Flow in Cu+Au collisions and unique tests of 3D medium evolution

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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**

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

n=1 Directed

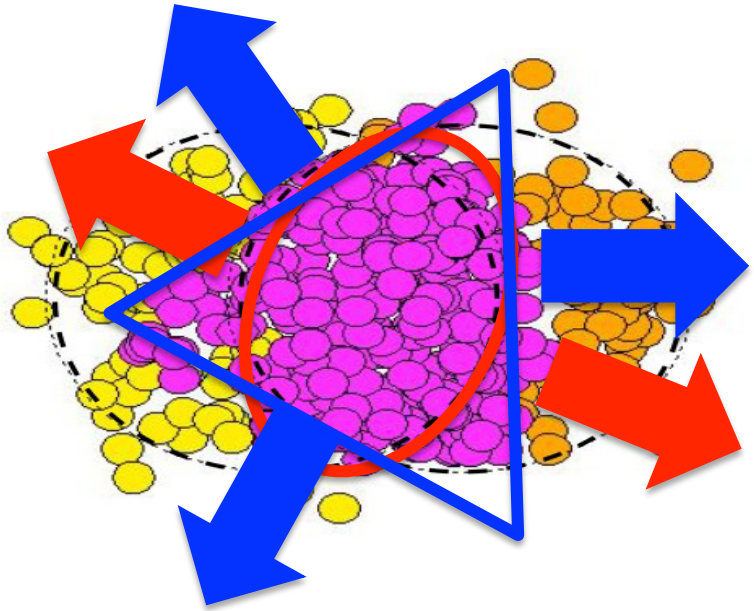
n=2 Elliptic

n=3 Triangular

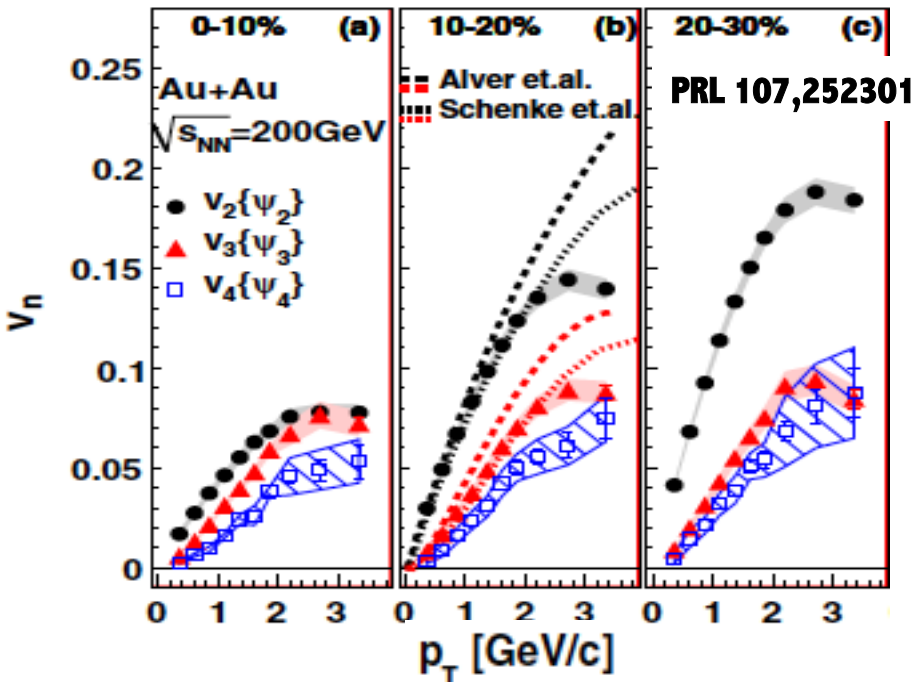
➔Initial state geometry

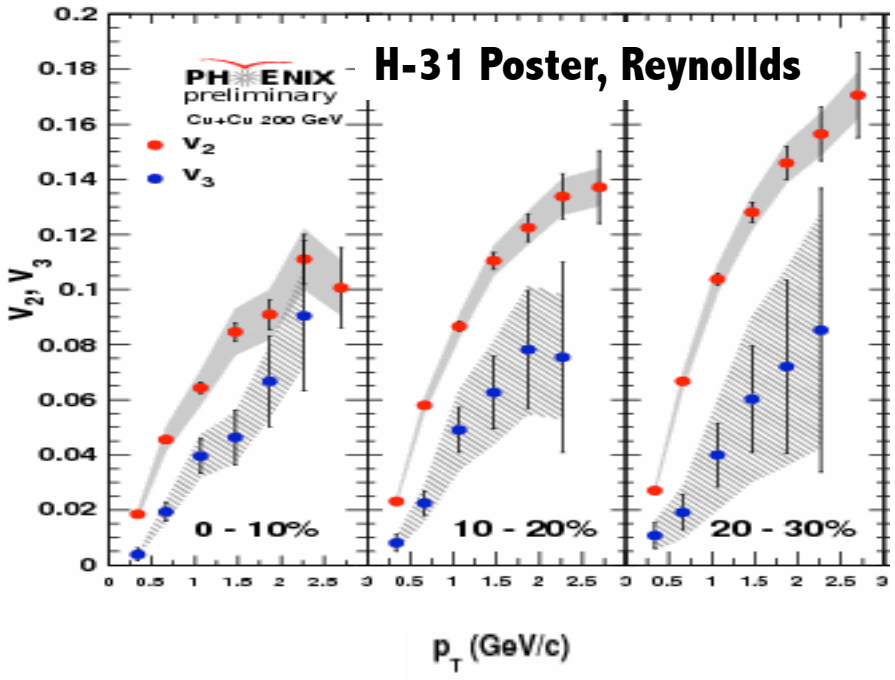
➔η/s

➔Equation of state



Flow in symmetric collision systems



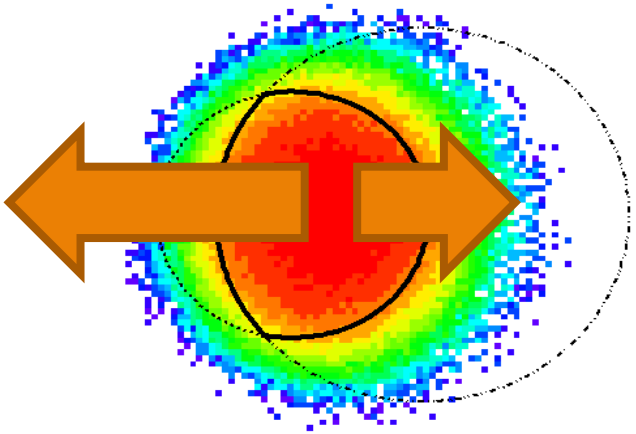


- ✓ v_n is studied in AuAu, CuCu collisions
  - Clear centrality dependence of v_2 in AuAu, CuCu
  - Weak / No significant centrality dependence of v_3 in AuAu, CuCu

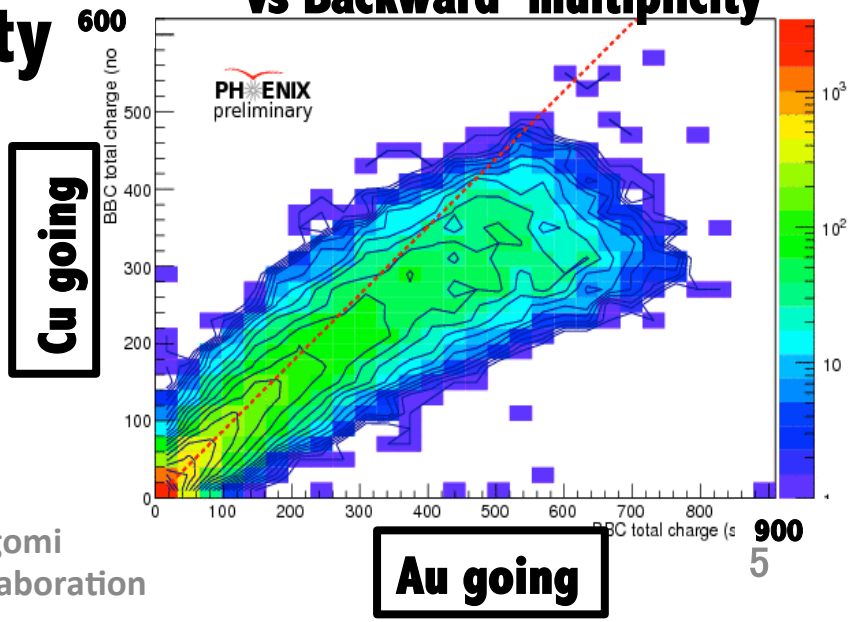
Introduction of CuAu collisions

- ✓CuAu asymmetric collision provide us unique information
  - -Left/Right difference in pressure gradient
    - ➔ v_1 is effective
  - - Initial spatial triangularity
    - ➔Lead to large v_3 ?
  - - Asymmetric rapidity distribution

Glauber Monte Calro



Forward multiplicity vs Backward multiplicity

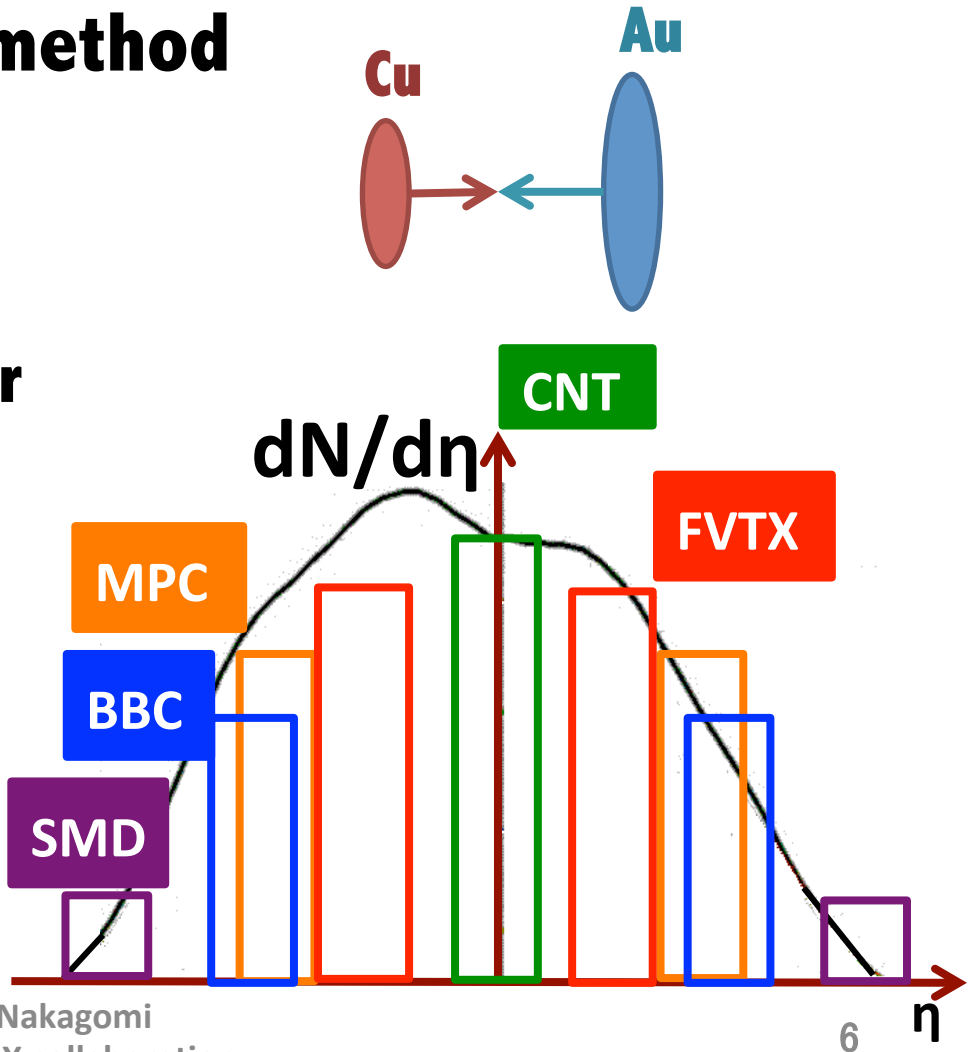


Flow Measurement via EP method

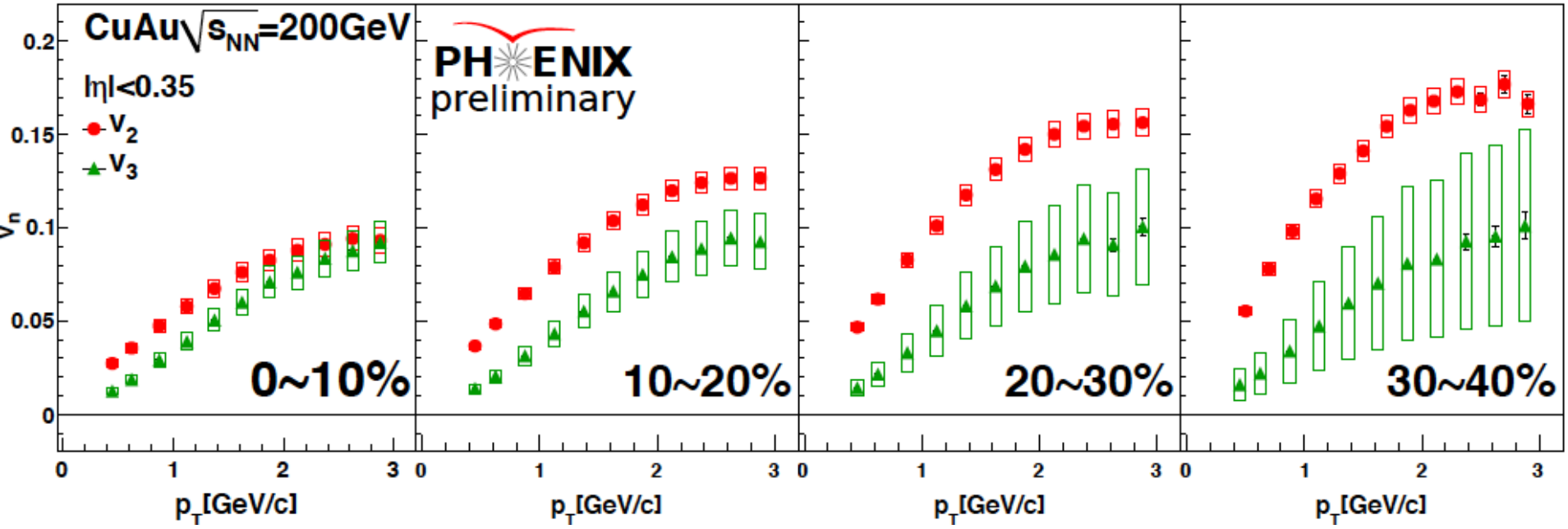
- ✓ vn is measured via EP method

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

- ✓ EP is measured by Forward/Backward detector
  - BBC (3.1<|η|<3.9)
  - MPC (3.1<|η|<3.8)
  - SMD (|η|>5)
- ✓ Charged Hadron track
  - CNT(|η|<0.35)
  - FVTX (1.5<|η|<3)



Centrality dependence of v_2, v_3 in 200 GeV CuAu

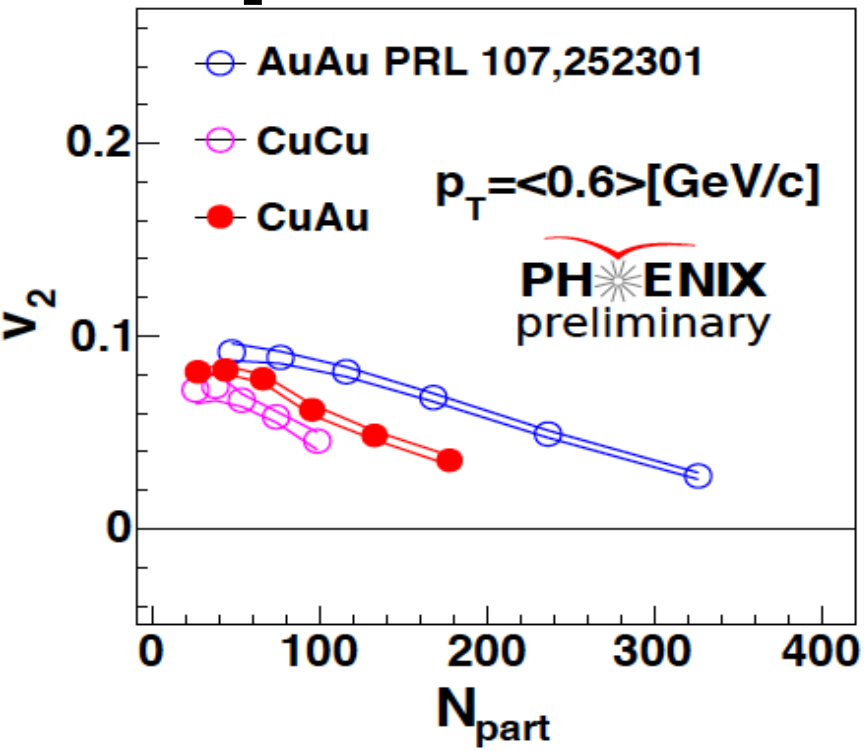


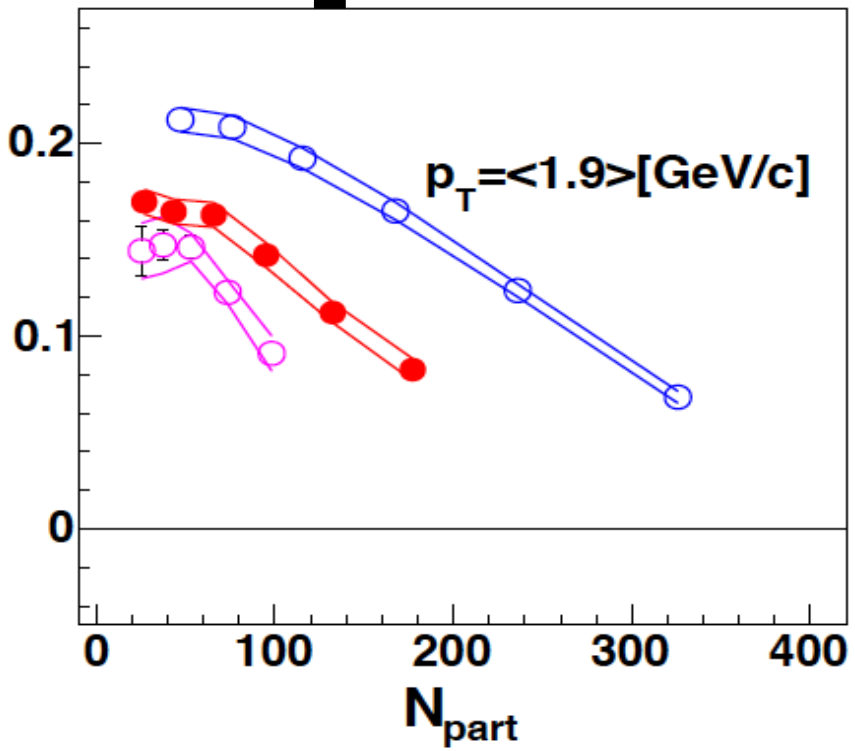
✓ CuAu v_2, v_3 (pt) are measured

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

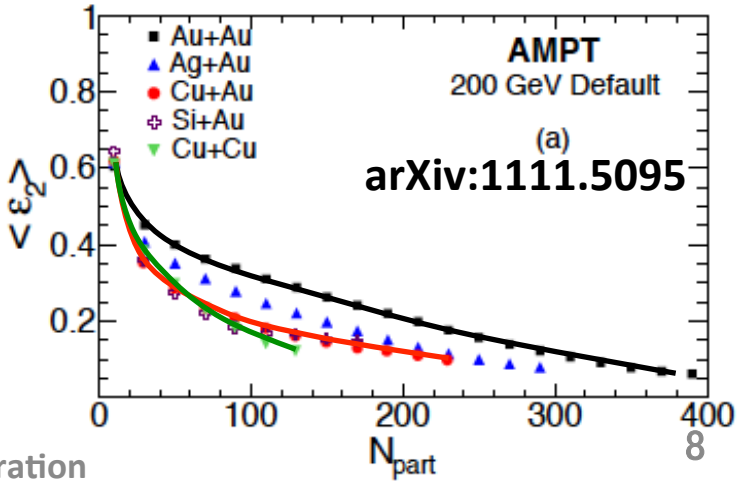
➔ Same centrality dependence as seen in symmetric collisions

Comparison to AuAu, CuCu v_2

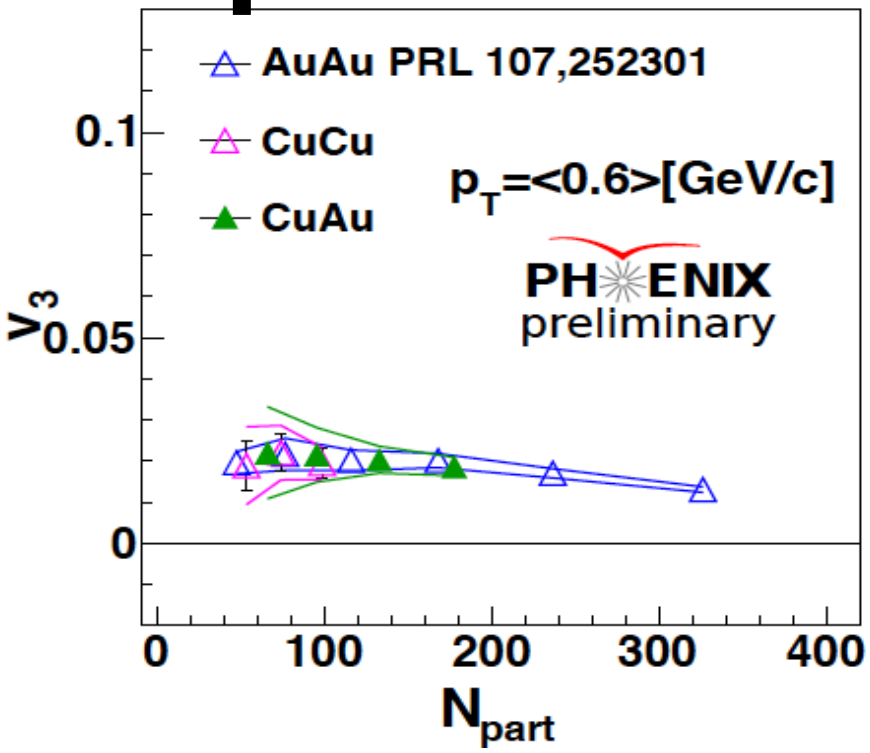


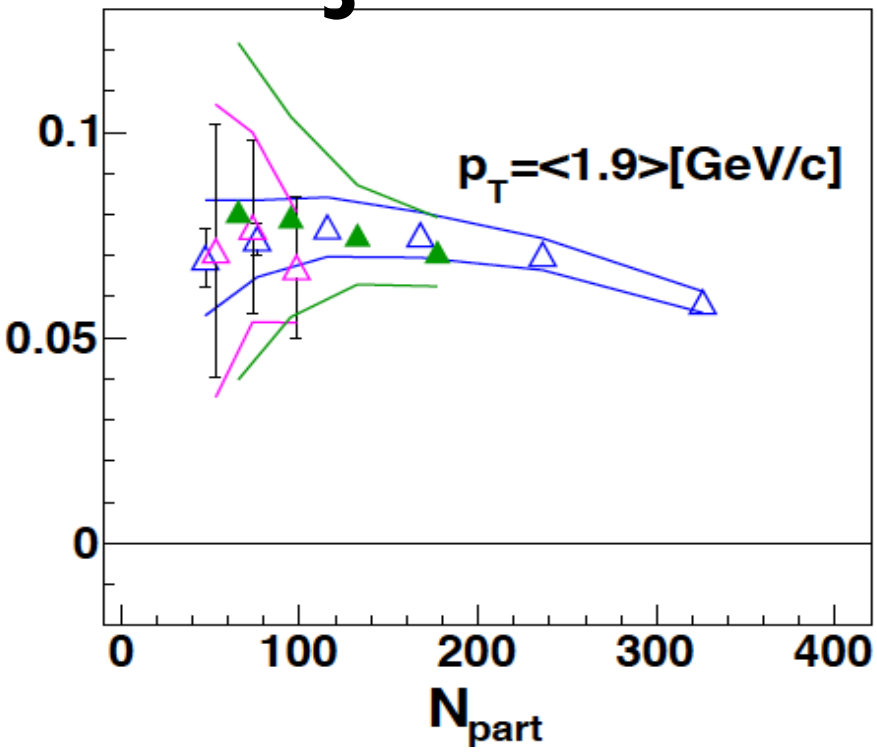


- ✓ System size dependence
  - AuAu > CuAu > CuCu
  - Originated from initial ε_2
- ✓ Expansion with enough N_{part}

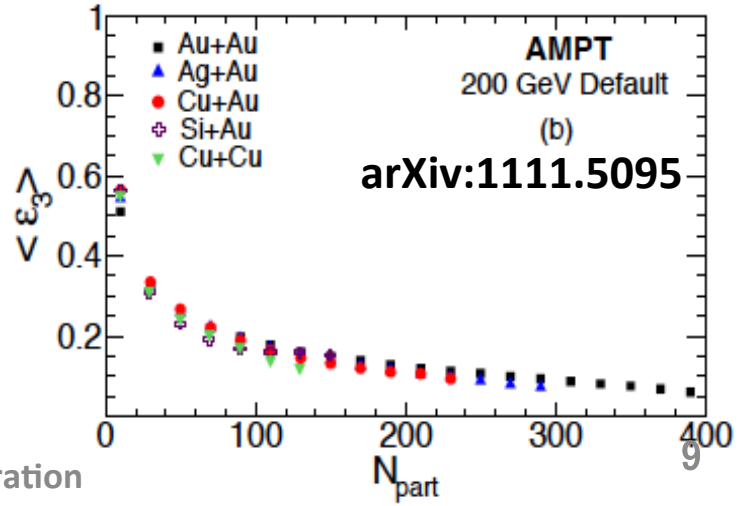


Comparison to AuAu, CuCu v_3

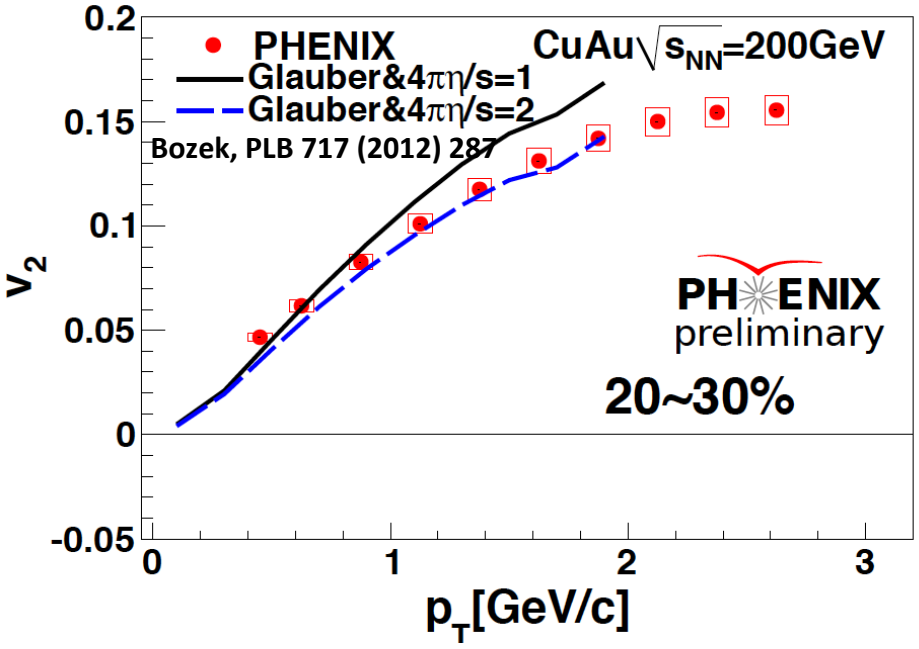


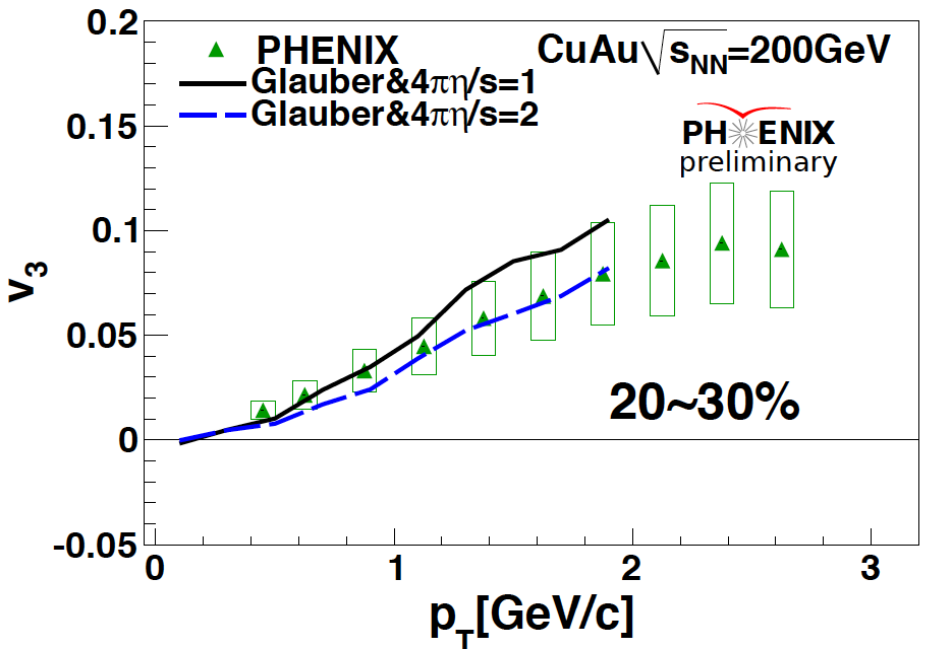


- ✓ **Small system size dependence**
  - **It is expected from similar ε_3**
  - **v_3 is given by multiplicity and ε_3**



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 $4\pi\eta/s=2$?**

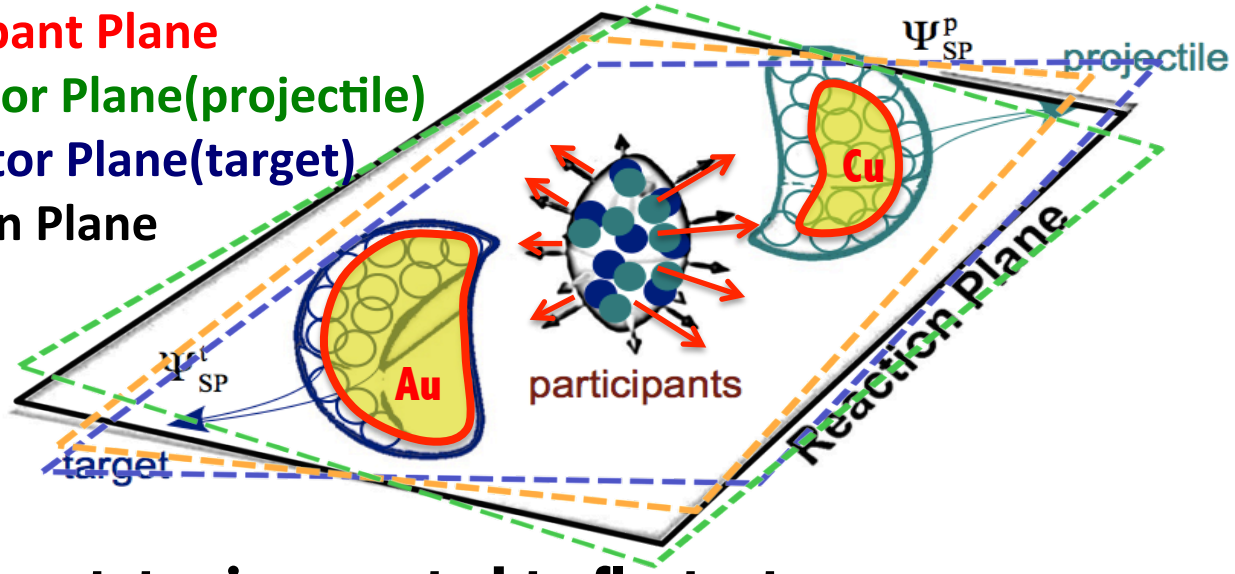
v_1 Fluctuation in CuAu

$\Psi^{(n)}_{PP}$: 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)

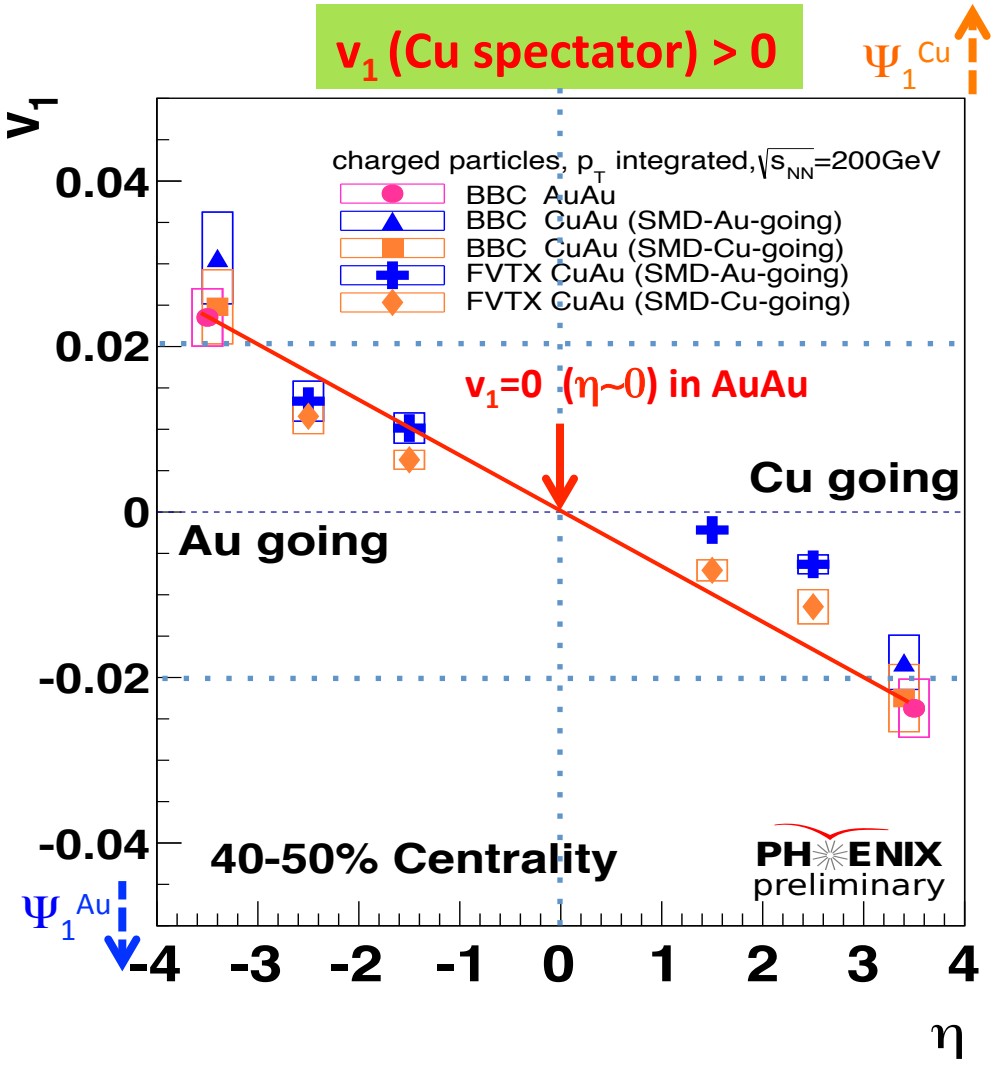
v_1(Traditional) : $v_1(\eta) = -v_1(-\eta)$

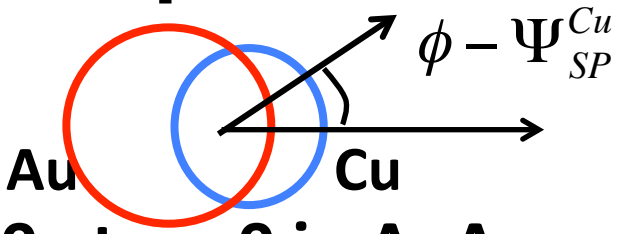
v_1(SP Fluctuation) : $v_1(\eta) = v_1(-\eta)$

✓ **Are there two v_1 components in CuAu ?**

✓ **How asymmetric two v_1 components are in CuAu ?**

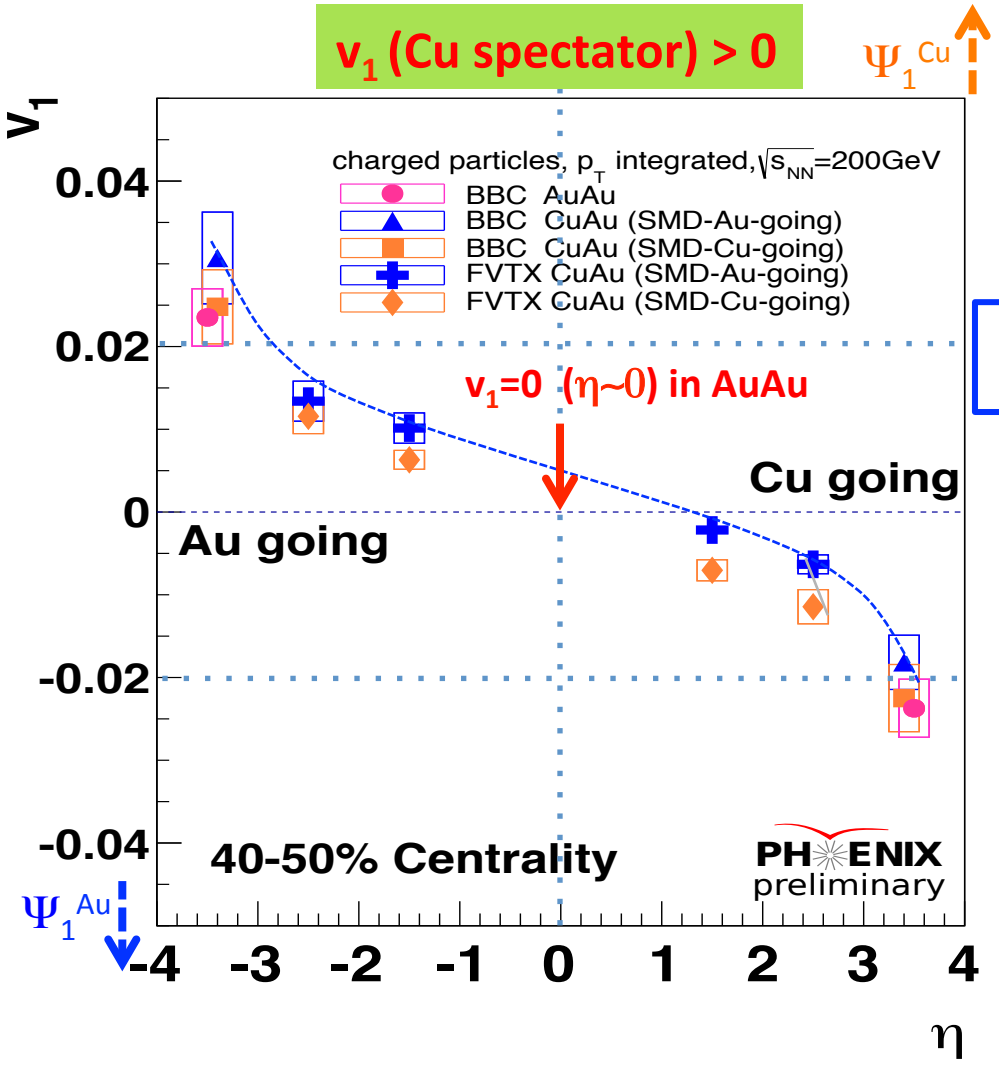
η Symmetric/Anti-symmetric v_1 in CuAu

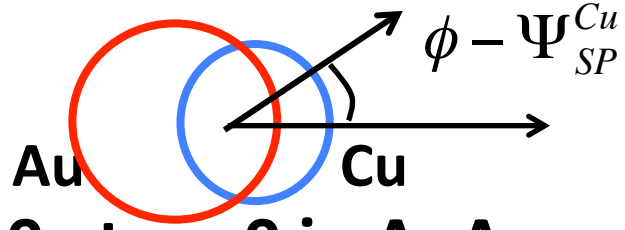




✓ v_1= 0 at η=0 in AuAu

η Symmetric/Anti-symmetric v_1 in CuAu

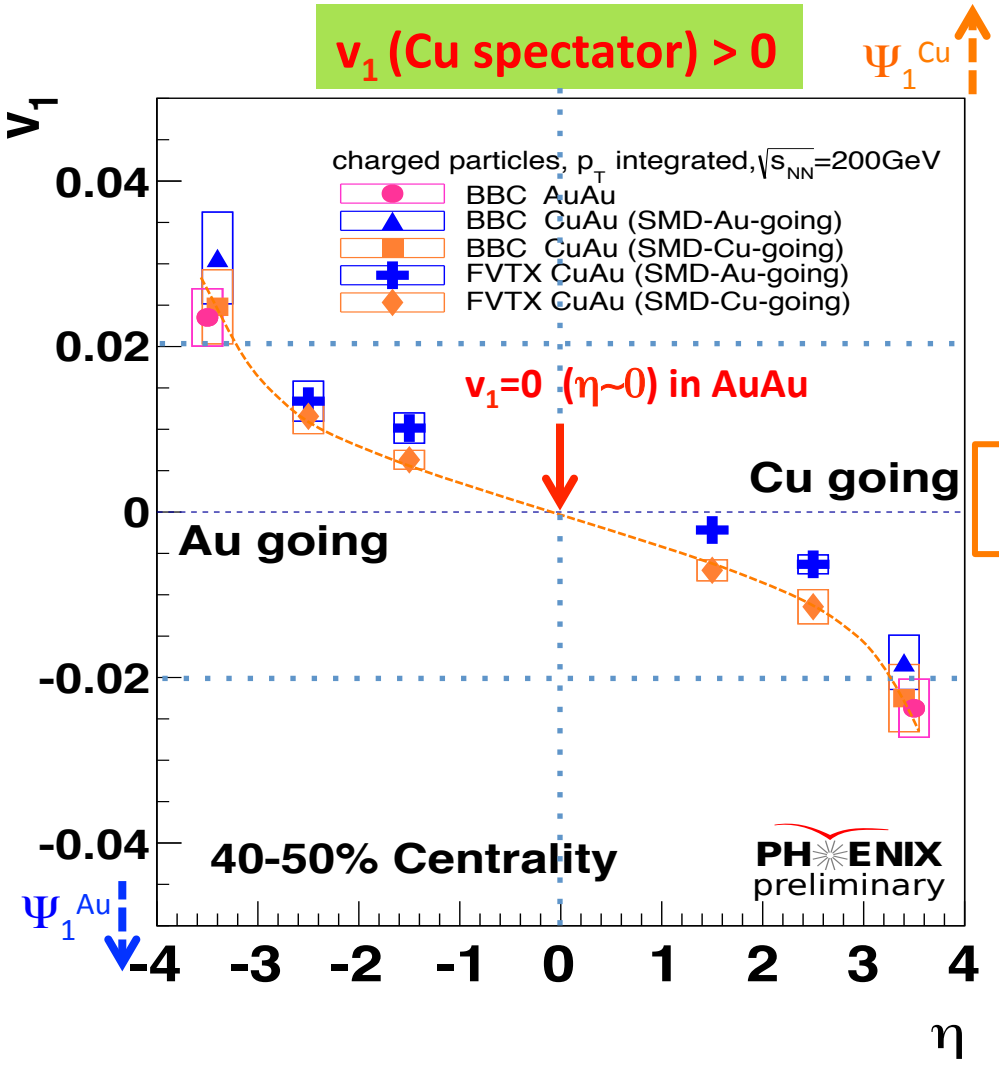


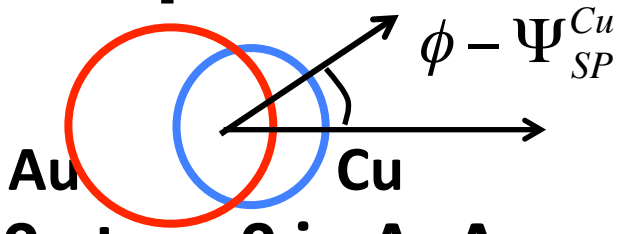


✓ v_1= 0 at η=0 in AuAu

✓ v_1 w.r.t Ψ_{SP}^{Au}

η Symmetric/Anti-symmetric v_1 in CuAu



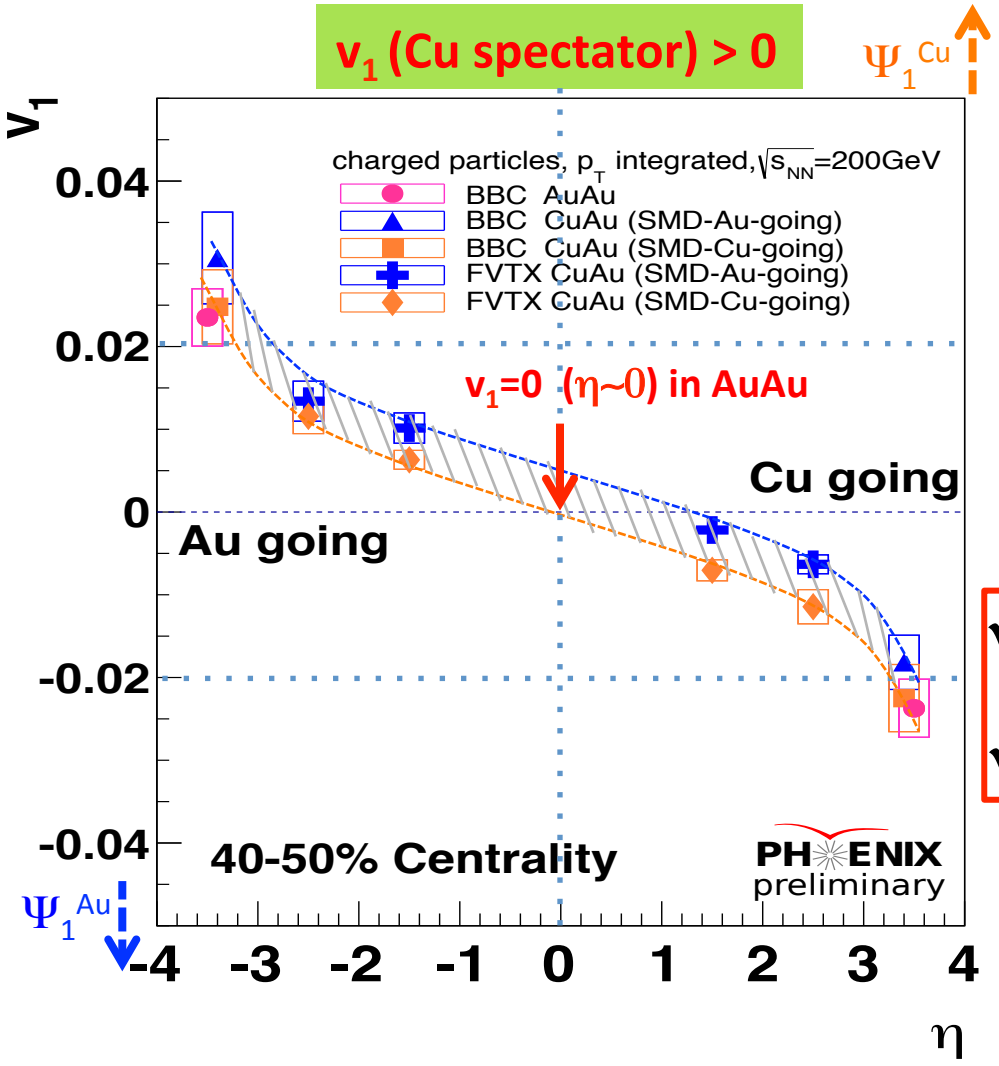


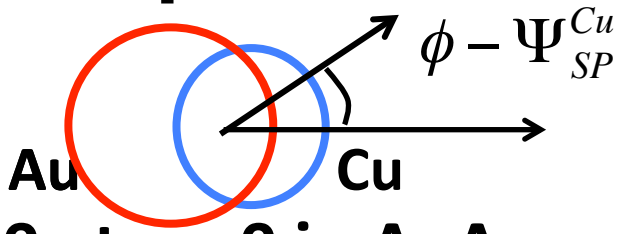
✓ v_1= 0 at η=0 in AuAu

✓ v_1 w.r.t Ψ_{SP}^{Au}

✓ v_1 w.r.t Ψ_{SP}^{Cu}

η Symmetric/Anti-symmetric v_1 in CuAu

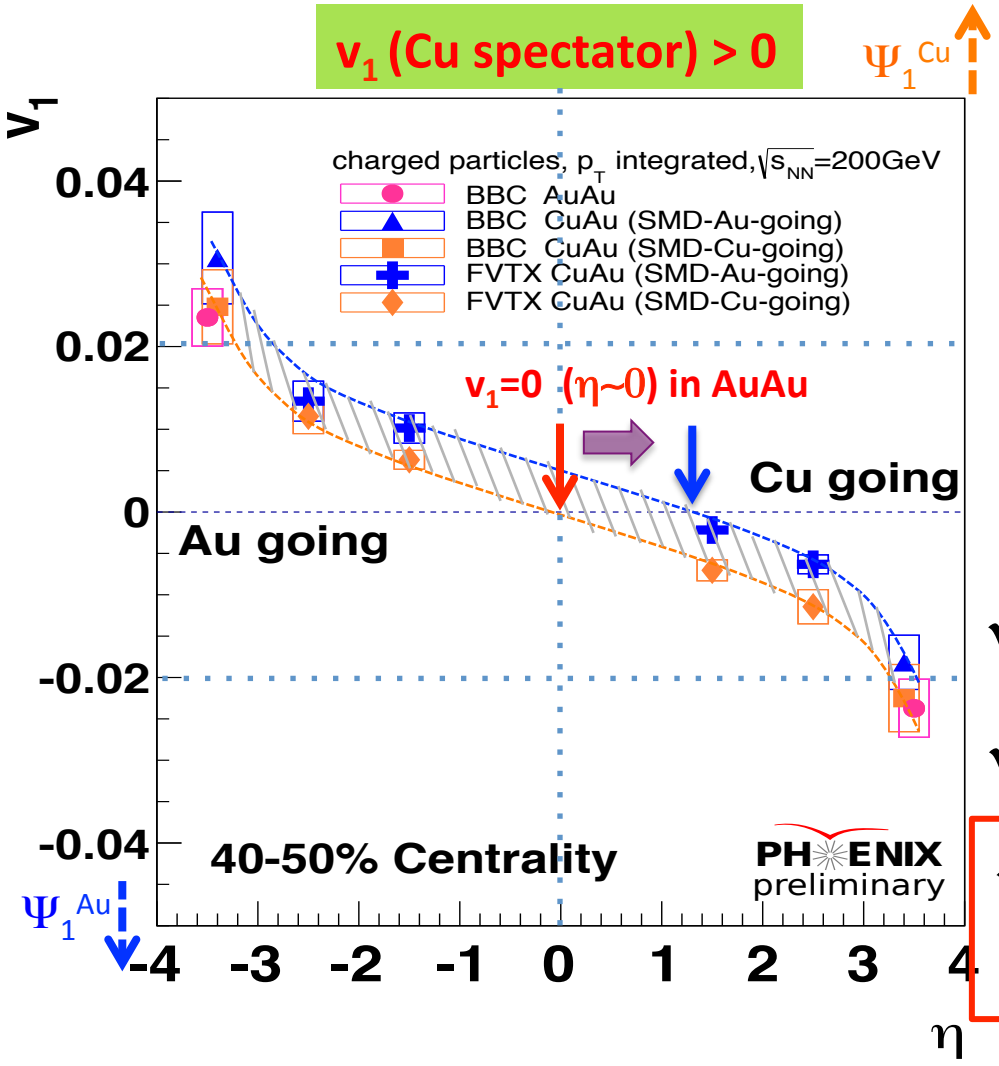


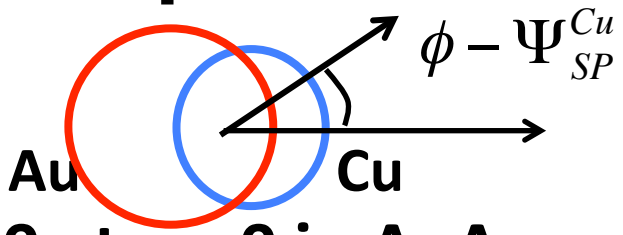


- ✓ v_1= 0 at η=0 in AuAu
- ✓ v_1 w.r.t Ψ_{SP}^{Au}
- ✓ v_1 w.r.t Ψ_{SP}^{Cu}

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

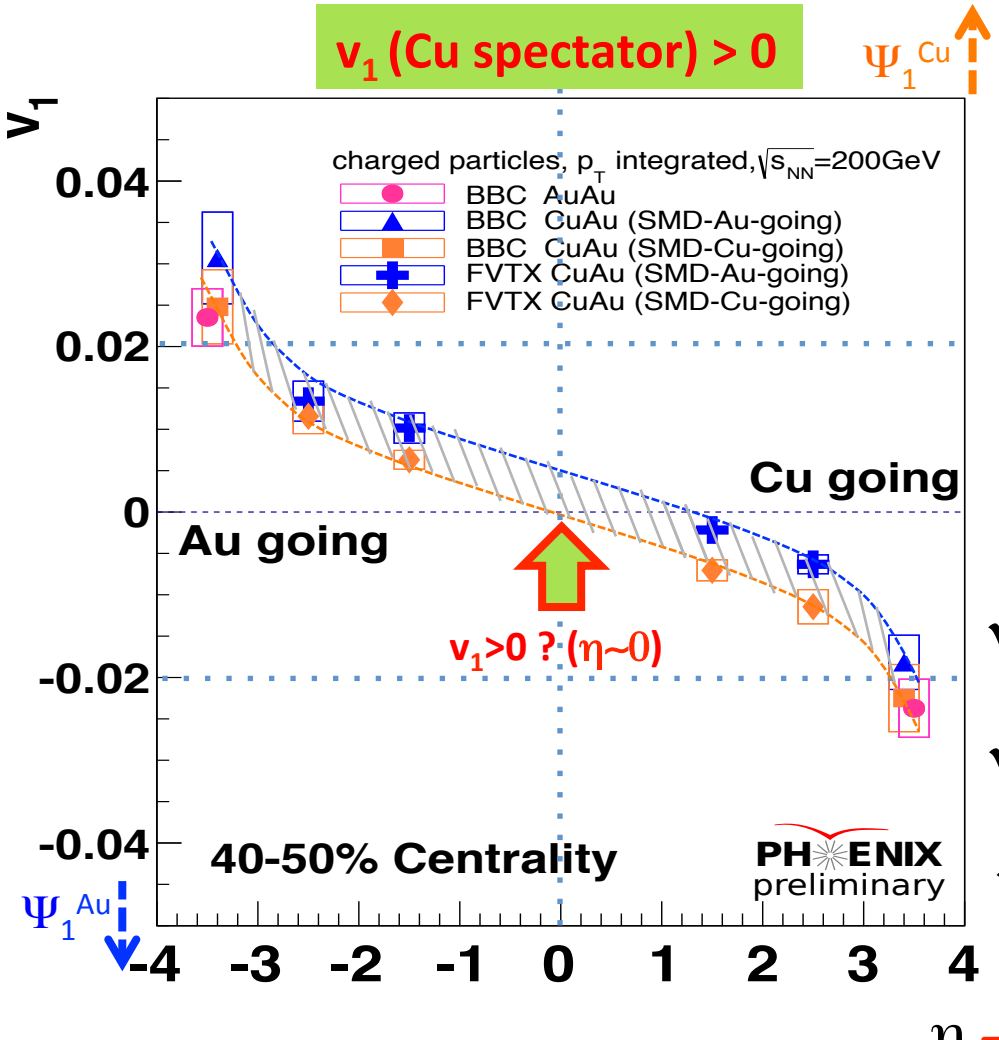
η Symmetric/Anti-symmetric v_1 in CuAu

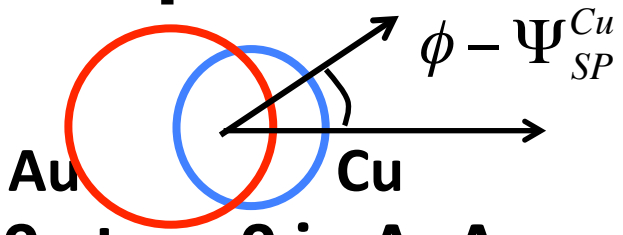




- ✓ v_1= 0 at η=0 in AuAu
- ✓ v_1 w.r.t Ψ_{SP}^{Au}
- ✓ v_1 w.r.t Ψ_{SP}^{Cu}
- ✓ v_1(flu) = (blue–orange)/2
- ✓ v_1(tra) = (blue+orange)/2
- ✓ v_1(tra) is shifted to Cu going side

η Symmetric/Anti-symmetric v_1 in CuAu



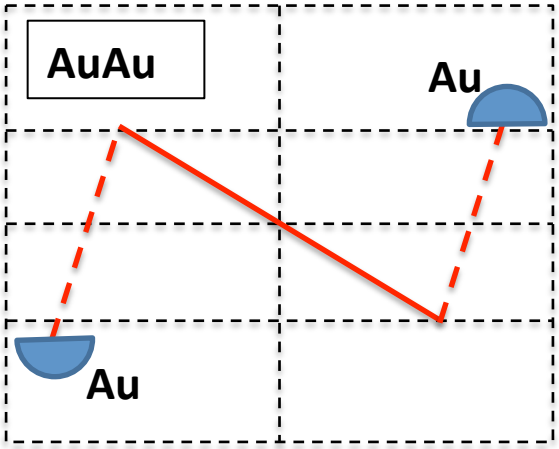


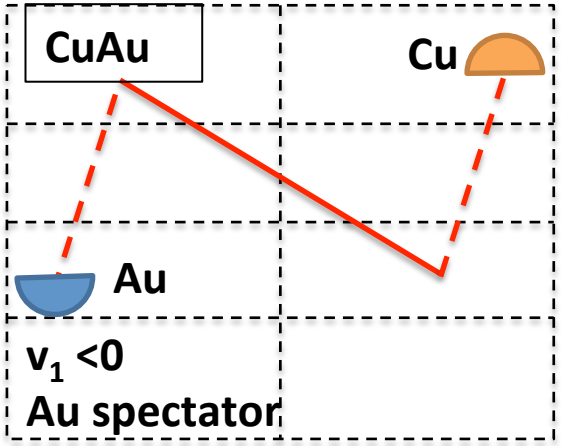
- ✓ v_1= 0 at η=0 in AuAu
- ✓ v_1 w.r.t Ψ_{SP}^{Au}
- ✓ v_1 w.r.t Ψ_{SP}^{Cu}
- ✓ v_1(flu) = (blue–orange)/2
- ✓ v_1(tra) = (blue+orange)/2
- ✓ v_1(tra) is shifted towards Cu going side

✓ v_1(tra) >0? at η=0

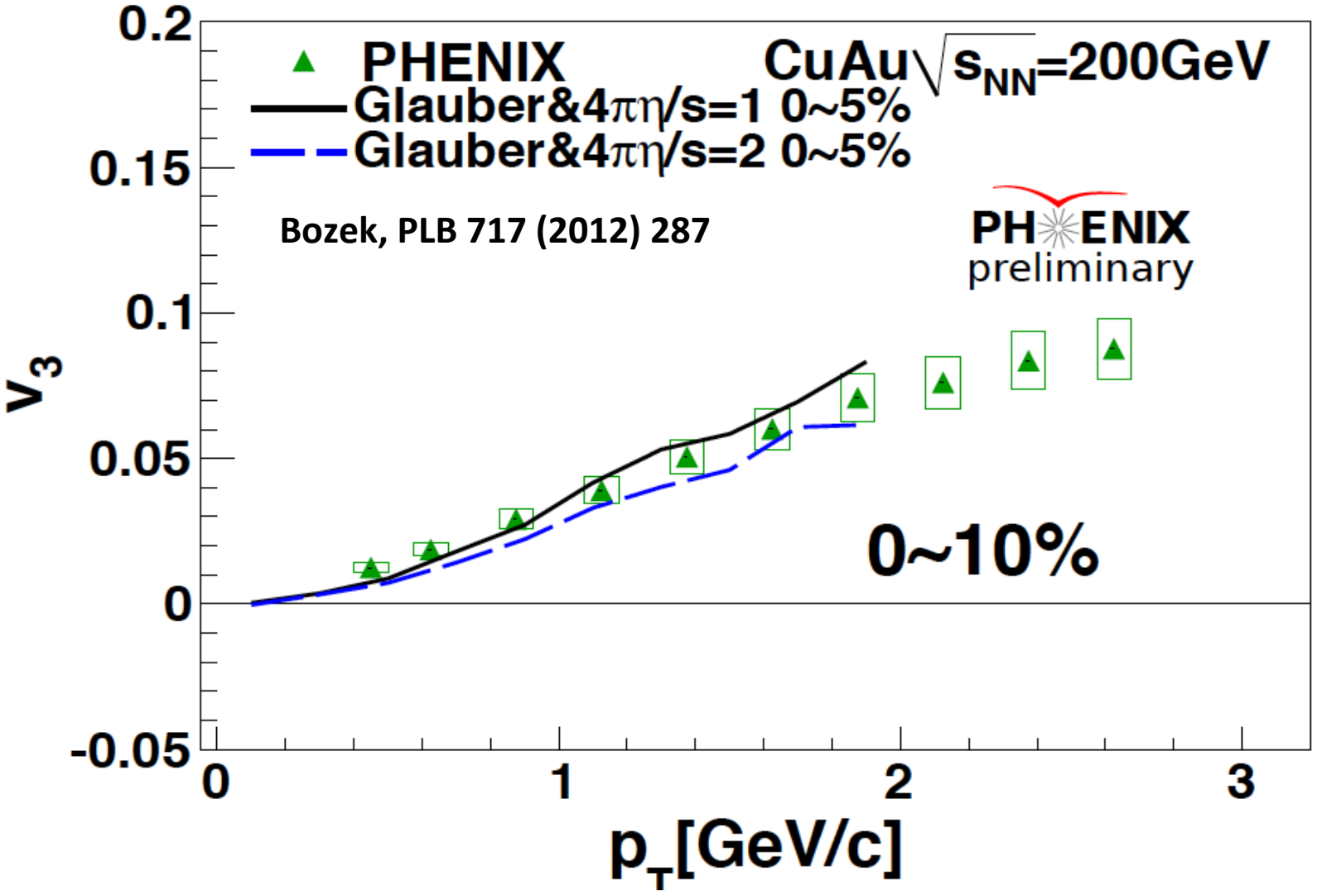
Summary

- ✓ 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 η_0 ($v_1 \sim 0$) is shifted towards Cu-going direction or $v_1 > 0$ at $\eta \sim 0$
  - negative v1 (SP Fluctuation) : $v1(\Psi_1^{Cu}) < v1(\Psi_1^{Au})$

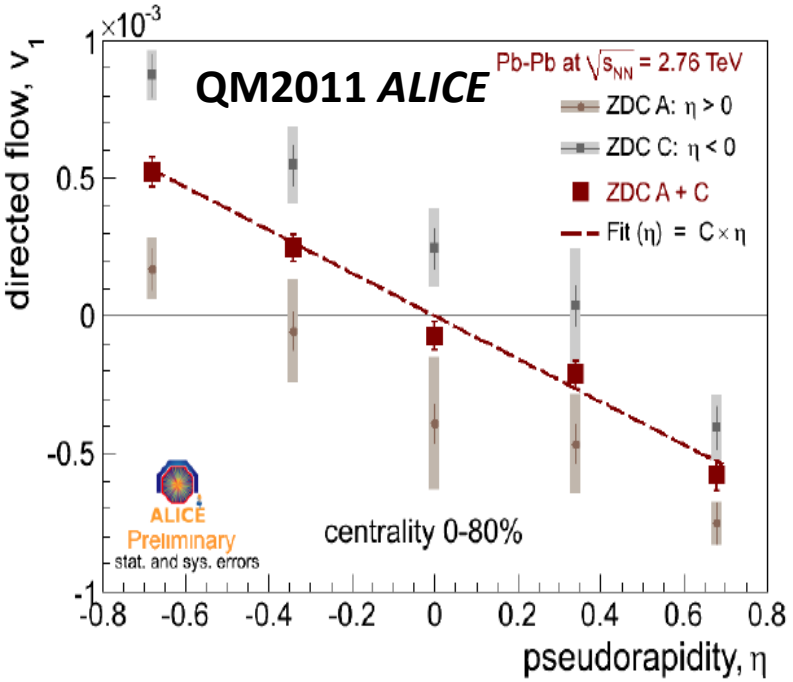




Comparison to Theory

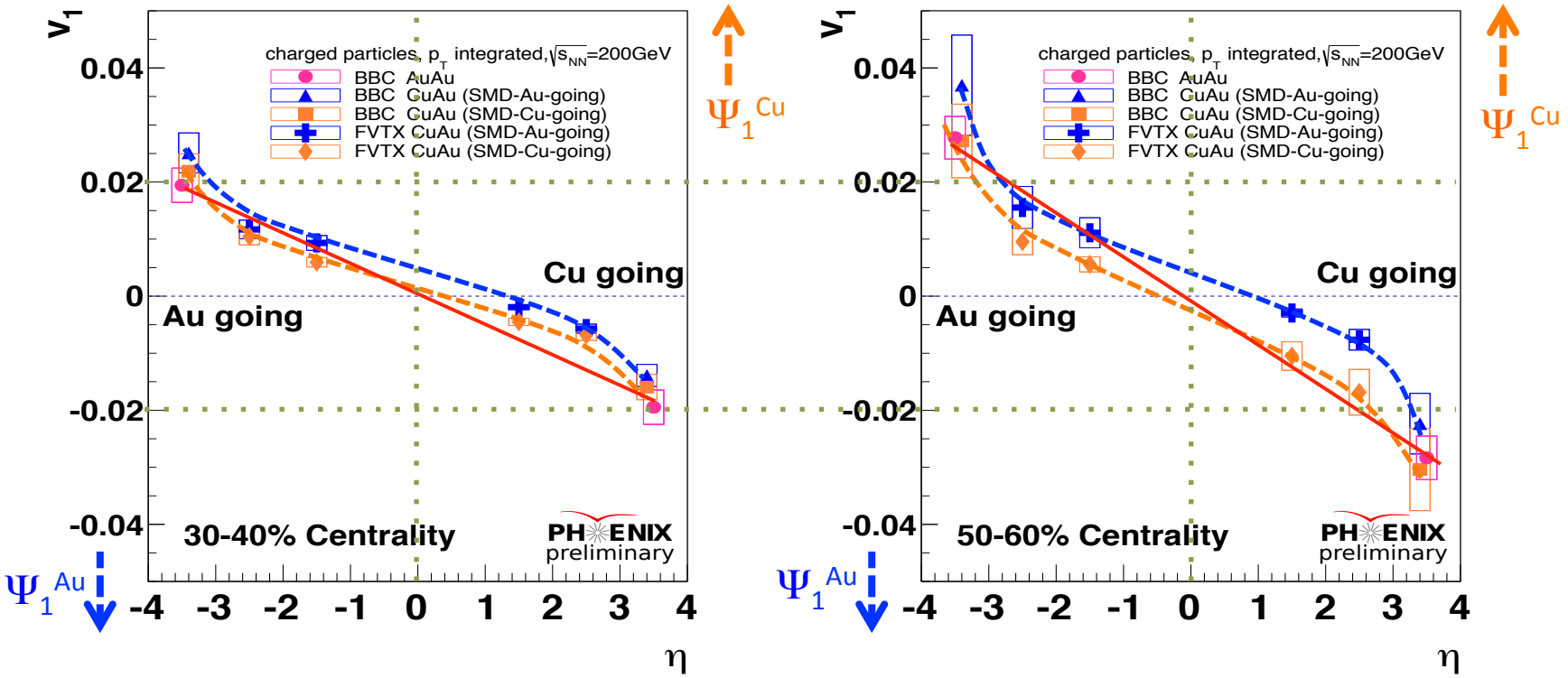


v_1 Even, Odd Components in PbPb



- ✓ 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 η<0) > v1(EP η>0)

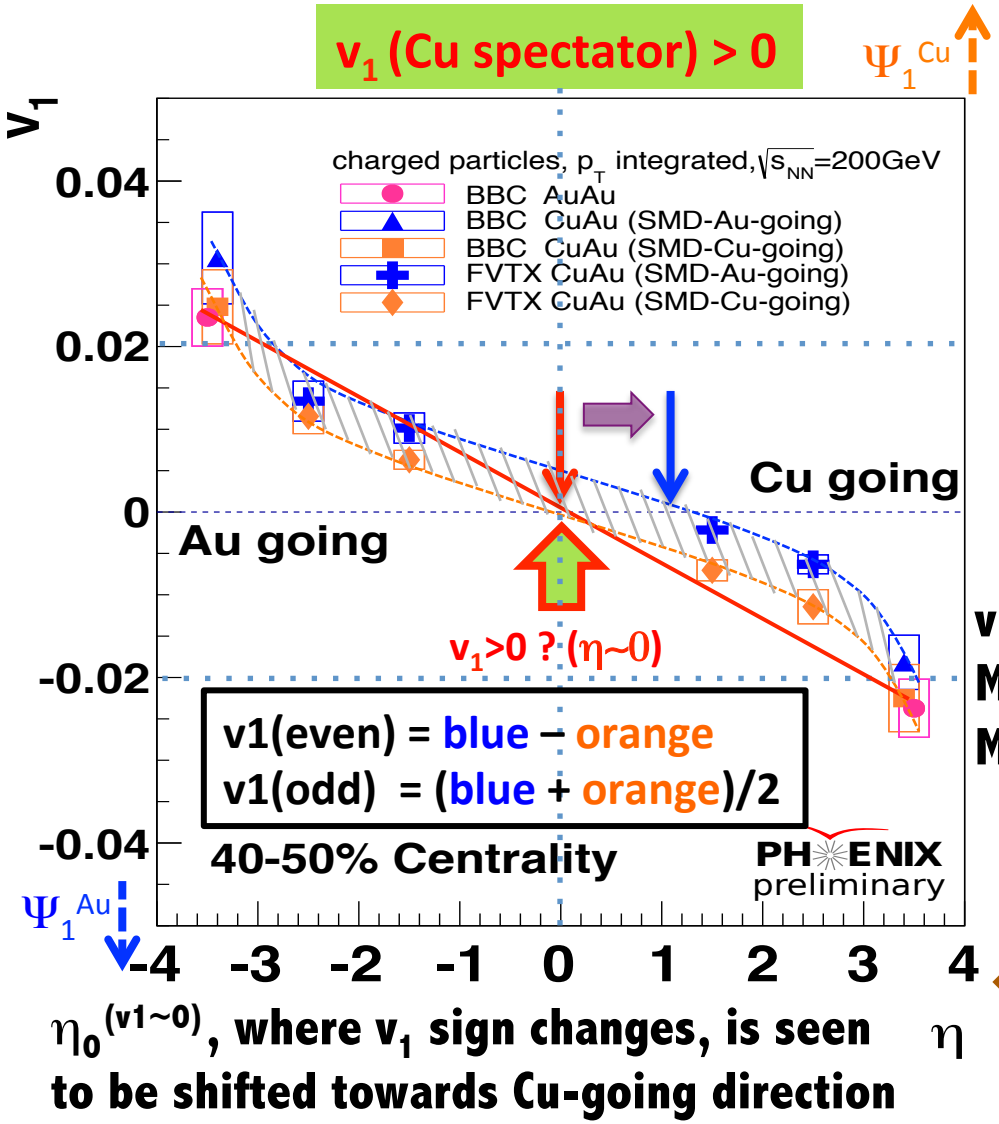
Centrality dependence of v1



- ✓ 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.)

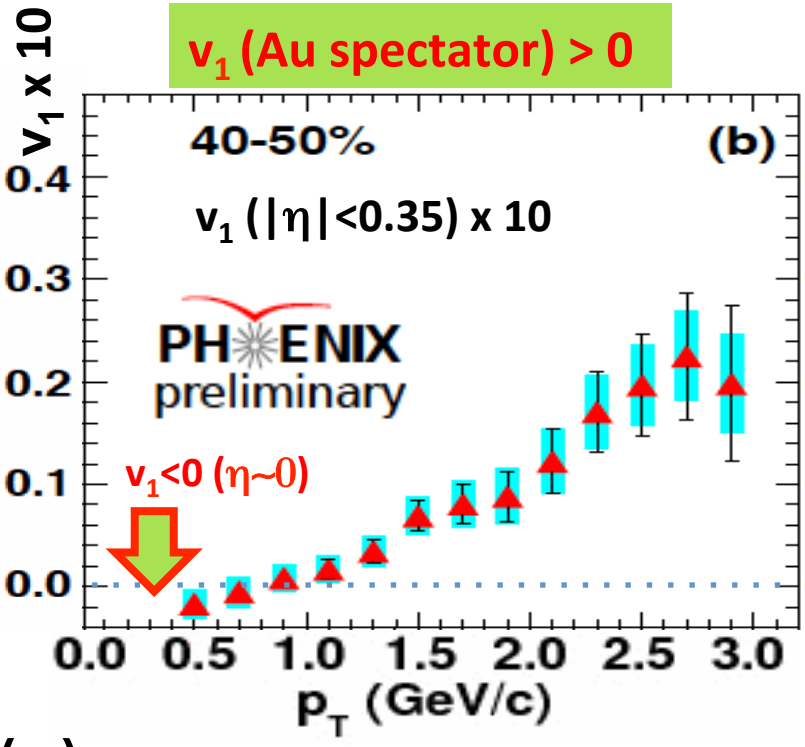
v1 in CuAu

v_1 (Cu spectator) > 0



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

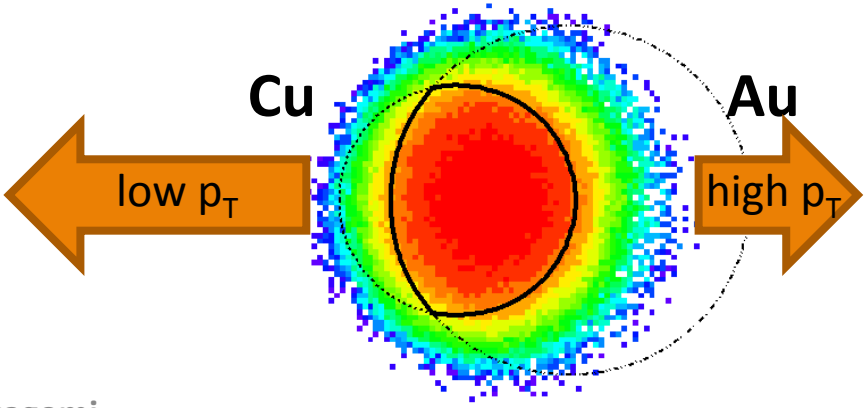
v_1 (Au spectator) > 0



$v_1(p_T)$:

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

v_1 (Au spectator) > 0