Azimuthal anisotropy in CuAu collisions at RHIC-PHENIX

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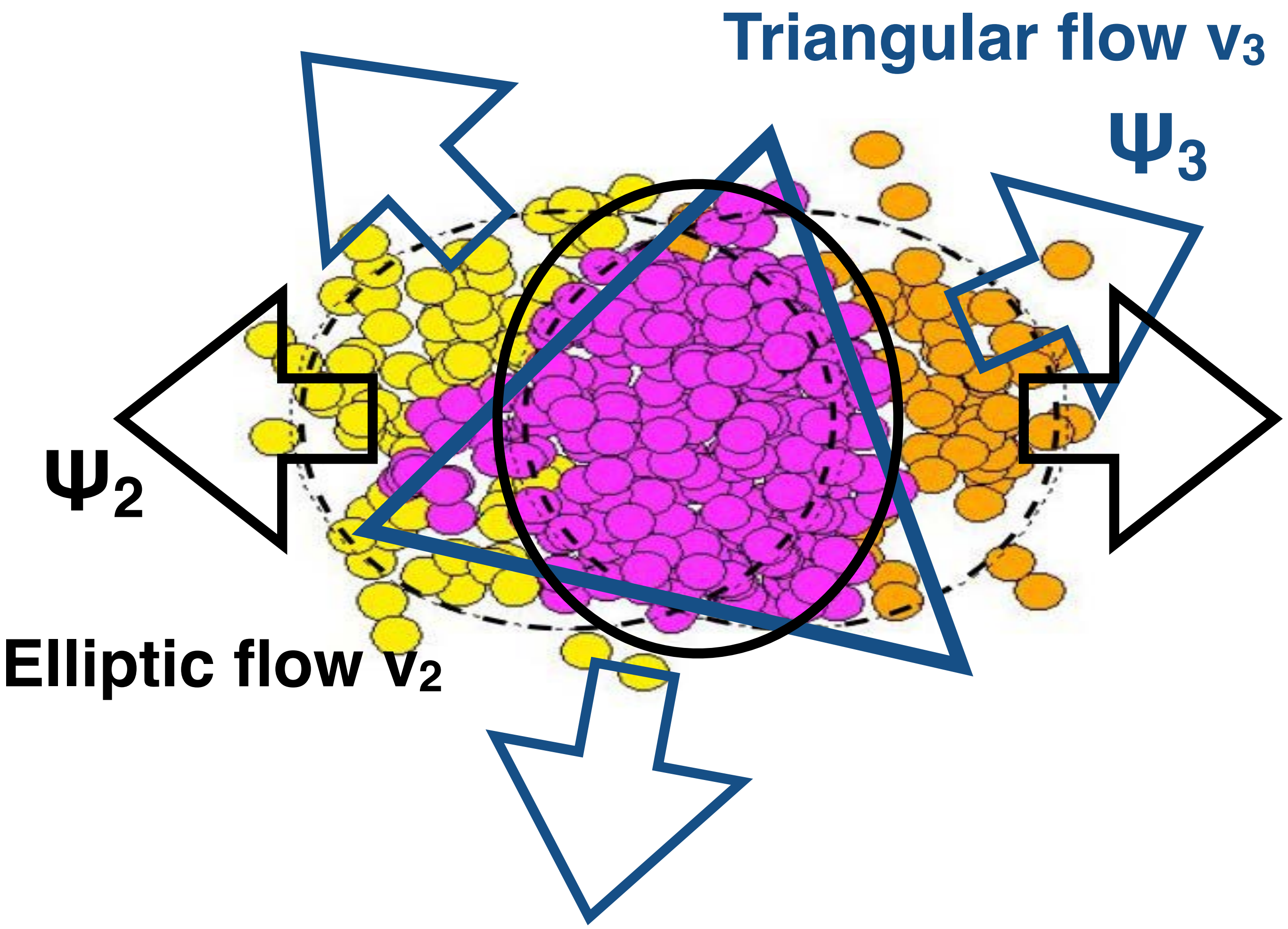
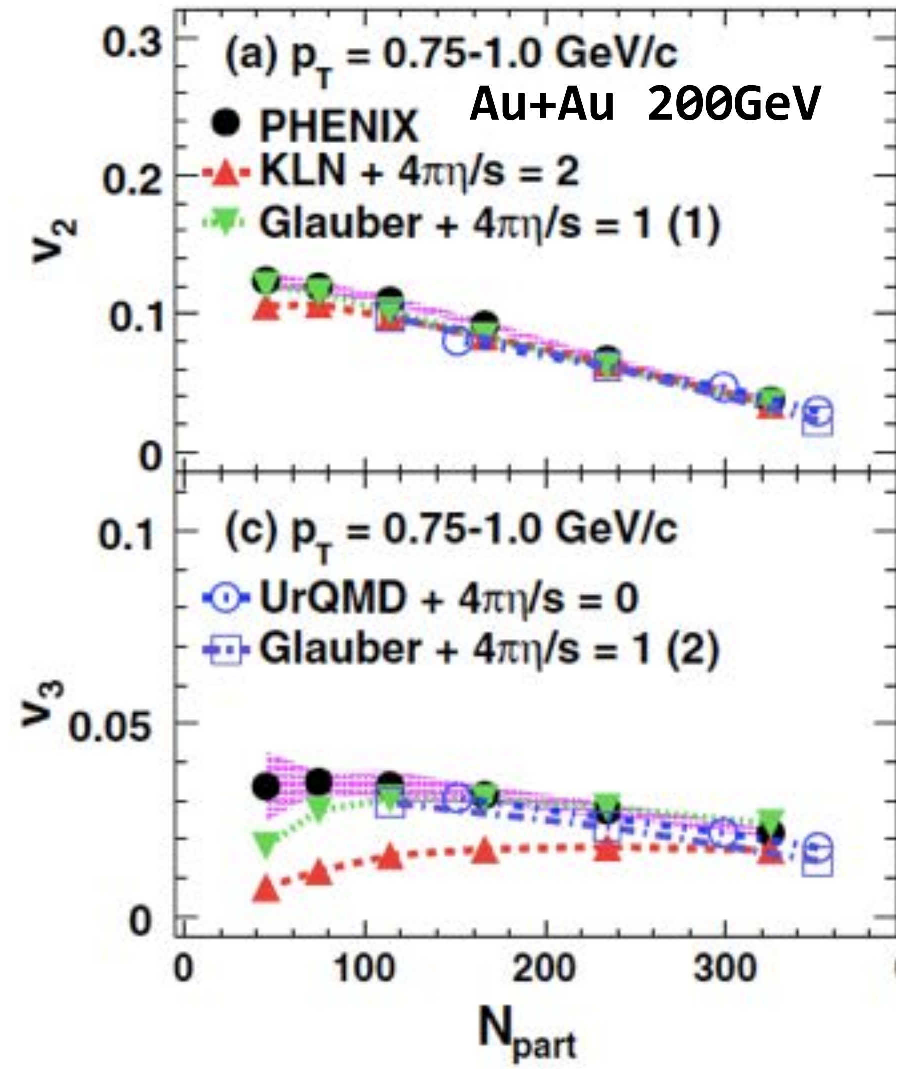
Azimuthla anisotropy:Elliptic & triangular flow





✓Initial spatial anisotropy ε_n -> Final momentum anisotropy v_n

- Converted through hydrodynamic expansion

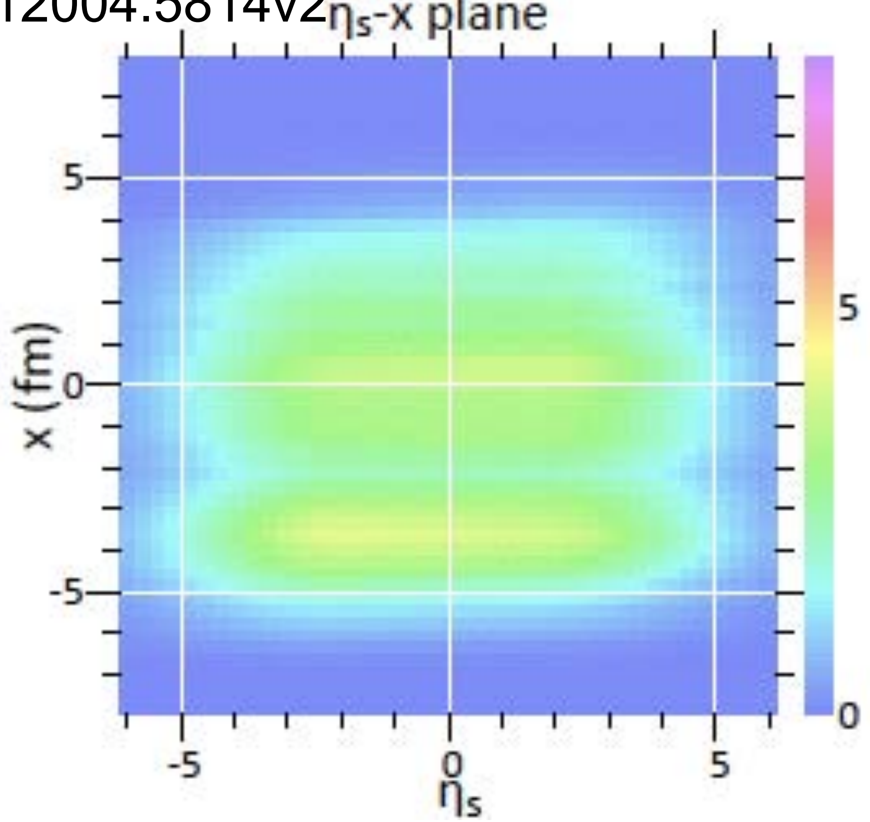
✓v_2, v_3 are sensitive to initial condition and viscosity of QGP

- Theoretically, initial condition and viscosity have uncertainty

Longitudinal structure

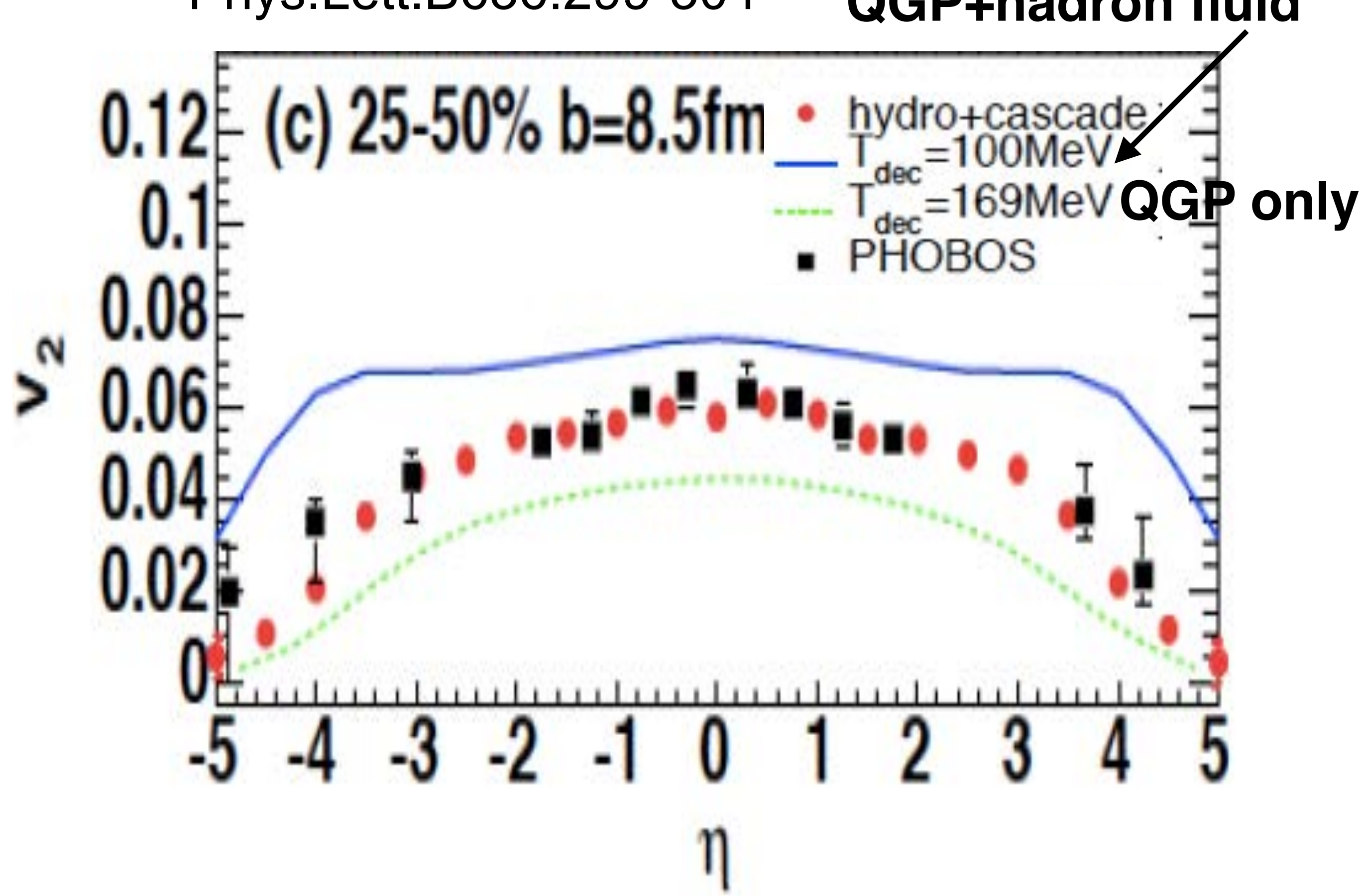
Initial geometry/density

arXiv:12004.5814v2



Final momentum anisotropy

Phys.Lett.B636:299-304



✓Similar geometry at whole η

-Almost rapidity independent

-Used in most models

✓Density decrease at higher rapidity

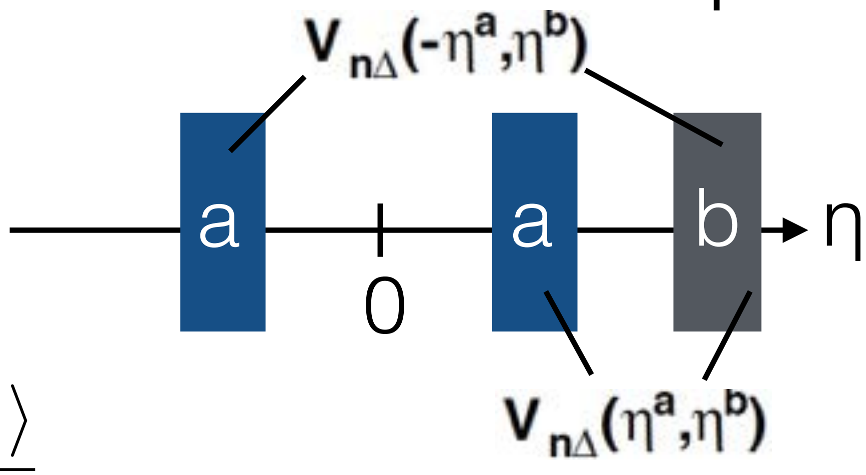
✓Trapezoidal rapidity dependence

- At higher rapidity, smaller energy density makes smaller v_2

Longitudinal flow fluctuation ?

✓CMS observed flow fluctuation at forward/backward rapidity

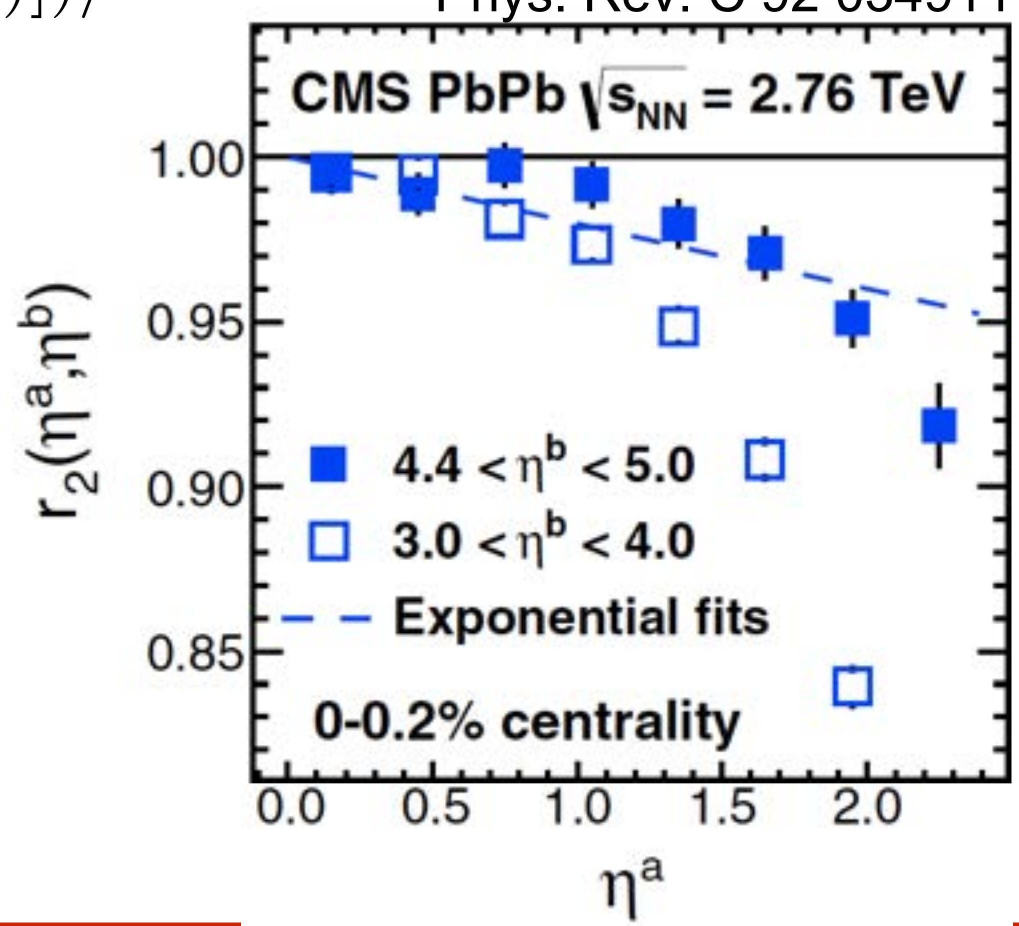
2-pc $C(\eta_a, \eta_b, \Delta\phi) = 1 + 2\sum V_{n\Delta}(\eta_a, \eta_b)\cos(n\Delta\phi)$



$$r_n(\eta_a, \eta_b) = \frac{V_{n\Delta}(-\eta_a, \eta_b)}{V_{n\Delta}(\eta_a, \eta_b)}$$

$$= \frac{\langle v_n(-\eta_a)v_n(\eta_b)\cos(n[\Psi_n(-\eta_a) - \Psi_n(\eta_b)])\rangle}{\langle v_n(\eta_a)v_n(\eta_b)\cos(n[\Psi_n(\eta_a) - \Psi_n(\eta_b)])\rangle}$$

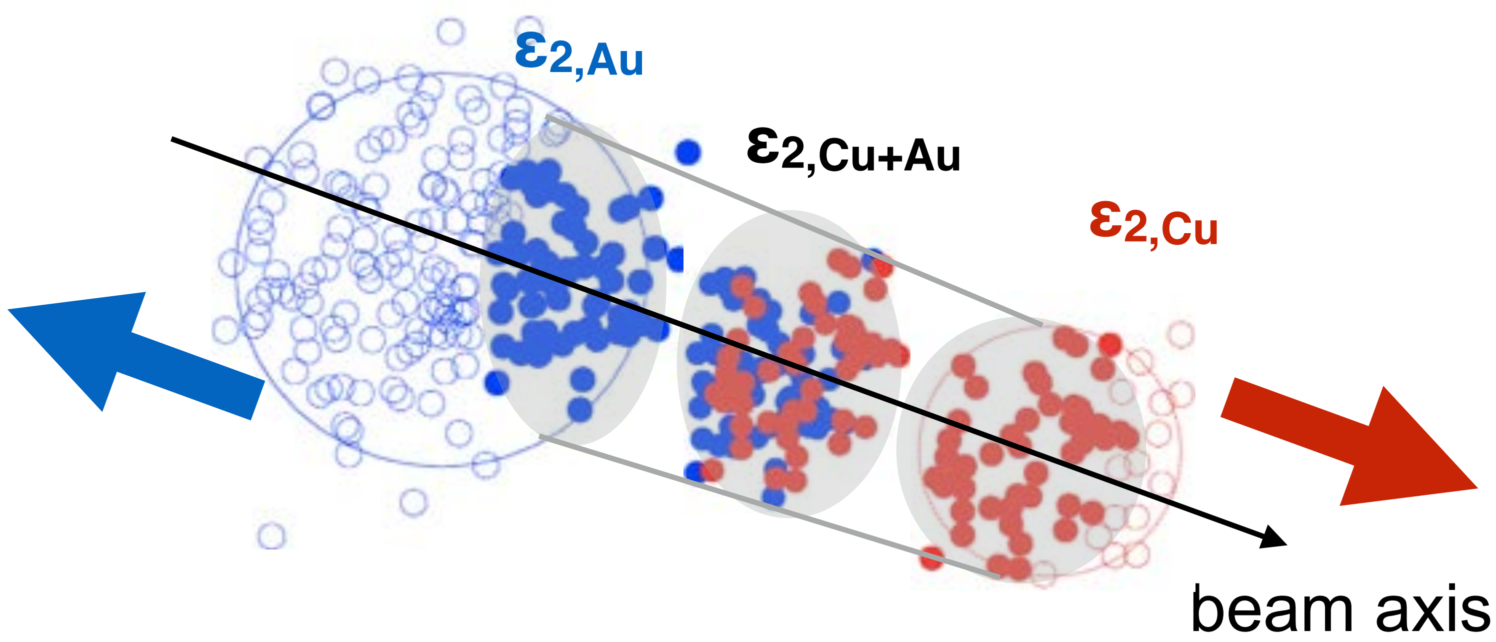
Phys. Rev. C 92 034911



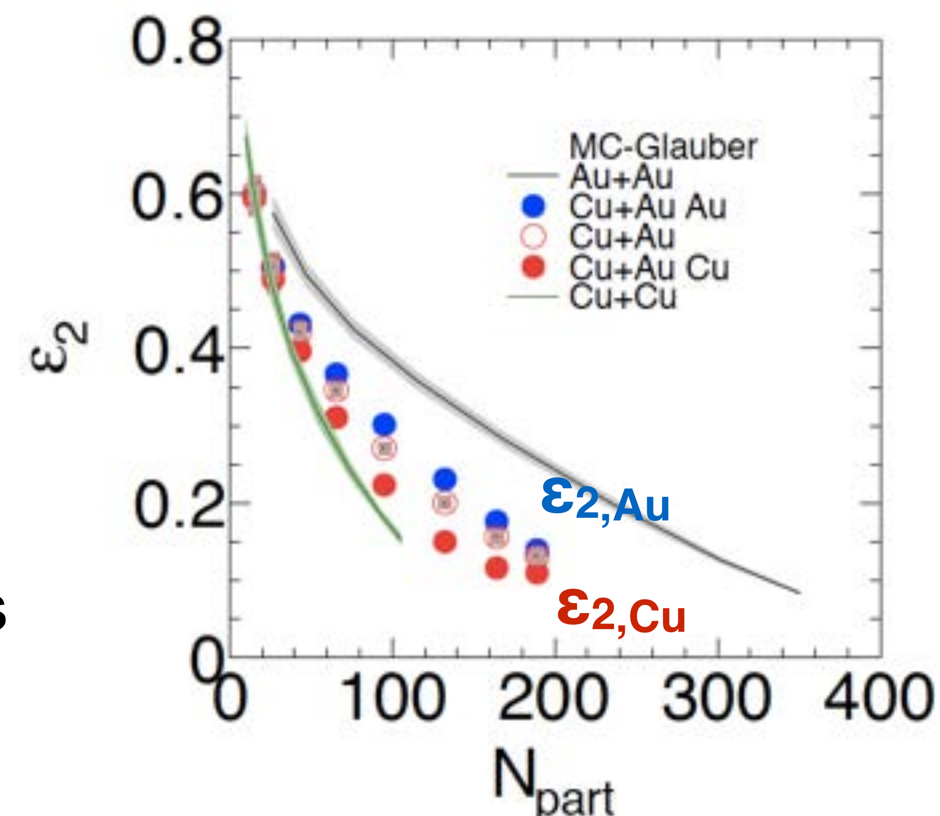
- $r_n = 1$ → No flow fluctuation
  - $v_n(\eta_a) = v_n(-\eta_a)$ & $\Psi_n(\eta_a) = \Psi_n(-\eta_a) = \Psi_n(\eta_b)$
- $r_n < 1$ → F/B flow fluctuation
  - $v_n(\eta_a) \neq v_n(-\eta_a)$: $\varepsilon_n(\eta_a) \neq \varepsilon_n(-\eta_a)$
  - $\Psi_n(\eta_a) \neq \Psi_n(-\eta_a) \neq \Psi_n(\eta_b)$: Twisted $\Psi_n(\eta)$

Cu+Au collisions

Collision picture



Initial spatial anisotropy:ε_2



✓First asymmetric Cu+Au collisions were operated in 2012

✓Asymmetric initial condition provides

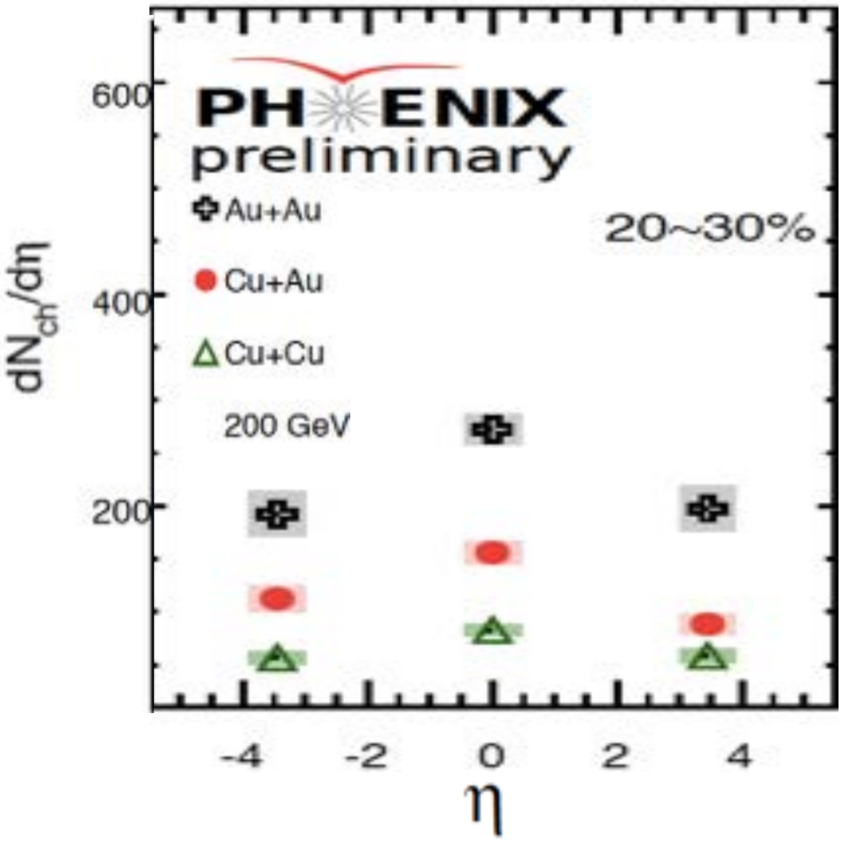
-Different Forward/Backward density and geometry

-> Rapidity asymmetric v_n

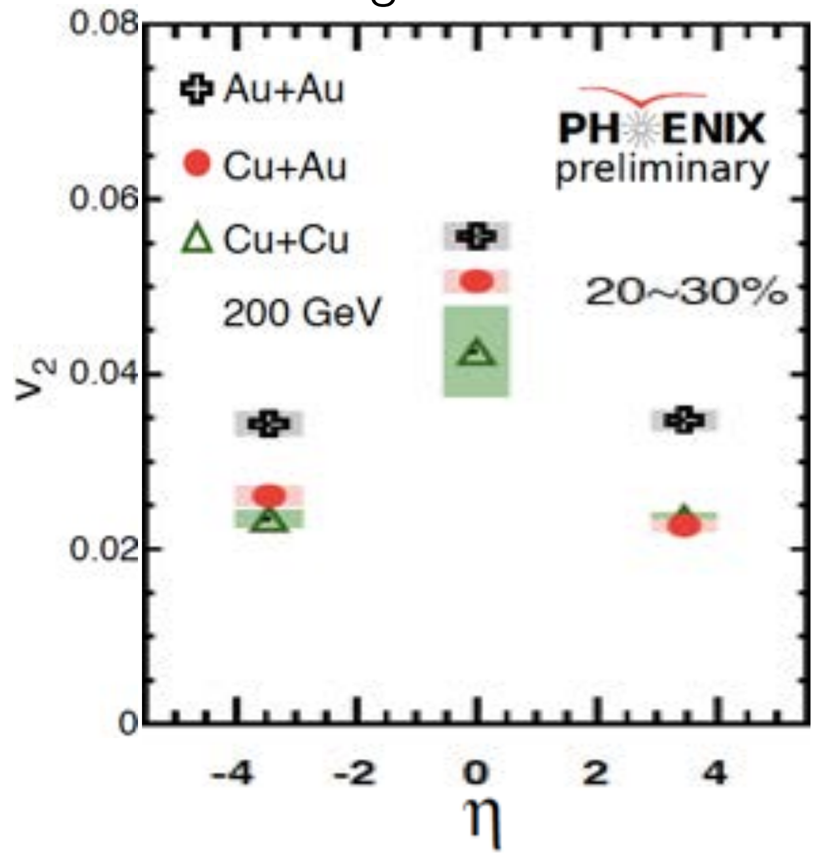
-> Measurements of v_n in asymmetric system could be good study of longitudinal structure

Result:η dependence of dN/dη and v_n

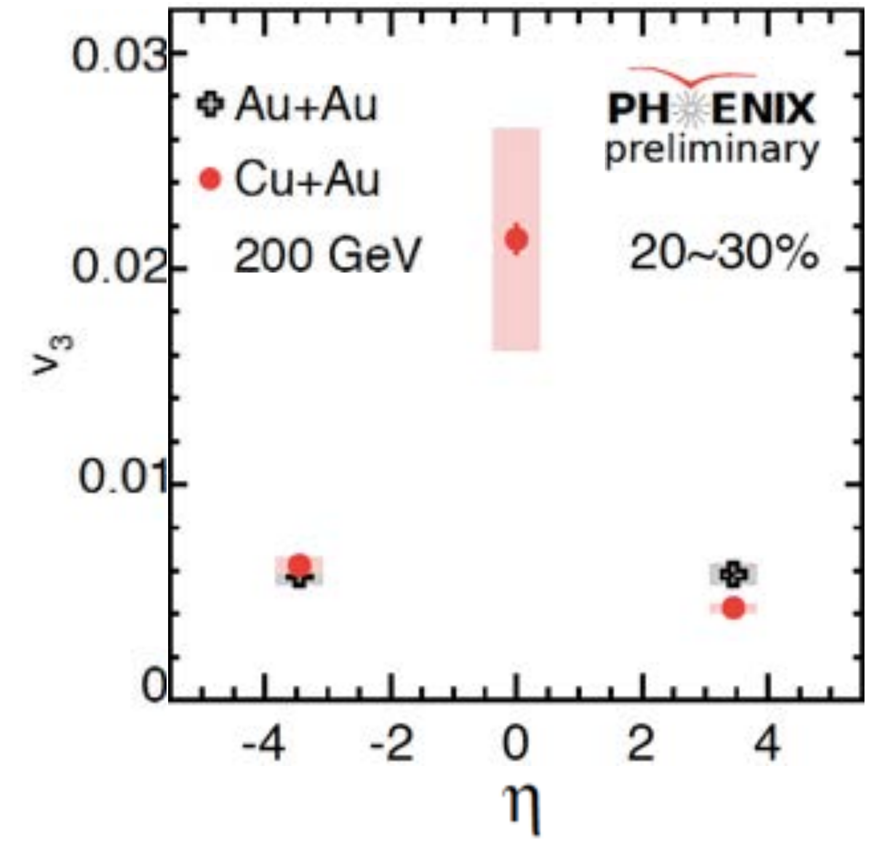
Charged hadron dN/dη



Charged hadron v_2



Charged hadron v_3



✓Au-going dN/dη > Cu-going dN/dη in Cu+Au collisions

-$N_{part,Au}$> $N_{part,Cu}$

→ Larger initial density in Au-going side

✓Au-going v_n > Cu-going v_n in Cu+Au collisions

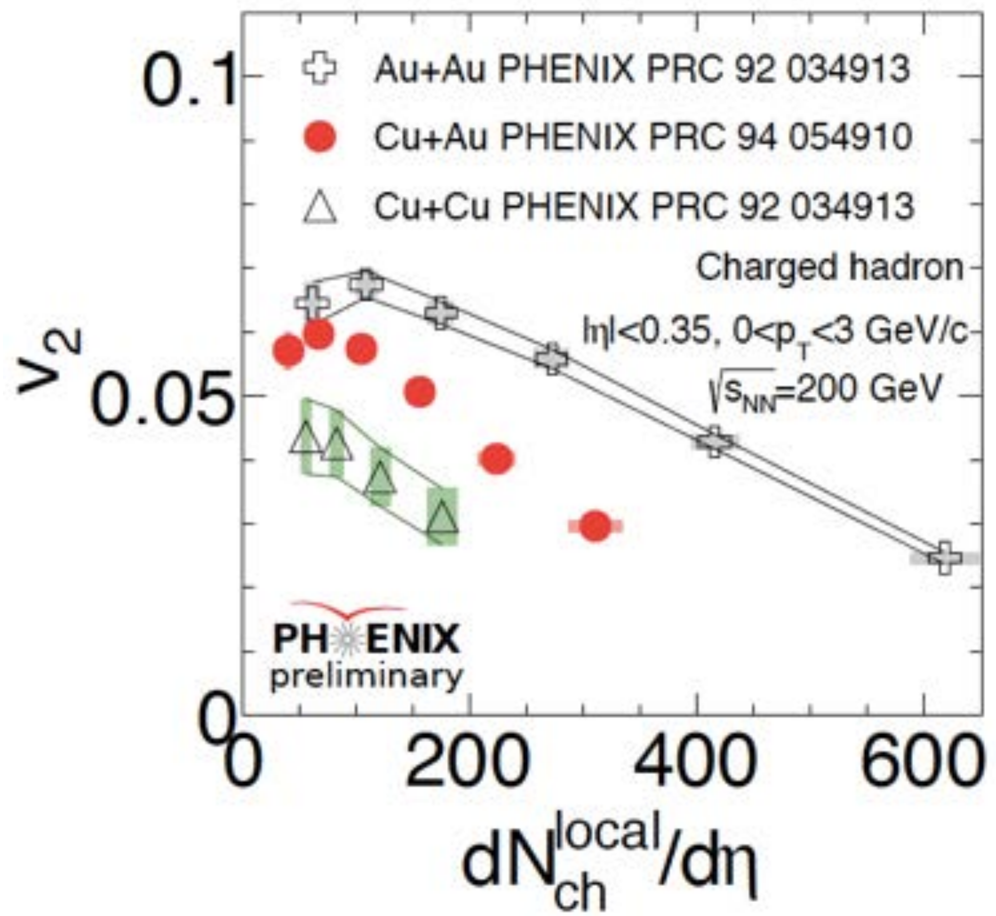
-Assume rapidity independent event plane

-$\varepsilon_{n,Au}$> $\varepsilon_{n,Cu}$, $N_{part,Au}$> $N_{part,Cu}$

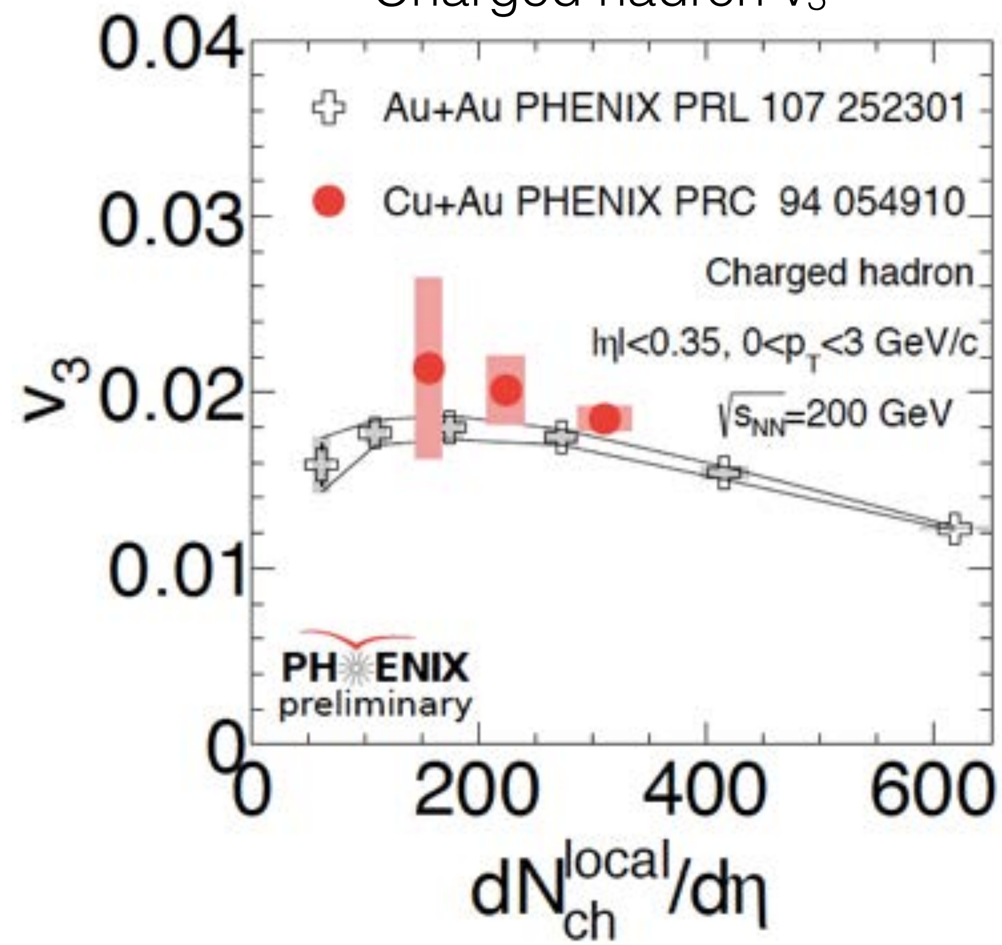
→Asymmetry of v_n is caused by geometry or energy density or both

Result:Mid-η v_n

Charged hadron v_2



Charged hadron v_3



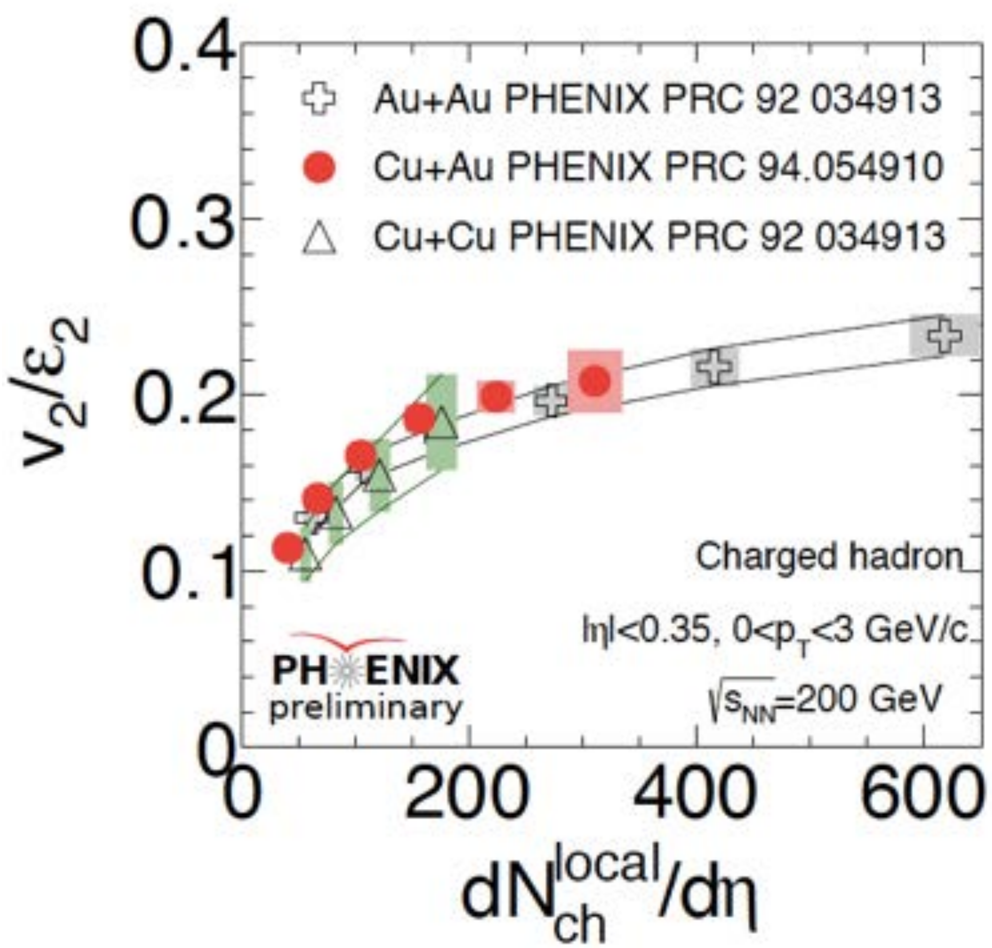
✓v_n is plotted as function of mid-rapidity dN/dη(∝ energy density)

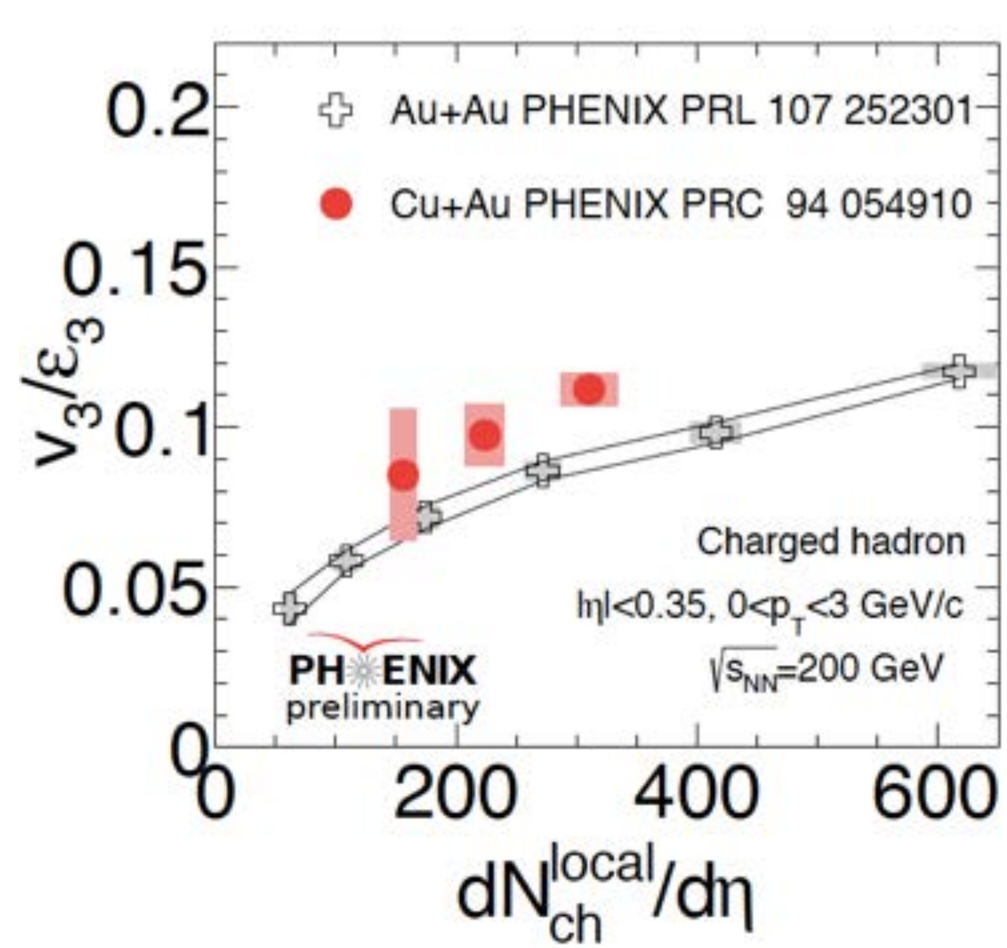
- $v_n \propto \varepsilon_n$, energy density
- At same dN/dη bin, the similar pressure gradient is expected.

✓v_2 in Cu+Au collisions is always between those in Au+Au and Cu+Cu

✓Unlike v_2, Cu+Au v_3 is consistent with Au+Au v_3

Result:Study of mid-η initial geometry





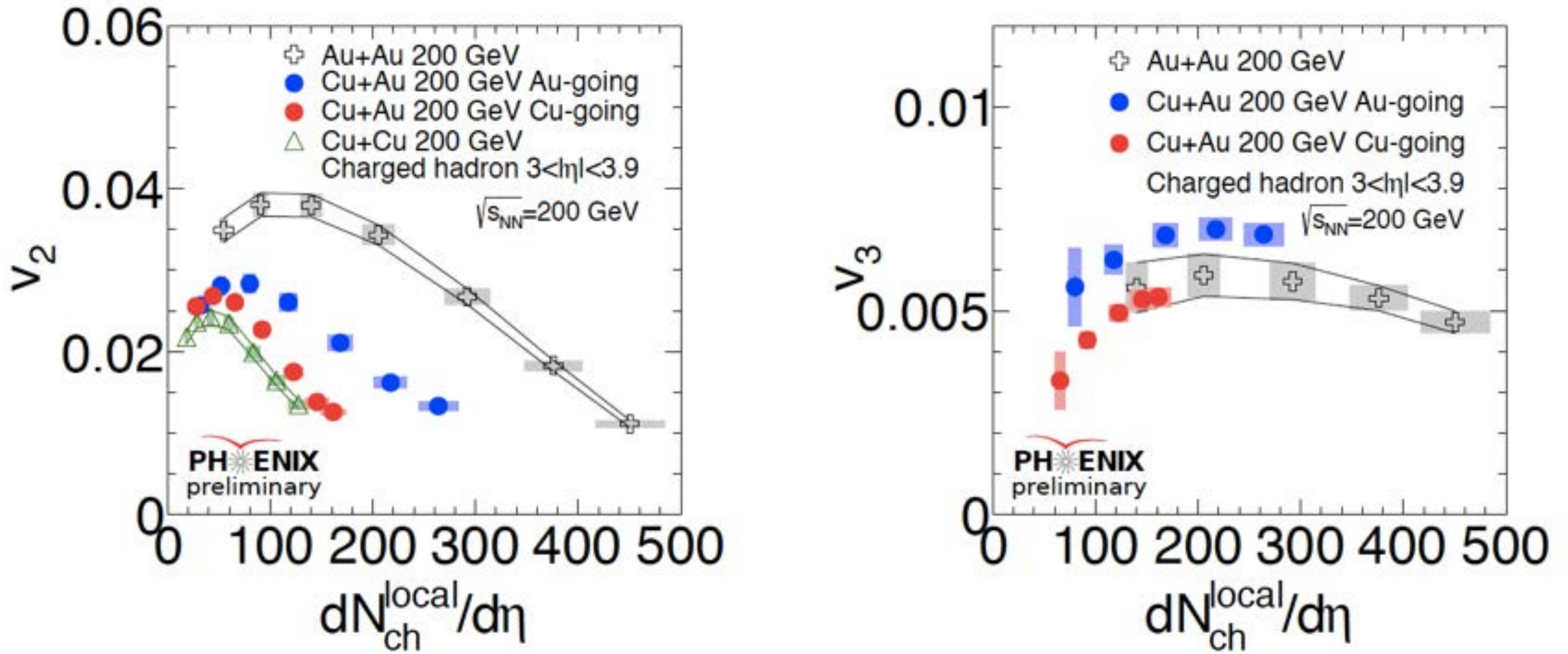
✓Cu+Au v_2/ε_2 is consistent with Au+Au and Cu+Cu results

→MC-Glauber reproduce ε_2 well

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

→MC-Glauber might not reproduce ε_3 correctly

Result:F/B-η v_n



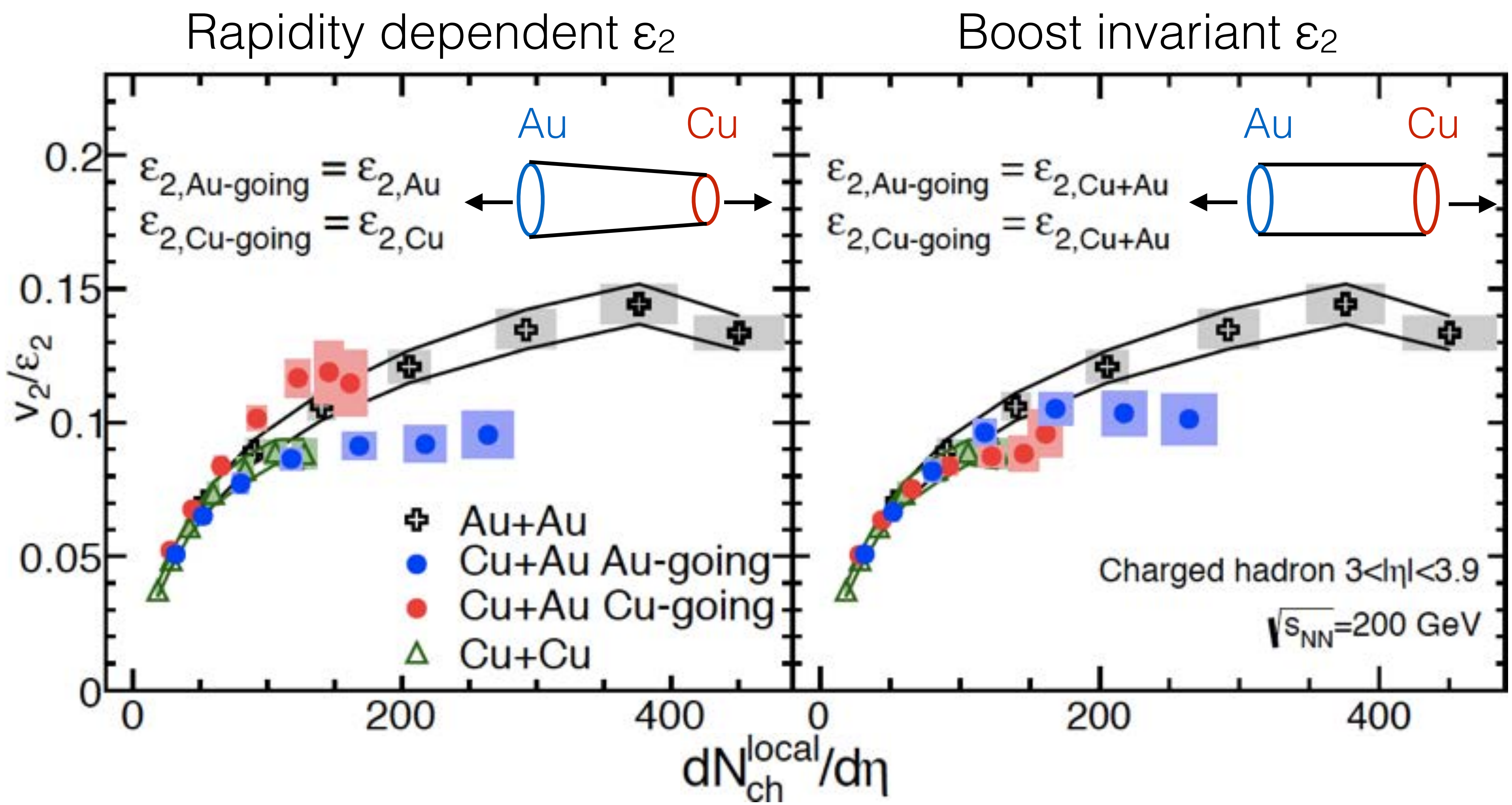
✓v_n is plotted as function of f/b-rapidity dN/dη

- Au-going dN/dη > Cu-going dN/dη

✓Au-going side shows larger v_n than Cu-going side

→Caused by difference of initial geometries between Au and Cu ?

Result:Study of f/b-η initial geometry for 2nd harmonics

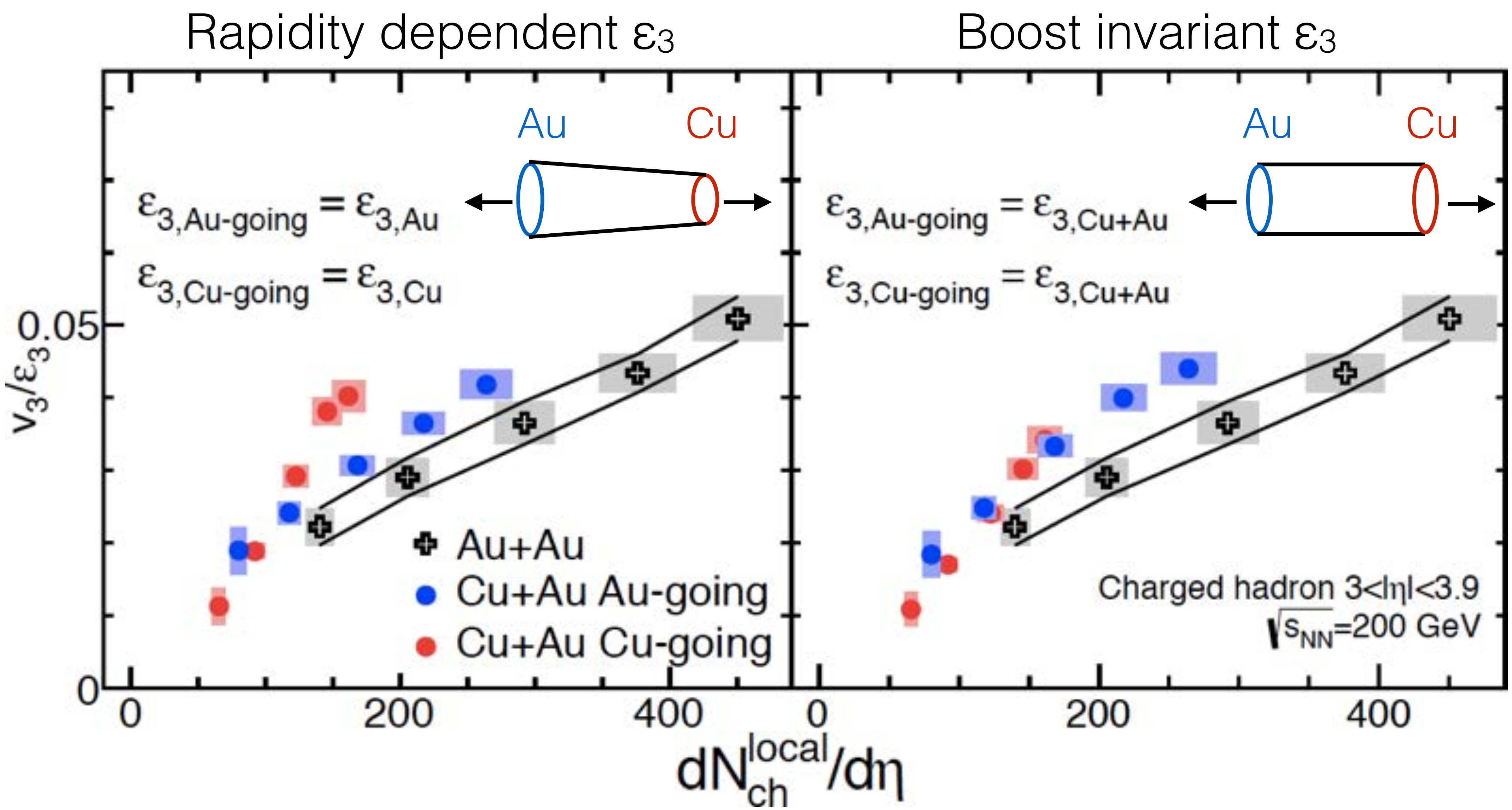


✓Failed to scaled with rapidity dependence of ε_2

✓common $\varepsilon_{2,\text{Au-going}} = \varepsilon_{2,\text{Cu-going}}$ is favored

-F/B asymmetry is caused by dN/dη(initial energy density)

Result:Study of f/b-η initial geometry for 3rd harmonics



✓common $\varepsilon_{3,\text{Au-going}} = \varepsilon_{3,\text{Cu-going}}$ is favored

-F/B asymmetry is caused by dN/dη(initial energy density)

✓Like mid-rapidity v_3, MC-Glauber can not describe system size dependence?

Summary

By studying azimuthal anisotropy in Cu+Au collisions,

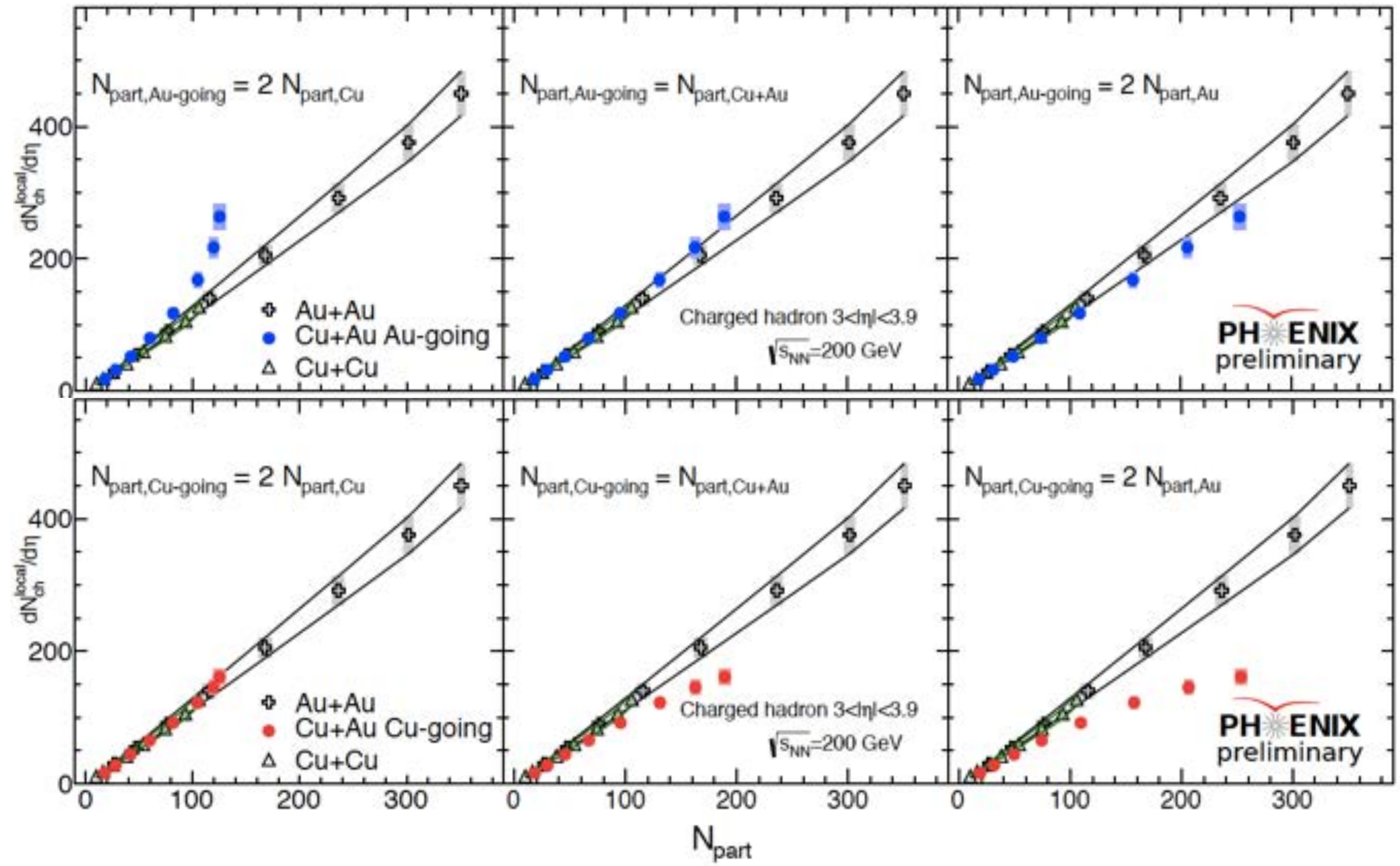
✓Initial geometry at Forward/Backward is common between $-4<\eta<+4$

✓F/B asymmetry of vn is caused by F/B asymmetry of initial density

✓MC-glauber does not describe ε_3 well

Result:Study of f/b-η initial density

$2N_{part,Cu}$ ⟵ $N_{part,Au(Cu)\text{-}going}$ ⟶ $2N_{part,Au}$

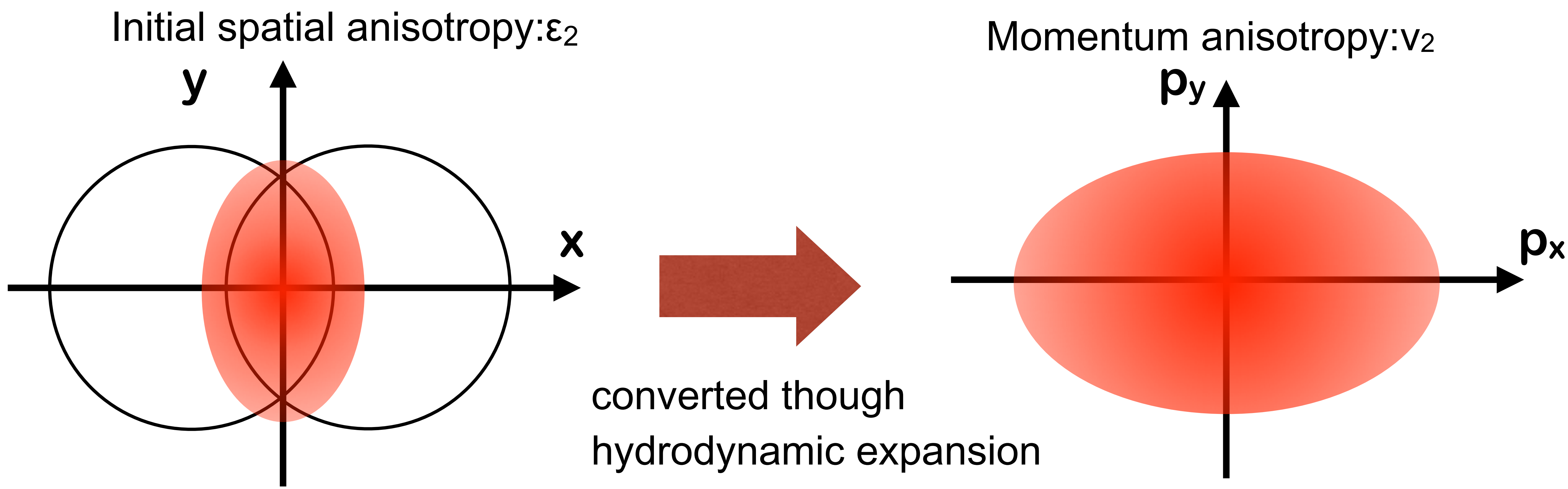


✓Weighted N_{part} scaling for CuAu dN/dη

- $N_{part,Au(Cu)\text{-}going} = wN_{part,Au} + (2-w)N_{part,Cu}$ $(2N_{part,Cu} < N_{part,Au(Cu)\text{-}going} < 2N_{part,Au})$
- $N_{part,Au}$ and $N_{part,Cu}$ are participants in Au and Cu, respectively

✓Au-going side -> $N_{part,Au}$ and $N_{part,Cu}$, Cu-going side -> $N_{part,Cu}$

Azimuthal anisotropy:elliptic flow



✓Initial spatial anisotropy ε_2 -> Final momentum anisotropy v_2

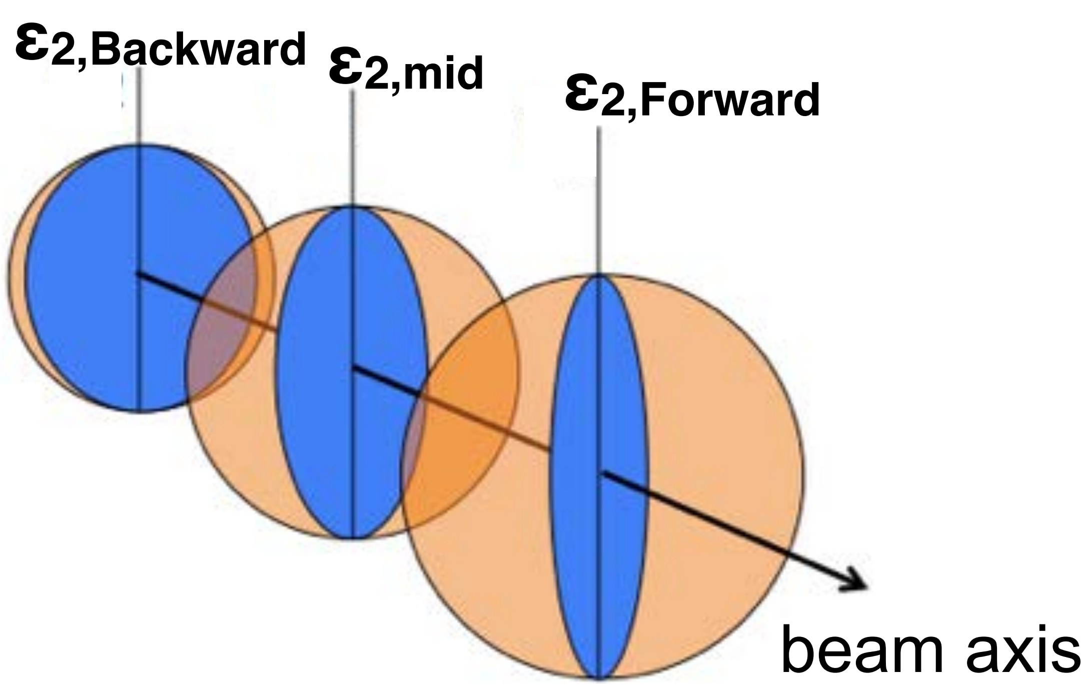
- Non-isotropic pressure gradient

✓Azimuthal anisotropy is strong probe!

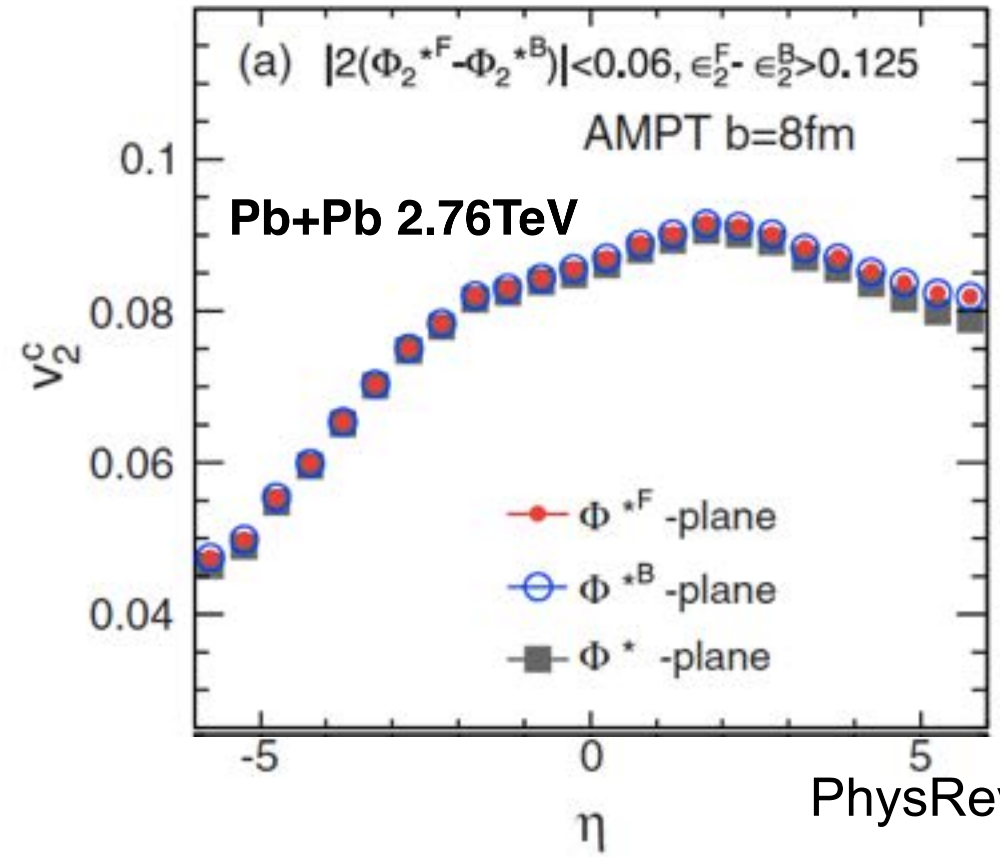
- Clear origin -> initial spatial geometry
- Influenced by hydrodynamic expansion

Theory prediction of F/B asymmetry of ε_n and v_n

Initial geometry



Final momentum anisotropy v_2



PhysRevC.90.034915

✓Event by event, forward/backward v_n might be asymmetric

- initial participant geometries of the two nuclei would be different
- Rapidity independent participant plane for ε_n and v_n
- $\varepsilon_{n,B} < \varepsilon_{n,F}$ ➡ $v_{n,B} < v_{n,F}$

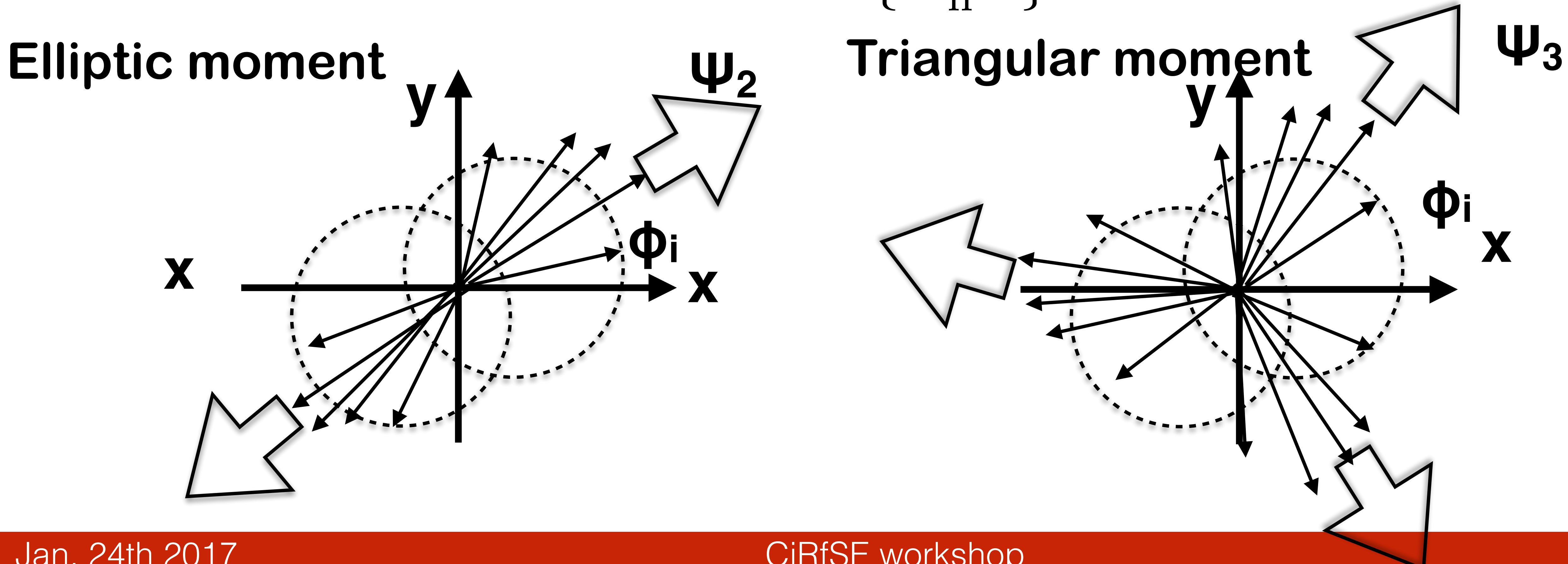
➡ Initial geometry has strong rapidity dependence

Event plane method

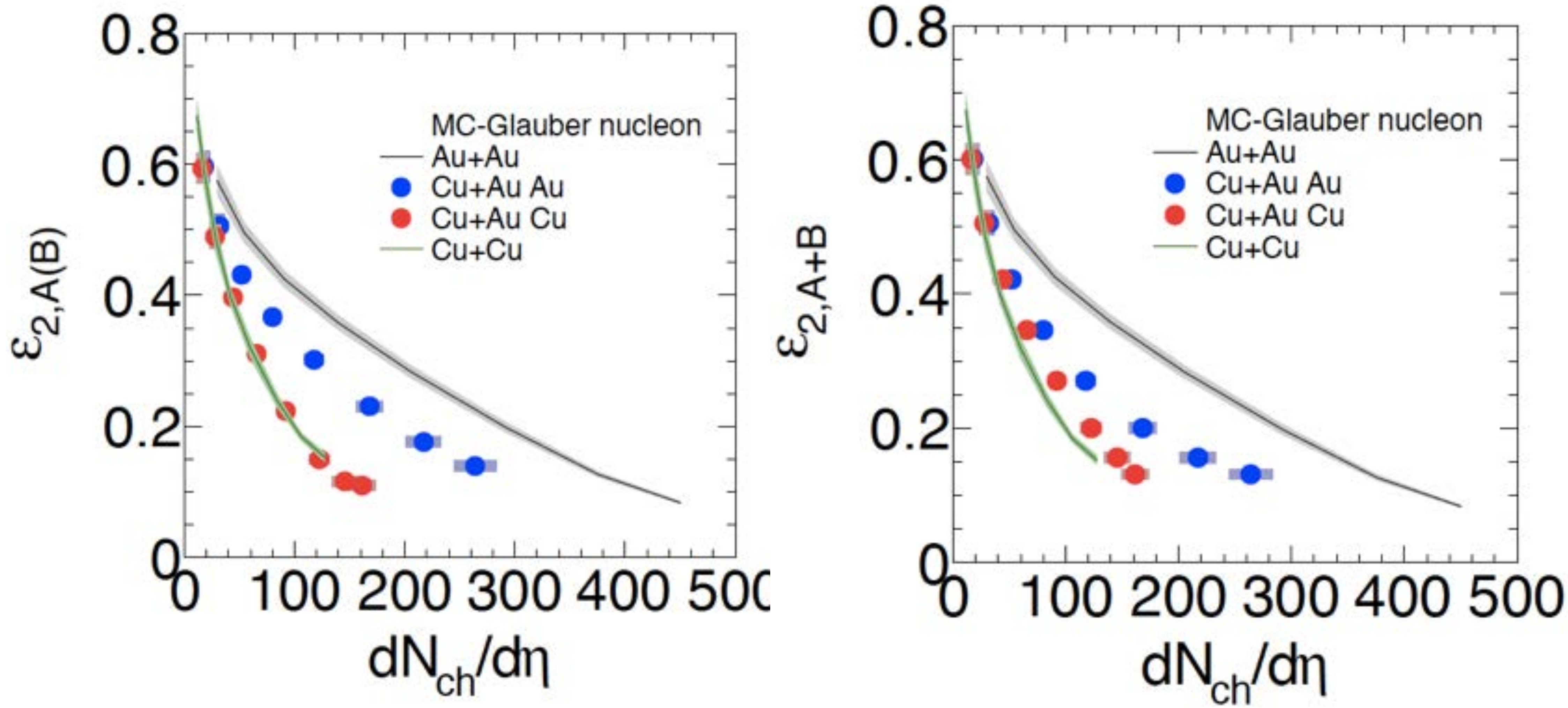
Event plane(EP) method

- 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

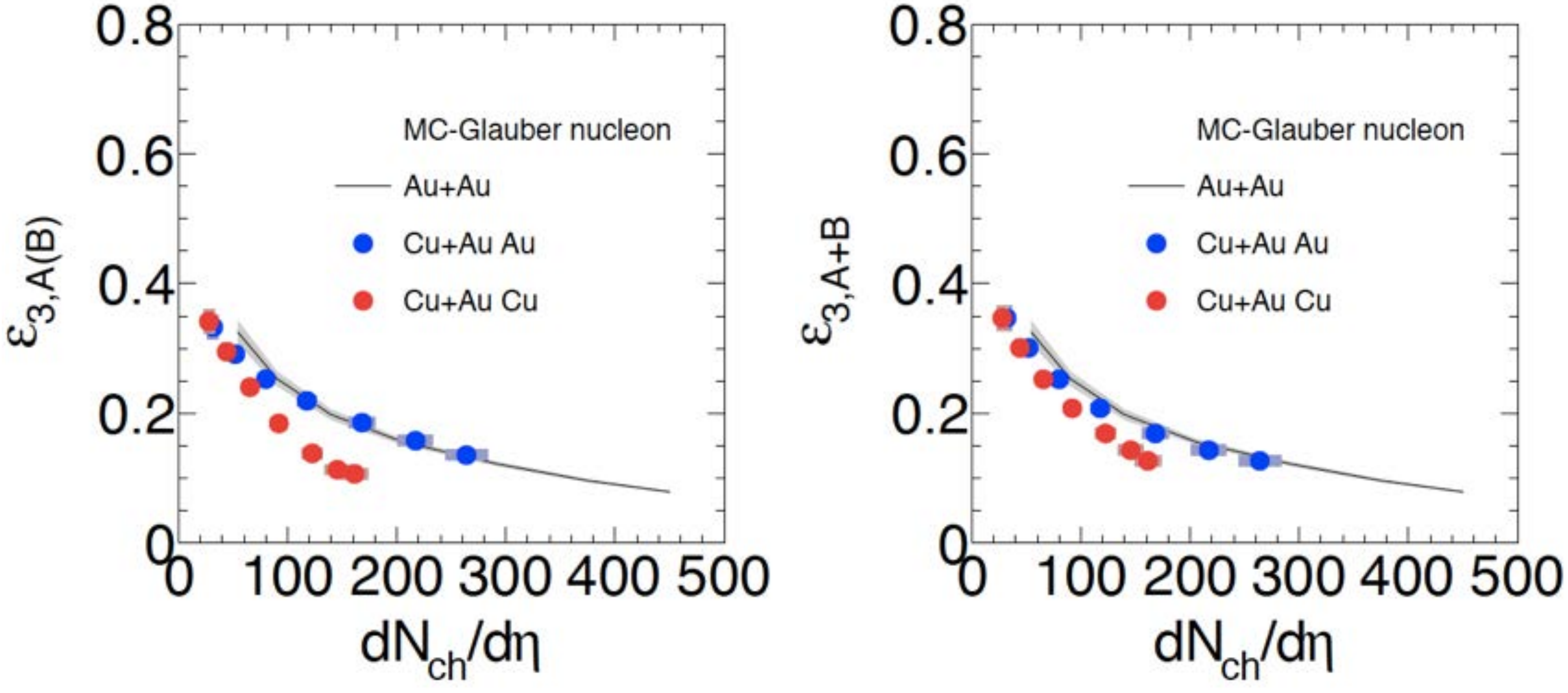
$$v_n = \frac{< \cos(n[\phi - \Psi_n^{obs}]) >}{\mathrm{Res}\{\Psi_n^{\mathrm{obs}}\}}$$



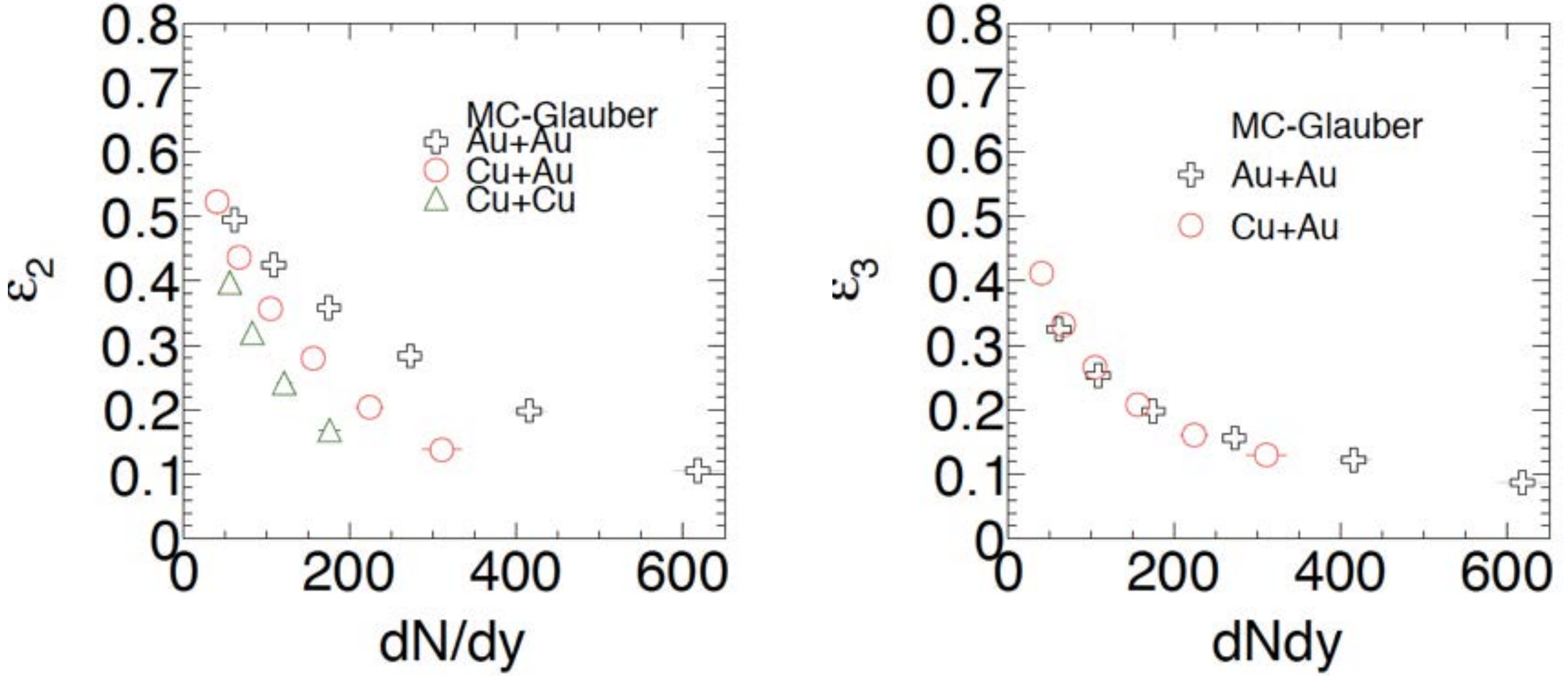
ε2 at F/B rapidity



ε3 at F/B rapidity



εn at mid-rapidity



Initial model dependence