Charged hadron flow in Cu+Au collisions at RHIC-PHENIX

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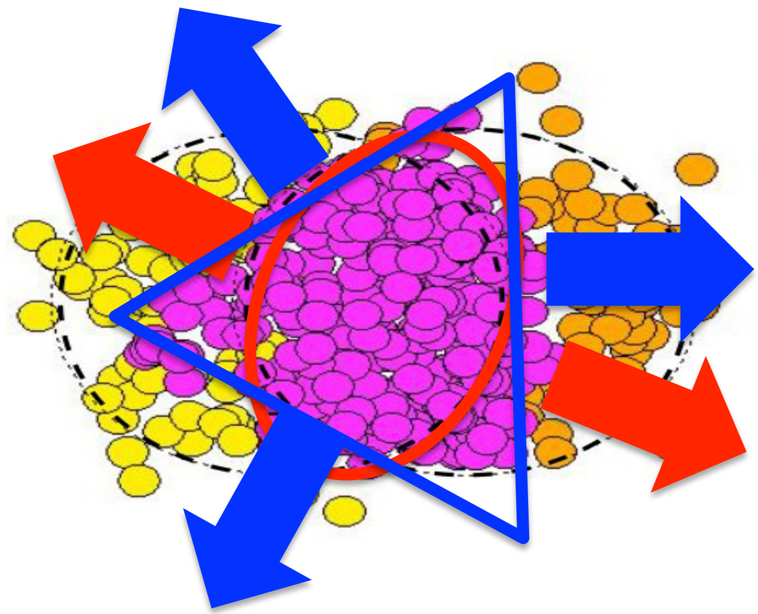
Outline

✓Introduction
✓v_2, v_3 in CuAu collision
✓v_1 in CuAu collision
✓Summary

Azimuthal Anisotropy

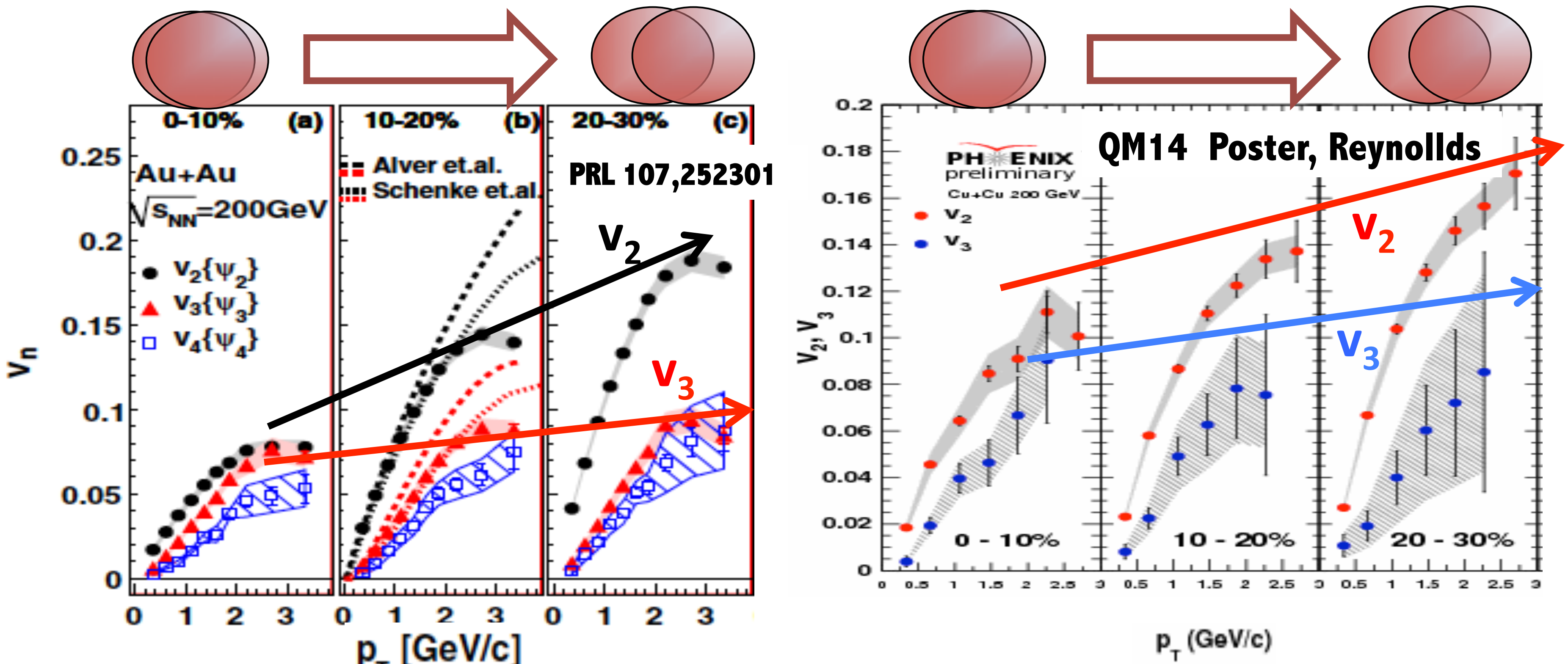
✓**The Azimuthal Anisotropy is good probe**

$$v_n = < \cos(n[\phi - \Phi_n]) >$$



n=1 Directed
n=2 Elliptic
n=3 Triangular
➔**Initial state geometry**
➔**η/s**

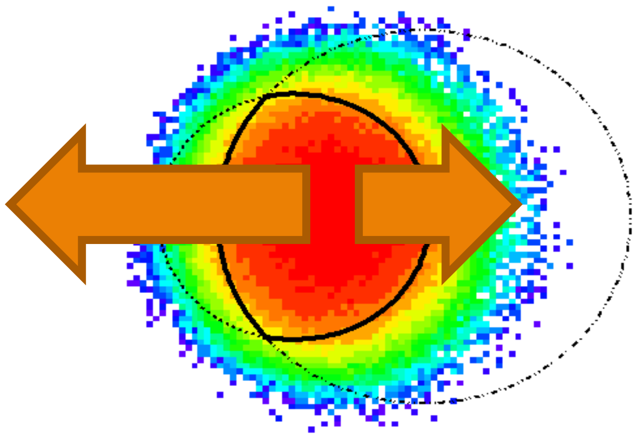
v_2,v_3 in symmetric collision systems



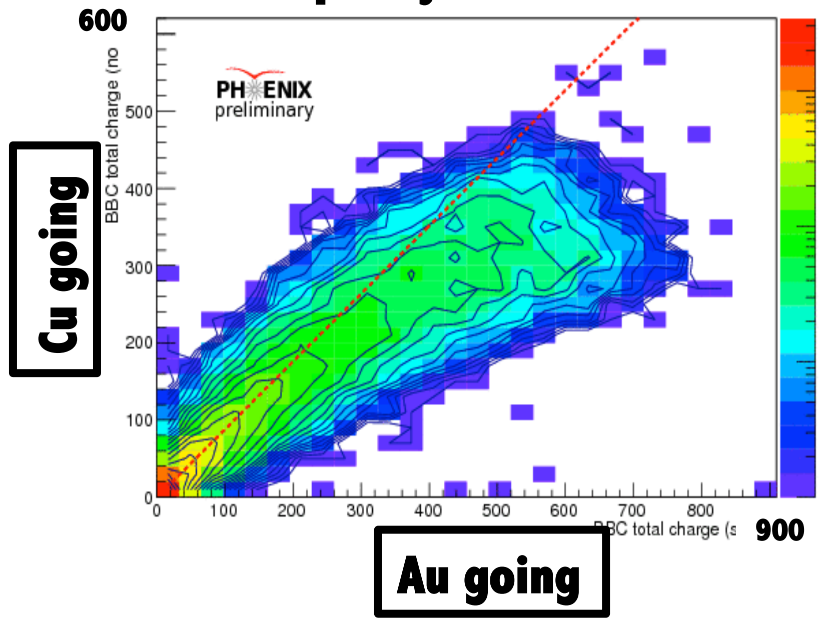
- ✓ v_n is studied in AuAu, CuCu collisions
  - Clear centrality dependence of v_2 in AuAu, CuCu
  - Weak / No significant centrality dependence of v_3 in AuAu, CuCu

Introduction of CuAu collisions

Glauber Monte Calro



Forward multiplicity vs Backward multiplicity



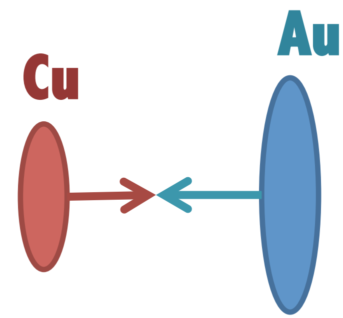
✓**Asymmetric collision provide us unique information**

- **Left/Right difference in pressure gradient**
- **Asymmetric η distribution**

Flow Measurement via EP method

✓vn is measured via EP method

$$v_n = \langle \cos(n[\phi - \Psi_n]) \rangle$$

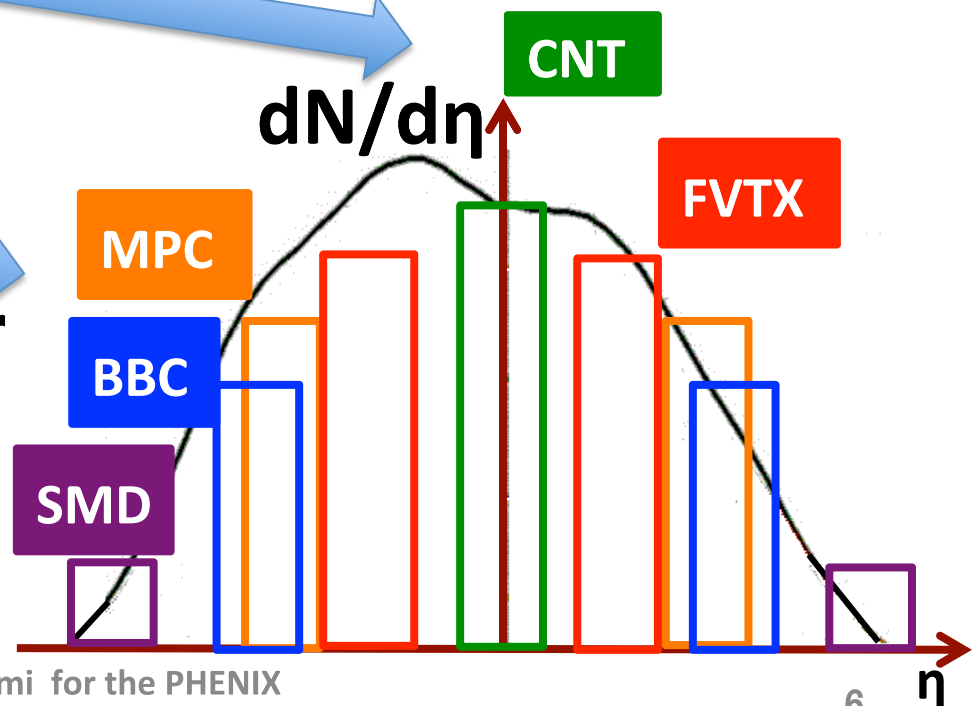


✓ Charged Hadron track

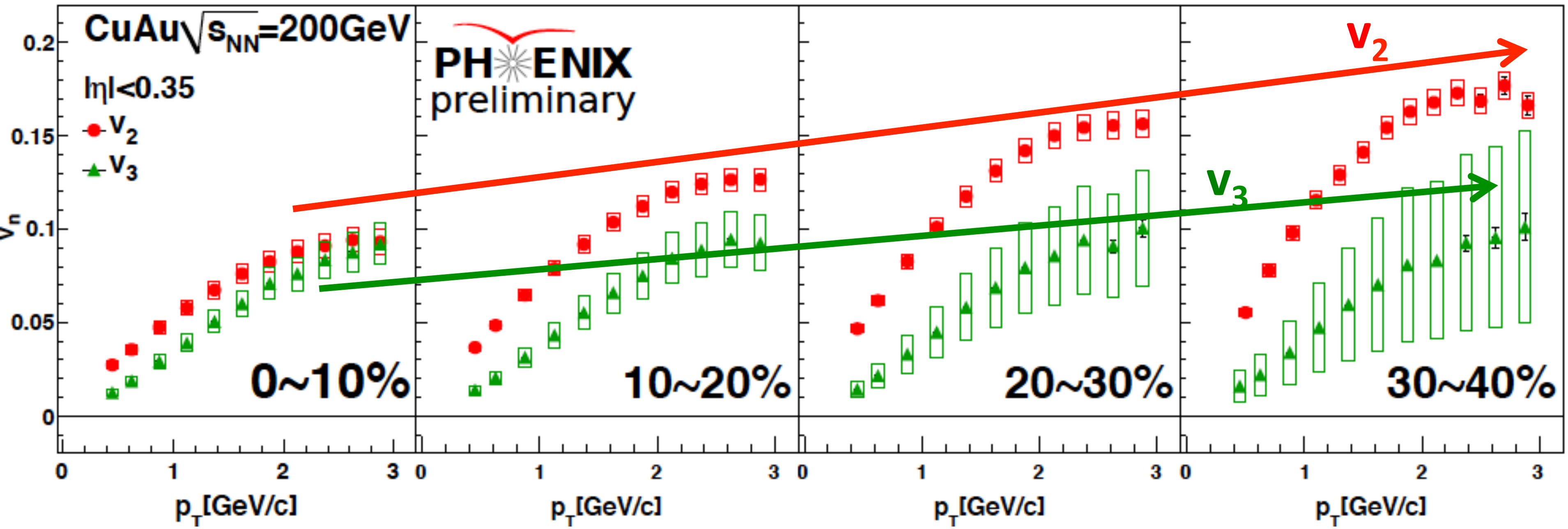
- CNT (| η | <0.35)
- FVTX (1< | η | <3)

✓EP is estimated by Forward/Backward detector

- BBC (3.1< | η | <3.9)
- MPC (3.1< | η | <3.8)
- SMD (| η | >6)



Centrality dependence of v_2, v_3 in 200 GeV CuAu

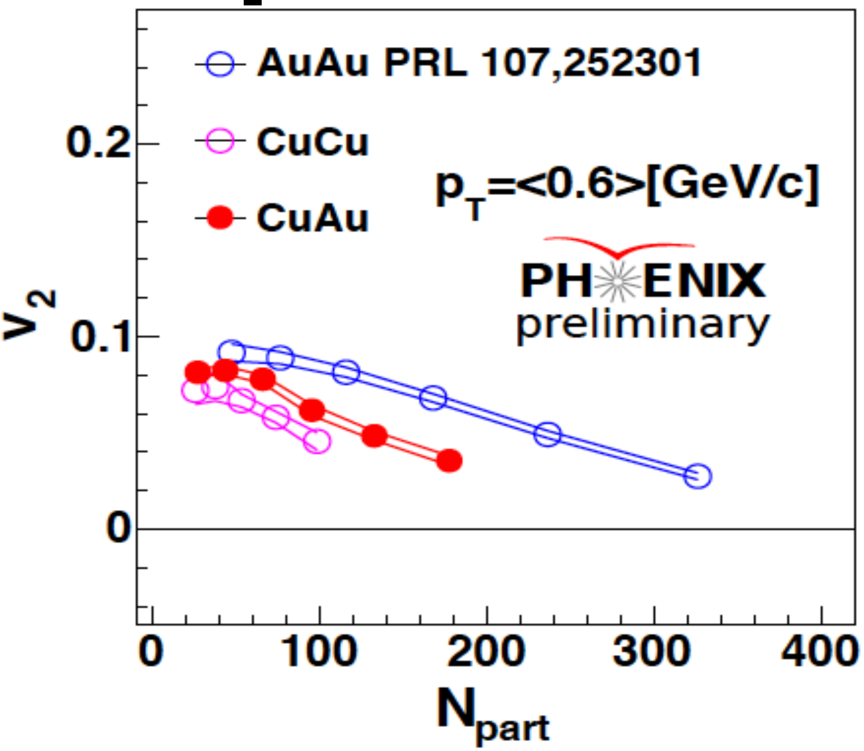


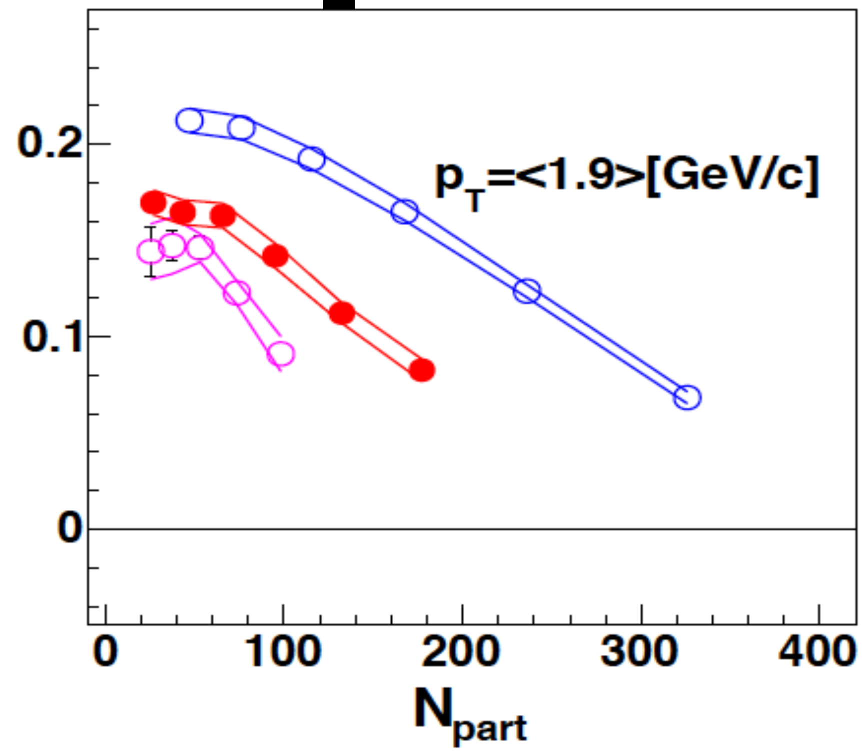
✓CuAu v_2, v_3 (pt) are measured

- Clear centrality dependence of v_2
- No Significant centrality dependence of v_3

➔ Same centrality dependence as seen in symmetric collisions

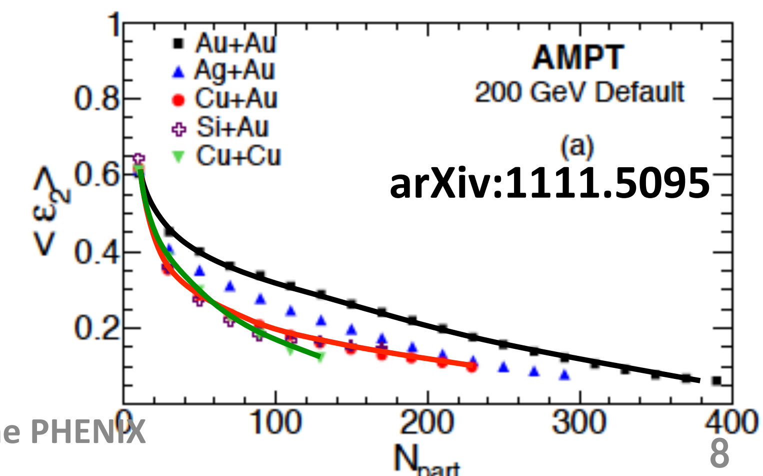
Comparison to AuAu, CuCu v_2



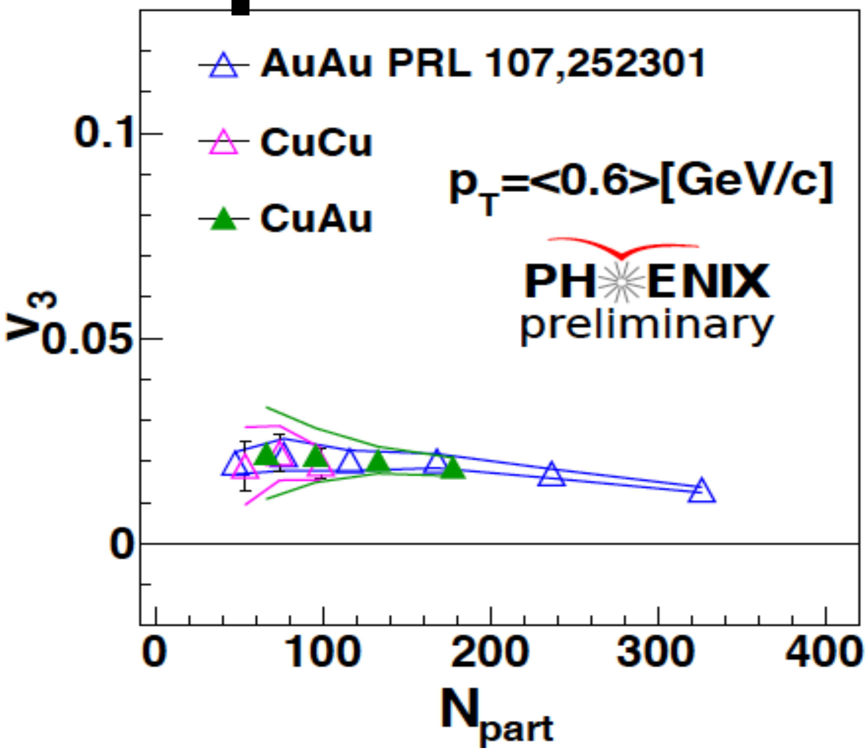


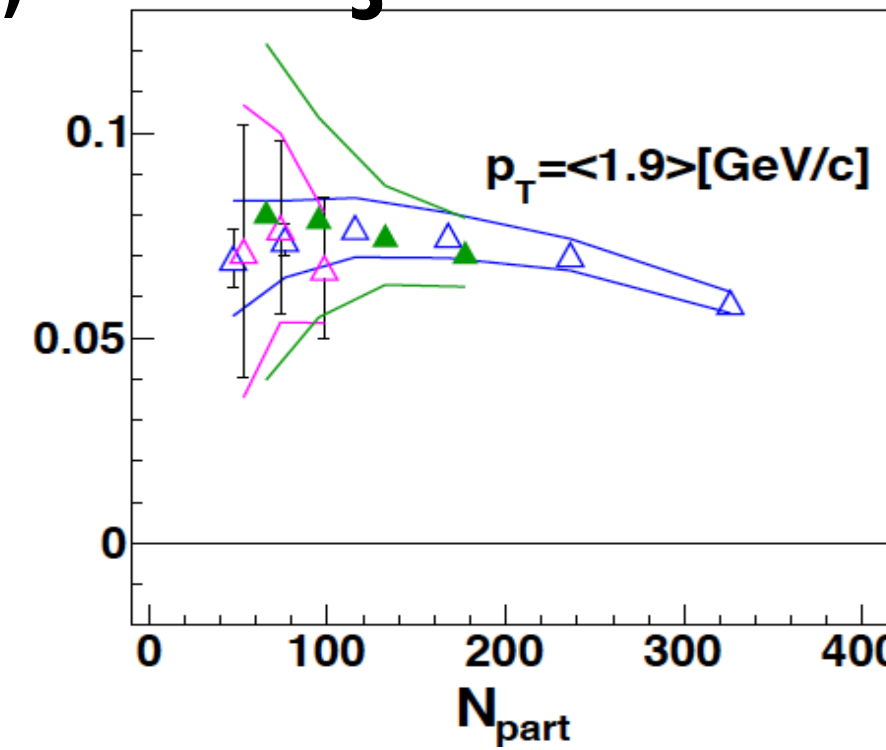
✓ **System size dependence**

- **AuAu > CuAu > CuCu**
- **Originated from initial ε_2**



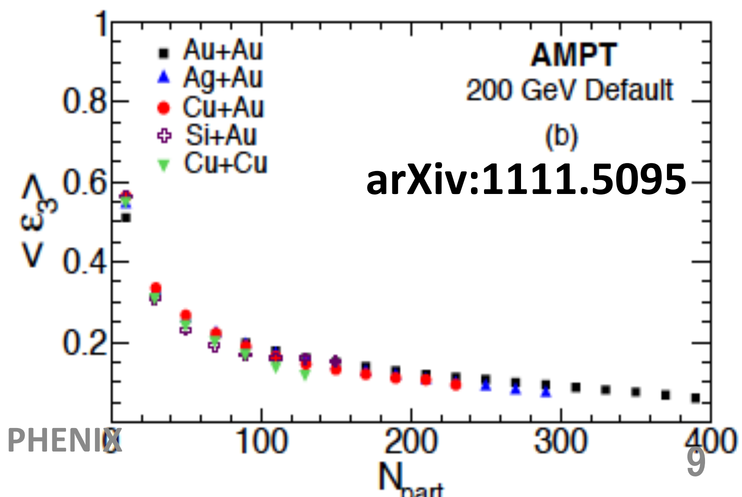
Comparison to AuAu, CuCu v_3



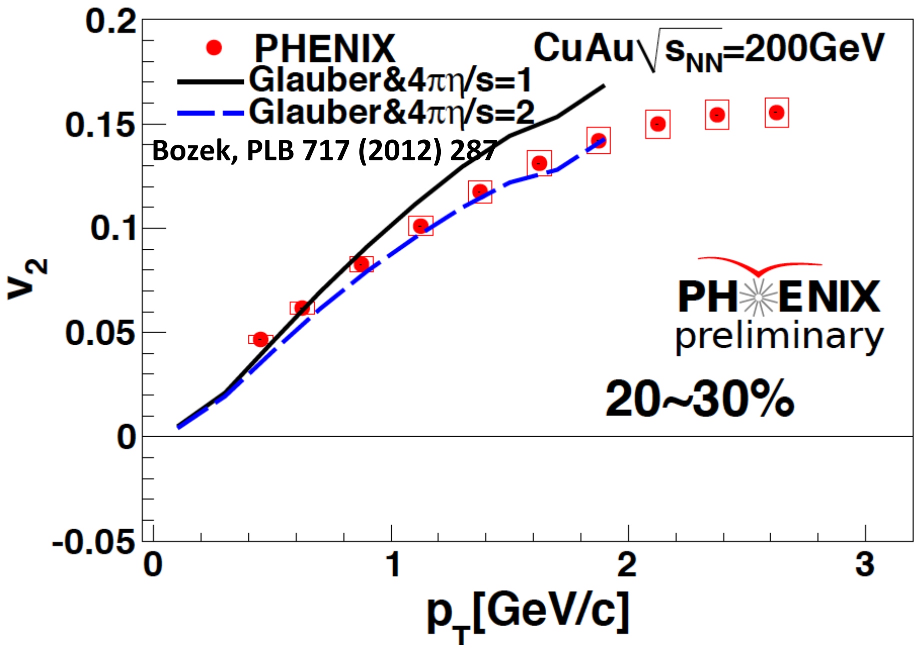


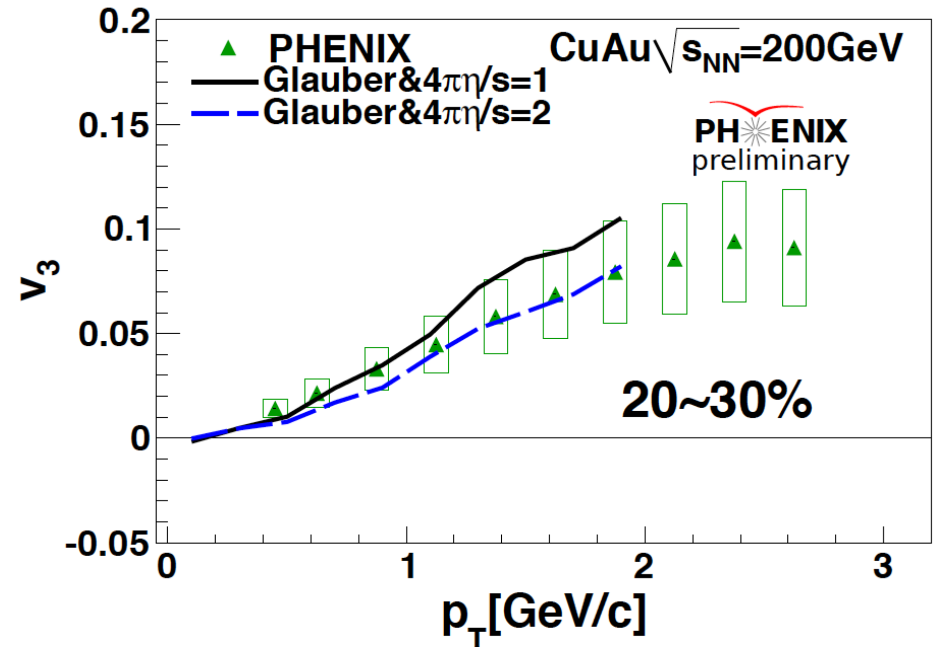
✓ **Small system size dependence**

- **It is expected from similar ε_3**
- **v_3 is given by ε_3**



Comparison to Theory



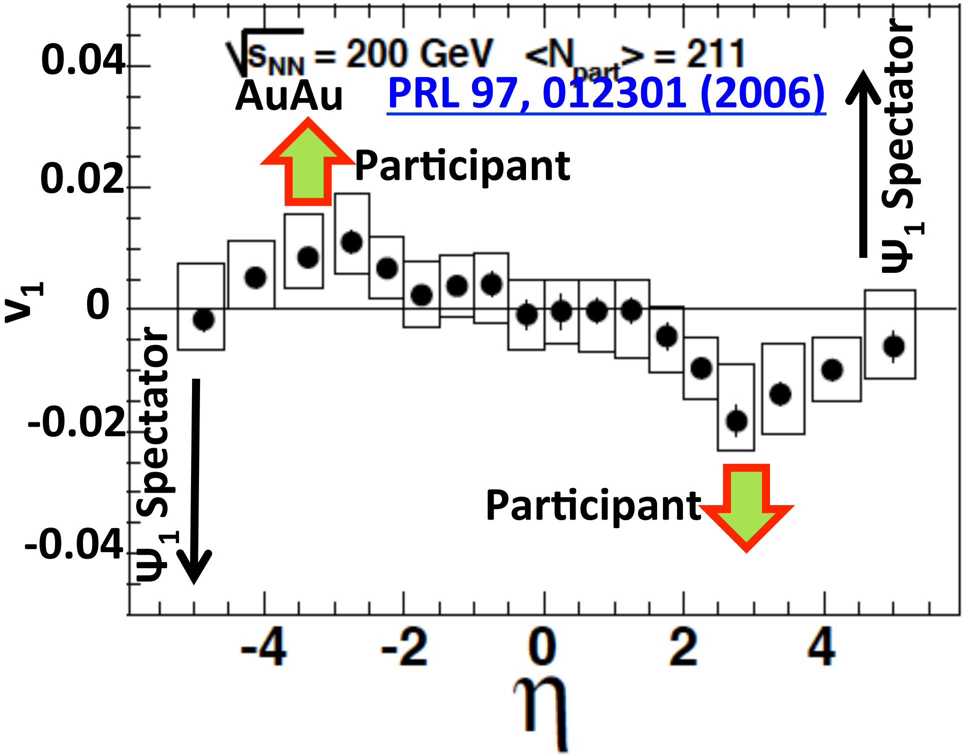


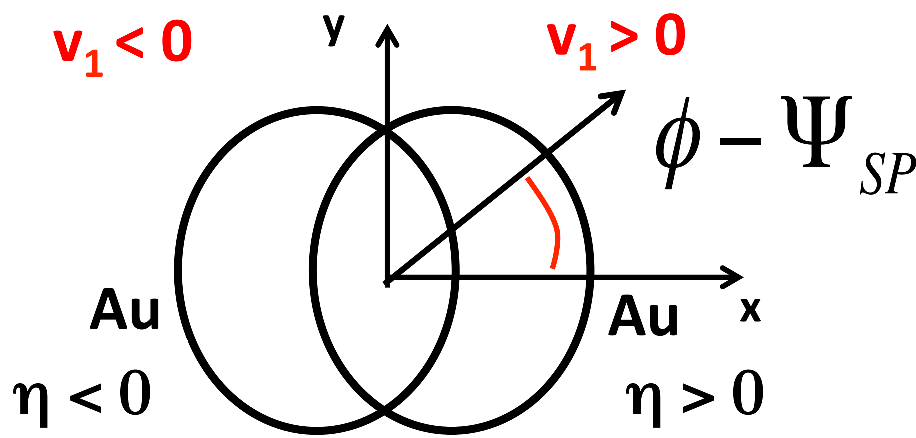
✓ **Comparison to Theory (Glauber and $4\pi\eta$ =1(2))**

- p_T<1[GeV/c], Experimental data agree better with $4\pi\eta/s=1$?

- p_T>1[GeV/c], Experimental data agree better with $4\pi\eta/s=2$?

v_1 in symmetric collision system



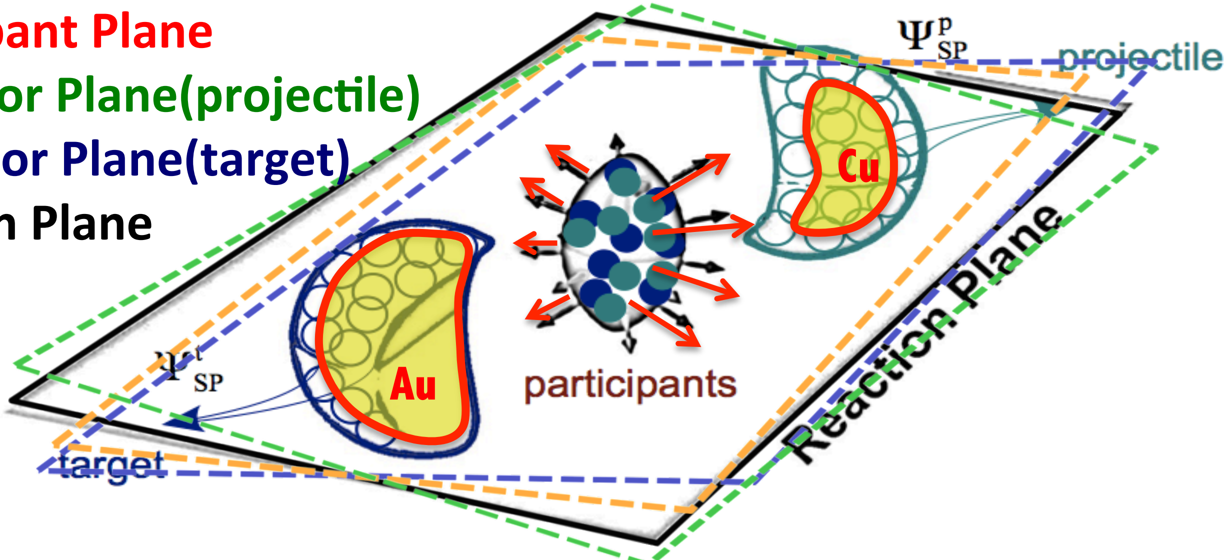


$$v_1 = < \cos(\phi - \Psi_1) >$$

- ✓ **Rapidity anti-symmetric (Traditional) : $v_1(\eta) = -v_1(\eta)$**
- ✓ **Definition of positive v_1 : Ψ_1 (η>0)**
  - **v_1<0 -> more particles are emitted to Ψ_1 (η<0)**
  - **v_1>0 -> more particles are emitted to Ψ_1 (η>0)**

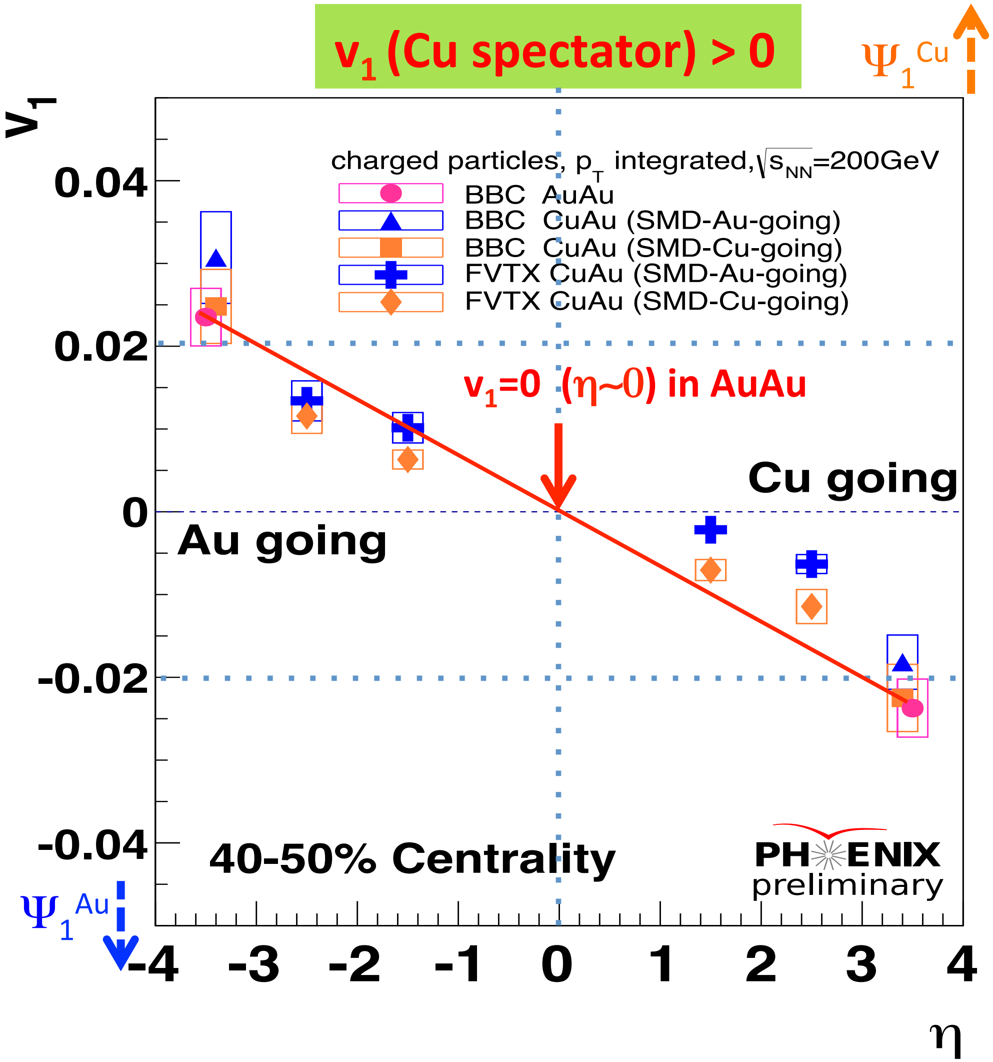
v_1 Fluctuation in CuAu

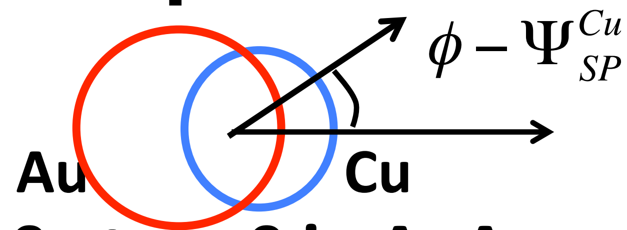
$\Psi^{(n)}_{PP}$: Participant Plane
Ψ^{p}_{SP} : Spectator Plane(projectile)
Ψ^{t}_{SP} : Spectator Plane(target)
Ψ_{RP} : Reaction Plane



- ✓ **Spectator is expected to fluctuate**
  - ➔ $\Psi^{p}_{SP} \neq \Psi_{PP} \neq \Psi^{t}_{SP}$ ➔ $v_1(\Psi^{p}_{SP}) \neq v_1(\Psi^{t}_{SP})$
  - ➔ $v_1 = v_1^{Traditional} + v_1^{SP\ fluctuation}$
    - $v_1^{Traditional}$: $v_1(\eta) = -v_1(-\eta)$
    - $v_1^{SP\ Fluctuation}$: $v_1(\eta) = v_1(-\eta)$
- ✓ **Are there two v_1 components in CuAu ?**
- ✓ **How asymmetric are two v_1 components in CuAu ?**

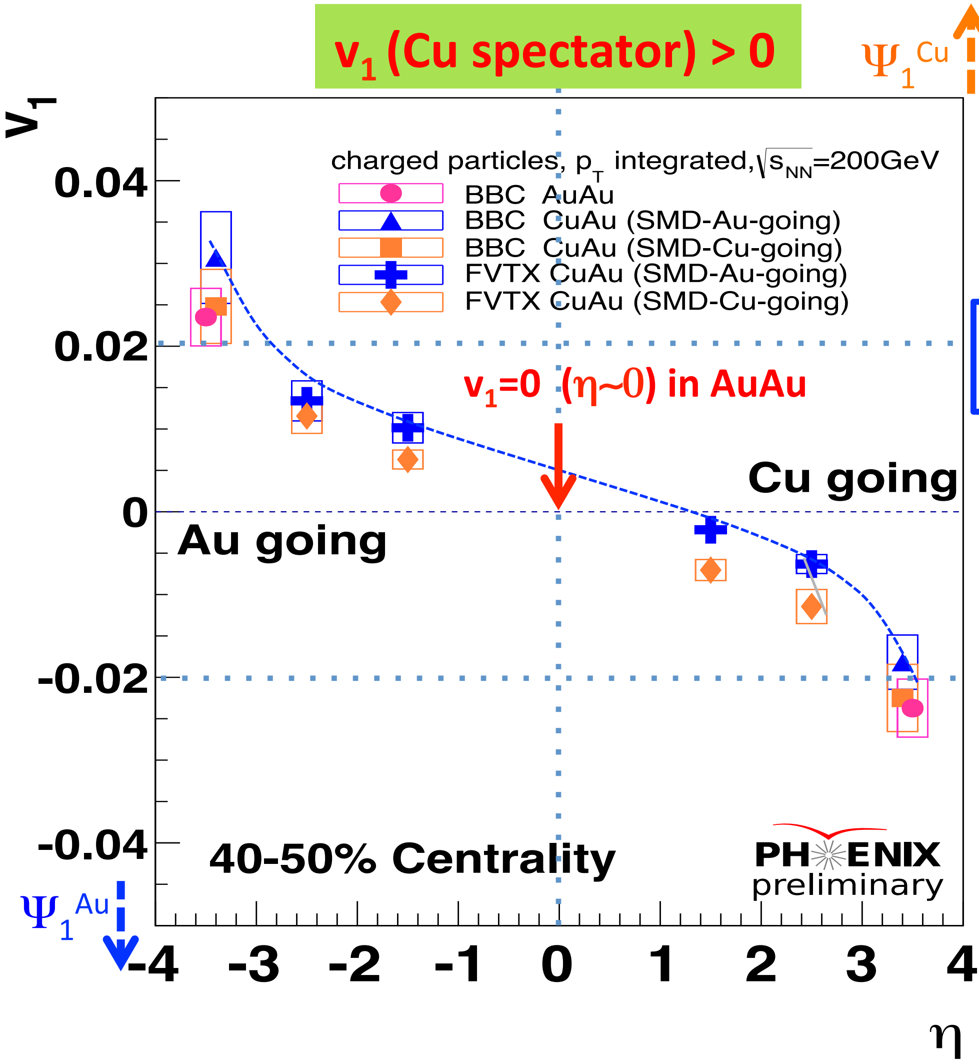
η Symmetric/Anti-symmetric v_1 in CuAu

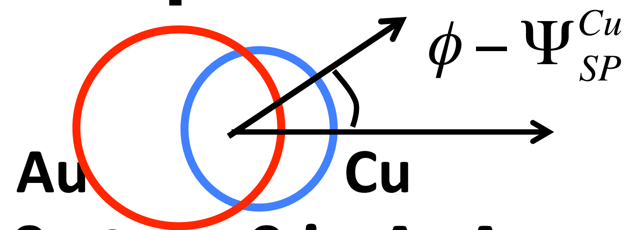




✓ v_1= 0 at η=0 in AuAu

η Symmetric/Anti-symmetric v_1 in CuAu

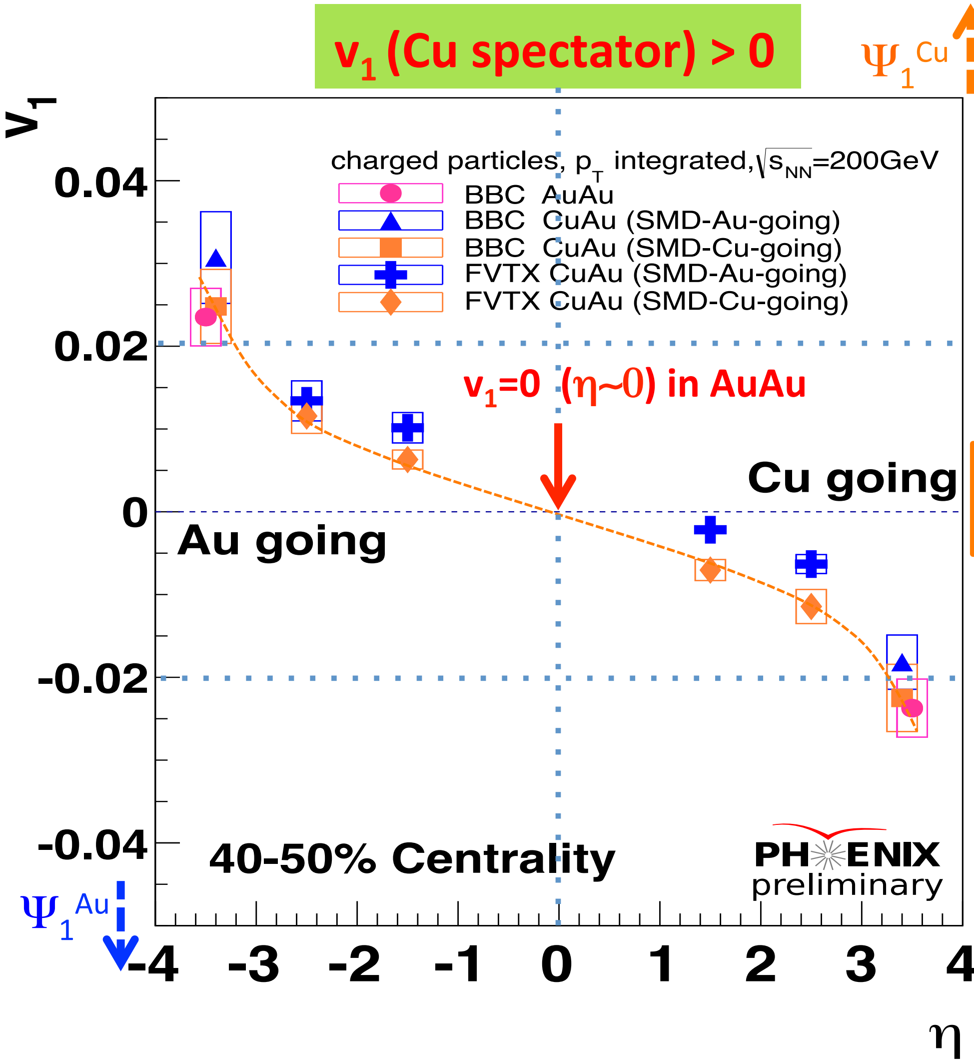


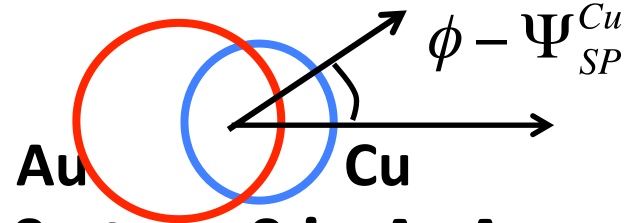


✓ v_1= 0 at η=0 in AuAu

✓ v_1 w.r.t Ψ_{SP}^{Au}

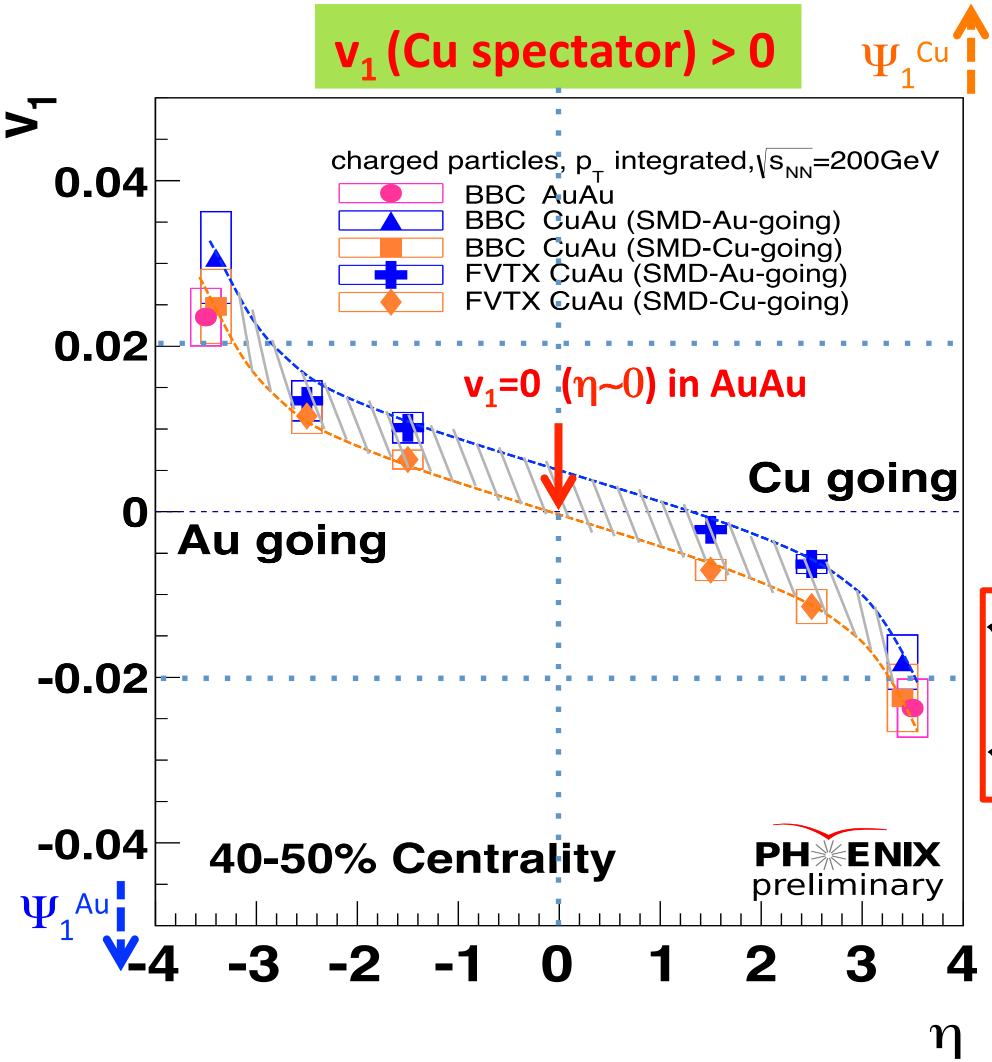
η Symmetric/Anti-symmetric v_1 in CuAu

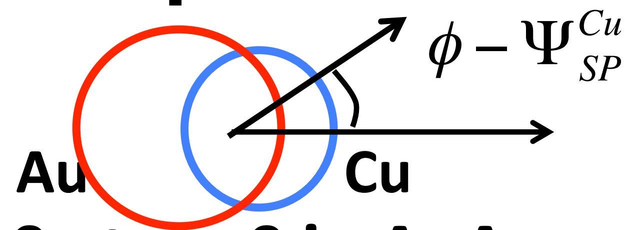




- ✓ v_1= 0 at η=0 in AuAu
- ✓ v_1 w.r.t Ψ_{SP}^{Au}
- ✓ v_1 w.r.t Ψ_{SP}^{Cu}

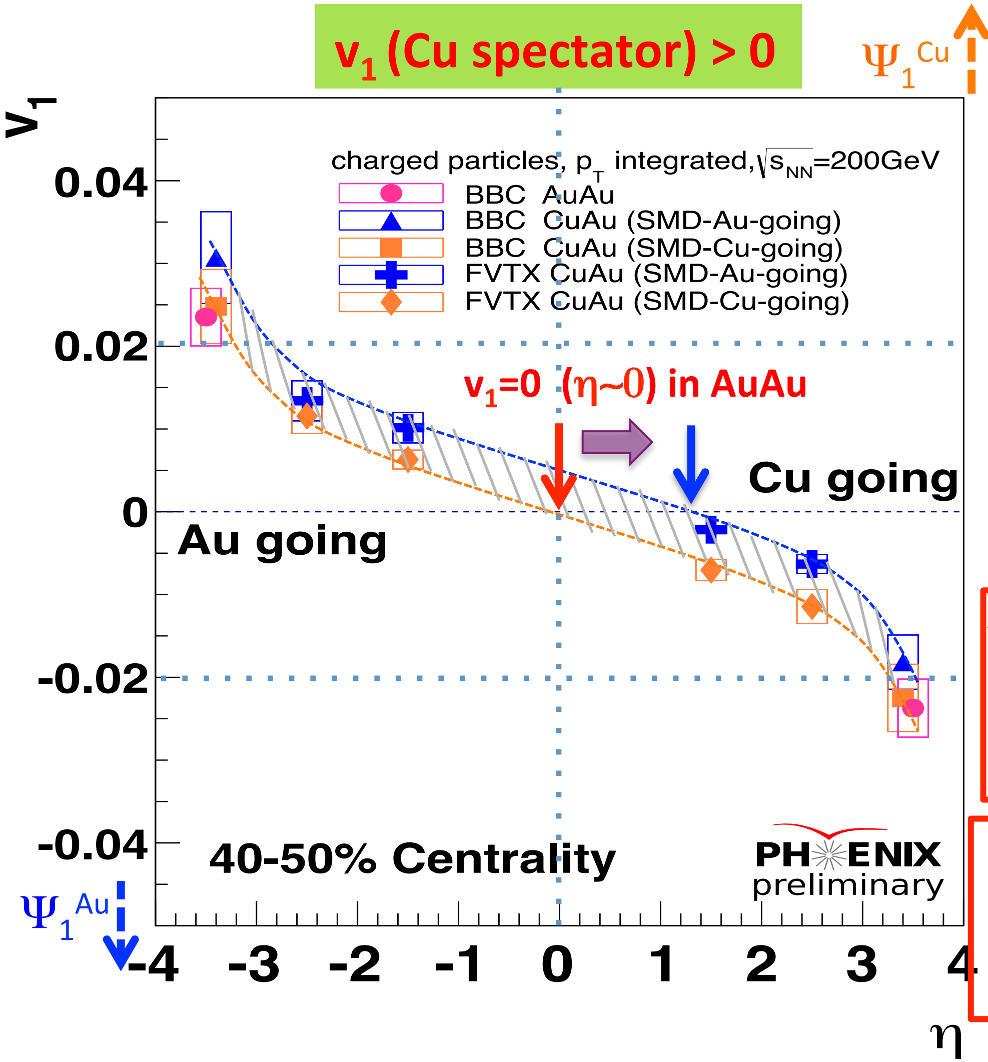
η Symmetric/Anti-symmetric v_1 in CuAu

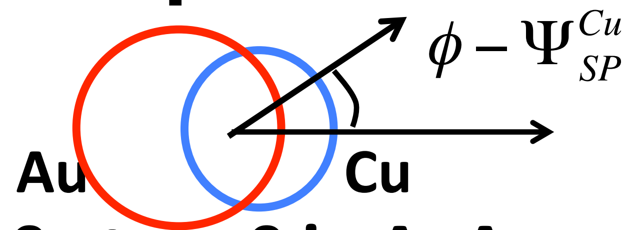




- ✓ v_1= 0 at η=0 in AuAu
- ✓ v_1 w.r.t Ψ_{SP}^{Au}
- ✓ v_1 w.r.t Ψ_{SP}^{Cu}
- ✓ v_1(flu) = (orange−blue)/2
- ✓ v_1(tra) = (orange+blue)/2

η Symmetric/Anti-symmetric v_1 in CuAu



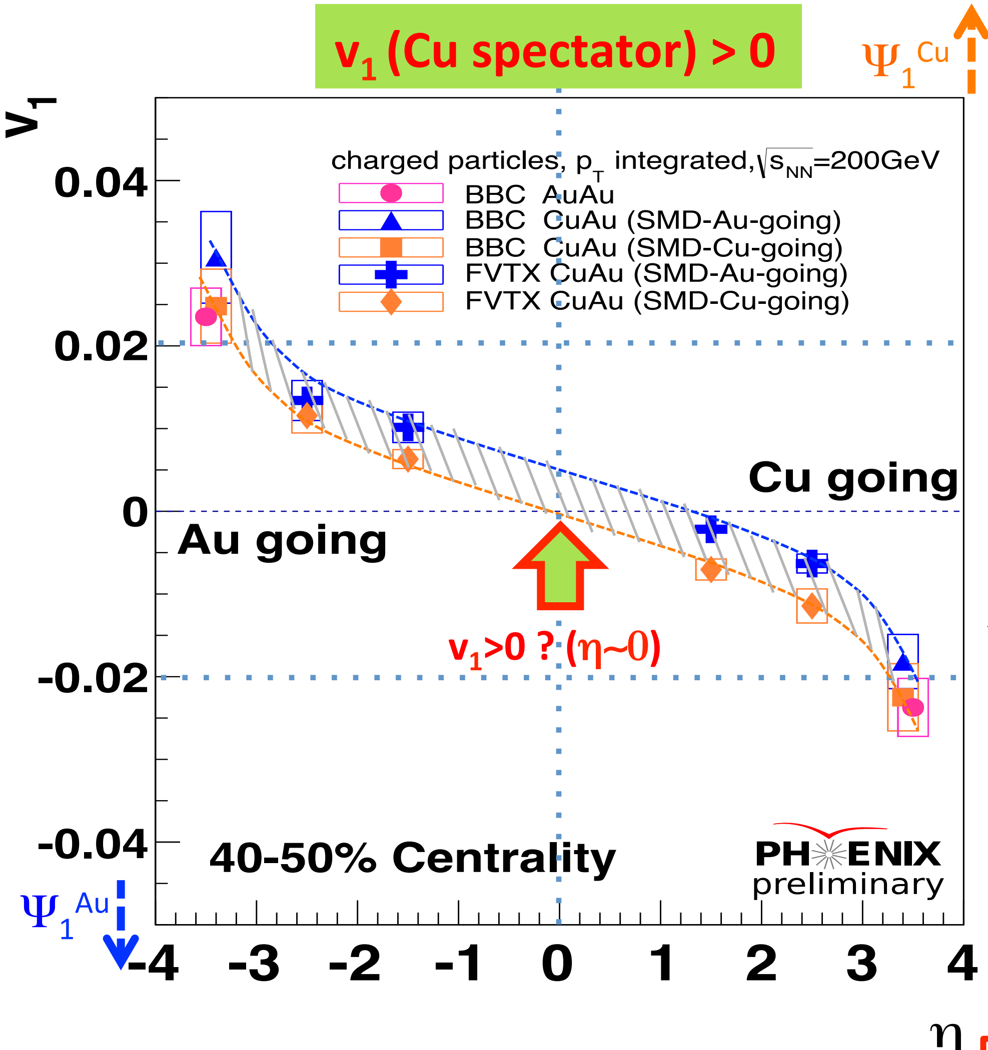


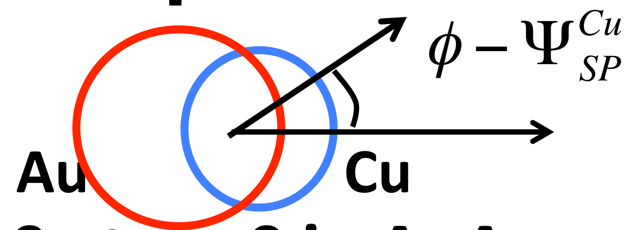
- ✓ v_1= 0 at η=0 in AuAu
- ✓ v_1 w.r.t Ψ_{SP}^{Au}
- ✓ v_1 w.r.t Ψ_{SP}^{Cu}

- ✓ v_1(flu) = (orange–blue)/2
- ✓ v_1(tra) = (orange+blue)/2

- ✓ v_1(tra) is shifted to Cu going side

η Symmetric/Anti-symmetric v_1 in CuAu





- ✓ v_1= 0 at η=0 in AuAu
- ✓ v_1 w.r.t Ψ_{SP}^{Au}
- ✓ v_1 w.r.t Ψ_{SP}^{Cu}
- ✓ v_1(flu) = (orange-blue)/2
- ✓ v_1(tra) = (orange+blue)/2
- ✓ v_1(tra) is shifted towards Cu going side

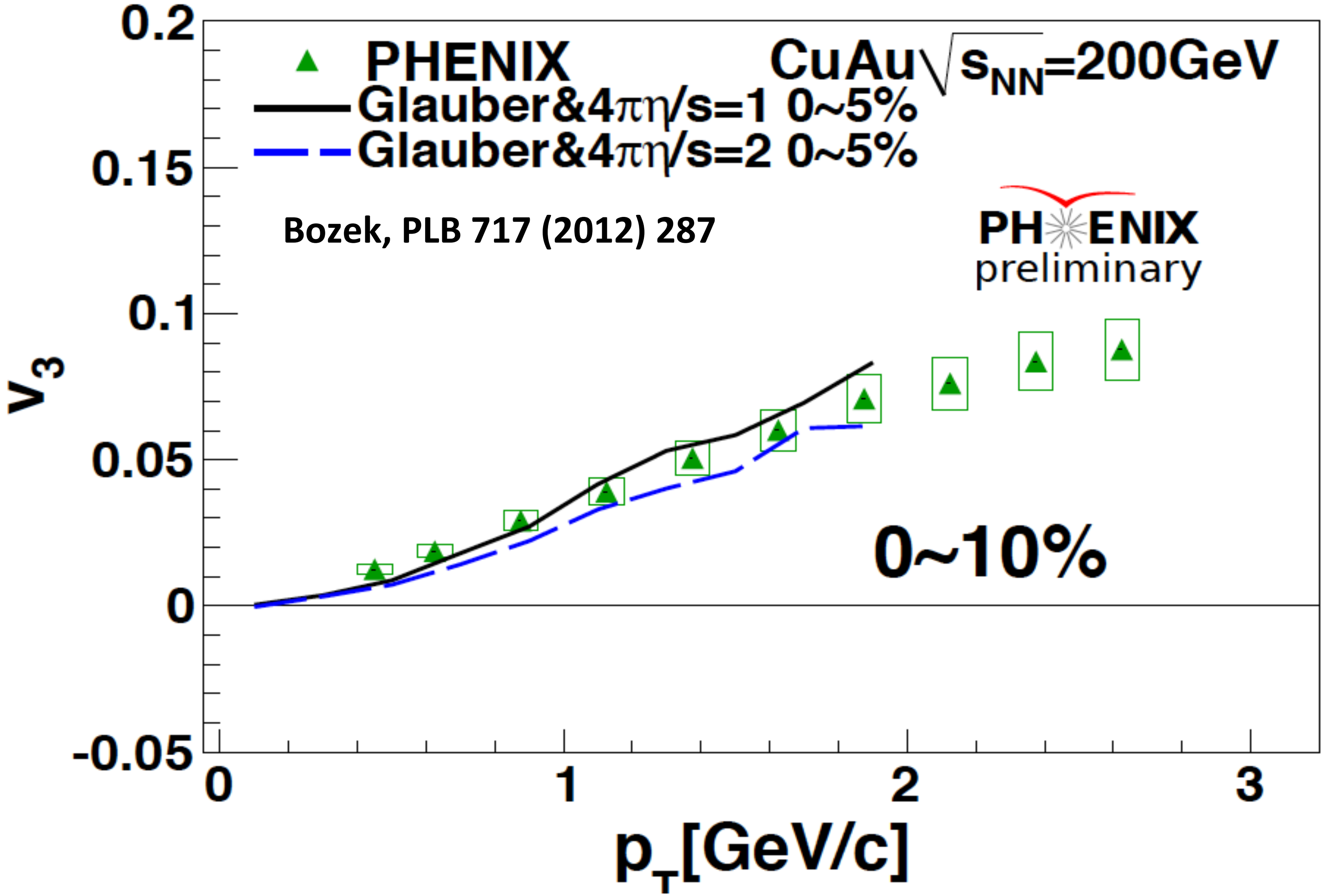
✓ v_1(tra) >0? at η=0

Summary

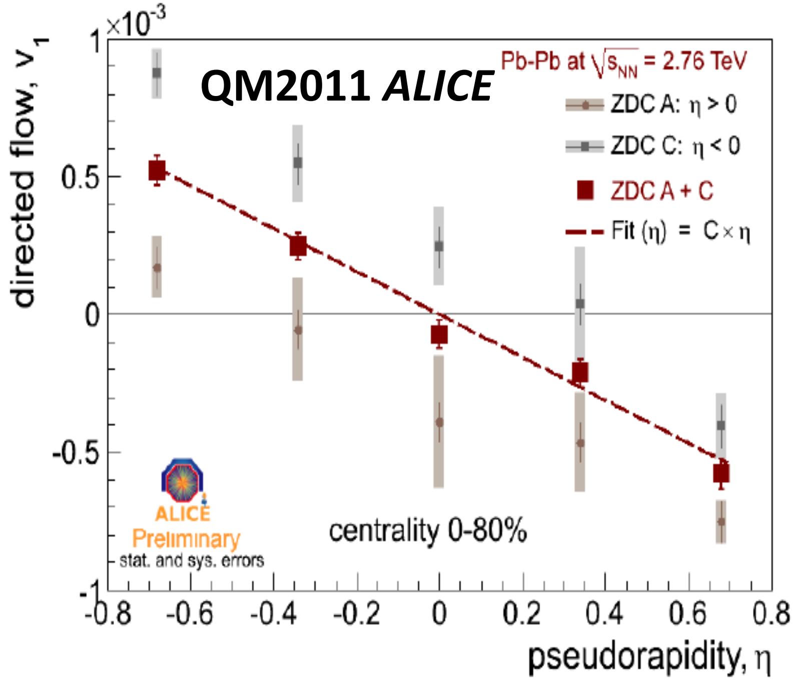
- ✓ CuAu v2, v3 (pt)
  - Clear centrality and system size dependence of v2
  - No significant centrality and system size dependence of v3

- ✓ CuAu v1 (η)
  - negative slope in v1 (Traditional) as a function of η
  - Rapidity $\eta_0(v_1 \sim 0)$ is shifted towards Cu-going direction or $v_1 > 0$ at $\eta \sim 0$
  - negative v1 (SP Fluctuation) : $v1(\Psi_1^{Cu}) < v1(\Psi_1^{Au})$

Comparison to Theory



v_1 Even, Odd Components in PbPb



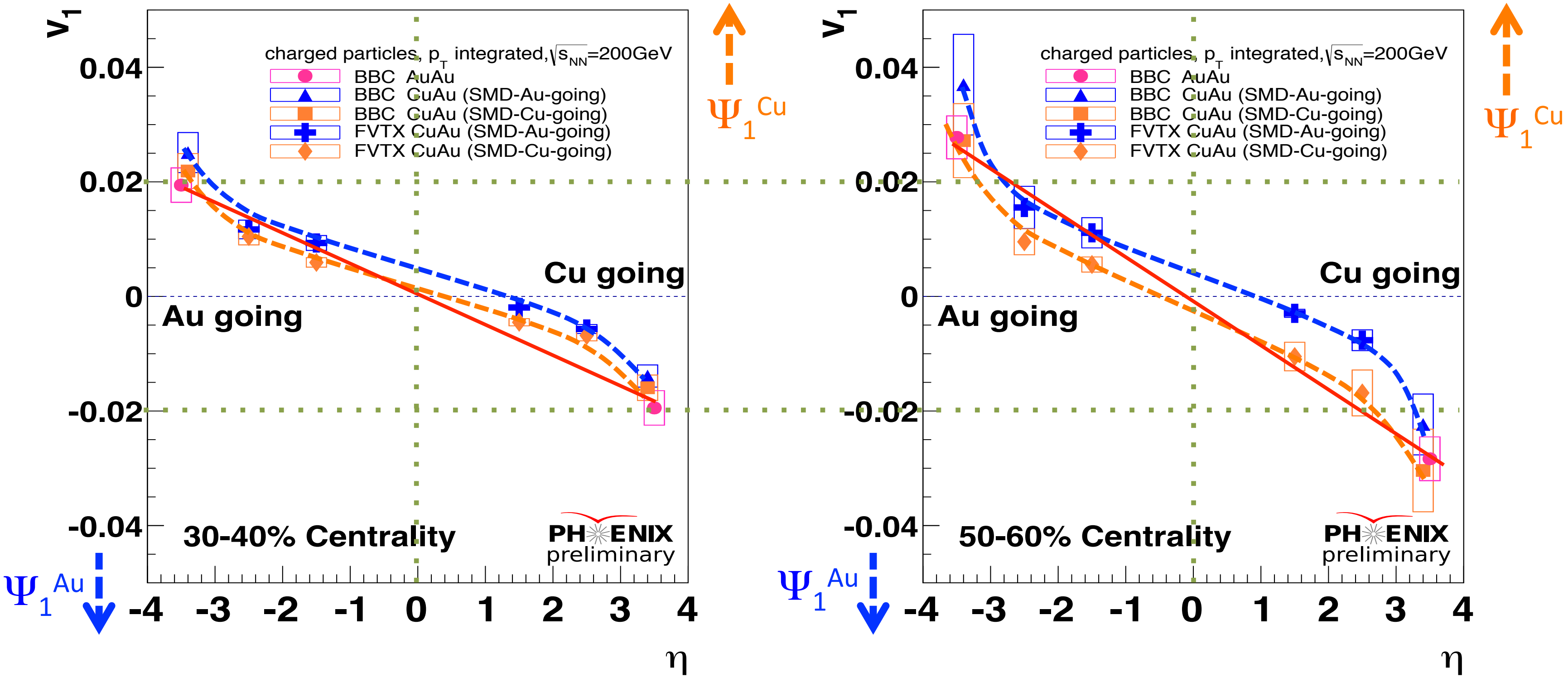
✓ v_1(even + odd) = v_1(even) + v_1(odd) is observed in PbPb 2.75 [TeV]

- v(even): v1(η) = v1(-η)
- v1(odd) : v1(η) = -v1(-η)
- The source of even component is expected from spectator fluctuation

✓ Same EP (Spectator) dependence is seen.

- v1(EP $\eta<0$) > v1(EP $\eta>0$)

Centrality dependence of v1



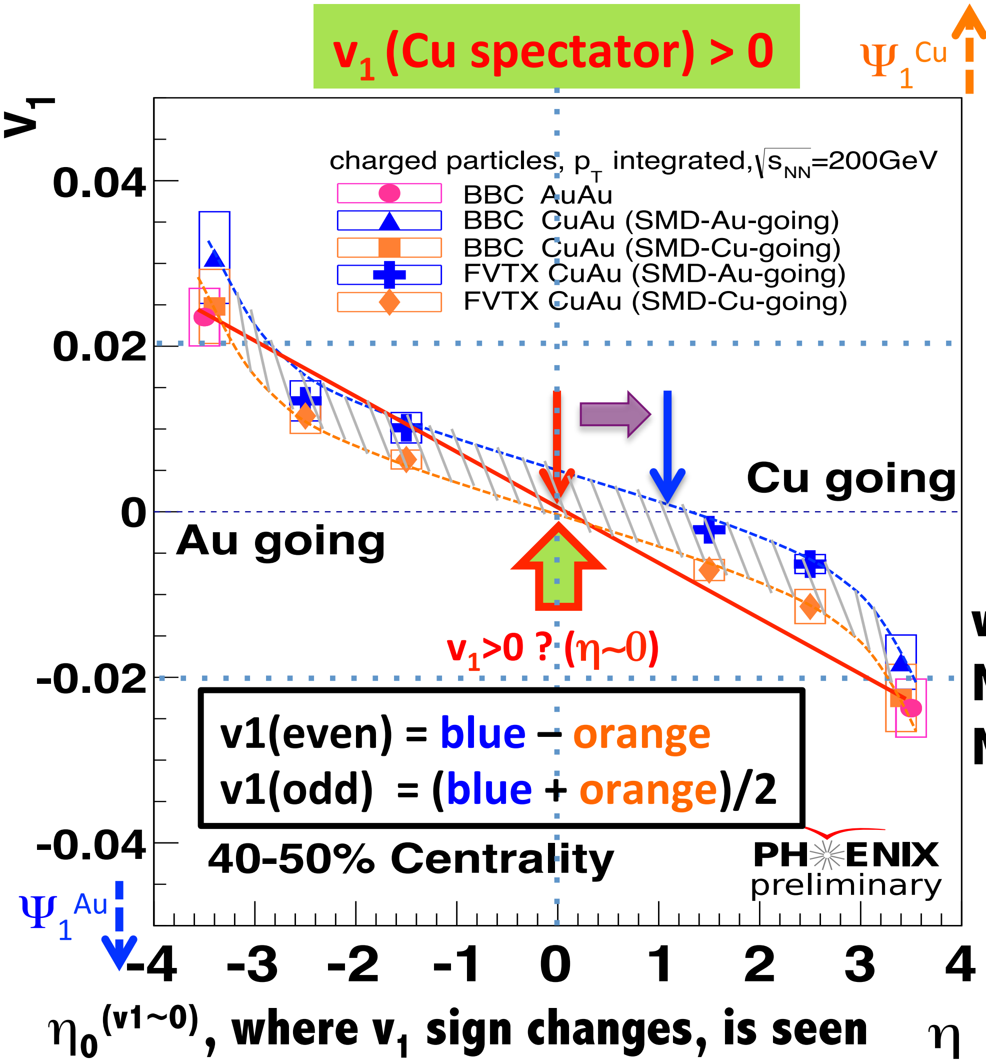
✓ **The shift of v_1 is seen between two spectator planes. (v_1^{even})**

- $v_1\{\Psi_{S.P.(SMD\ Au\text{-}going\ \eta<0)}\} > v_1\{\Psi_{S.P.(SMD\ Cu\text{-}going\ \eta>0)}\}$
- **Same direction as seen in ALICE**

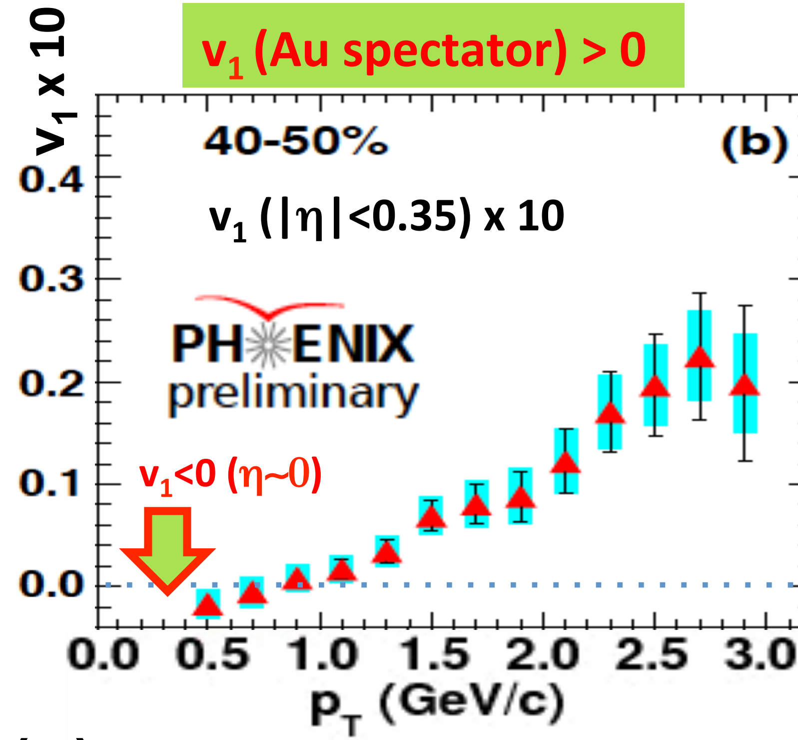
✓ **Both components show some centrality dependences**

- **Odd : Clear shift of $\eta_0^{(v1\sim0)}$ towards Cu-going direction (asymmetry in v_1^{odd})**
- **Even : No clear asymmetry (some possible difference between for./back.)**

v1 in CuAu



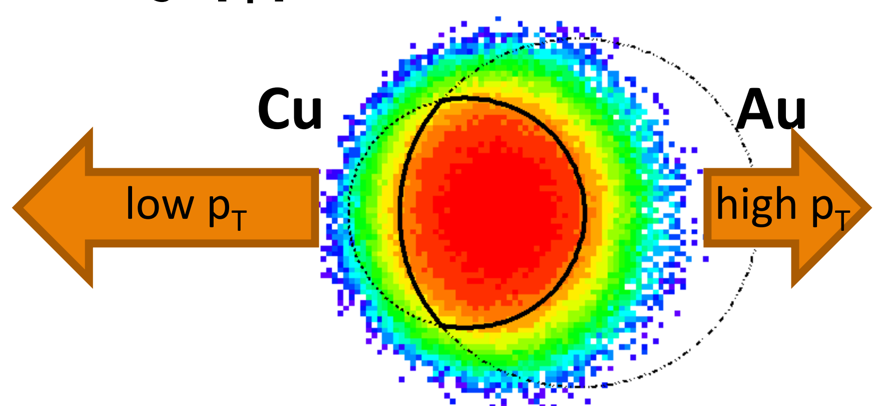
$\eta_0^{(v1\sim0)}$, where v_1 sign changes, is seen to be shifted towards Cu-going direction



$v_1(p_T)$:

More low p_T particles are emitted to Cu side

More high p_T particles are emitted to Au side



v_1 (p_T) in CuAu

v1 (Au spectator) > 0