(Filling in For Takahito Todoroki, his suggestions + A. Taranenko's slides)

The PHENIX Flow Data: Current Status

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NSF

PHENIX

RHIC

PHENIX v_n Measurements at RHIC

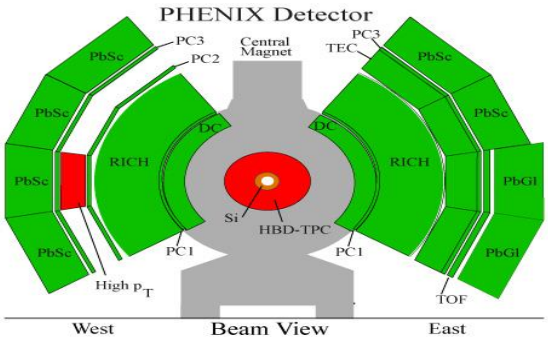
1) Introduction / Methods

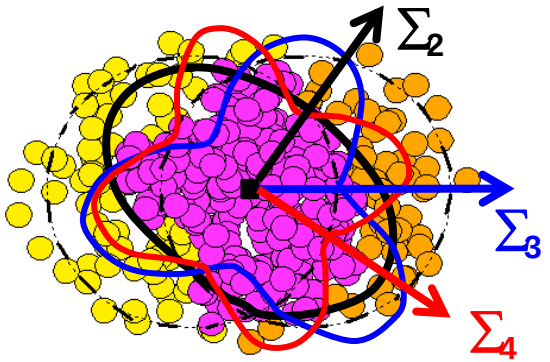
2) **NOT :** Azimuthal anisotropy in small systems: **NOT** d+Au and ^{3}He+Au at 200GeV : **Paul Stankus Talk Later This Morning**

3) System size dependence of anisotropy?

4) Energy Scan Results

5) PID V_n results confronting theory





Motivation: "Solving" Hydro

- To get from here to here
- we need:

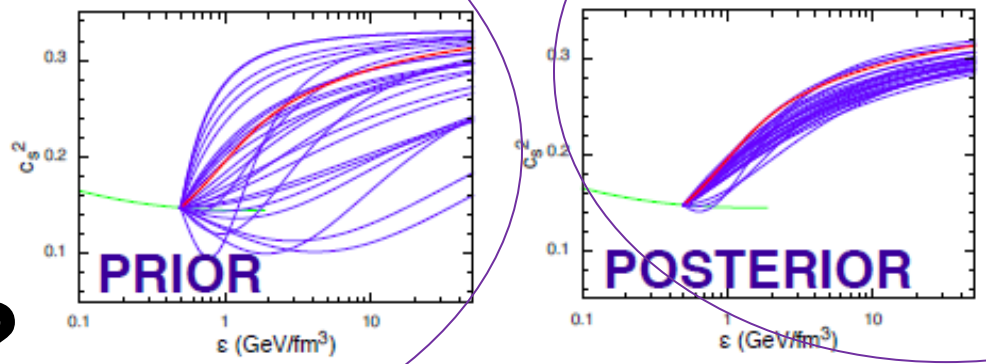
Lots O' Data

$\frac{\eta}{s}$ =?

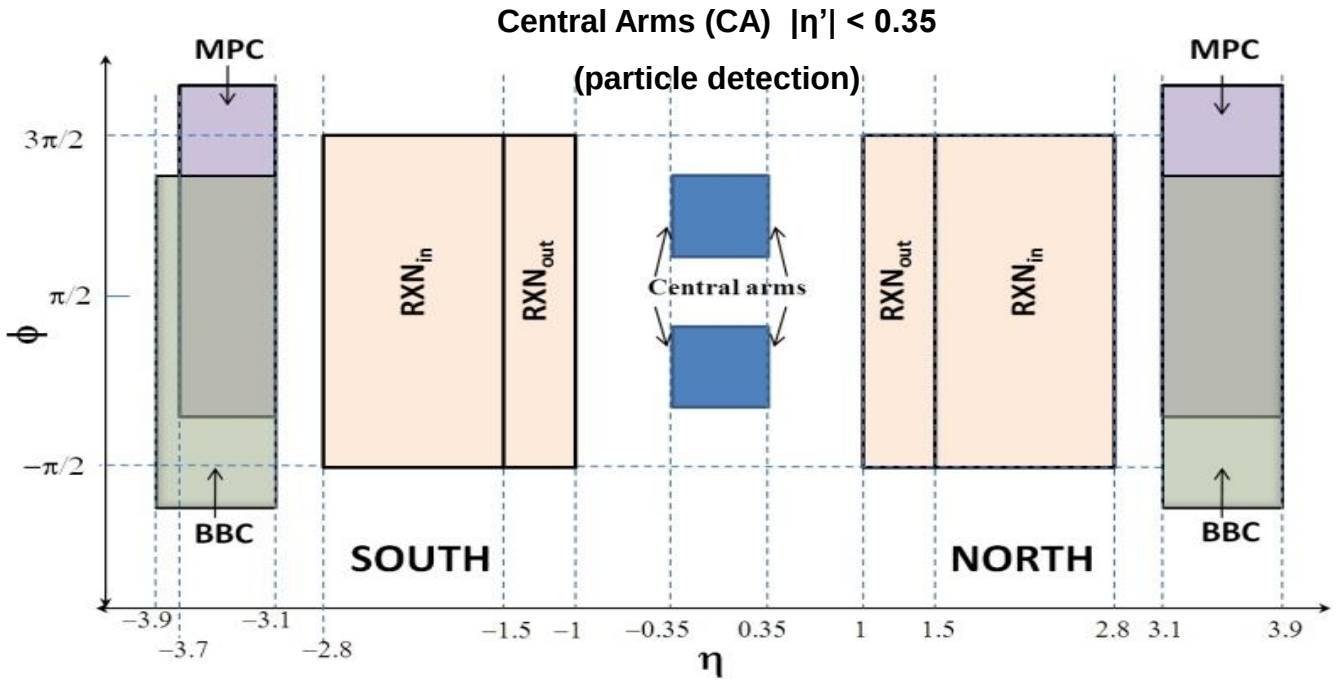
Shape = ?

τ_i=?

Eq. of State from Spectra/V2/HBT vs. Lattice (speed of sound)



PHENIX Methods: Event Plane v_ns



ψ_n RXN (|η|=1.0~2.8)

MPC (|η|=3.1~3.7)

BBC (|η|=3.1~3.9)

From 2012:

- FVTX (1.5<|η|<3)

Correlate hadrons in central Arms with EVENT PLANE (RXN, etc)

$$\frac{dN}{d\varphi} \propto \left(1+2\sum_{n=1}^{+\infty} v_n \cos\left[n(\varphi-\psi_n)\right]\right) \quad \textit{(I)}$$

$$v_n\{\psi_n\} = \left\langle \cos\left[n(\varphi-\psi_n)\right]\right\rangle, \quad n=1,2,3..,$$

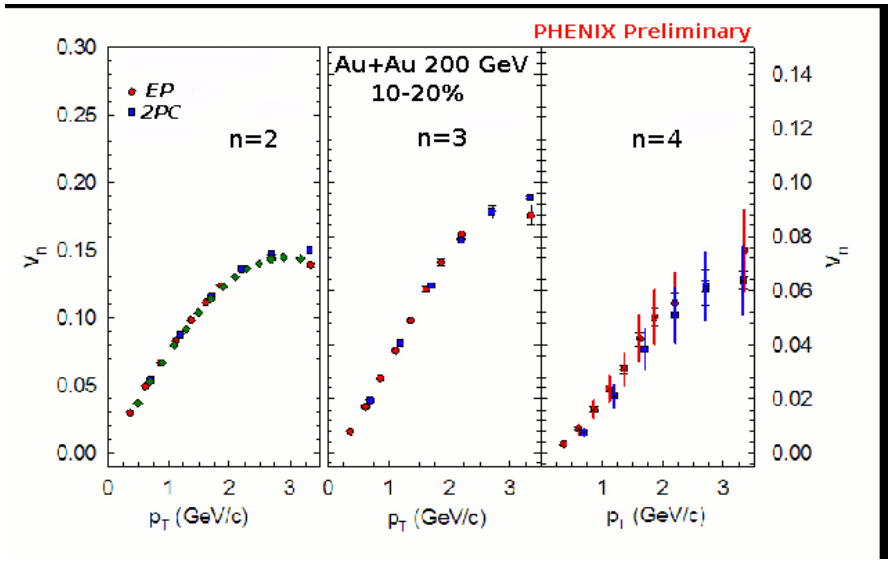
➢ *Δφ correlation function for EP_N - EP_S*

$$\frac{dN^{\text{pairs}}}{d(\Delta\varphi)} \propto \left(1+\sum_{n=1} 2v_n^a v_n^b \cos(n\Delta\varphi)\right) \quad \textit{(II)}$$

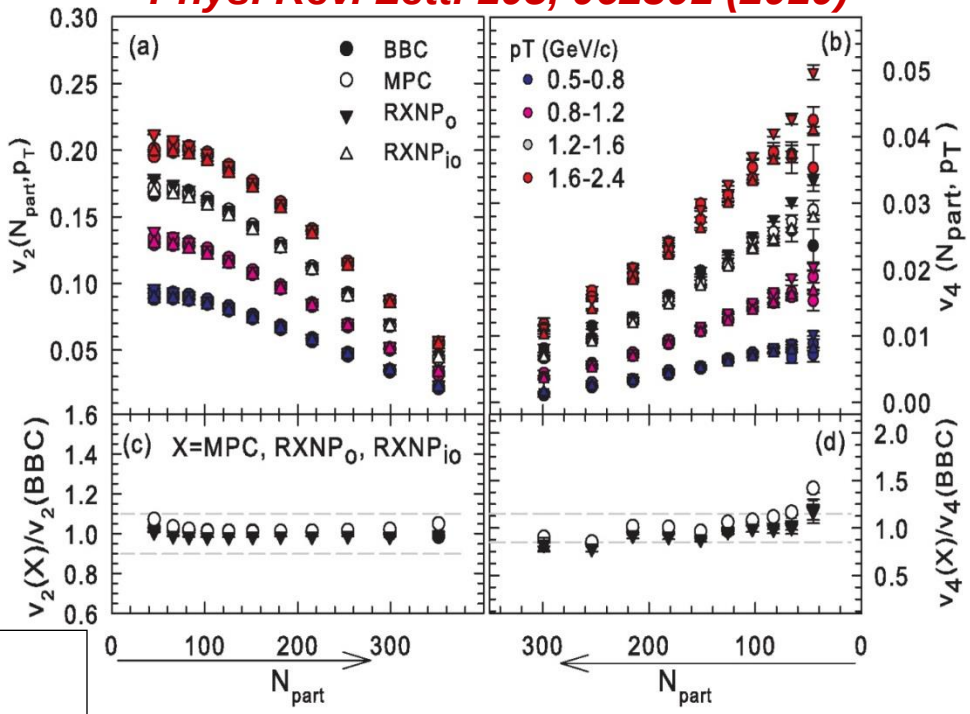
➢ *Δφ correlation function for EP - CA*

PHENIX Methods: History/Non-Flow

V_n (EP): ***Phys.Rev.Lett. 107 (2011) 252301***



Phys. Rev. Lett. 105, 062301 (2010)



- Good agreement between V_n results obtained by event plane (EP) and two-particle correlation method (2PC)
- No evidence for significant η-dependent non-flow contributions from di-jets for pT=0.3-3.5 GeV/c.
- Systematic uncertainty : event plane: 2-5% for v2 and 5-12% for v3.

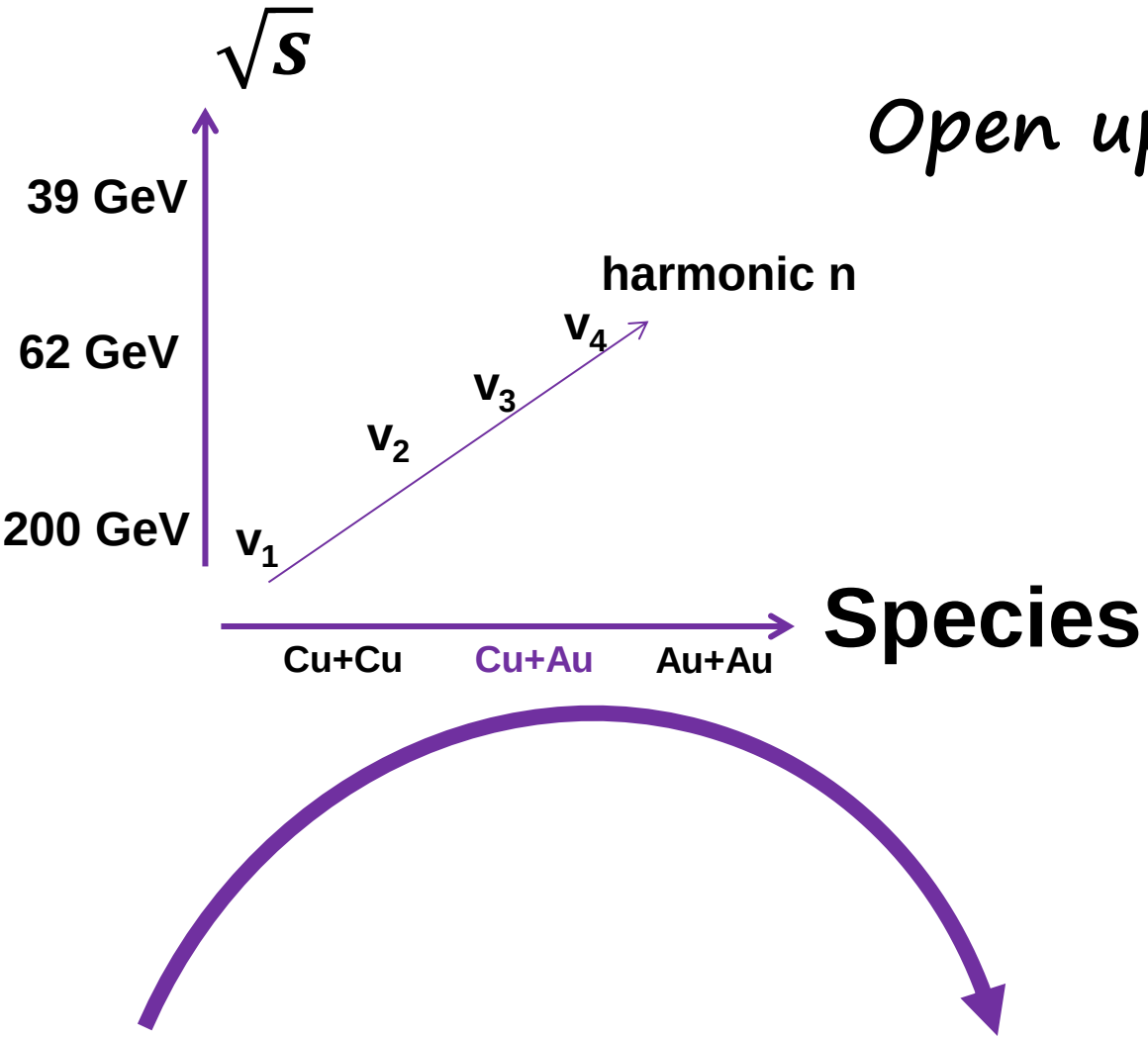
Ψ_n **RXN (|η|=1.0~2.8)**

MPC (|η|=3.1~3.7)

BBC (|η|=3.1~3.9)

arXiv:1412.1038 , arXiv:1412.1043

Using RHIC's Flexibility



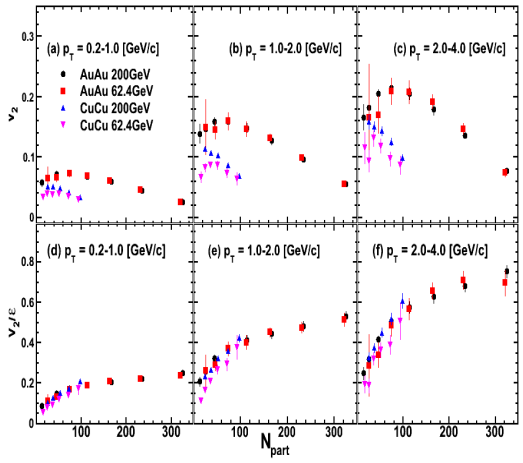
Open up new axes

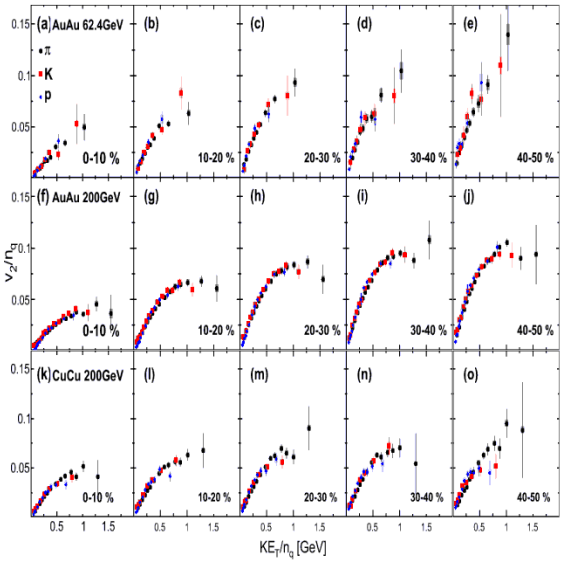
Recent PHENIX publications on flow at RHIC:

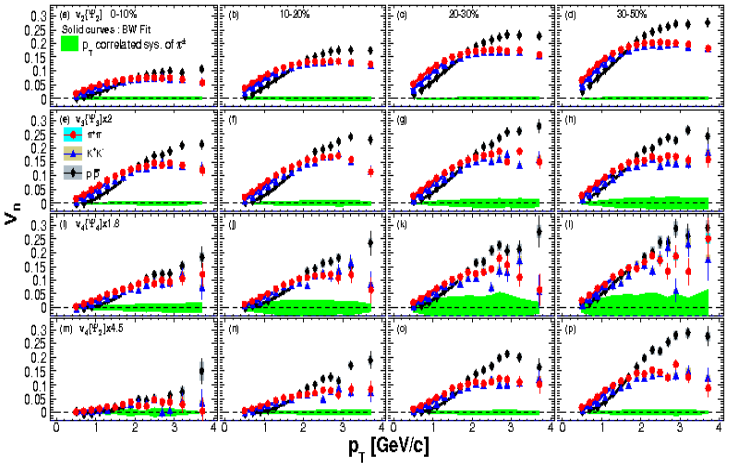
1) Systematic Study of Azimuthal Anisotropy in Cu+Cu and Au+Au Collisions at 62.4 and 200 GeV: arXiv:1412.1043

2) Measurement of the higher-order anisotropic flow coefficients for identified hadrons in Au+Au collisions at 200 GeV : arXiv:1412.1038

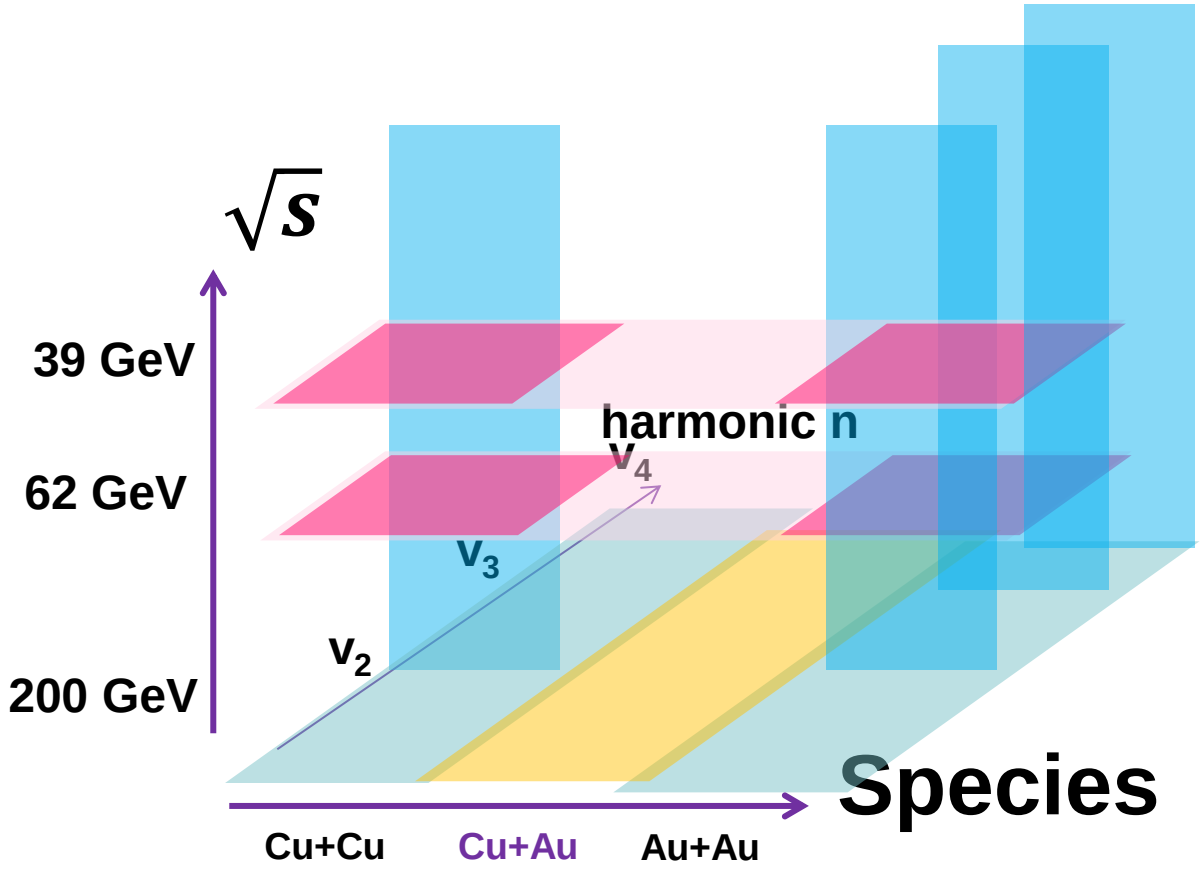
+ Cu+Au Preliminary Results





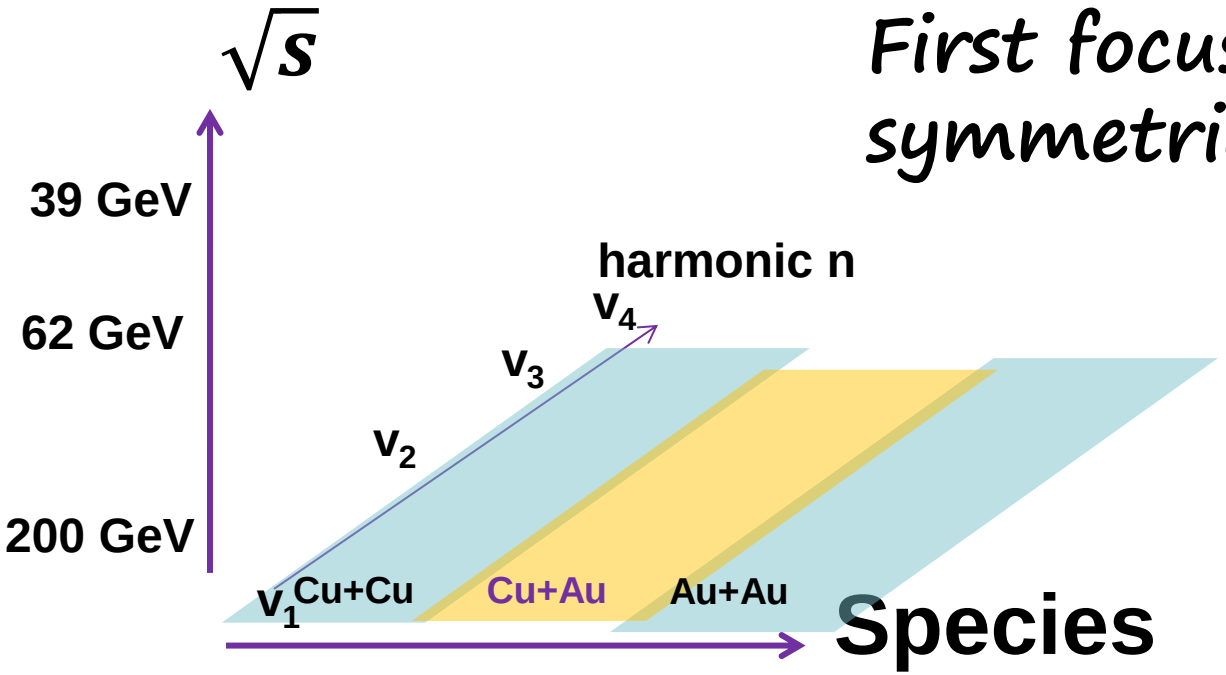


PHENIX Data: Preview



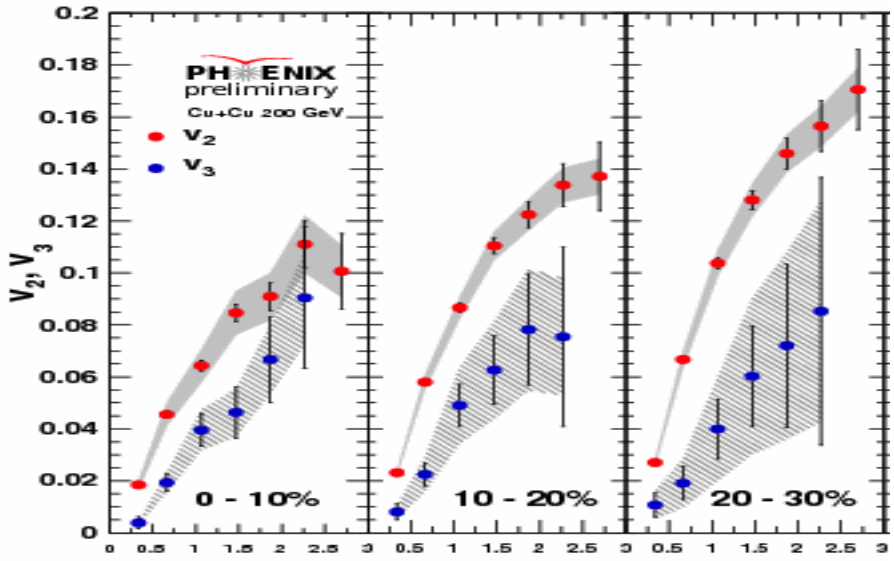
We are filling up this three dimensional space in PHENIX with more and more precision

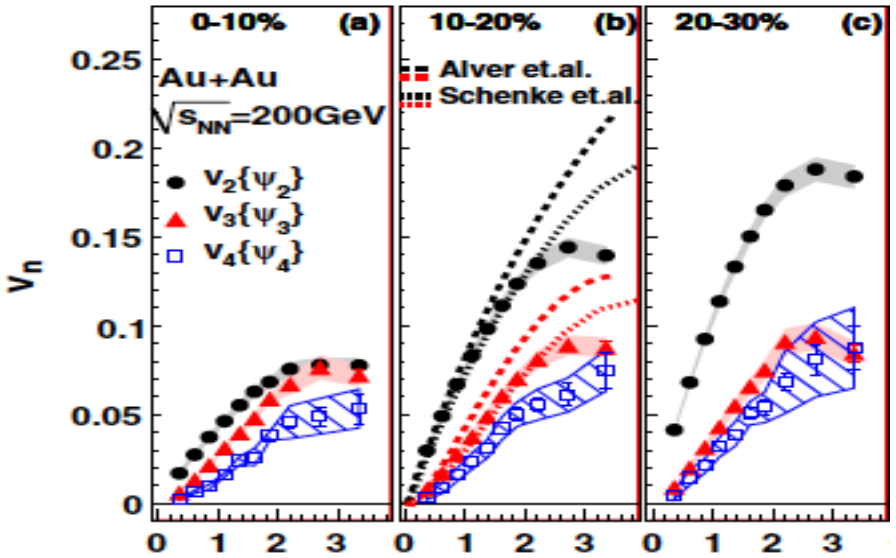
Different (LARGE) Heavy Collisions Systems



First focus on symmetric systems

Flow in symmetric colliding systems : Cu+Cu vs Au+Au





Phys.Rev.Lett. 107 (2011) 252301

Strong centrality dependence of v_2 in AuAu, CuCu

Weak centrality dependence of v_3

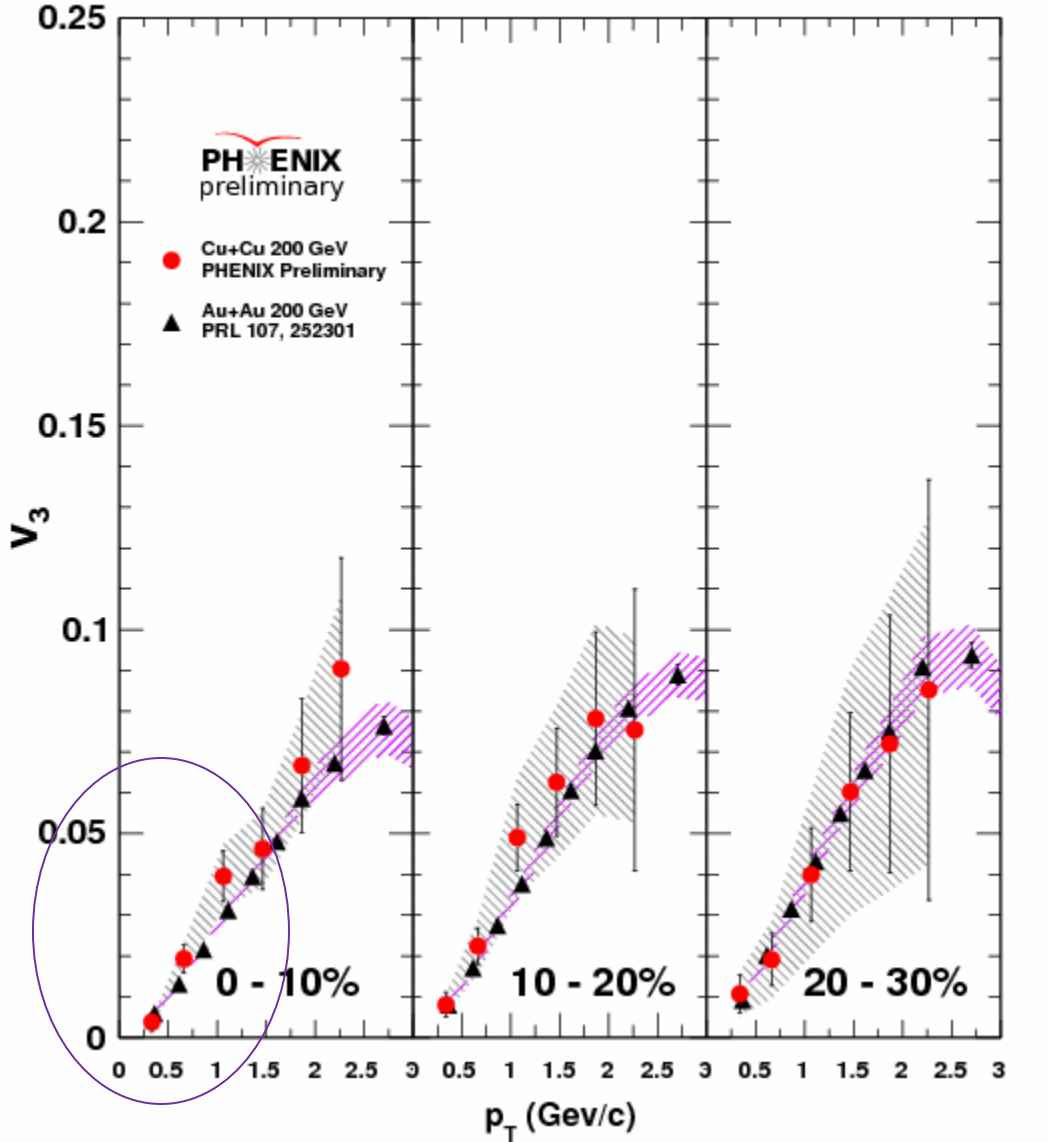
Simultaneous measurements of

v2 and v3 → Crucial constraint for η/s

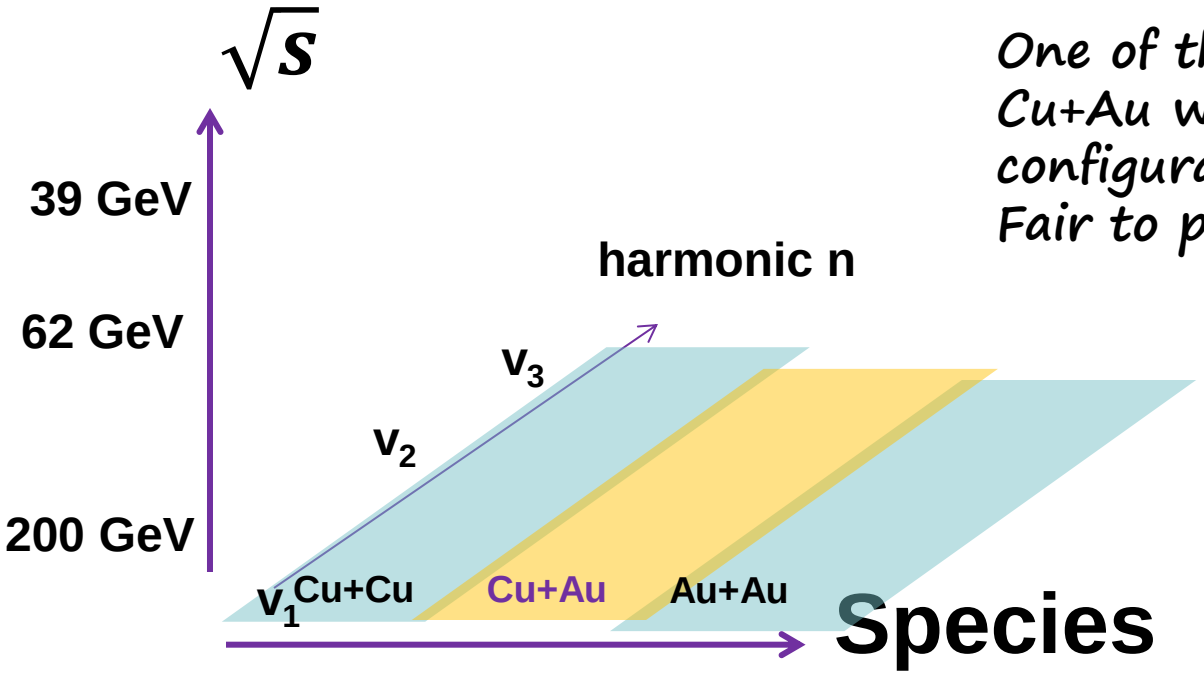
Updates for HYDRO constraints from Cu+Cu?

v_3 Au+Au vs. Cu+Cu

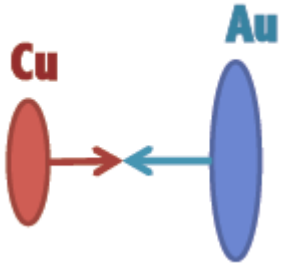
- Within largish errors over larger p_T the same
- But some constraining power at low pt (0-1 GeV/c)

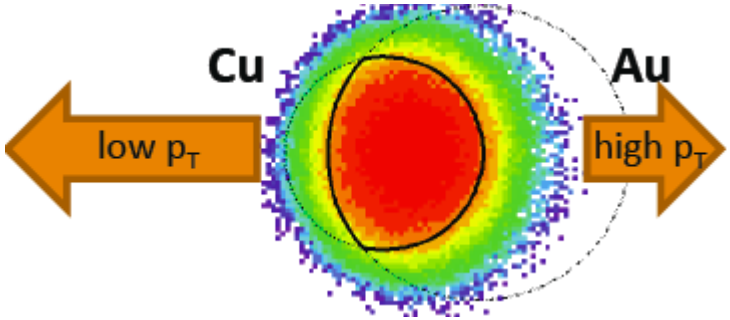


Should Cu+Au be on this axis?

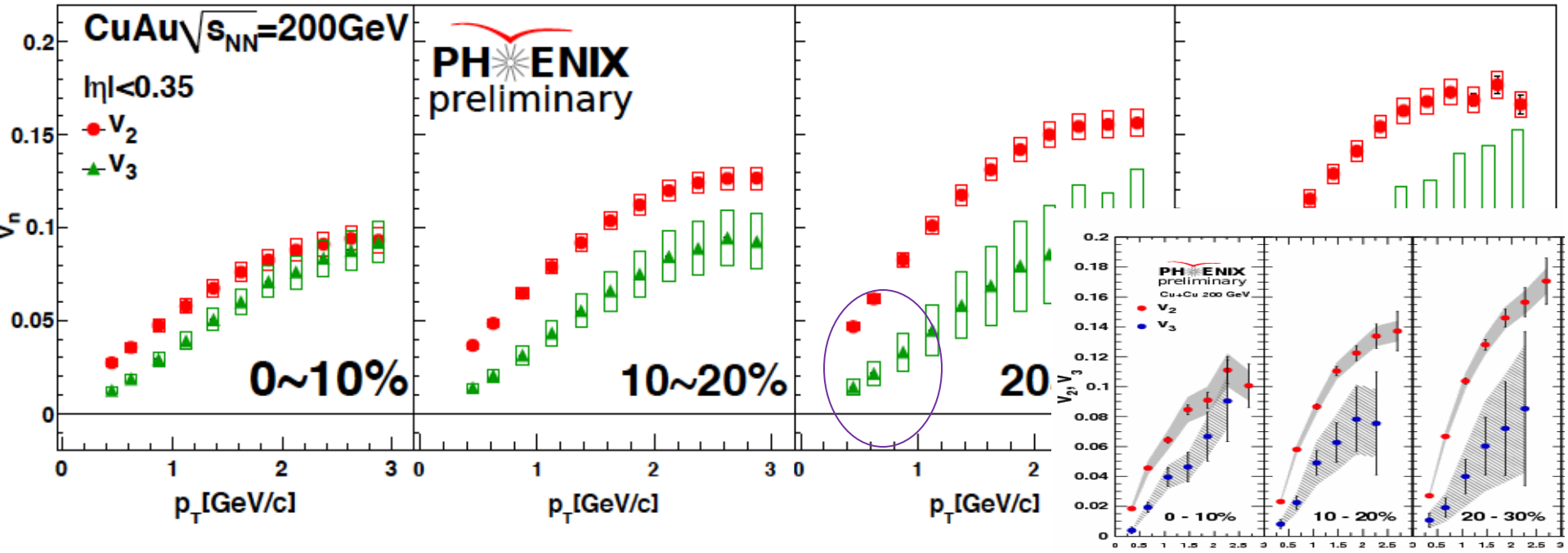


One of the motivations for Cu+Au was "exotic" configurations?
Fair to put it on this axis?





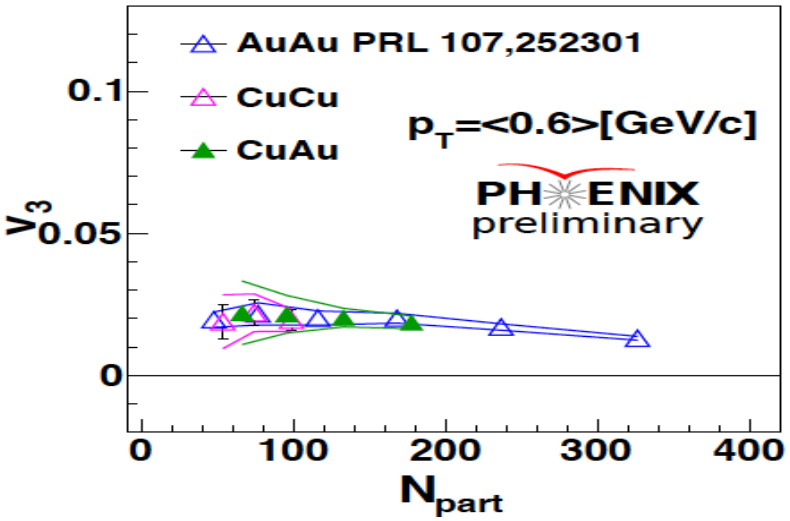
Centrality/Pt dependence of v_2, v_3 in 200 GeV Cu+Au

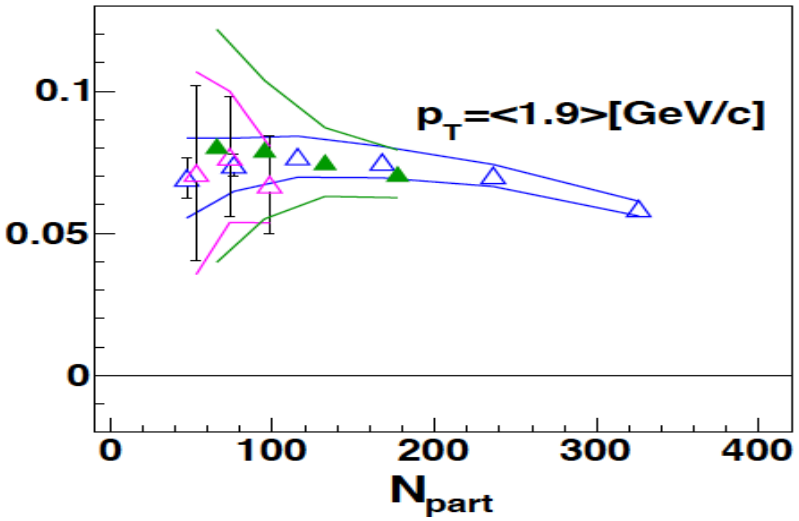


- Centrality dependence of v_2 v_3 similar to Au+Au…
- What? No Significant centrality dependence of v_3 !

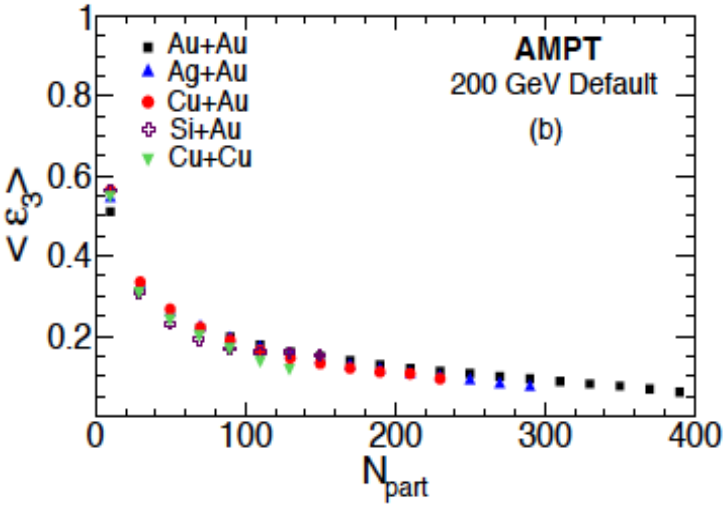
➔ Same centrality dependence as seen in symmetric collisions: Au+Au and Cu+Cu

v_3 in 200 GeV Cu+Au vs Cu+Cu/Au+Au



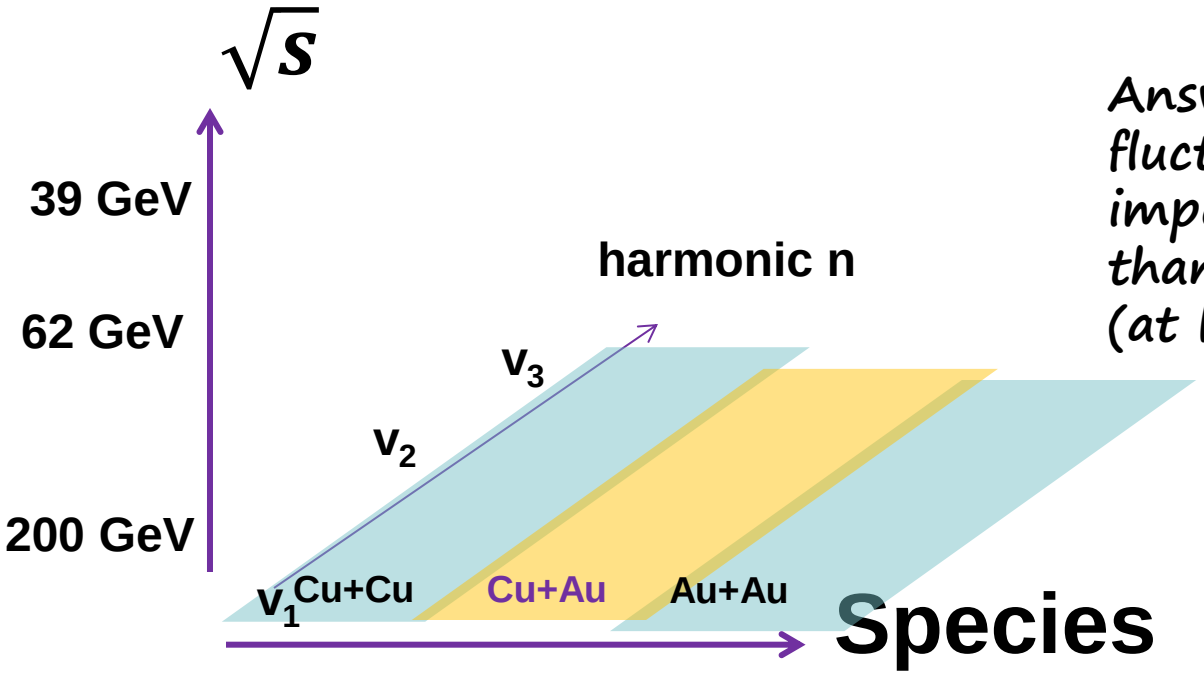


The observed system size independence of v_3 Is expected from the similar values of ε_3

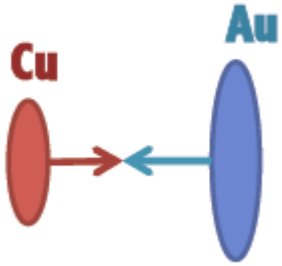


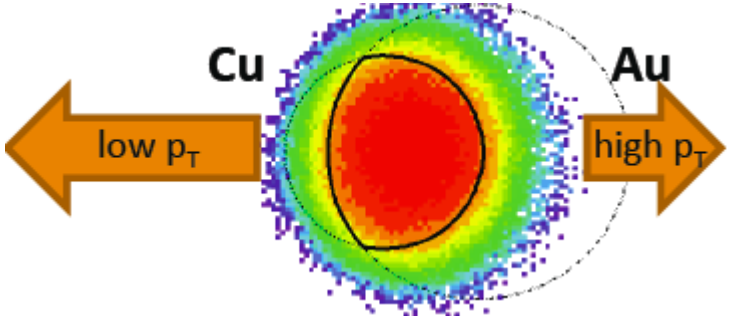
Phys.Rev. C84 (2011) 067901

Should Cu+Au be on this axis?

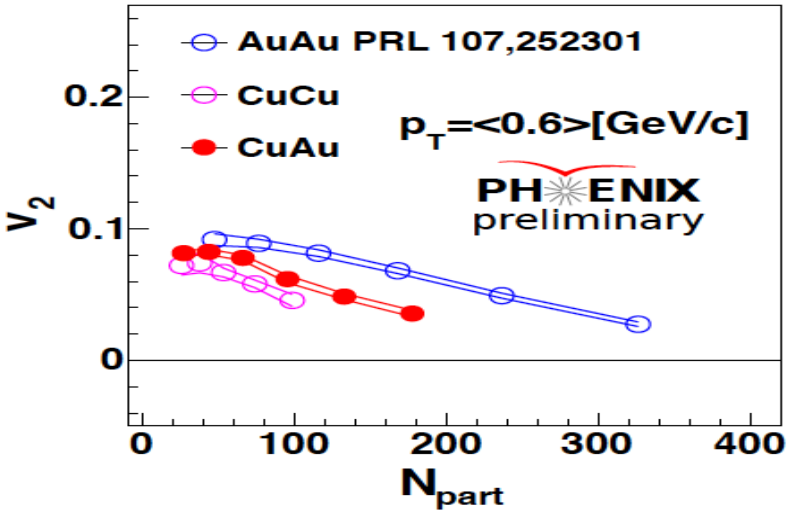


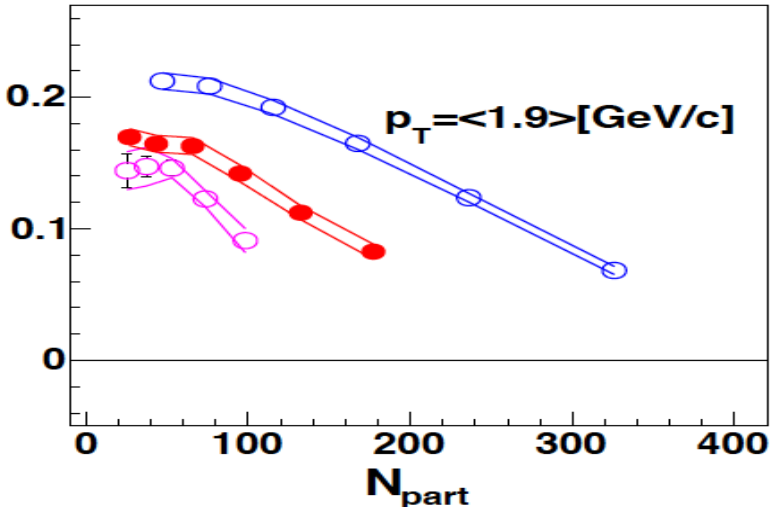
Answer: Yes : I.S. fluctuations are more important/dominant than overlap shapes! (at least for v_3)





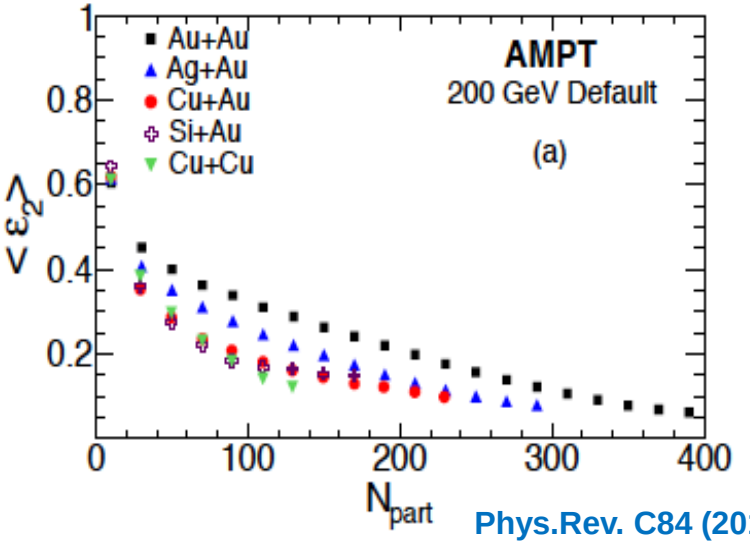
v2, in 200 GeV Cu+Au vs Cu+Cu/Au+Au





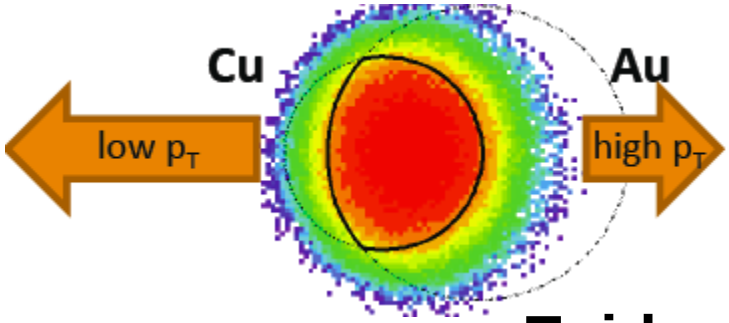
The observed system size dependence of v2: AuAu>Cu+Au>CuCu originate from the differences in initial ε_2

Overlap region of course does affect v_2



Phys.Rev. C84 (2011) 067901

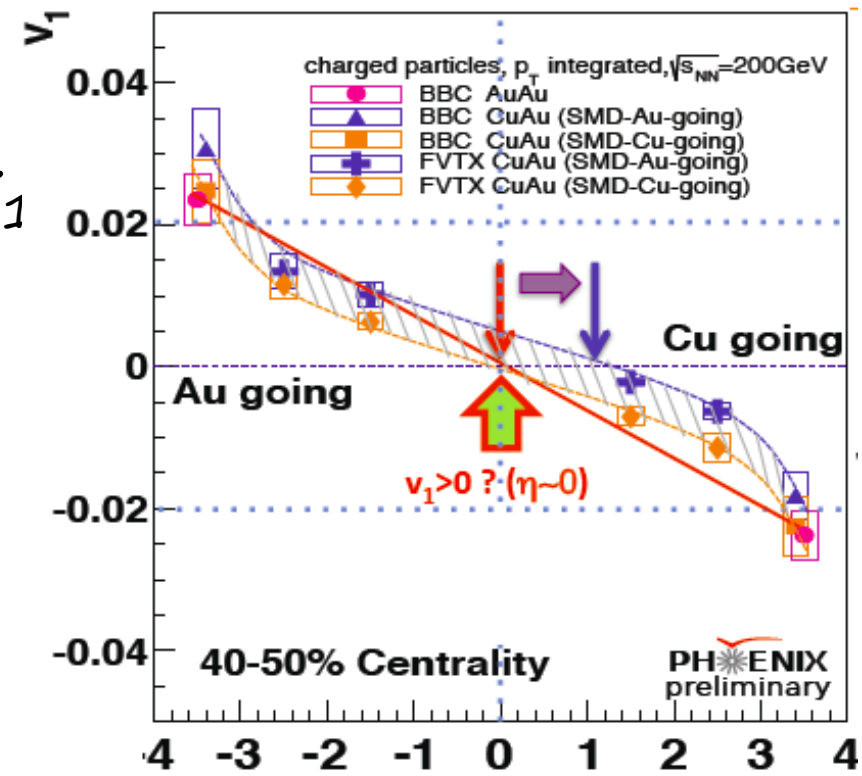
Note: Caveat v_1?

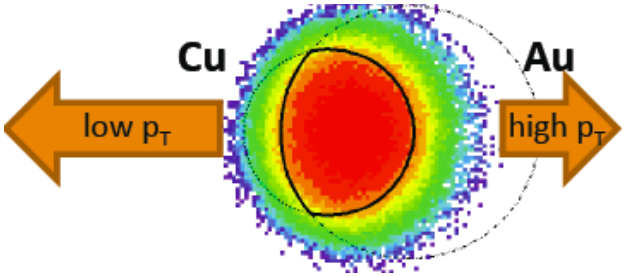


Evidence of exotic overlaps making a difference?: v1 possibly

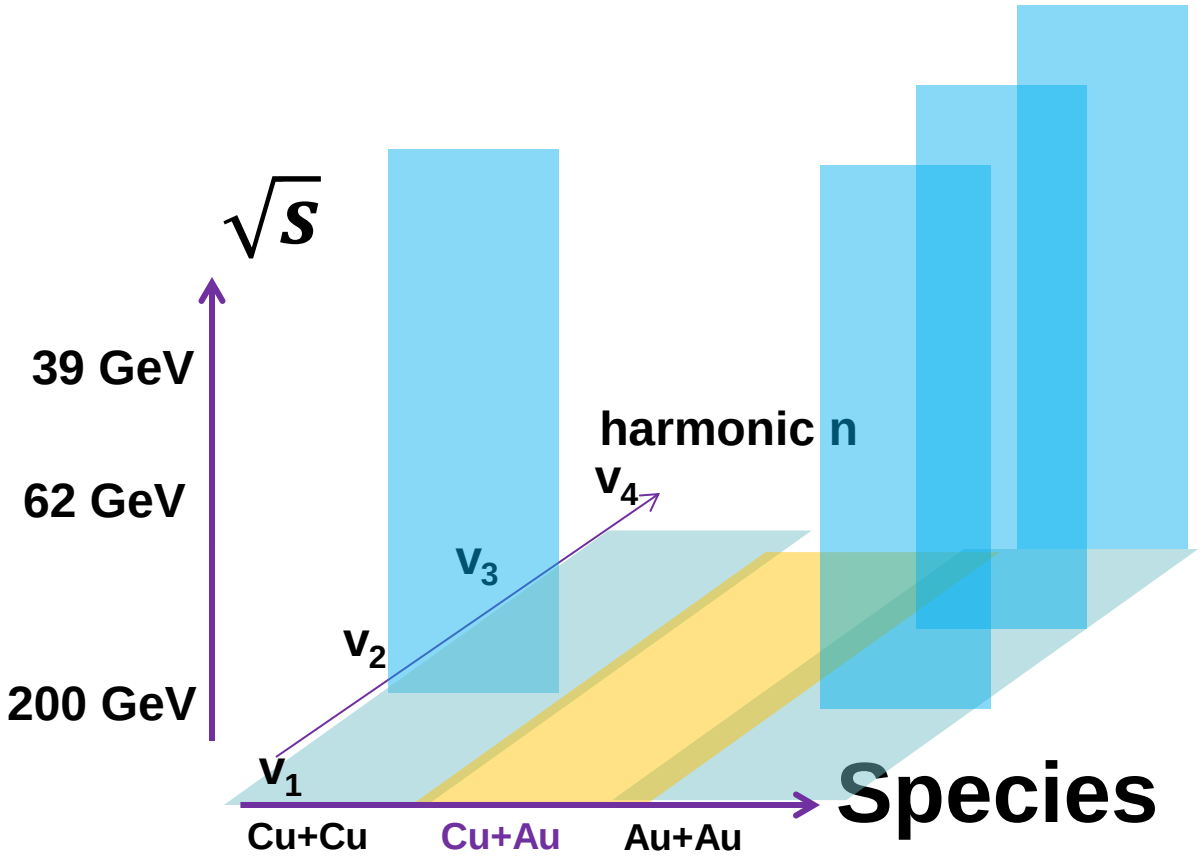
Note: Understanding v_1

- ATLAS: hydro like dipolar v_1 ?
- PHENIX disentangling v_1 components in Cu+Au using spectator-part. correlations
- Another dimension η from new FVTX!
- Longitudinal Assym Clear
- Translate to Midrapidity "exotic shape" effect?





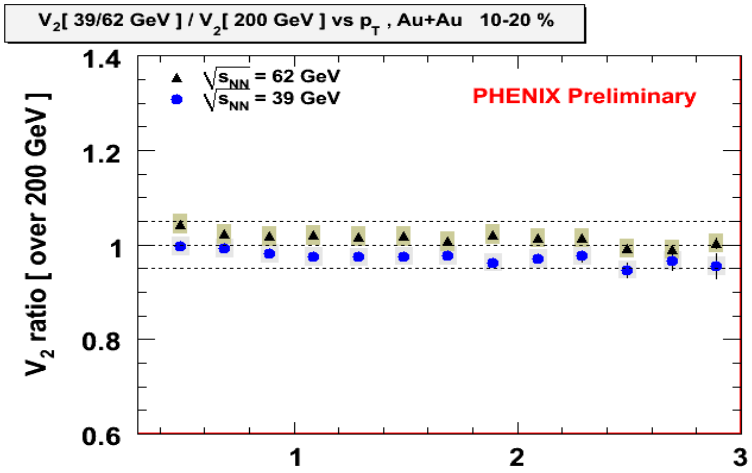
Energy Scan

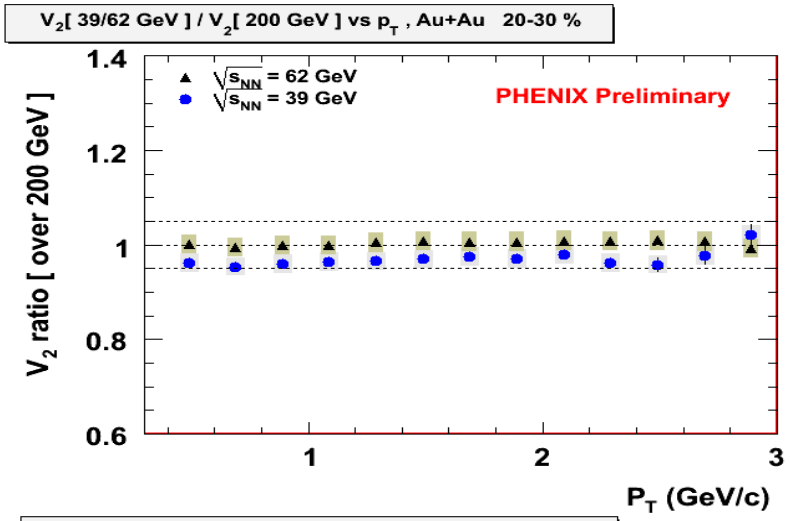


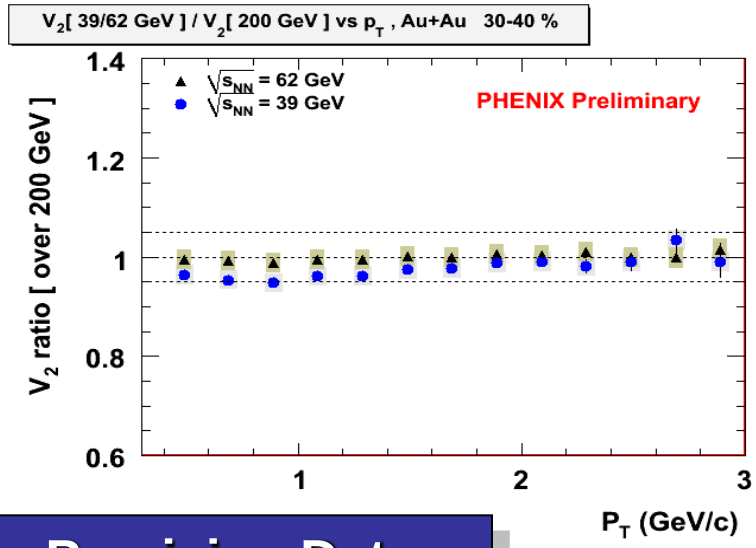
We have energy scan data for Au+Au both v_2 , v_3 , v_4

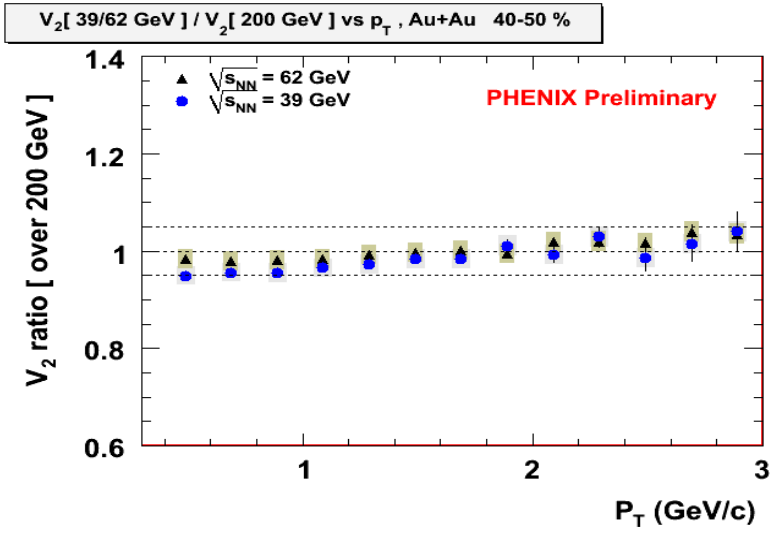
For Cu+Cu we have it just for v_2

Incl. Hadron v_2 Au+Au, 39-200 GeV





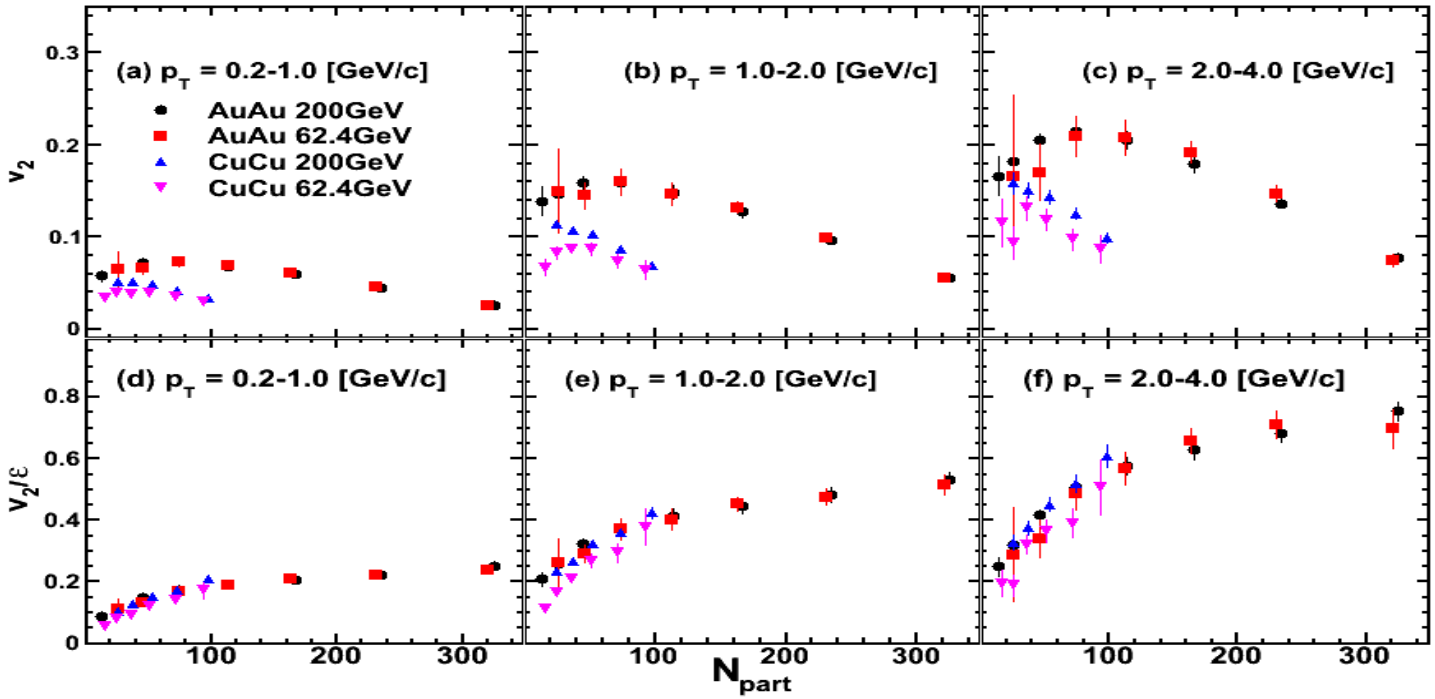




Precision Data

No significant change in $v_2(p_T)$ for $\sqrt{s}$ = 39 -200 GeV !

v2 in CuCu/AuAu collisions at 62.4-200 GeV



- *Eccentricity scaling is broken.*
- *Just the transverse size R in the ecc model or could there be implications for viscosity?* *HYDRO?*

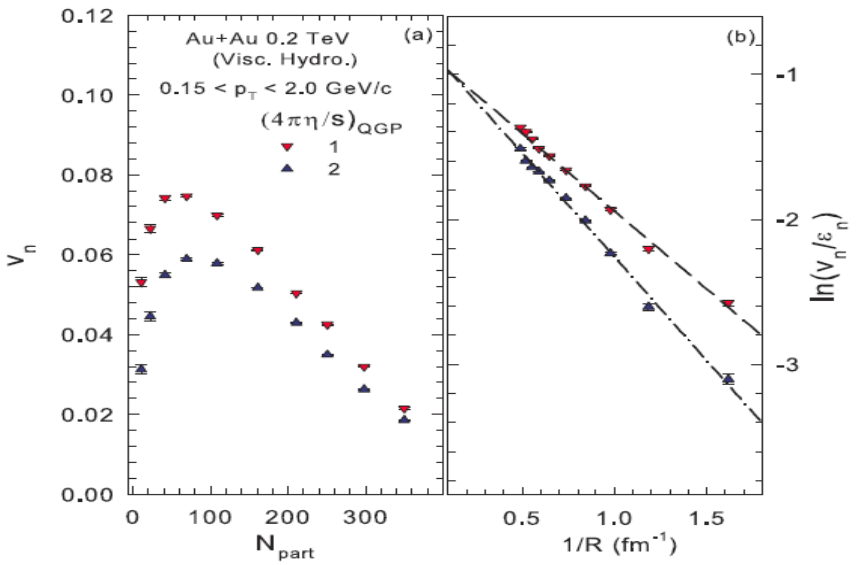
$$\frac{1}{\bar{R}} = \sqrt{\left(\frac{1}{\sigma_x^2} + \frac{1}{\sigma_y^2}\right)}$$

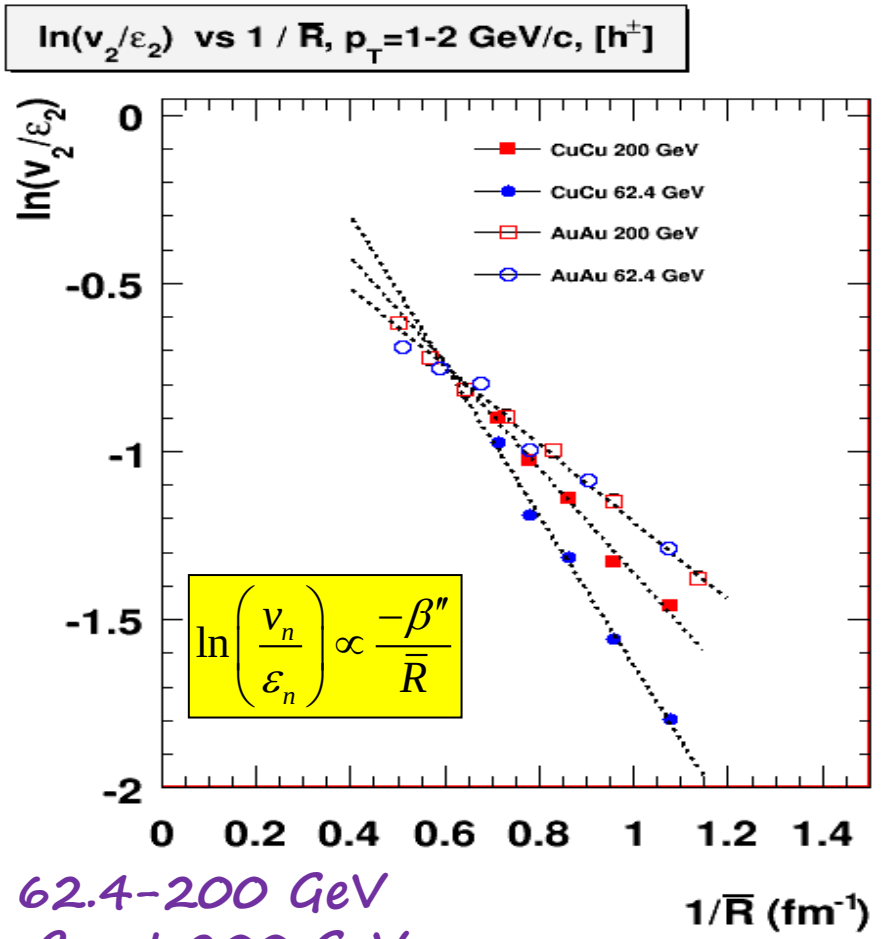
σ_x & σ_y → RMS widths of density distribution defined in Glauber MC

E.g. Data-based 1/R Scaling Model Interpretation

Lacey et.al. 1/R Scaling Model: viscosity is the difference?

PRL112, 082302(2014)





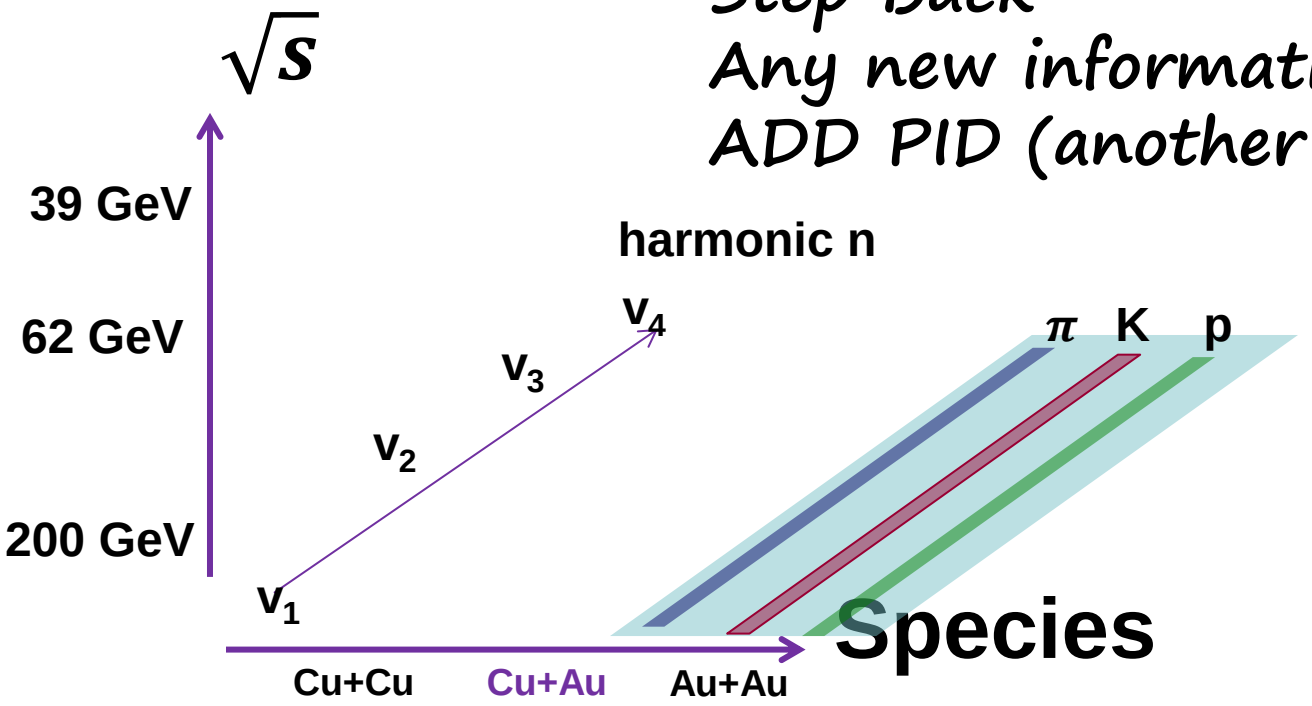
Slope parameter β″ same Au+Au at 62.4–200 GeV but shows change from Au+Au to Cu+Cu at 200 GeV .

Different η / damping in smaller systems / energies?

Interesting to see what REAL HYDRO MODEL will say!

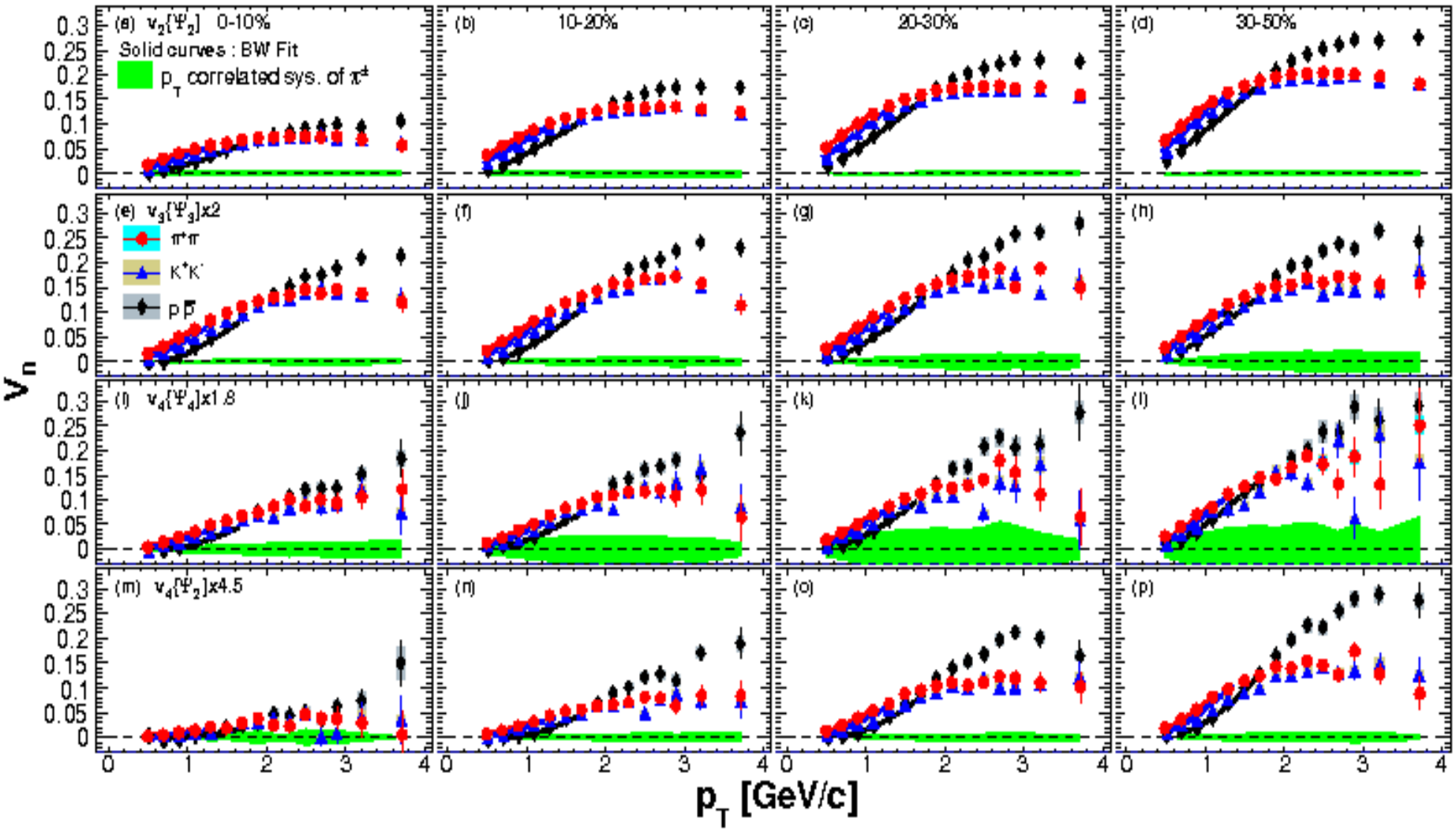
Good Old Au+Au

Step Back
Any new information here?
ADD PID (another dimension)



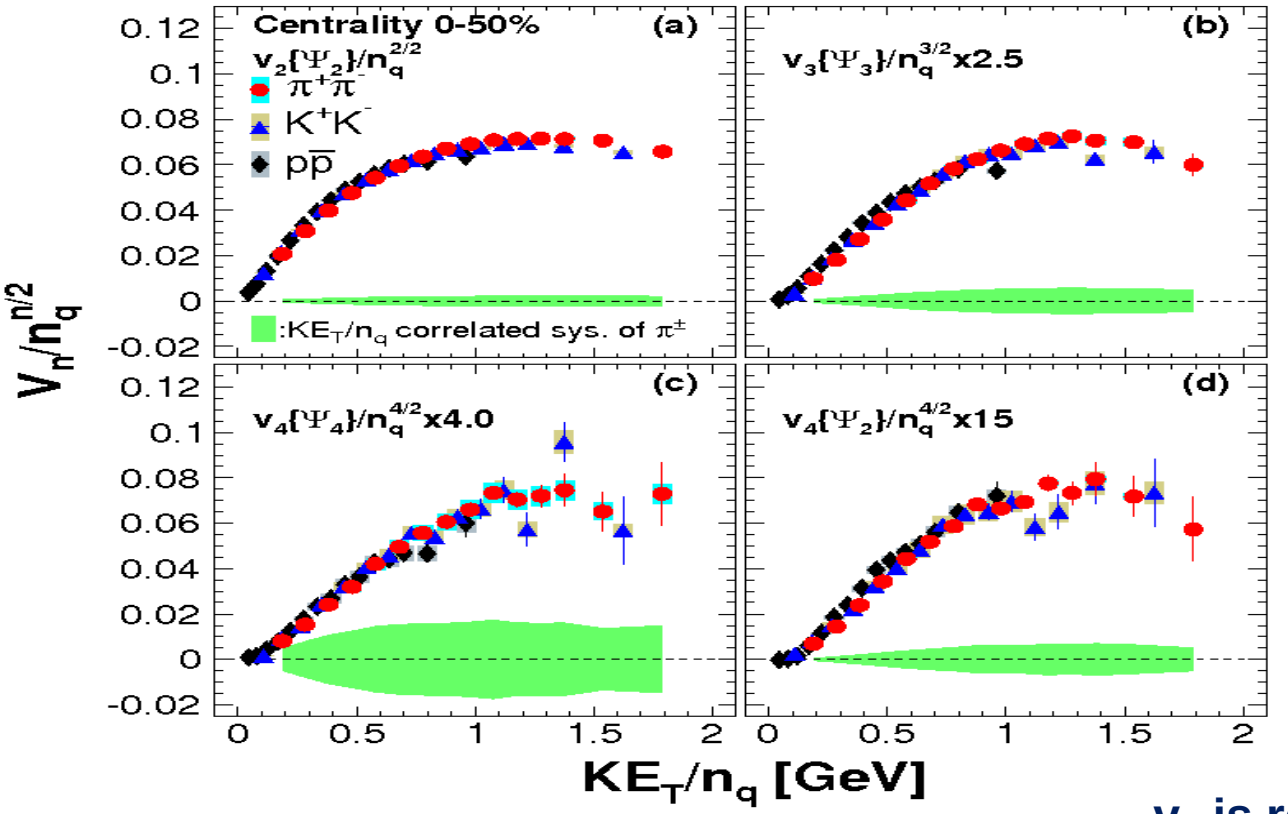
v_2 , v_3 , v_4 of Identified charged hadrons Au+Au at 200 GeV

arXiv:1412.1038



Scaling Properties of Vn Flow at 200 GeV

arXiv:1412.1038



v_n is related to v_2

$$v_{n,q}(KE_T) \sim v_{2,q}^{n/2} \quad \text{or} \quad \frac{v_n}{(n_q)^{n/2}}$$

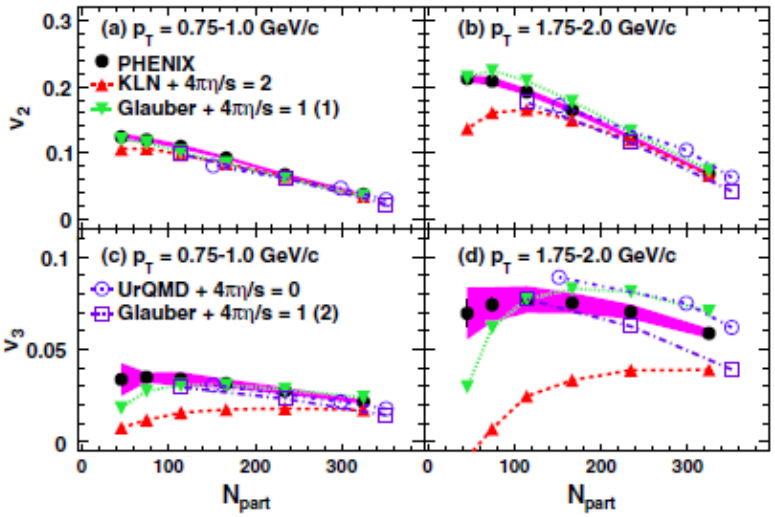
$$\frac{v_n(p_T)}{v_2(p_T)} = \frac{\varepsilon_n}{\varepsilon_2} \cdot \exp\left(-\beta(n^2-4)\right)$$

- NCQ-scaling holds well for v_2,v_3,v_4 below 1GeV in KE_T space, at 200GeV

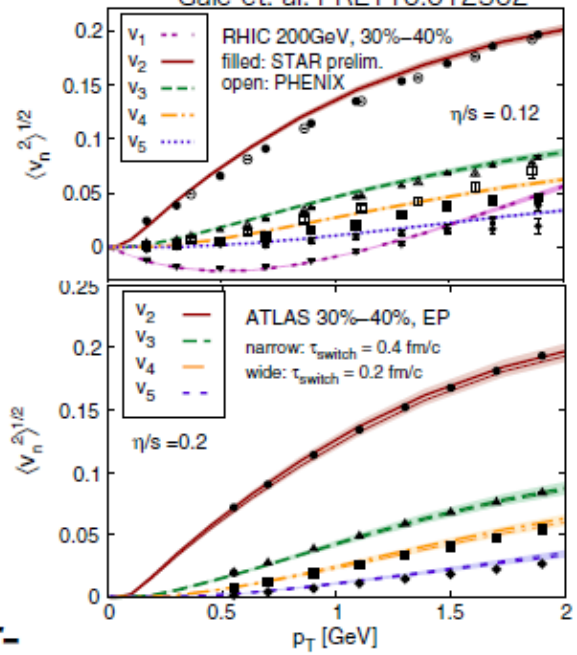
Model Constraints from All Moments

We all know what a big constraint the vn has been

PHENIX PRL107.252301

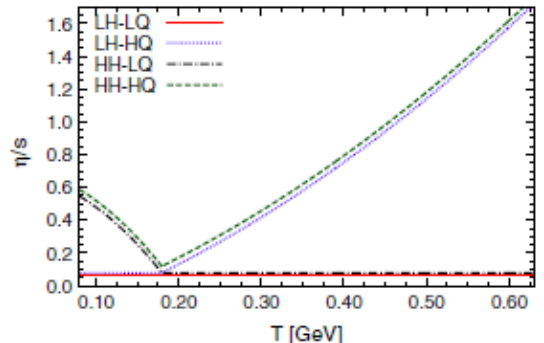


Gale et. al. PRL110.012302



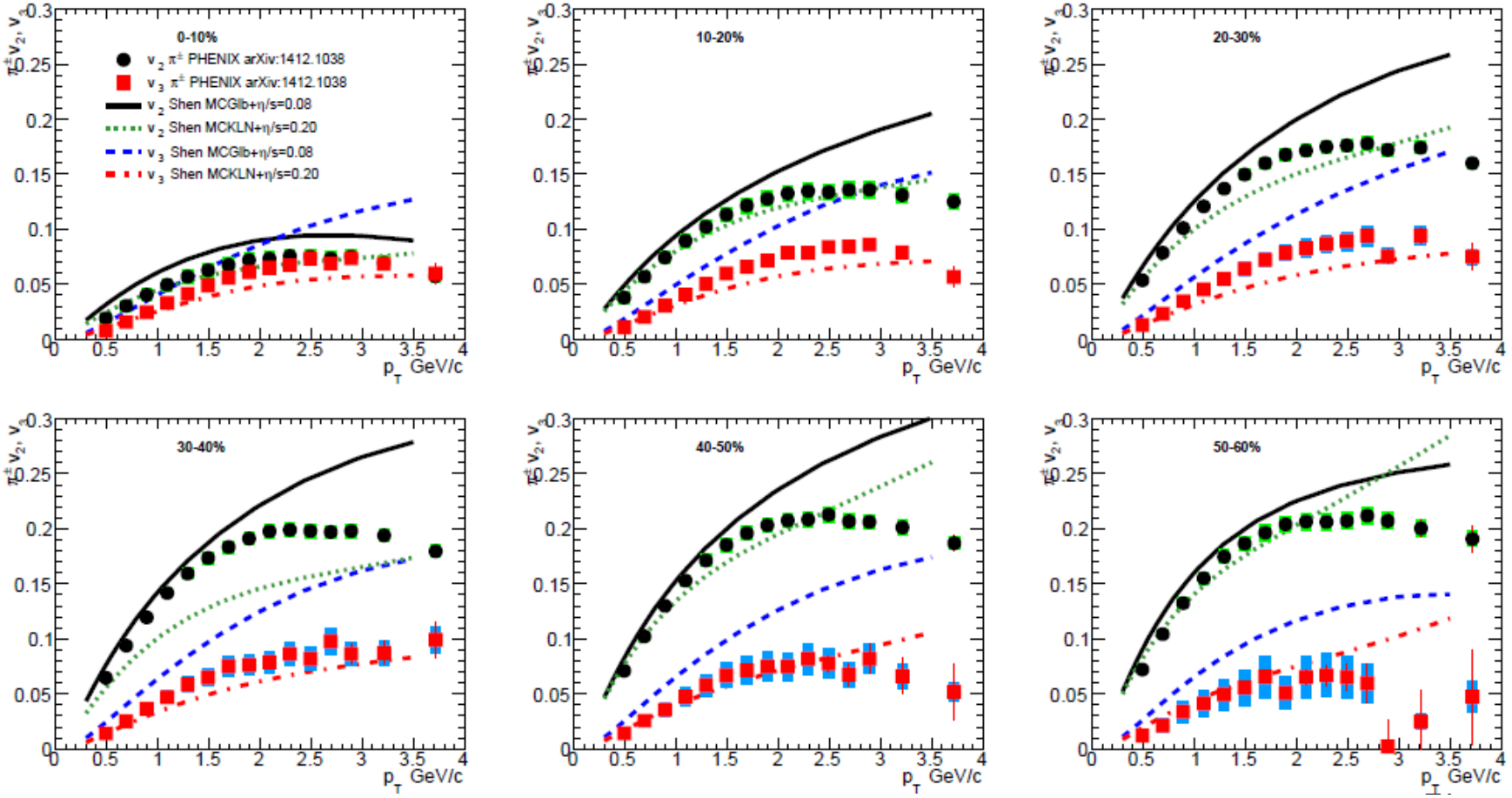
- Stringent constraints to IC and shear-viscosity by higher-order harmonics
  - Still Multiple Combinations
- Temperature dependence of viscosity $\eta/s(T_{\mathrm{RHIC}}) < \eta/s(T_{\mathrm{LHC}})$

Niemi et.al. PRL106.212301



Break the Glb/KLN ambiguity?

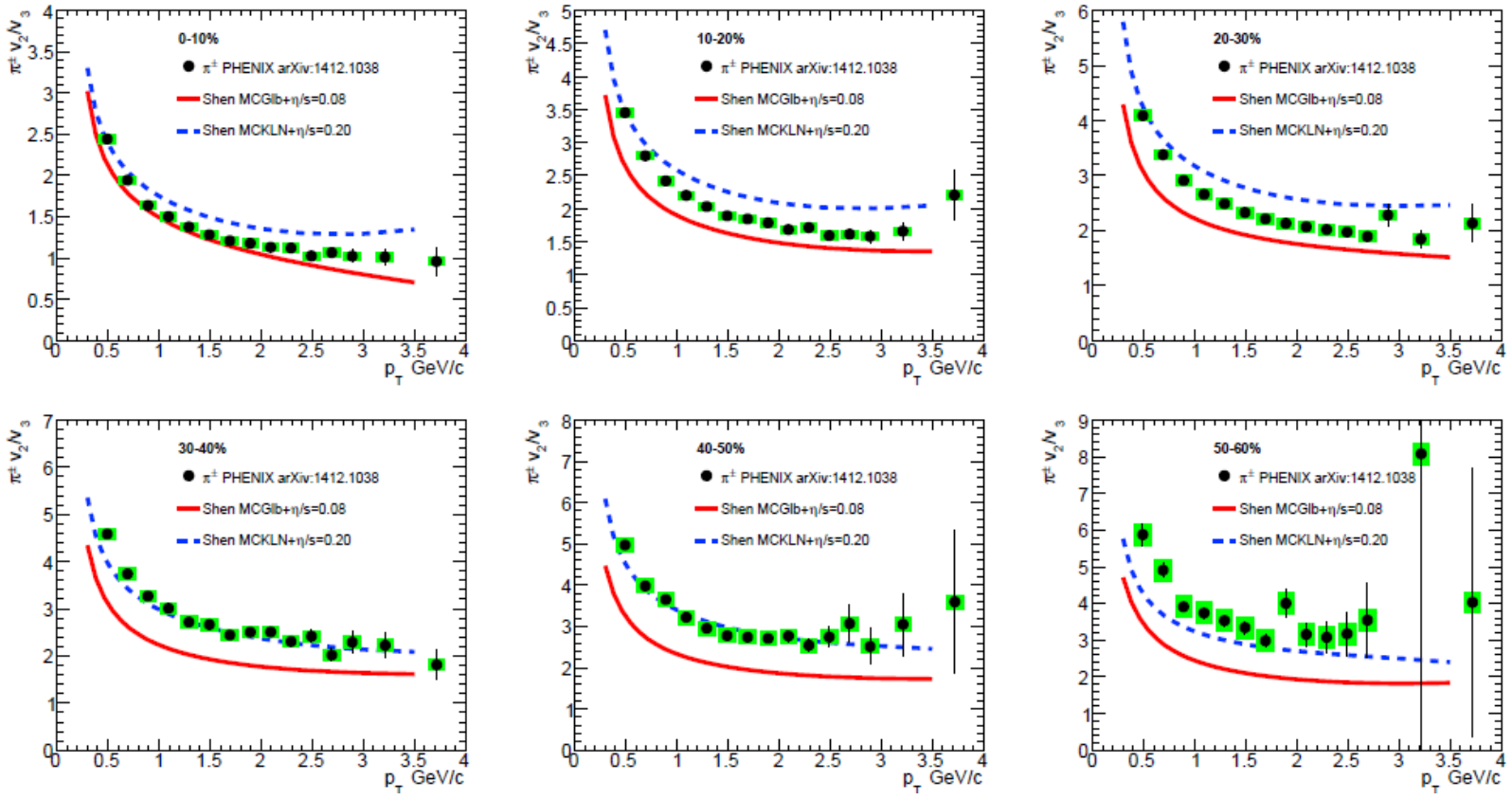
- Can we resolve this with PID?



Private Communication: Shen, C. et. al. arXiv:1110.3033

Model Comparisons v2/v3 ratio

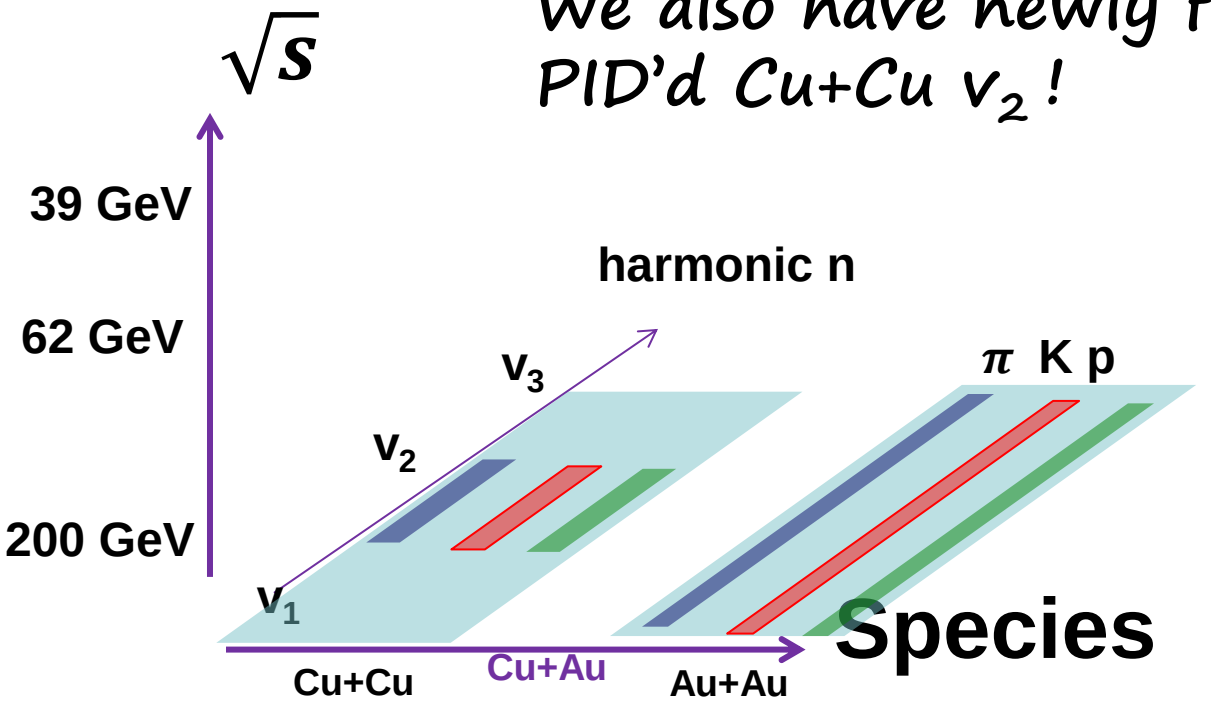
- MCKLN works better for peripheral
- Glauber better for most central
  - We need a new model / New physics effect?



Private Communication: Shen, C. et. al. arXiv:1110.3033

Some More Space Filled in with Cu+Cu

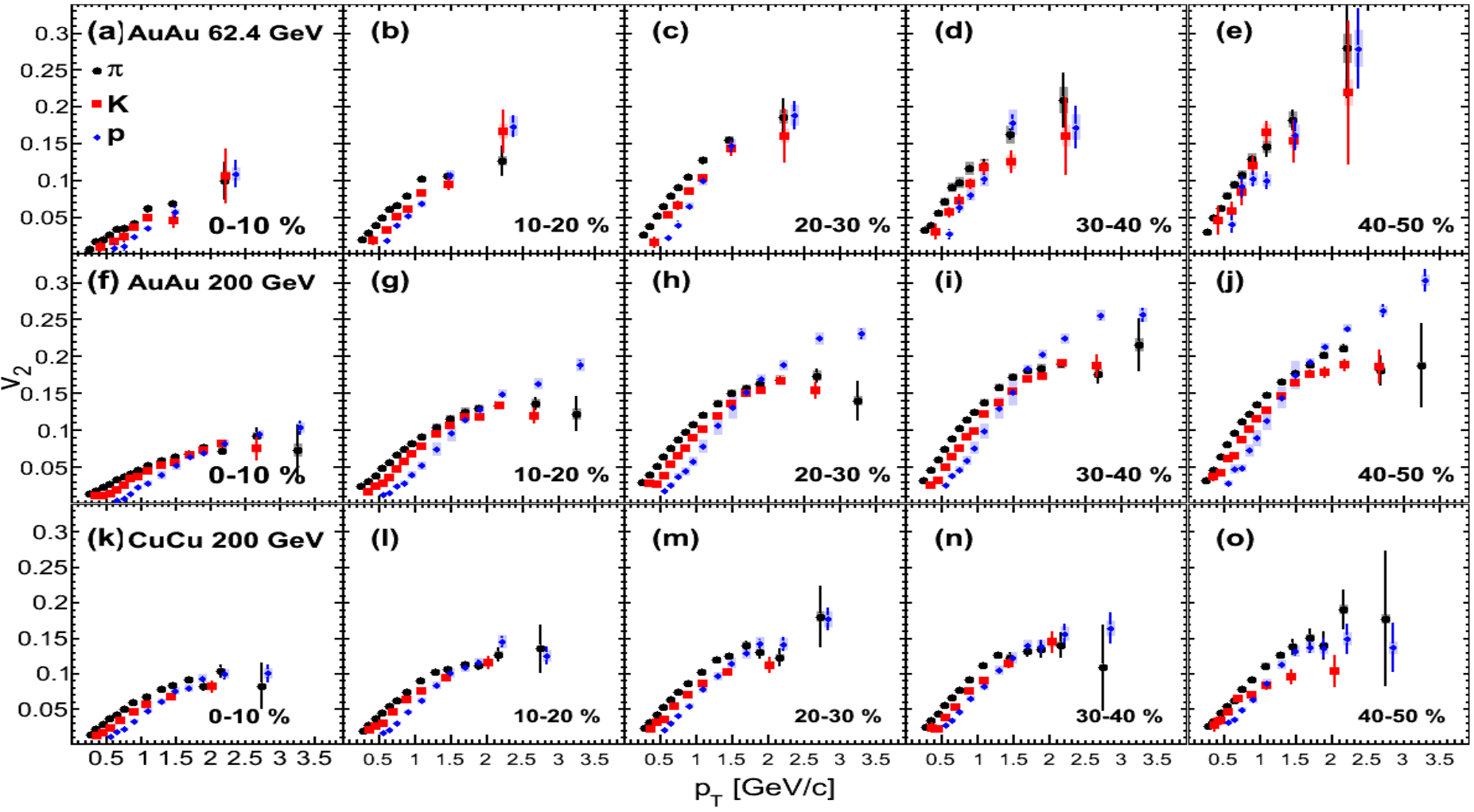
We also have newly finalized PID'd Cu+Cu v_2 !



Au+Au

v_2 of Identified charged hadrons Au+Au/Cu+Cu at 200 GeV

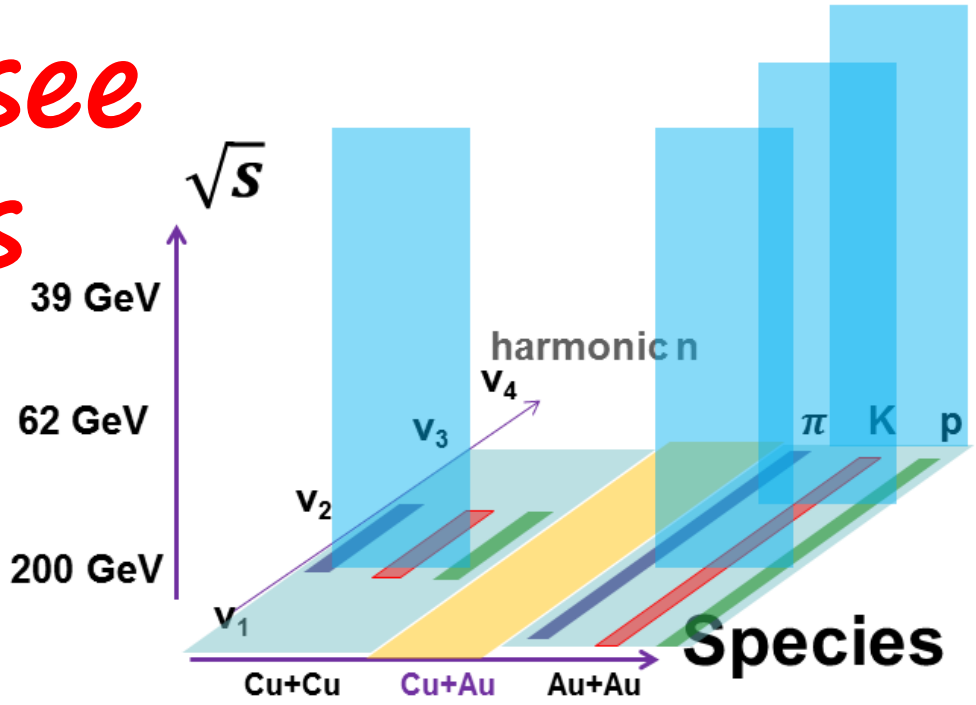
arXiv:1412.1043



Which hydro parameters/inputs would be needed match the Cu+Cu data as well?

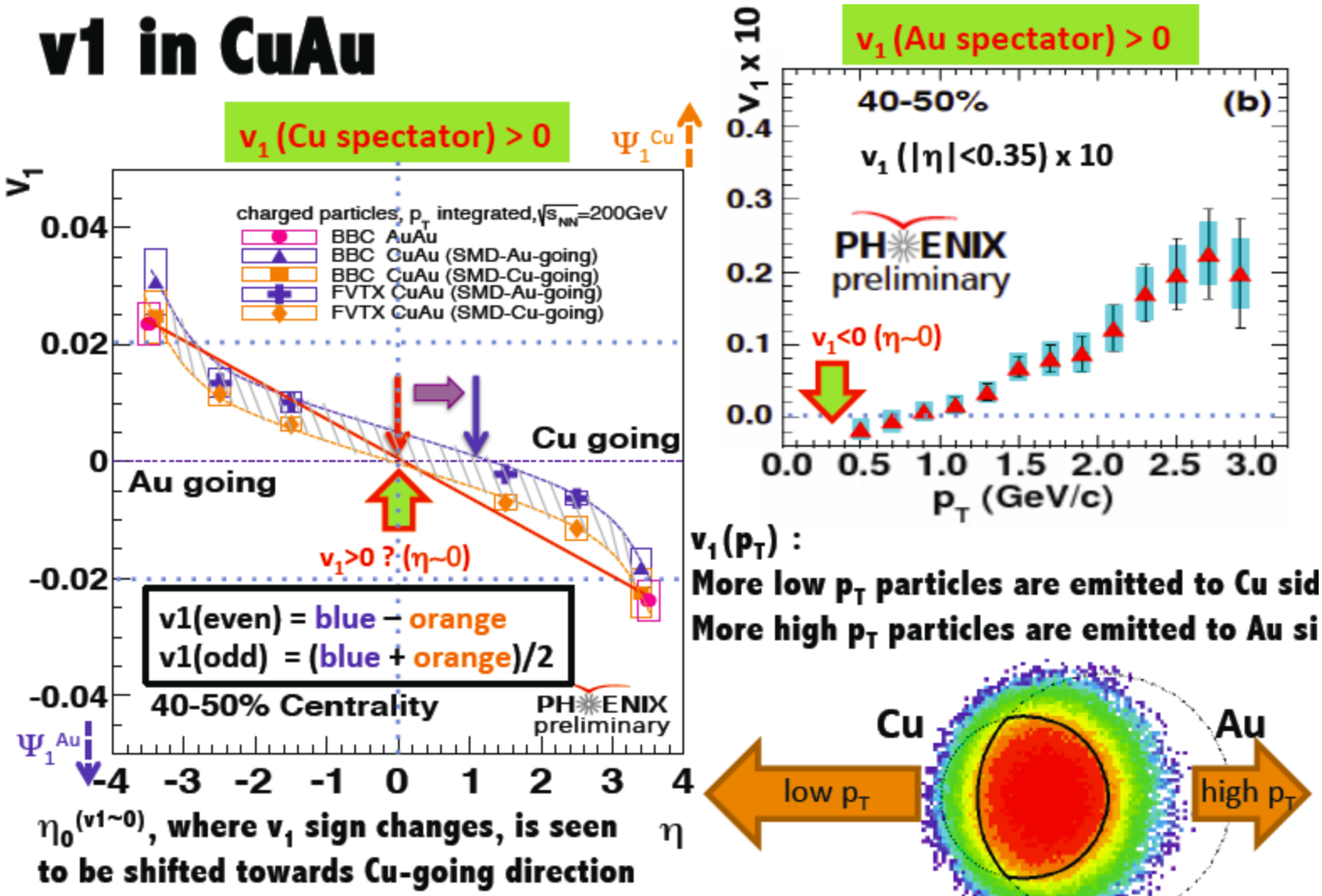
Summary

- PHENIX is filling in the 3-D (5-D!) space!
- Already confronting Theory adding more constraints to our field's hoped-for "Solving" of Hydro
- **Anxious to see more of this and other RHIC data included!**

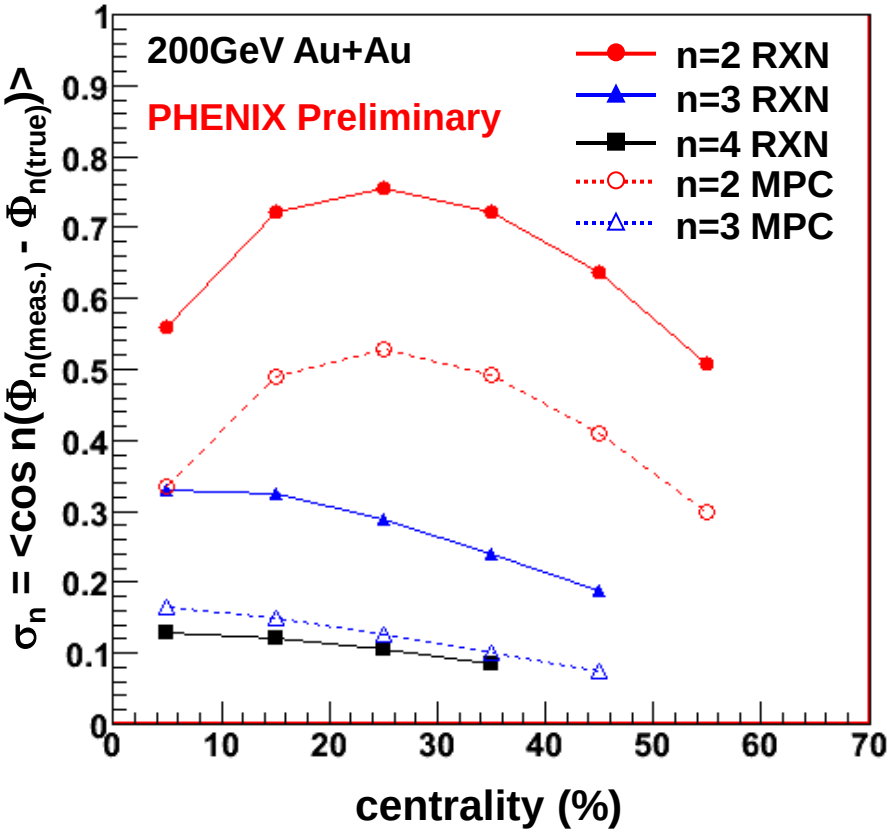


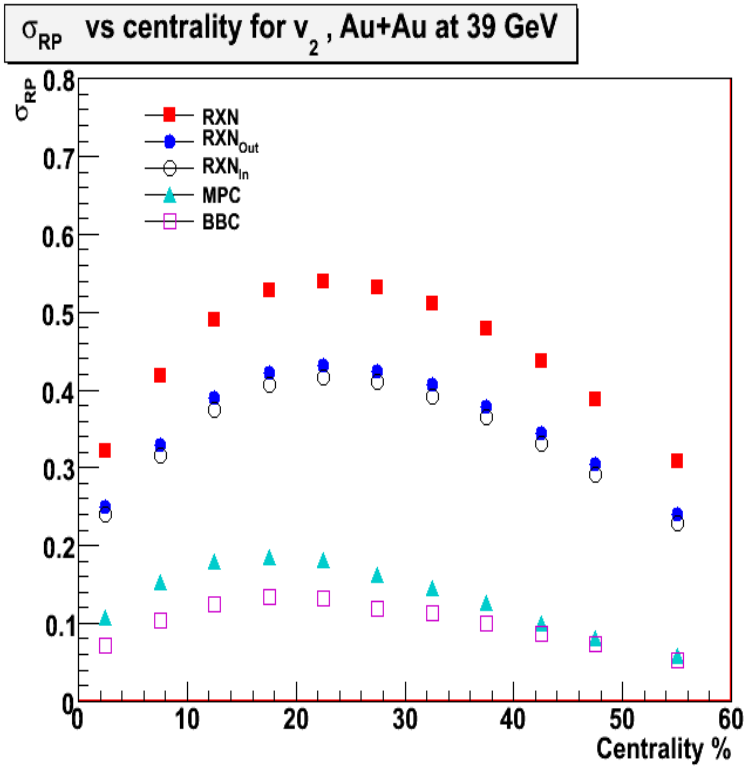
Backup Slides

more on v1 thing



PHENIX Flow Measurements : Event Plane Resolution





ψ_n RXN ($|\eta|$=1.0~2.8)

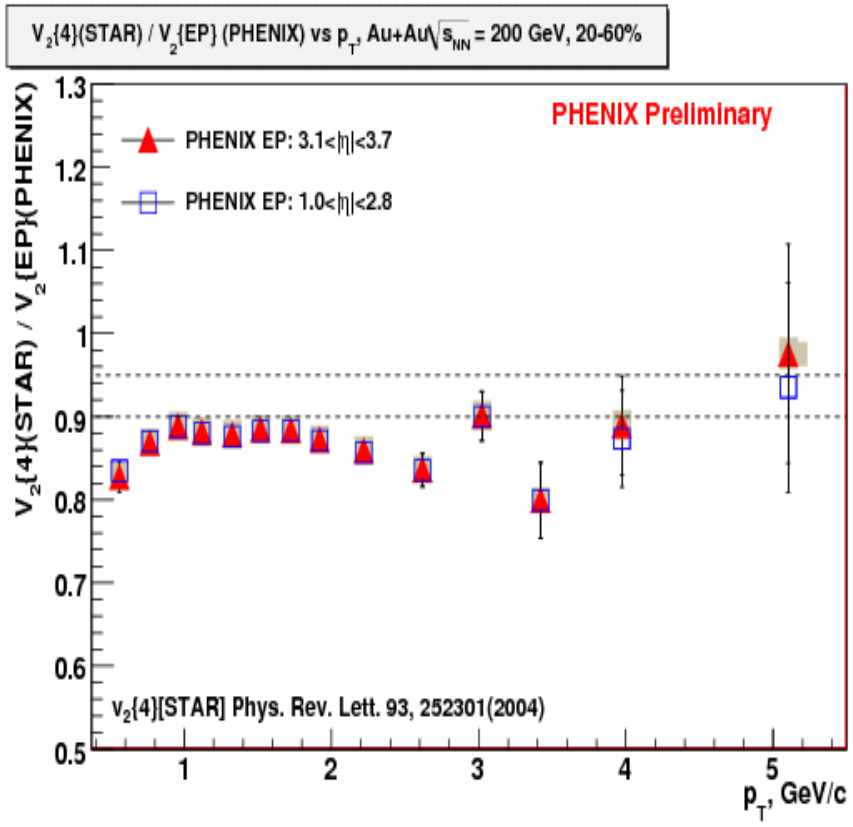
MPC ($|\eta|$=3.1~3.7)

BBC ($|\eta|$=3.1~3.9)

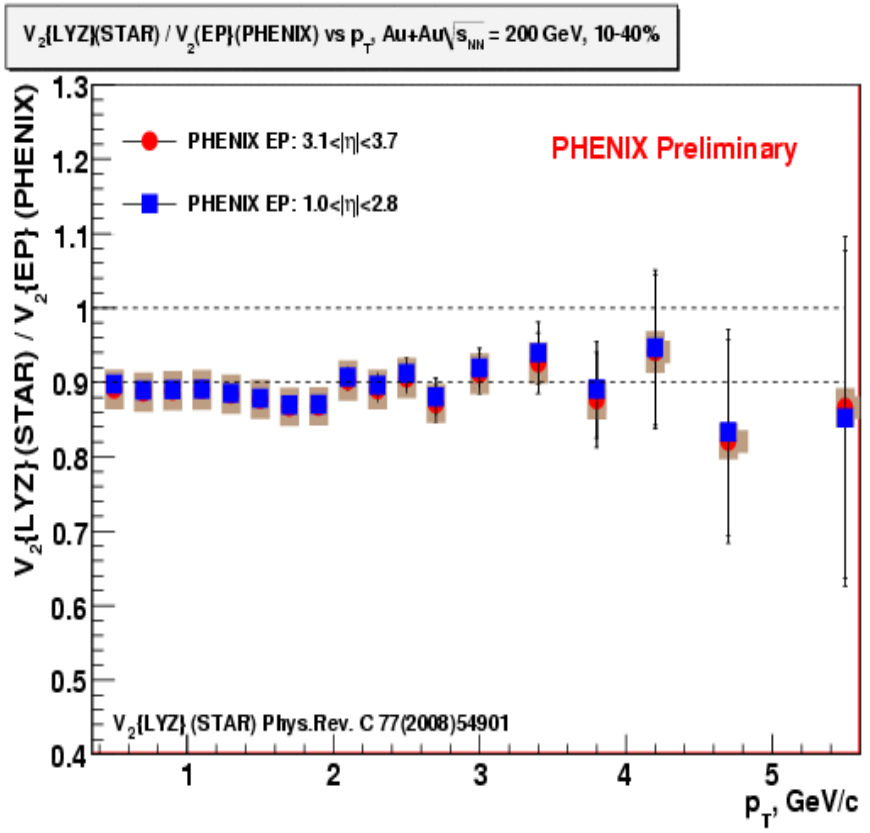
Overall good event plane resolution for V_n measurements and study beam energy dependence of the flow.

Differential $v_2(p_T)$: Comparison with STAR Multi-particle methods

4p cumulant method



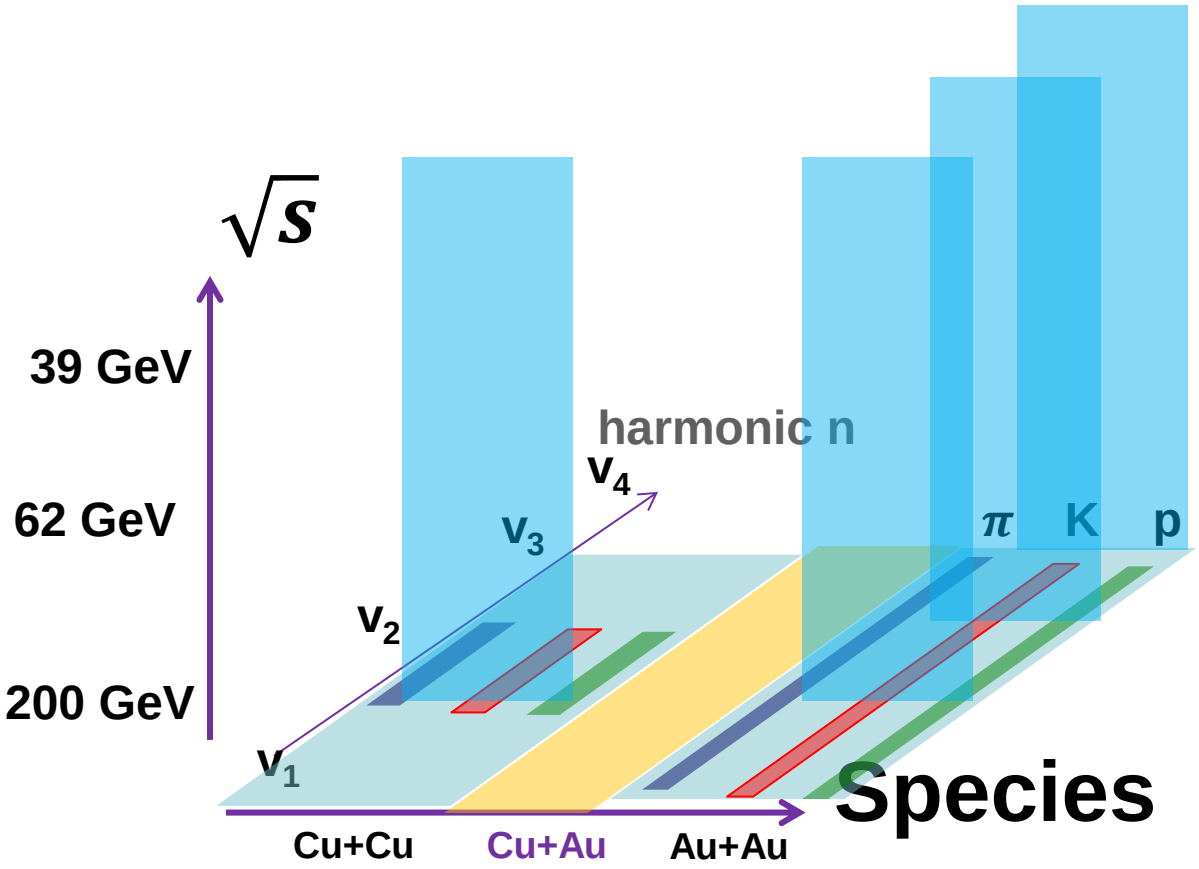
Lee-Yang-Zeros Method



Ratio V_2 {STAR} / V_2{PHENIX EP} < 1.0 for 4p cumulant and LYZ method .

LYZ : Lee-Yang-Zeros Method

Some More Space Filled in with Cu+Cu



Au+Au