Measurements of 1st, 2nd and 3rd azimuthal anisotropy in $\sqrt{s_{NN}}$=200GeV Cu+Au collisions at RHIC-PHENIX

RHIC-PHENIX実験における$\sqrt{s_{NN}}$=200GeV

銅・金衝突での1次、2次、3次方位角異方性の測定

Pre-Defense

Oct. 28th 2016

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Outline

✓Introduction

- Quark Gluon Plasma(QGP)
- Azimuthal anisotropy
- CuAu collisions

✓Experiment/Analysis

- PHENIX
- centrality, event plane
- Simulation

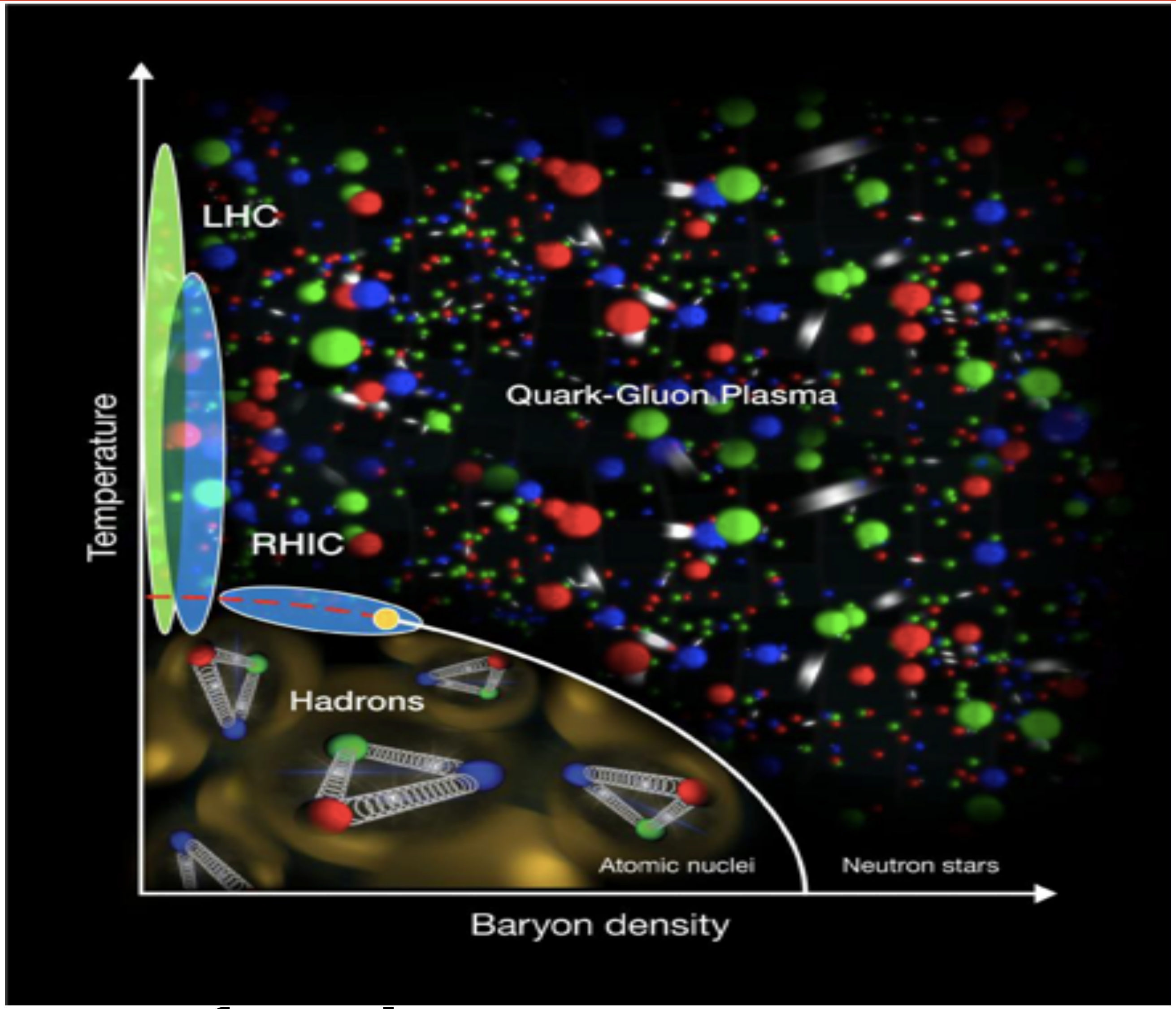
✓Results/Discussions

- v_n at mid, forward/backward rapidities
- Initial model study
- Theory comparison

✓Summary

Introduction

Quark Gluon Plasma(QGP)



QGP is a state of nuclear matter

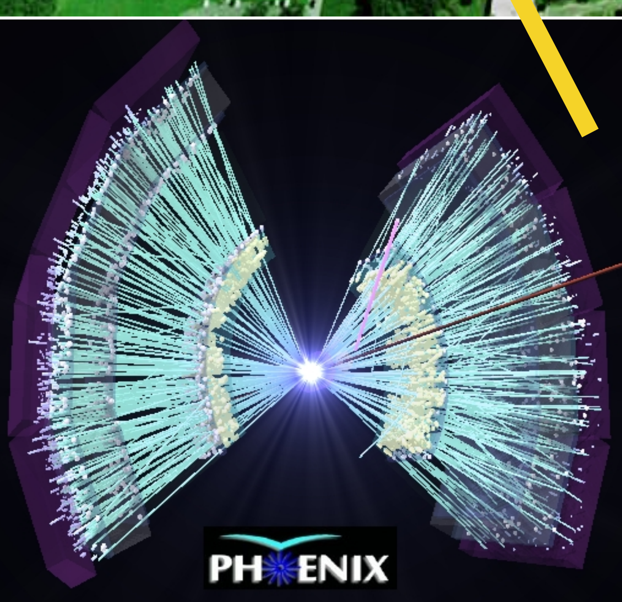
- **extremely high temperature, density**
- **consist of asymptotic free quarks and gluons**
- **Almost perfect liquid**

Predicted phase transition ε_c and T_c by Lattice QCD calculation

- **$T_c \sim 170$ MeV**
- **$\varepsilon_c \sim 1$ [GeV/fm^3]**

Relativistic 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



Wide range of species and energies

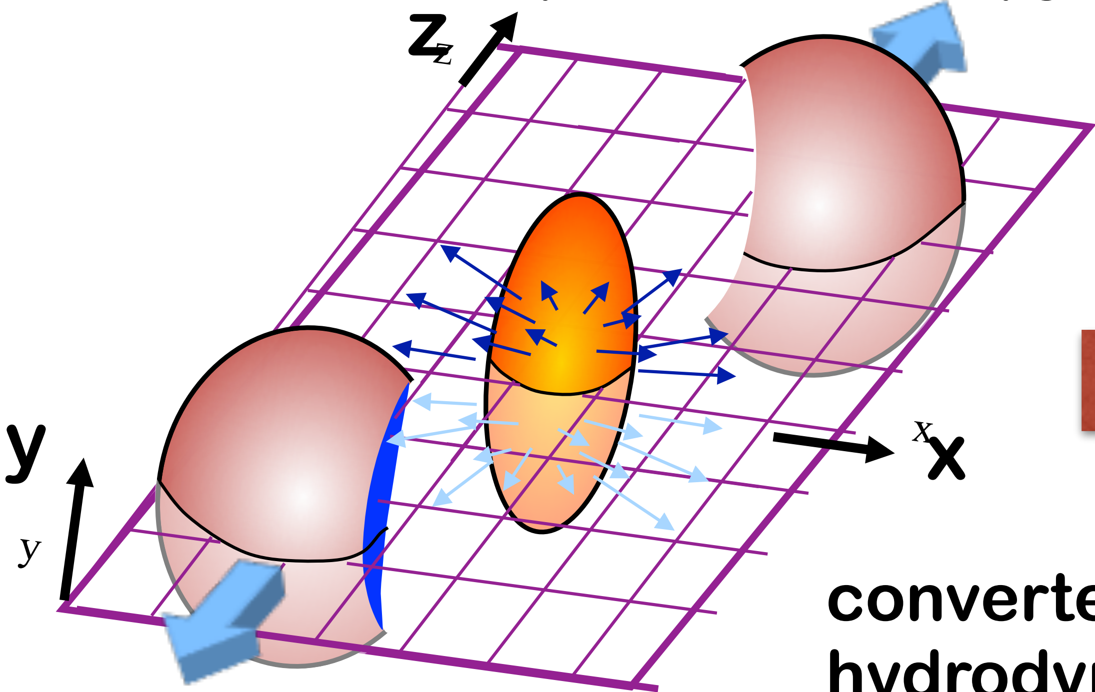
Relativistic heavy ion collision is unique tool to form QGP

Au+Au 200GeV@RHIC

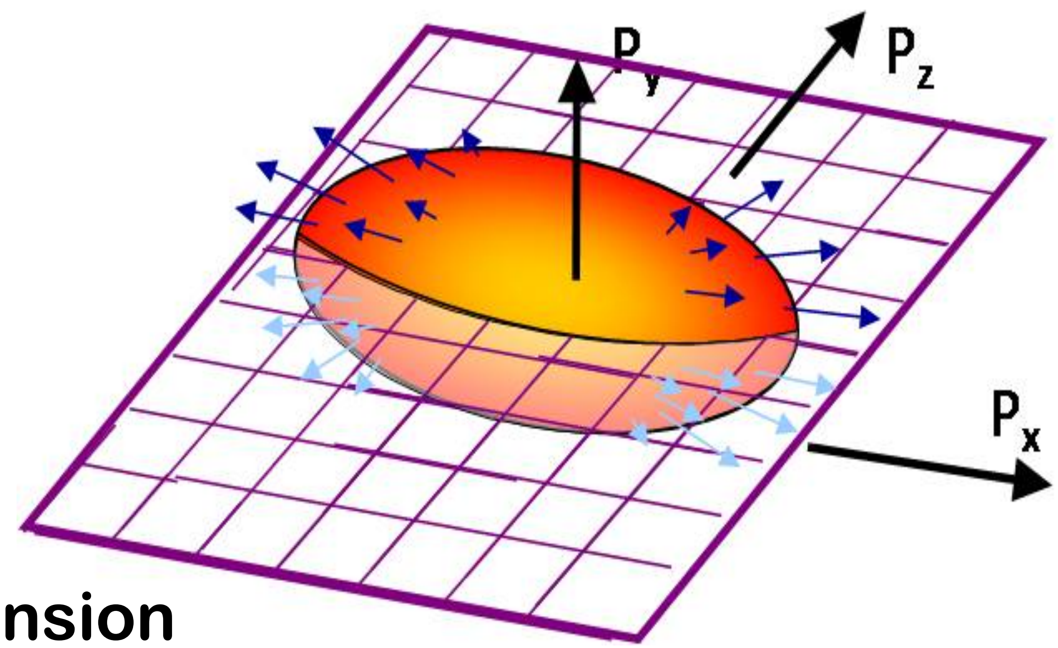
- $\varepsilon_{Bj} \sim 5$ [GeV/fm^3] > ε_c

Azimuthal anisotropy:Elliptic flow

Initial spatial anisotropy:ε_2



Momentum anisotropy:v_2



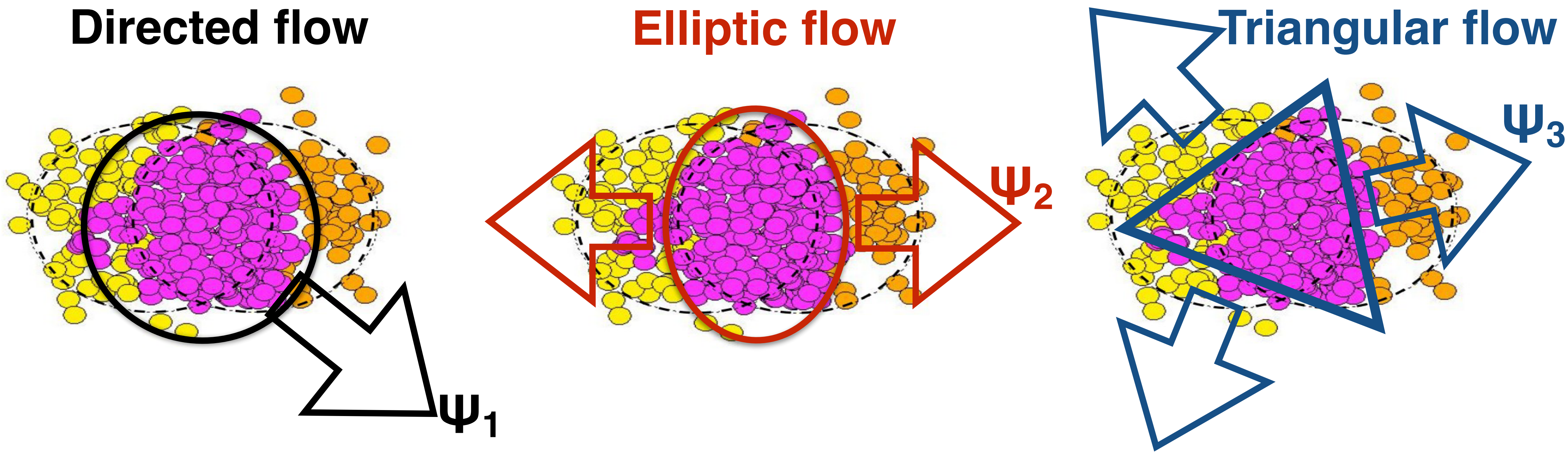
converted though hydrodynamic expansion

✓Particle production will have an elliptical azimuthal distribution.

- **Initial spatial anisotropy ε_2 -> Momentum anisotropy v_2**
- **Non-isotropic pressure gradient**

Sensitive to
-initial condition
(Glauber(nucleon),KLN(gluon)..etc.)
-viscosity of QGP (η/s)

Azimuthal anisotropy:Directed,Triangular flow



Event by event, initial participant fluctuation can lead to

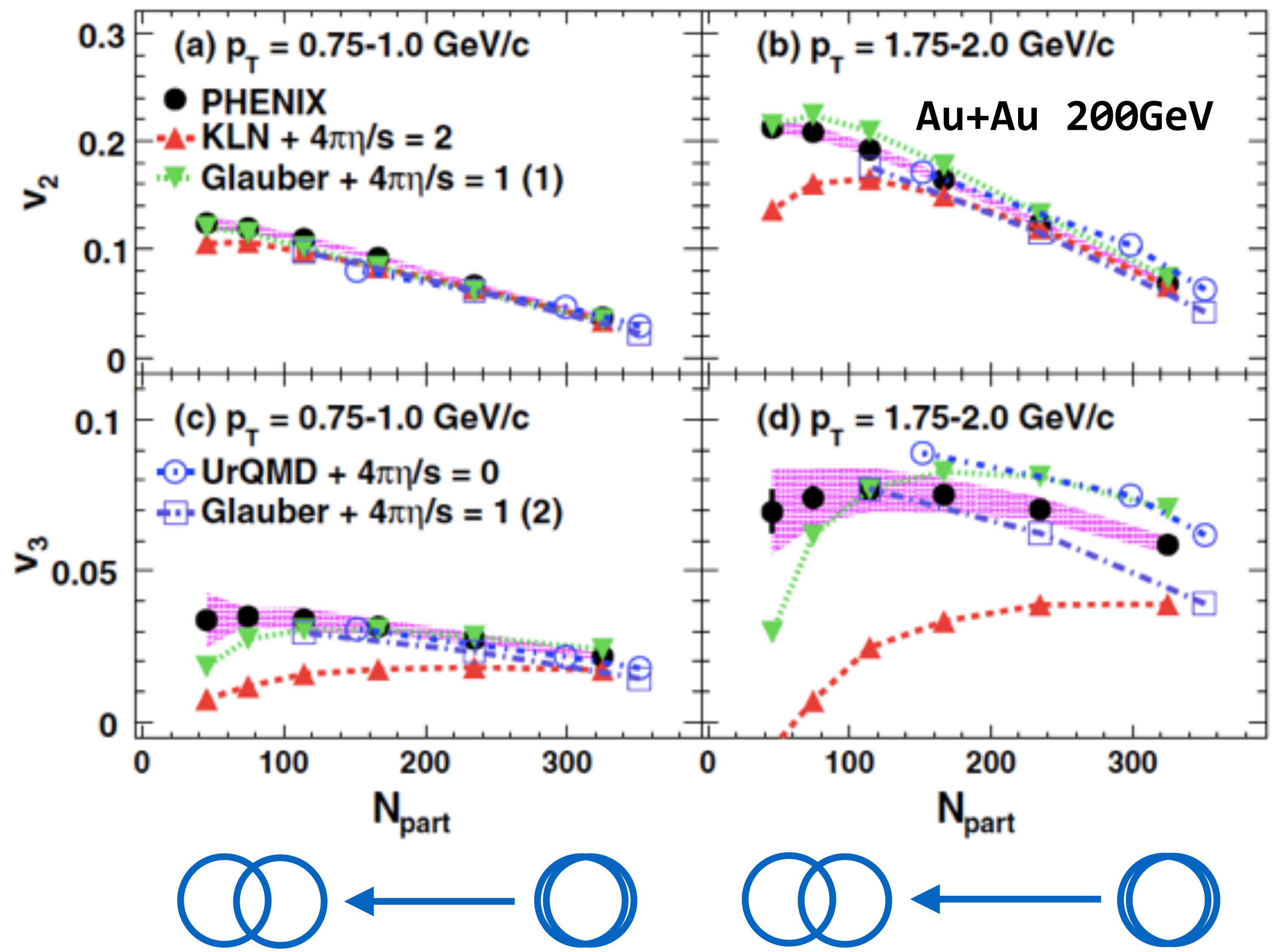
-Directed particle production anisotropy v_1

-Triangular particle production anisotropy v_3

-v_4, v_5, v_6

v_n constrain initial condition & viscosity

v2, v3 theory comparison

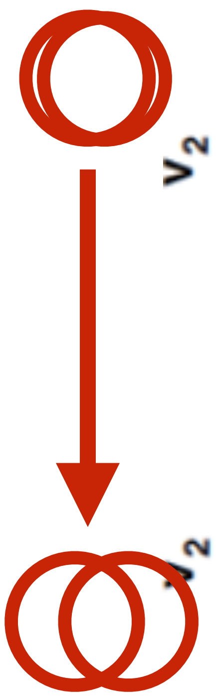


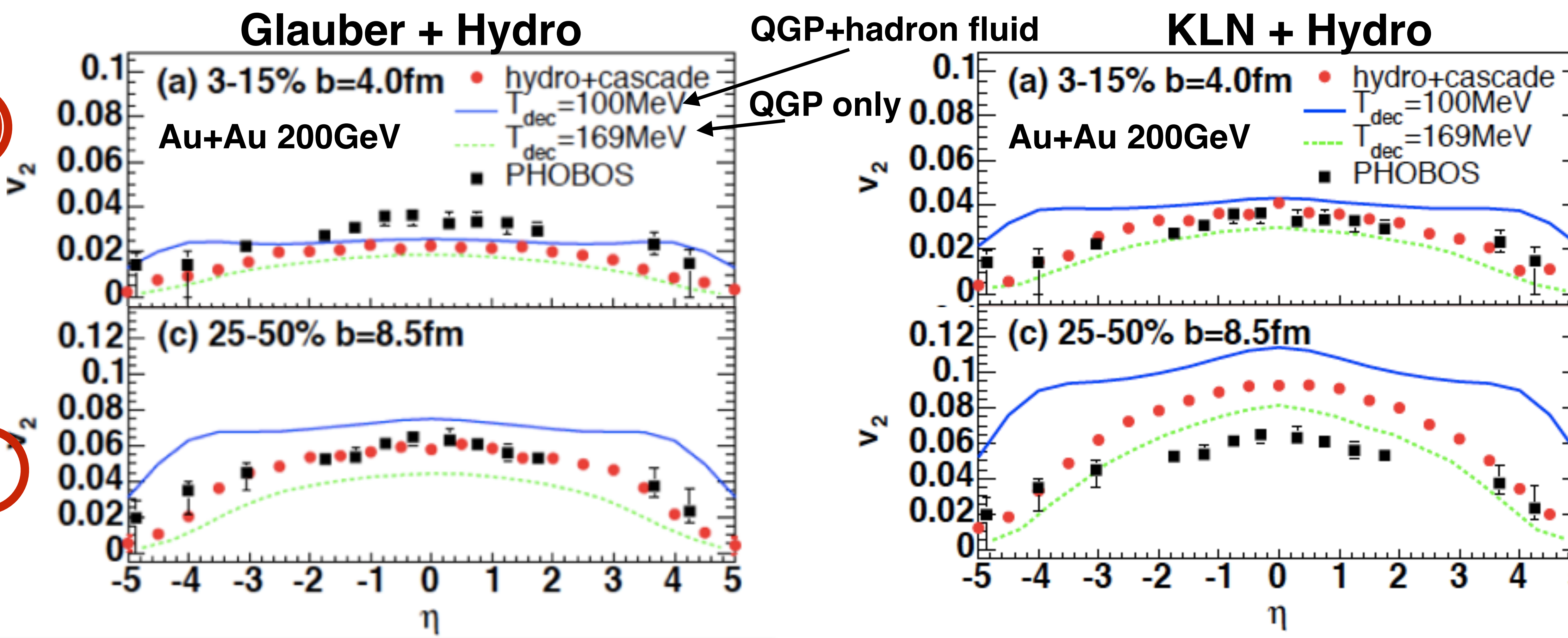
v_2, v_3 are sensitive to initial condition and viscosity of QGP

- Theoretically, initial condition and viscosity have uncertainty

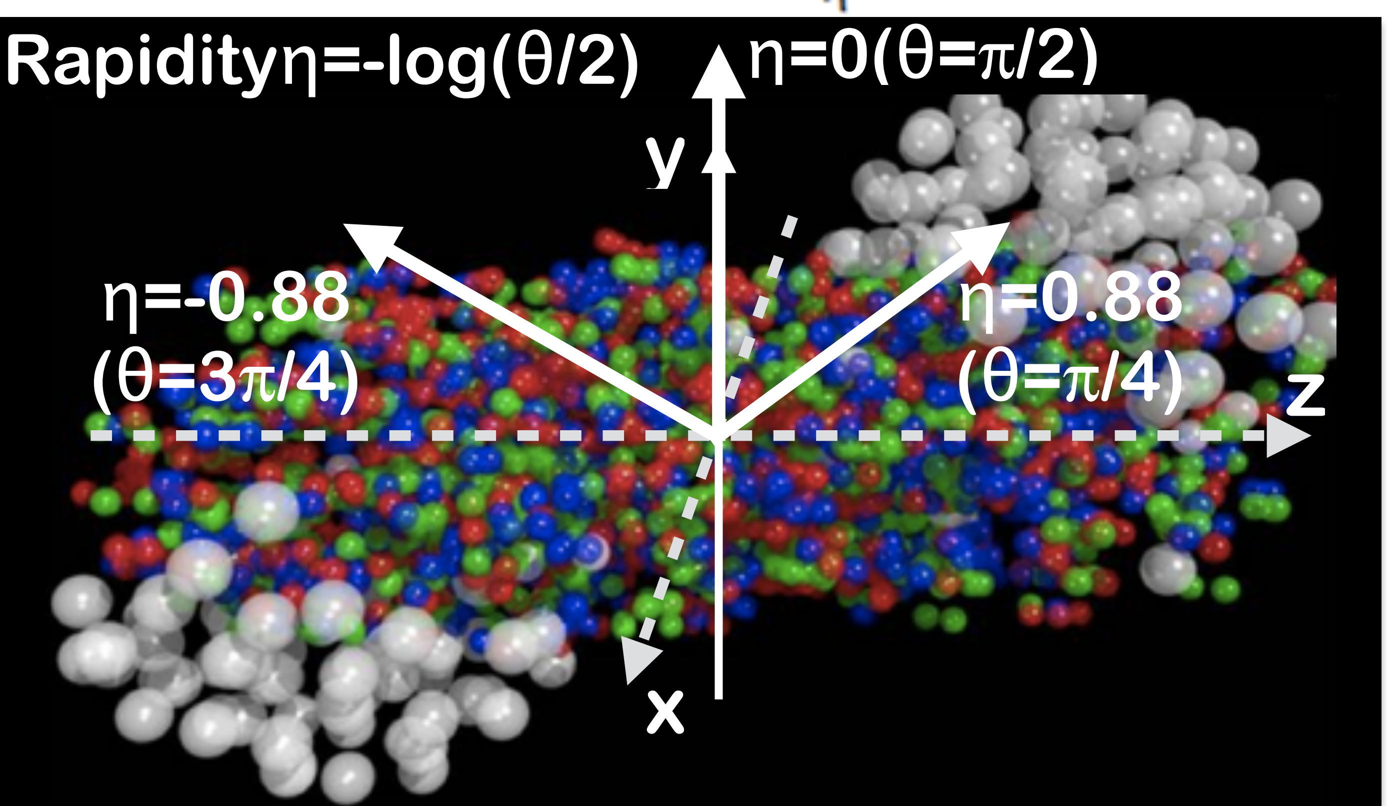
->v_n are good constraint of both of them

η dependence of v_2 with different initial conditions





Phys.Lett.B636:299-304

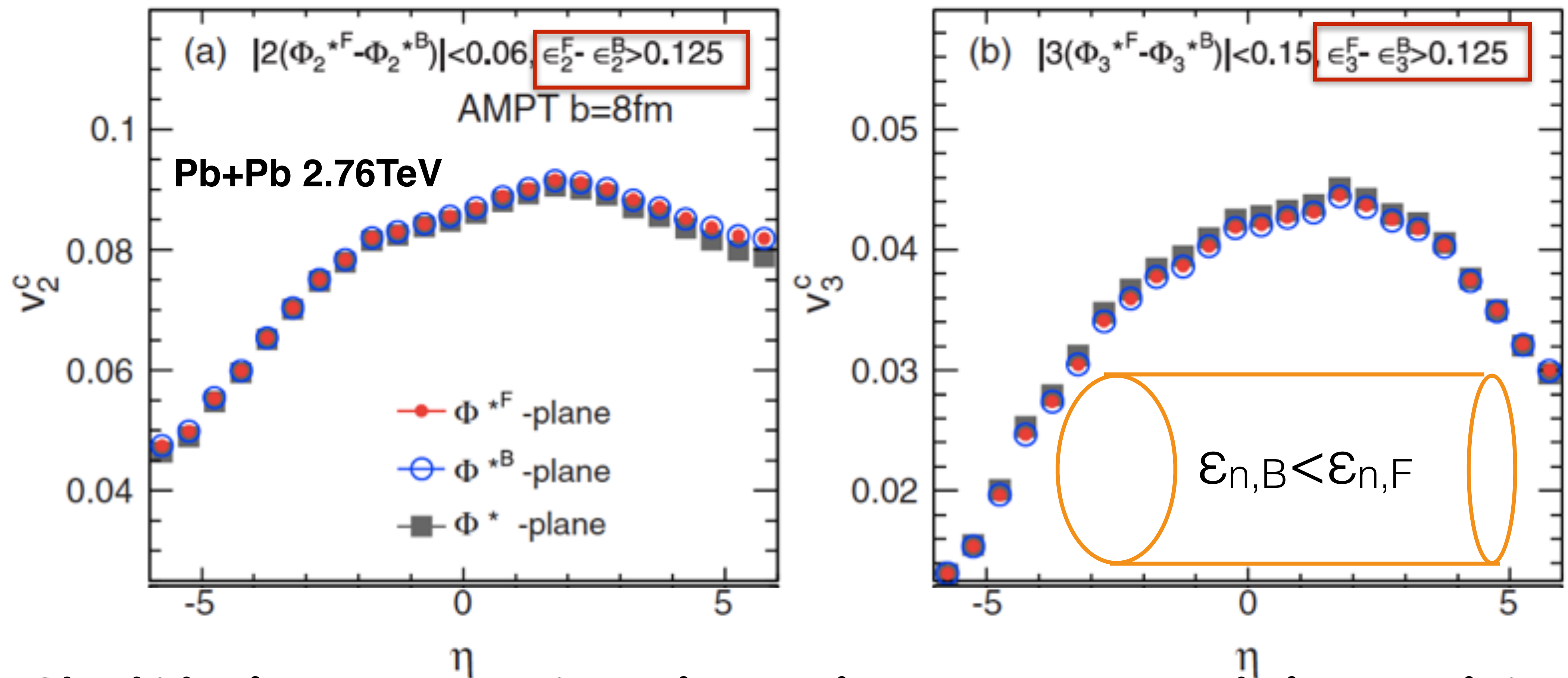


 $v_2(\eta)$ depends on initial condition

- v_2 with KLN > v_2 with Glauber
- v_2 with Glauber reproduce data in mid-central collision
- v_2 with KLN reproduce data in central collision

Rapidity dependence of initial condition

PhysRevC.90.034915



✓initial geometry has been considered to be **rapidity independent**

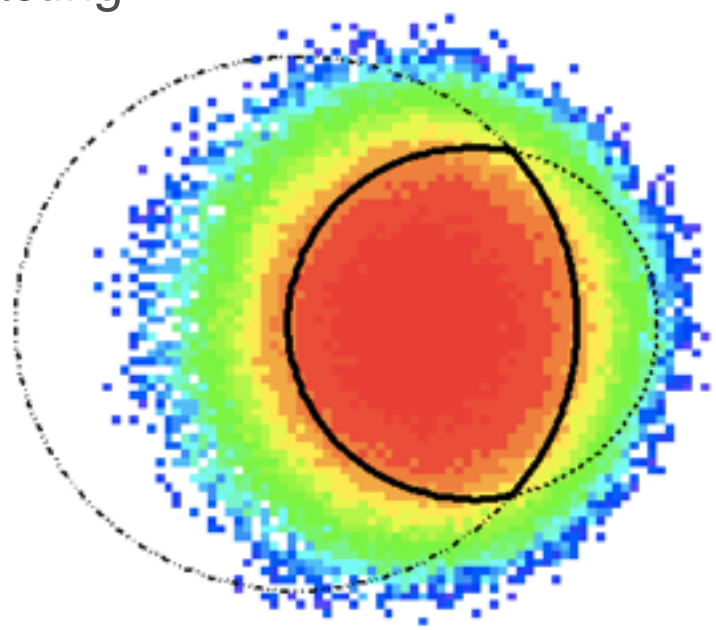
✓Initial conditions on target and projectile nuclei are not same event

$\varepsilon_n(+\eta) > \varepsilon_n(-\eta)$ ➡ $v_n(+\eta) > v_n(-\eta)$

✓ Initial geometry has strong rapidity dependence

➡ $\varepsilon_n(\eta) = \alpha\varepsilon_n(+\eta) + \beta\varepsilon_n(-\eta)$

Motivation: Why Cu+Au is analyzed ?



So far, vn have been studied in symmetric collision systems
First asymmetric Cu+Au collisions were operated in 2012

Asymmetric initial condition provides

- **Intrinsic triangularity of overlap zone -> larger v_3**
- **Different left/right pressure gradient -> v_1**
- **Different Forward/Backward density and geometry -> Rapidity asymmetric v_n**

-> Measurements of v_n in asymmetric system could be good study of initial condition

My activity

M1~M2 (2011~2013)

Repair VTX @BNL
JPS Spring & Fall (Talk)
QM2012 (poster)
ATHIC 2012 (Talk)
Au+Au flow analysis using VTX

D1(2013~2014)

Repair VTX @BNL
Shift taking & detector expert for Run 13, Run14

Cu+Au flow analysis

D2 (2014~2015)

QM2014(Talk)
JPS-DNP(Talk)
Shift taking & detector expert for Run 14, Run15

D3(2015~2016)

QM2015(Poster)
TGSW2015 (Talk)
WWND2016(Talk)

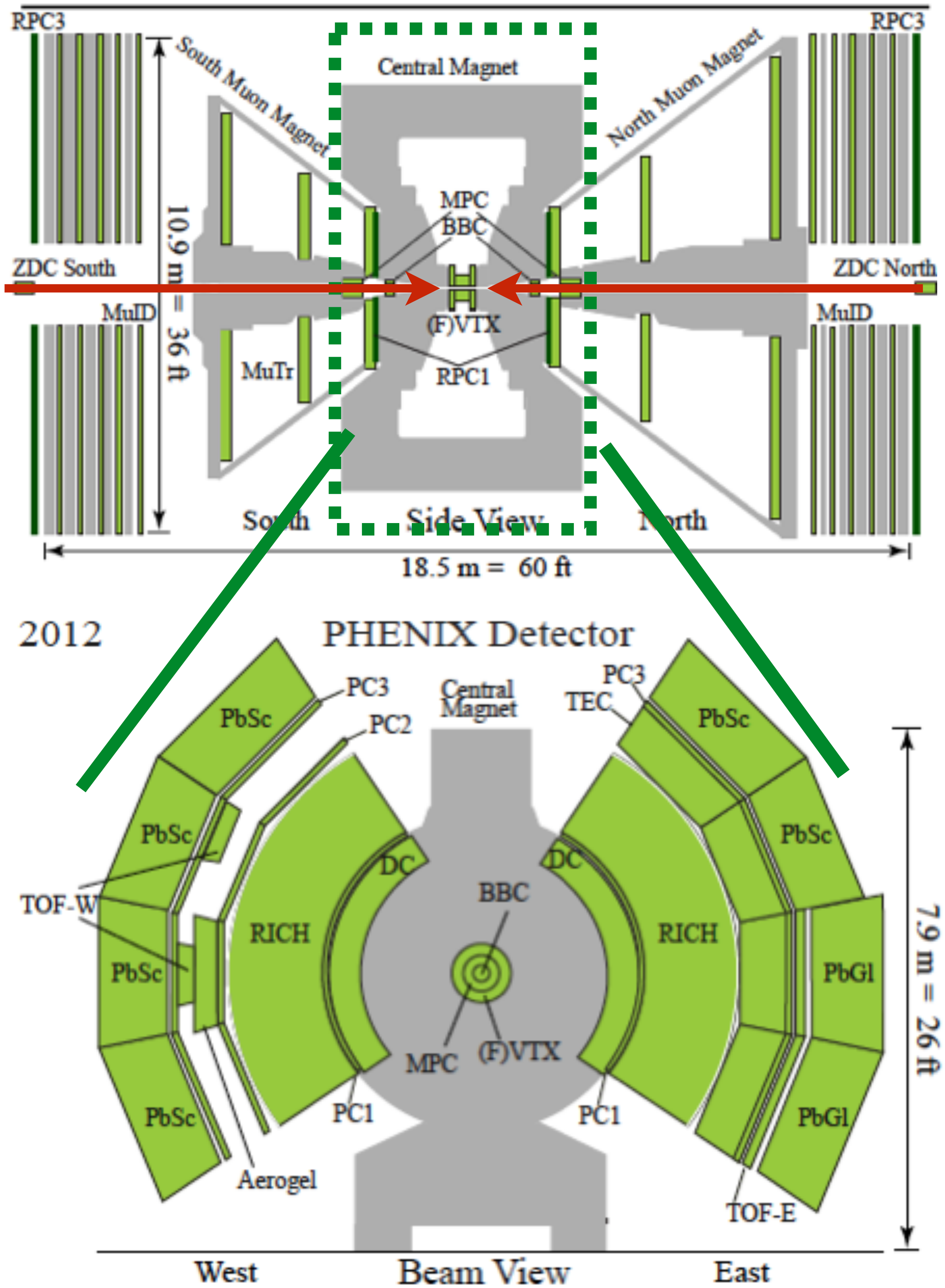
D4 (2016~)

Cu+Au flow paper is accepted by PRC

Domestic conference
International conference
Hardware and shift
Analysis

Experiment Analysis

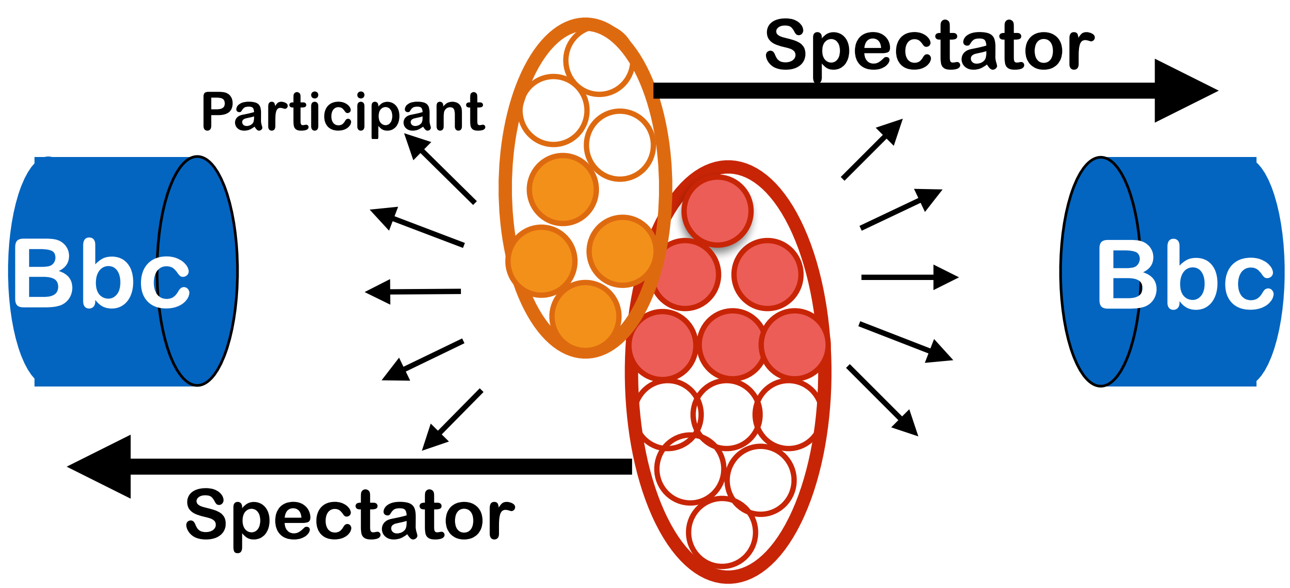
PHENIX detectors

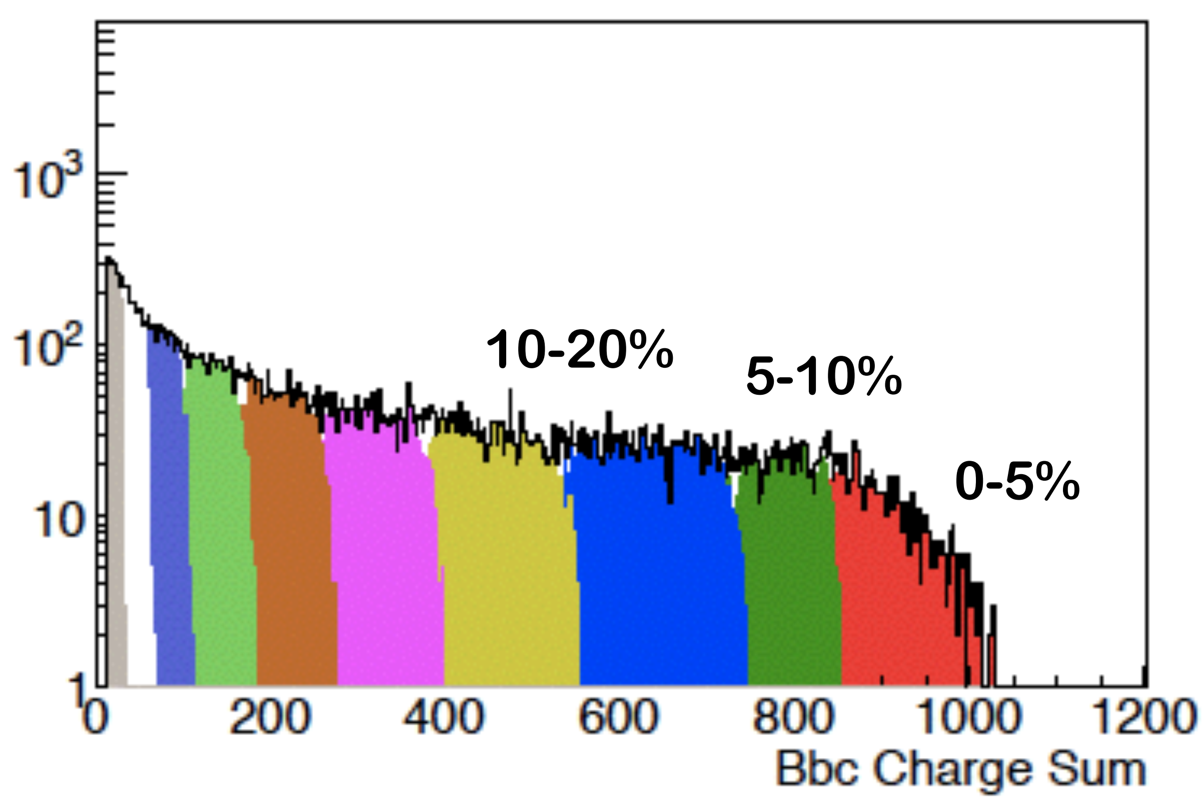


Trigger, centrality, collision vertex
Event plane
-Beam Beam counter(BBC)
($3<|\eta|<4$)
Event plane
-Zero degree calorimeter
-Shower max detector

Charged particle Tracking
-Drift Chamber(DC) ($|\eta|<0.35$)
- Momentum
-Pad Chamber(PC) ($|\eta|<0.35$)
- Hit position
-Electro magnetic calorimeter(EMC) ($|\eta|<0.35$)
- Hit position

Collision centrality





✓Fraction of events in terms of total geometrical cross section
-Overlap zone of two nuclei

∝ Multiplicity

✓ Experimentally, overlap zone is classified by multiplicity in Bbc
- Multiplicity in Bbc
∝ Overlap zone

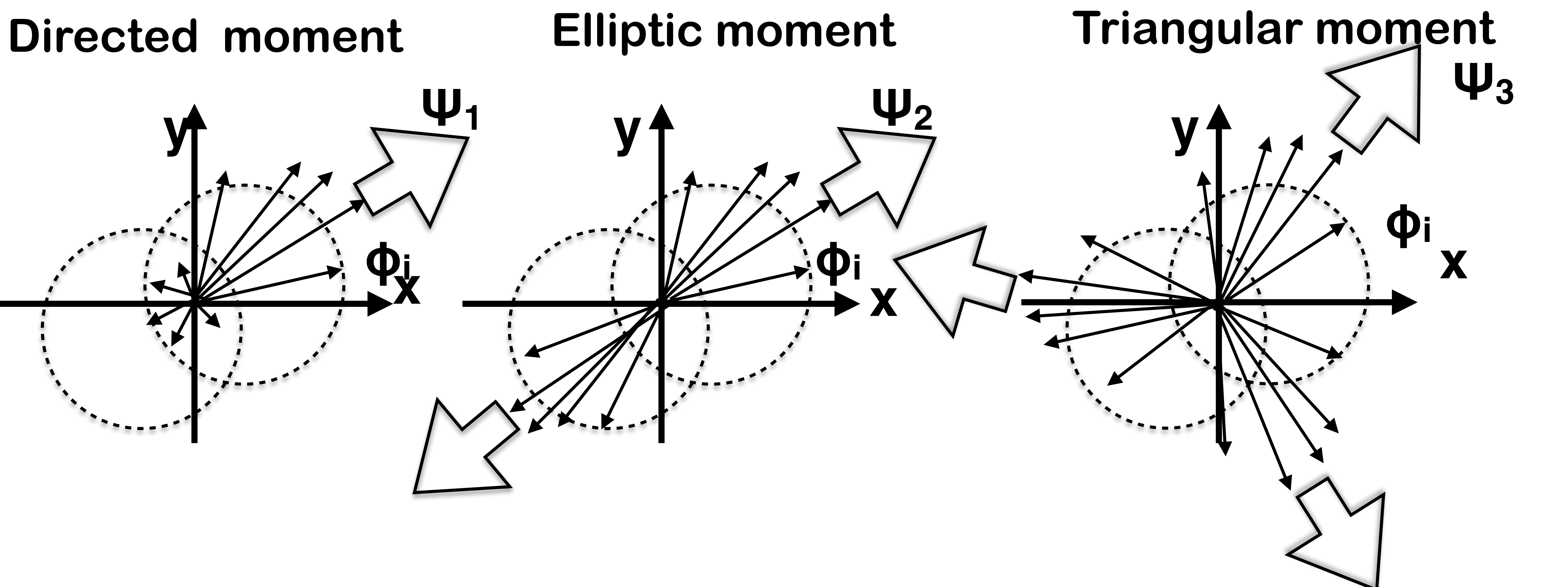
✓ Each percentile contains same number of events
- Most central collision 0 %
- Most peripheral collisions 100%

Anisotropy measurement via Event Plane method

Event plane(EP) method

- one of the flow measurement methods
- produced particles are measured with respect to EP
- EP is the azimuthal direction most particles are emitted to
- observed v_n is corrected by EP resolution

$$v_n = \frac{< \cos(n[\phi - \Psi_n^{obs}]) >}{\mathrm{Res}\{\Psi_\mathrm{n}^\mathrm{obs}\}}$$



Event plane detectors and resolutions

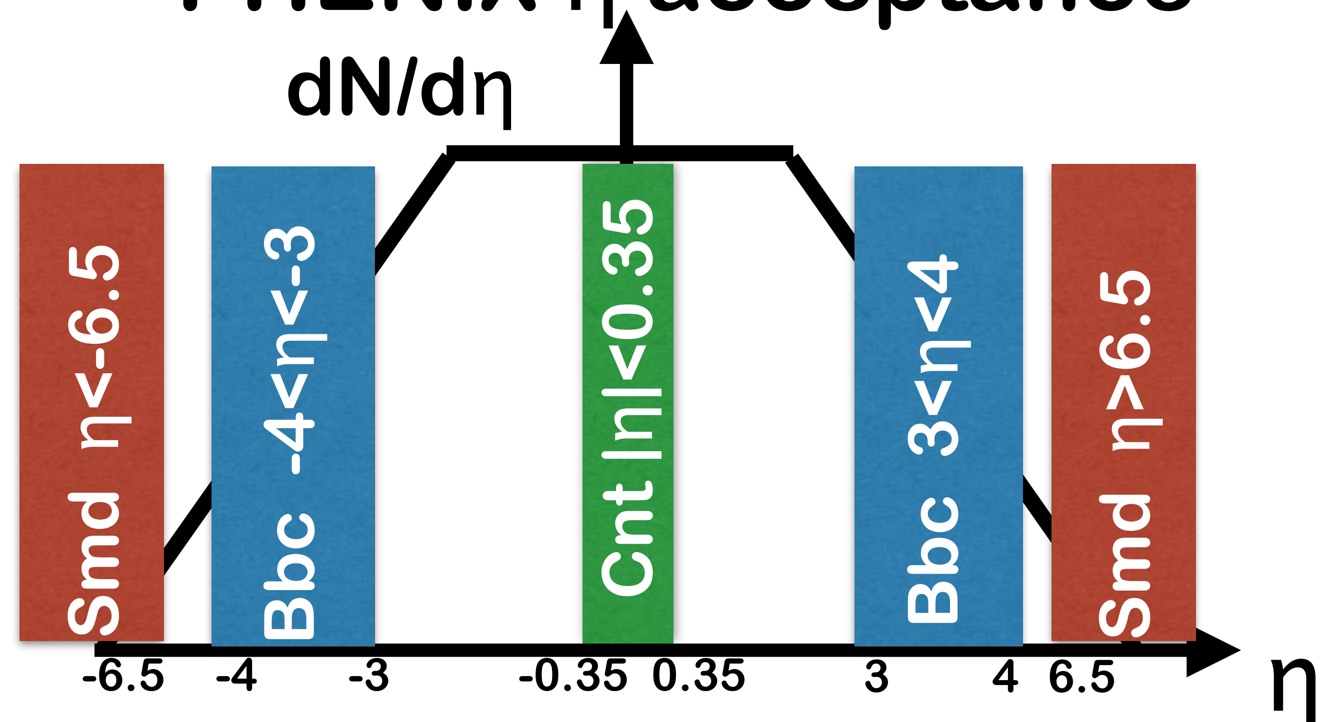
Event Plane detectors

- 2nd, 3rd Event plane
  - Bbc, Cnt
- 1st Event plane
  - Bbc, Smd

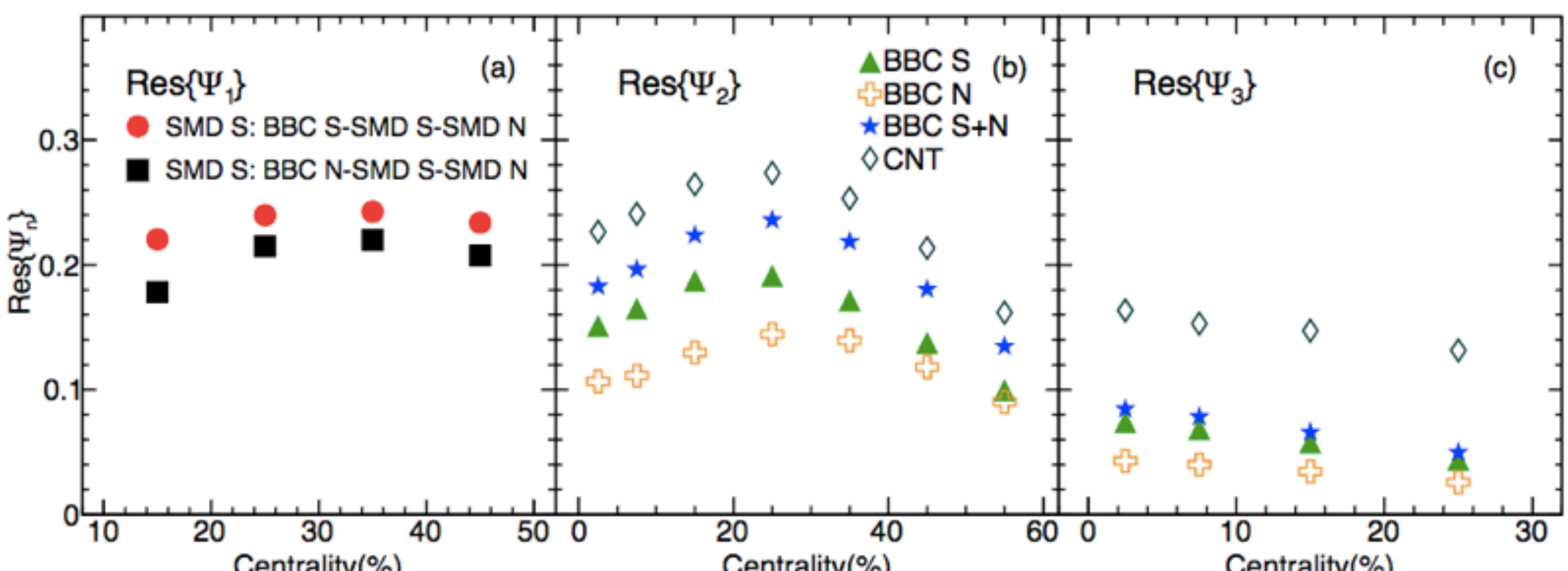
Event Plane resolution

-Estimated from EP correlations(3sub method)

PHENIX η acceptance



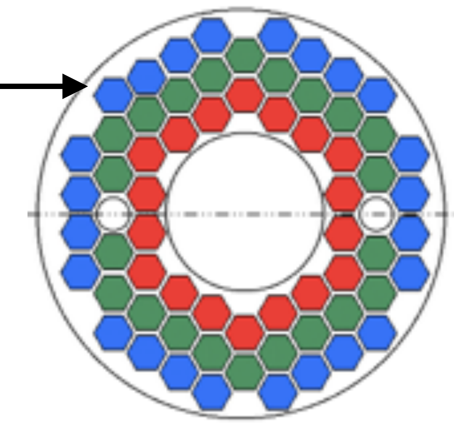
$$\mathrm{Res}\{\Psi_n^{obs}\} = < \cos(n[\Psi_n^{obs} - \Psi_n^{true}]) >$$



v_n measurement at Bbc($3<|\eta|<4$)

✓ v_n is measured using 64 Bbc pmts

- Bbc can not reconstruct tracks
- Measured v_n include back ground



✓ Full Geant simulation with PHENIX configuration

- Measured v_n -> True v_n

$$v_n^{\text{true}} = \frac{v_n^{\text{mes}}}{R_n} \qquad R_n = \frac{v_{n,\text{output}}^{\text{Sim}}}{v_{n,\text{input}}^{\text{Sim}}}$$

$v_{n,\text{input}}^{\text{Sim}}$ Input v_n from particle simulation

$v_{n,\text{output}}^{\text{Sim}}$ Output v_n from Geant simulation

✓ Correction factor R_n

- R_2 : 0.74
- R_3 : 0.66

✓ Systematic study

- dN/dη
- p_T spectra
- v_n (pt)
- v_n (eta)

Systematic sources

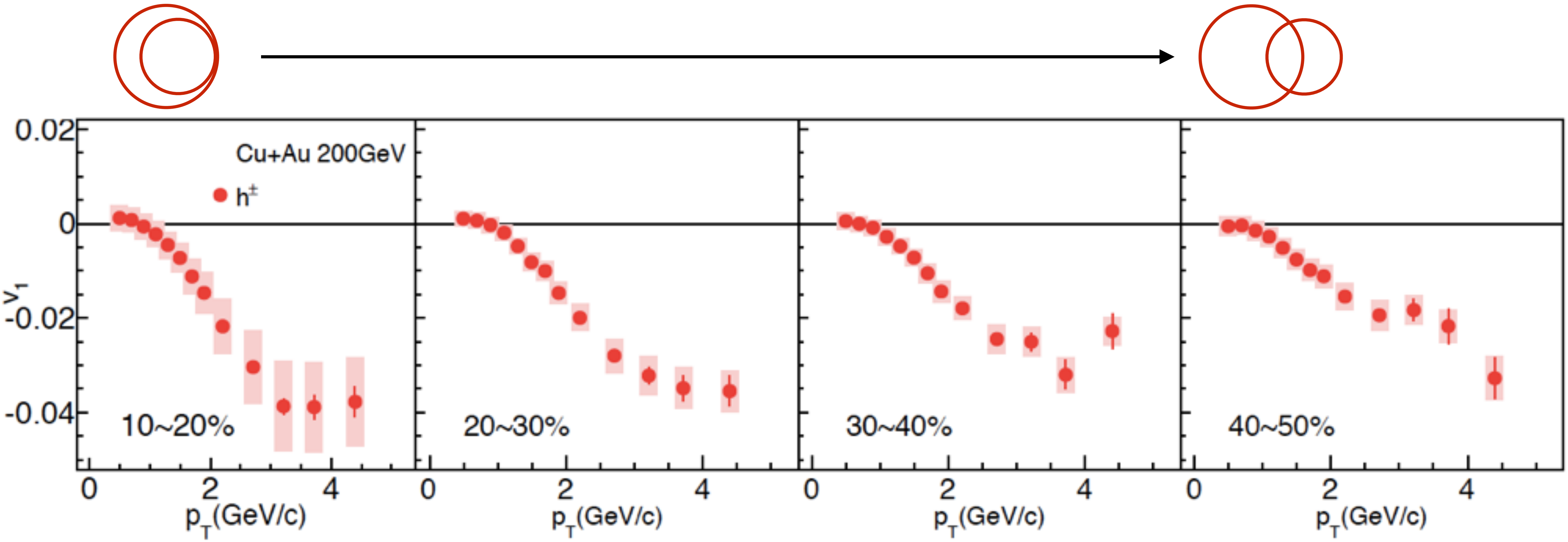
✓ v_n at mid-η
- East and West arm difference
- CNT track cut
- Event Plane difference
- Event Plane resolution difference

✓ v_n at F/B-η
- Event Plane difference
- Geant simulation
  - $dN/d\eta$ distribution
  - p_T distribution
  - p_T dependence of v_n
  - η dependence of v_n

Results
Discussions

- v_1, v_2, v_3 at mid-η
- v_2, v_3 at F/B -η
- Initial condition study
- v_1, v_2, v_3 theory comparison

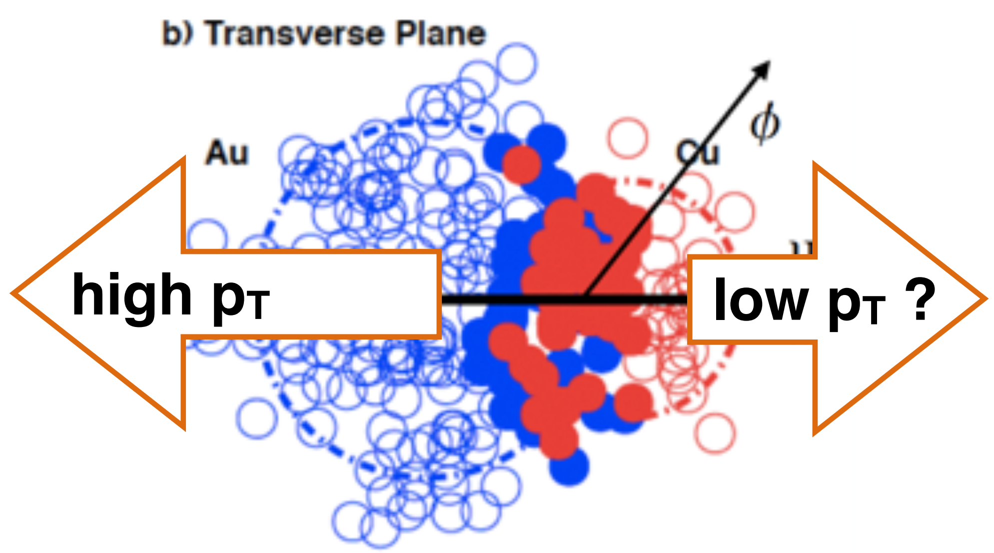
Charged hadron $v_1(p_T)$ in Cu+Au collisions



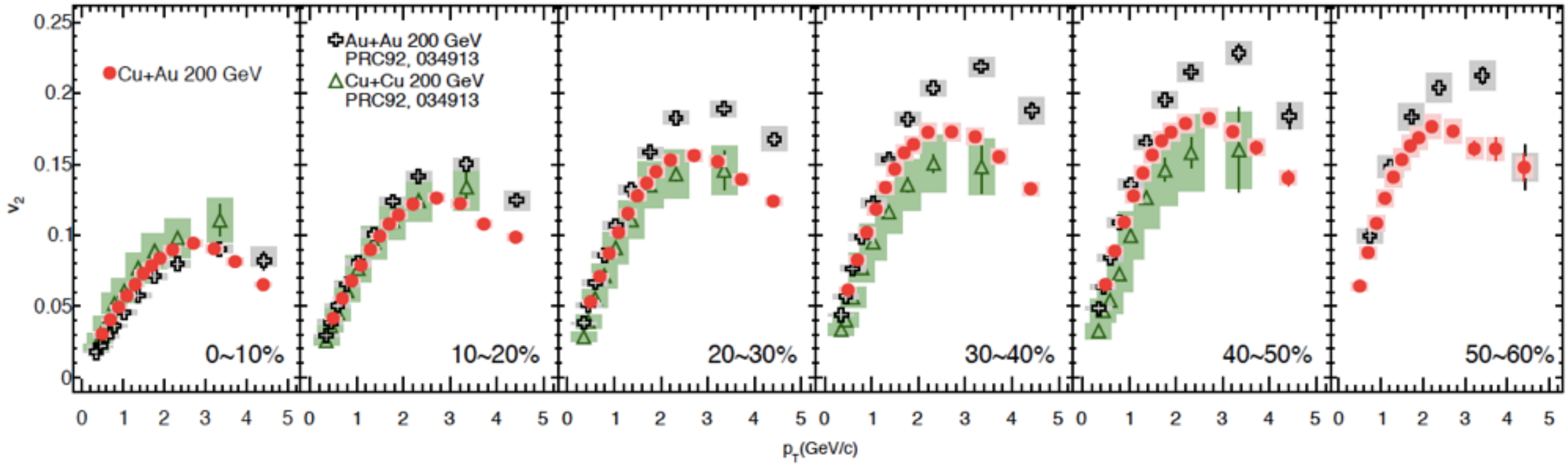
✓v_1 at mid-rapidity is observed for 10-50%

✓Negative v_1 indicates high p_T particle are emitted to Au side

- -Magnitude decreases from central to more peripheral events
- -In peripheral events, Left/Right path length becomes similar



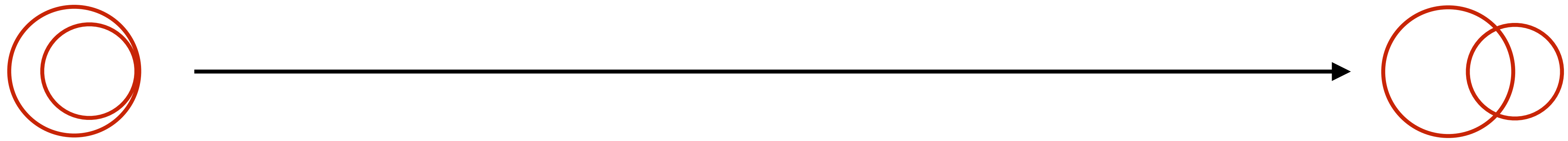
Charged hadron $v_2(p_T)$ in Cu+Au collisions

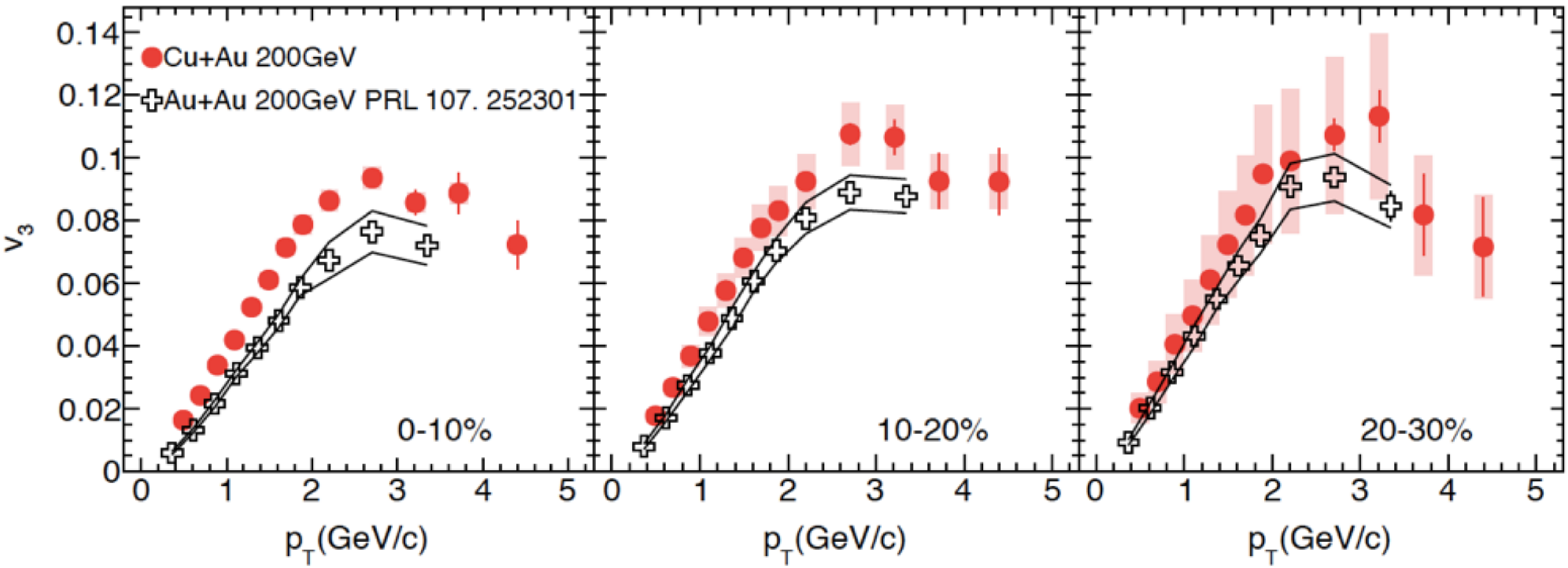


✓Similar p_T and centrality dependence of v_2 as seen in symmetric collisions

- Strong centrality dependence, magnitude increase from central to peripheral
- Cu+Au v_2 is between symmetric Au+Au and Cu+Cu collisions

Charged hadron $v_3(p_T)$ in Cu+Au collisions

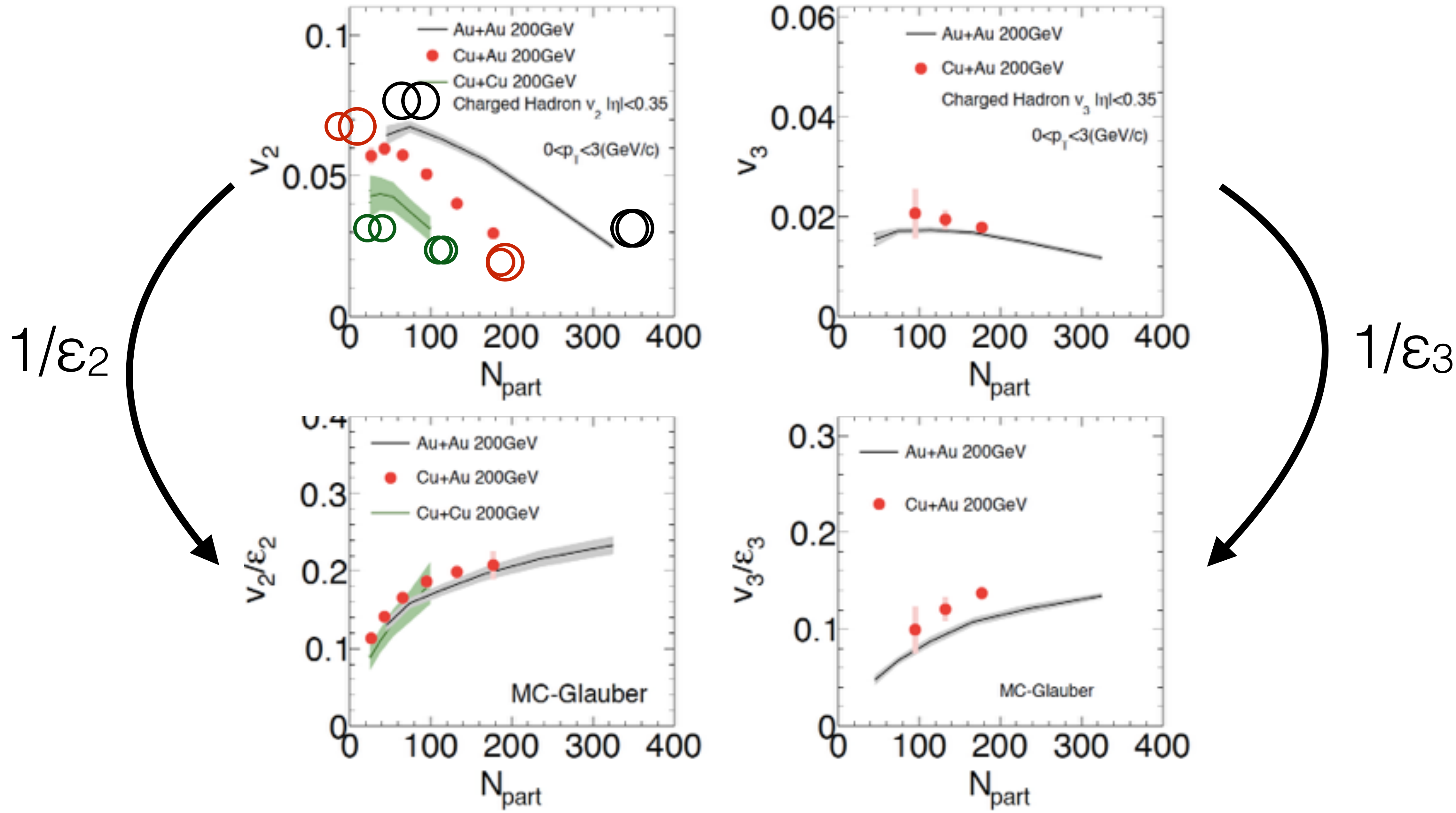




✓Similar p_T and centrality dependence of v_3 as seen in symmetric collisions

- Weak centrality dependence, magnitude slightly increase from central to peripheral
- Cu+Au v_3 shows larger values than Au+Au restuls

System size dependence of $v_n(N_{part})$



✓Cu+Au v_2/ε_2 is consistent with Au+Au and Cu+Cu results

✓Unlike v_2, Cu+Au v_3 is slightly larger than Au+Au v_3

- Cu+Au v_3 arises from not fluctuations but also intrinsic triangularity of overlap zone ?

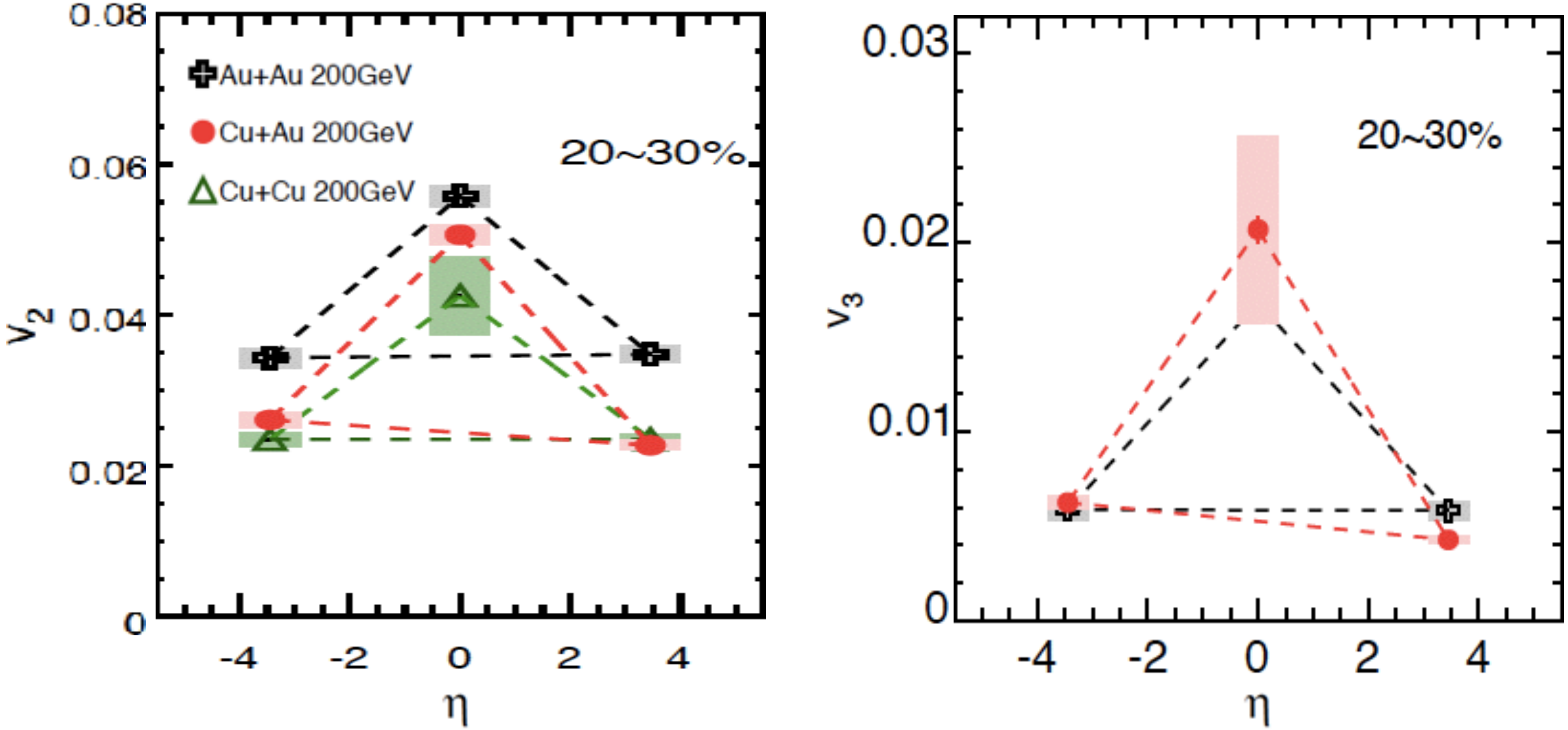
✓Cu+A v_3/ε_3 is not consistent with Au+Au results

- MC-Glauber might not reproduce ε_3 correctly

Results
Discussions

- v_1, v_2, v_3 at mid-η
- v_2, v_3 at F/B-η
- Initial condition study
- v_1, v_2, v_3 theory comparison

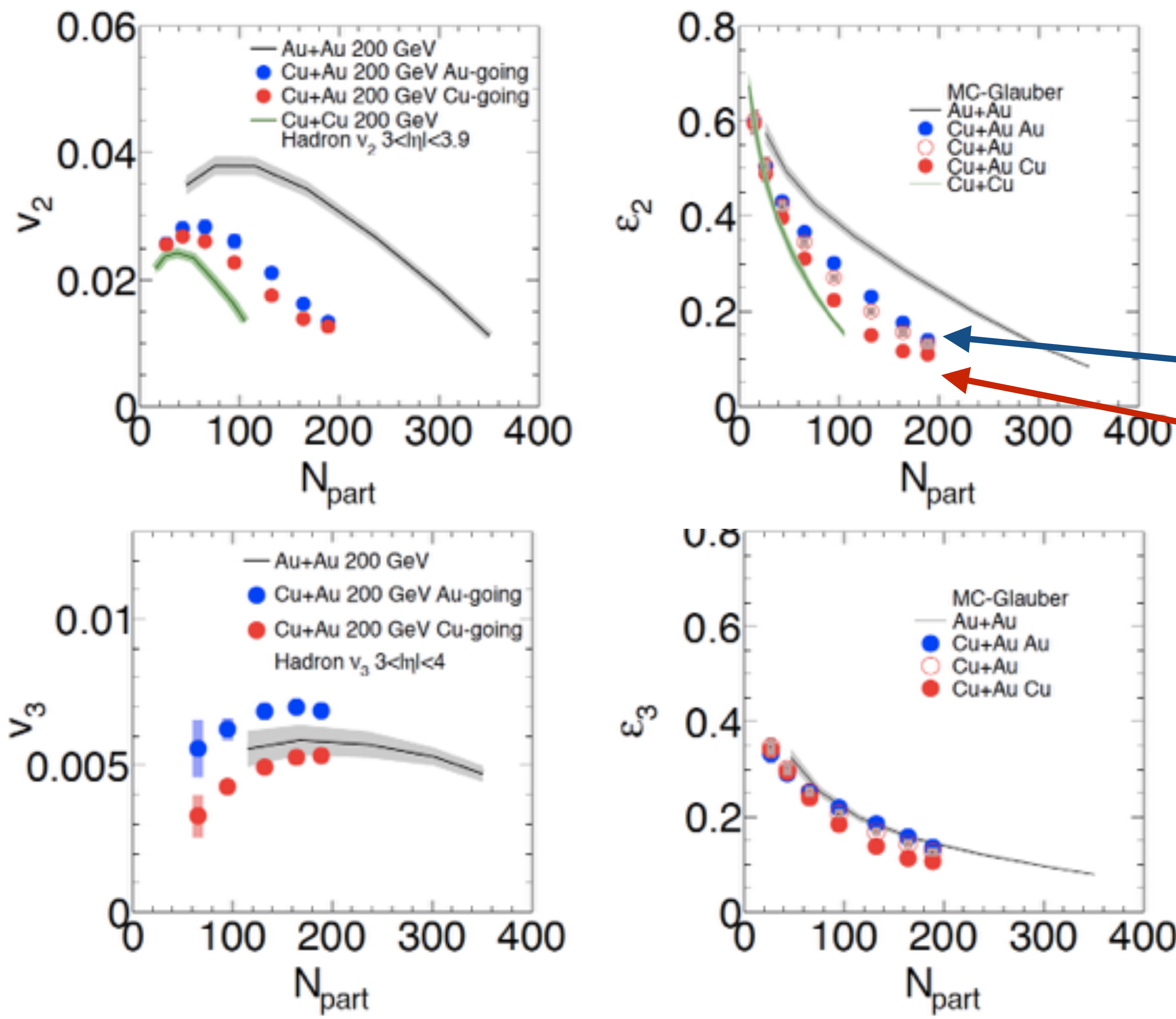
Rapidity dependence of v_n in Cu+Au collisions

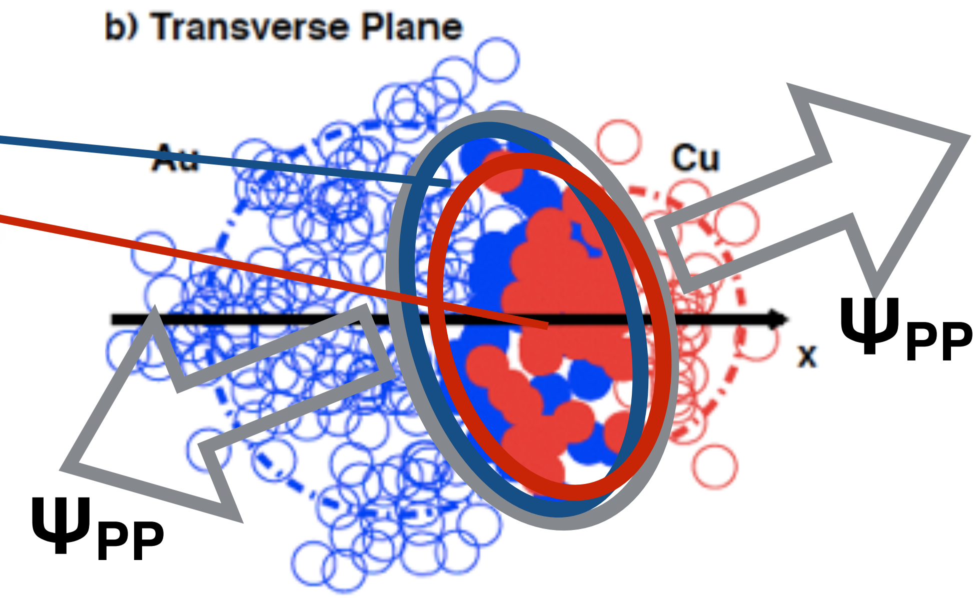


✓In Cu+Au collisions, F/B asymmetry of v_n is observed.
- v_2(Au-going) > v_2(Cu-going)
- v_3(Au-going) > v_3(Cu-going)
- ->caused by different initial geometries in Au and Cu ?

✓Unlike v_2 , Au-going v_3 in Cu+Au show similar values of Au+Au v_3

System size dependence of $v_n(N_{part})$ at F/B rapidity



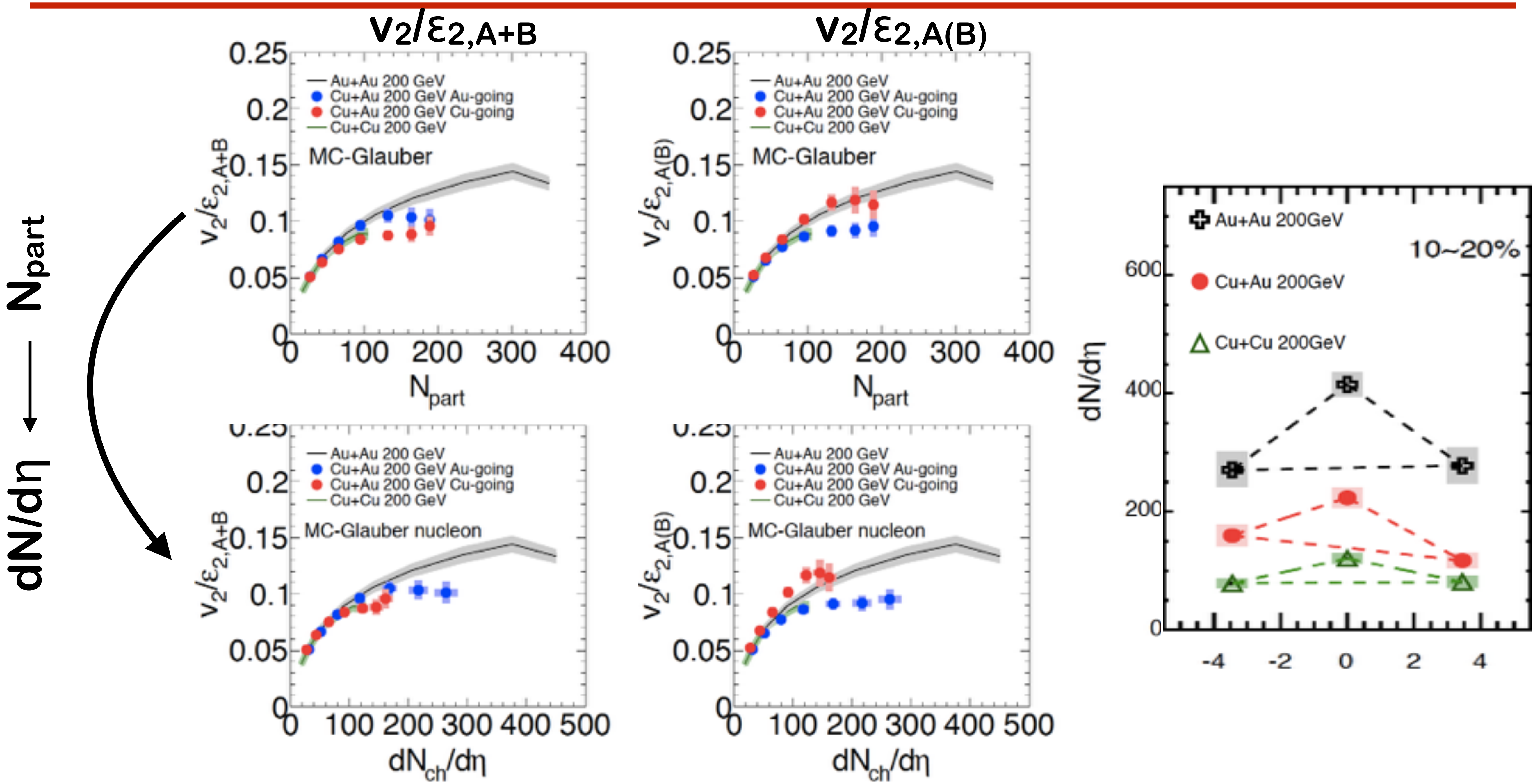


✓F/B asymmetry of v_2 is consistent that of ε_2

-$\varepsilon_{n,Au}$ and $\varepsilon_{n,Cu}$ are estimated from Au and Cu participants separately

$\varepsilon_{n,Au} > \varepsilon_{n,Cu}$ ➡ $v_{n,Au} > v_{n,Cu}$?

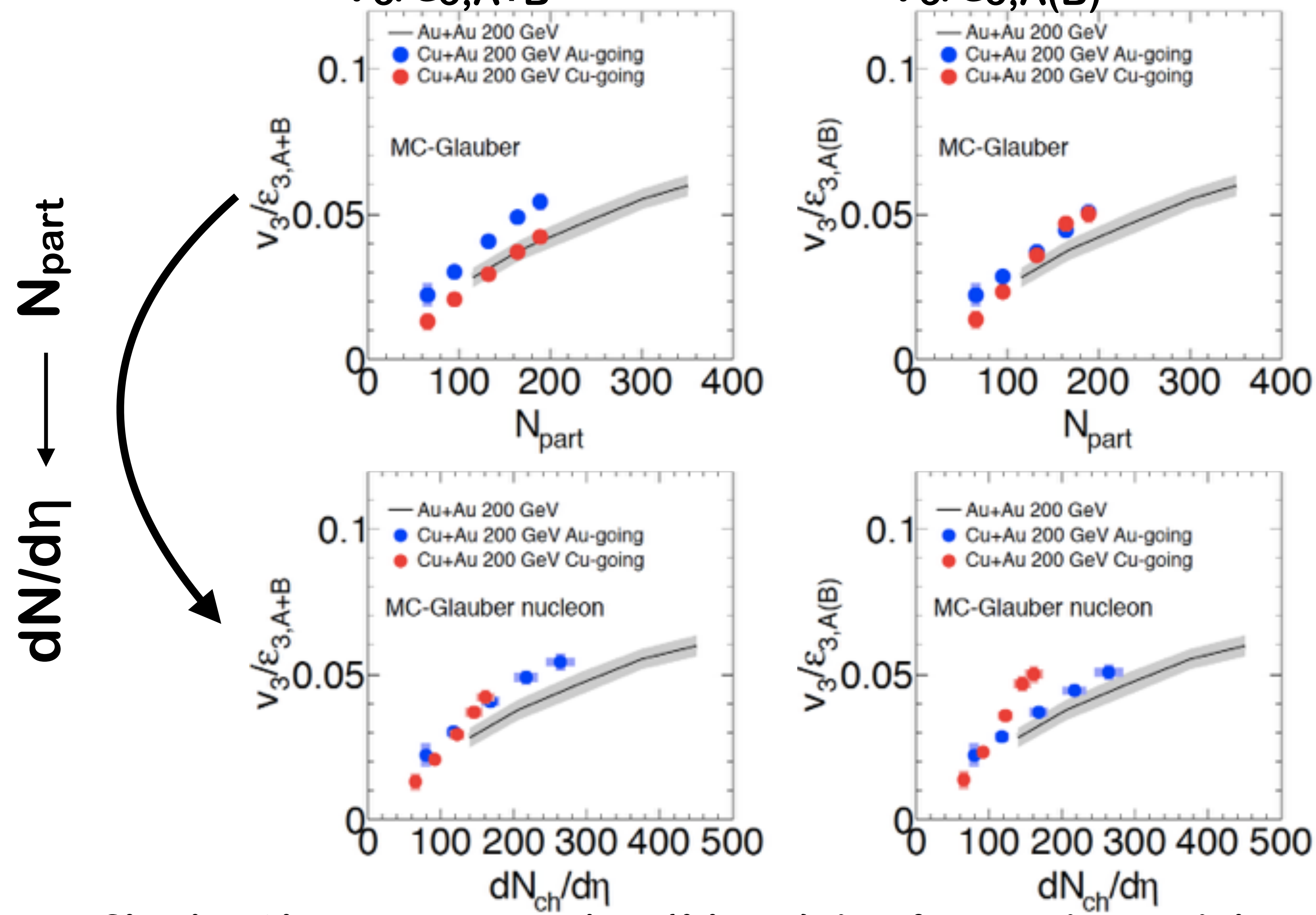
Eccentricity scaling of v_2 at F/B rapidity

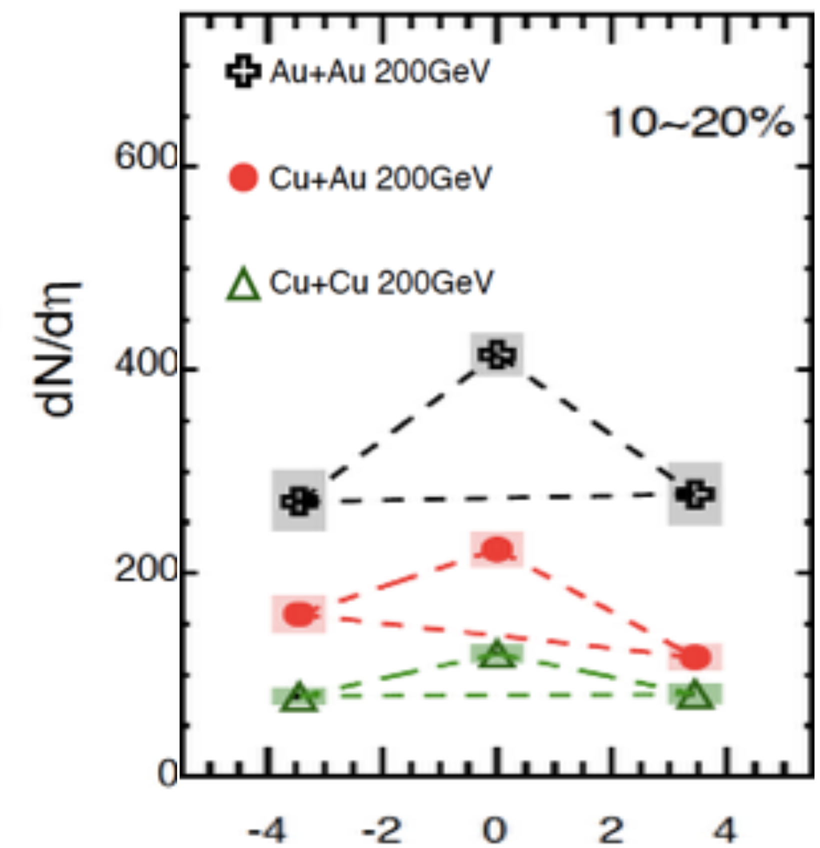


- ✓In both cases, v_2/ε_2 (N_{part}) in Au-going side and Cu-going side are not consistent ->Need take into account different energy ?
- ✓dN/dη(Au-going) > dN/dη(Cu-going) ->v_n(Au-going) >v_n(Cu-going)
- ✓Scaled $v_2/\varepsilon_{2,A+B}$ are consistent between Au-going and Cu-going

Eccentricity scaling of v_3 at F/B rapidity

$v_3/\varepsilon_{3,A+B}$ $v_3/\varepsilon_{3,A(B)}$





√In both cases, v_3/ε_3 (N_{part}) in Au-going side and Cu-going side are not consistent

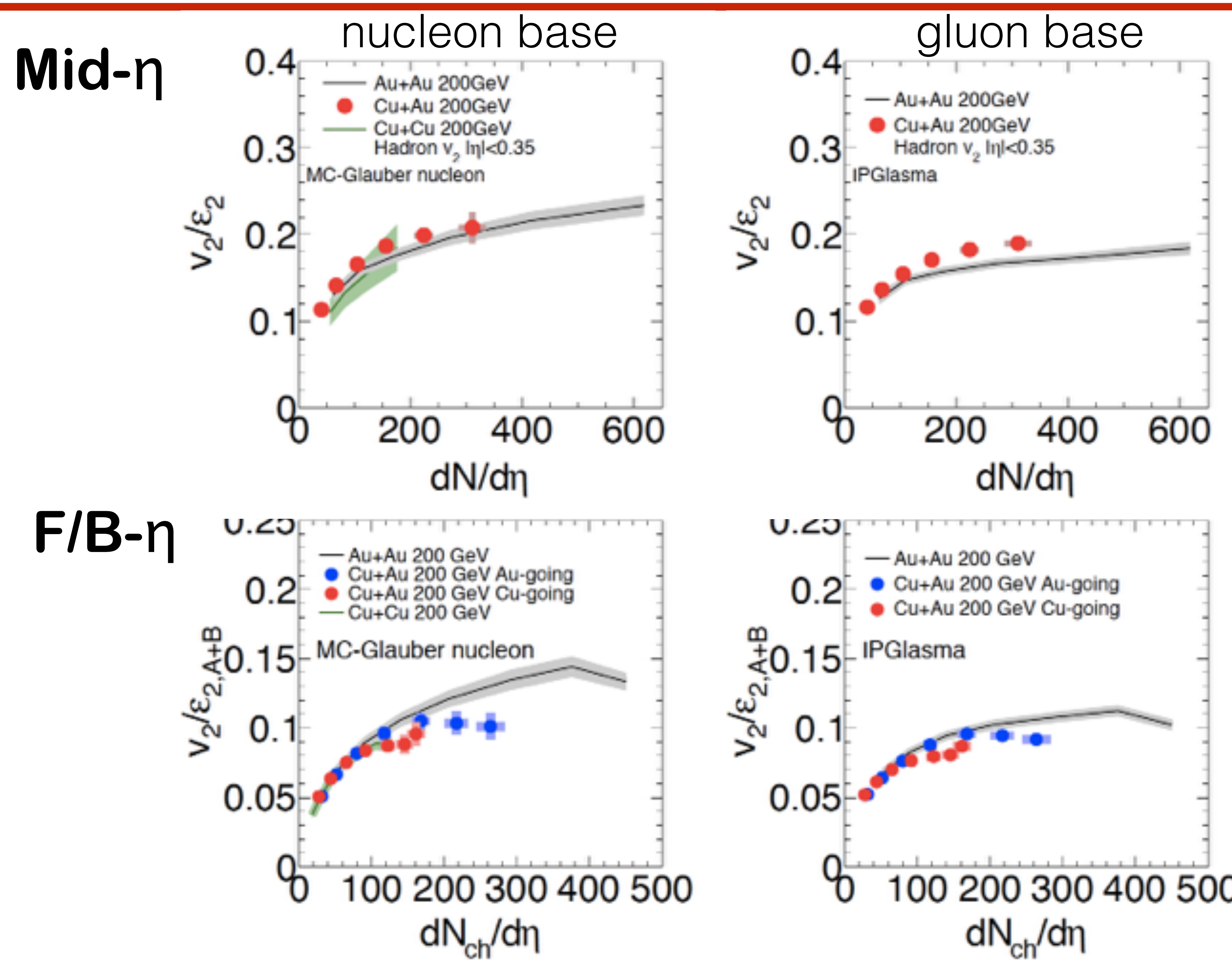
√Scaled $v_3/\varepsilon_{3,A+B}$ are consistent between Au-going and Cu-going

√F/B asymmetry of v_n arise from F/B asymmetry of density($dN/d\eta$)

Results
Discussions

- v_1,v_2,v_3 at mid-η
- v_2,v_3 at large-η
- **Initial condition study**
- v_1,v_2,v_3 theory comparison

v_2/ε_2 scaling with Glauber and IPGlasma

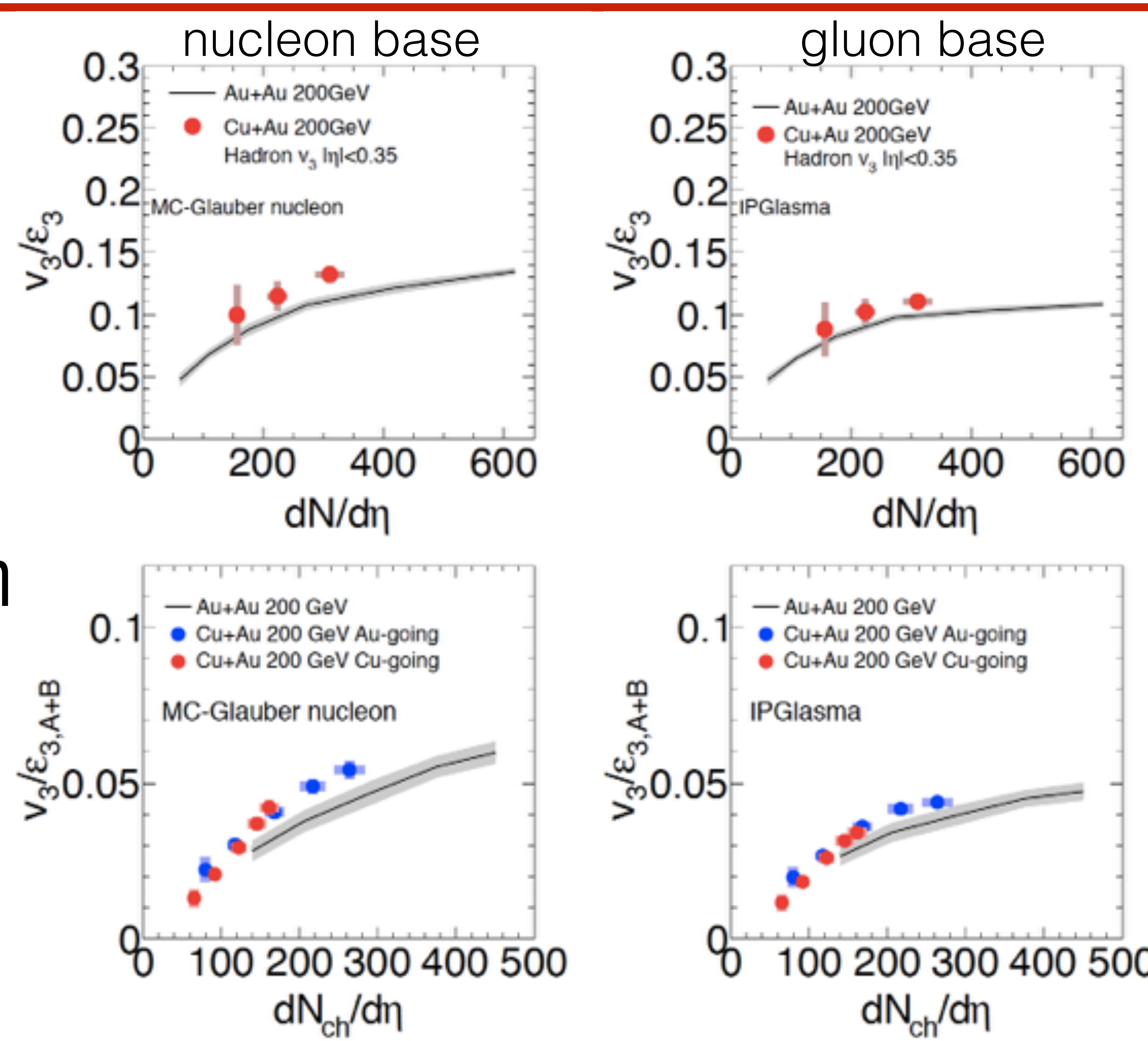


- ✓At-mid η, the v_2 scaled with nucleon base model are consistent among three collision systems
- ✓At-F/B η, the v_2/ε_2 with gluon base model in Cu+Au is closer to that in Au+Au

v_3/ε_3 scaling with Glauber and IPGlasma

Mid-η

F/B-η

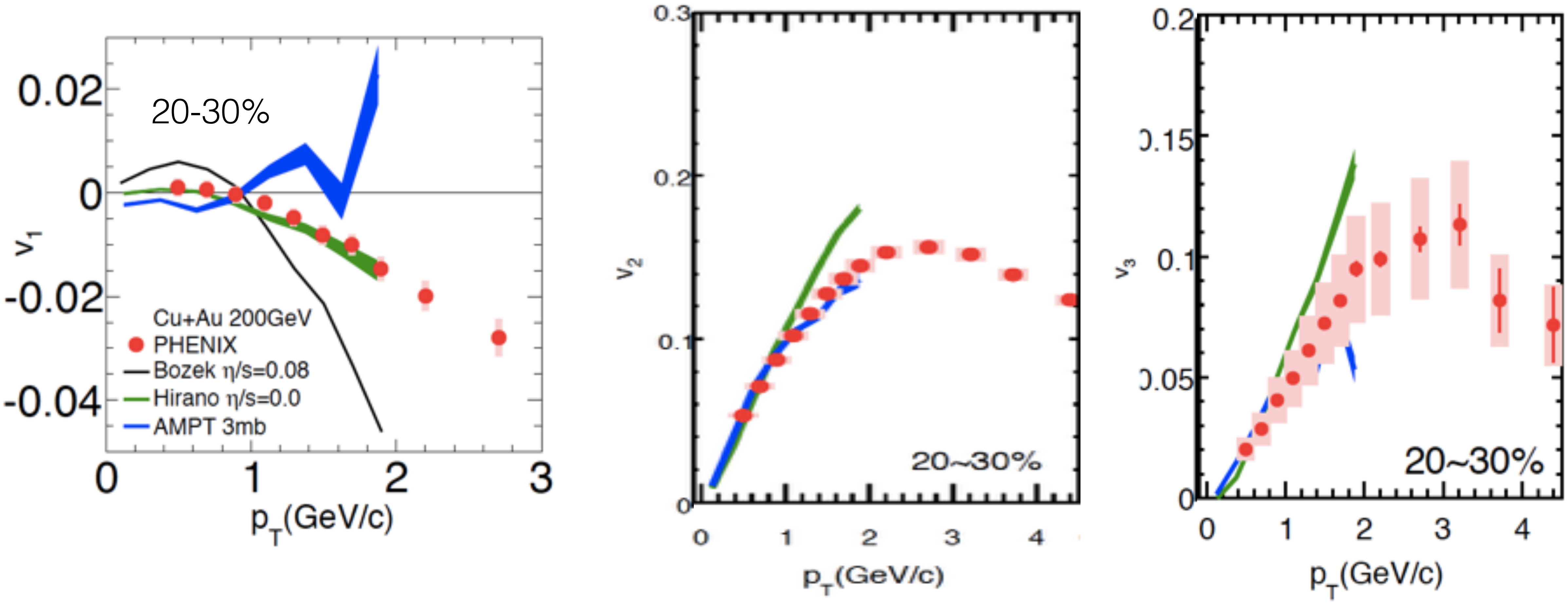


- ✓At-mid η, the v_3 scaled with gluon base model in Cu+Au is closer to that in Au+Au
- ✓At-F/B η, the v_3/ε_3 with gluon base model in Cu+Au is closer to that in Au+Au

Results
Discussions

- v_1, v_2, v_3 at mid-η
- v_2, v_3 at F/B-η
- Initial condition study
- v_1, v_2, v_3 theory comparison

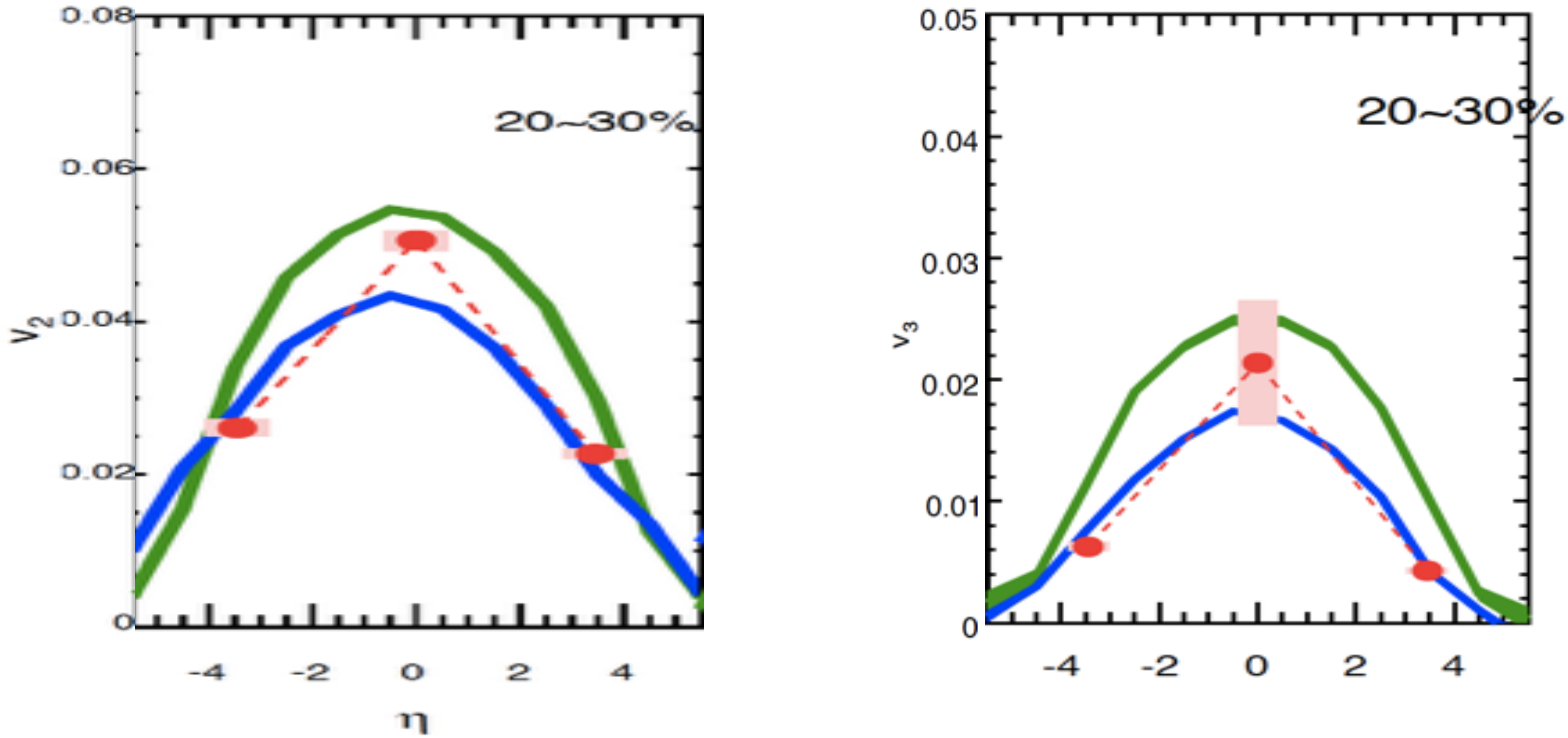
Parton cascade and hydro $v_n(p_T)$



- Hydro(Bozek):Glauber + hydro
- Hydro(Hirano):Glauber + hydro + hadron cascade
- AMPT :Glauber + parton cascade + hadron cascade

✓Hydrodynamic reproduce v_n
✓AMPT model well reproduce v_2 and v_3 , but shows opposite sign of v_1

Parton cascade and hydro $v_n(\eta)$



✓AMPT and Hydro predict the magnitude of v_2 at F/B rapidity well
✓AMPT reproduce the magnitude of v_3 at F/B rapidity well
✓Hydro overestimate the magnitude of v_3 at F/B rapidity
-Hydro:Smooth longitudinal density+hydro
-AMPT:Fluctuated longitudinal density+parton cascade

Summary

✓ v_1 at mid-η

High p_T particles are emitted to Au side

✓ v_2, v_3 at mid-η

- Similar centrality and p_T dependence as seen in symmetric collisions
- Cu+Au v_3 is larger than Au+Au results, which might arise from intrinsic triangularity of overlap zone

✓ v_2, v_3 at F/B-η

- Forward/Backward asymmetry of v_n in Cu+Au arise from Forward/Backward asymmetry of density ($dN/d\eta$)

✓ Initial model study

-Glauber model describes mid-rapidity v_2 well

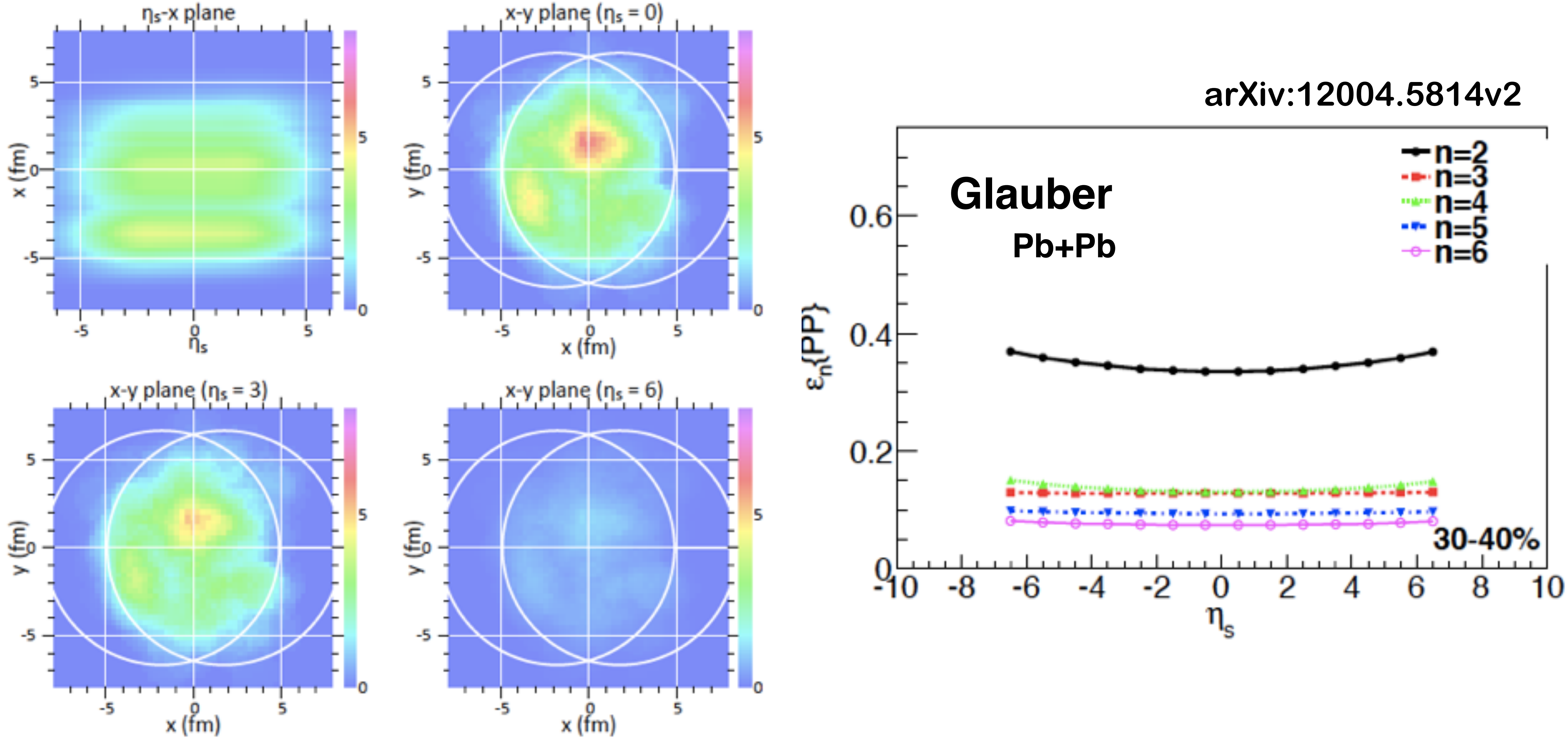
-IPGlasma model describes mid-rapidity v_3 and preferred at F/B η, which might indicate different initial conditions between central and F/B η

✓ Theory comparison

-Parton cascade (AMPT) does not well describe sign of v_1

Back Up

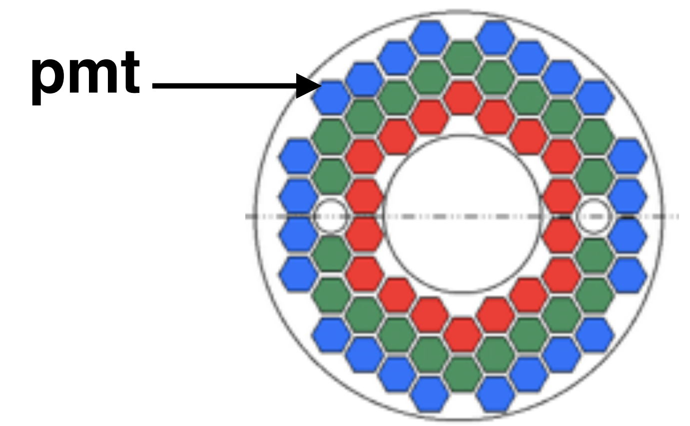
η_s dependence of ε_n



✓Longitudinal structure is less understood
-Transverse direction can be described by Glauber, CGC…

✓Initial spatial geometry $\varepsilon_n(\eta)$ are η symmetric
- Smooth longitudinal density profile, streak-like structure

v_n measurement at Bbc($3<|\eta|<4$)



✓ v_n is measured using 64 Bbc pmts

- Bbc can't reconstruct tracks
- pmt based v_n include back ground

✓ Full Giant simulation with PHENIX configuration

- pmt based v_n -> track based v_n

$$v_n^{track} = R_n * v_n^{pmt} \qquad R_n = \frac{v_{n,input}^{Sim}}{v_{n,output}^{Sim}}$$

$v_{n,input}^{Sim}$
Input v_n from particle simulation

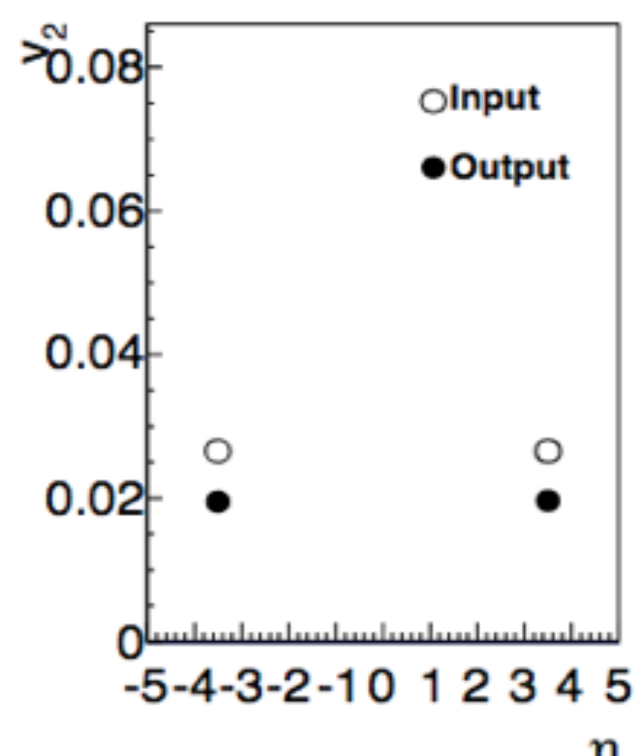
$v_{n,output}^{Sim}$
Output v_n from Giant simulation

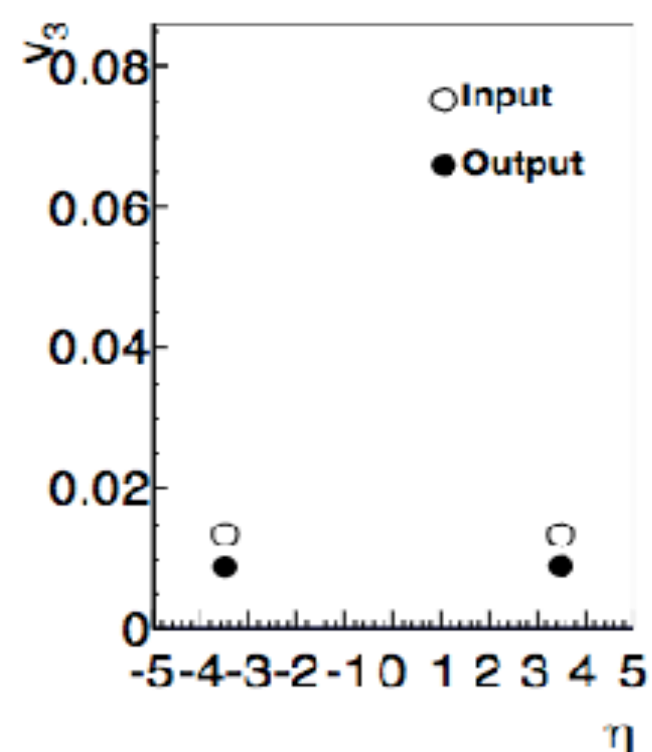
✓ Correction factor R_n

- R_2 : 0.73
- R_3 : 0.65

✓ Systematic study

- dN/deta
- pT spectra
- vn(pt)
- vn(eta)





Initial spatial anisotropy

Glauber Monte Carlo simulation

-Wood Saxon density profile

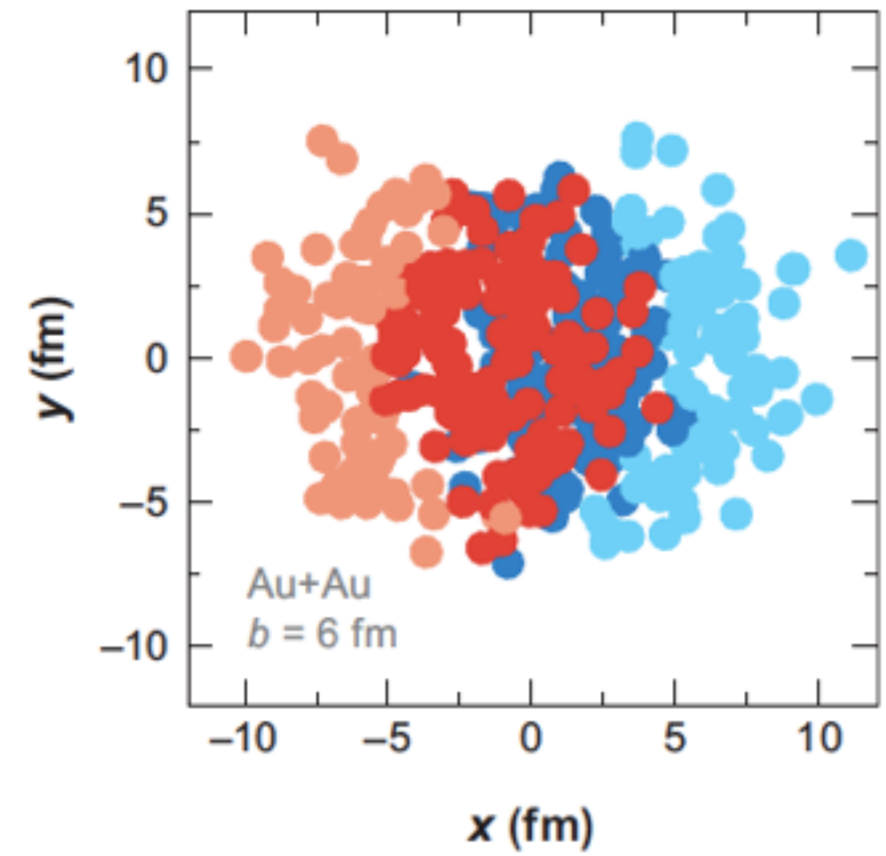
- collision is occurred, if $d < \sqrt{(\sigma_{nn}/\pi)}$

d:distance between nucleons

σ_{nn}:total cross section(pp collision)

$$\epsilon_n = \frac{\langle r^2 \cos[n(\phi - \Psi_{n,PP})] \rangle}{\langle r^2 \rangle}$$

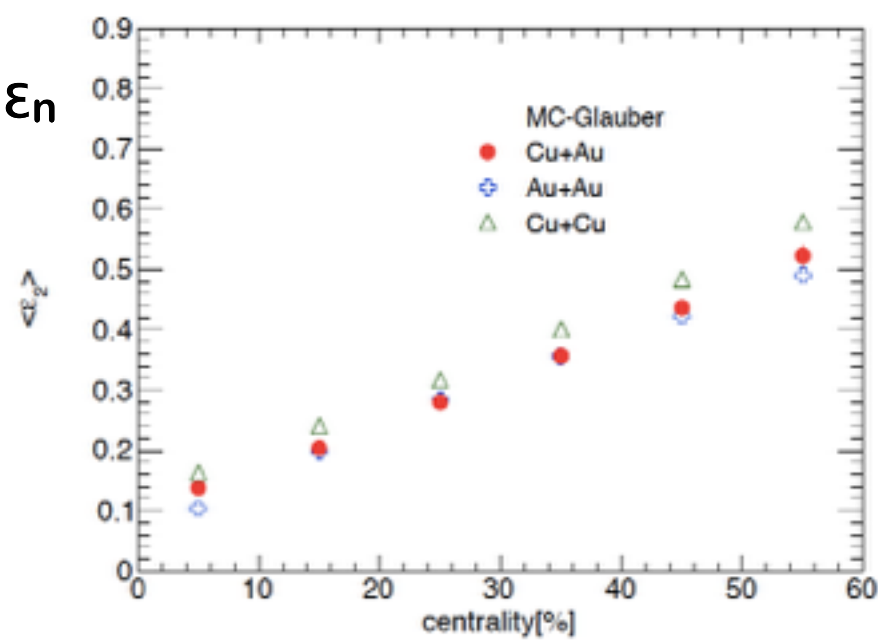
$$\Psi_{n,PP} = \frac{1}{n}[\tan^{-1} \frac{\langle r^2 \sin(n\phi) \rangle}{\langle r^2 \cos(n\phi) \rangle} + \pi]$$

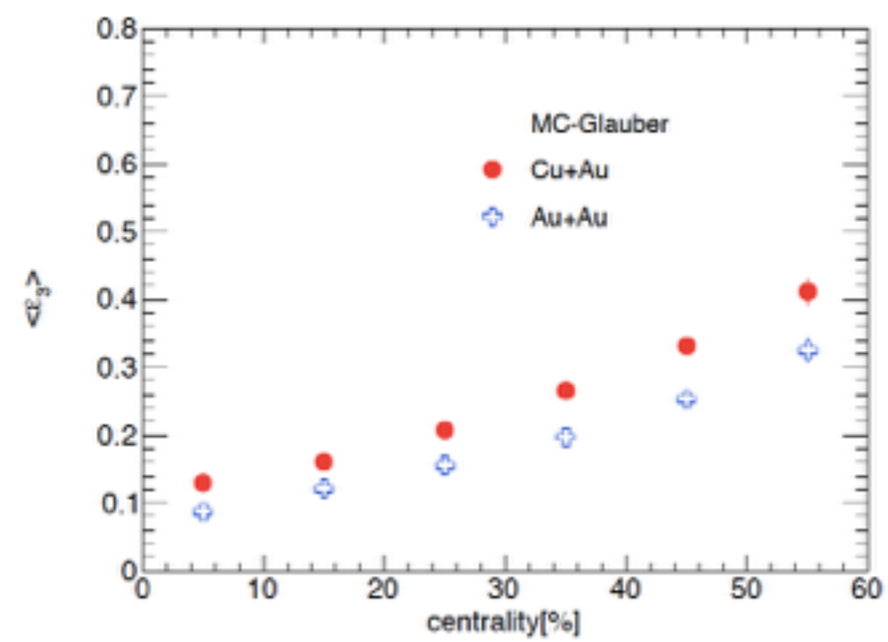


Centrality dependence of ε_n

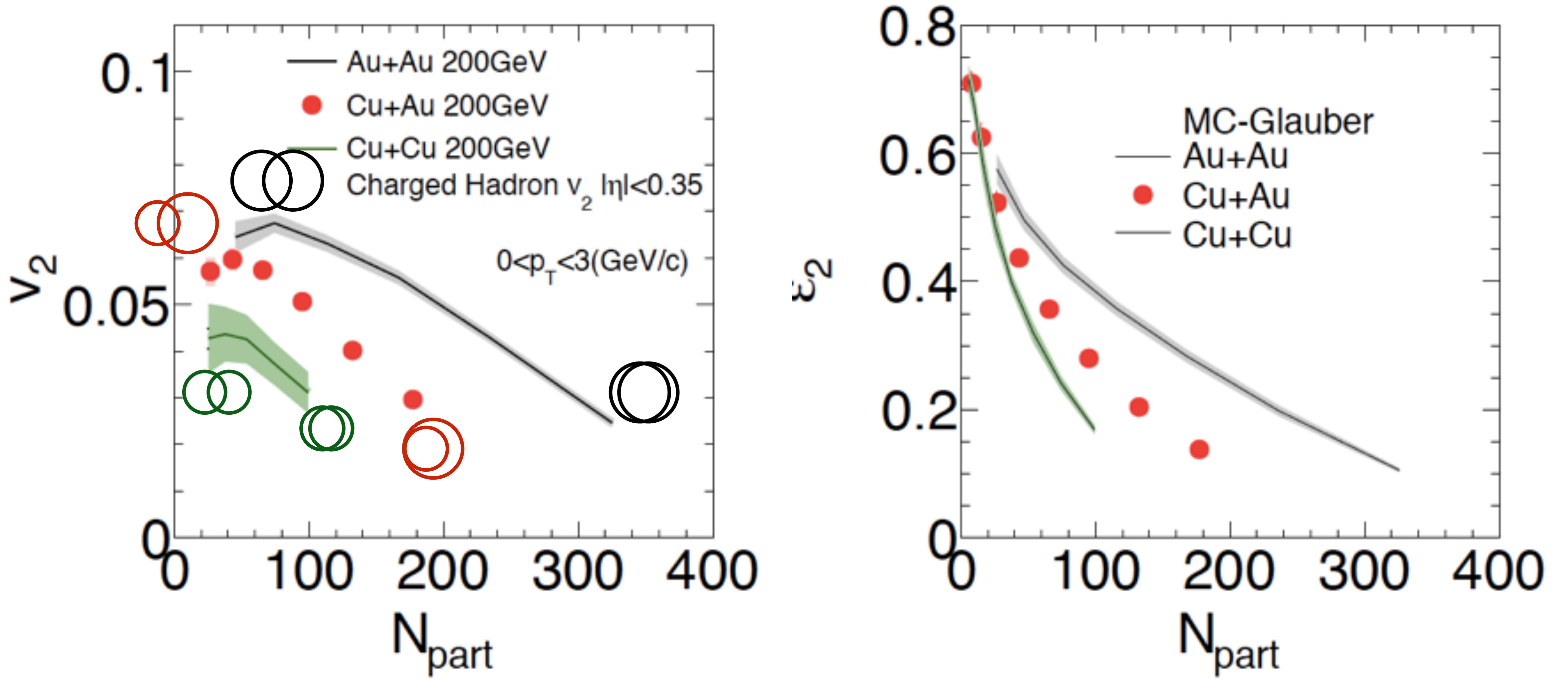
ε_2:CuCu>CuAu~AuAu

ε_3:CuAu>AuAu





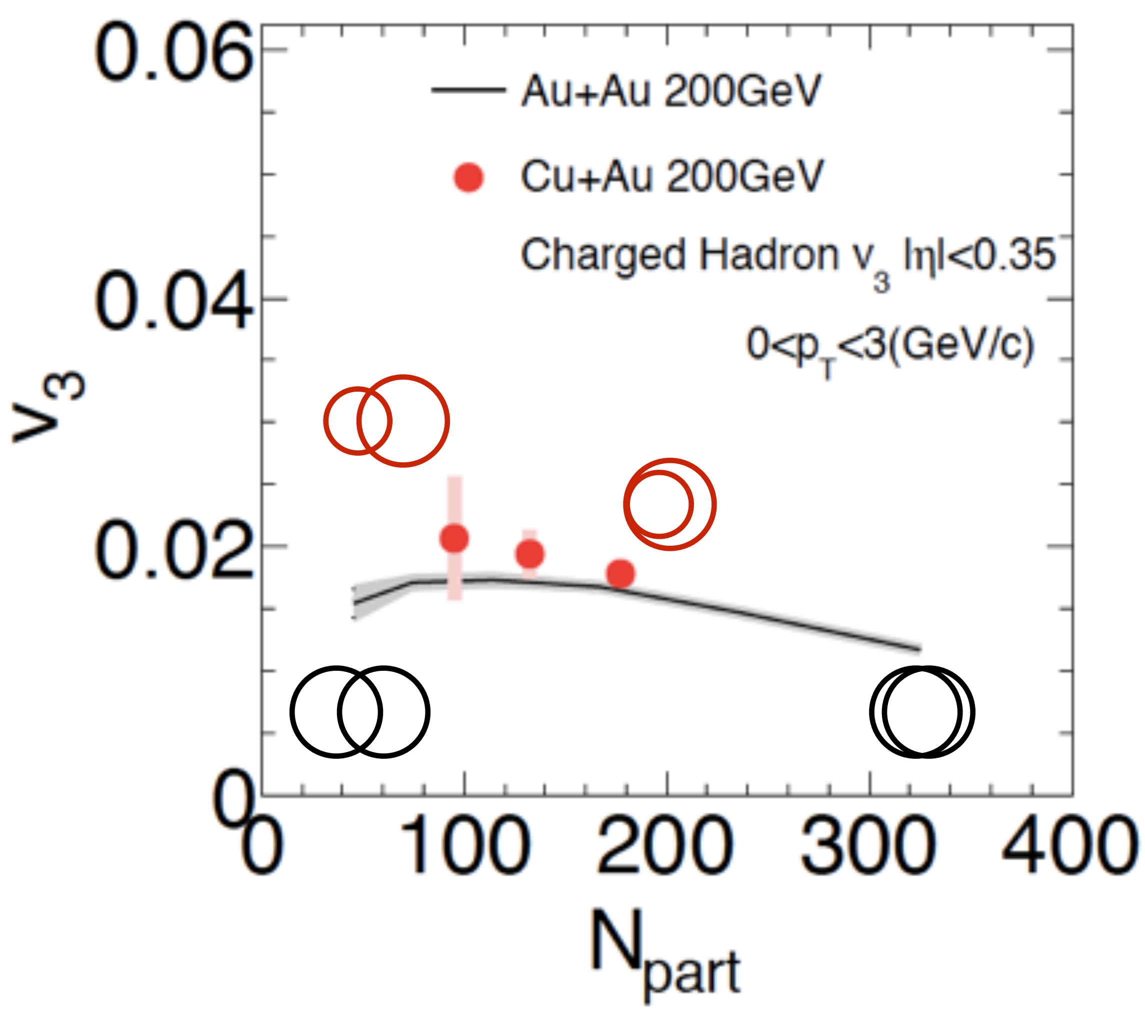
System size dependence of $v_2(N_{part})$ and $\varepsilon_2(N_{part})$

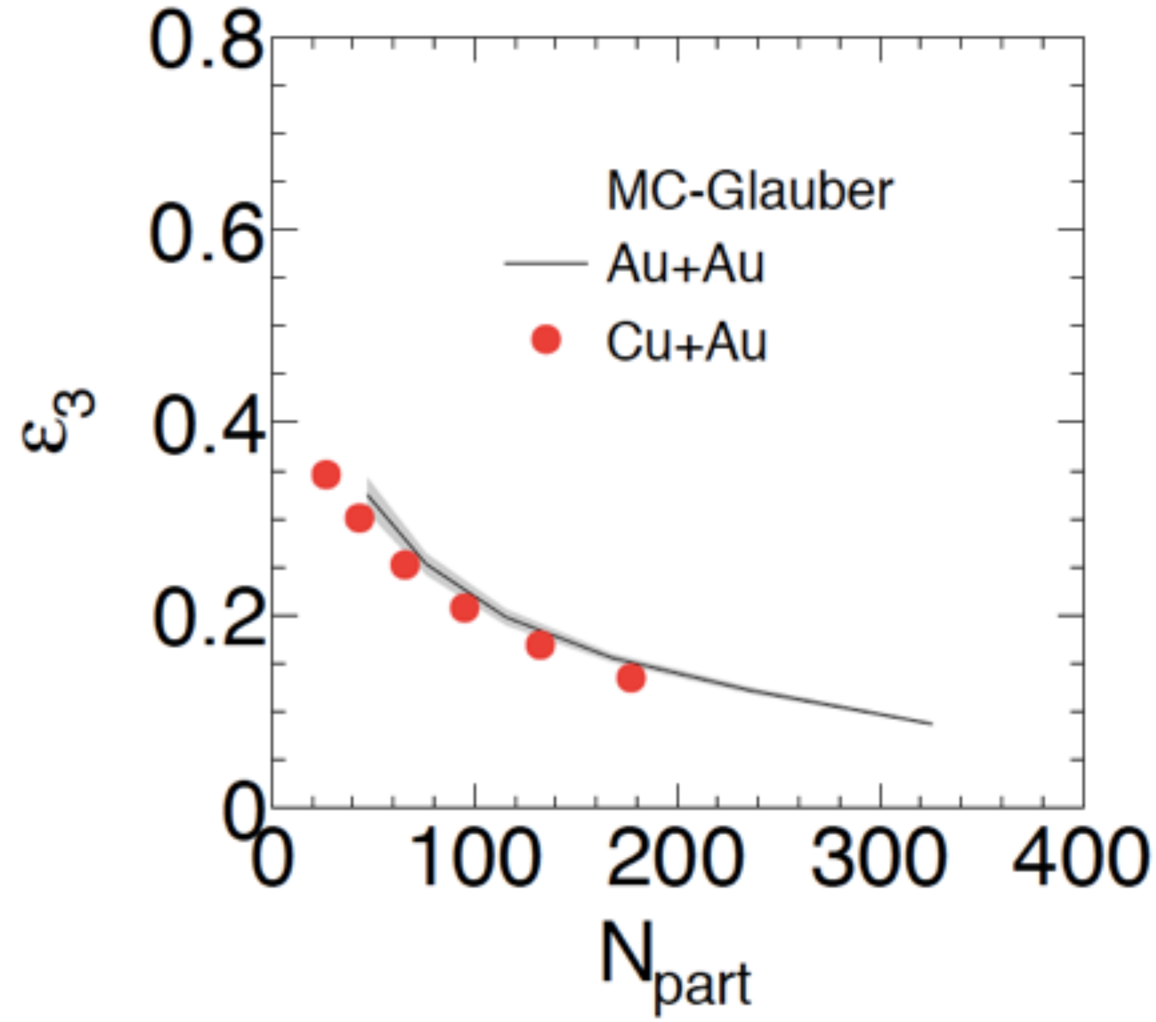


✓ $v_2(N_{part})$ and $\varepsilon_2(N_{part})$ are similar system size dependence

- N_{part}:Number of participants from MC-Glauber
- $v_2(AuAu) > v_2(CuAu) > v_2(CuCu) \sim \varepsilon_2(AuAu) > \varepsilon_2(CuAu) > \varepsilon_2(CuCu)$

System size dependence of $v_3(N_{part})$ and $\varepsilon_3(N_{part})$

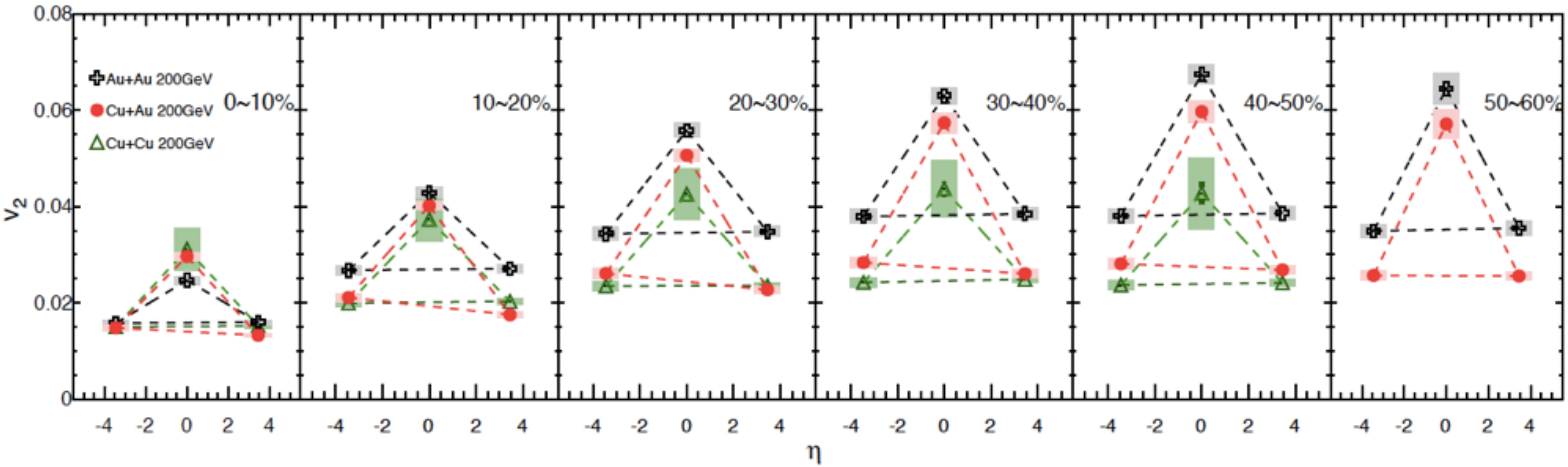




✓Unlike $v_2(N_{part})$, no significant system size dependence of $v_3(N_{part})$ and $\varepsilon_3(N_{part})$

- The ordering of the magnitude of v_3 is reversed with that of ε_3
- v_3 in Cu+Au are almost same or slightly larger than those in Au+Au
  -> intrinsic triangularity of asymmetric overlap zone?

System size dependence of v_2 at F/B



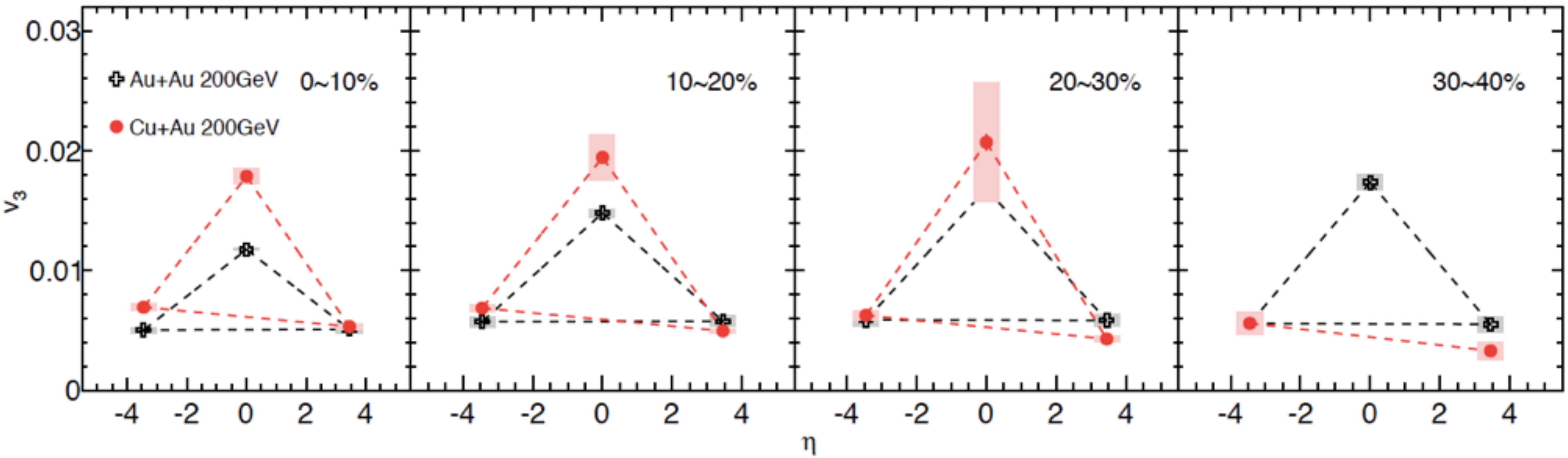
✓In Cu+Au collisions, F/B asymmetry of v_2 is observed.

-central & peripheral collisions: v2(Au-going) ~ v2(Cu-going)

-mid-central collisions : v2(Au-going) > v2(Cu-going)

->caused by different initial geometries in Au and Cu ?

System size dependence of v_3 at F/B



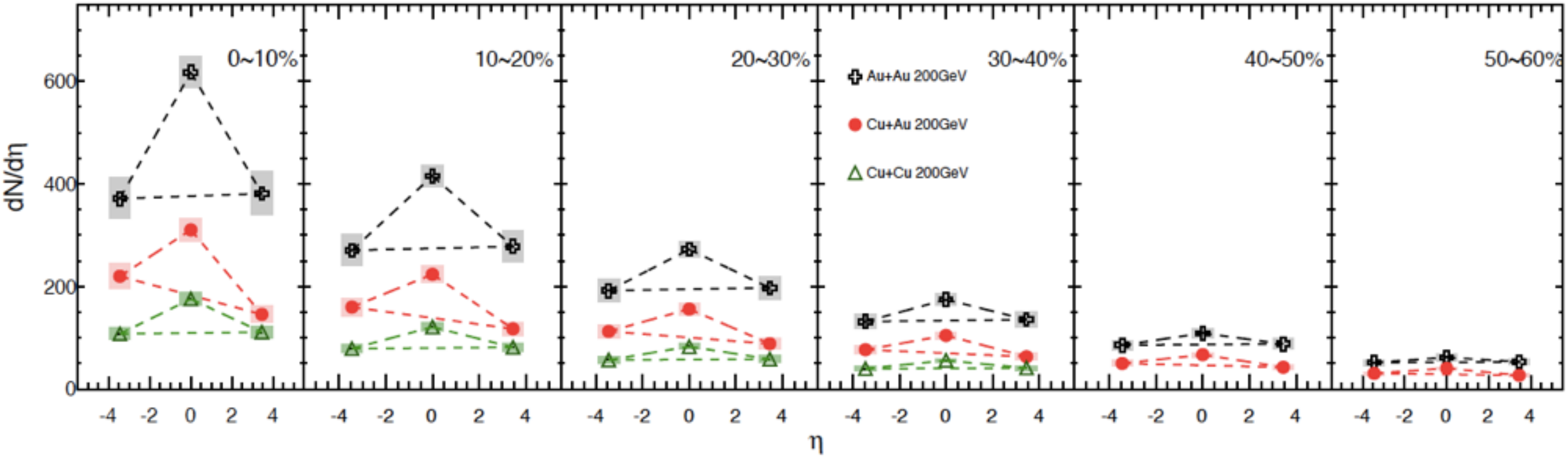
✓Weak centrality dependence of v_3 is seen for all collision systems

- AuAu:same centrality dependence as seen mid η
- CuAu: v_3 decrease as centrality decrease

✓In CuAu collisions, v_3(Au-going) > v_3(Cu-going) for all centrality bins

-> Like v_2, the different initial geometry cause the different v_3 ?

F/B asymmetry of dN/dη

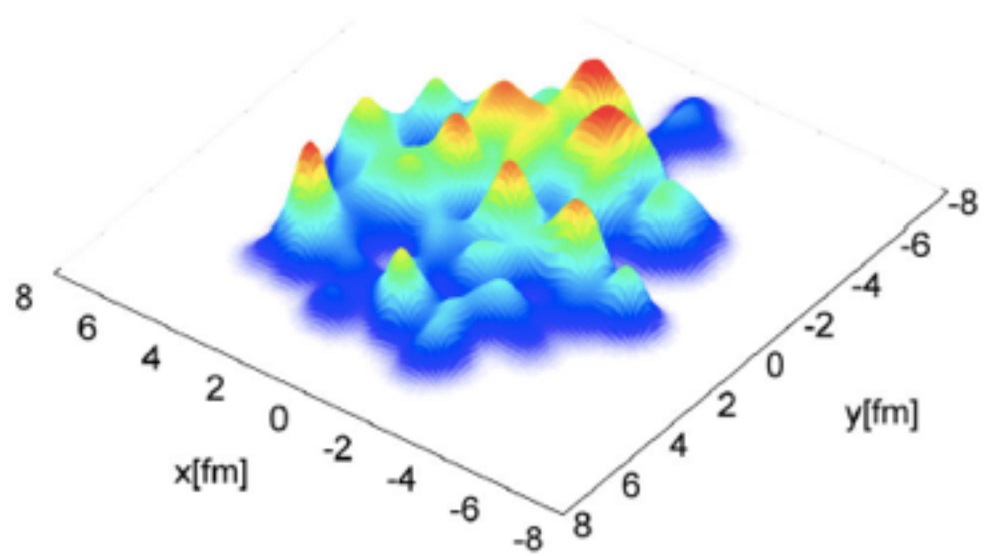


√Like the v_n, the dN/dη in Au-going side is higher

√In 50-60%, the dN/dη in Au-going side and Cu-going side are almost same due to similar N_{part}.

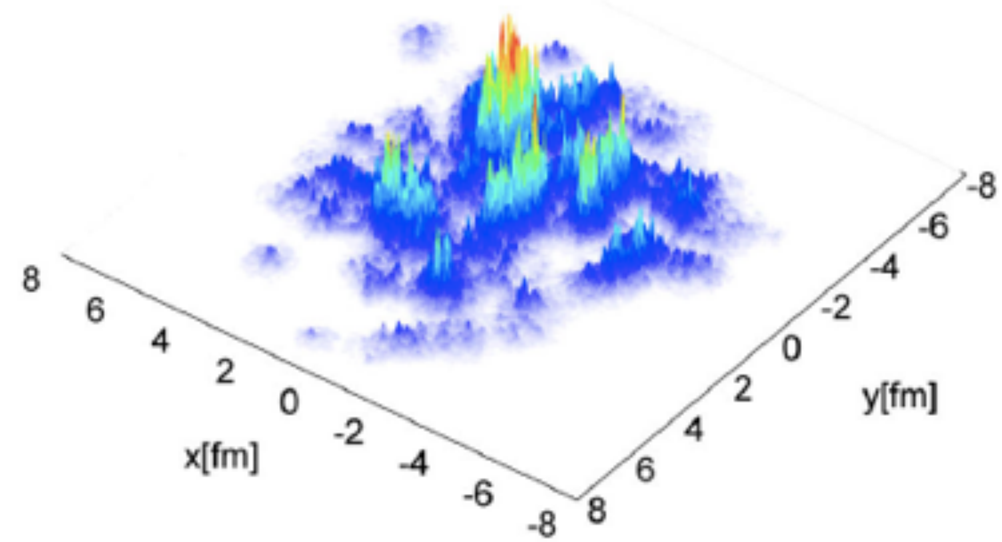
Initial geometry model

Glauber nucleon



Smooth structure

IPGlasma

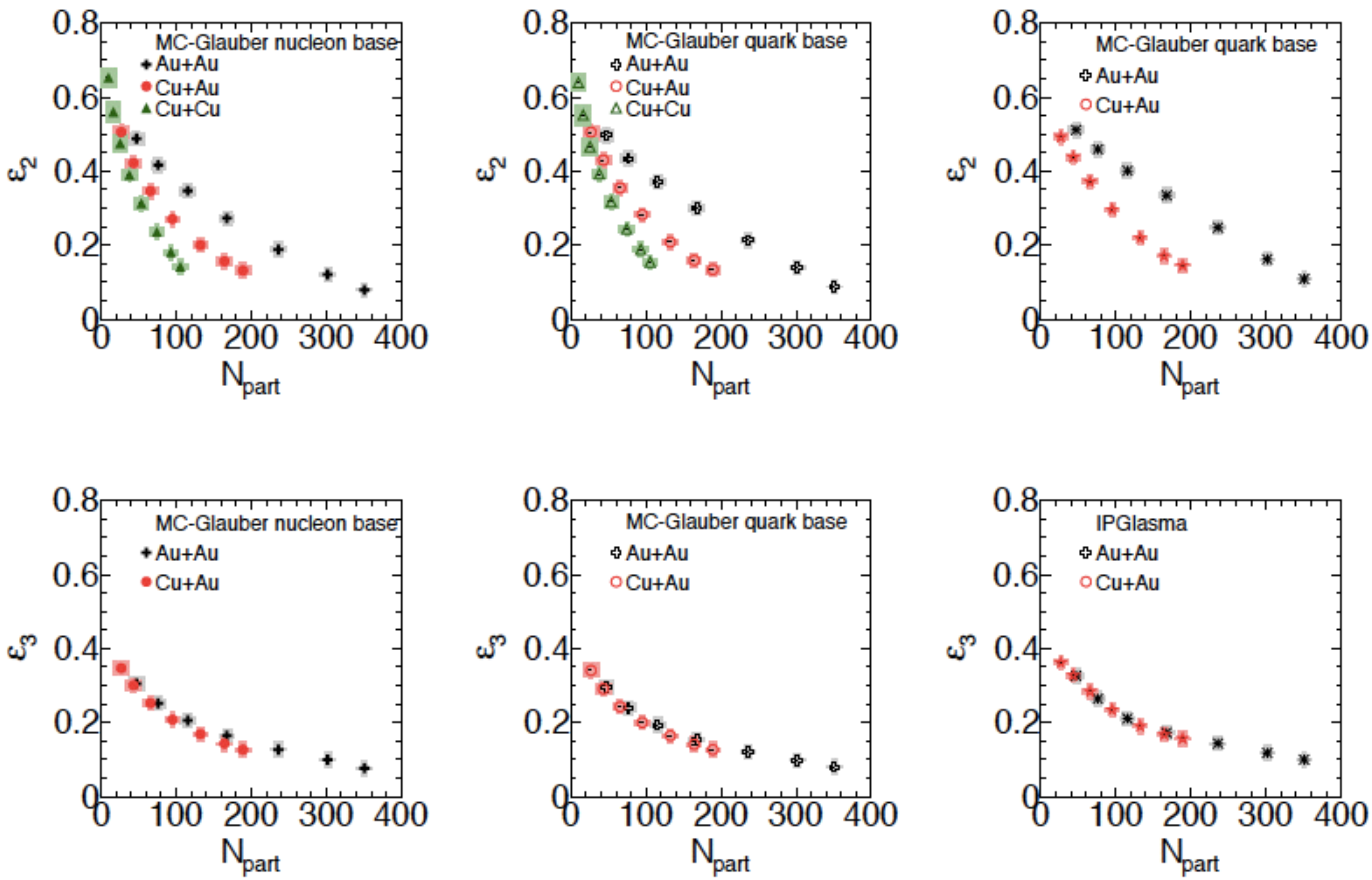


Fine structure

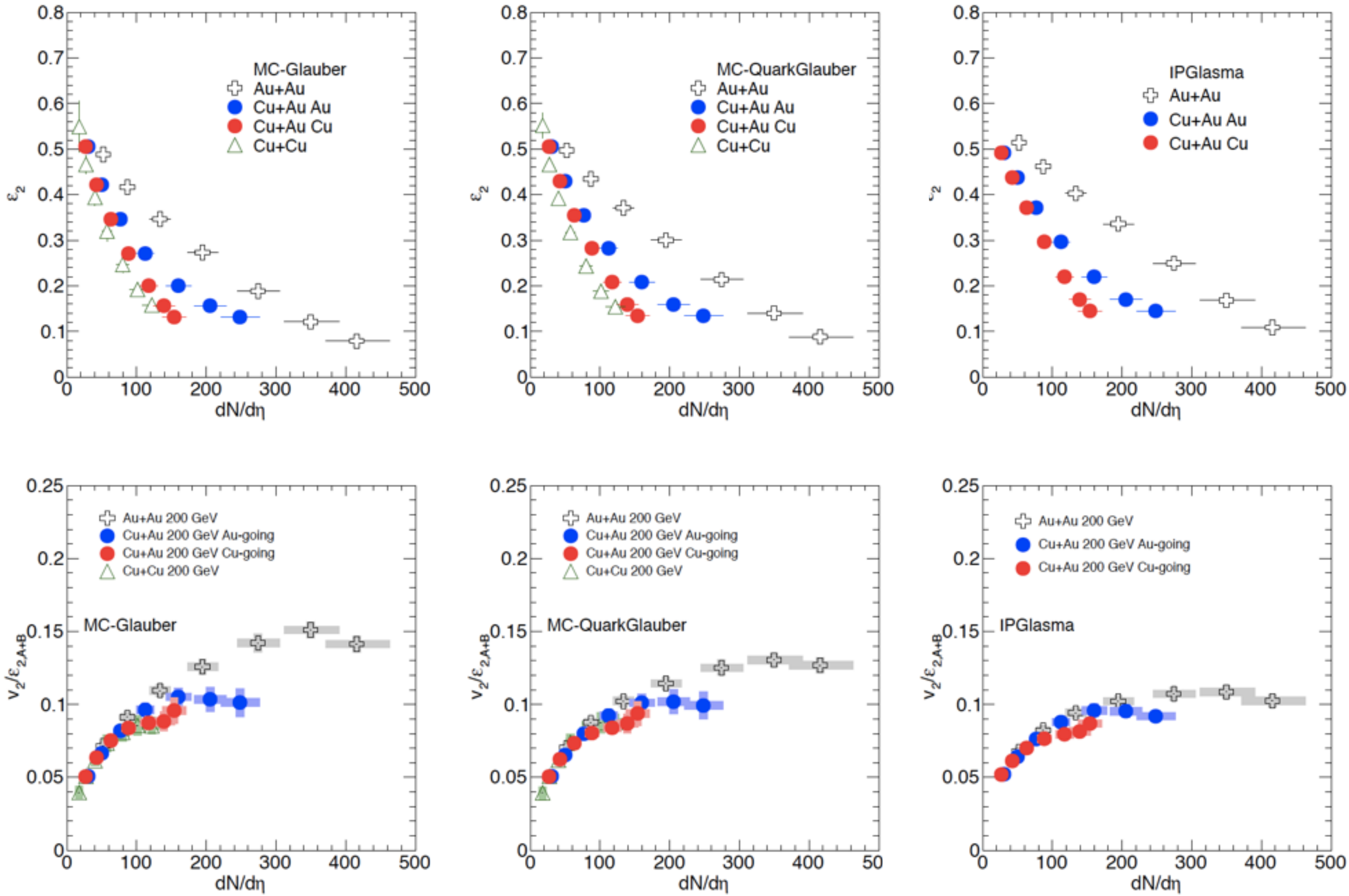
√Glauber Monte Carlo model:nucleon base
√Glauber Monte Carlo model:Constituent quark base
PRC 93 024901
√IPGlasma Model : gluon base(CGC), PRC 89, 064908

->fineness: gluon base>quark base > nucleon base

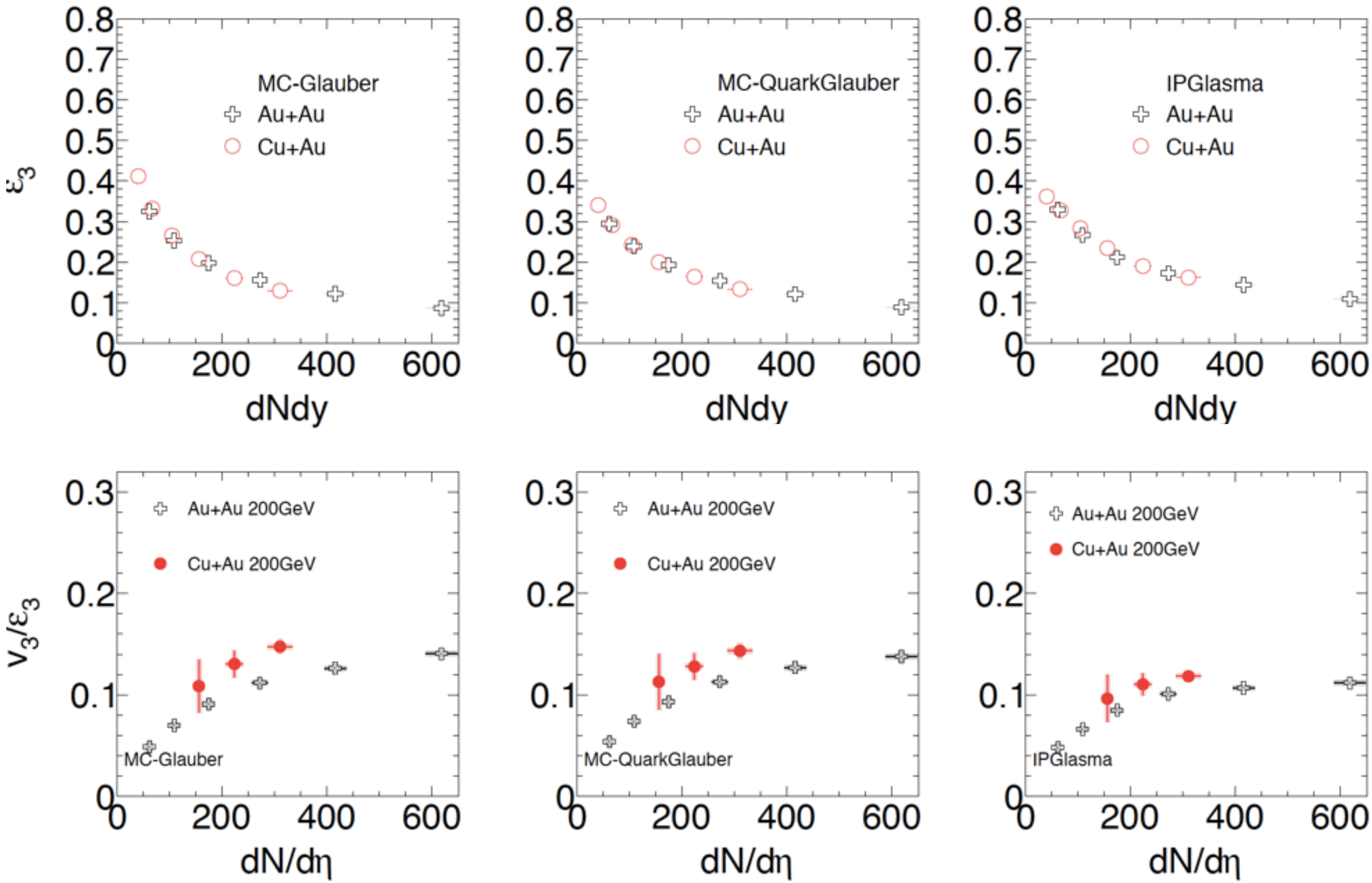
Model dependence of 2nd and 3rd Eccentricity



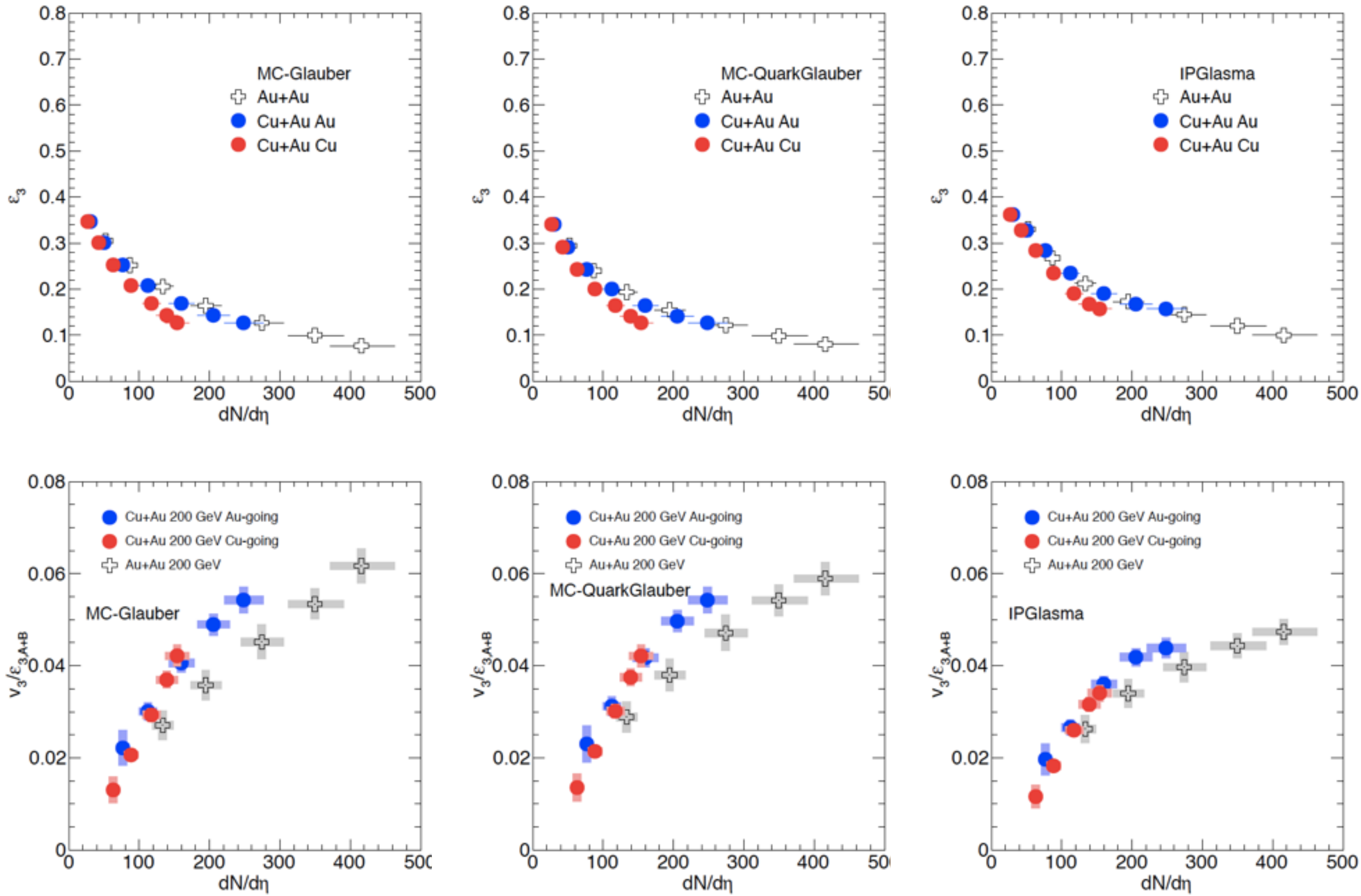
v2/e2 at f/b rapidity vs dN/dy



v3/e3 at mid rapidity vs dN/dy

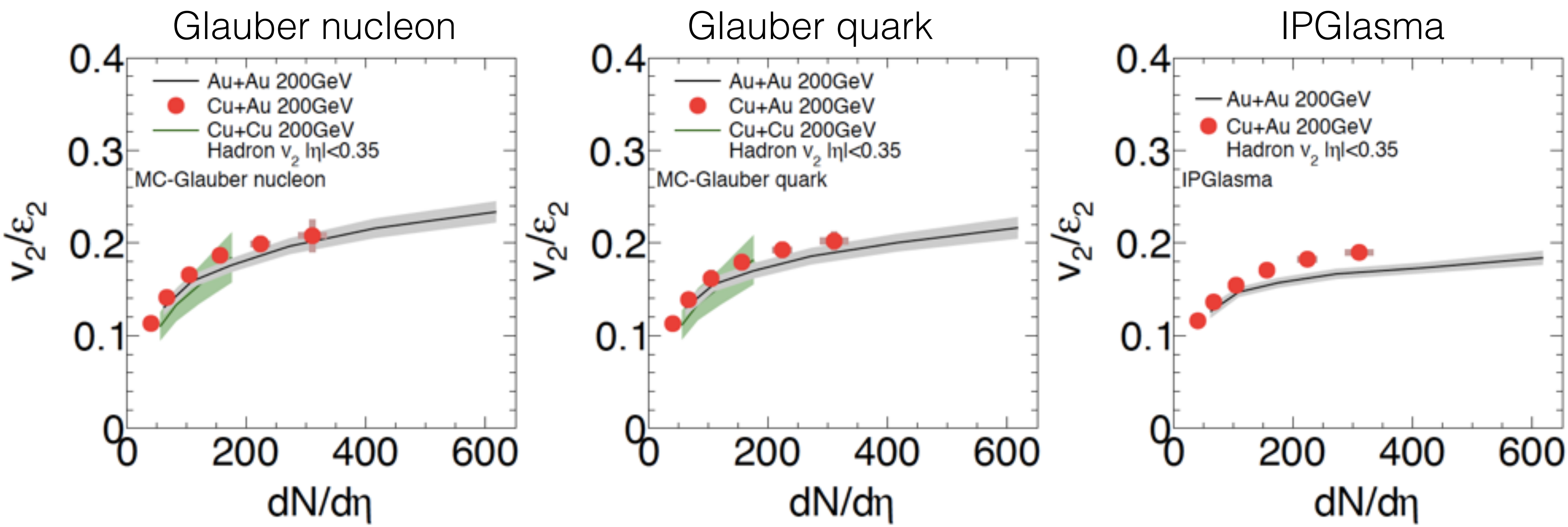


v3/e3 at f/b rapidity vs dN/dy



vn vs Npart

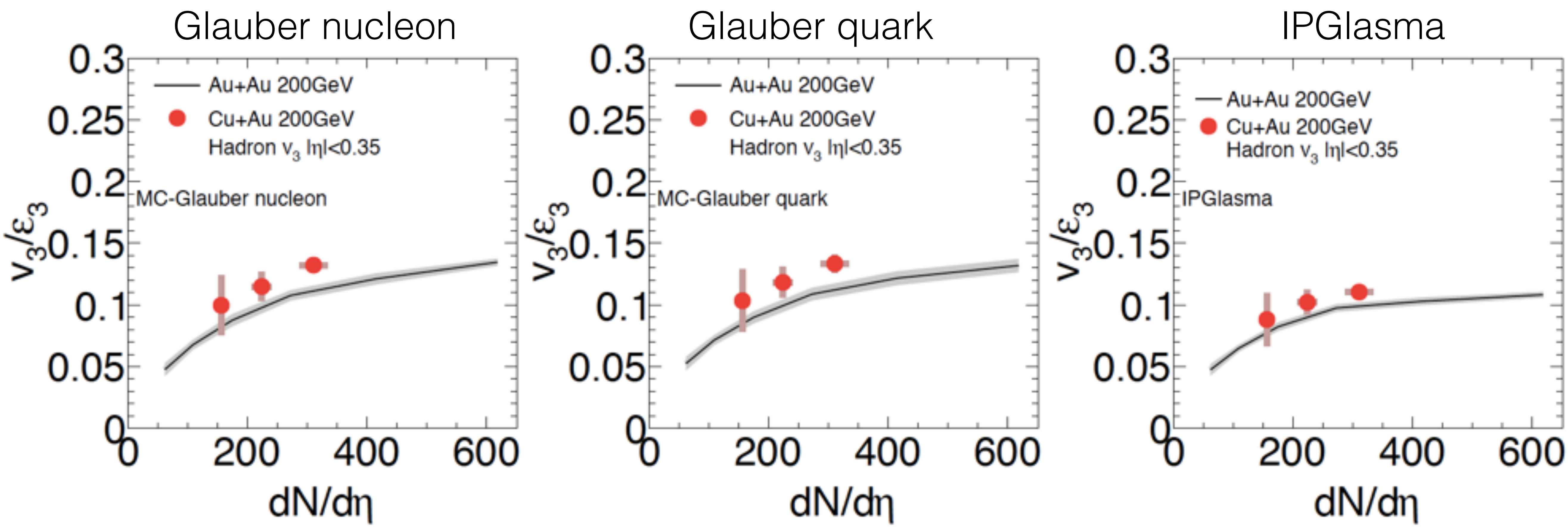
v_2/ε_2 scaling at mid-rapidity



✓ v_2 scaled with Glauber model(nucleon,quark) are consistent among three collision systems

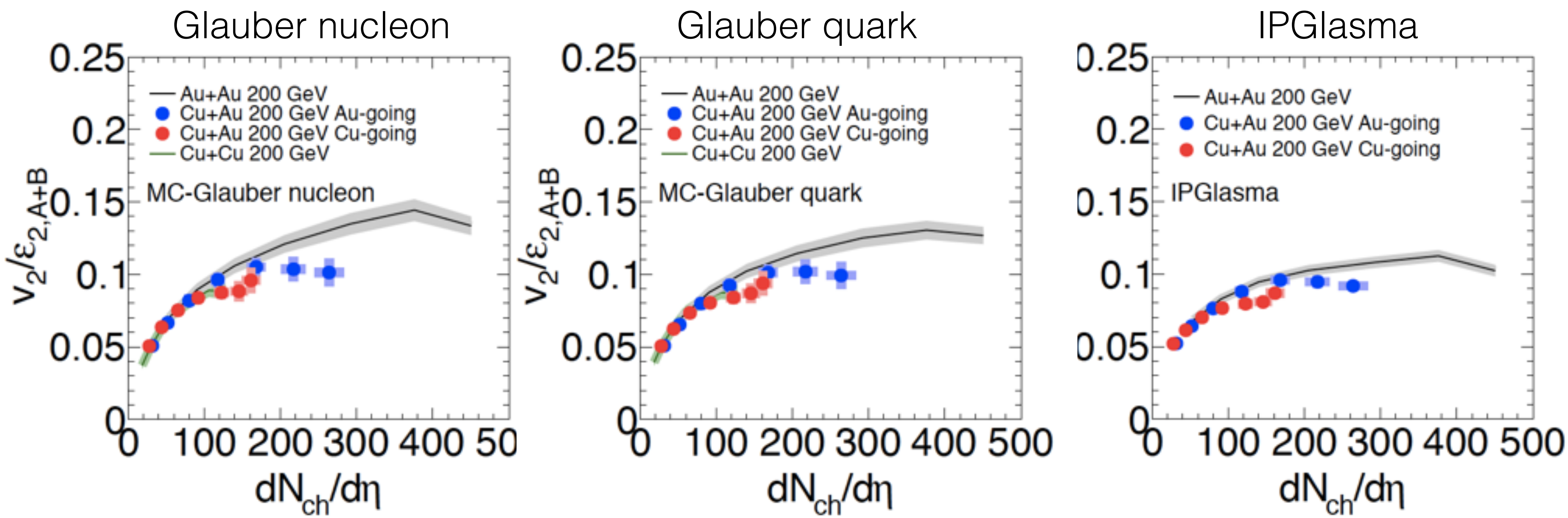
✓ The deviation is seen in central for IPGlasma model

v_3/ε_3 scaling at mid-rapidity



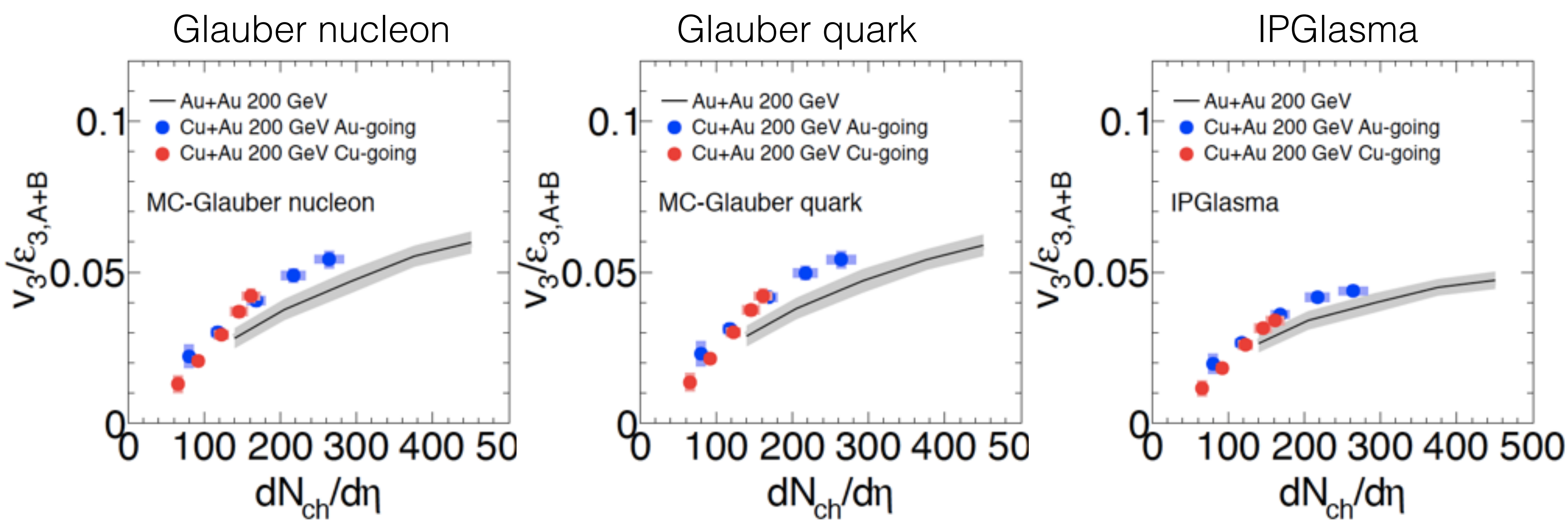
- ✓ **In Glauber model(nucleon,quark), the deviation is seen at central bin**
- ✓ **In IPGlasma model, AuAu v_3/ε_3 and CuAu v_3/ε_3 are close to each other**

v_2/ε_2 scaling at f/b-rapidity



- ✓In Glauber model(nucleon,quark), the deviations between CuAu and AuAu are seen at central bin
- ✓In IPGlasma model, AuAu v_2/ε_2 and CuAu v_2/ε_2 are close to each other

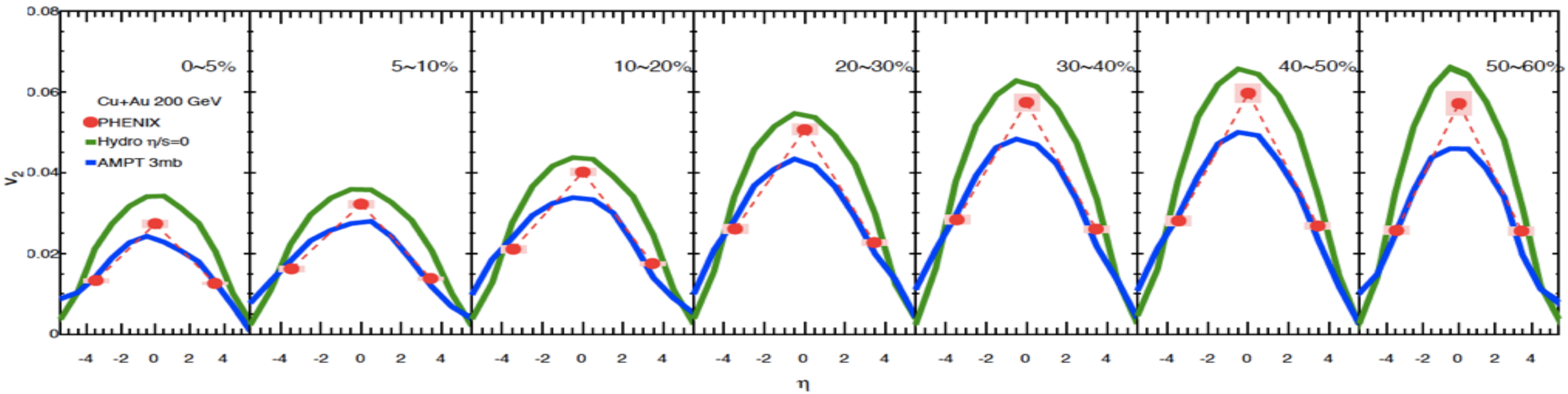
v_3/ε_3 scaling at f/b-rapidity



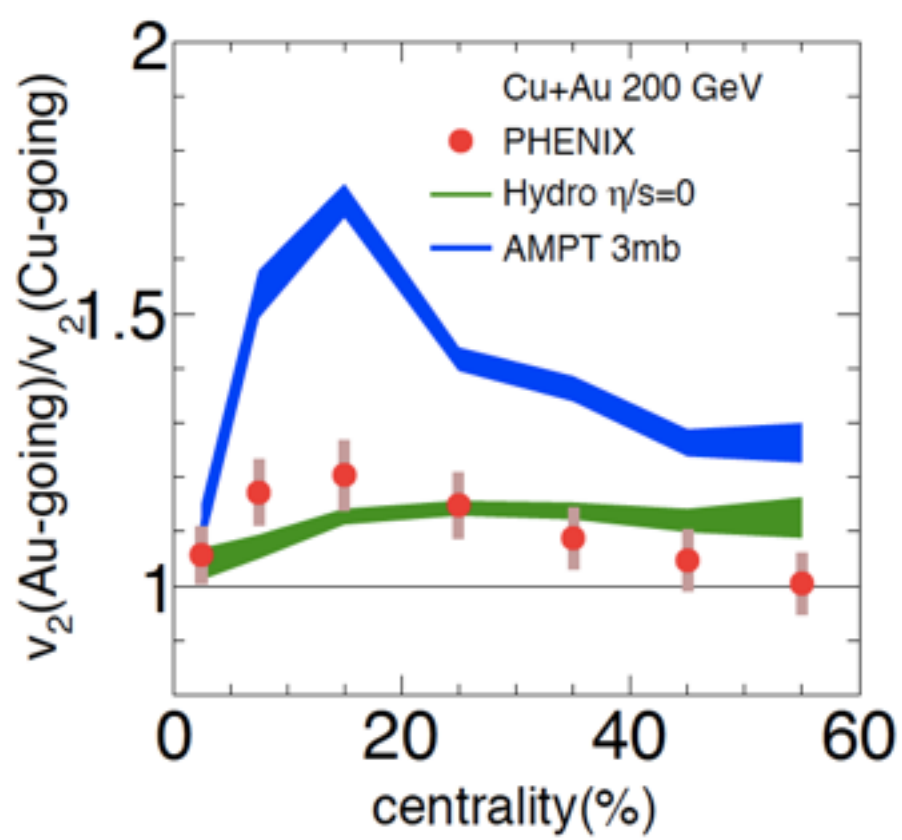
√In Glauber model(nucleon,quark), the deviation is seen from central to mid-central

√In IPGlasma model, AuAu v_3/ε_3 and CuAu v_3/ε_3 are close to each other

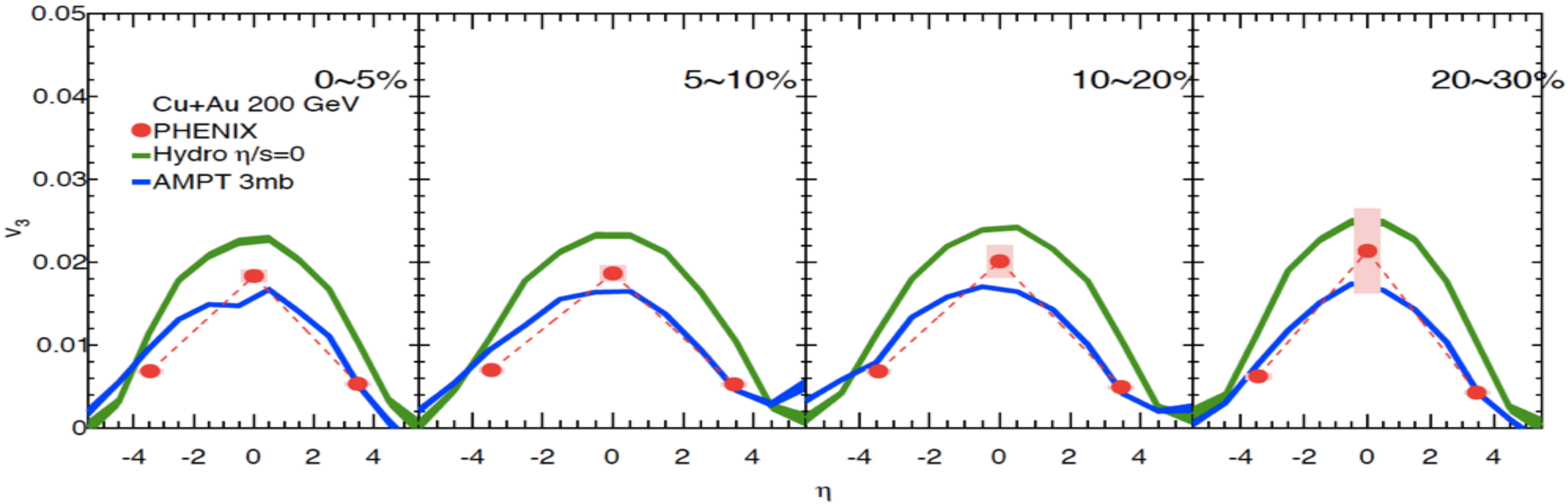
Parton cascade and hydro $v_2(\eta)$



- ✓AMPT and Hydro predict magnitude of v2 at F/B rapidity well
  - -Hydro:Smooth longitudinal density+hydro
  - -AMPT:Fluctuated longitudinal density+parton cascade
- ✓Hydro reproduces the ratio of F/B v2
  - - In peripheral collisions, the F/B ratio becomes constant
- ✓AMPT model over-estimate the ratio

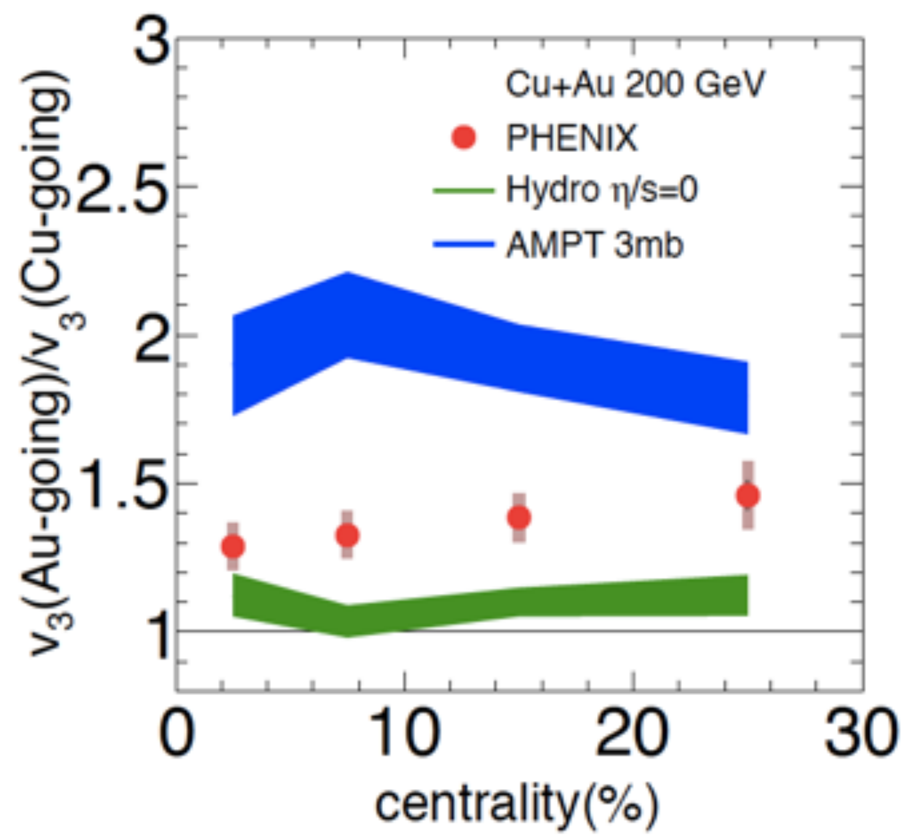


Parton cascade and hydro $v_3(\eta)$



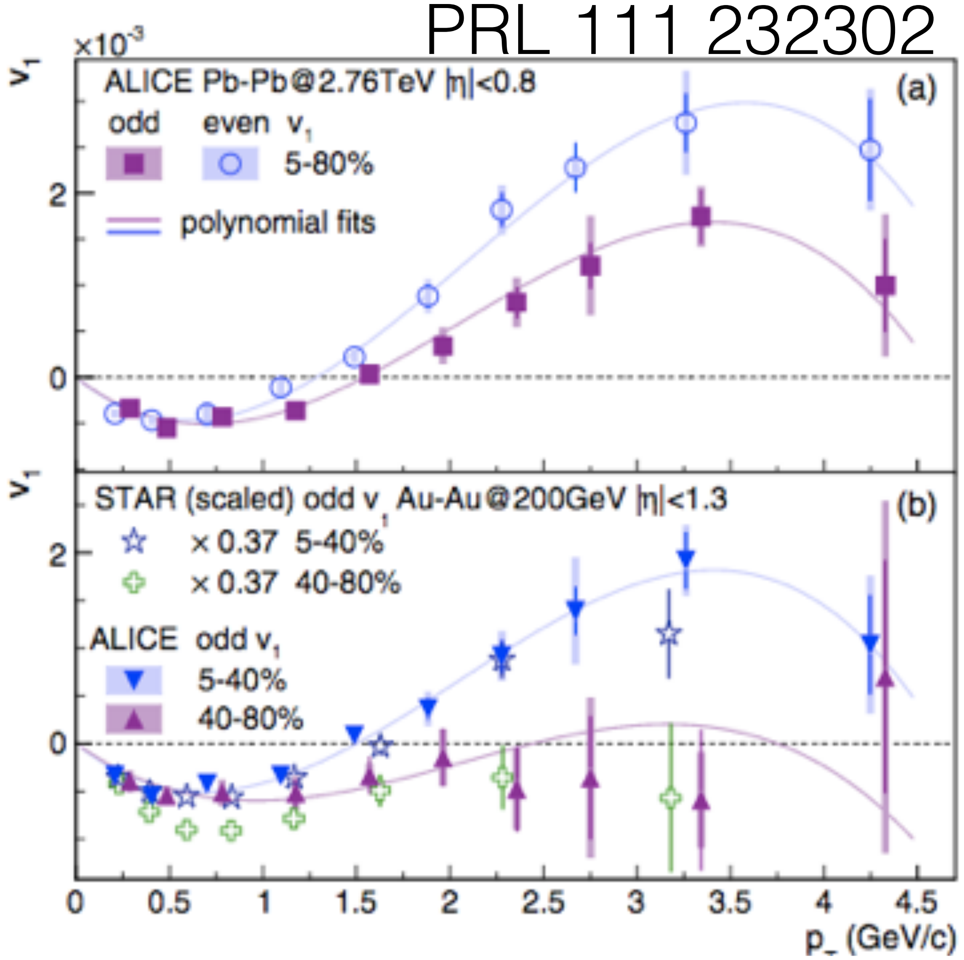
✓AMPT show the F/B asymmetry of v3
- v_3 (Au-going) > v_3(Cu-going)
->Fluctuated longitudinal density show larger F/B asymmetry of v_n

✓Hydrodynamics show weak F/B asymmetry of v3
-v_3(Au-going) ~ v_3(Cu-going)
->Smooth longitudinal density show weaker F/B asymmetry of v_n

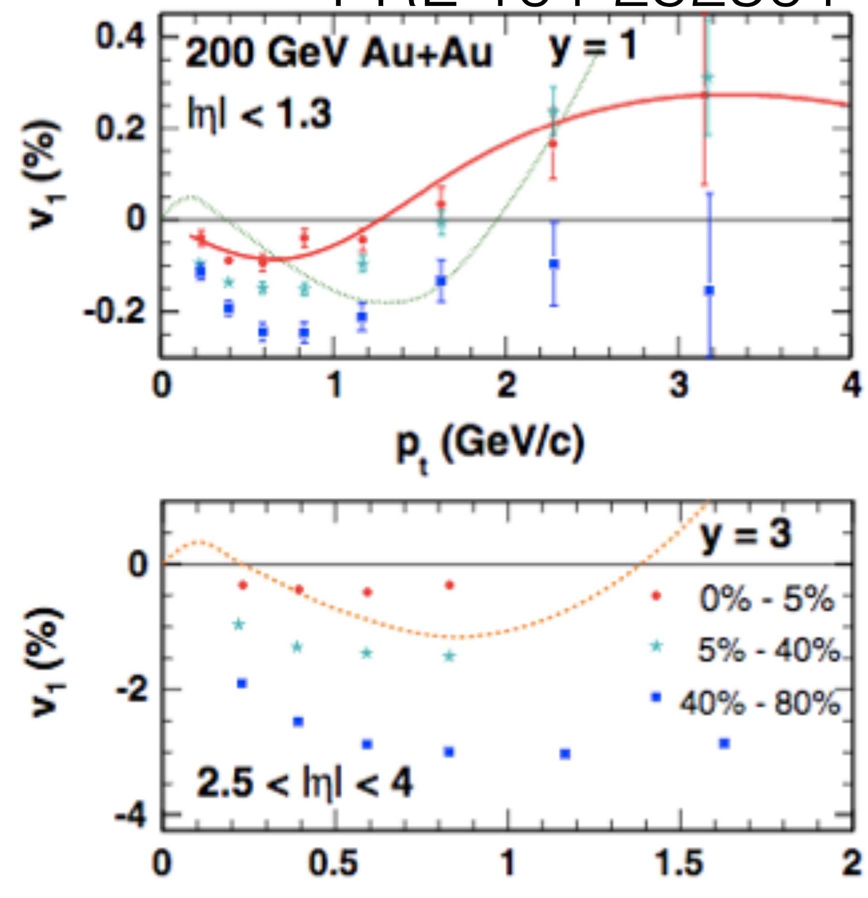


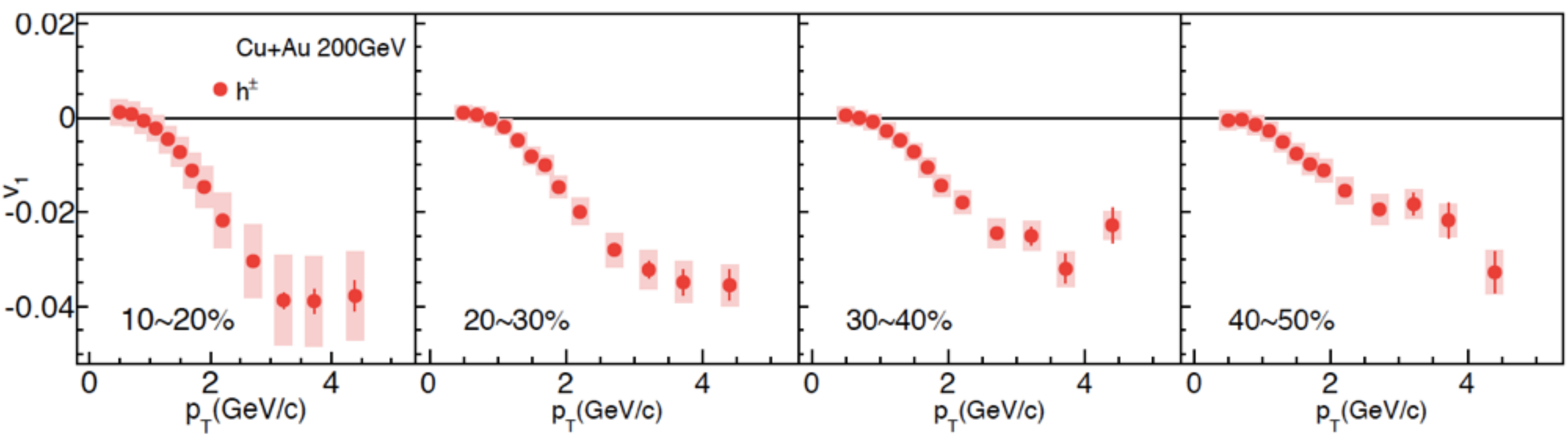
Directed flow in comparison to STAR and ALICE

PRL 111 232302

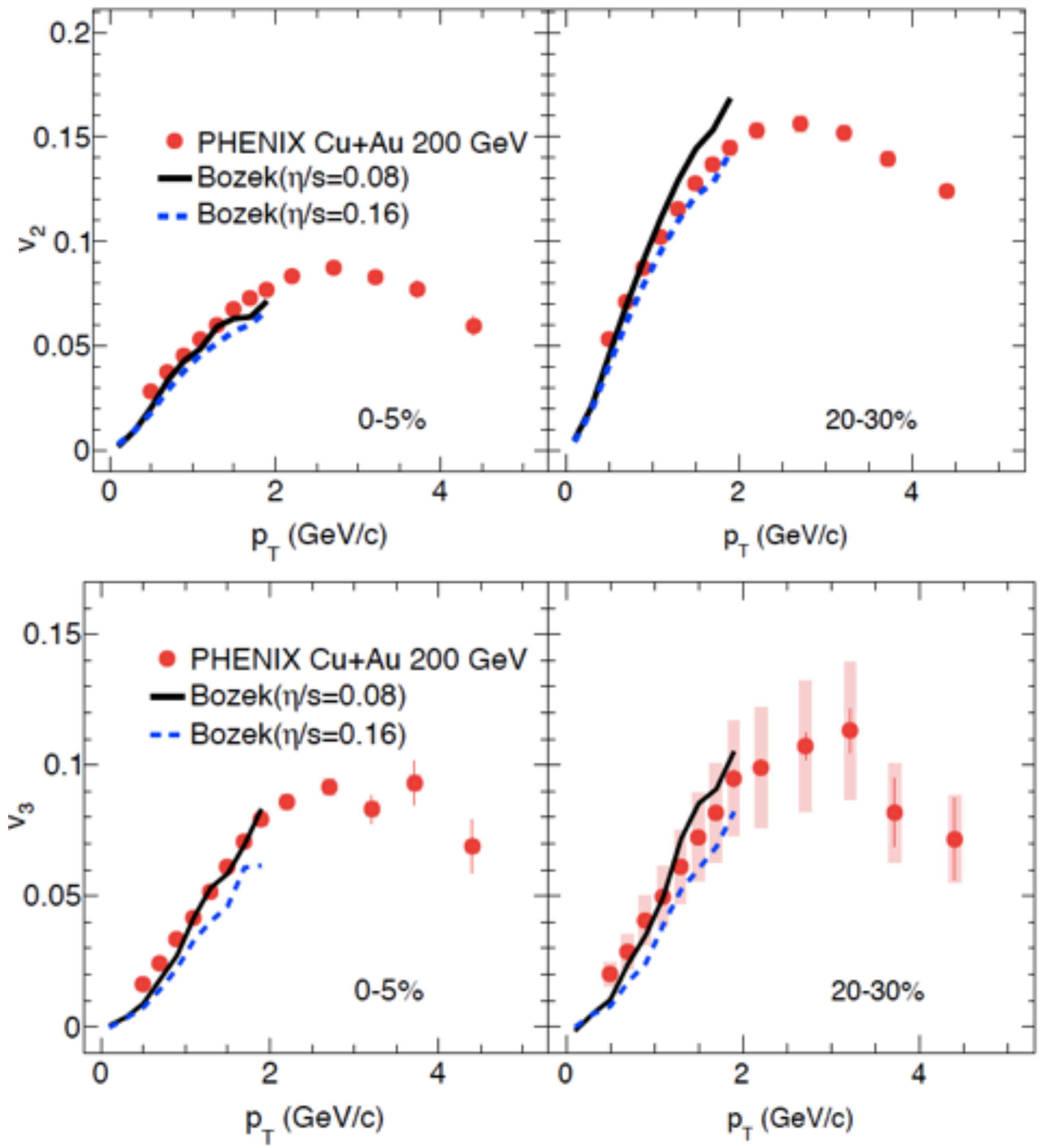


PRL 101 252301



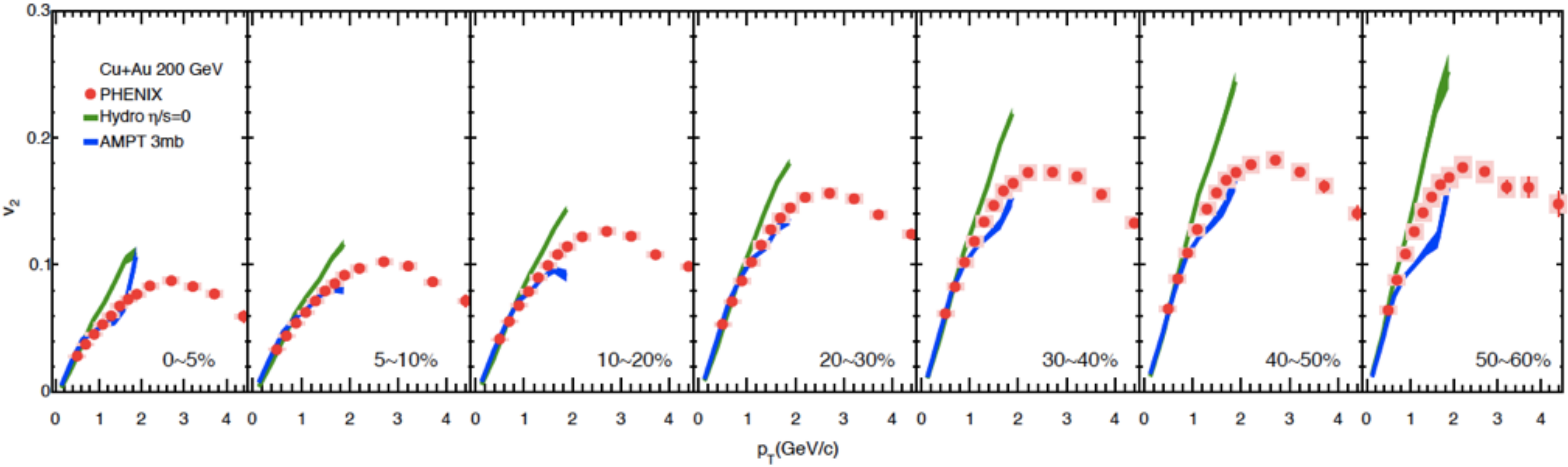


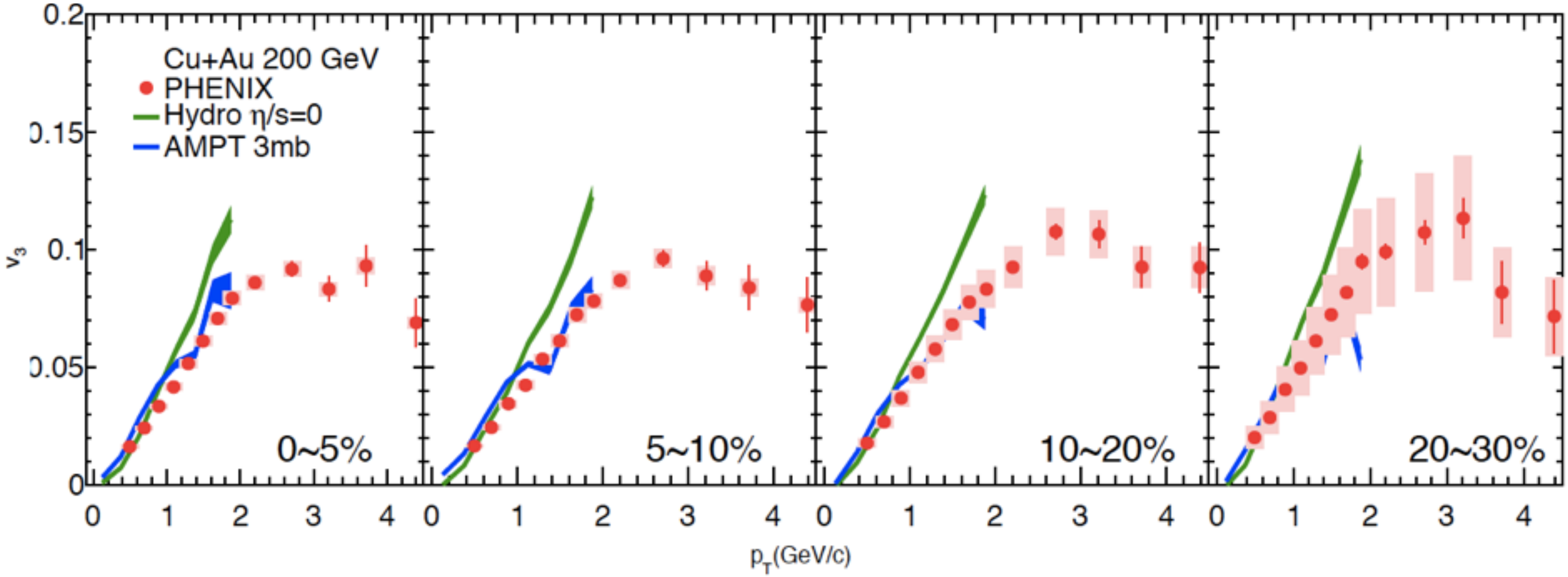
MC-Glauber E-by-E hydro v_2, v_3 at mid-η



For both centrality, both value of η/s agree with data

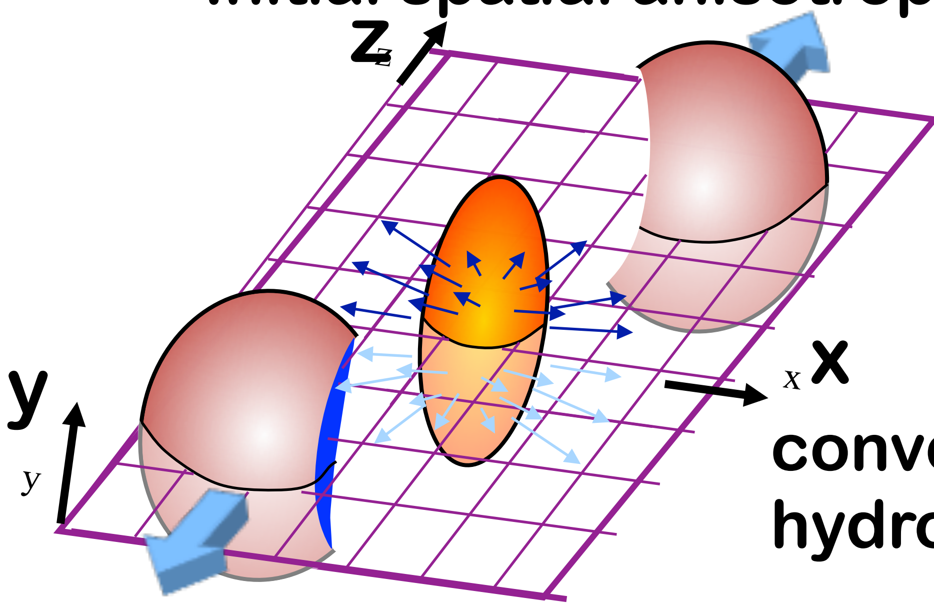
v_n:AMPT and Hydrodynamics



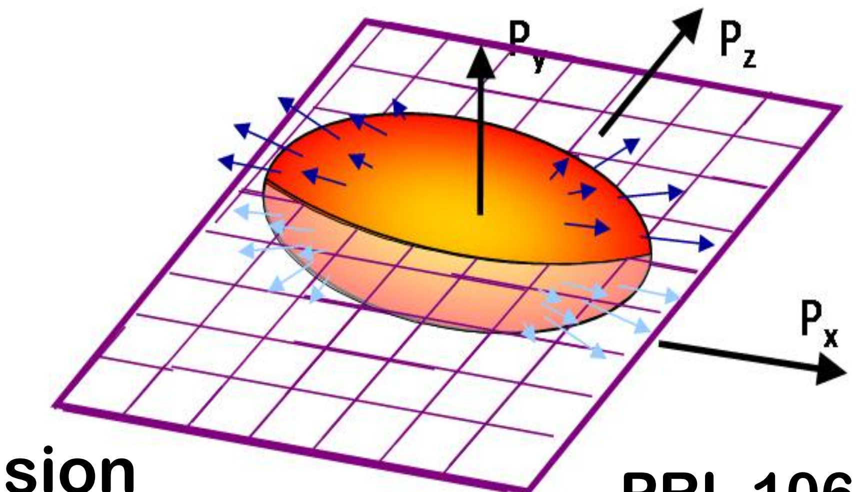


Azimuthal anisotropy:Elliptic flow

Initial spatial anisotropy:ε_2

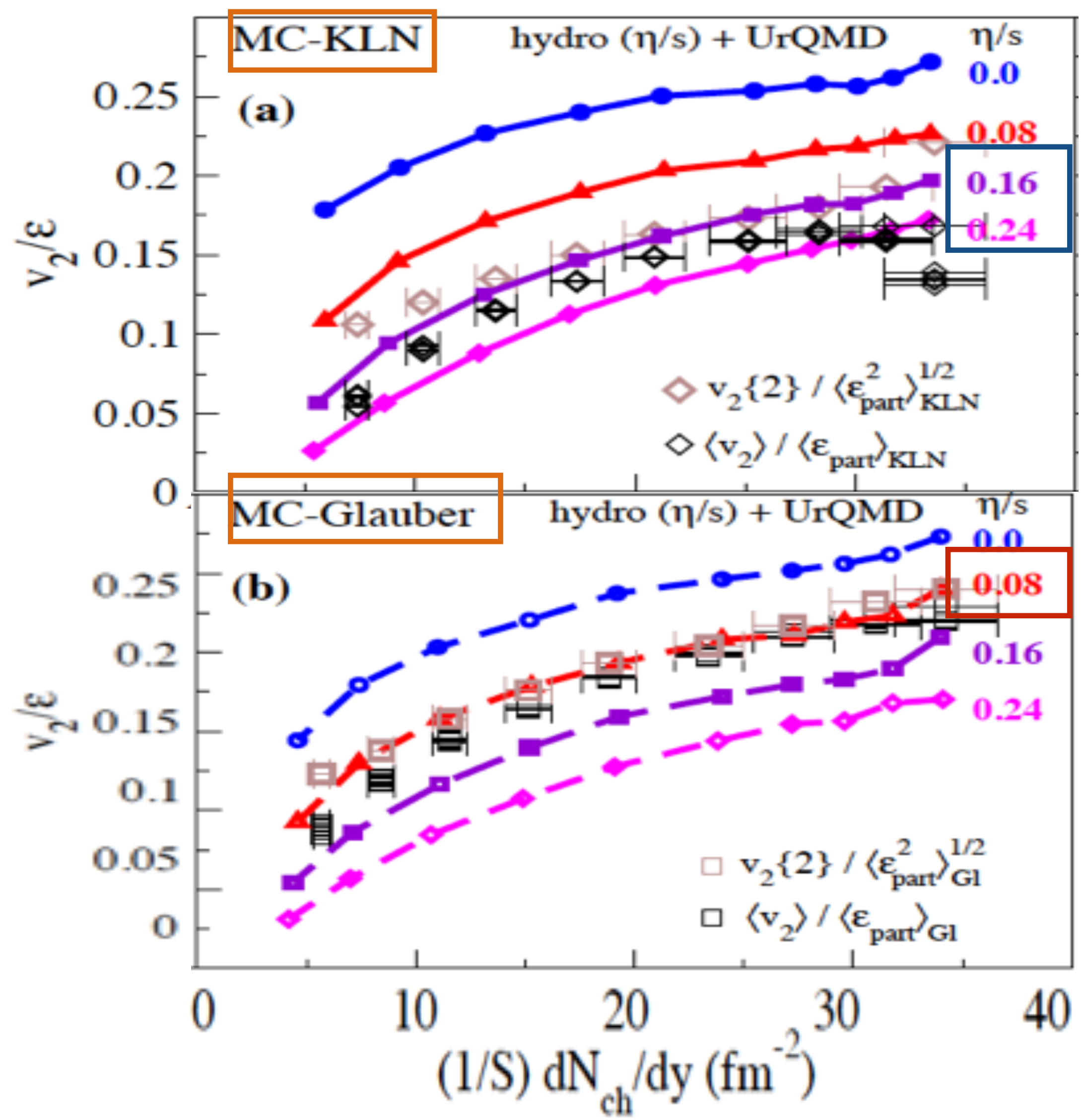


momentum anisotropy:v_2



converted though hydrodynamic expansion

PRL 106.192301



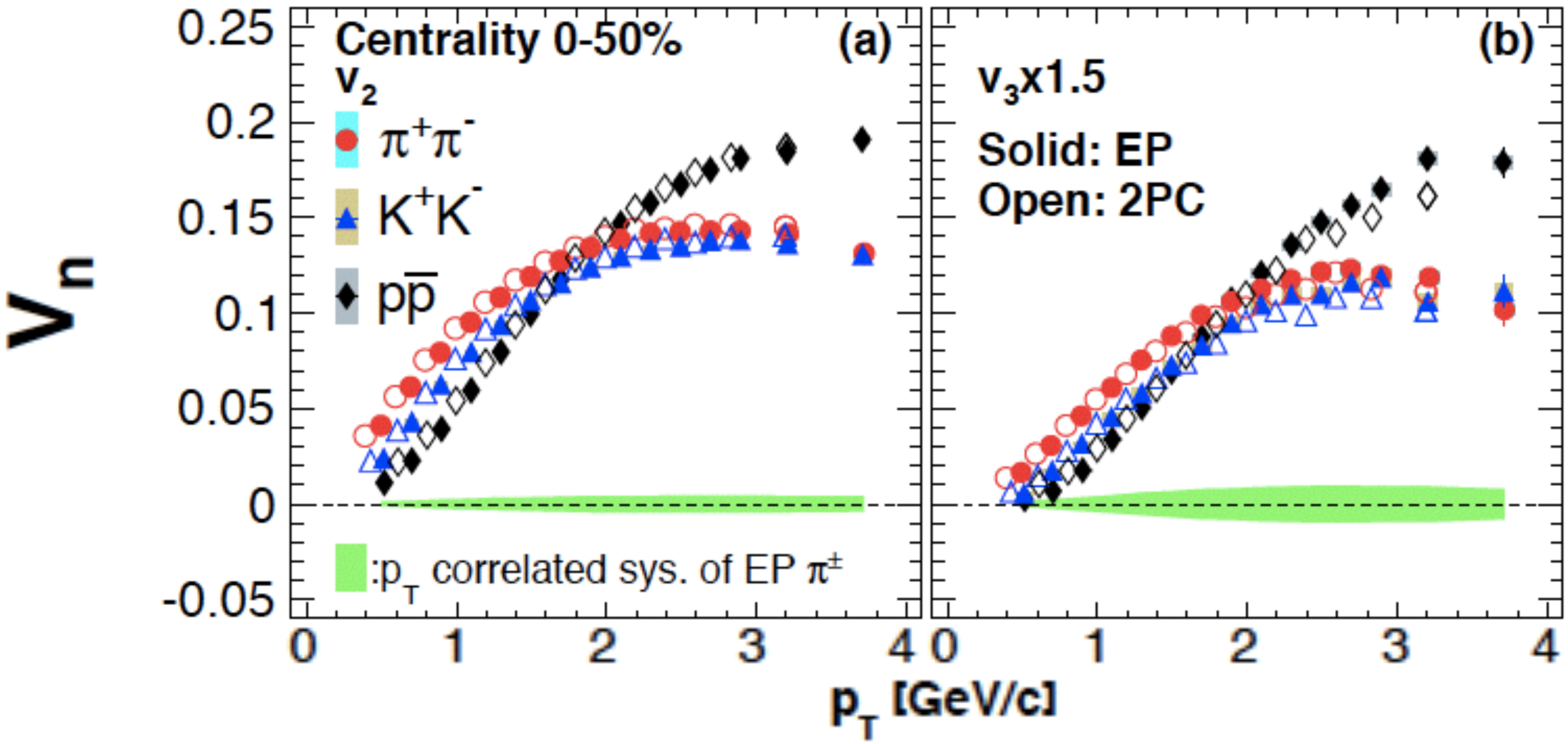
particle production will have an elliptical azimuthal distribution.

- **Non-isotropic pressure gradient**

Sensitive to
-initial condition
(Glauber,KLN..etc.)
-viscosity
(η/s)

pi, K, p flow

arXiv:1412.1038

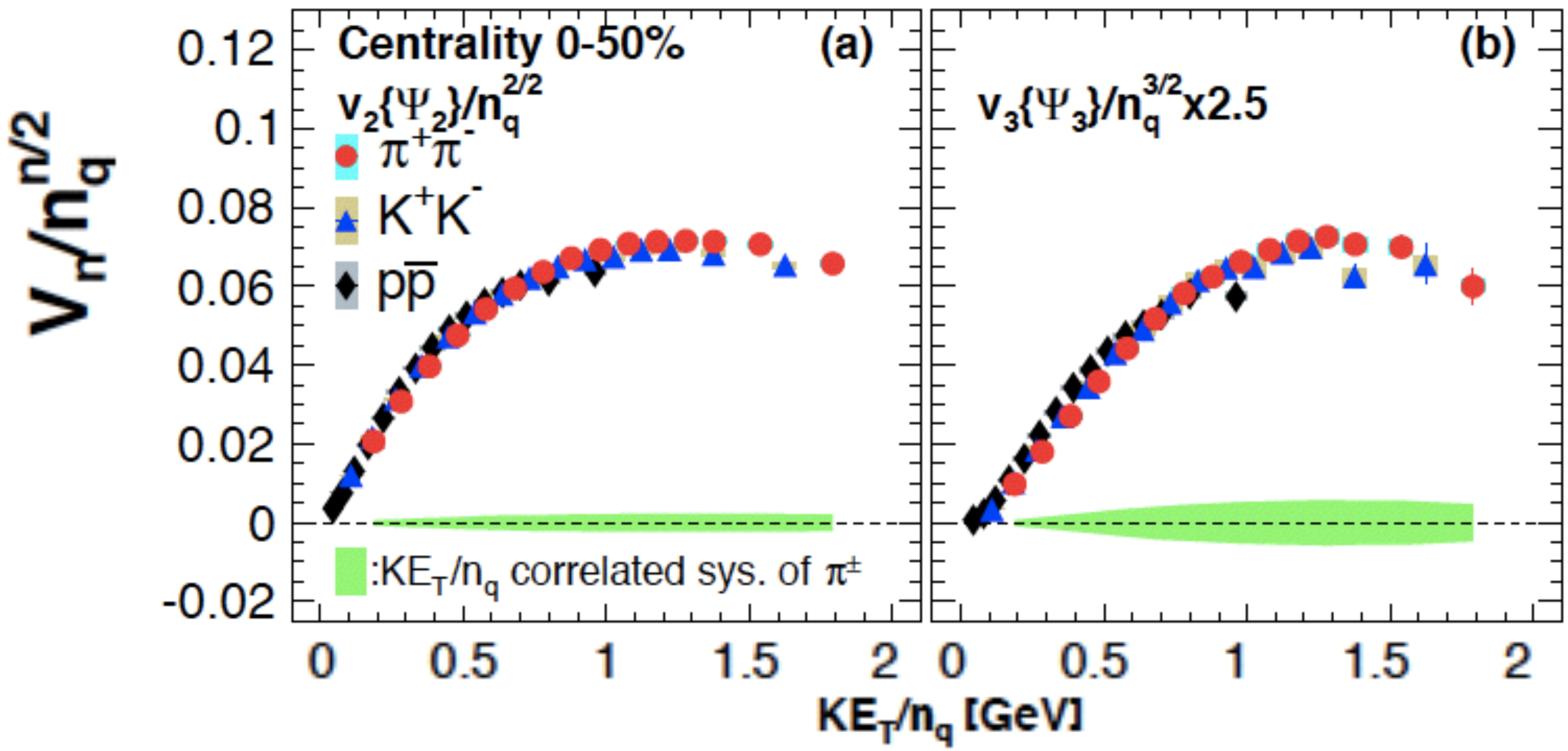


v_2,v_3 have similar particle dependence

v_3 scaled with $n_q^{3/2}$

Scaling property : quark number scaling

arXiv:1412.1038



v_2,v_3 have similar particle dependence

v_3 scaled with $n_q^{3/2}$

Track identification at CNT(|η|<0.35)

TOF.E and TOF.W are used

-TOF.E : Scintillation counter 130ps
-TOF.W : MRPC 95ps

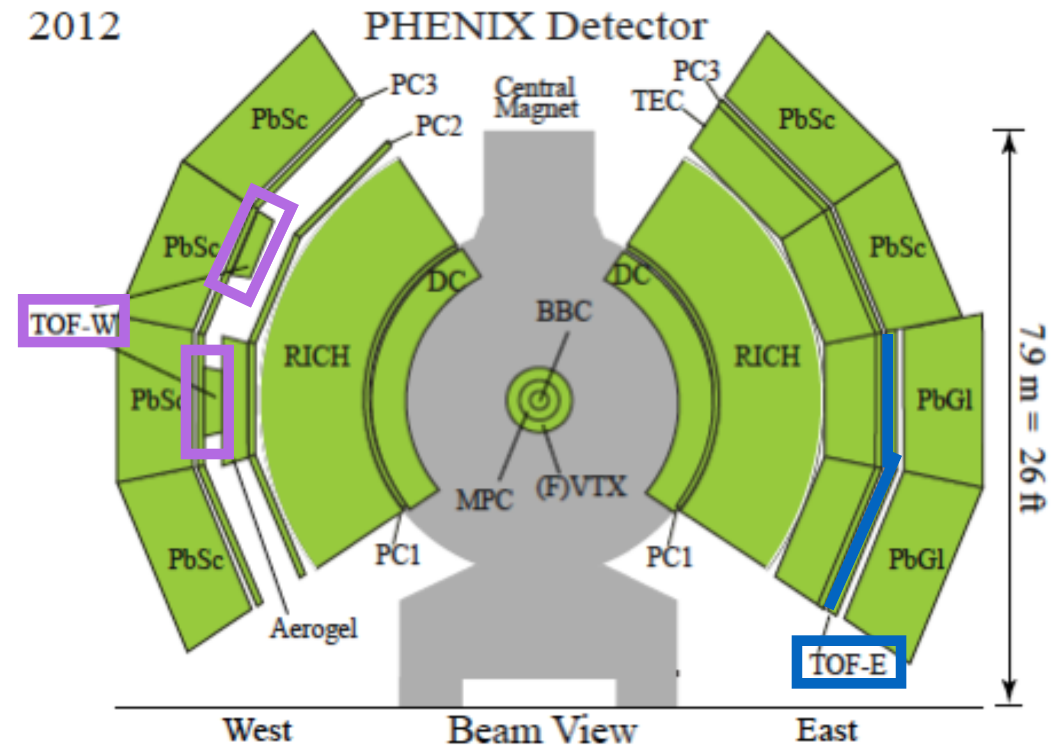
Time of flight method

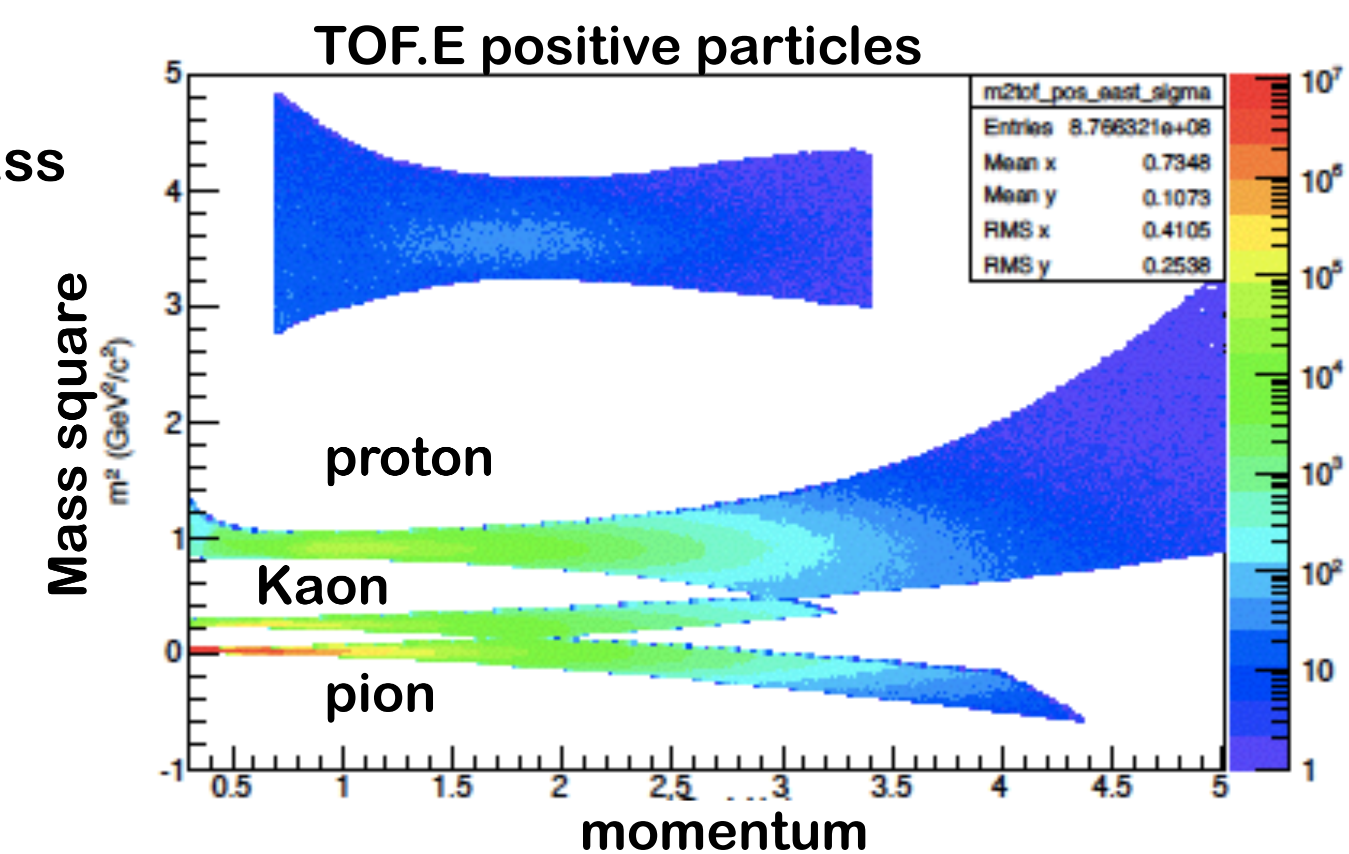
$$m^2 = p^2\left(\left(\frac{ct}{L}\right)^2 - 1\right)$$

m:particle mass, p:momentum, L:flight pass
c:light velocity, t:time of flight

Charged pi,K,p

-pi/K up to 3GeV
-K/p up to 4GeV



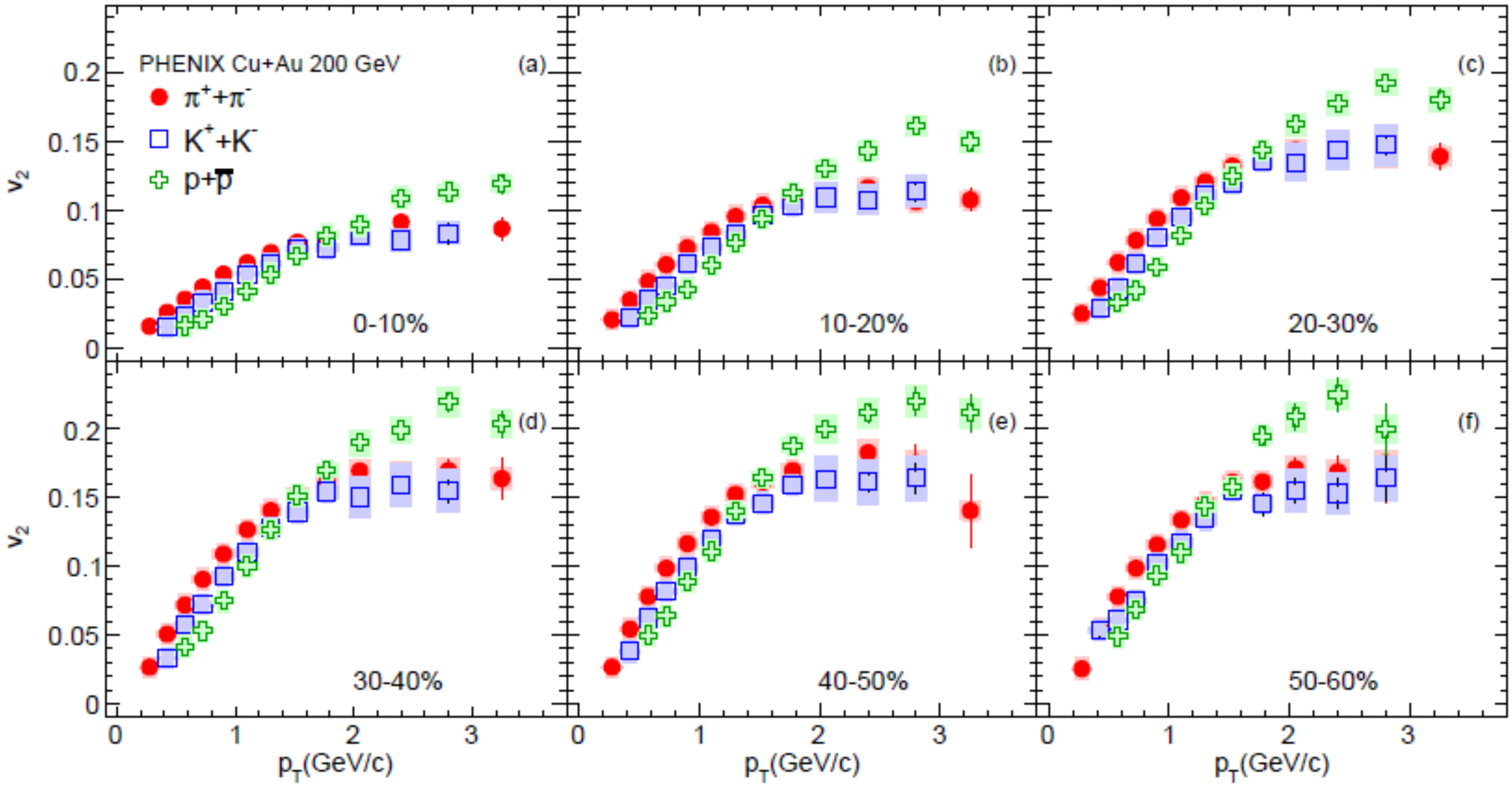


Results
&
Discussions

- System size dependence
- PID v_n
- Rapidity dependence
- Theory comparison

Identified particle v_2 in Cu+Au

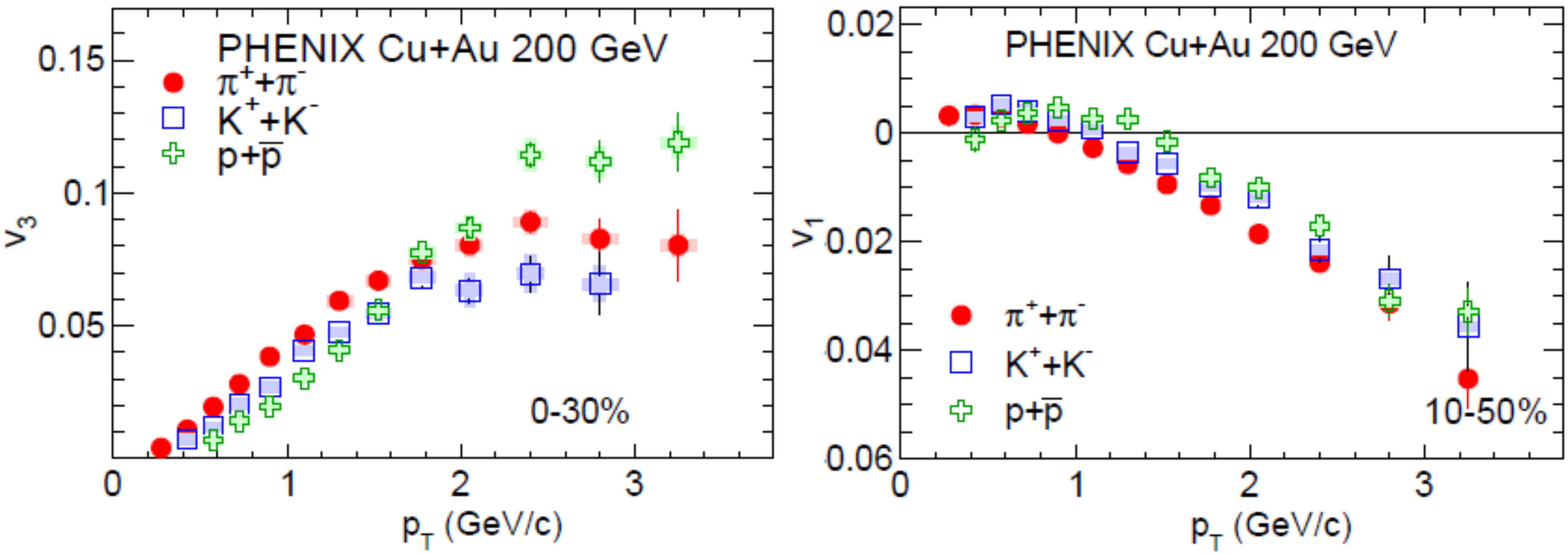
arxiv:1509.07784



Mass ordering at low p_T for v_2 for all centralities
Baryon and meson splitting at mid-p_T is seen

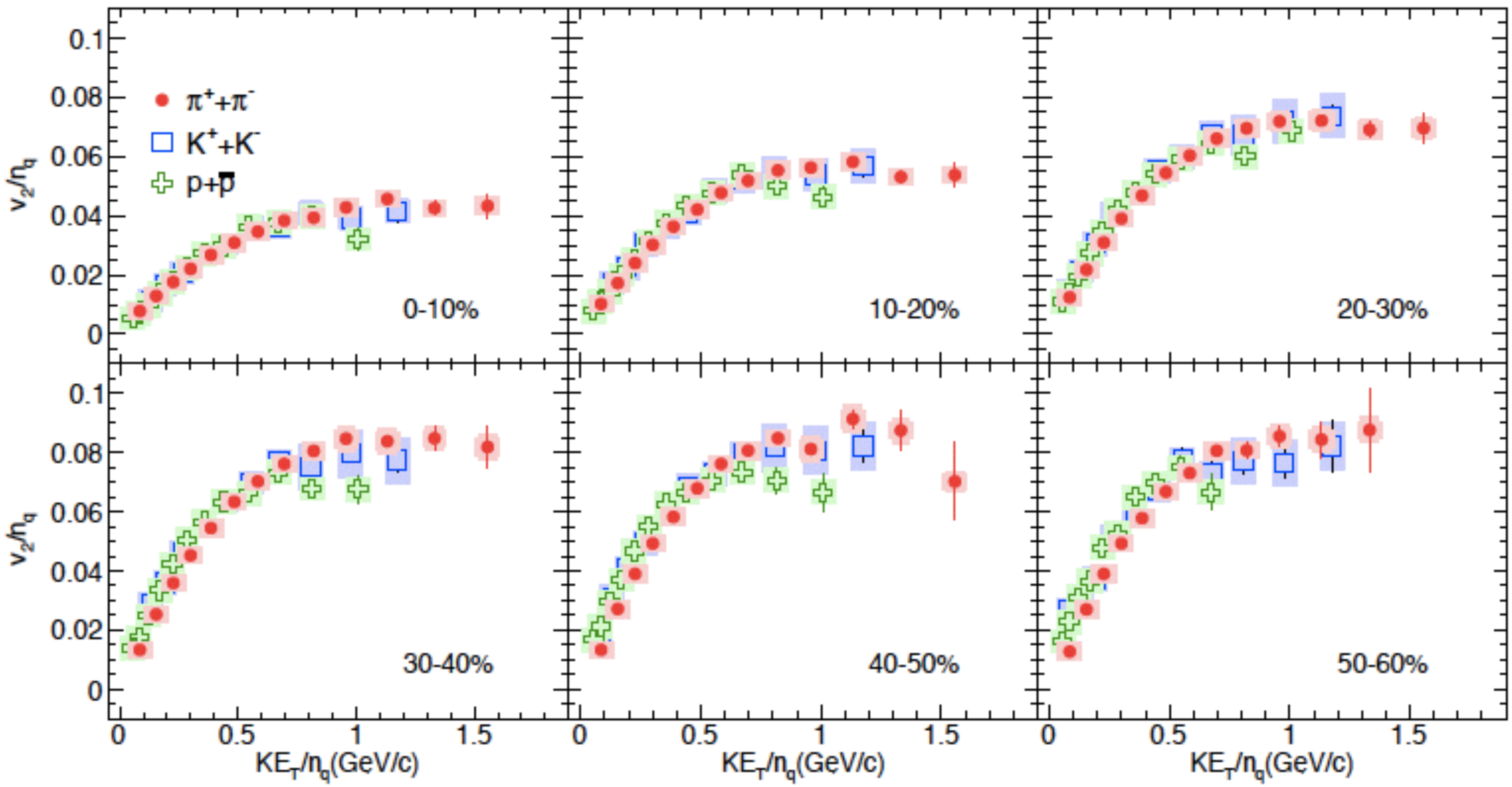
Identified particle v_1, v_3 in Cu+Au

arxiv:1509.07784



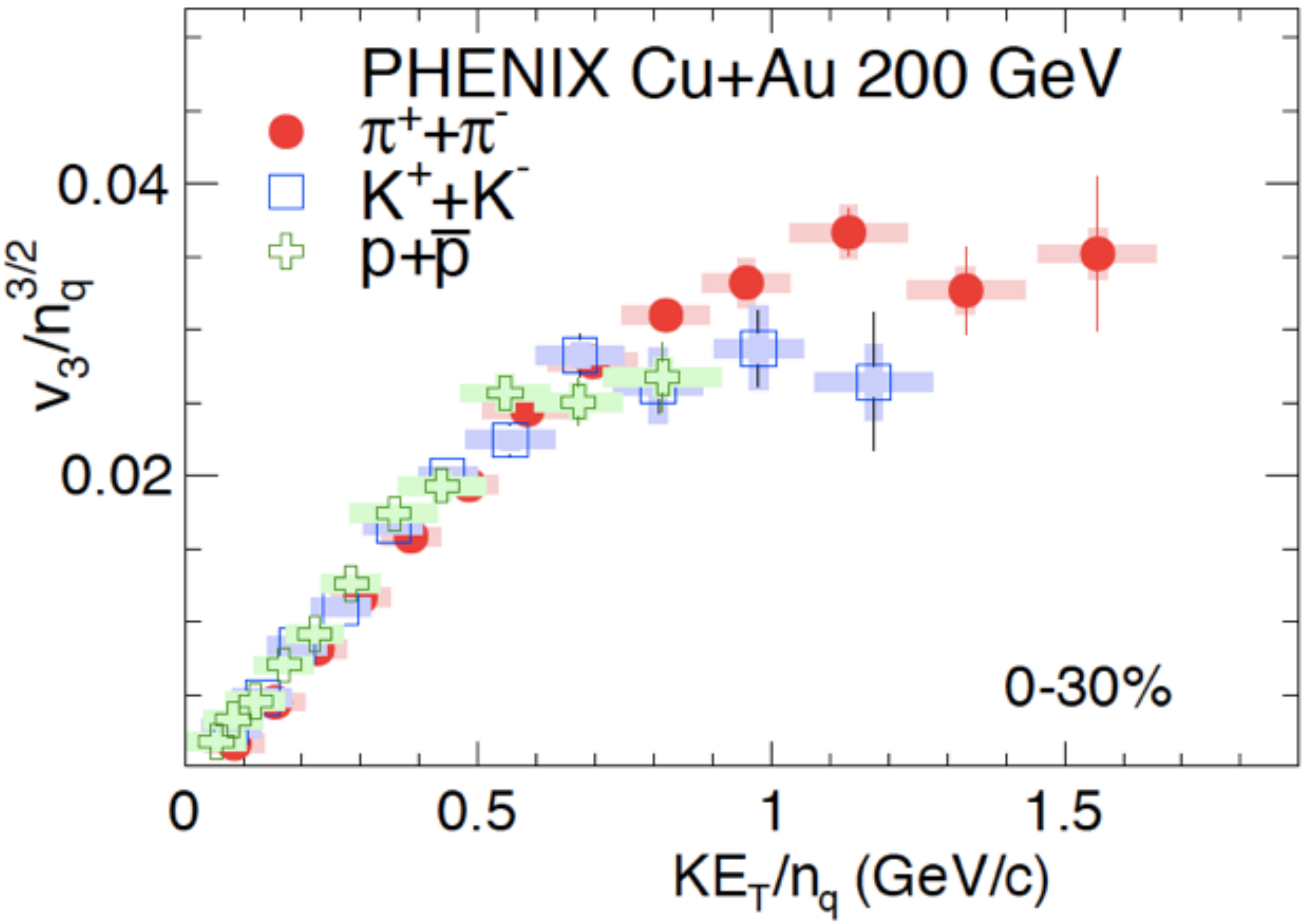
Same particle dependence of v_3 is seen as seen in v_2
Mass ordering is also seen for v_1
- At 1<pT<2.5GeV, Mass ordering is seen
- At low and high pt region, baryon v_1 ~ meson v_1
-Not same trend as seen in v_2, v_3

Quark Number Scaling of v2



Quark Number Scaling works v2 in CuAu

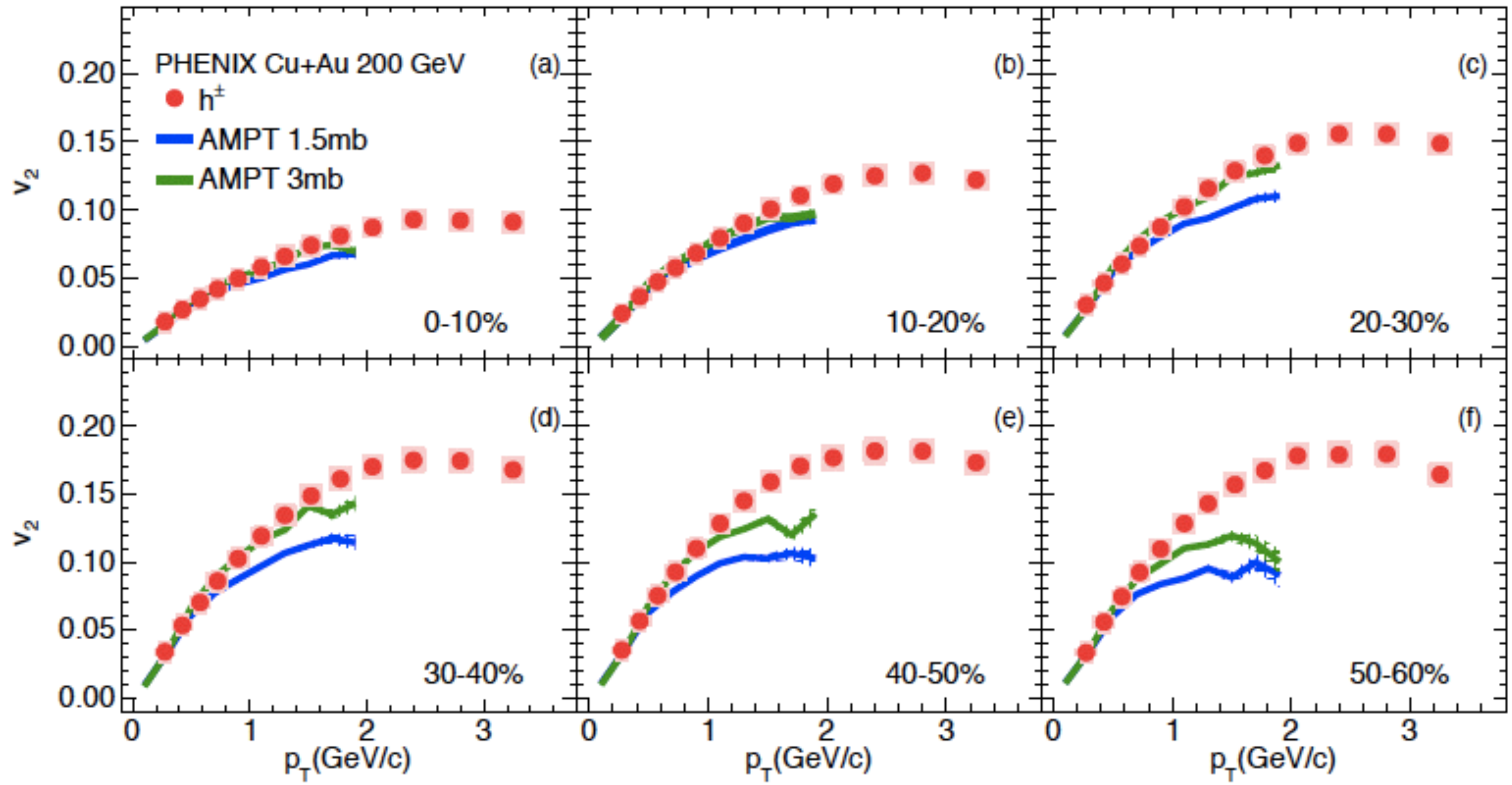
Quark Number Scaling for v3



Quark Number Scaling work v3 in CuAu

Comparison to AMPT v2

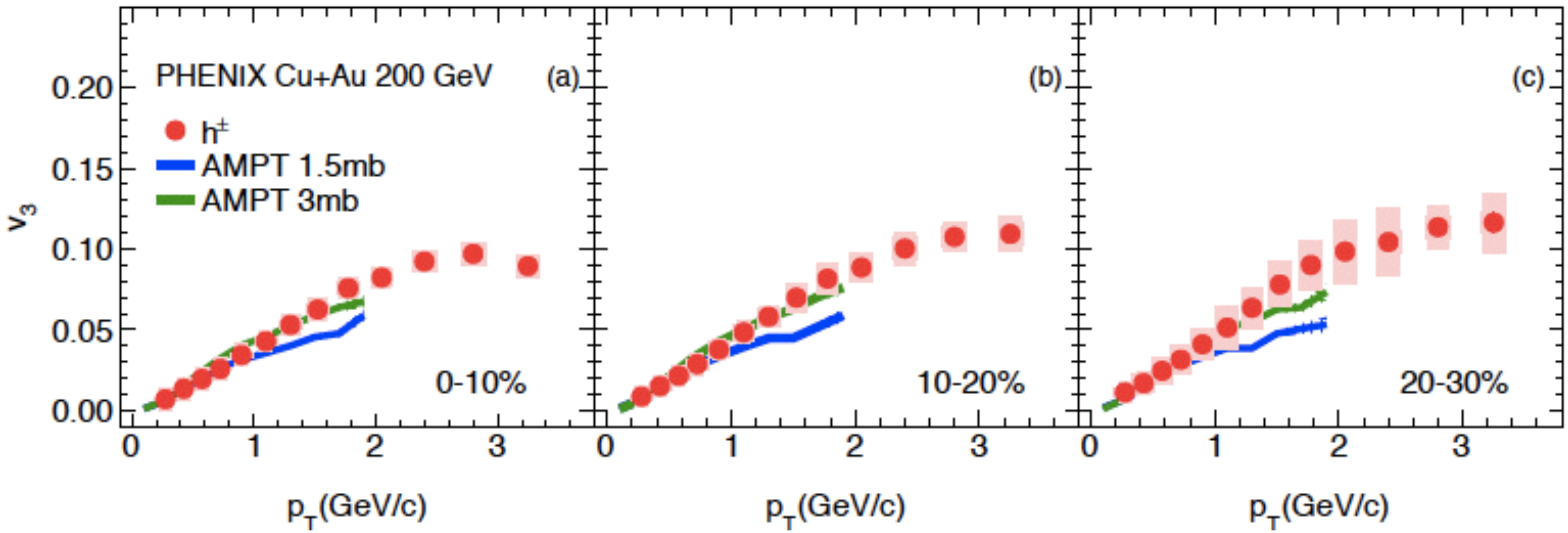
arxiv:1509.07784



AMPT with 3mb reproduce v2
-In 0-30%, up to 2GeV
-In 30-60%, up to 1GeV

Comparison to AMPT v3

arxiv:1509.07784



AMPT with 3mb reproduce v3
-In 0-30%, up to 2GeV

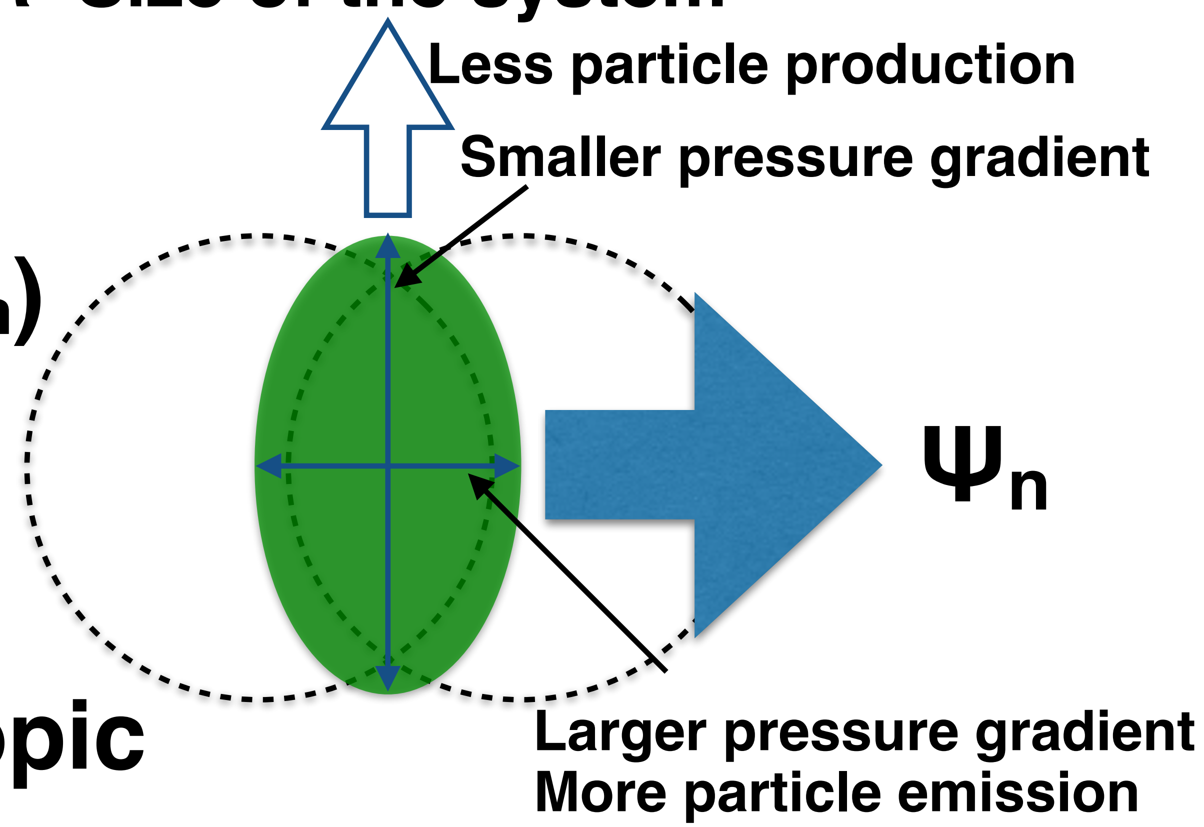
Azimuthal anisotropic flow

In relativistic heavy ion collisions, the azimuthal distribution of produced particles is anisotropic

Anisotropic initial overlap region(ε_n)

If $\lambda \ll R$, pressure gradient ΔP becomes anisotropic.

λ=Mean free path R=Size of the system



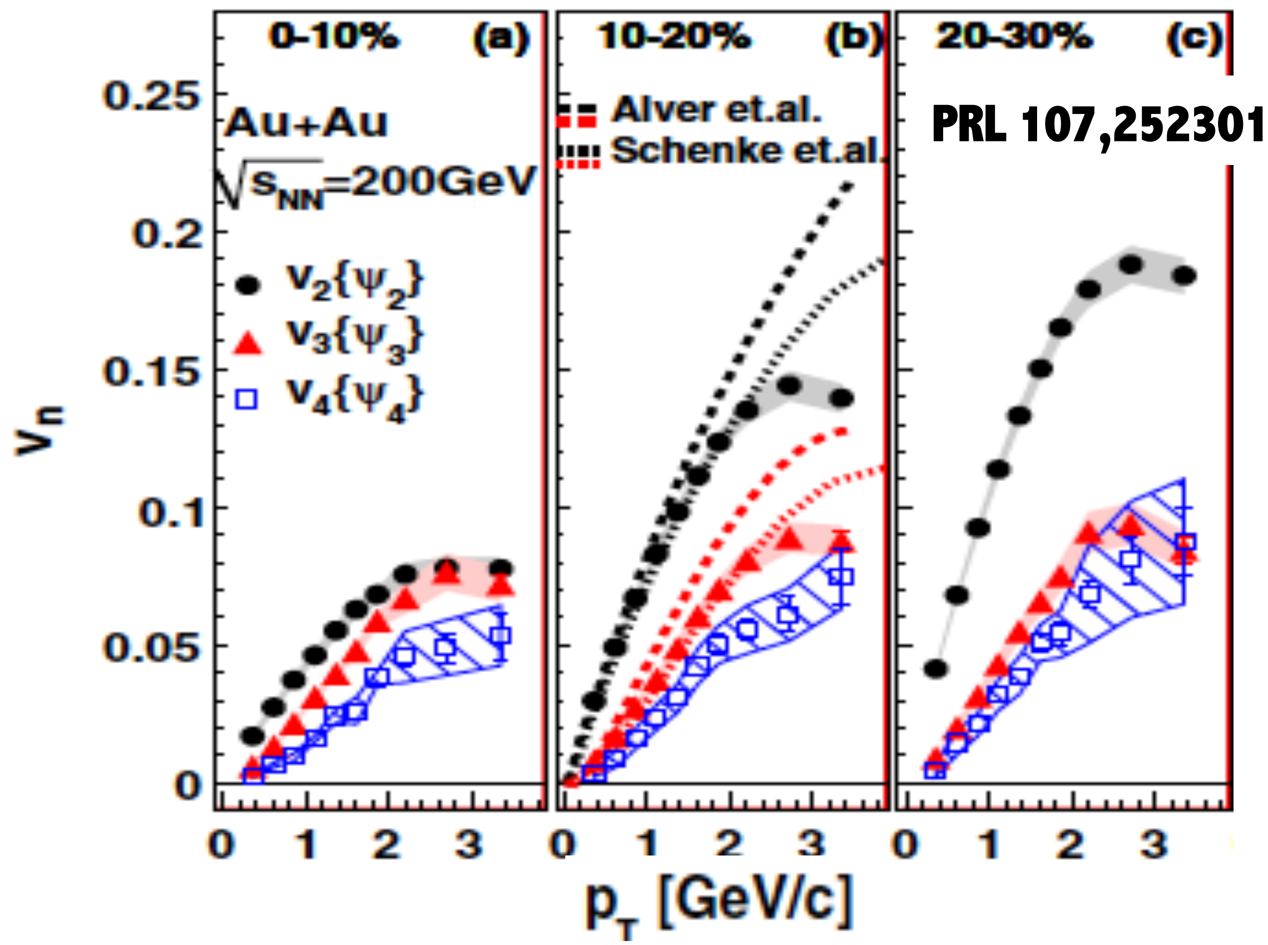
Anisotropic particle emission(v_n)

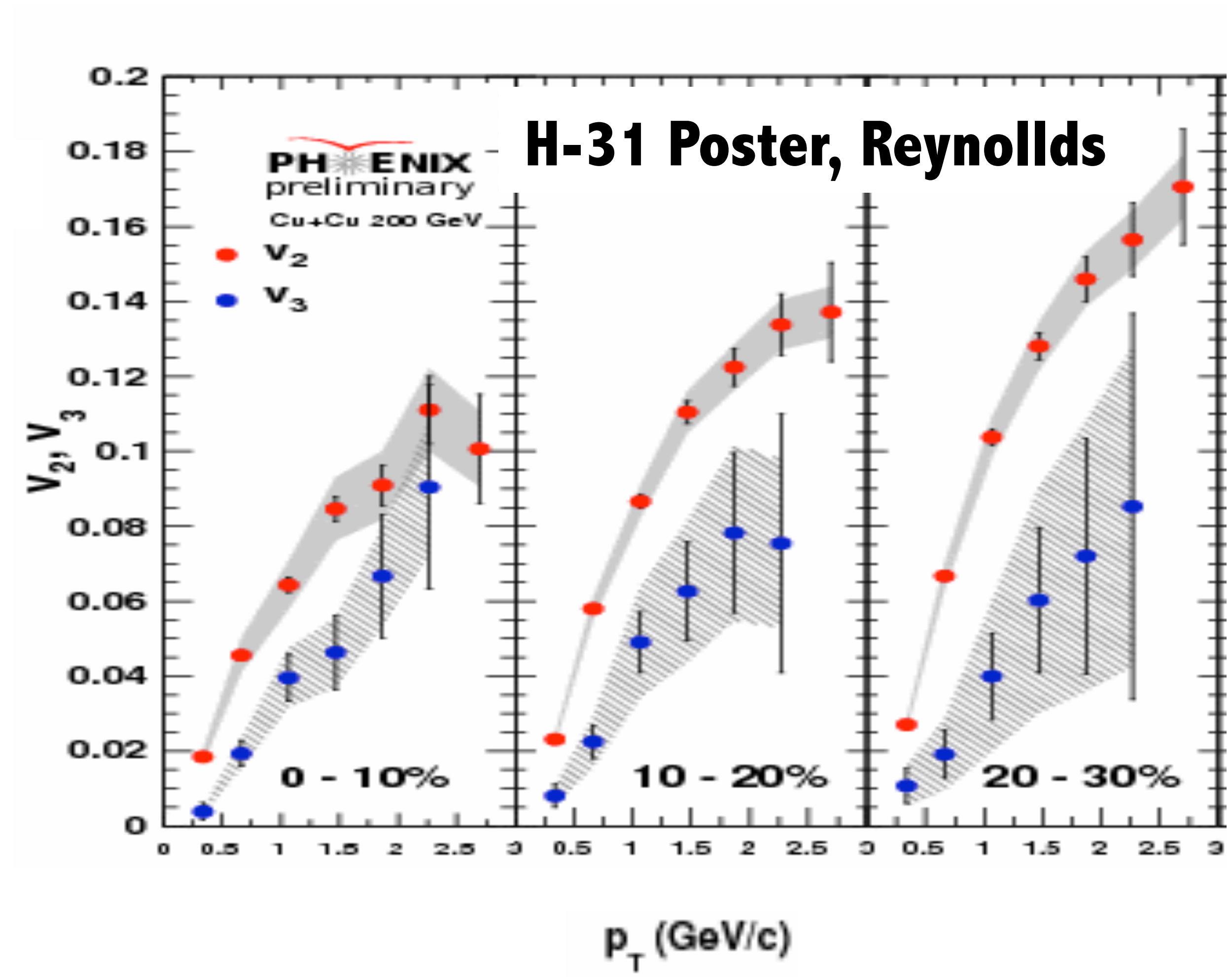
Expansion to short axis direction
by anisotropic pressure gradient

Magnitude of azimuthal anisotropic particle emission is evaluated as

$v_n = \langle \cos(n[\phi - \Psi_n]) \rangle$ ellipticity with respect to Ψ_n

Flow in symmetric collisions system





3sub method

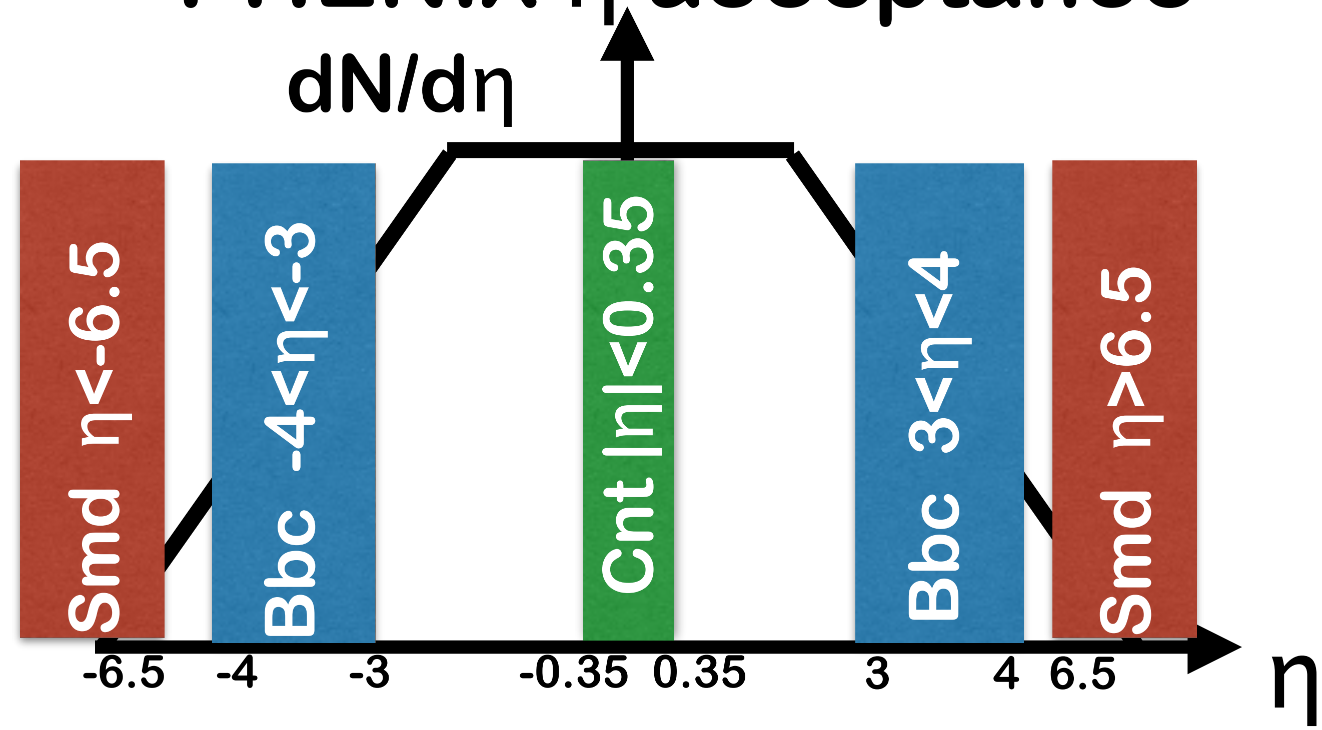
Event Plane detectors

- 2nd, 3rd Event plane
  - Bbc, Cnt
- 1st Event plane
  - Bbc, Smd

Event Plane resolution

-Estimated from EP correlations(3sub method)

PHENIX η acceptance



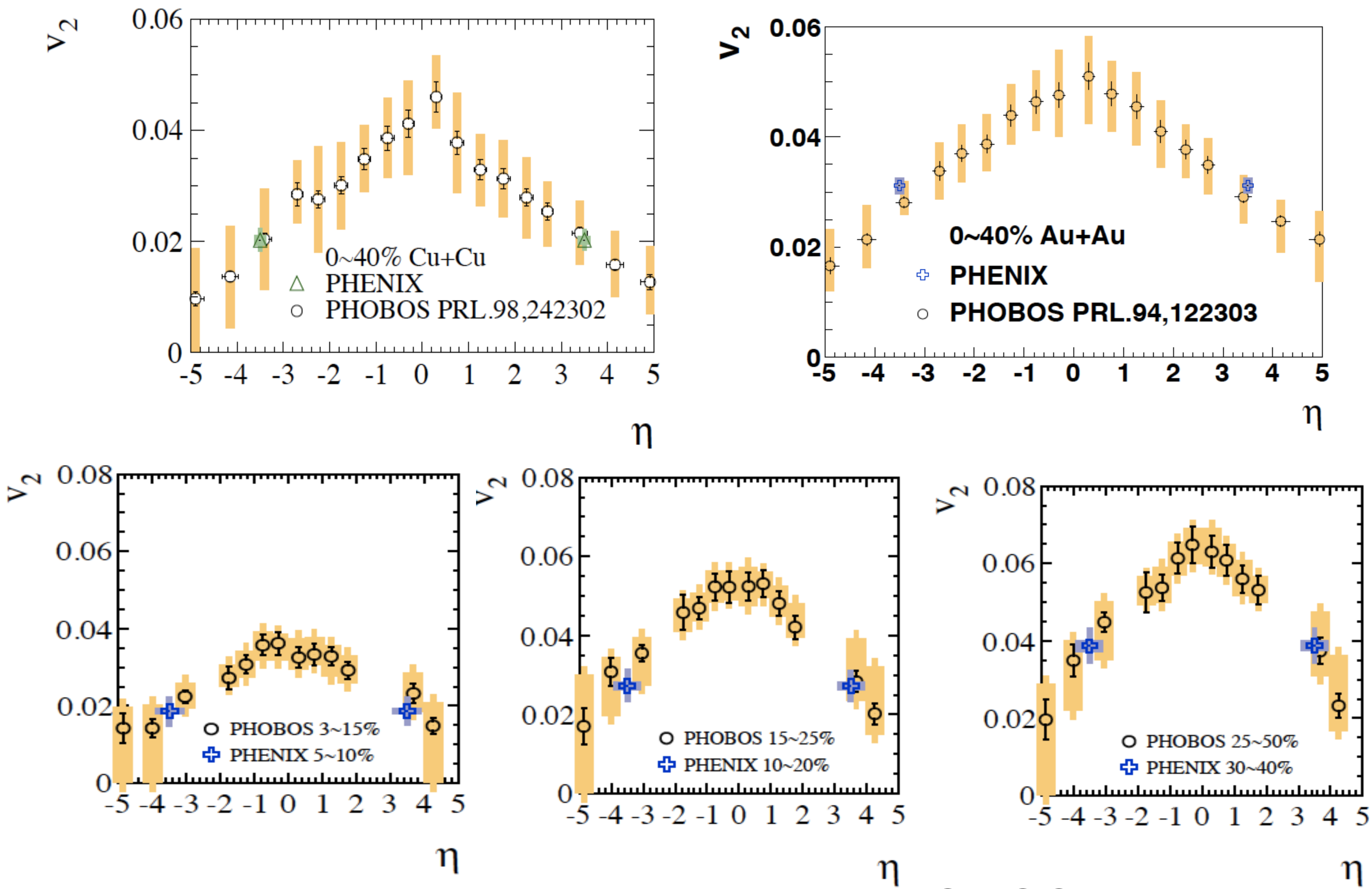
$$Res\{\Psi^{obs}_{n,A}\} = \sqrt{\frac{< cos(n[\Psi^{obs}_{n,A} - \Psi^{obs}_{n,B}]) >< cos(n[\Psi^{obs}_{n,A} - \Psi^{obs}_{n,C}]) >}{< cos(n[\Psi^{obs}_{n,B} - \Psi^{obs}_{n,C}]) >}}$$

$$< \cos(n[\Psi^{obs}_{n,A} - \Psi^{obs}_{n,B}]) > = < \cos(n[\Psi^{obs}_{n,A} - \Psi^{true}_{n} + \Psi^{true}_{n} - \Psi^{obs}_{n,B}]) >$$

$$= < \cos(n[\Psi^{obs}_{n,A} - \Psi^{true}_{n}]) >< \cos(n[\Psi^{true}_{n} - \Psi^{obs}_{n,B}]) >$$

$$= Res\{\Psi_{n,A}\} Res\{\Psi_{n,B}\}$$

Comparison to PHOBOS: v_2



My results are consistent with PHOBOS's results

$dN_{ch}/d\eta$ measurements at Bbc

Like vn measurements, correction factors is estimated from single particle simulation

$$dN_{ch}/d\eta = R * \text{Bbc Charge sum(real)}$$

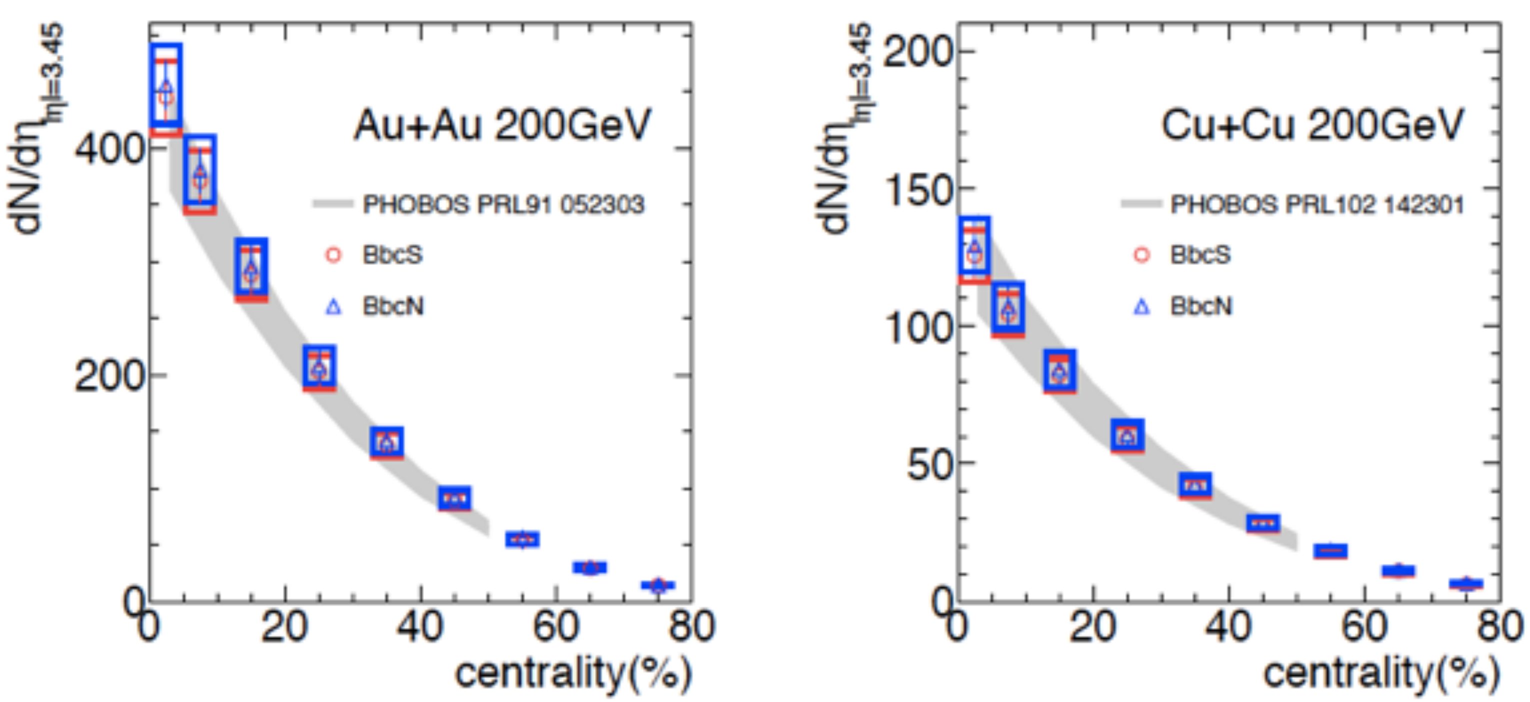
$$R = (2/3) / \text{Bbc Charge sum(simulation)}$$

+-π/(+-π,π0)

R ~0.5

Systematic source:Different η, pT distributions

Comparison to PHOBOS



My results are consistent with PHOBOS's results

Average v_n at Mid-rapidity

How to integrate vn(pT)

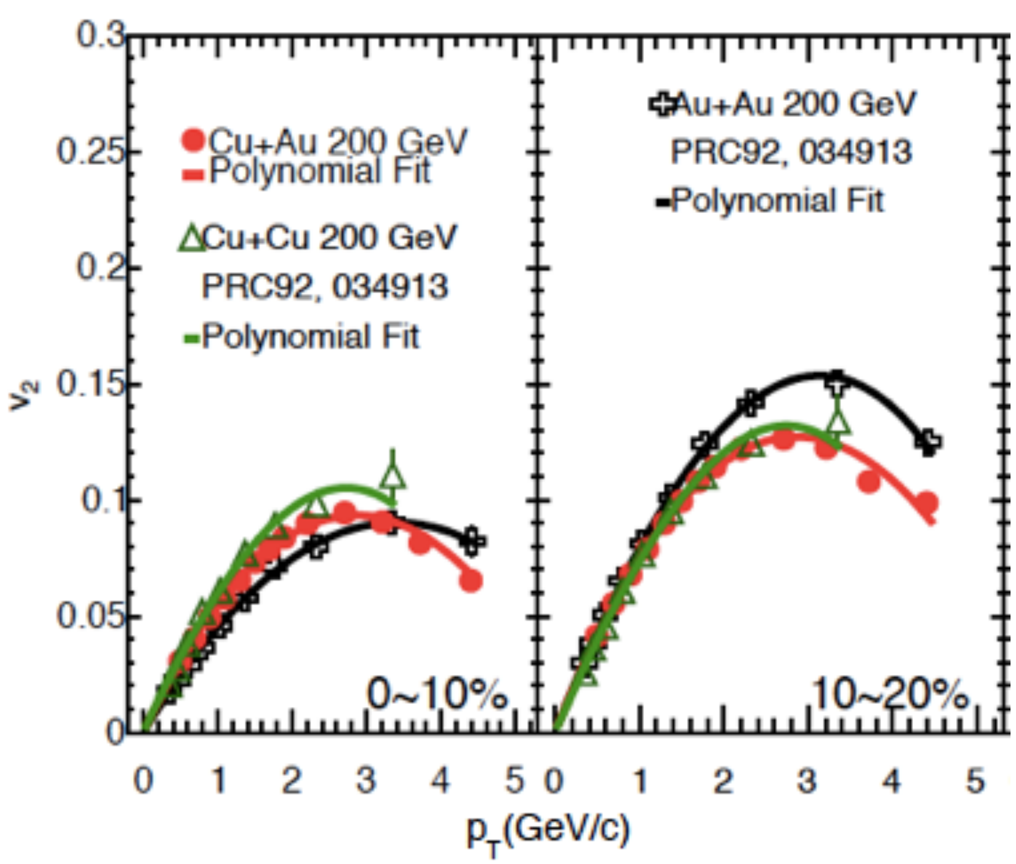
Weighted average using pT spectra as weights

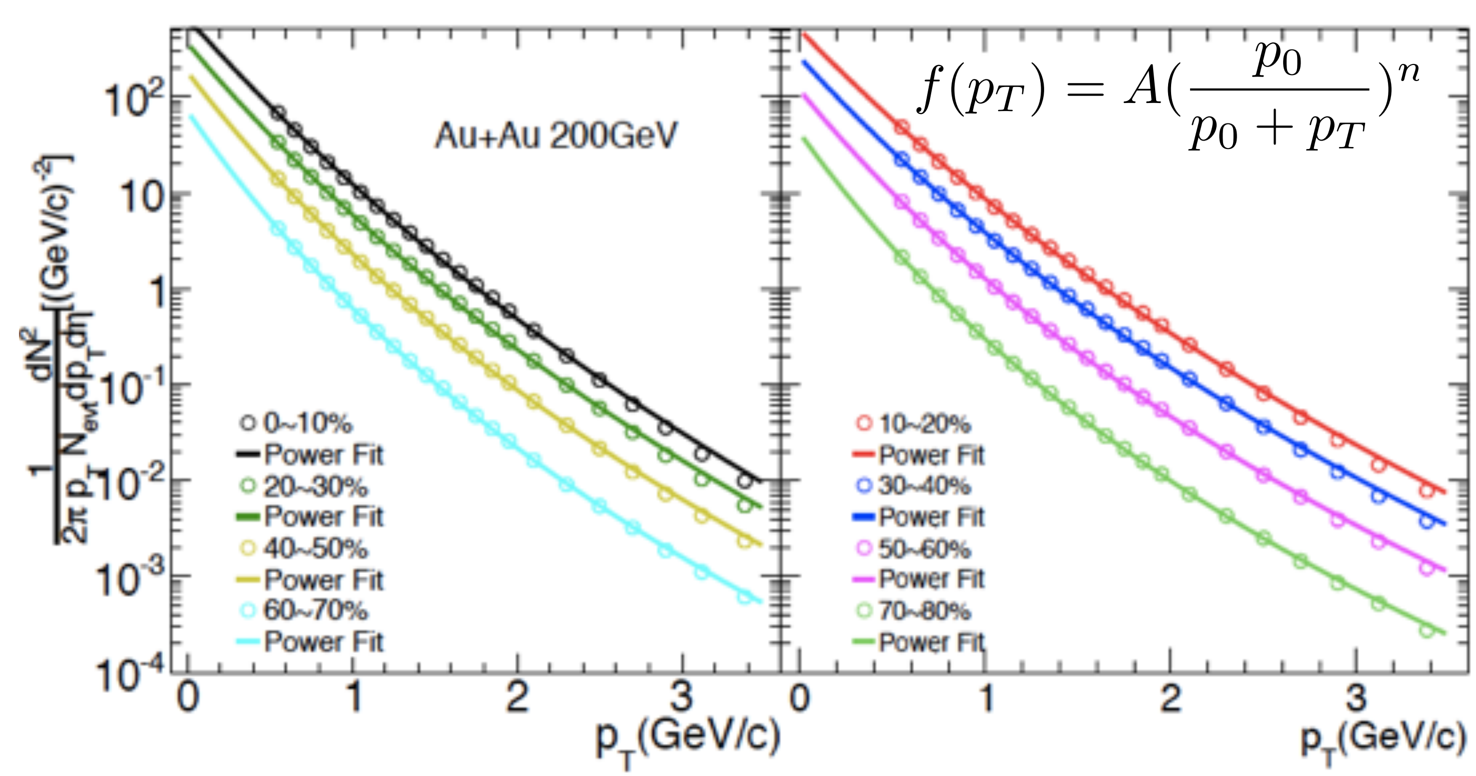
-pT spectra: PHENIX AuAu (ppg023)

-vn : PHENIX AuAu,CuAu,CuCu(ppg124,132,183)

$$< v_n >= \frac{\sum_i \frac{dN}{dp_{T,i}} v_n(p_{T,i})}{\sum_i \frac{dN}{dp_{T,i}}}$$

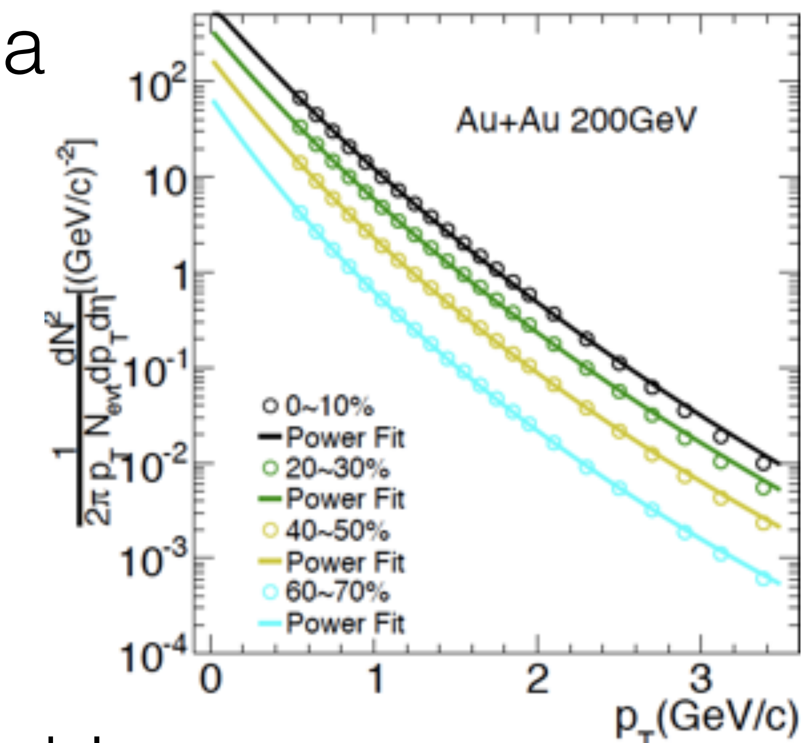
-vn(pT,i) and dN/dpT,i values are obtained from fitting functions





Determination of pT spectra in Cu+Cu and Cu+Au

Cu+Cu and Cu+Au spectra are assumed using Au+Au spectra
-There no published Cu+Cu and Cu+Au spectra
-$dN_{ch}/d\eta$ and <pT> depends on Npart

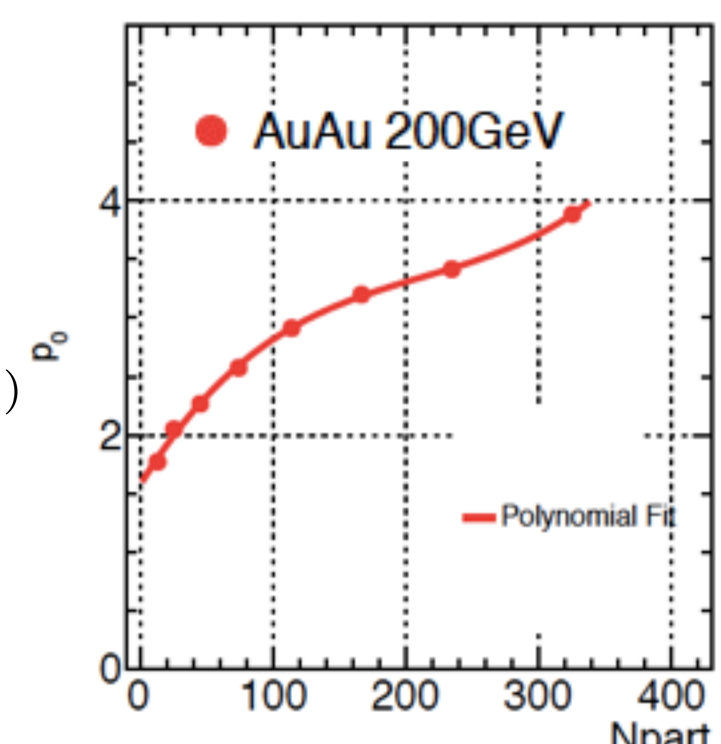


Procedure

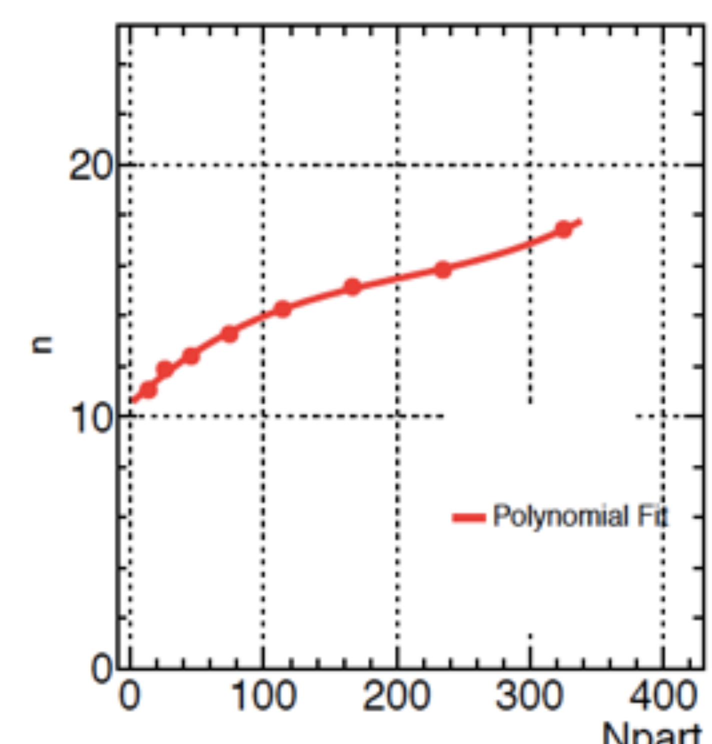
1. Fit Au+Au spectra with $f(p_T) = A(\frac{p_0}{p_0 + p_T})^n$
   p_0 and n are free parameter
2. Obtain p_0 and n as a function of Npart
3. Make pT spectra for Cu+Cu and Cu+Au
   using $p_0(N_{part})$ and $n(N_{part})$ for corresponding N_{part} bins

$$f(p_T, N_{part}) = (\frac{p_0(N_{part})}{p_0(N_{part}) + p_T})^{n(N_{part})}$$

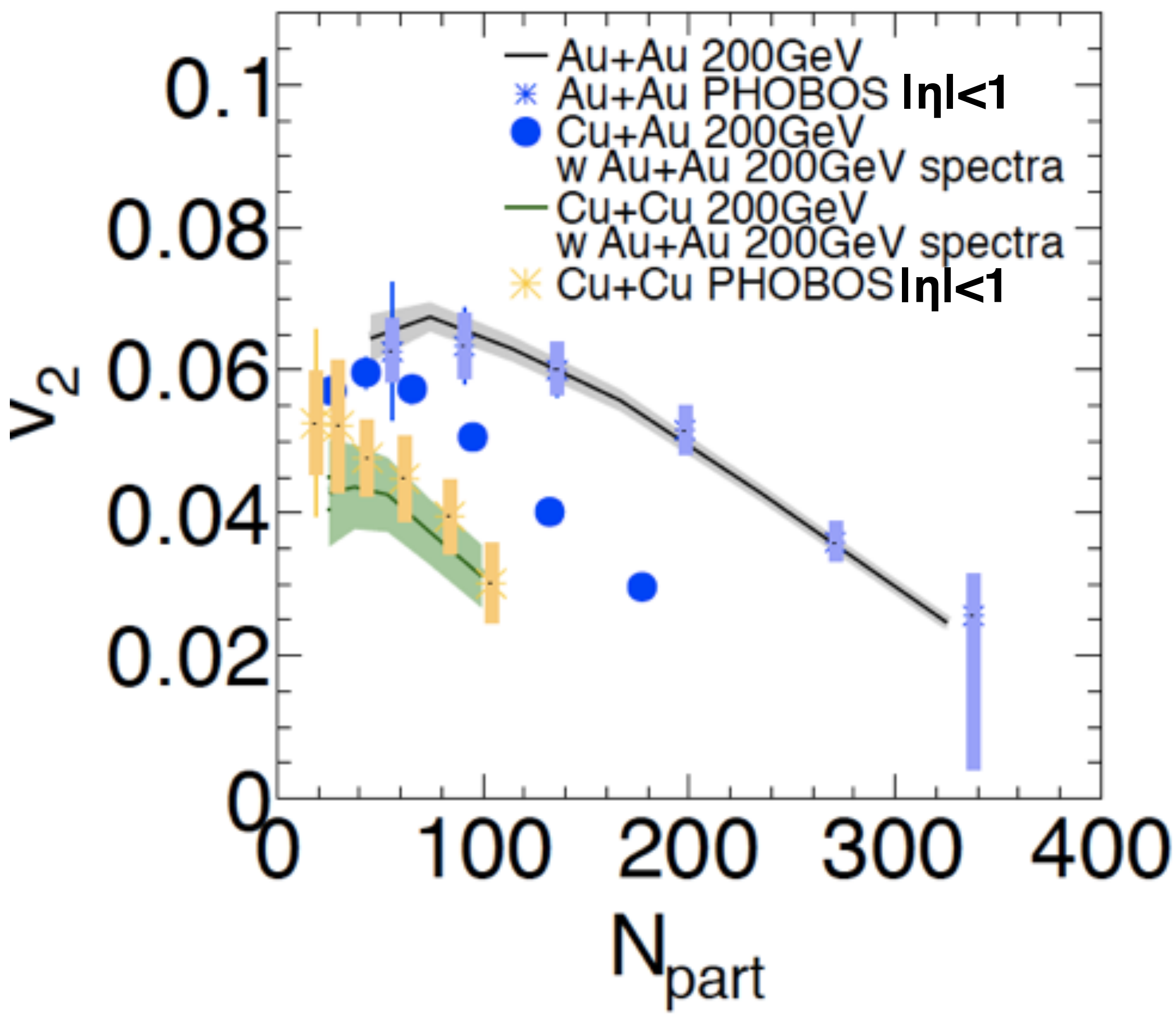
$p_0(N_{part})$



$n(N_{part})$



Comparison to PHOBOS



My results are consistent with PHOBOS within the error

-η range is different, PHOBOS's results are obtained wider range

pT integration is successfully done