PHENIX Results on Collective Effects in Small Systems

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for the PHENIX Collaboration

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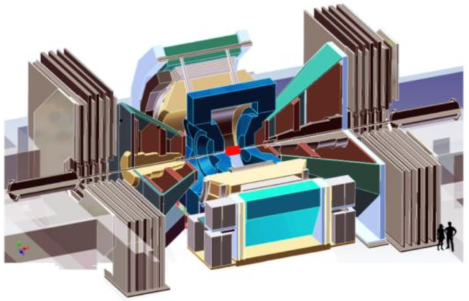
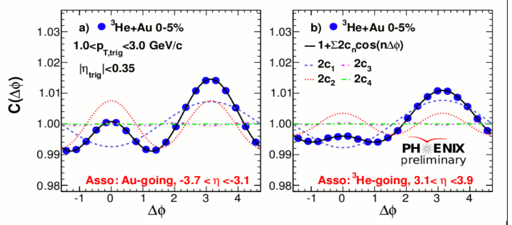
PHENIX Results on Collective Effects in Small Systems

- Physics Motivation
- Experimental details
- Results



  - Correlation functions in p/d/ ^{3}He+Au
  - Charged particle v_2 in p/d/ ^{3}He+Au; v_3 in ^{3}He+Au



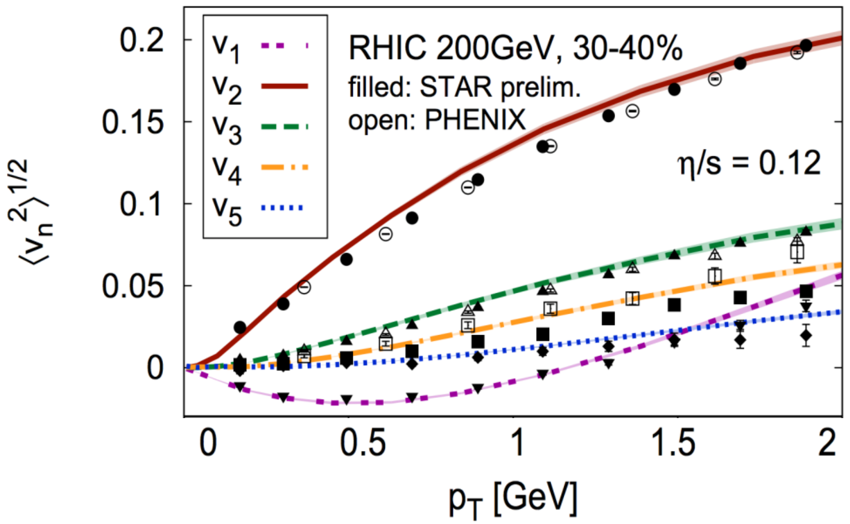
  - Comparison to models
  - Identified particle v_2 in d+Au and ^{3}He+Au
  - Outlook for Run 16
- Summary and Conclusions

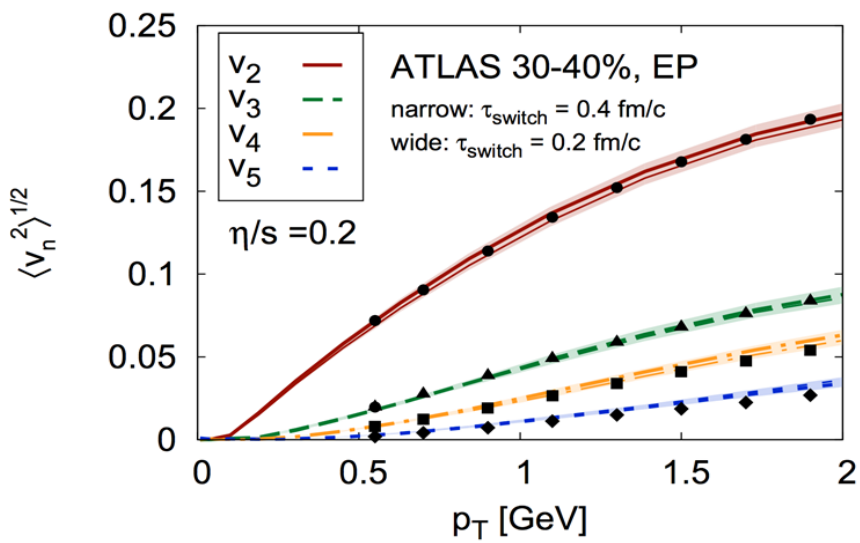
Collective effects in A+A collisions at RHIC/LHC – signal of sQGP

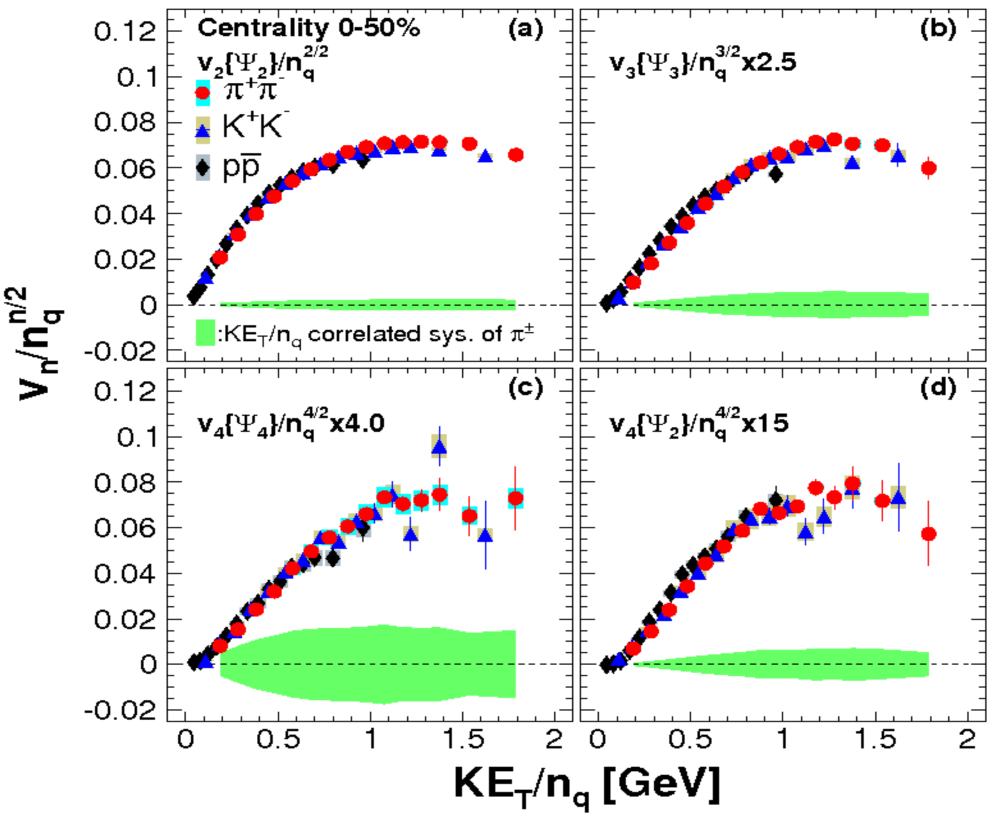
Gale, Jeon, et al., Phys. Rev. Lett. 110, 012302

Au+Au at 200 GeV

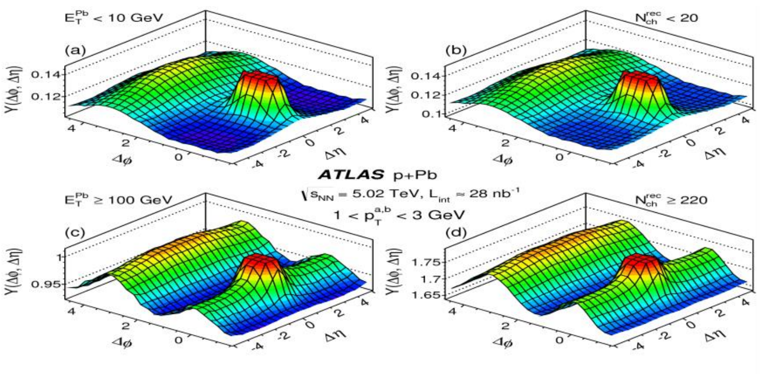
PHENIX: PRC.93.051902(R)

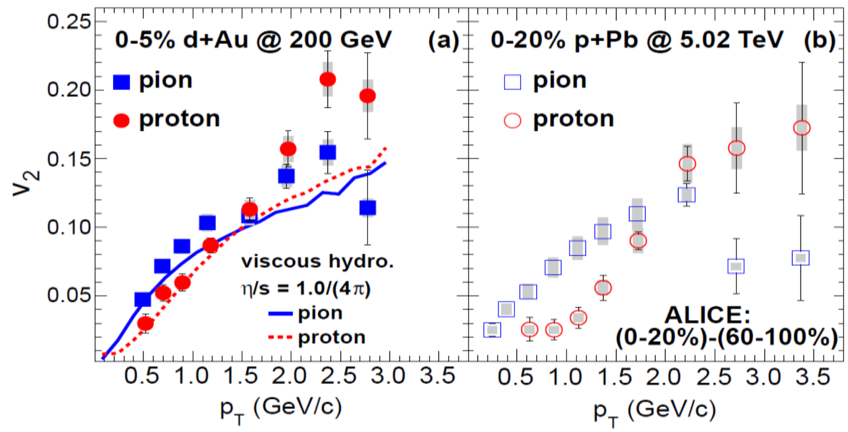






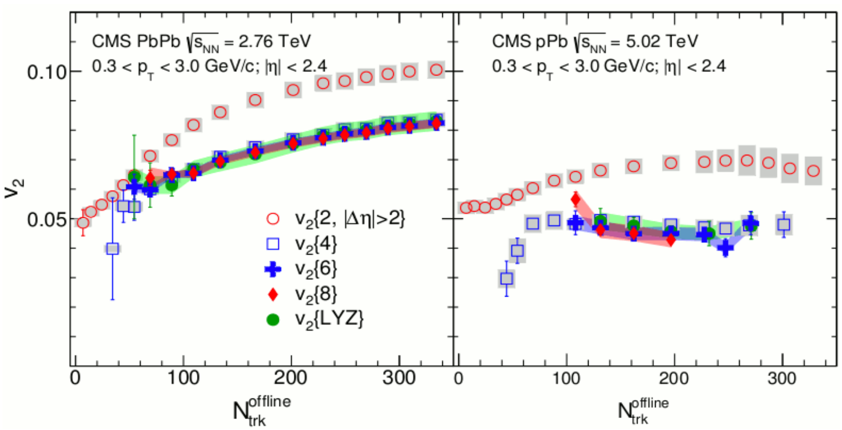
Collective Effects in Small Systems at LHC and RHIC: p+Pb , d+Au

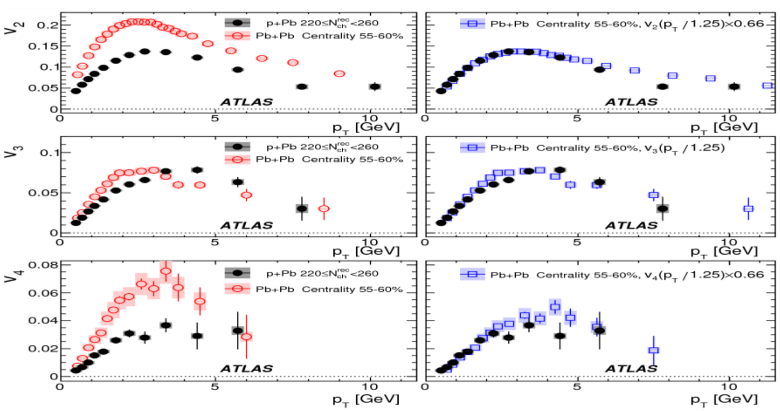




Long-range correlations: double ridge : CMS, ATLAS, ALICE, PHENIX,STAR

Mass ordering of PID v2 in p+Pb (ALICE,CMS) and d+Au (PHENIX)

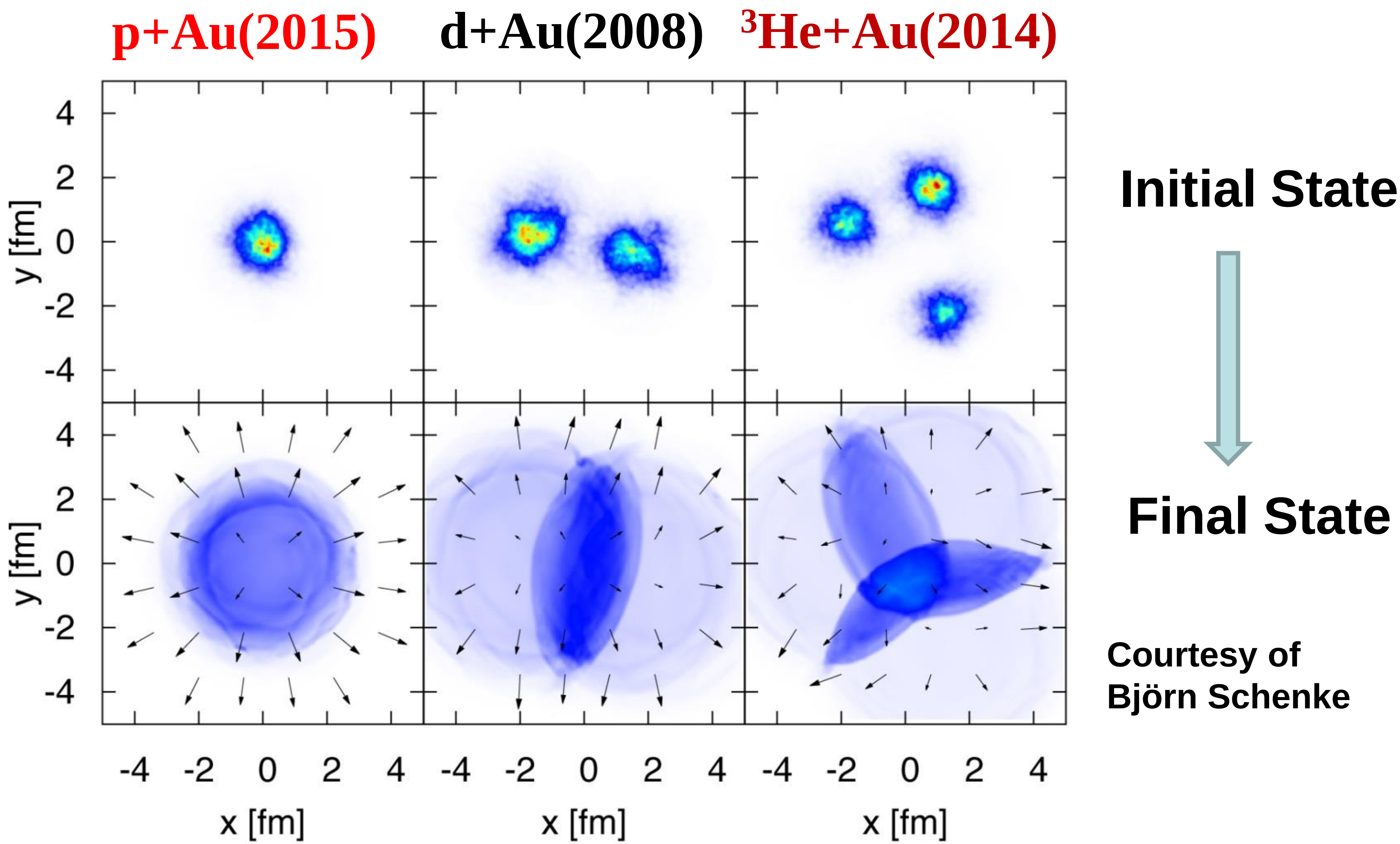




Scaling relations: p+Pb vs Pb+Pb: CMS,ATLAS

Multiparticle correlations: CMS, ATLAS, ALICE

Geometry Engineering at RHIC

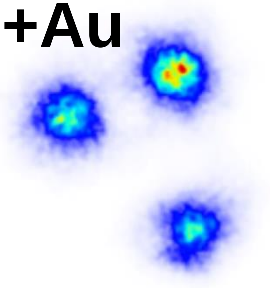


Courtesy of
Björn Schenke

➢ **Different initial geometry → different final state particle emission for p+Au, d+Au and ^{3}He+Au collisions**

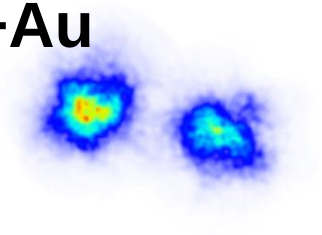
PHENIX Azimuthal Correlations and v_n Measurements

^{3}He+Au



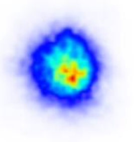
Phys. Rev. Lett. 115, 142301 (2015)

d+Au



Phys. Rev. Lett. 114, 192301 (2015)

p+Au



Preliminary Status

PHENIX Flow Measurements : Methods

Correlate hadrons in central Arms

with event plane (FVTX, BBC etc)

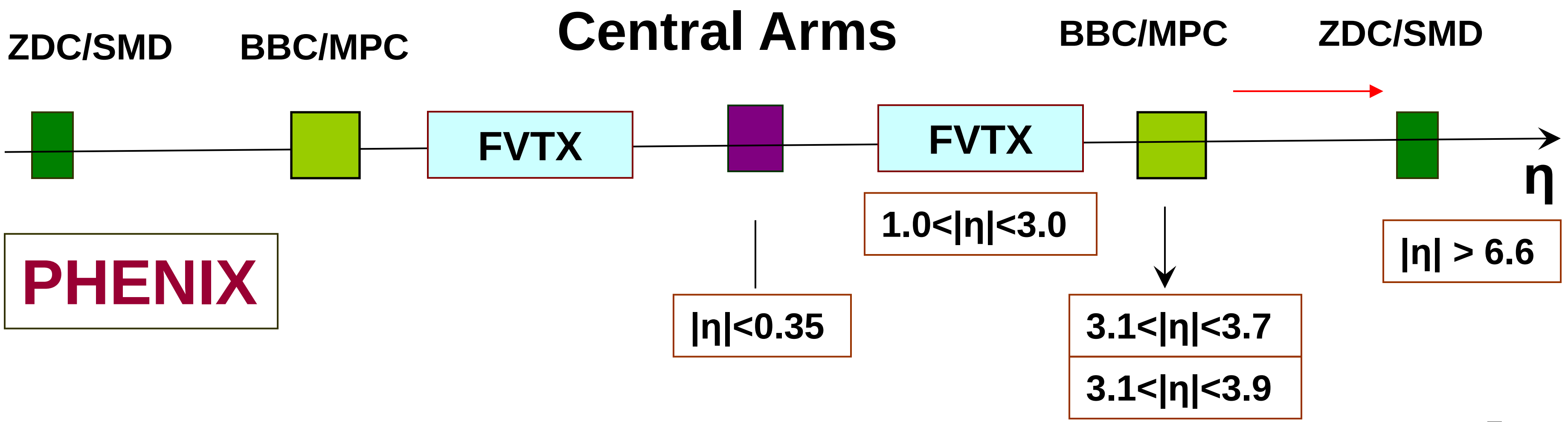
$$\frac{dN}{d\varphi} \propto \left(1 + 2\sum_{n=1}^{+\infty} v_n \cos\left[n(\varphi - \psi_n)\right]\right)$$

$$v_{\mathrm{n}}\{\psi_n\} = \left\langle \cos\left[n\left(\varphi - \psi_n\right)\right]\right\rangle, \quad n = 1, 2, 3..,$$

- ***$\Delta\varphi$ correlation function for EP_N - EP_S***

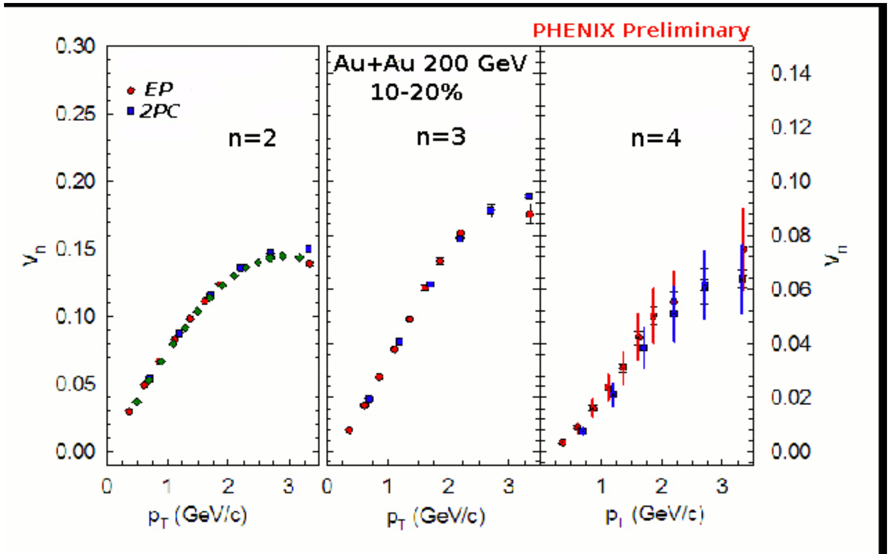
$$\frac{dN^{\mathrm{pairs}}}{d\left(\Delta\varphi\right)} \propto \left(1 + \sum_{n=1} 2 v_n^a v_n^b \cos(n\Delta\varphi)\right)$$

- ***$\Delta\varphi$ correlation function for EP - CA***

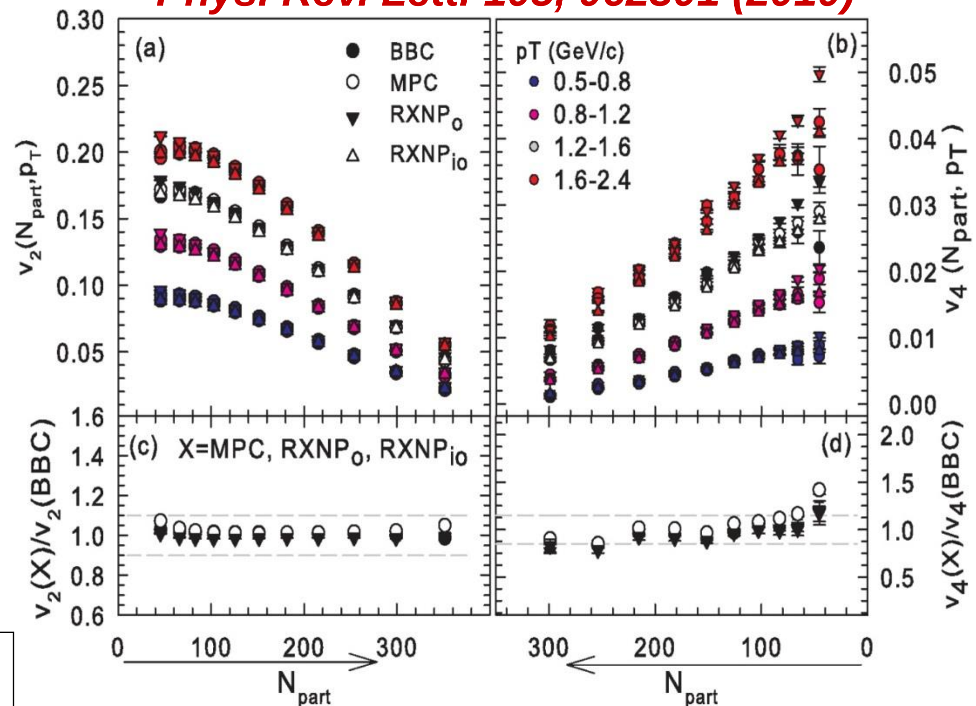


PHENIX Flow Measurements : Methods

V_n **(EP):** ***Phys.Rev.Lett. 107 (2011) 252301***



Phys. Rev. Lett. 105, 062301 (2010)



- ***Good agreement between V_n results obtained by event plane (EP) and two-particle correlation method (2PC)***
- ***No evidence for significant η-dependent non-flow contributions from di-jets for pT=0.3-3.5 GeV/c.*** **Systematic uncertainty : event plane: 2-5% for v2 and 5-12% for v3.**

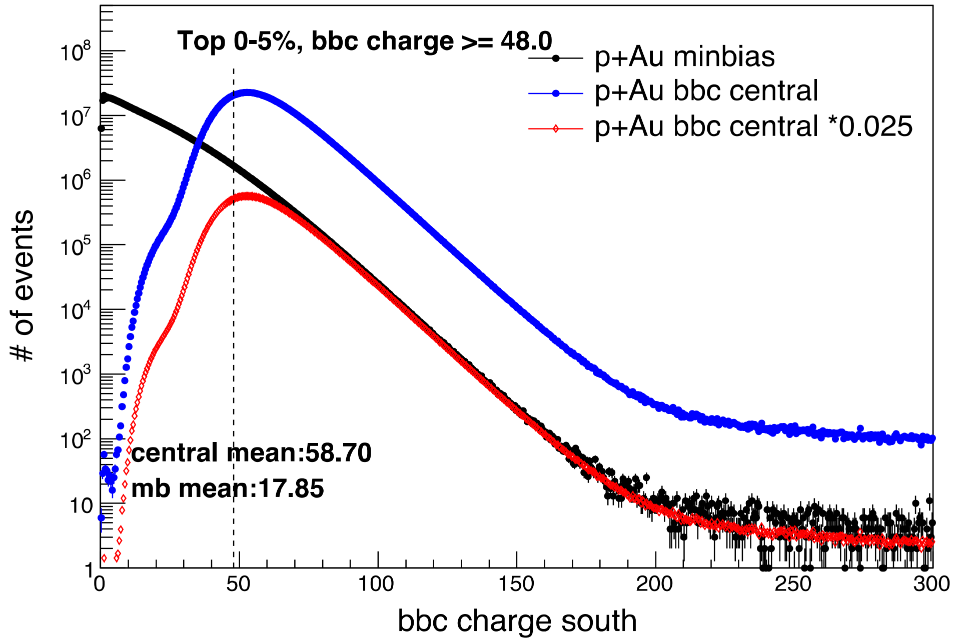
Ψ_n^{RXN} **(|η|=1.0~2.8)**

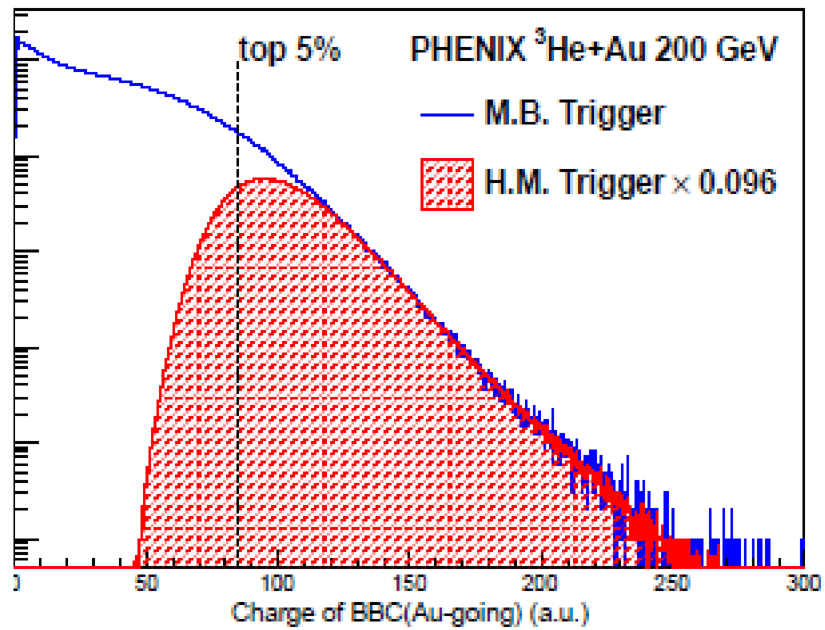
^{MPC} **(|η|=3.1~3.7)**

^{BBC} **(|η|=3.1~3.9)**

High-multiplicity trigger in BBC

Phys. Rev. Lett. 115, 142301





More central collisions

More central collisions

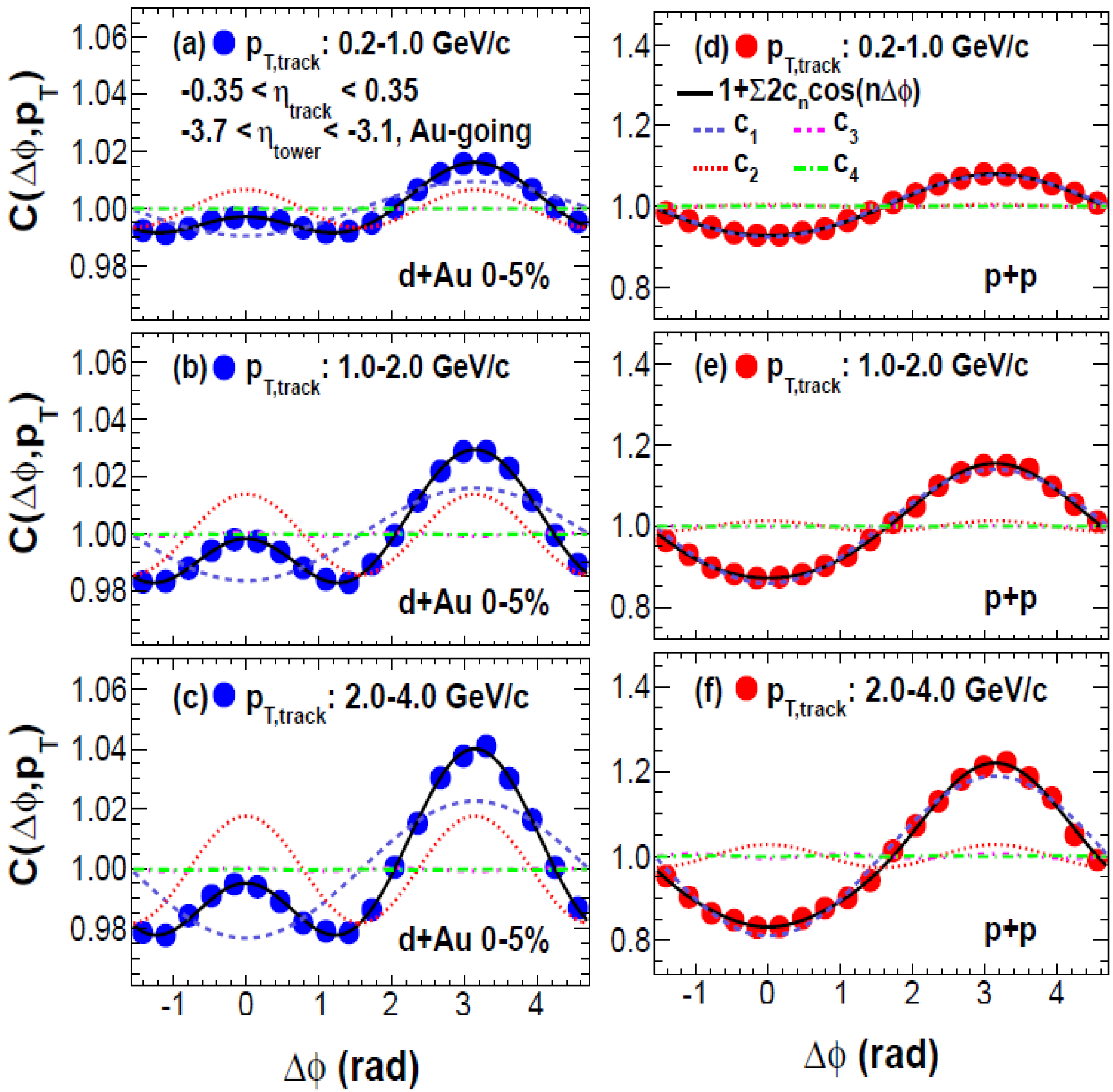
p+Au: 3.1 billion min. bias events
1.2 billion central events

³He+Au: 2.2 billion min. bias events
0.8 billion central events

- **The trigger increase 0-5% most central events by 40 times in p+Au**
- **The trigger increase 0-5% most central events by 10 times in ³He+Au**

Long range correlations in d+Au and p+p

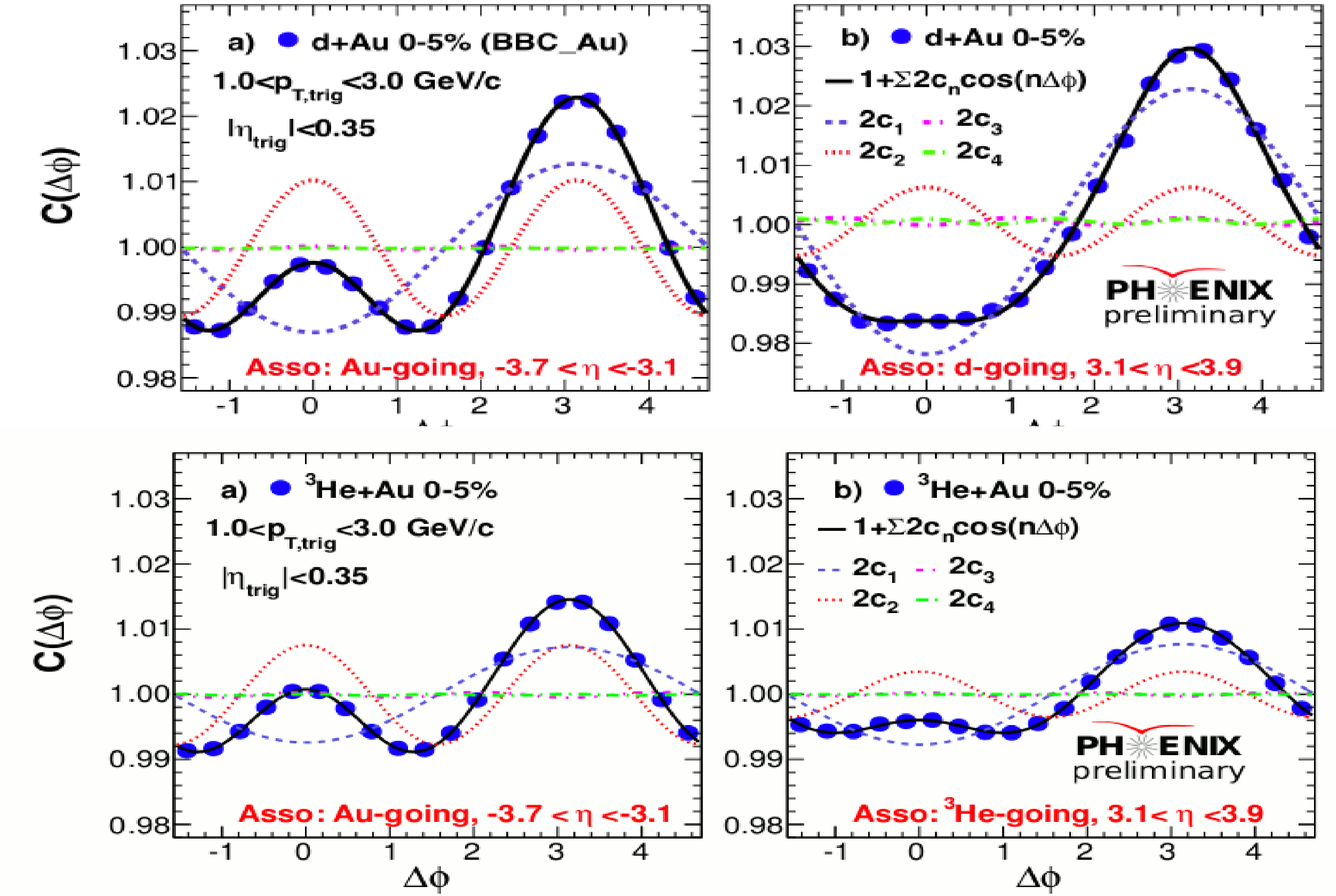
Phys. Rev. Lett. 114, 192301 (2015)



In pp, the distribution is dominated by the dipole term cos(Δϕ), which may due to the momentum conservation

- In dAu, the distribution shows a near side peak
- Dijet contribution can't be taken out by subtracting the conditional yield of pp from dAu
- Dijet contributions to c2 in dAu can be estimated from c2 in pp

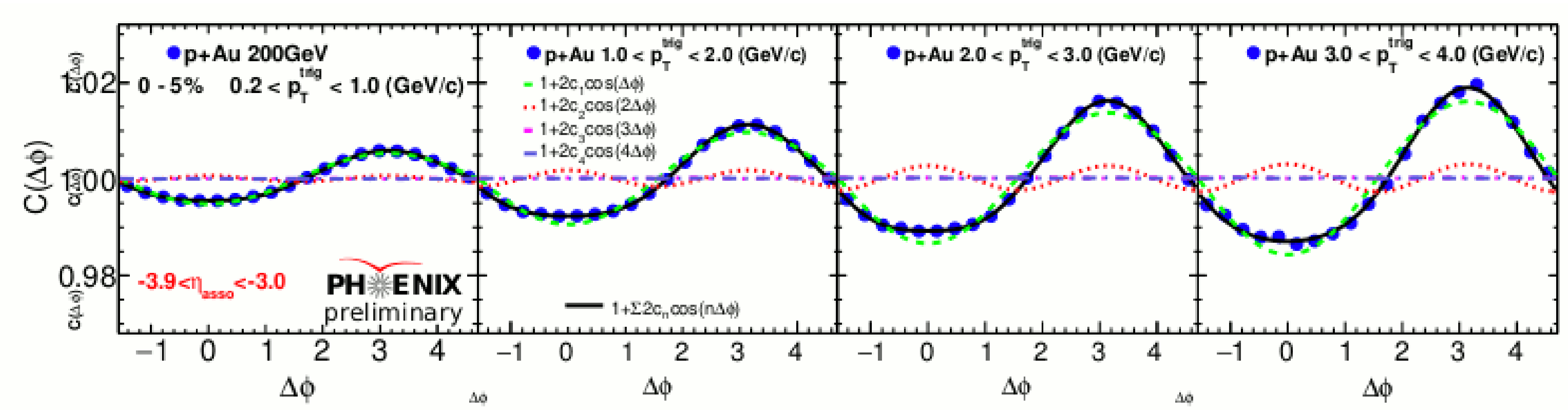
Long range correlations in d+Au/^{3}He+Au



Ridges are seen on both Au-going and ^{3}He-going sides

| Δη| > 2.75 : MPC – hadron correlations

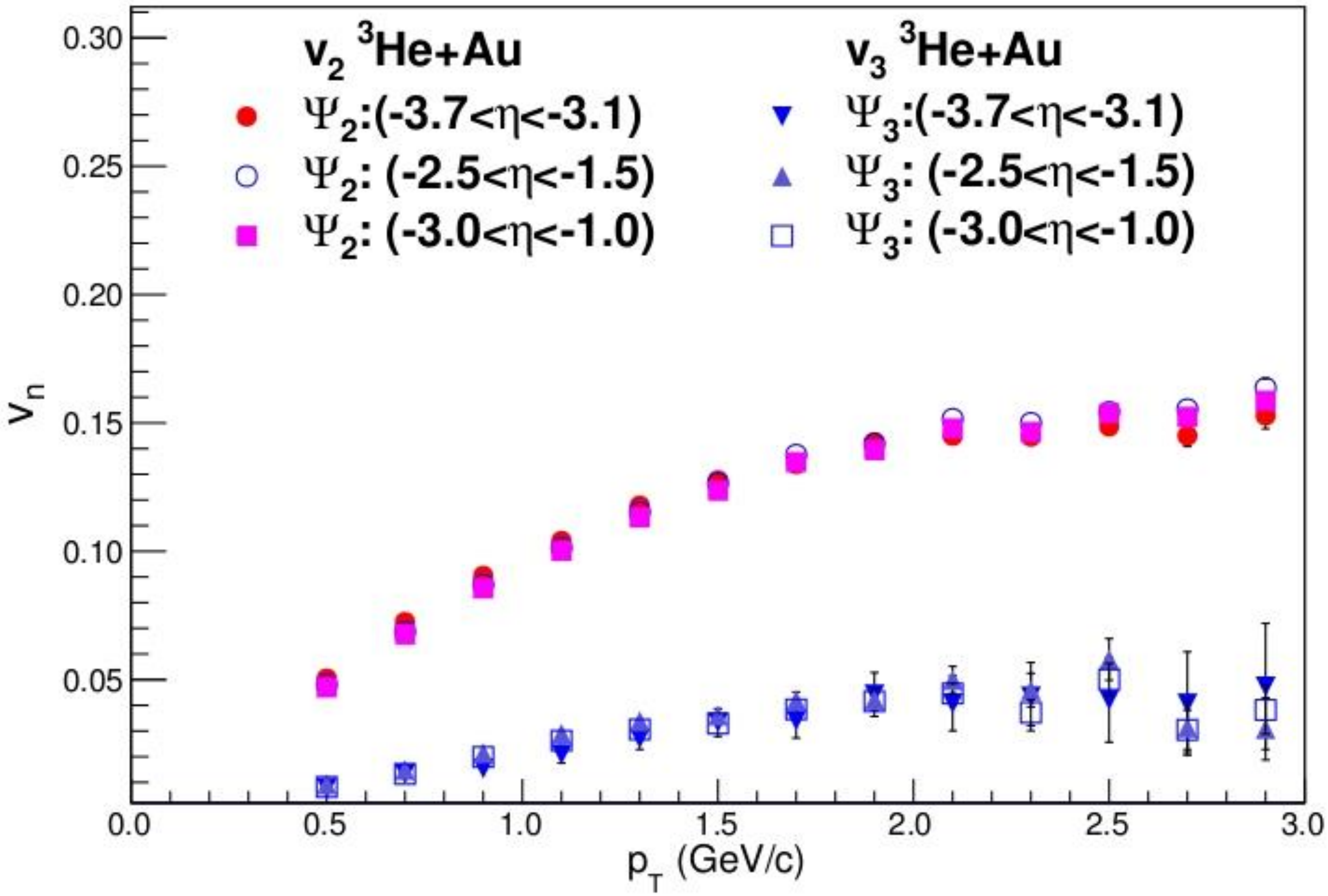
Correlation functions in central p+Au



- **2-particle correlation between mid-rapidity tracks and backward (Au-going) charge particles**
- **Separated by 2.75 units in pseudo-rapidity**

v_2 and v_3 in 0-5% ^{3}He+Au: Event Plane Method

$$v_n\{\psi_n\} = \left\langle \cos\left[n\left(\varphi - \psi_n\right)\right]\right\rangle, \quad n = 1, 2, 3..,$$

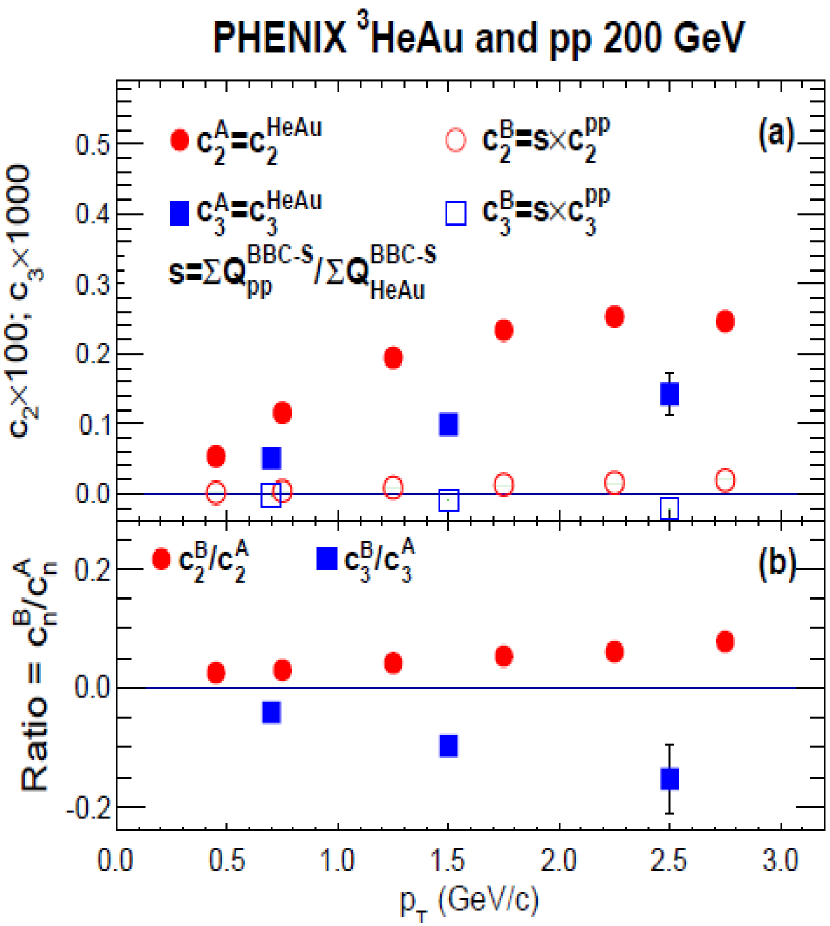


BBC-S
FVTX-S
FVTX-S

Event plane resolution estimated from correlation of three independent sub-events

Estimation of Nonflow

$c_2\,(p_T) = c_2^{\text{Non-Elementary}} + c_2^{\text{Elementary}}$



$c_2^{\text{Elementary}}$ - due to elementary processes such as dijet fragmentation and resonance decays

Estimate under on assumptions

1) All correlations present in minbias p+p collisions are due to elementary processes
2) Those elementary processes occur in p+Au/d+Au/^{3}He+Au systems as a simple superposition of several nucleon-nucleon collisions.

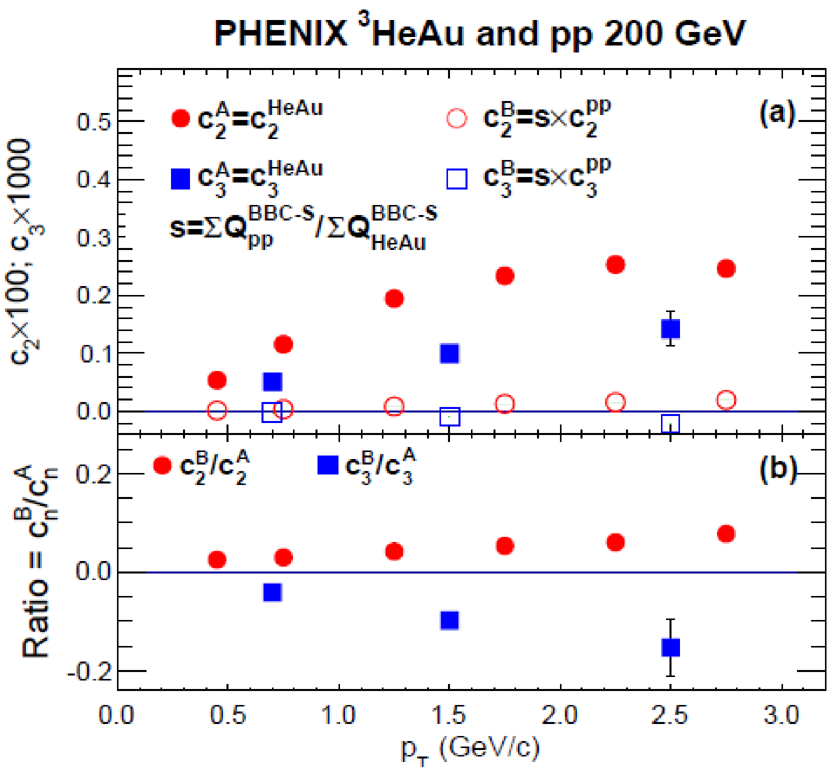
Estimation of Nonflow

$$c_2\,(p_T) = c_2^{\text{Non-Elementary}} + c_2^{\text{Elementary}}$$

$$c_2\,(p_T) = c_2^{\text{Non-Elementary}} + c_2^{p+p} \times \frac{\text{Charge at Forward } \eta \text{ in p+p}}{\text{Charge at Forward } \eta \text{ in p+Au}}$$

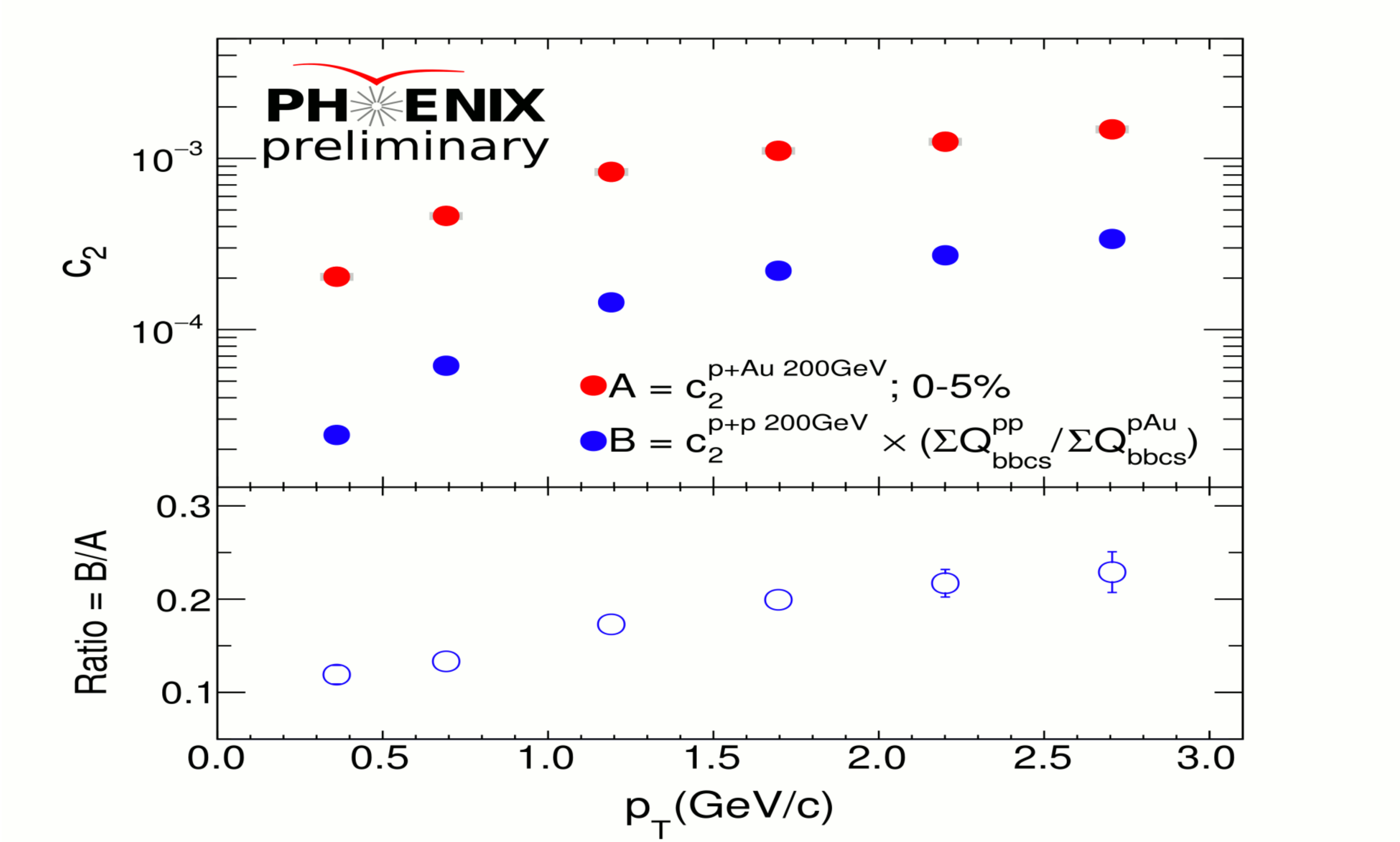
Use p+p as a reference

Scale it down by relative multiplicity



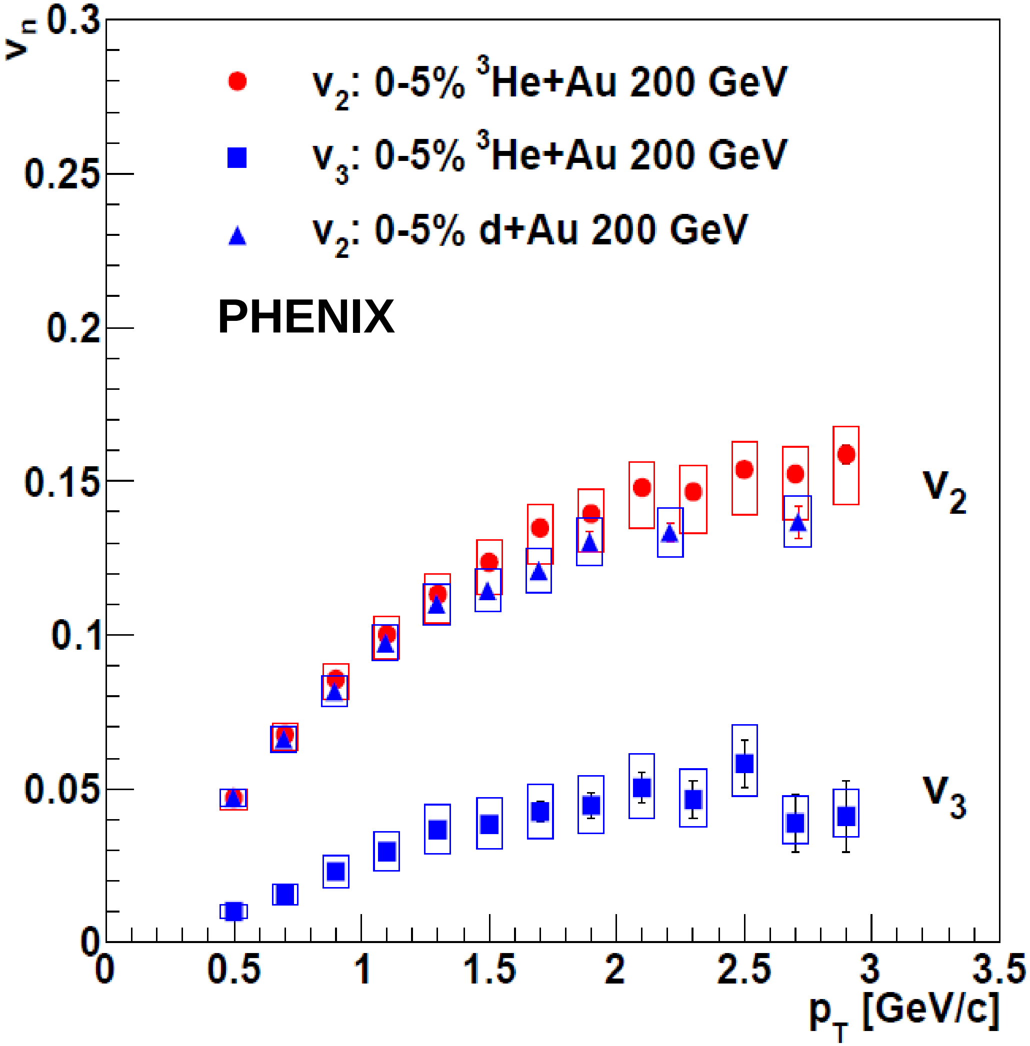
Nonflow estimation in d/ ³He+Au is small (<7% for v_2 , <15% for v_3)
Cited as a systematic uncertainty

Nonflow Estimation in p+Au



- **Jet contribution (estimated from p+p) rises with p_T and reaches 25%; Cited as a systematic uncertainty**
- **Working on evaluating different subtraction methods**

v_2 and v_3 in 0-5% ^{3}He+Au



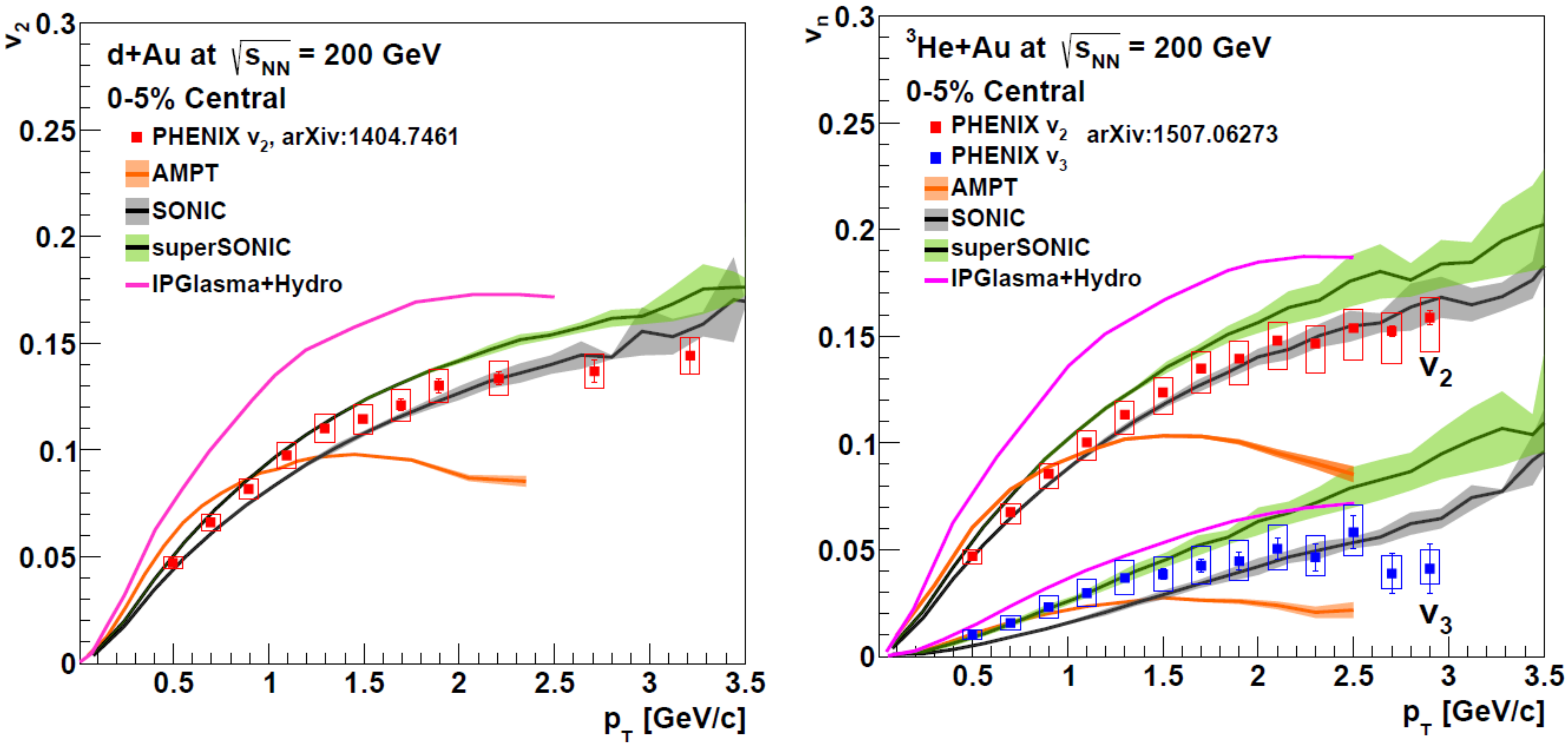
Phys. Rev. Lett. 114, 192301 (2015)

Phys. Rev. Lett. 115, 142301 (2015)

A sizeable v_2 and v_3 are observed in 0-5% ^{3}He+Au collisions, extracted by event plane method

The v_2 in 0-5% ^{3}He+Au and 0-5% d+Au collisions are very similar

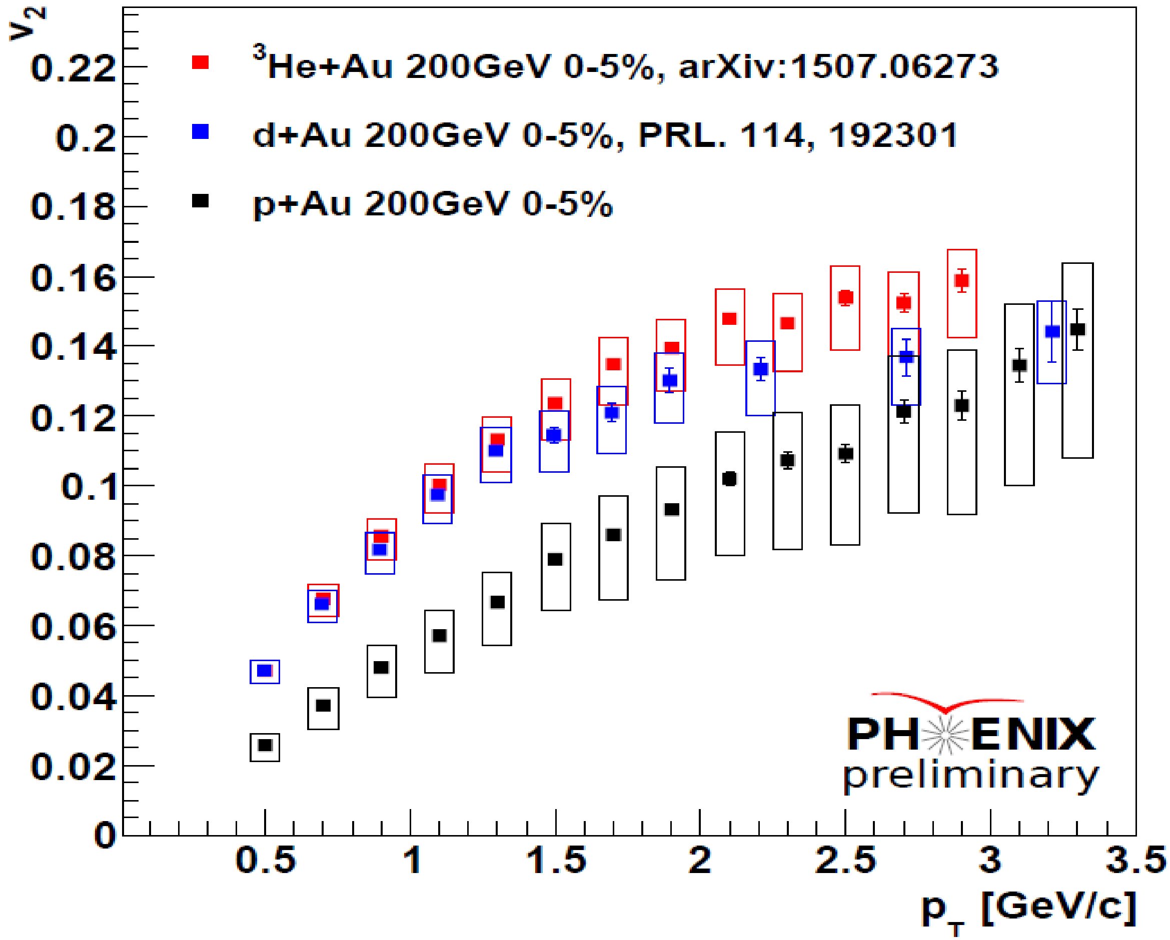
Comparison with theory calculations



AMPT: arXiv:1501.06880 SONIC: arXiv:1502.04745 IP+Hydro:arXiv:1407:7557

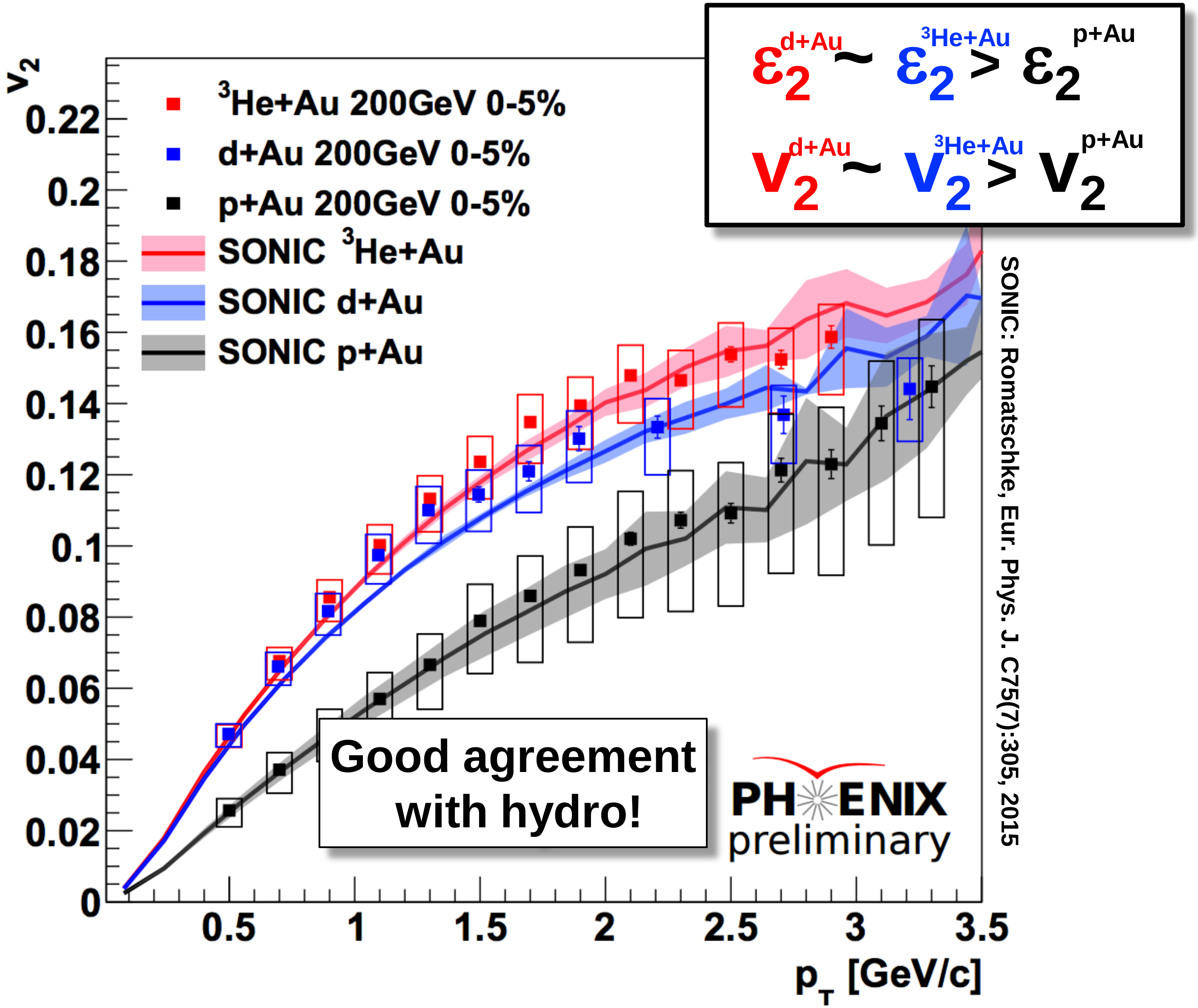
Several models can reproduce the v_n measurements in d+Au and ^{3}He+Au collisions simultaneously

Comparison with central p+Au at 200 GeV

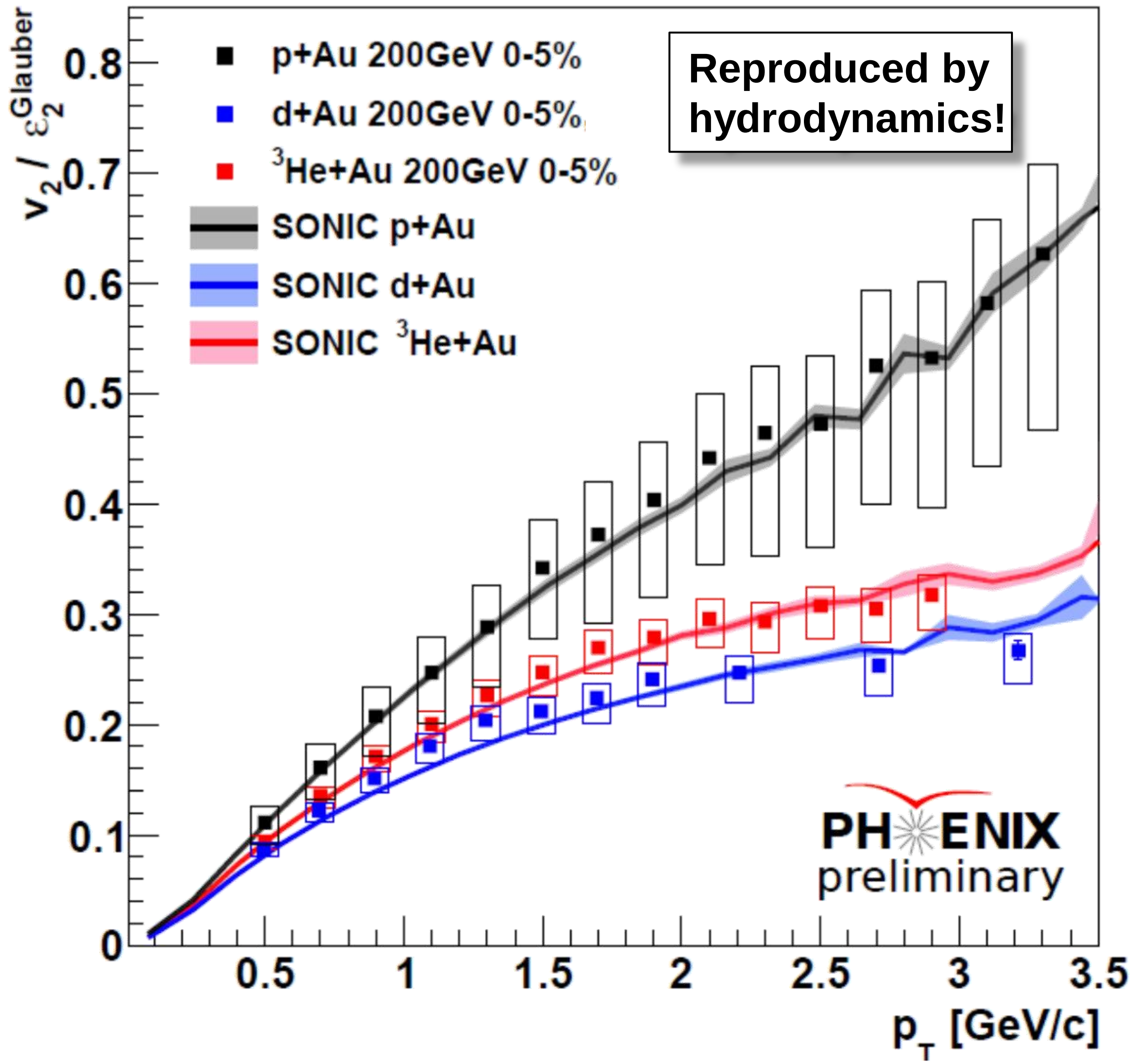


- The measured v_2 from central p+Au collisions is lower than that of central d+Au and ^{3}He+Au collisions
- Smaller initial geometry eccentricity → smaller v_2

v_2 in central p+Au/d+Au/^{3}He+Au collisions



v_2/ε_2 in central p+Au/d+Au/^{3}He+Au collisions

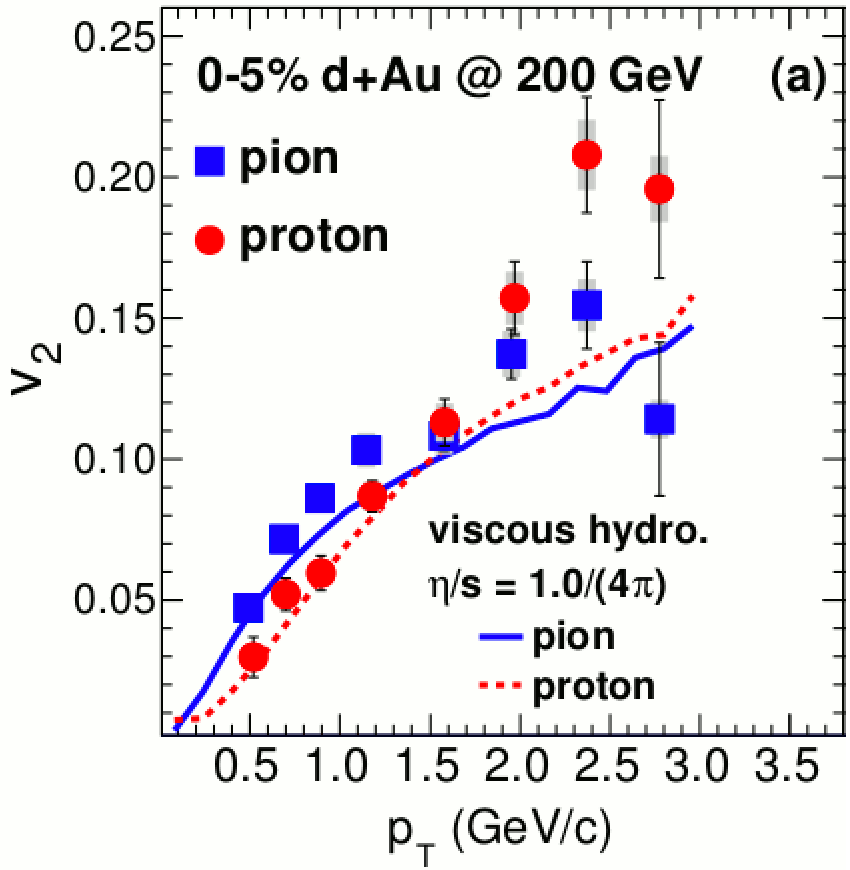


From nucleon Glauber to quark Glauber ?

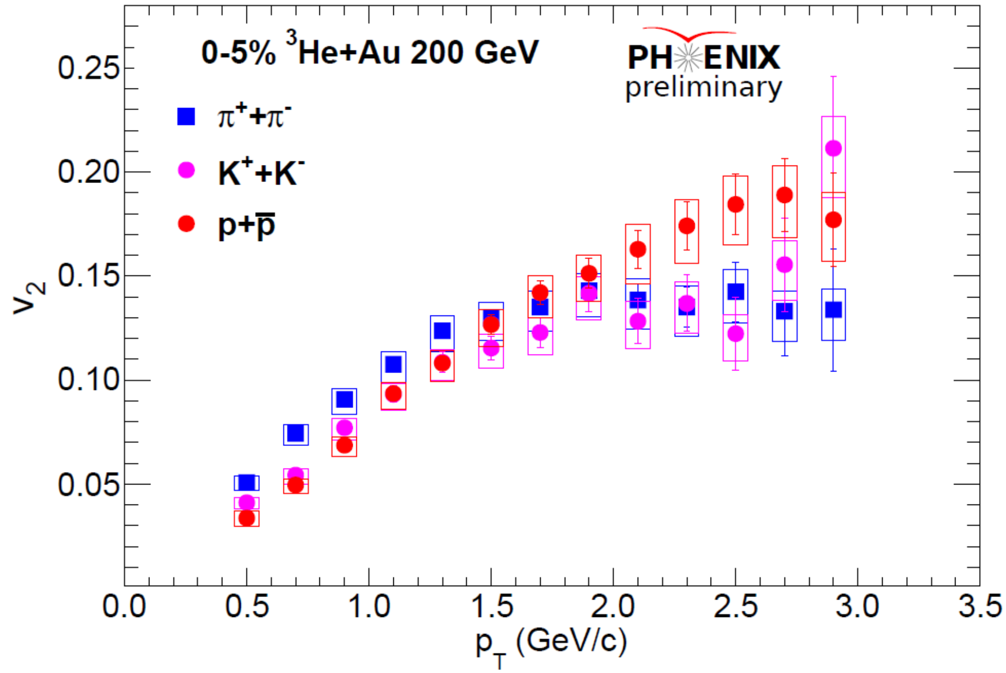
v_2 of identified charged hadrons in central d+Au/^{3}He+Au collisions

Phys. Rev. Lett. 114, 192301

Central d+Au

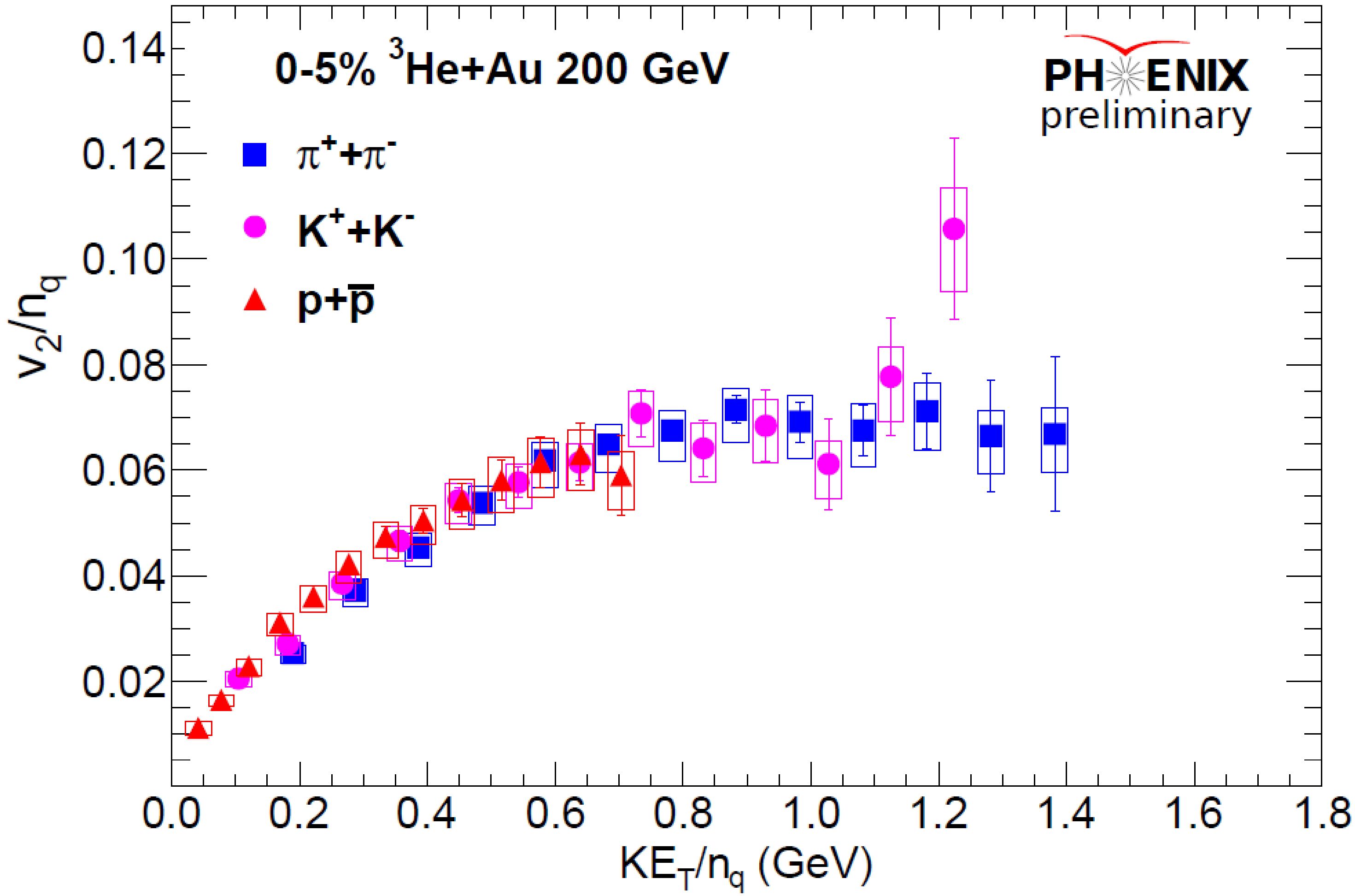


Central ^{3}He+Au



- **Mass-ordering feature also observed in d/^{3}He+Au**

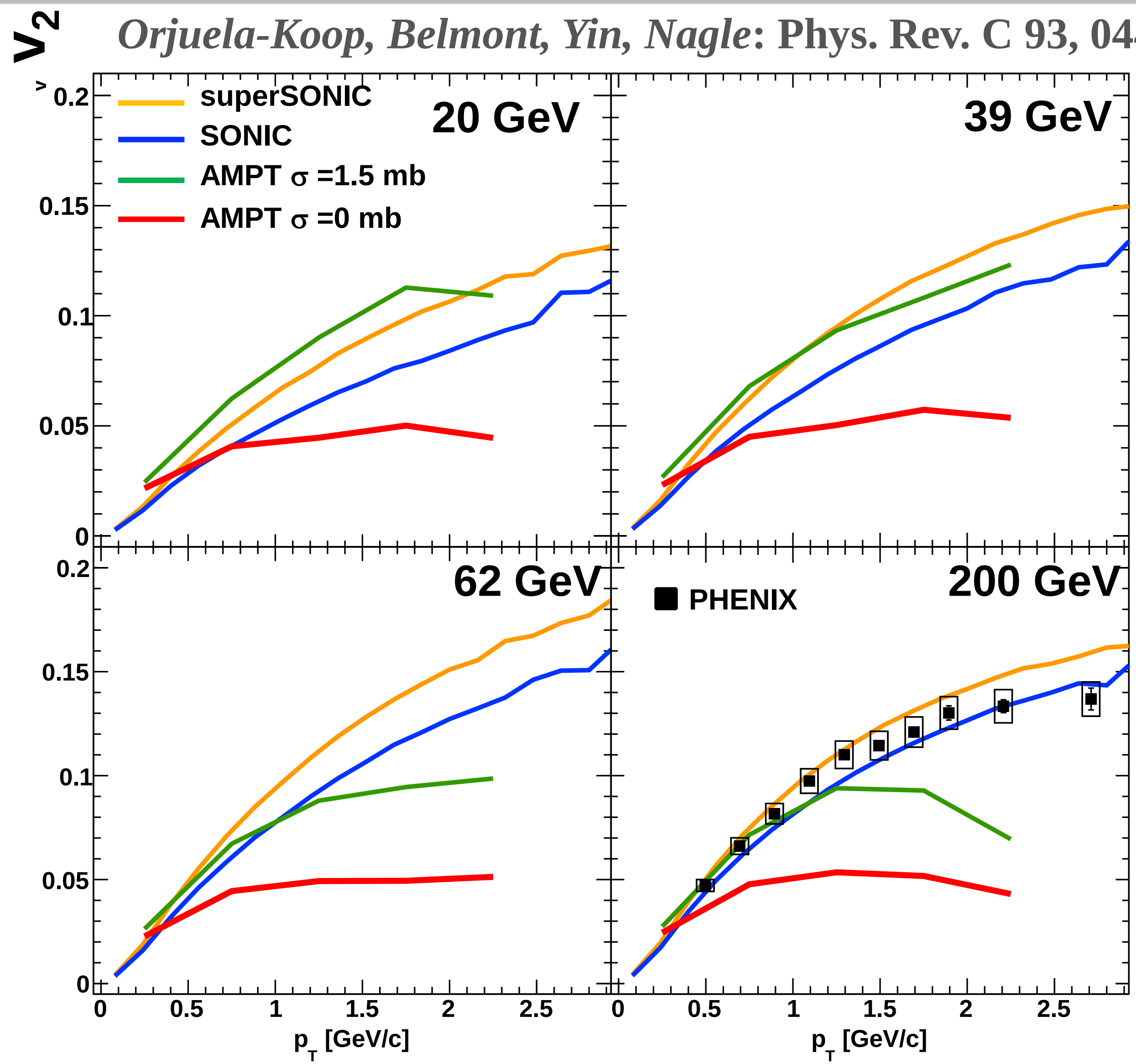
Number of Quark Scaling in central ^{3}He+Au



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

2016: d+Au Beam Energy Scan at RHIC

Orjuela-Koop, Belmont, Yin, Nagle: Phys. Rev. C 93, 044910 (2016)



Hydro With
Pre-Equilibrium

Hydro Without
Pre-Equlibrium

AMPT Parton
+ Hadron

AMPT Hadron
Only

Summary and Conclusions

- The v_n anisotropies of charged hadrons have been measured in 0-5% central p+Au/d+Au and ^{3}He+Au collisions at 200 GeV via event plane method.
- Sizable v_2 is seen in central p+Au collisions, smaller than in d+Au/ ^{3}He+Au collisions
- Mass ordering and quark-number scaling of v_2 of identified charged hadrons is seen in central in d+Au and ^{3}He+Au collisions
- The comparison of v_n in different systems, and theoretical calculations, indicates that the initial geometry plays an important role in the small systems' evolution

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