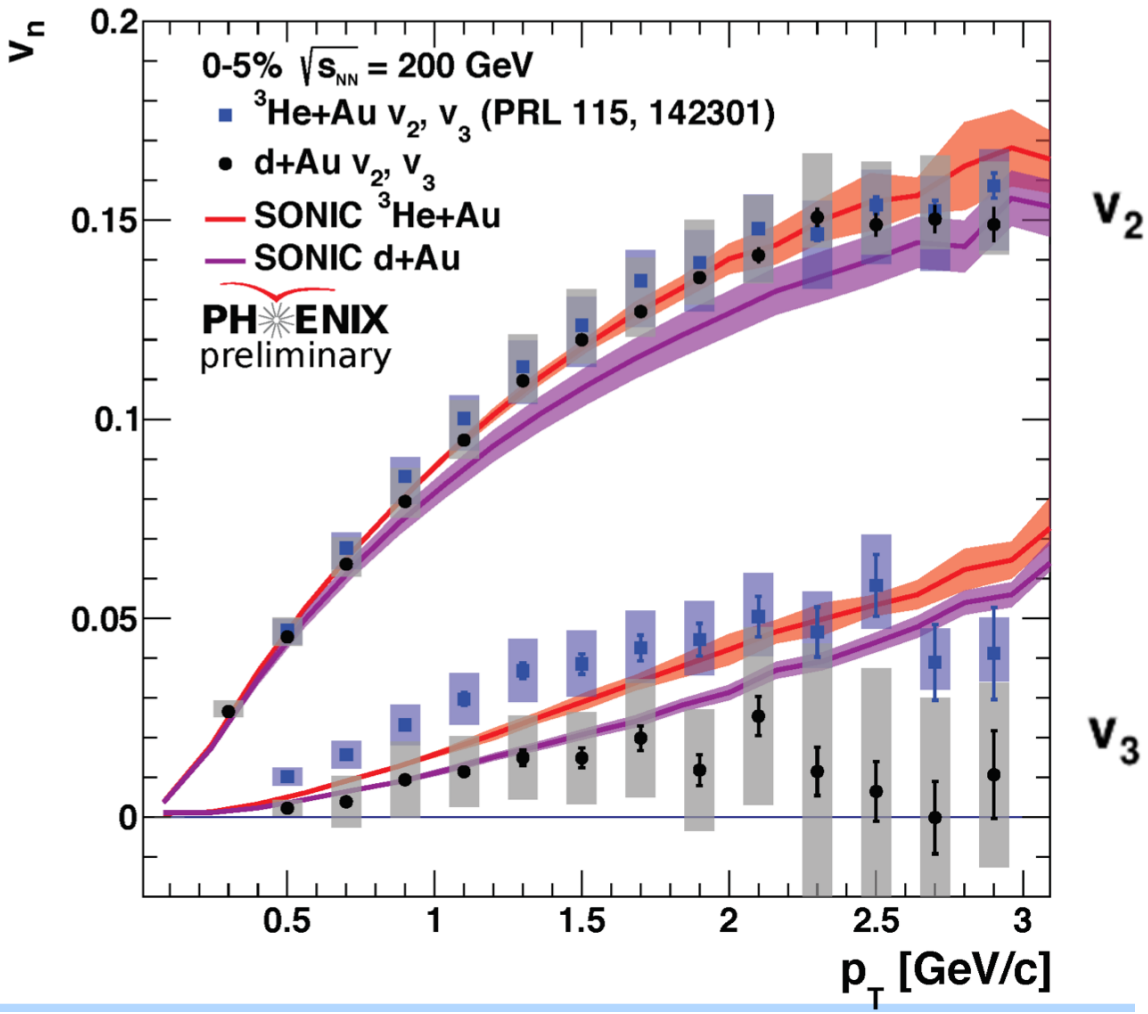
For a fixed <Nch>, the v_2/ε_2 are similar for different systems

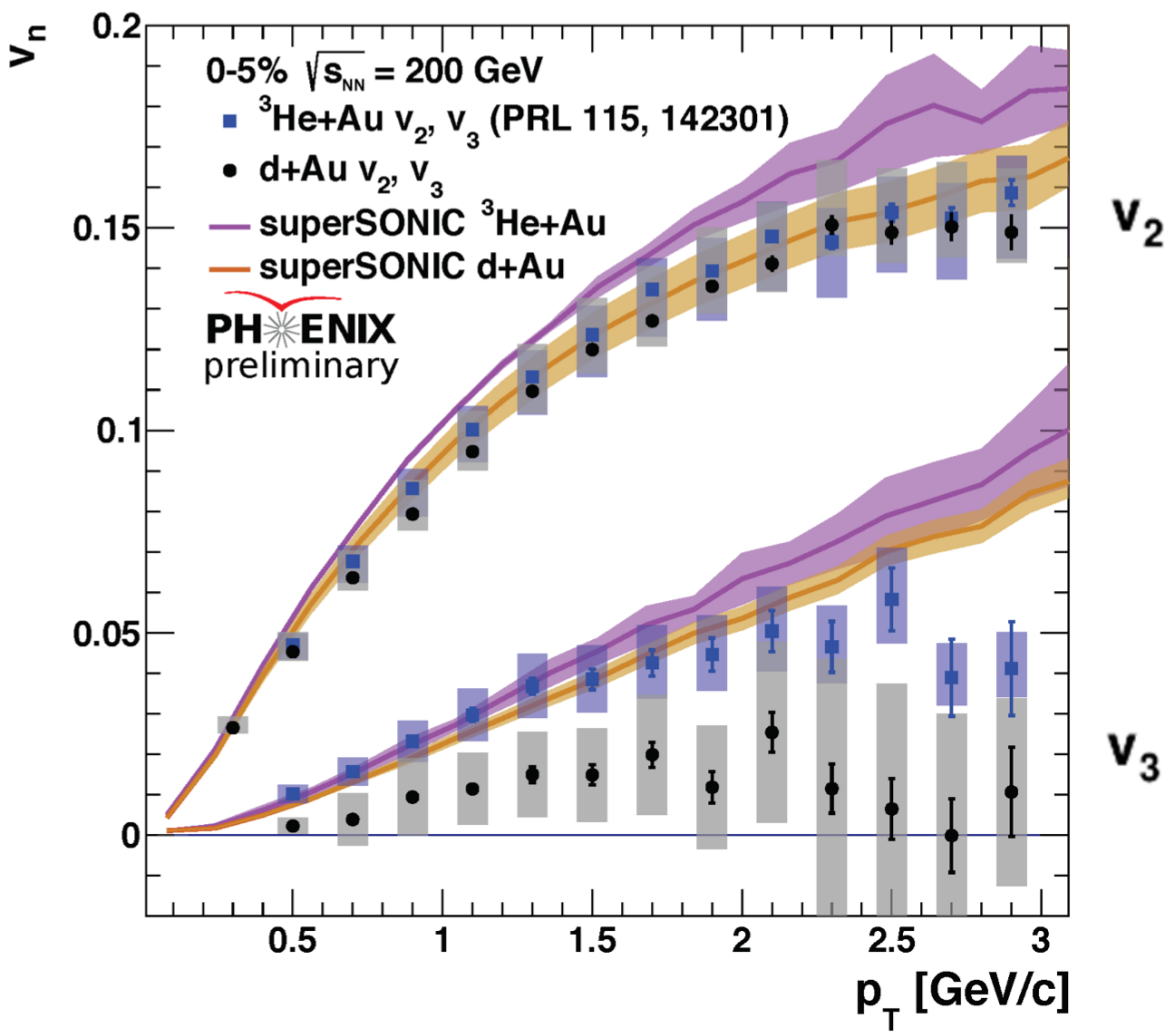
V_1 and v_3 for a fixed <Nch>



For a fixed <Nch>, the v_1 even and v_3 are also similar for different systems since the ε_3 is proportional to the <Nch>

Comparing with (super)SONIC

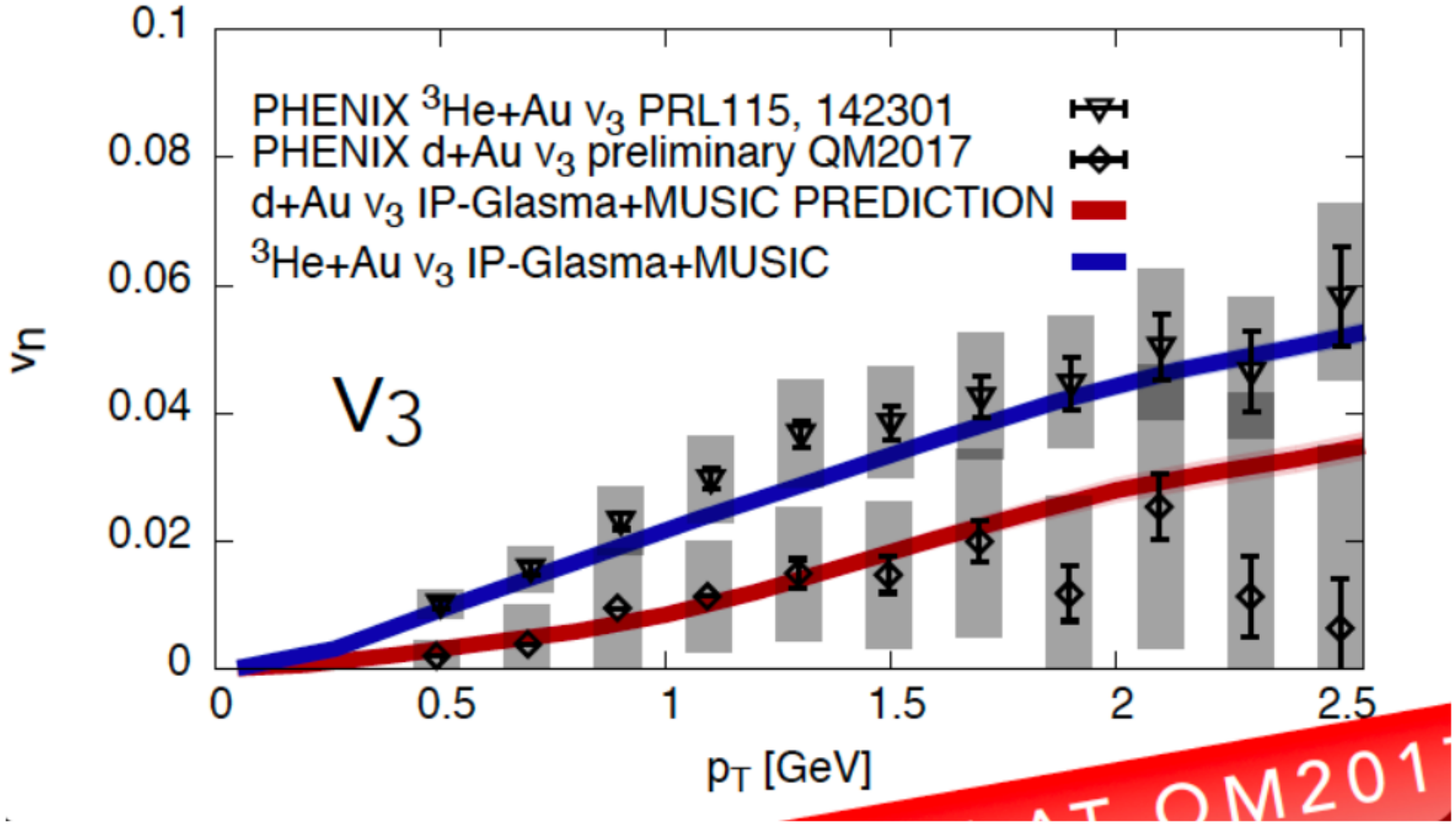




Hydro without preflow(SONIC) under estimates the v_3 in He+Au

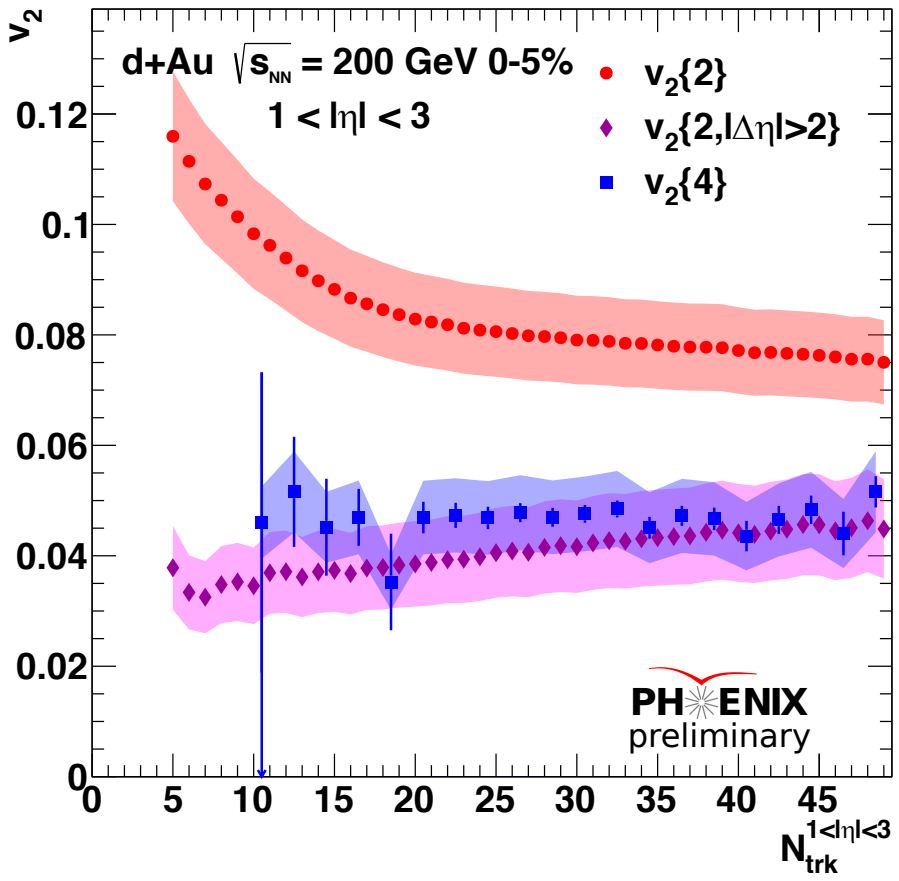
Hydro with preflow(super SONIC) over estimates v_3 in d+Au

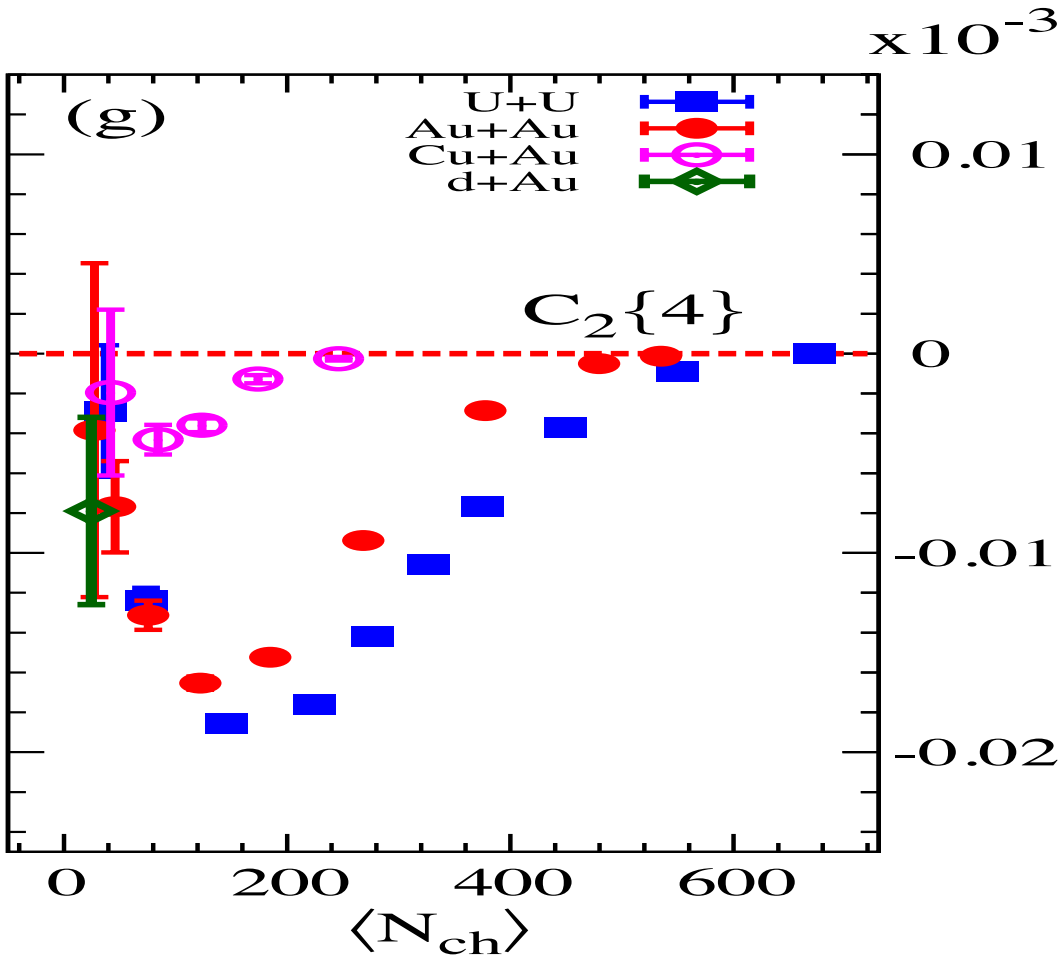
IP-GLASMA+MUSIC



State-to-art calculation from IP-Glasma+Music can describe v_3 for both d+Au and ^{3}He+Au collisions

Cumulant Method

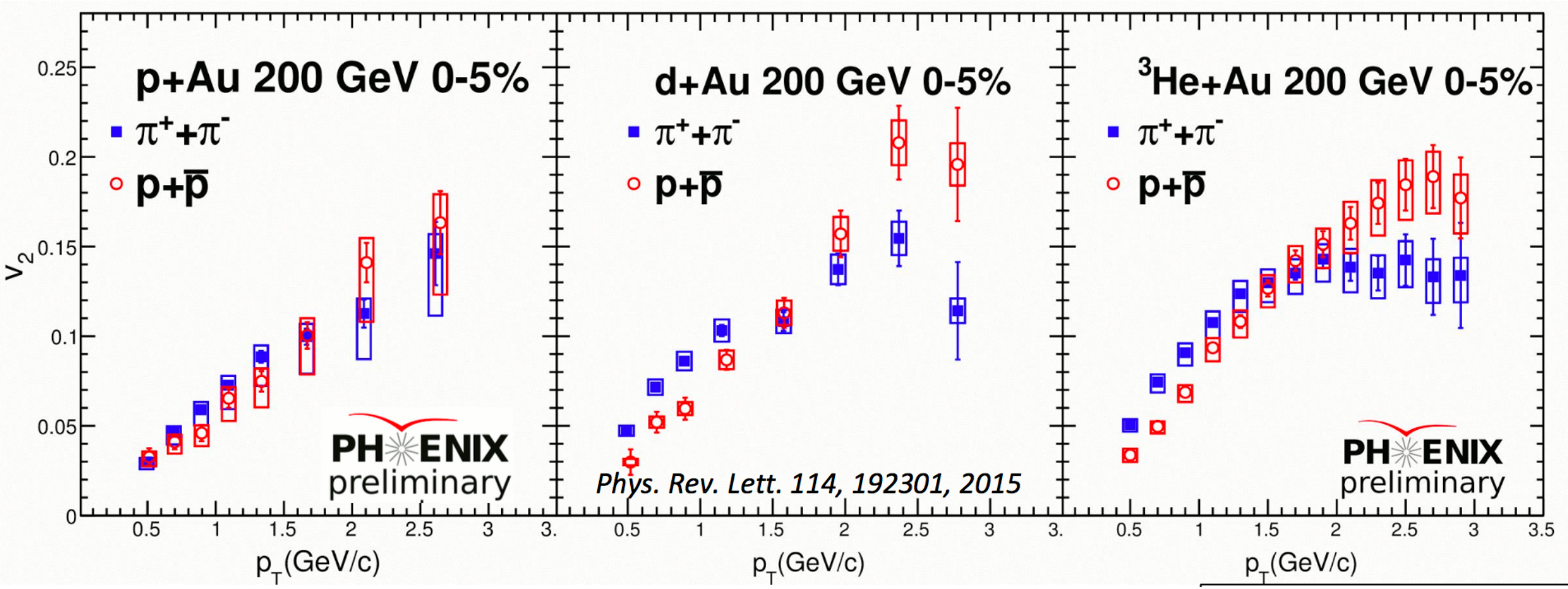




PHENIX and STAR both observe the second order flow by four particles cumulant method

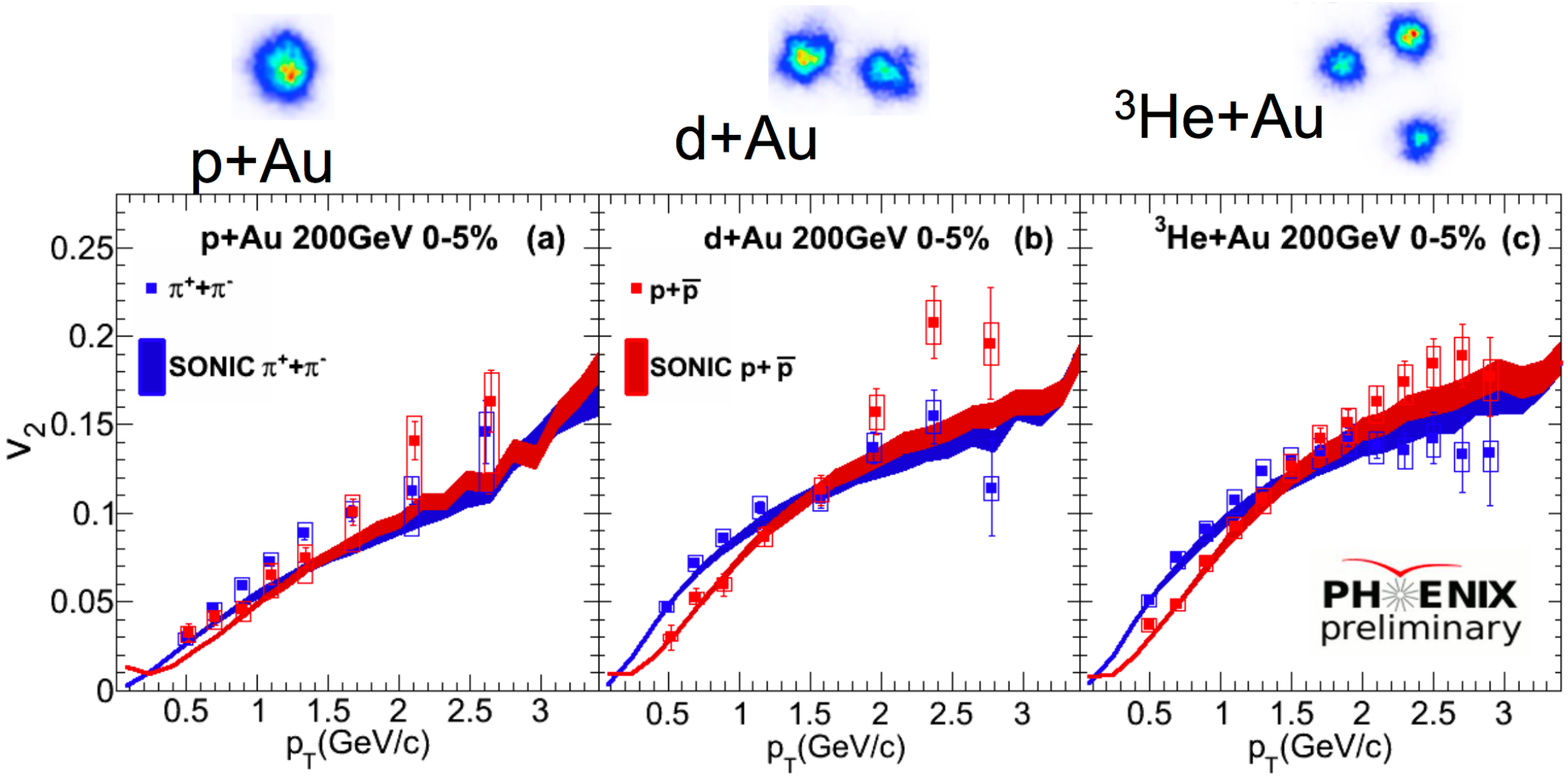
It strongly indicates a collective behavior in small system

Identified particles v_2



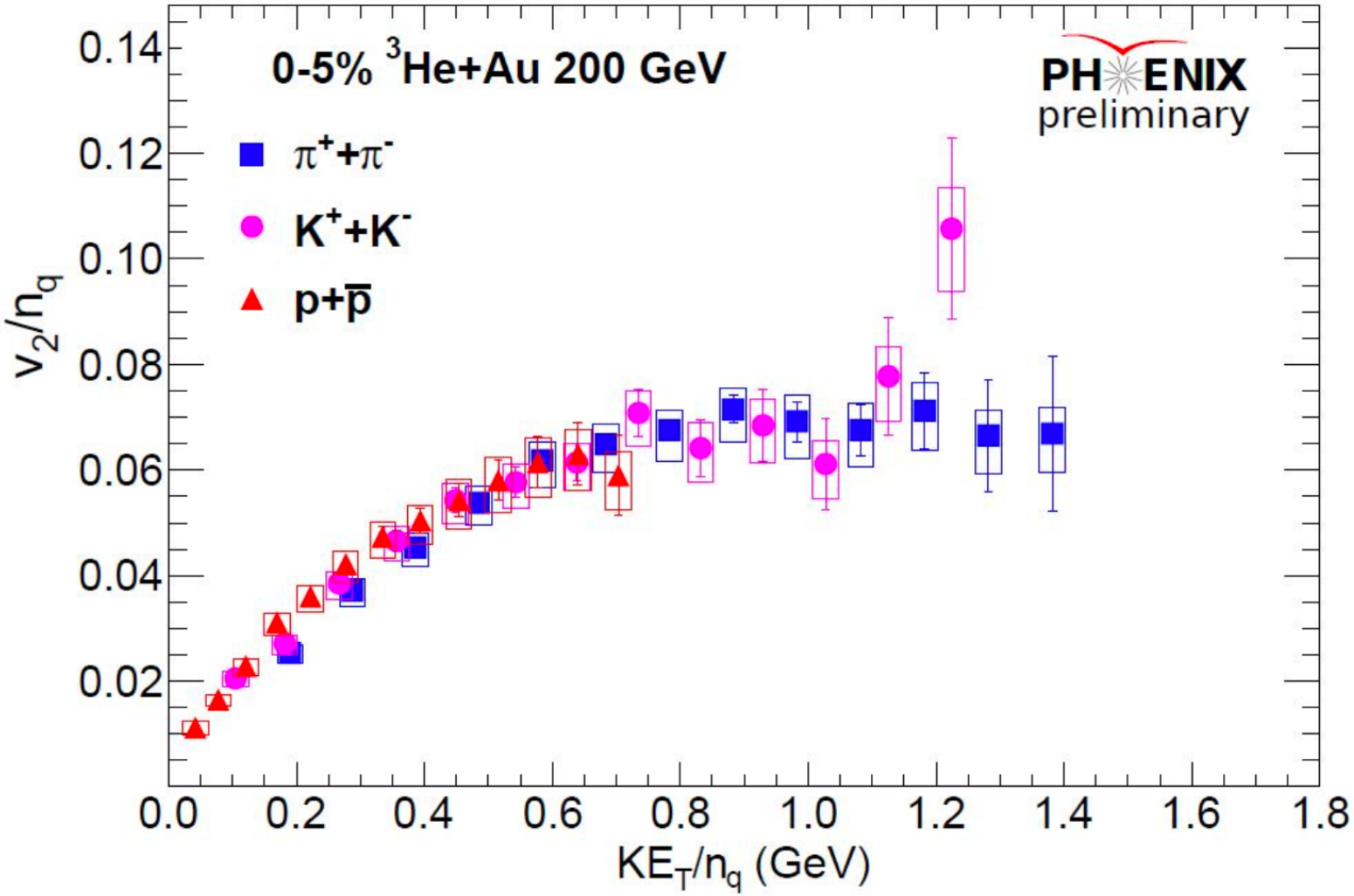
- A clear mass ordering is seen in d/^{3}He+Au collision while not in p+Au
- A stronger radial flow in d/^{3}He+Au?

Comparison with Hydro.



- Smaller split at p+Au is predicted which implies smaller radial push

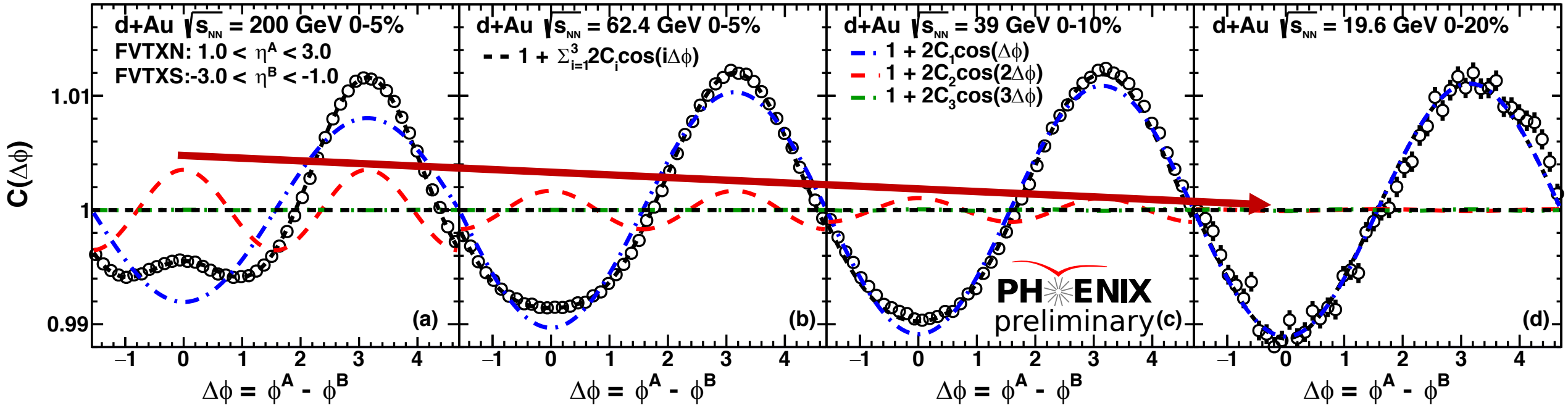
NCQ scaling in ^{3}He+Au



The familiar behavior of number of quark scaling observed in Au+Au collisions is also seen in the small ^{3}He+Au system

II. The Energy Scan

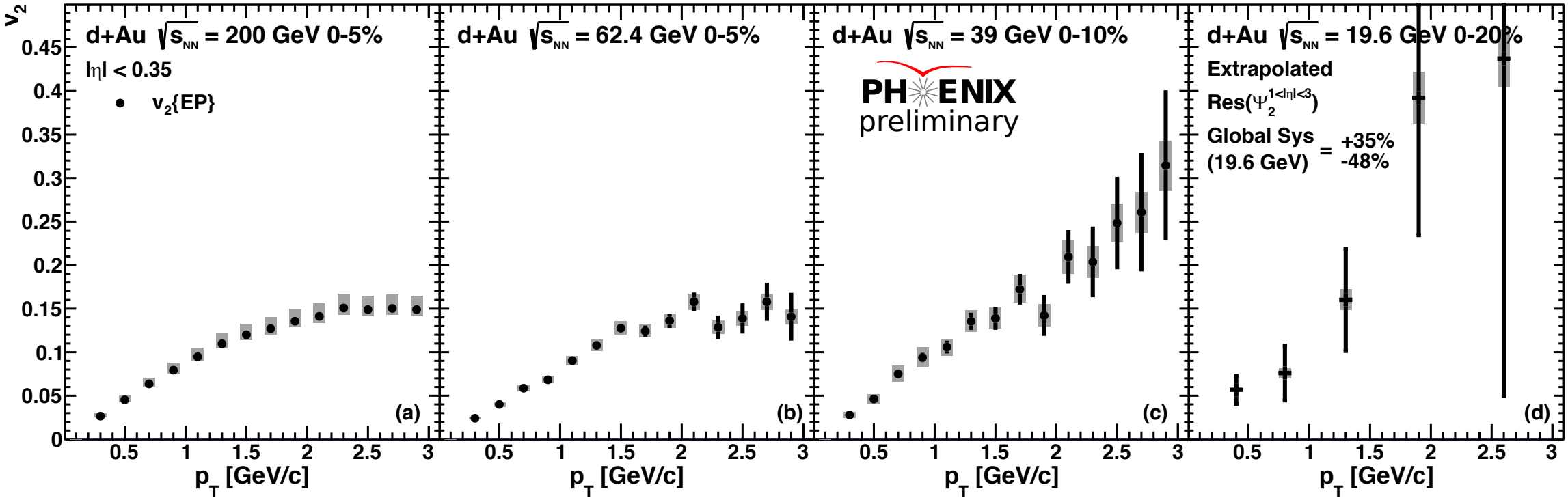
Long-range correlation vs. collision energy



The ridge is more clear in d+Au collisions at top energy

The c_2 component decreases from 200 GeV to 19.6 GeV

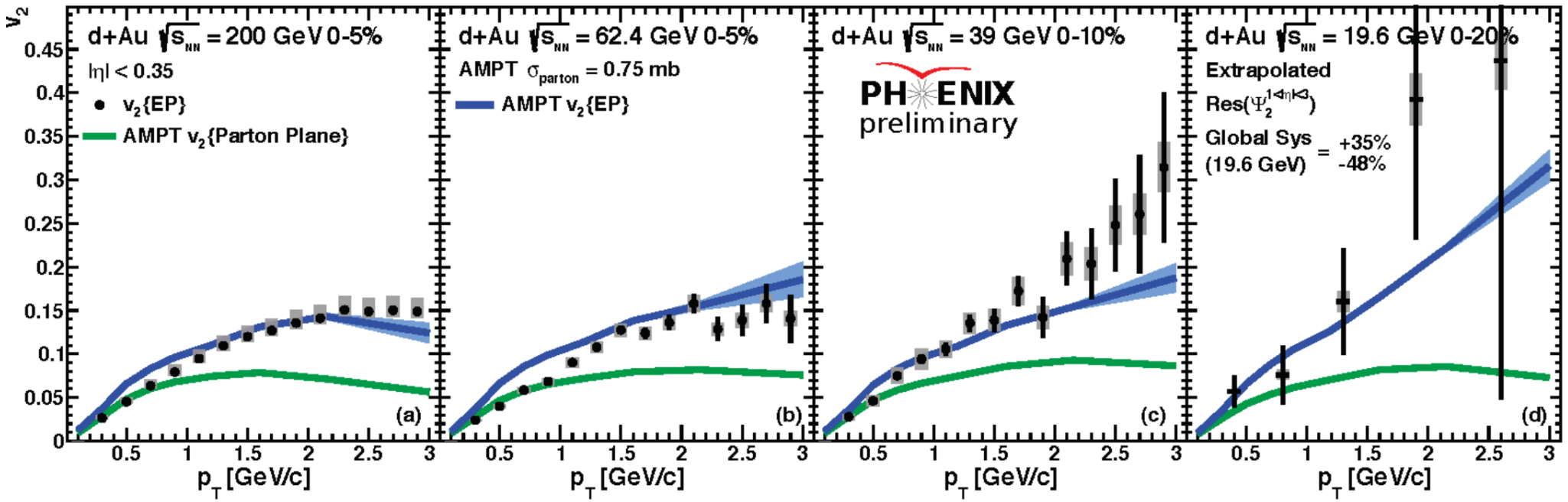
V_2(EP) vs collision energy in d+Au

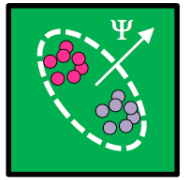


1. The v_2(EP) in 62.4 and 200 GeV dAu collisions are pretty similar
2. At lower collision energies, the v_2 increases at high p_T which may be due to the larger nonflow

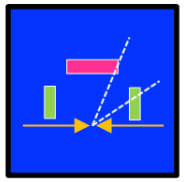
Comparison with AMPT

200 GeV **62 GeV** **39 GeV** **20 GeV**





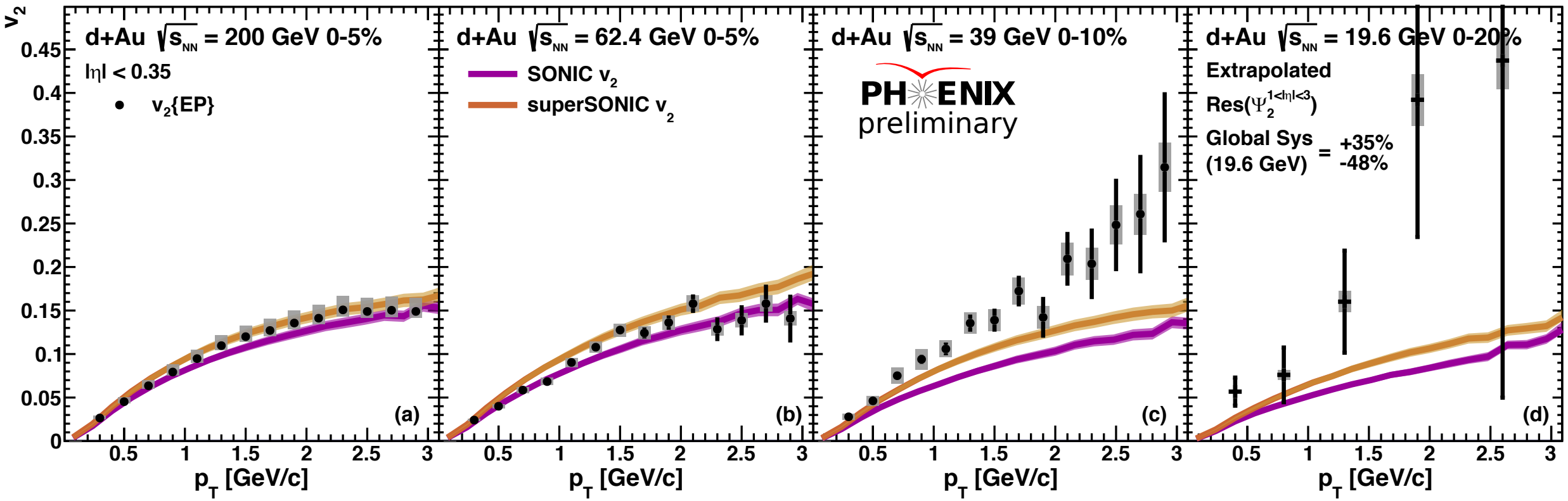
Pure Flow



With Non-Flow

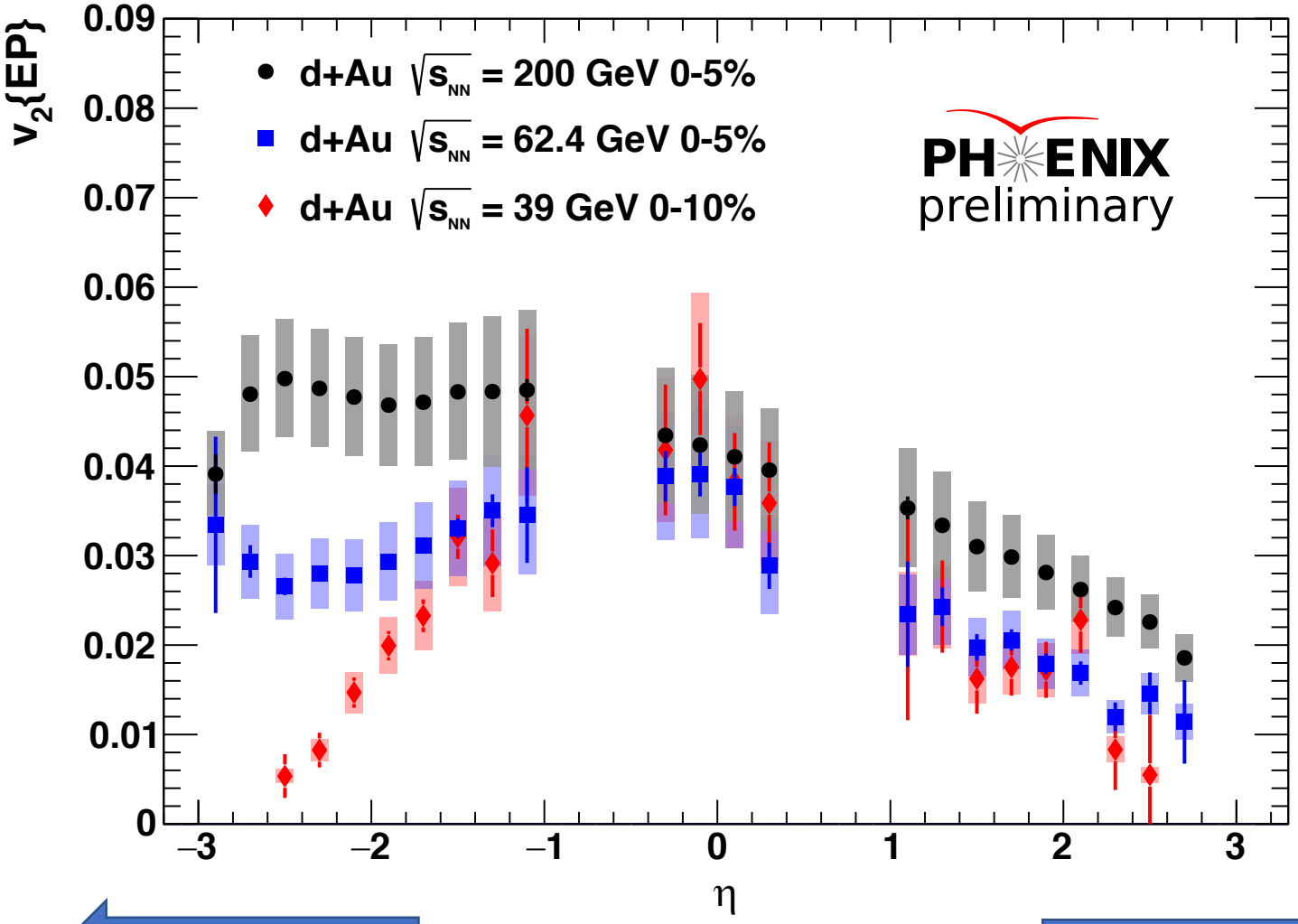
- The nonflow effect can be reproduced in AMPT

Comparing with viscous Hydro.



1. Both SONIC and super SONIC calculations are lower than measurements at lower collision energies.
2. Nonflow need to be subtracted for the comparison

The $v_2(\eta)$



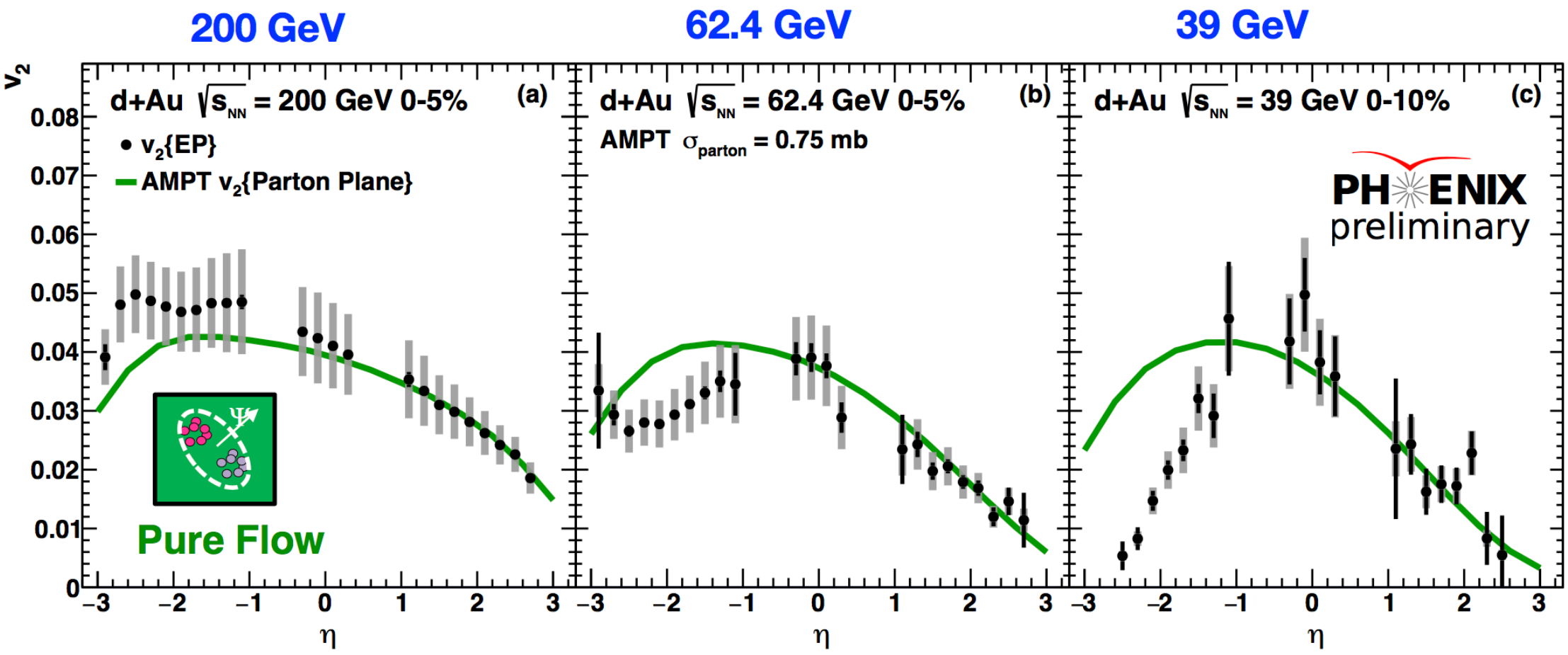
Backward

Forward

Forward:
similar values at all $\sqrt{s_{NN}}$

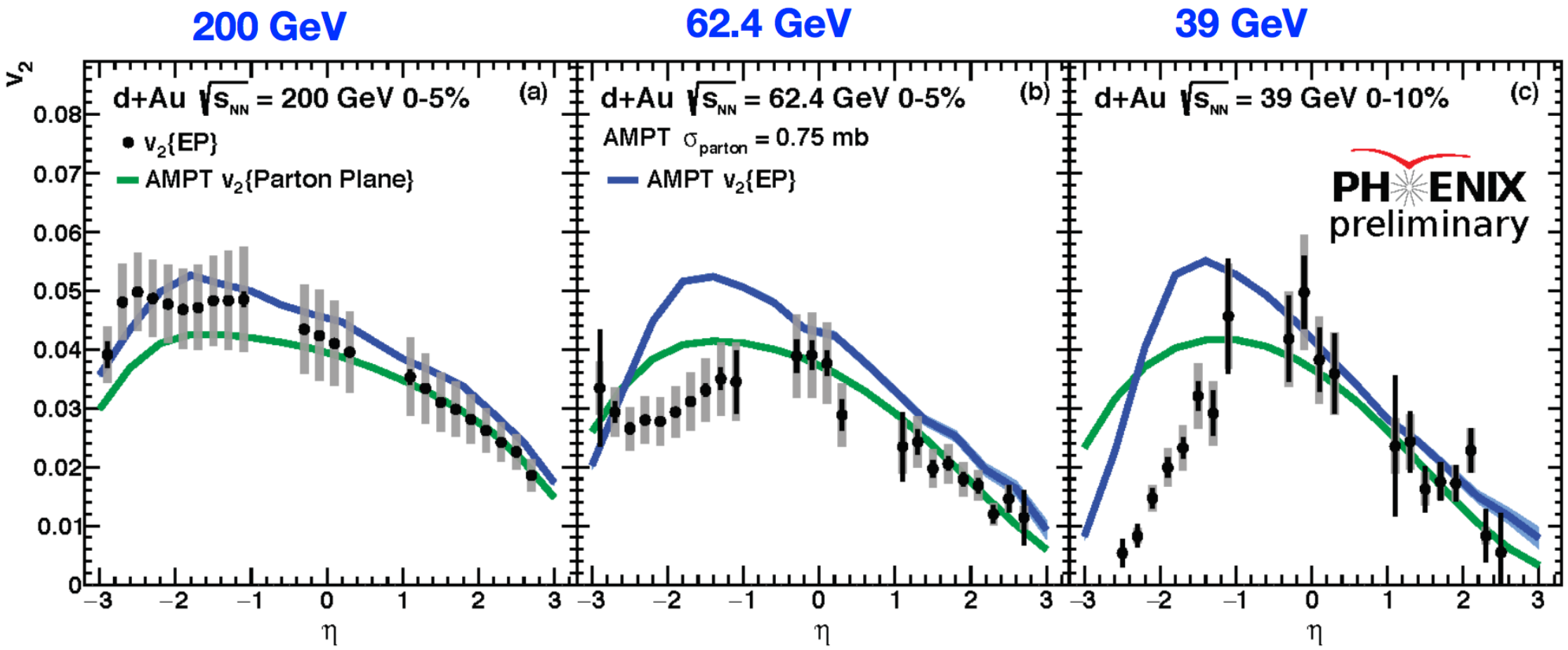
Backward:
decrease with $\sqrt{s_{NN}}$

Comparing with AMPT



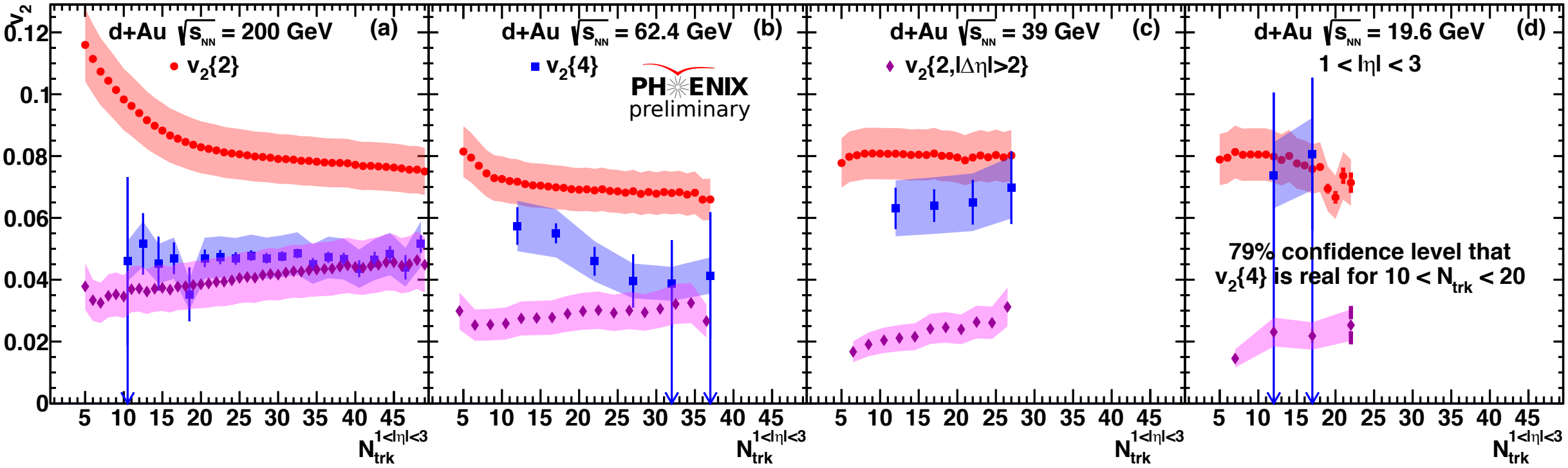
- AMPT can describe the $v_2(\eta)$ at forward for three collision energies
- But over-estimate the $v_2(\eta)$ at backward for 39 GeV. It may be due to the nonflow effect in the measurements

Nonflow with AMPT



Using the EP calculated with particles in AMPT, the model can describe the $v_2(\eta)$ trend at both backward and forward for 39 GeV

Cumulant results vs Beam Energy



- The four particles cumulant results at lower energy d+Au collisions is higher than $v_2(2, |\Delta\eta|>2)$. Different average of $v_2(\eta)$ or else?

- How about the $v_2(4)$ with two particles at backward and other two at forward?

Summary

- 1. By scanning different geometry, RHIC found that the initial geometry and multiplicity play important roles for the ridge and v_n in small systems. And these results can be well described by the viscous hydro.

- 2. The mass ordering, NCQ scaling and four particles cumulant results indicate a collective behavior in small system

- 3.The v_2 has been measure in small system from 200 GeV to 19.6 GeV by event plane method, but nonflow effect need to be further studied

- 4.The $v_2(4)$ at lower collision energy is higher than $v_2(2, |\Delta\eta|>2)$,why?