# Flow and Correlations from RHIC-PHENIX

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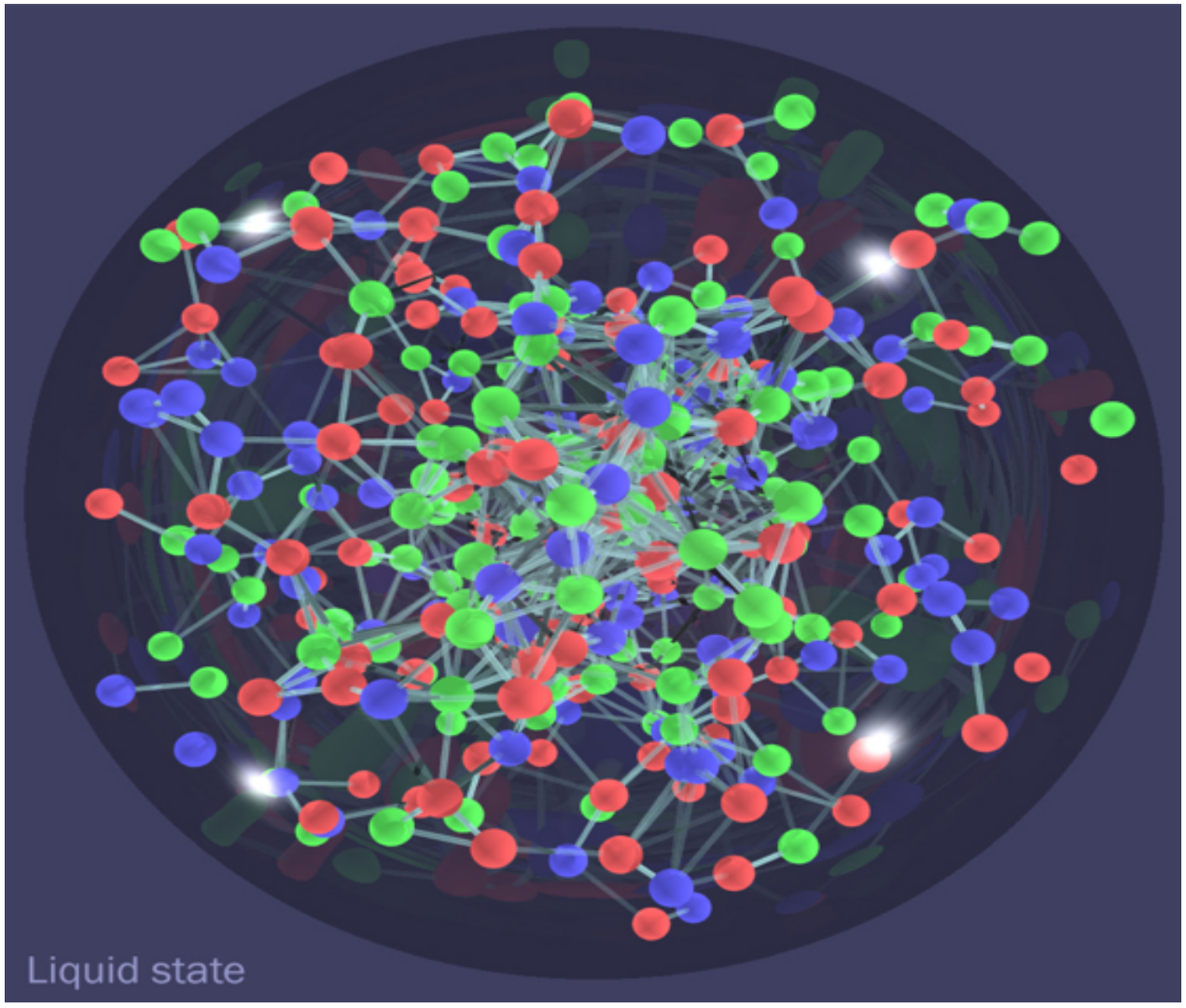
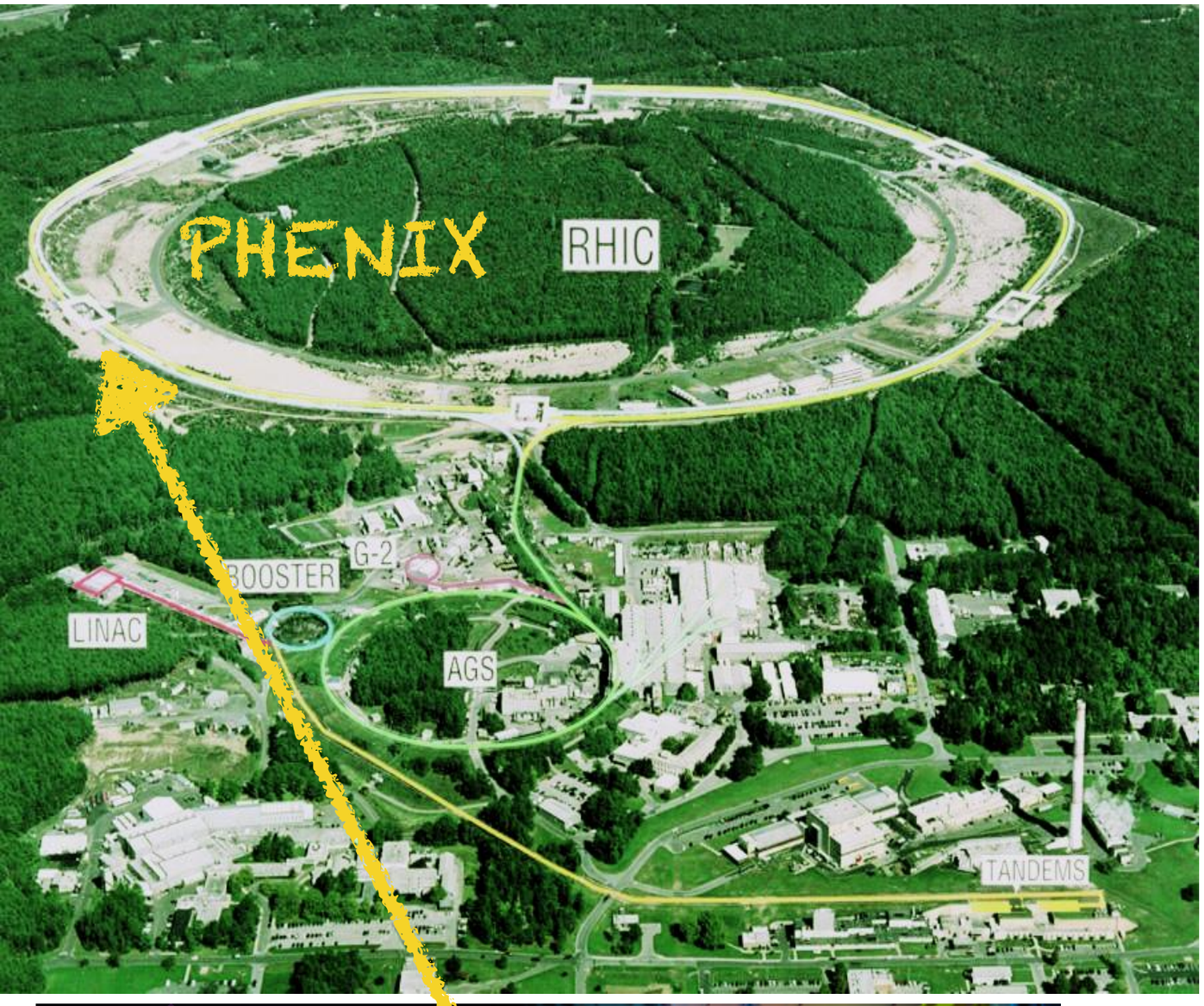
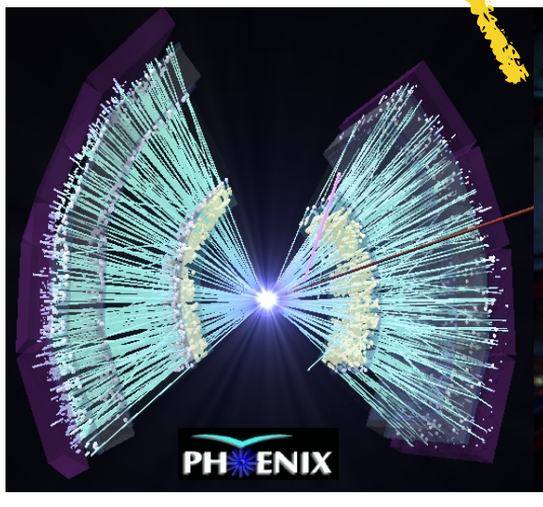
# Quark gluon plasma(QGP)

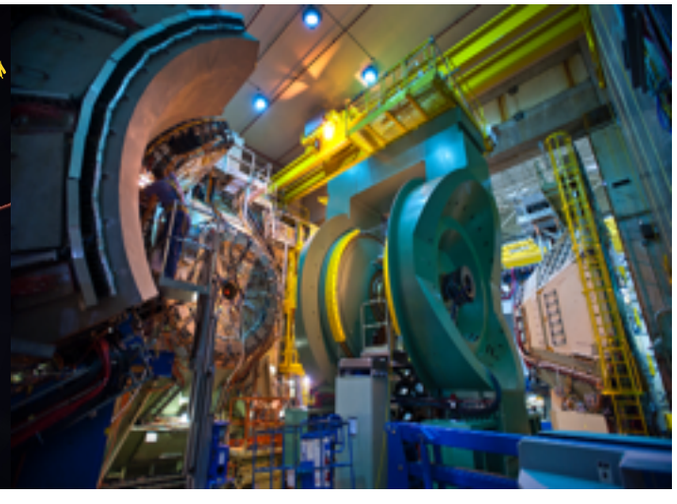



-consist of asymptotic free quarks and gluons
-State at few micro sec. after Big bang
-Extremely hot and dense matter

# Relative Heavy Ion Collider(RHIC)

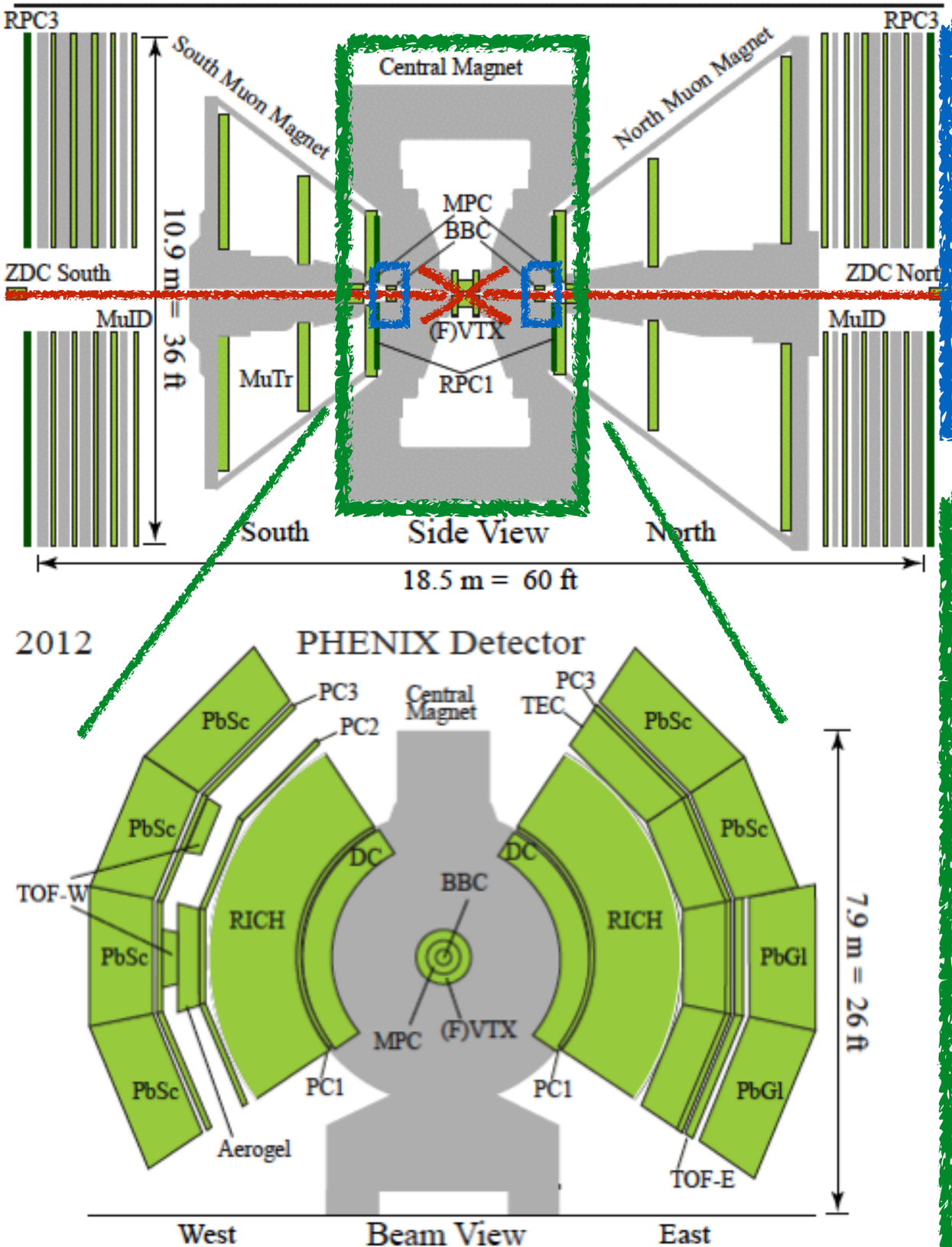


| Species | Energies |
|---|---|
| Au+Au | 200, 130, 62.4GeV |
| | 39, 27, 22.4GeV |
| | 19.6 14.6, 7.7GeV |
| Cu+Cu | 200, 62.4, 22.4GeV |
| U+U | 193GeV |
| Cu+Au | 200GeV |
| 3He+Au | 200GeV |
| d+Au | 200GeV |
| p+Au | 200GeV |
| p+Al | 200GeV |
| p+p | 510, 500, 200GeV |
| | 62.4GeV |

# PHENIX detectors




Event categorization

Trigger and

multiplicity counter

-Beam Beam counter(BBC)

Charged particle Tracking

-Drift Chamber(DC)

-Pad Chamber(PC)

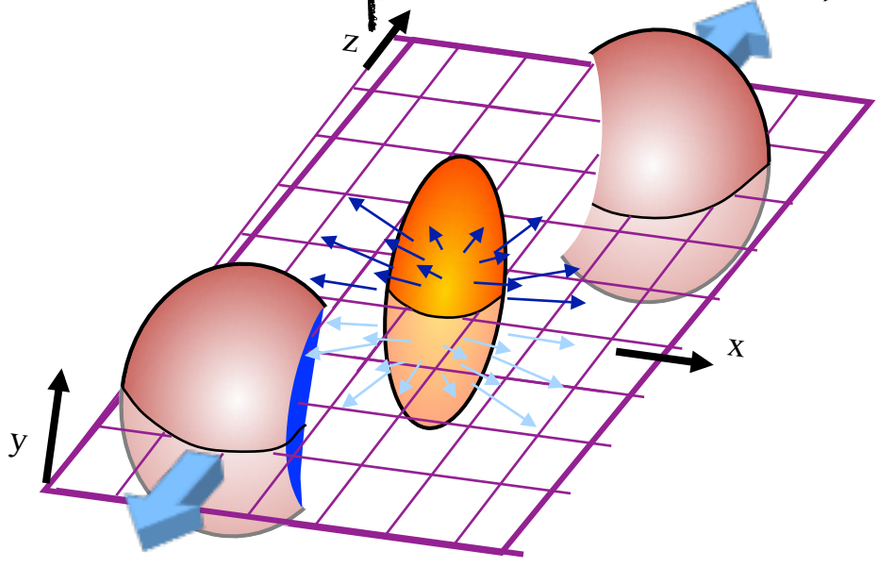
Hadron identification

-Time of flight(TOF)

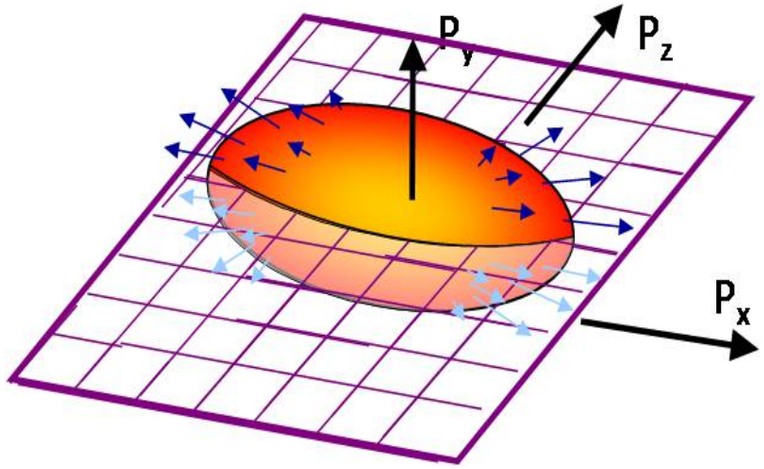
-Electro magnetic calorimeter(EMC)

# Azimuthal anisotropic flow

Initial spatial anisotropy:$e_2$



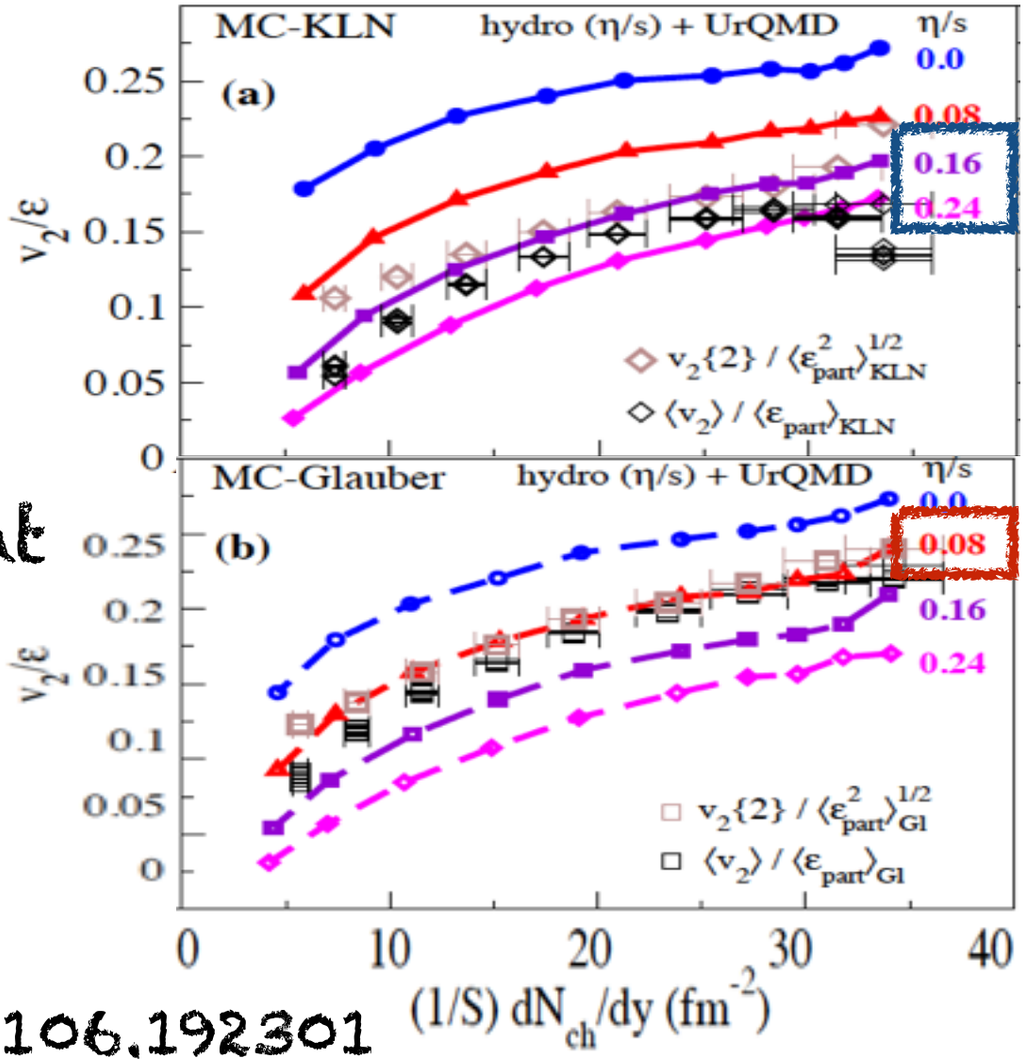

momentum anisotropy:$v_2$




particle production will have an elliptical azimuthal distribution.

- Non-isotropic pressure gradient

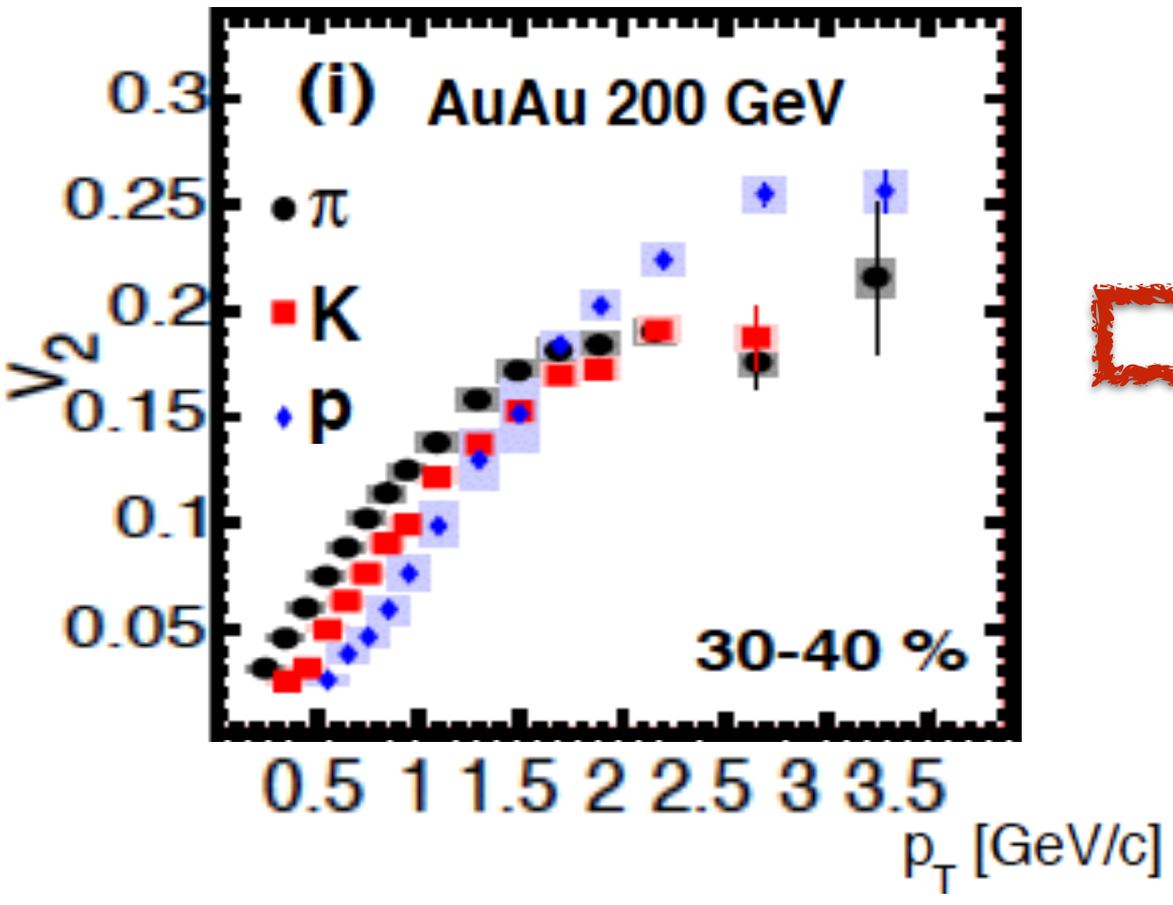
Sensitive to
-initial condition
-viscosity

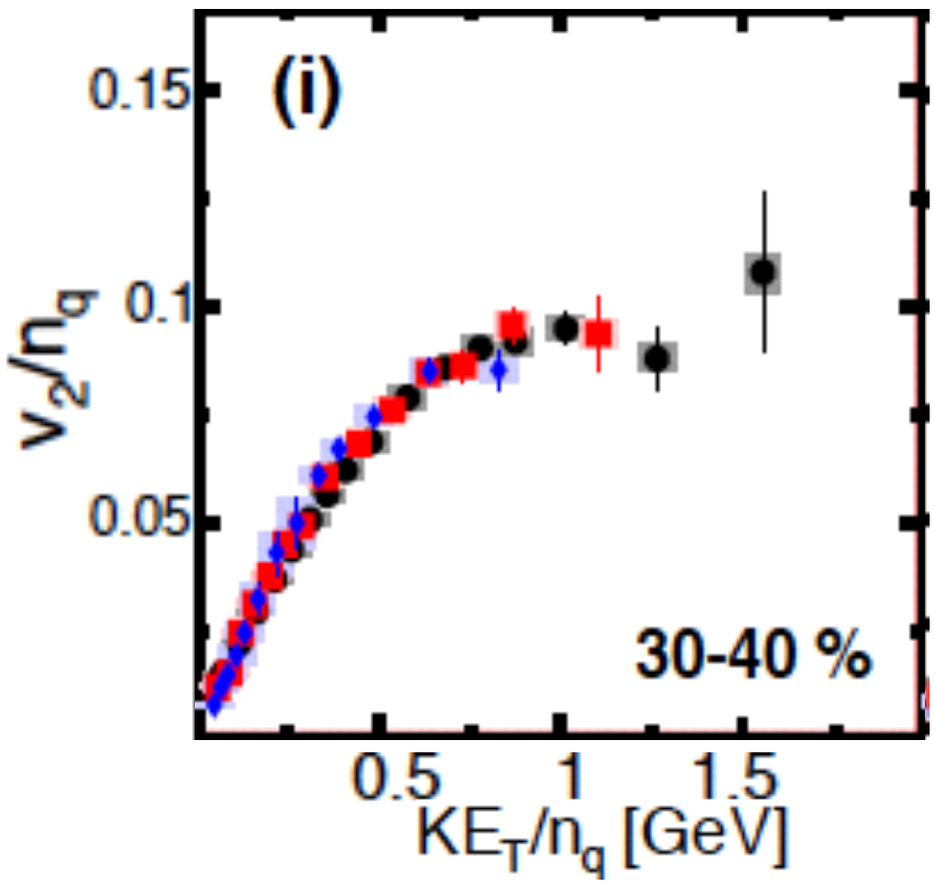



PRL 106.192301

# Partonic collectivity

PRC 92, 034913

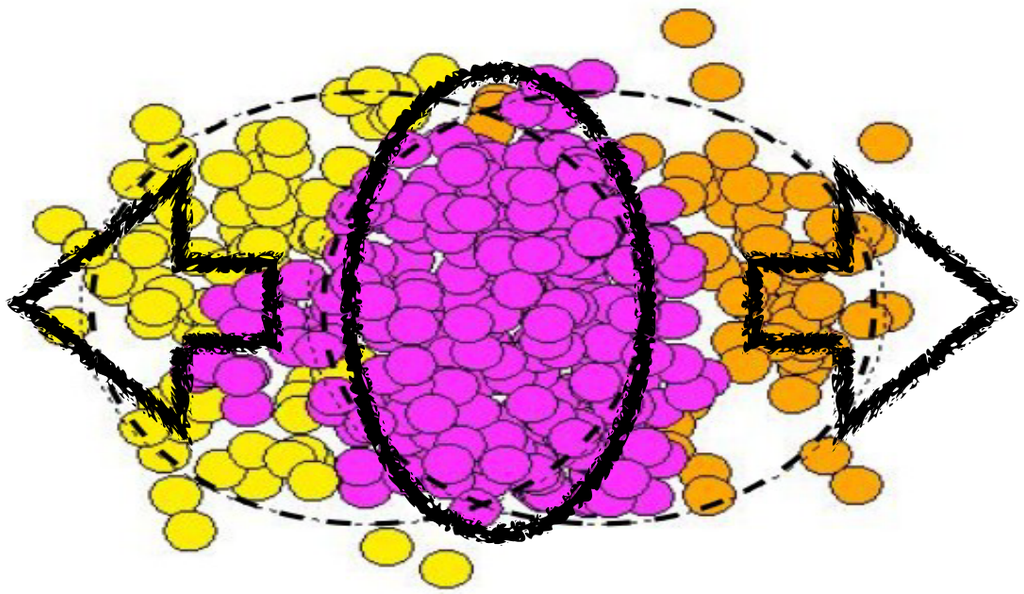


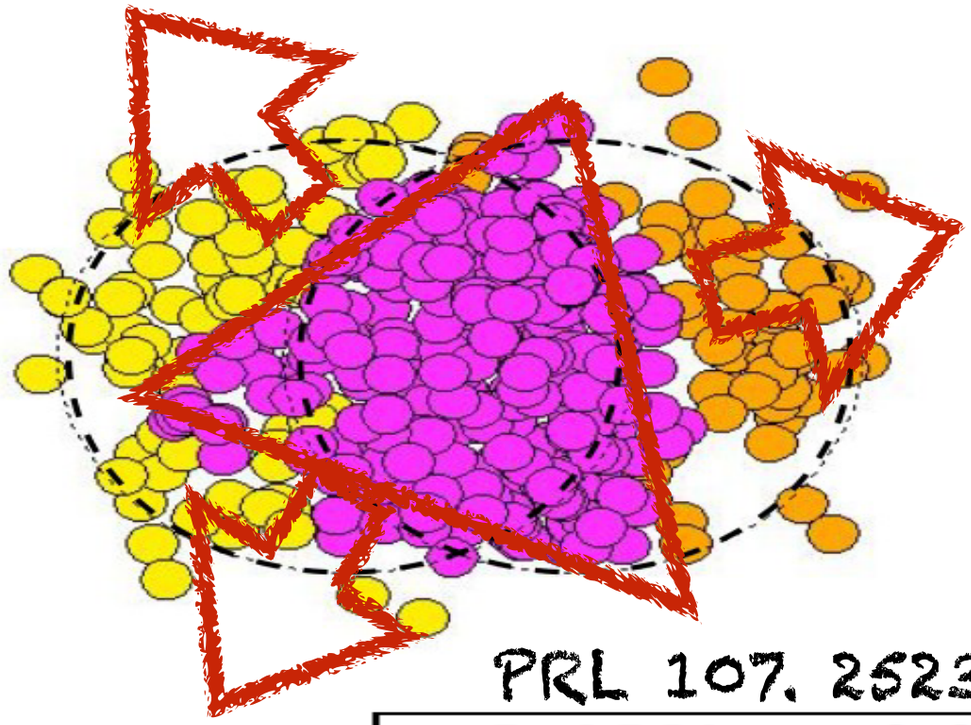




Quark number scaling for pion, Kaon, proton $v_2$

- meson : $n_q = 2$
- baryon : $n_q = 3$
- Azimuthal anisotropic flow is measured at parton level

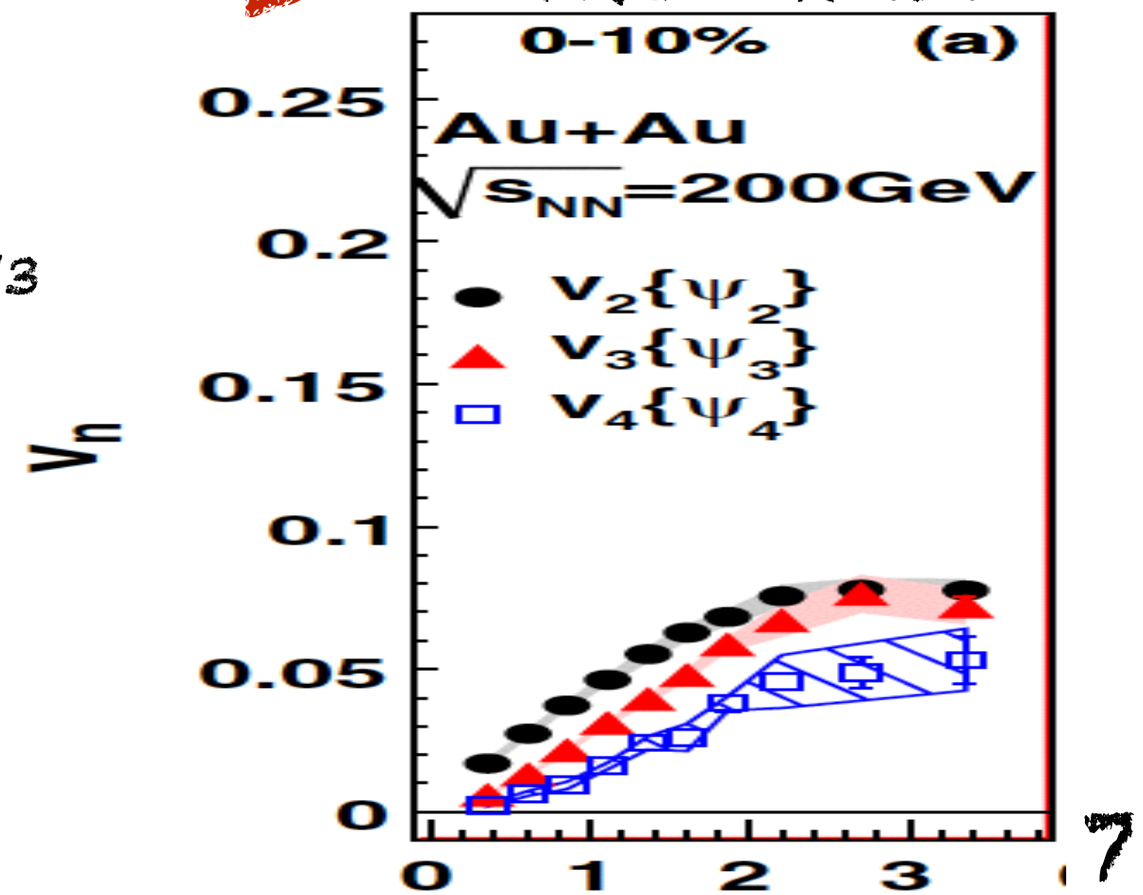
# Higher order flow harmonics





PRL 107, 252301

Participant Fluctuation make $v_3$
- constrain initial condition
- constrain viscosity

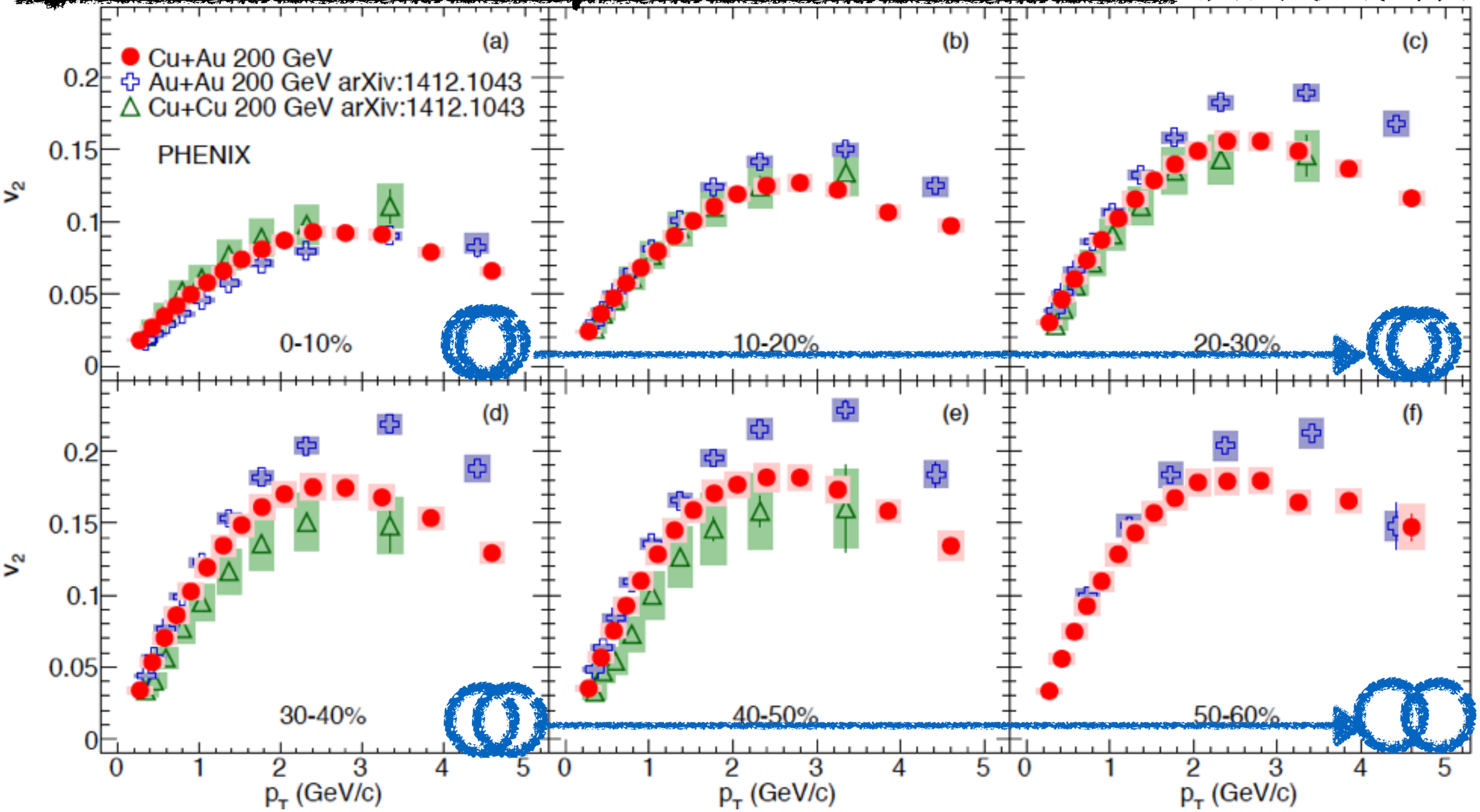


# System size dependence of $v_n$

- Au+Au, Cu+Cu, Cu+Au are tested
- Initial spatial condition
  - Symmetric : Au+Au, Cu+Cu
  - Asymmetric : Cu+Au
- Number of participants
  - Au+Au > Cu+Au > Cu+Cu

# System size dependence of $v_2$

arXiv:1509.07784

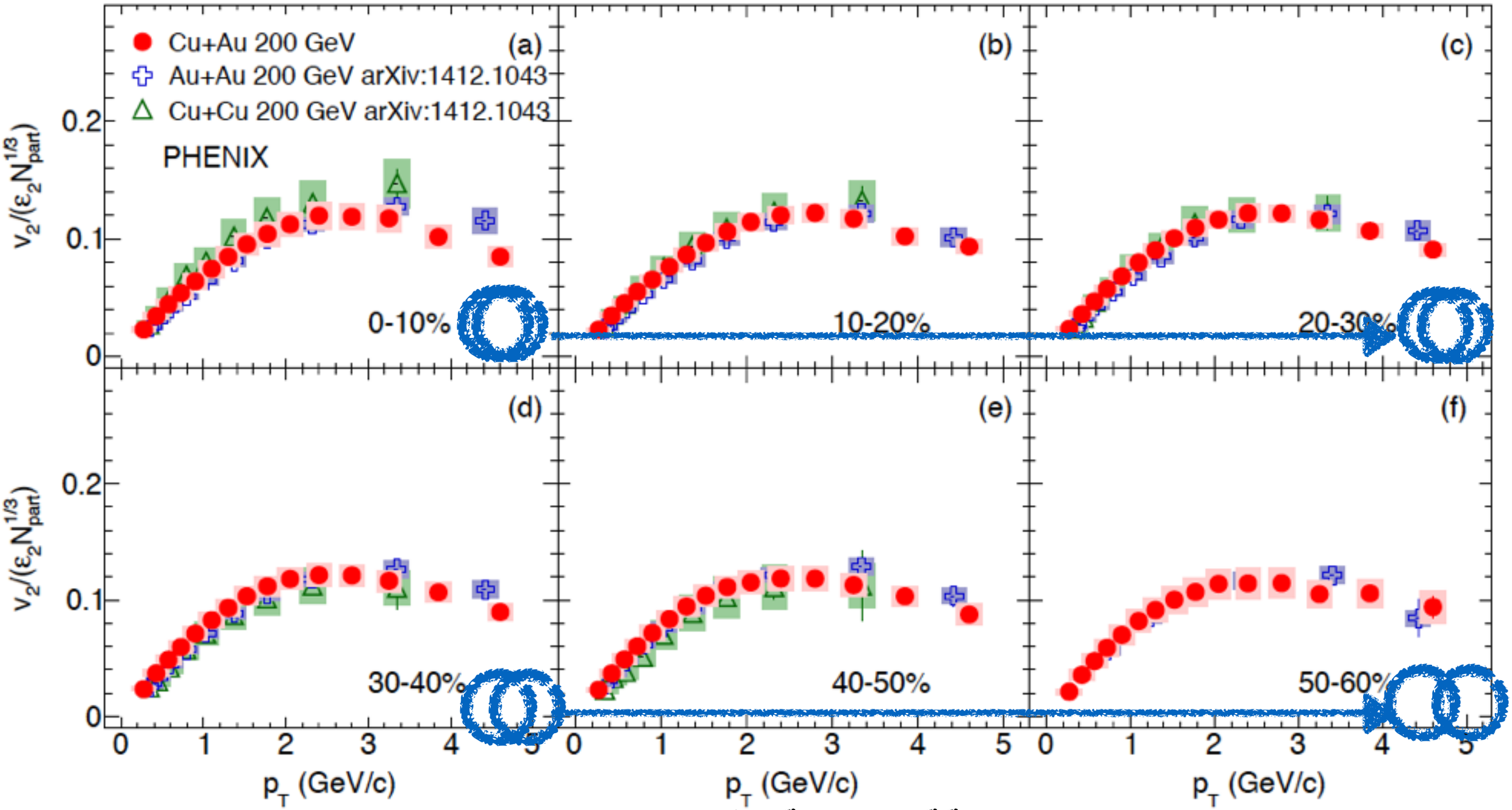



$v_2$ for different systems has centrality and pT dependence

$v_2$ in CuAu is always between those in AuAu and CuCu

# scale v2 with e2*Npart^(1/3)

arXiv:1509.07784



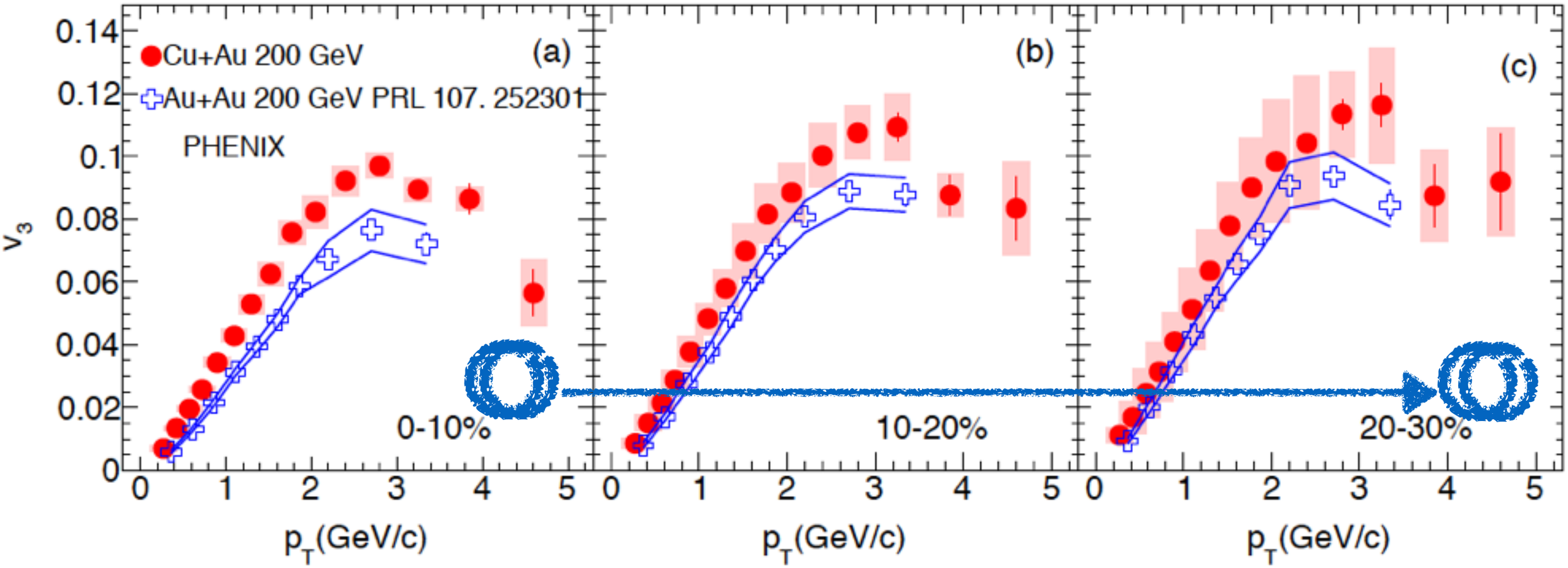

v2 is scaled with e2*Npart^(1/3) for different systems.

-e2 is initial elliptical anisotropy

-Npart^(1/3) is proportional to length scale or expansion time

# System size dependence of $v_3$

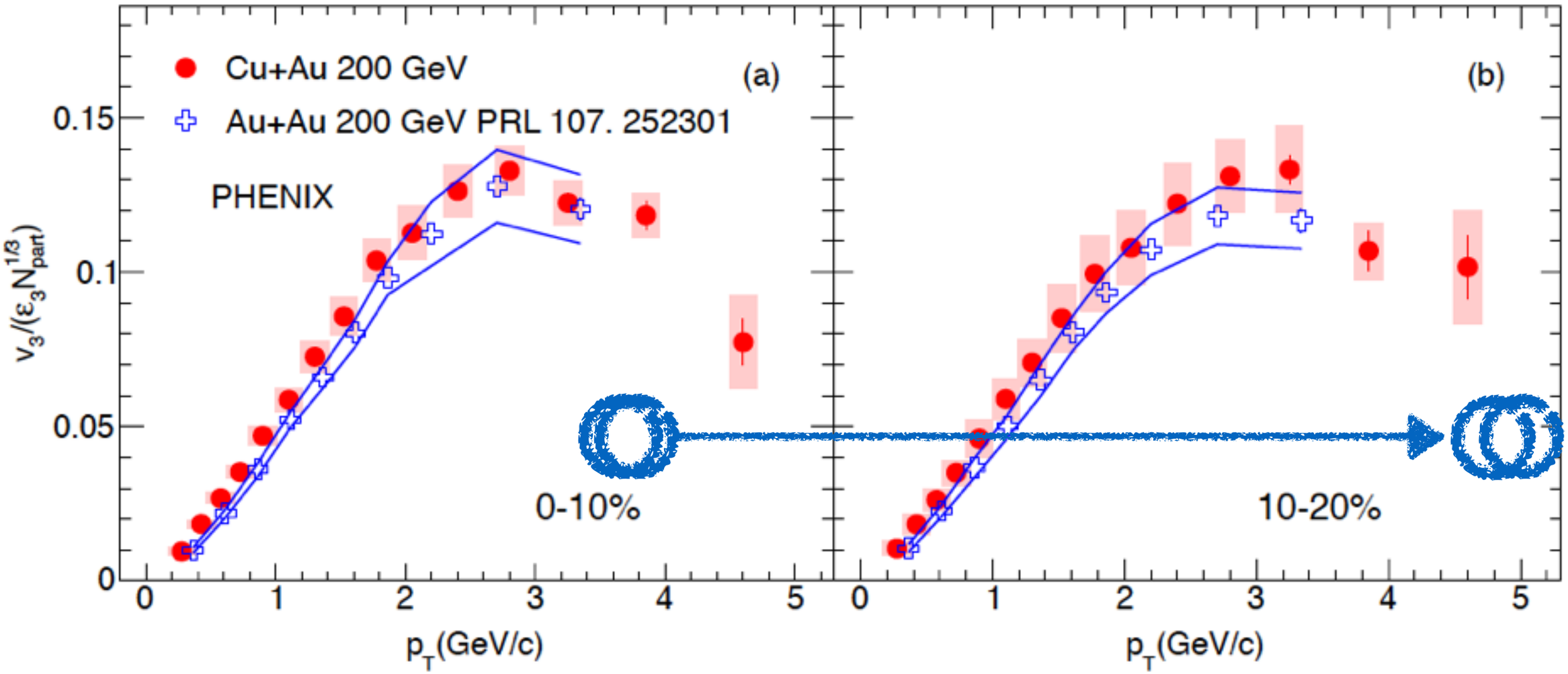
arXiv:1509.07784




$v_3$ for different systems has weak centrality dependence

$v_3$ in CuAu is always bigger than those in AuAu

# scale v3 with e3*Npart^(1/3)




v3 is scaled with e3*Npart(1/3) for different systems.

-v3 is initial triangularity

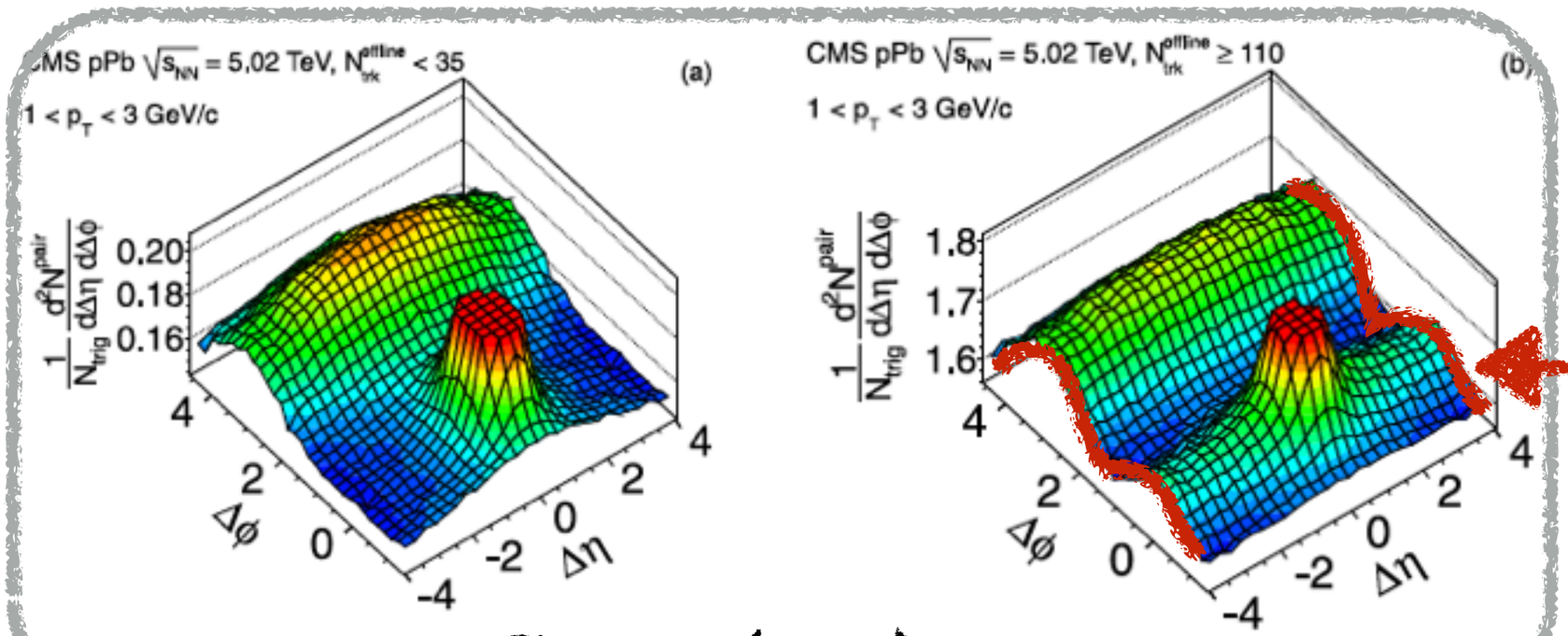
-Npart^(1/3) is proportional to length scale or expansion time

# Small system collisions

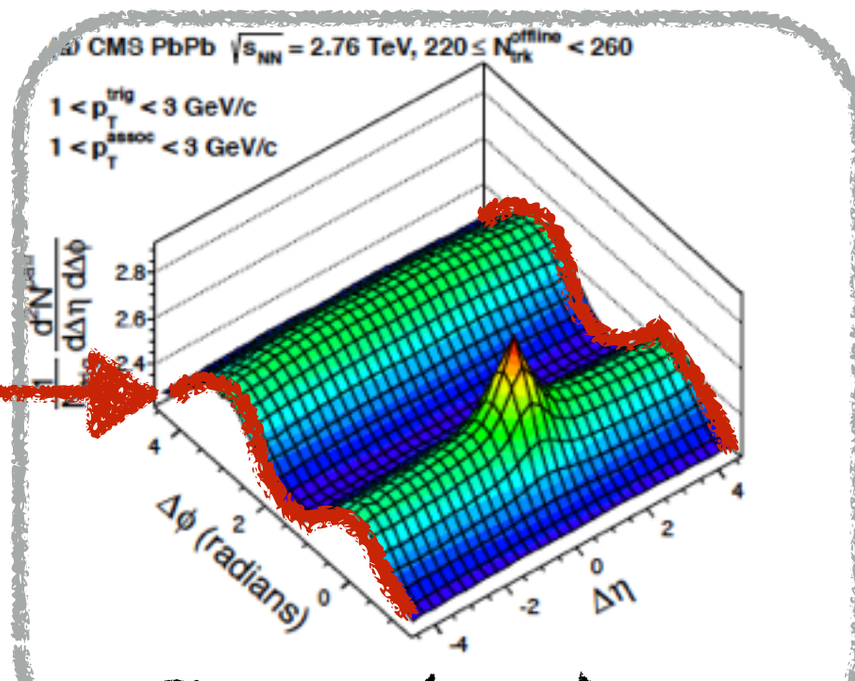
LHC

-v2(Ridge) at high multiplicity event in pPb

pPb → Higher Multiplicity → PbPb




PLB 718 (2013) 795-814



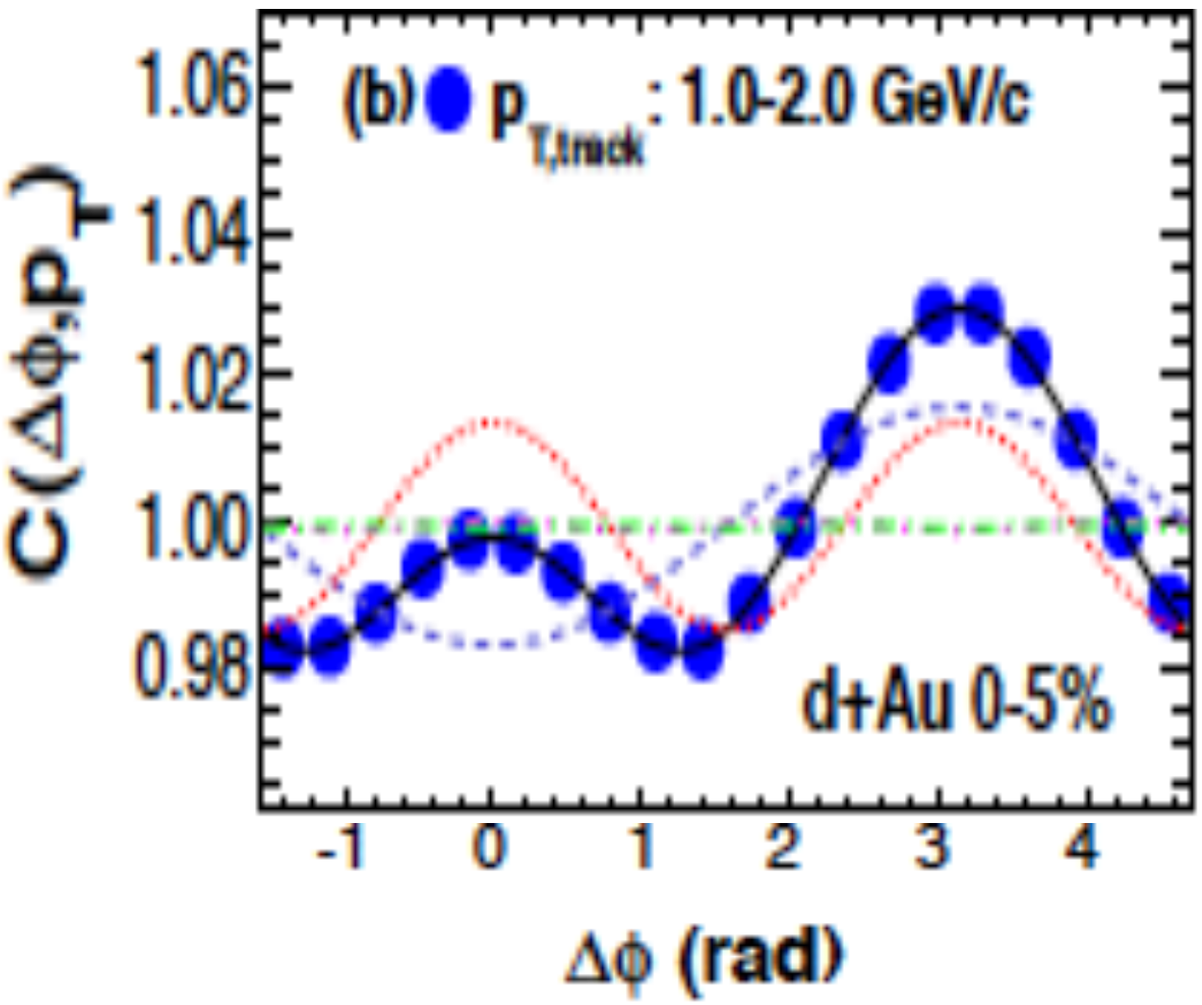

PLB 724 (2013) 213

RHIC

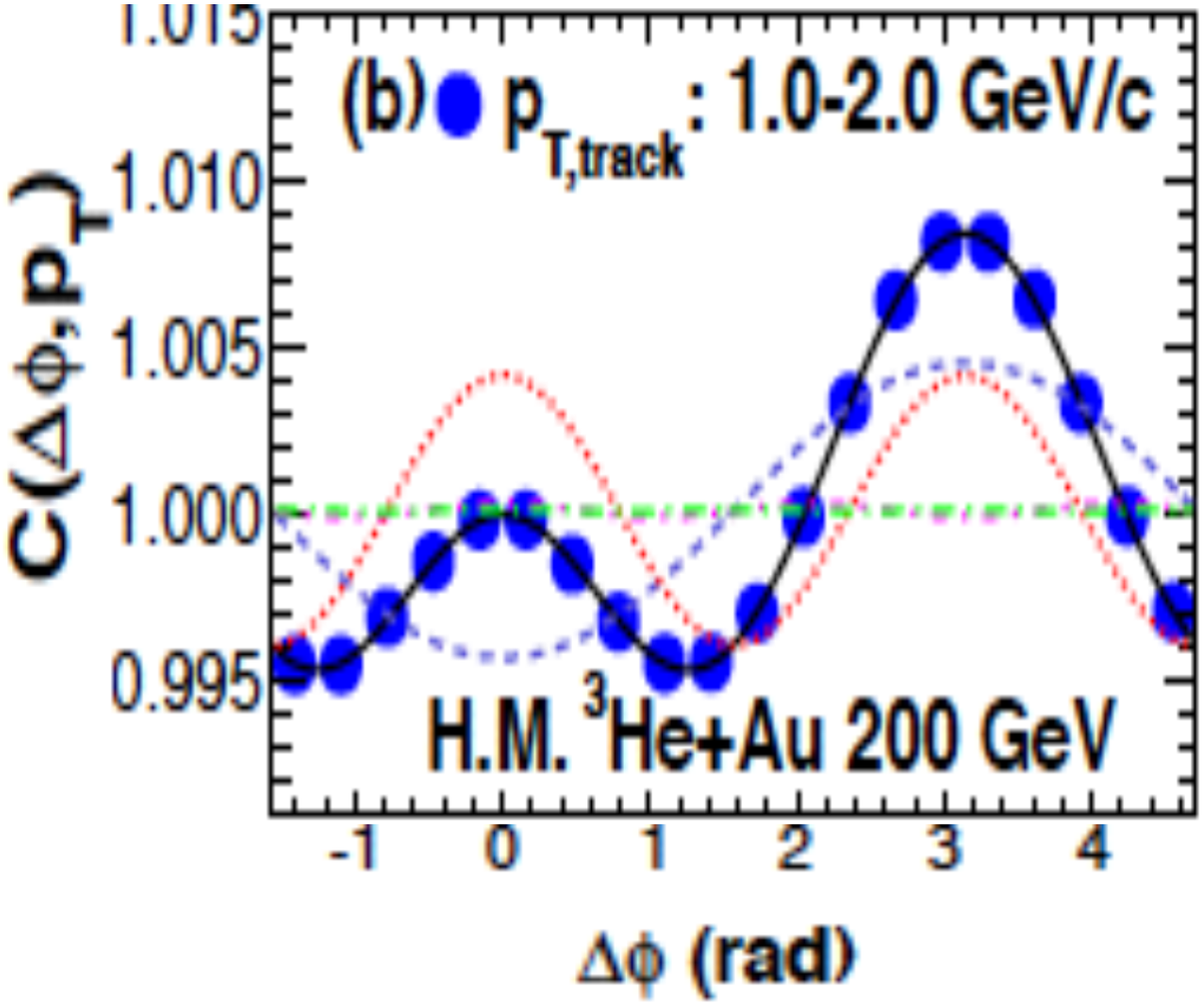
-$^3$HeAu, dAu, pAu collisions

# Flow in dAu/$^3$HeAu ?

PRL. 114, 192301




PRL 115,142301



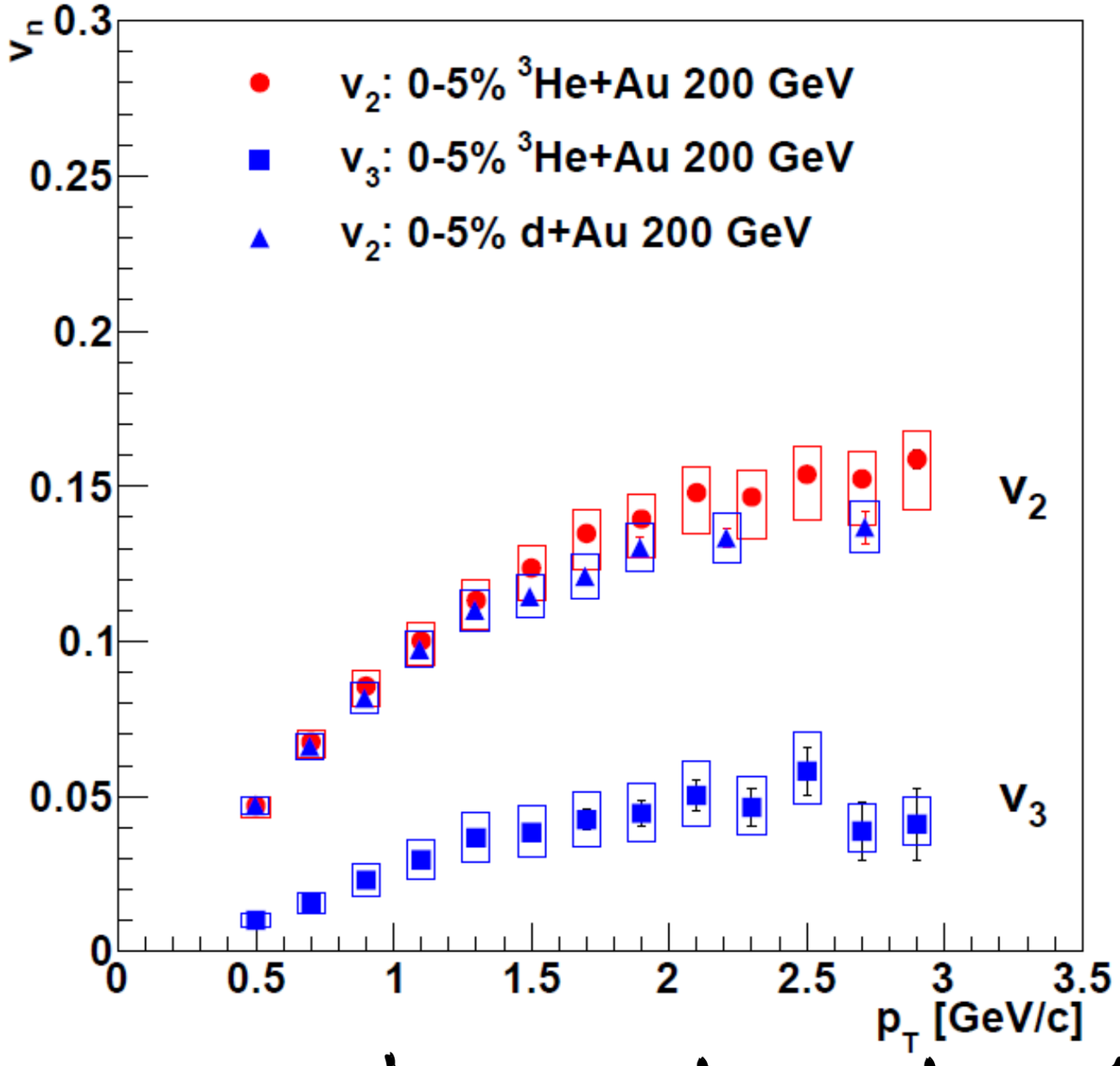

v2 oscillation is observed

-dAu/$^3$HeAu collisions

-Au-going side

-small QGP is created ?

# v2 in d+Au/$^3$He+Au

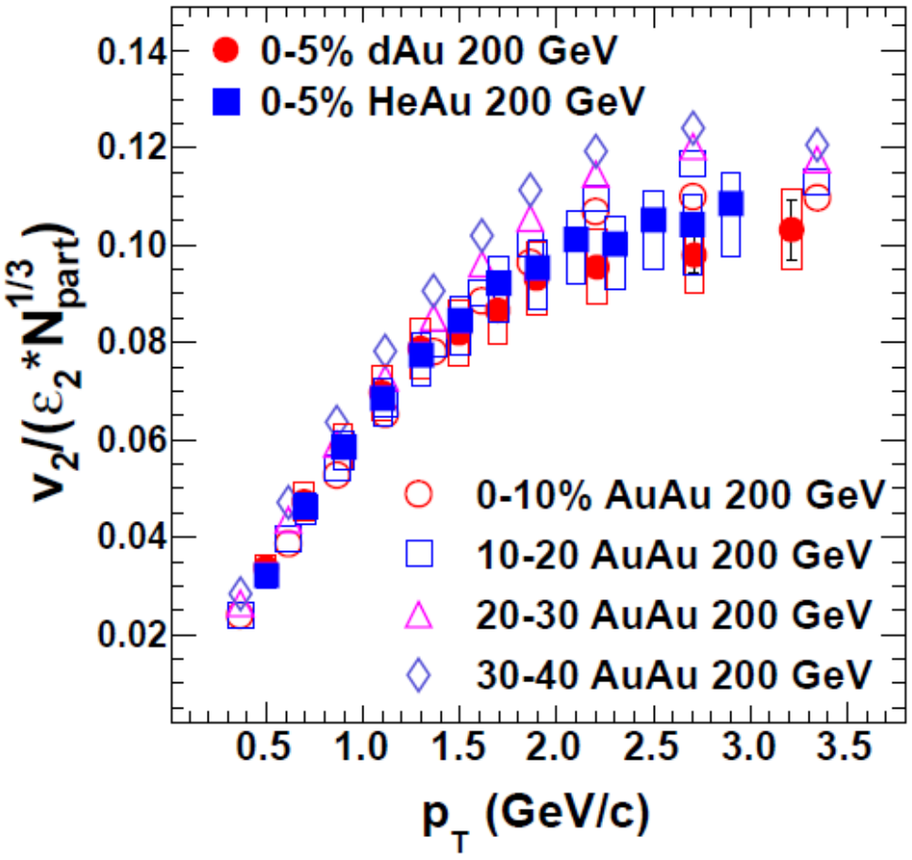


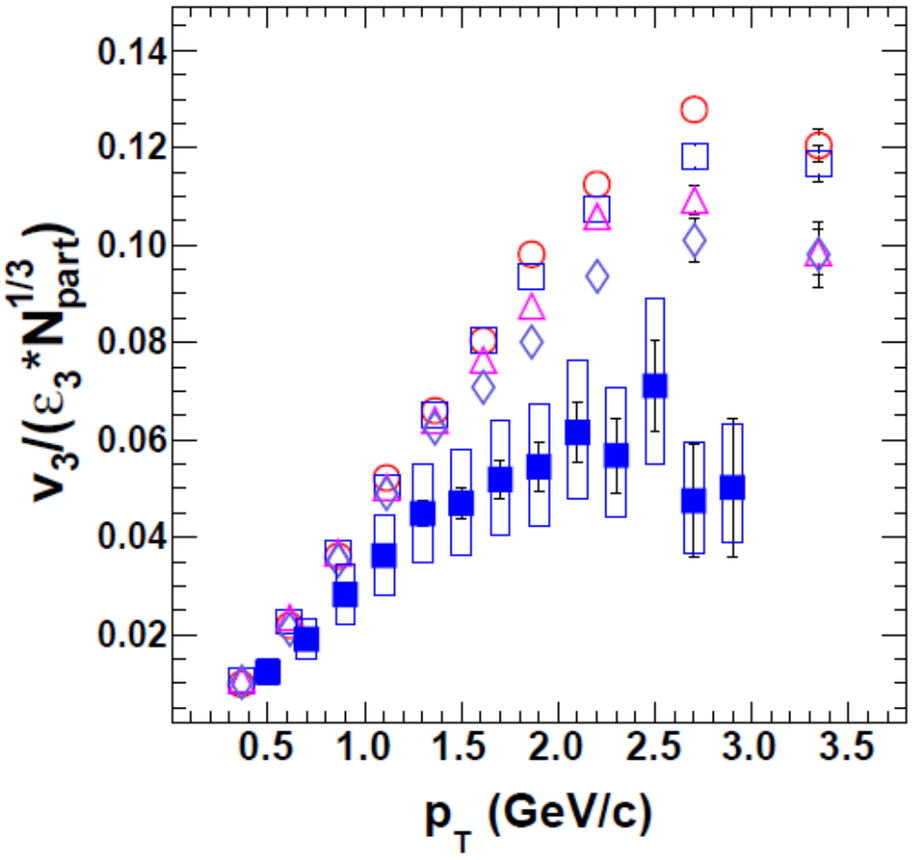

Sizable v2 are observed in dAu for 0-5%

Sizable v2, v3 are observe in HeAu for 0-5%

v2 in dAu and $^3$HeAu are similar

# en*Npart^(1/3) scaling in dAu/$^3$HeAu

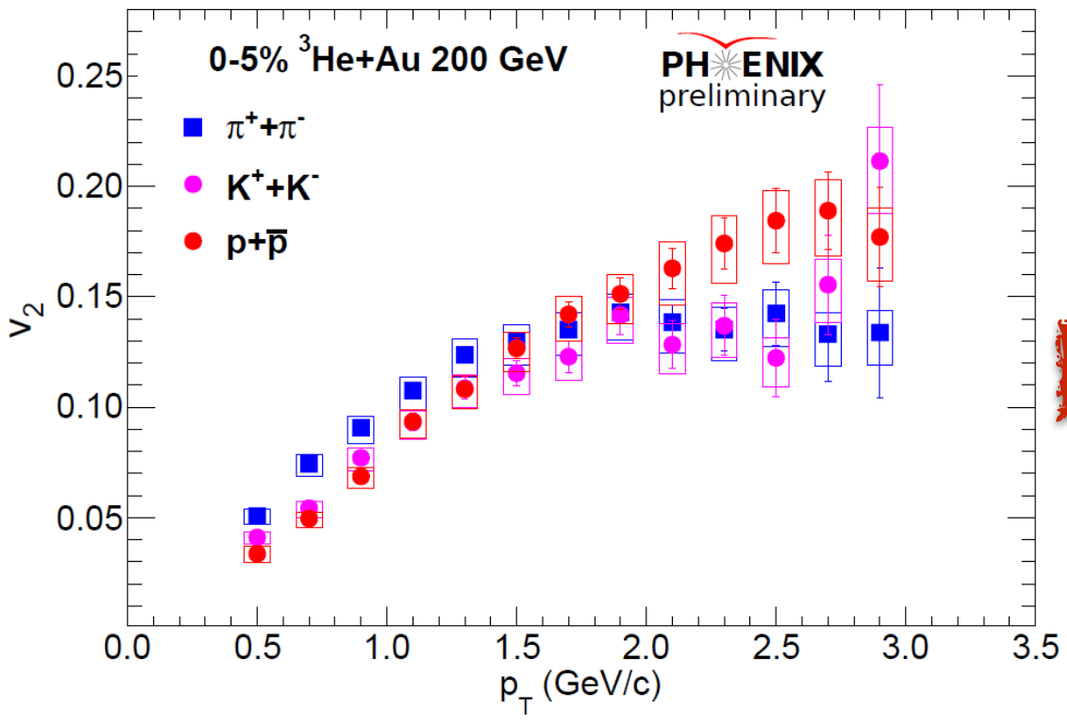


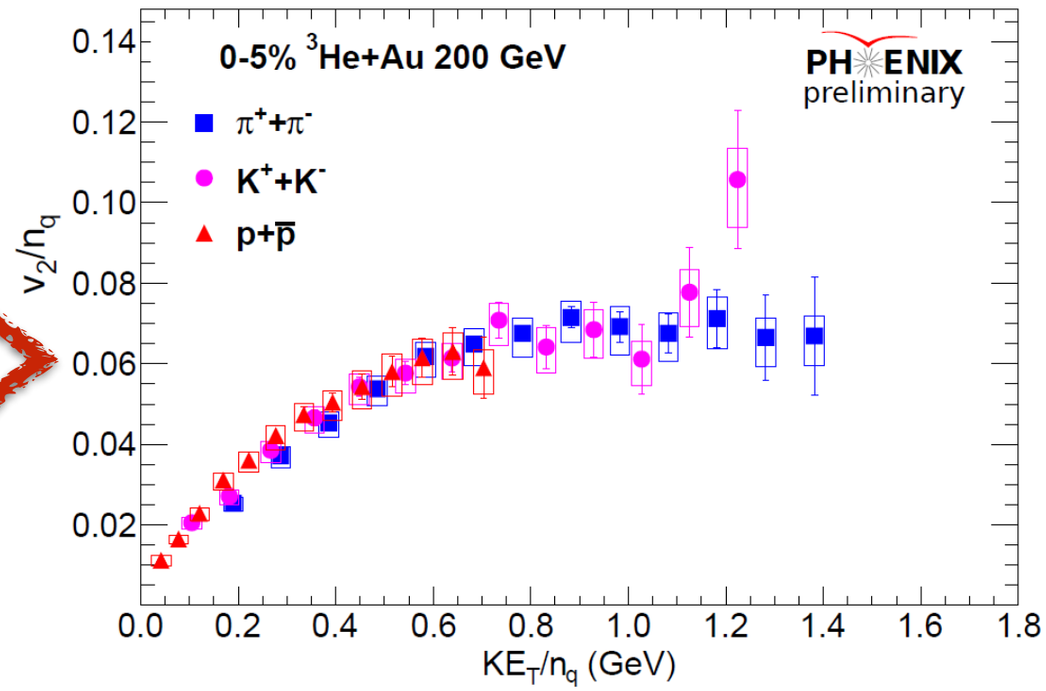




en*Npart^(1/3) scaling are tested

- Npart^(1/3) is proportional to length scale or expansion time
- works for v2
- not work well for v3

# Partonic collectivity in $^3$HeAu ?




At $p_T$ < 1.5 GeV/c: mass order -- v3(proton)< v2(kaon)< v2(pion)

At $p_T$> 2.0 GeV/c: difference for meson and baryon

These behaviors are very similar to that in Au+Au collisions

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

# Summary

$v_2$ and $v_3$ are studied in different colliding systems

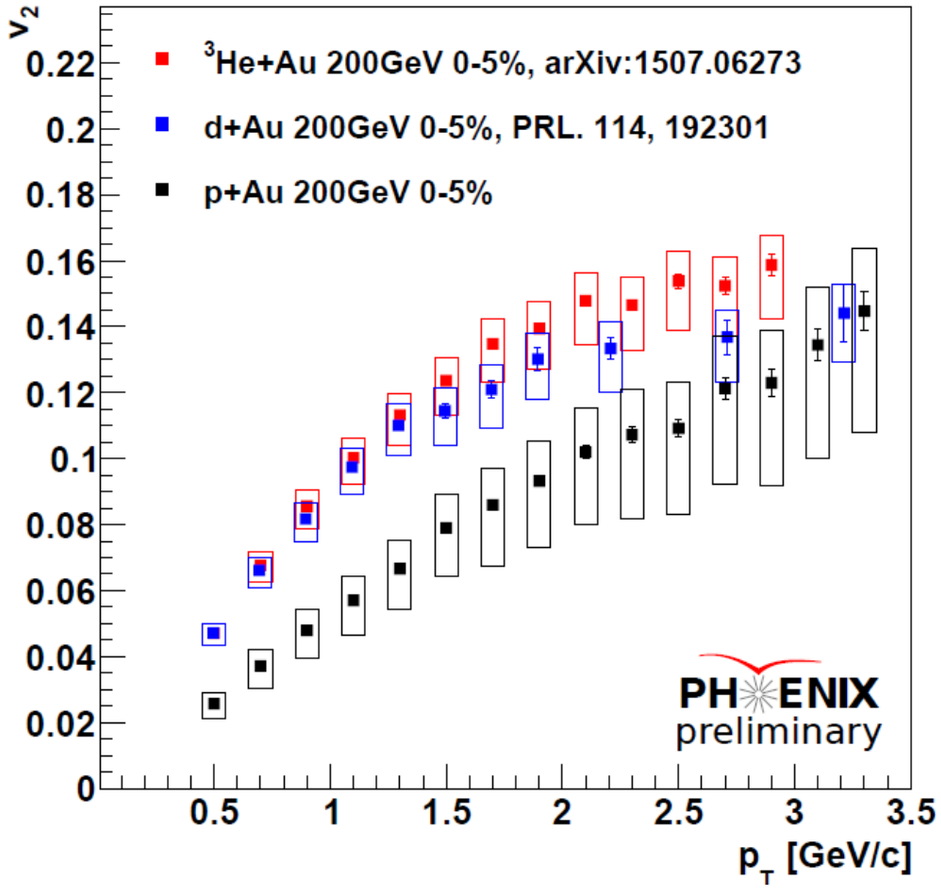
Heavy ion collisions:CuCu, CuAu, AuAu

- similar centrality and pT dependence
- $v_2$, and v3 are scaled with $\varepsilon_n * N_{part}^{1/3}$

Small system collisions:dAu, 3HeAu

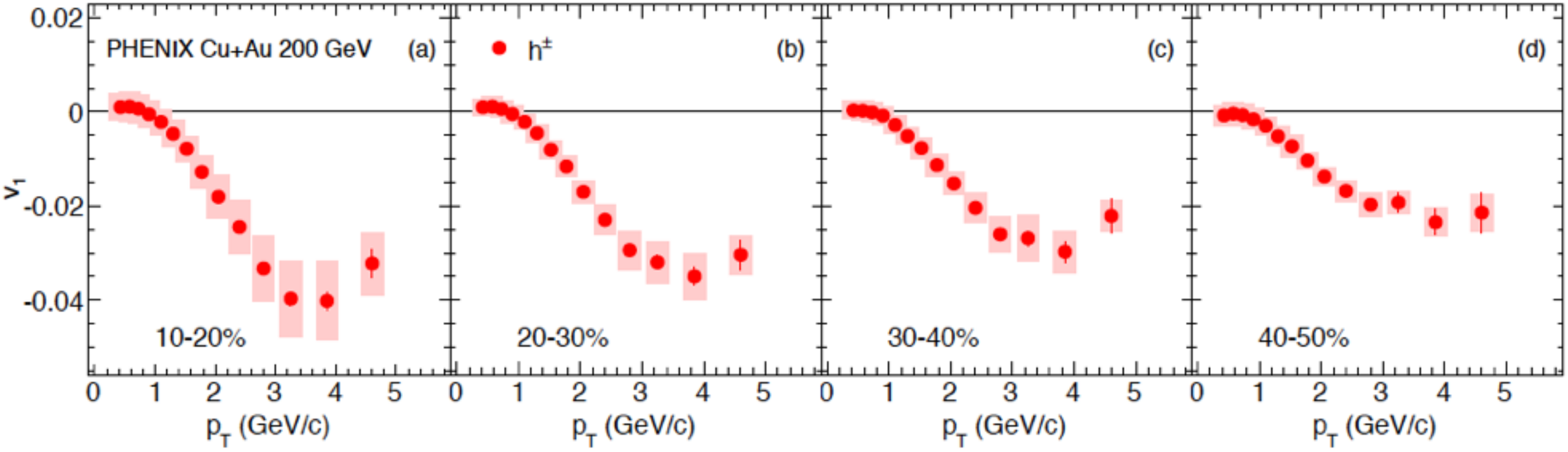
- sizable $v_2$ are observed in dAu
- sizable $v_2$,$v_3$ are observed in 3HeAu
- $v_2$ in dAu/3HeAu are scaled with $\varepsilon_2 * N_{part}^{1/3}$
- $v_3$ in 3HeAu are not scaled with $\varepsilon_3 * N_{part}^{1/3}$
- pion, Kaon, proton $v_2$ in $^3$HeAu are scaled
  - partonic collectivity ?

# v2 in p+Au collisions



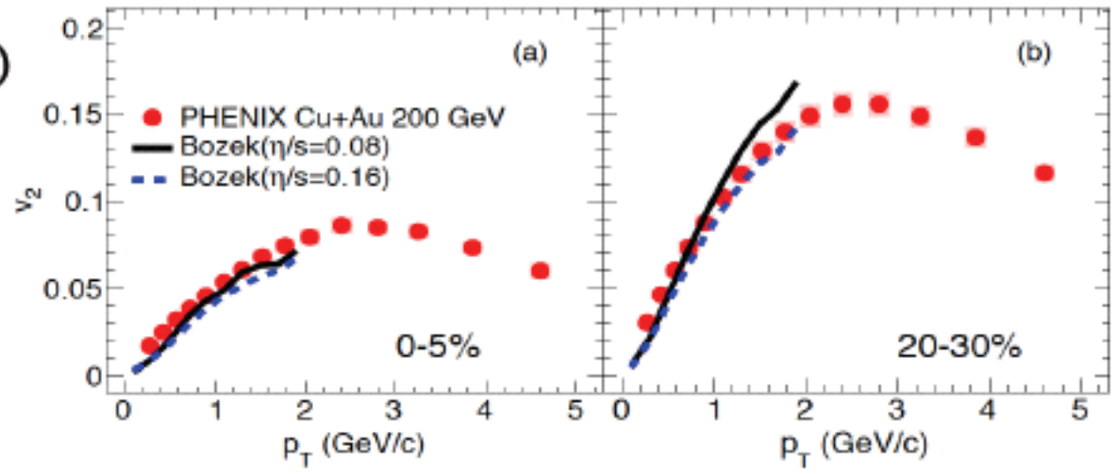
# v1 in CuAu

arXiv:1509.07784

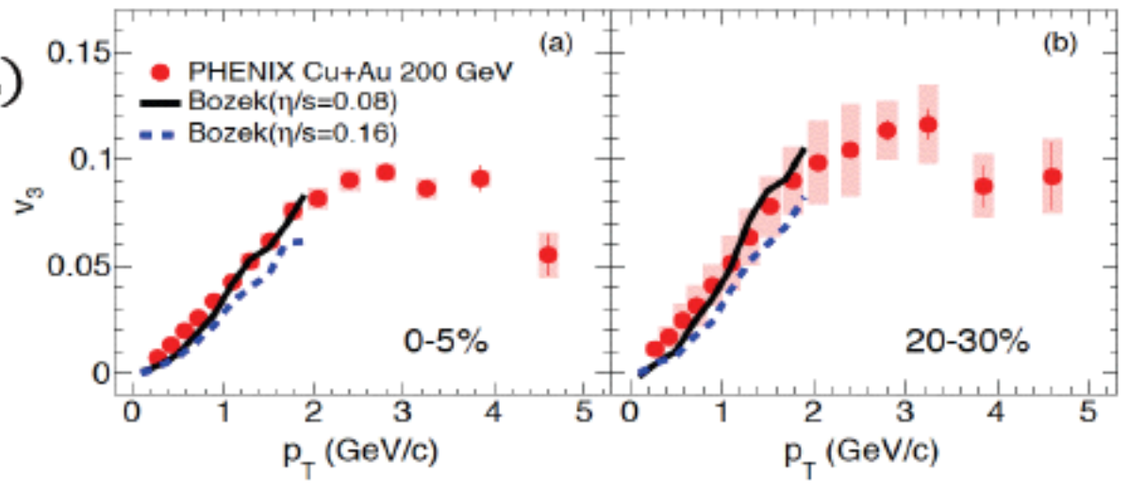


arXiv:1509.07784

✓ $v_2(p_T)$

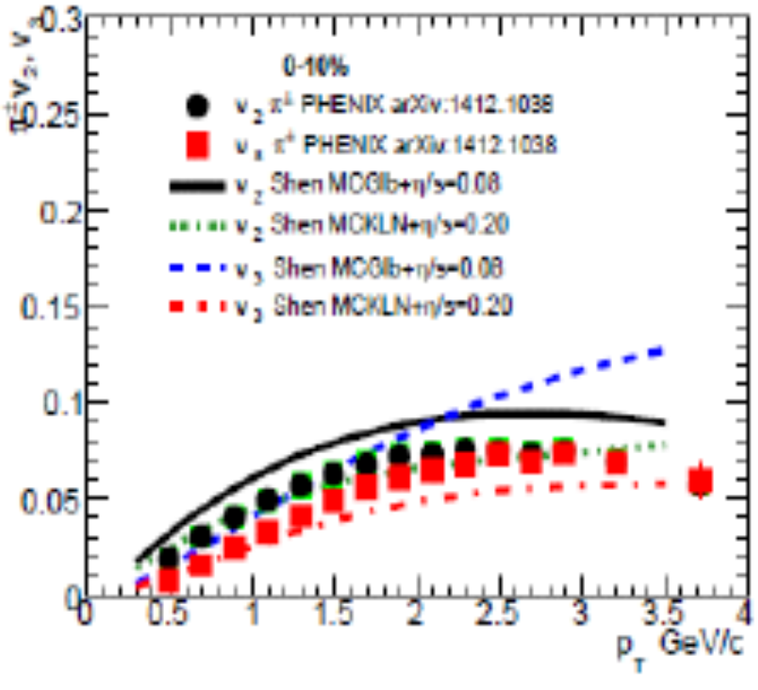


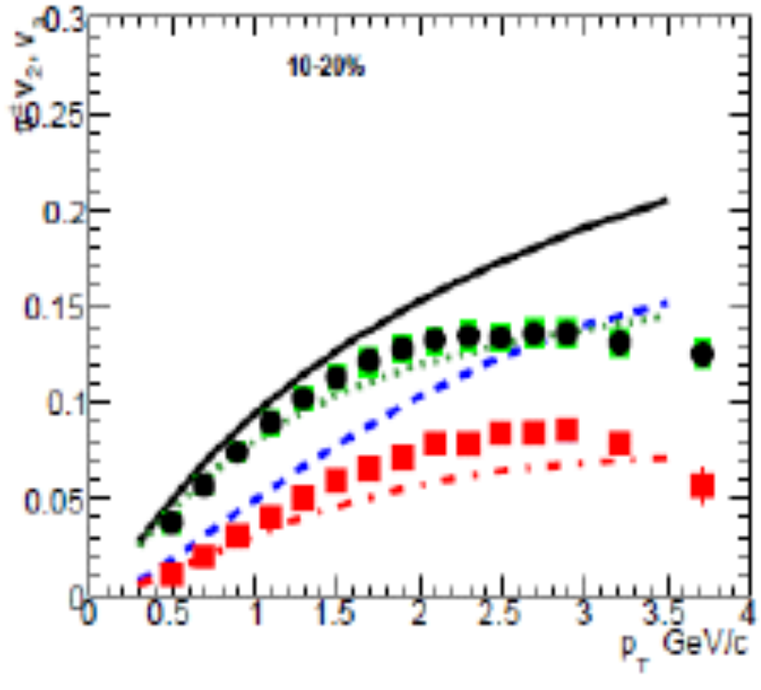

✓ $v_3(p_T)$

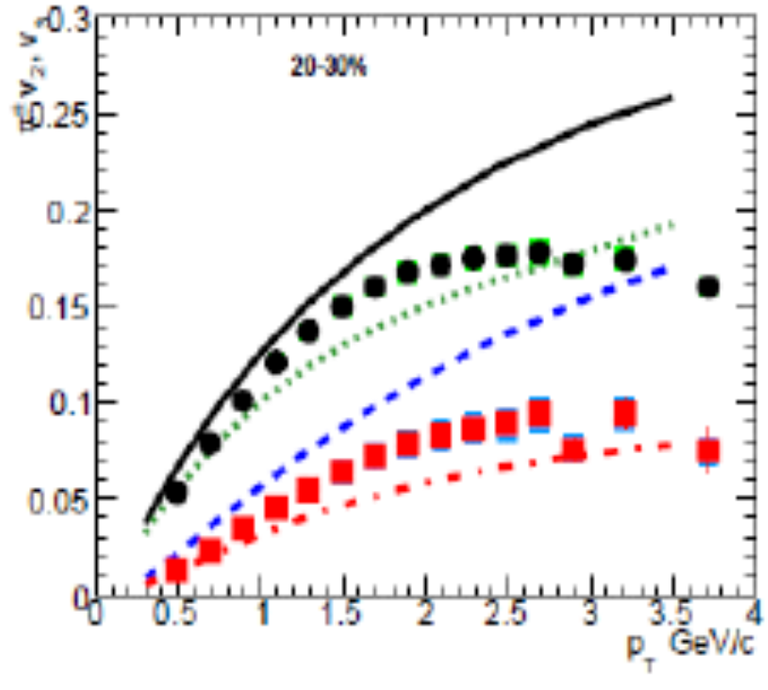


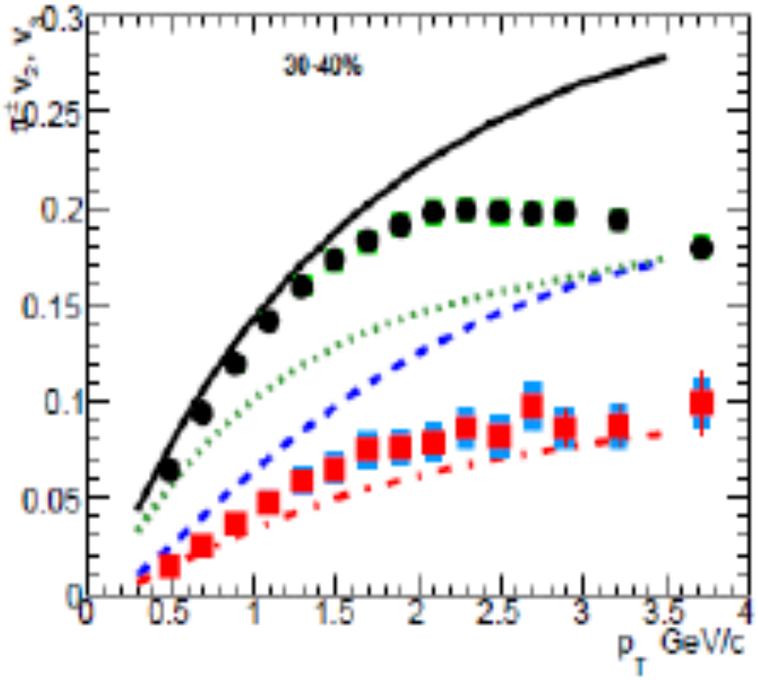

Glauber + even-by-event hydrodynamics calculations with $\eta/s$ =0.08, 0.16 are compared to measured $v_2$,$v_3$ for 0-5%, 20-30% centrality bins. Our measurements in 20-30% are well reproduced. For the most 0-5%, a value of $\eta/s$ =0.08 is preferd by data

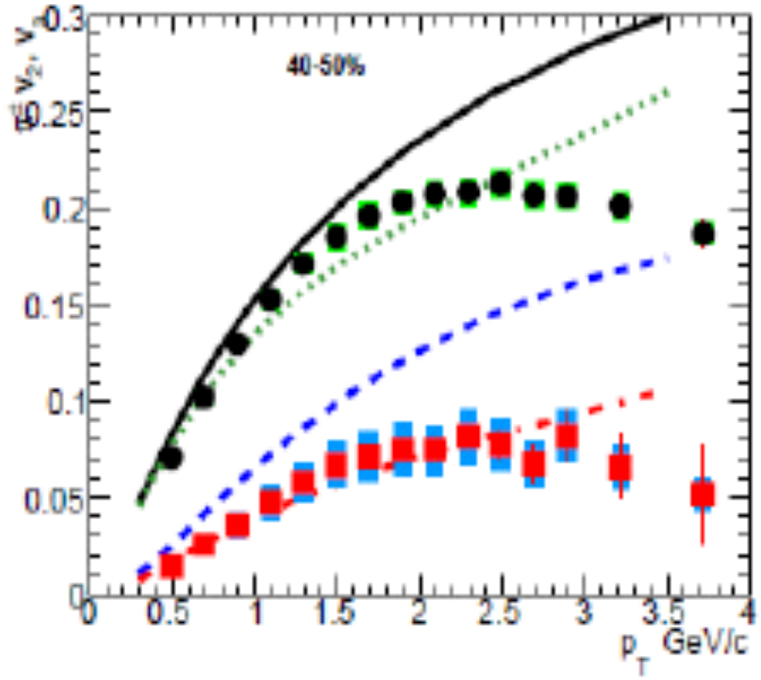
# pion v2 in AuAu

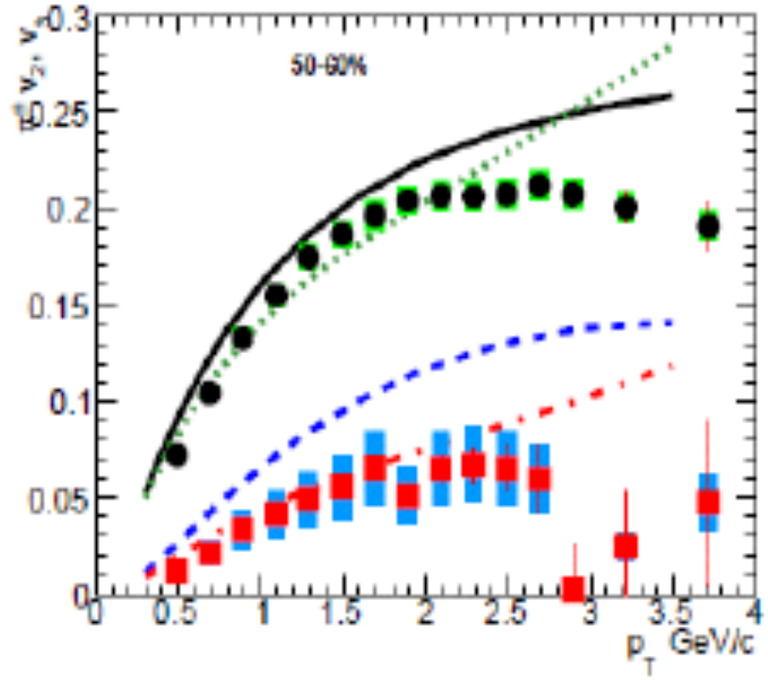



From Justin slide at WWND15

Gale et. al. PRL 110.012302