Recent Flow Results From PHENIX

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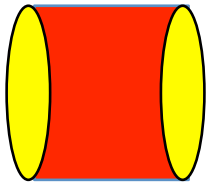
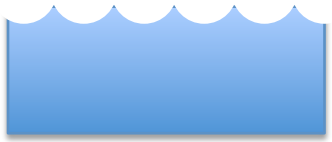
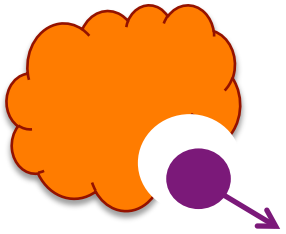
Initial Energy Deposit



Hydro Evolution



Freezeout/Hadronization



(This talk is presented in reverse order.)

Note:

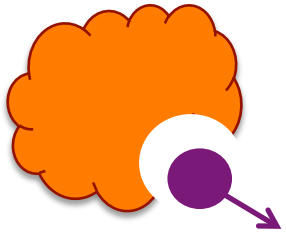
Unless otherwise stated, all PHENIX anisotropy parameters shown here are of this type:

$$v_n\{\Psi_n\}$$

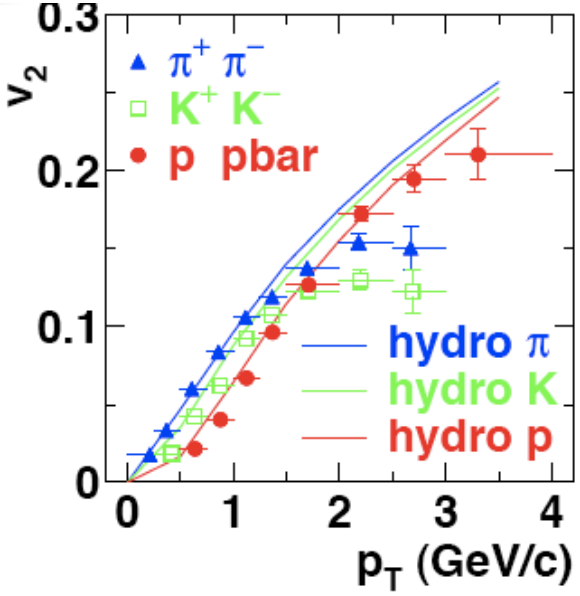
n^{th}-order anisotropy of hadrons at mid-rapidity

n^{th}-order event plane measured at high rapidity

The Flowing Final State

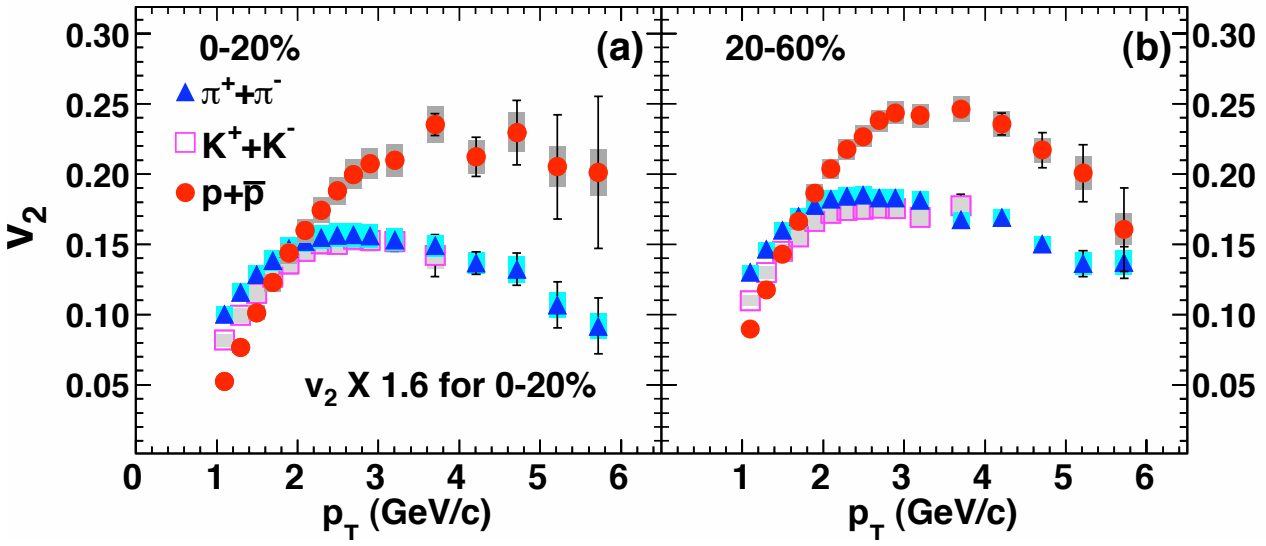


The data that initially led us to believe in hydrodynamics…



PHENIX Phys. Rev. Lett. 91, 182301 (2003)

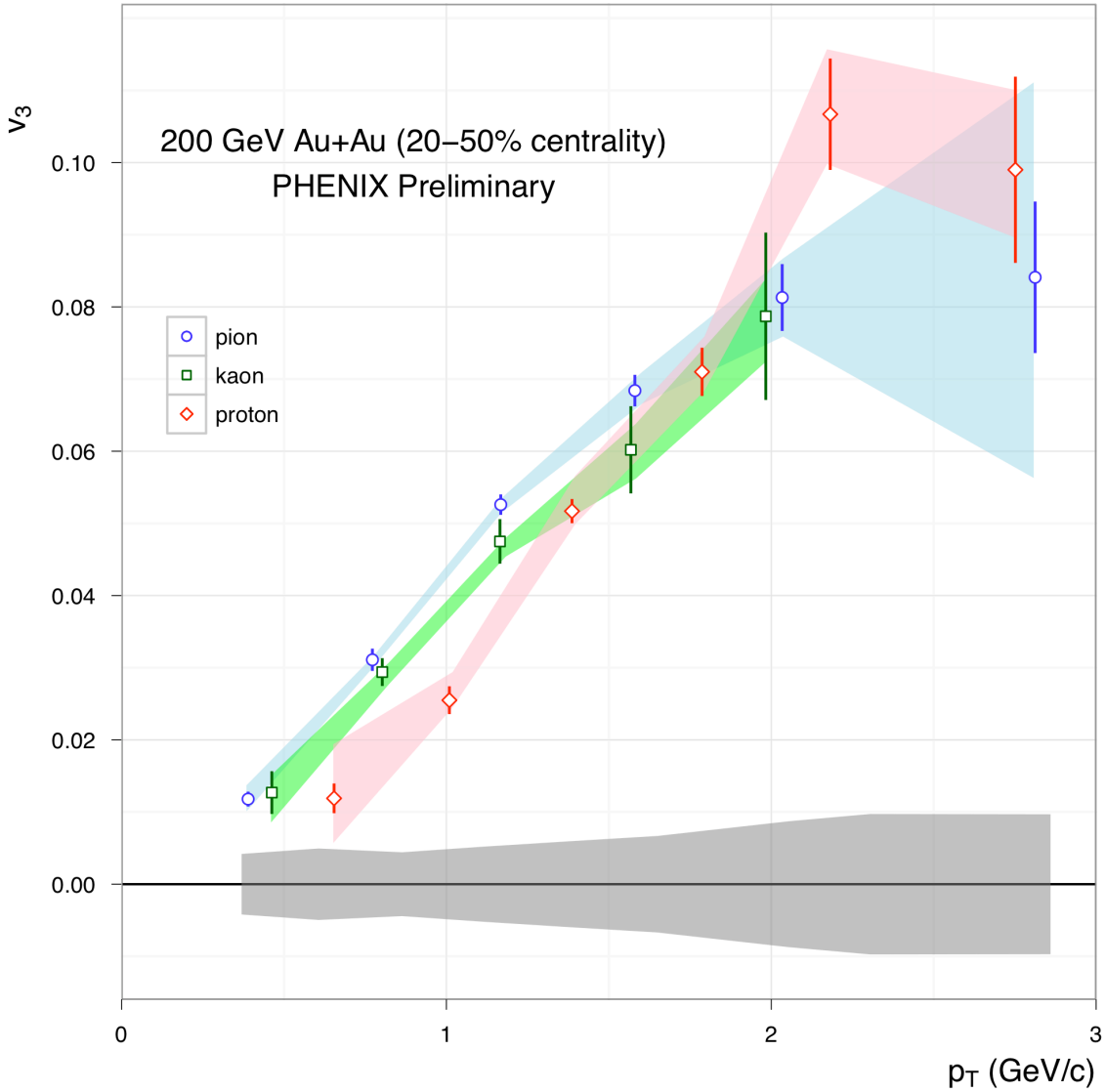
… is now available in high-def.

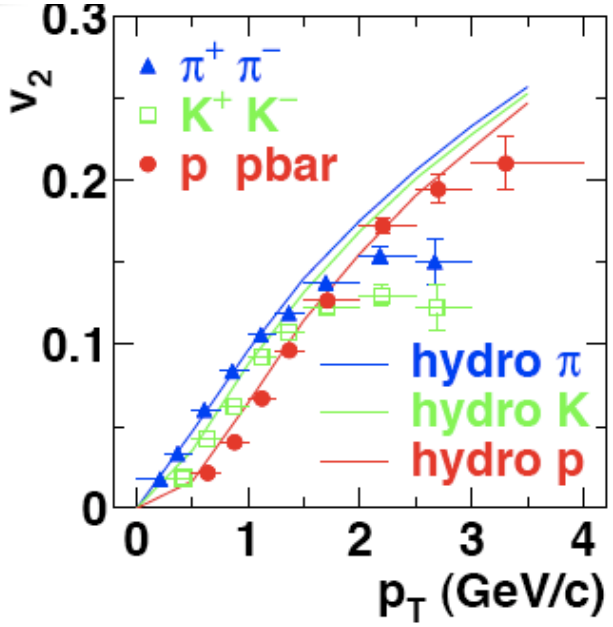


PHENIX arXiv:1203.2644, submitted to Phys Rev C in March 2012

Preliminary results for v_3 of identified hadrons

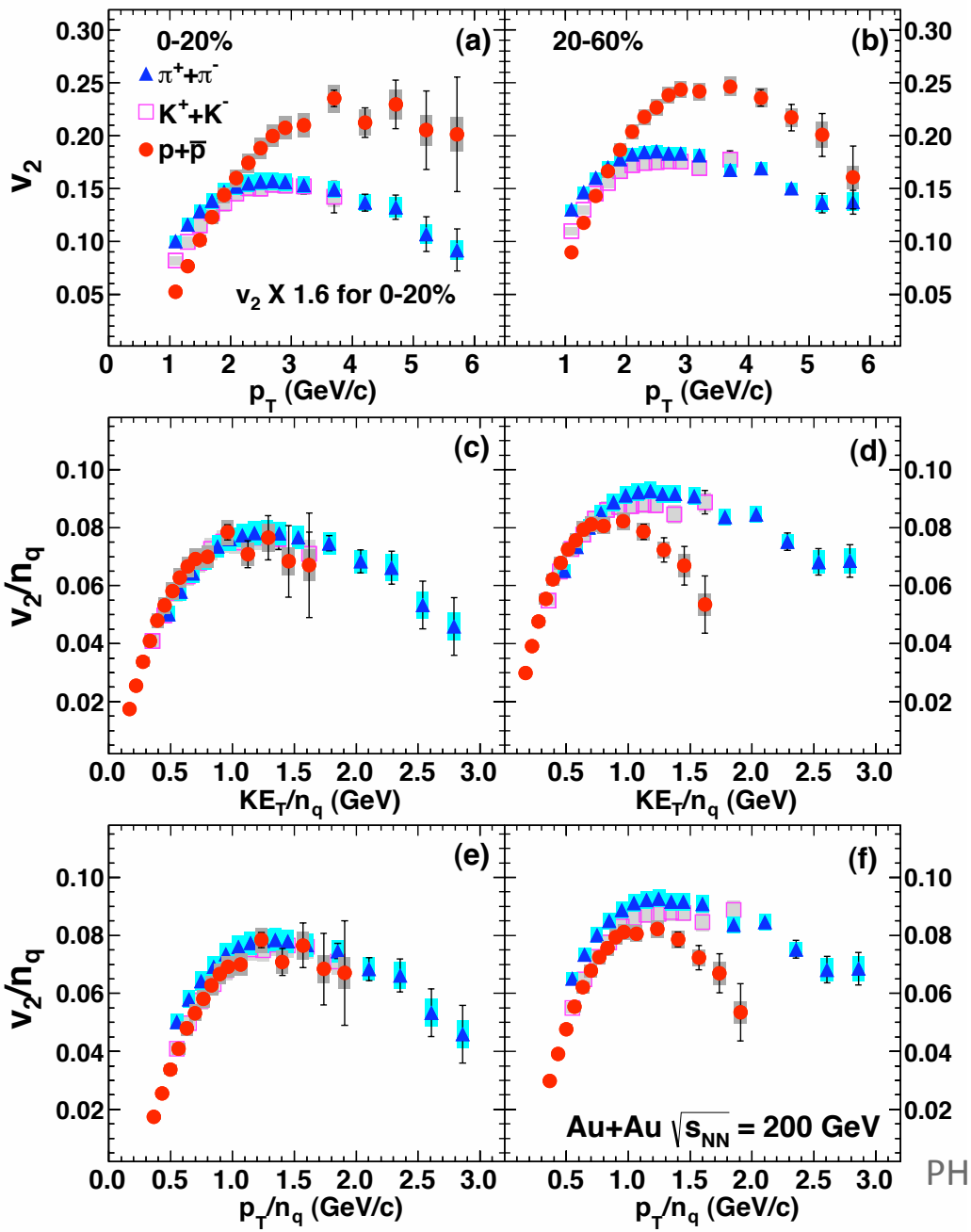
indicates similar mass splitting, (nominally) consistent with hydro final state





Much more detailed data on identified hadron v_3 and v_4 available soon!

Most Central Mid-Central

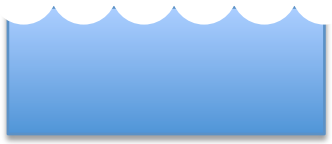


Possible "plateau" in v2 for higher p_T protons in central, but not mid-central or peripheral collisions.

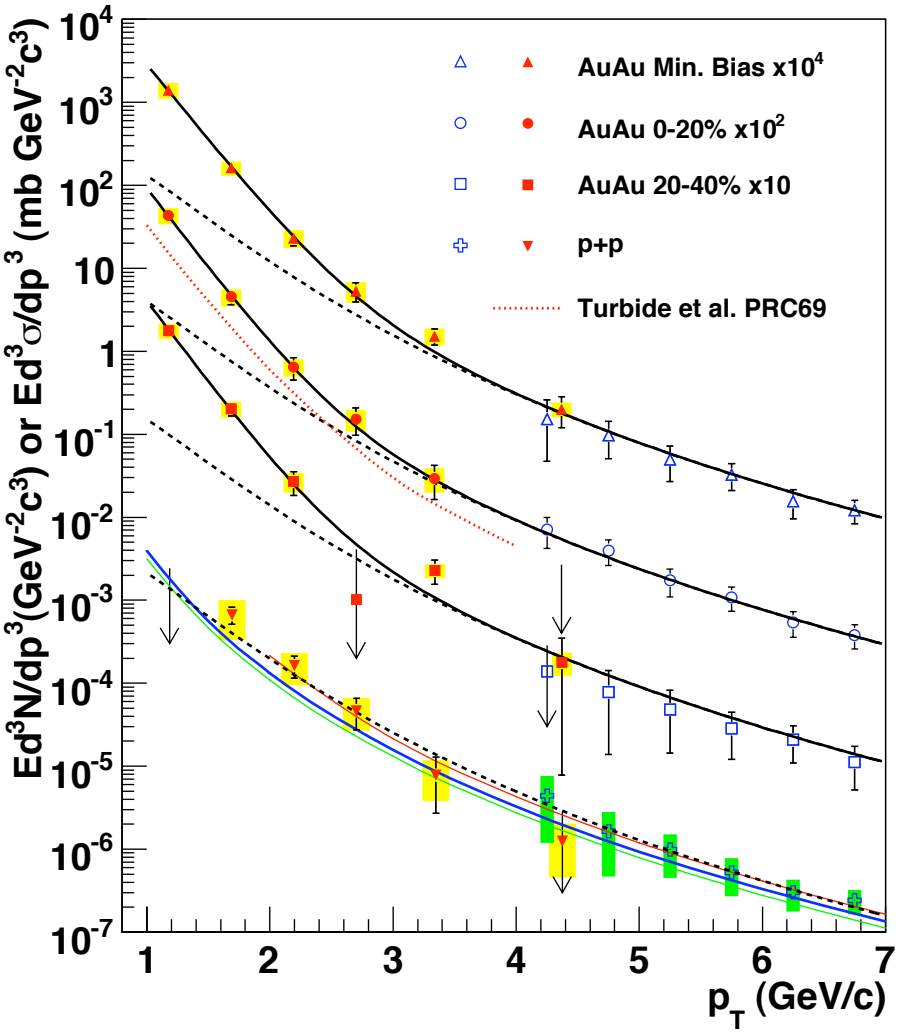
Quark number scaling is better in KE_T/n than in p_T/n, but still breaks for non-central collisions at about $KE_T/n \sim 0.7$ GeV and above.

PHENIX arXiv:1203.2644

The Evolution of Flow



Signals from the interior?



PHENIX Phys. Rev. Lett. 104, 132301 (2010)

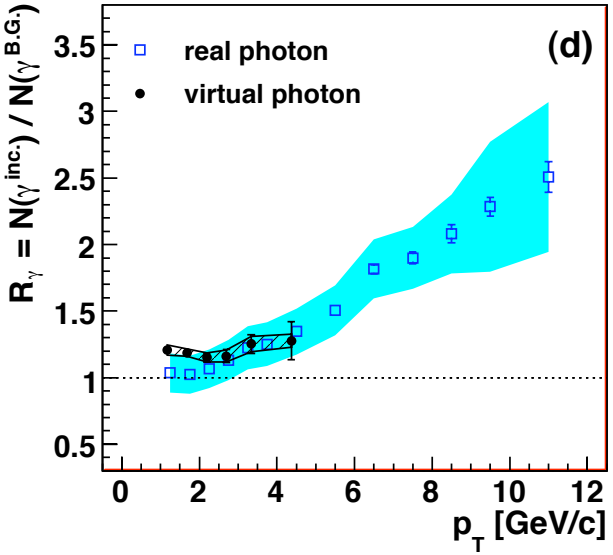
Let's consider Direct Photons

Previous PHENIX result strongly suggests that low-ish $p_T < 3$ GeV/c direct photons in Au+Au are from a thermal, ie non-prompt source.

They could encode a flow signal from an intermediate stage of the hydro evolution.

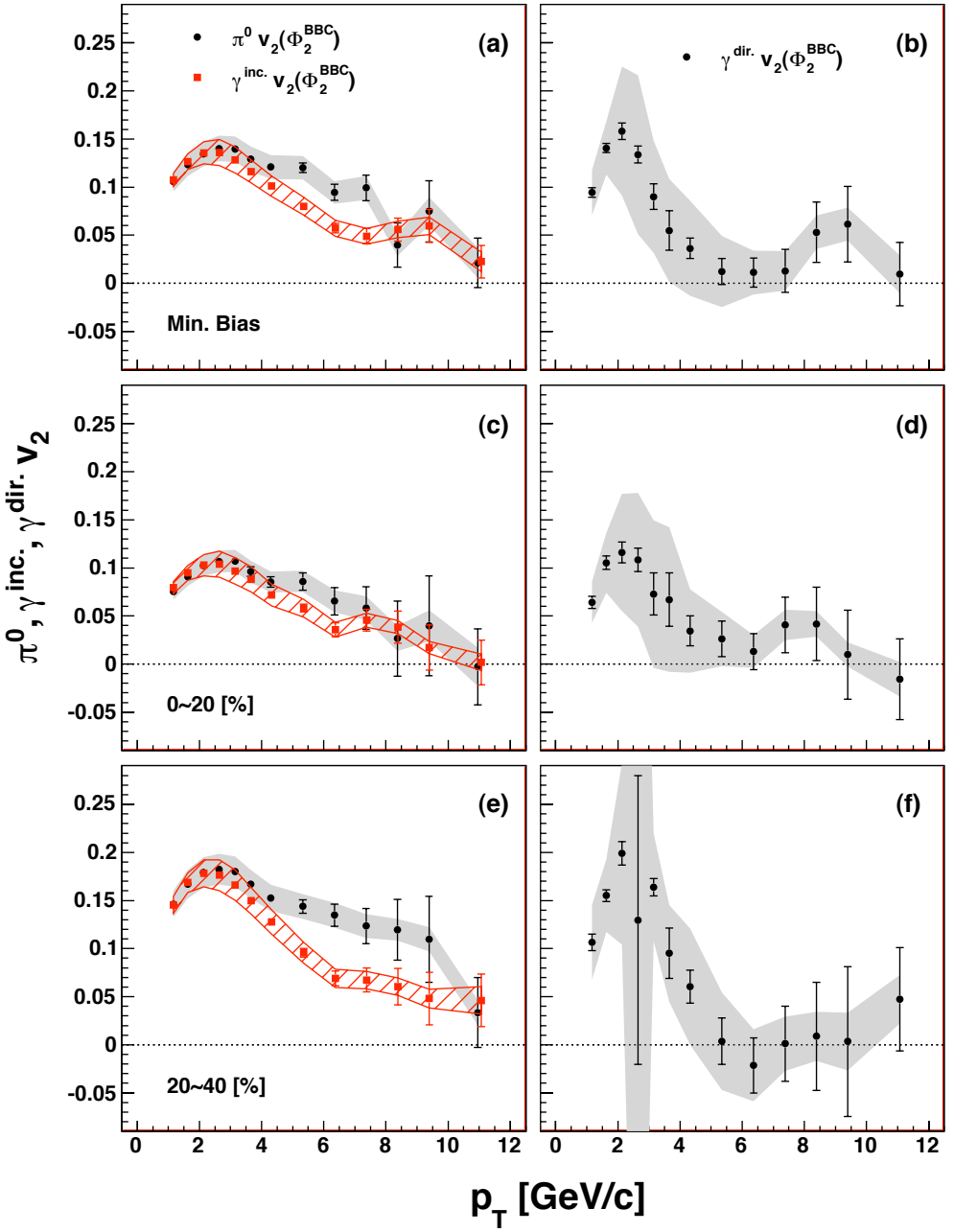
Direct Photon v_2

Technique: The v_2 for a set of particle types is the number-weighted average of the v_2 for each type, particularly decay vs direct.



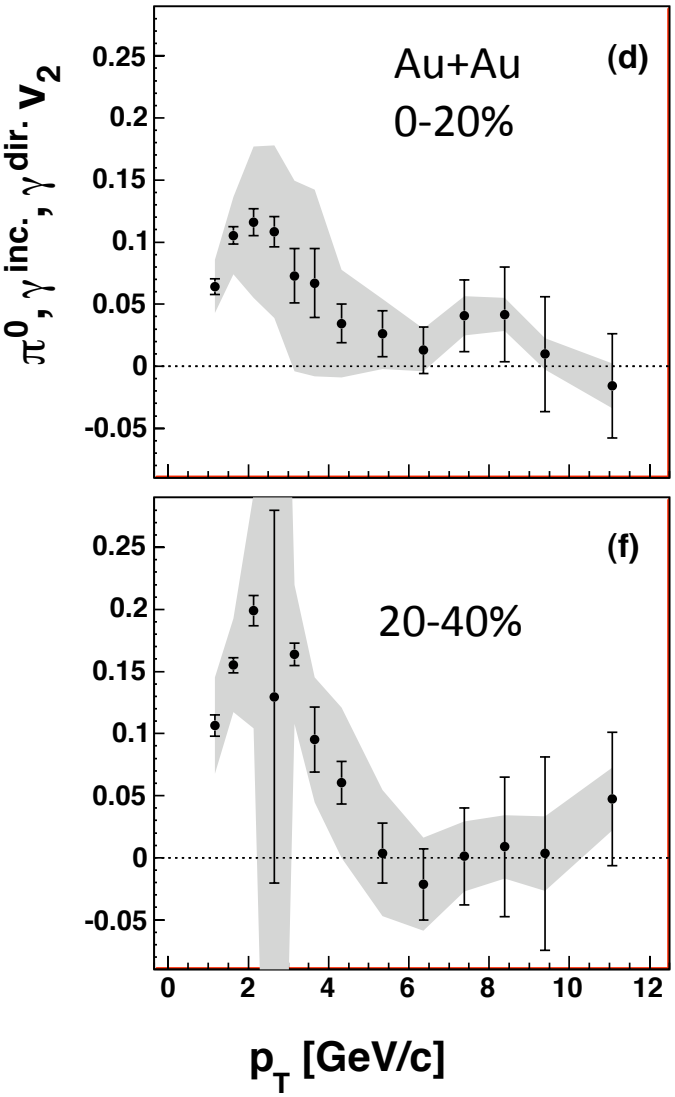
The R_γ ratio lets us partition the inclusive γ v_2 into decay and direct components.

Inclusive γ, π^0 Direct γ



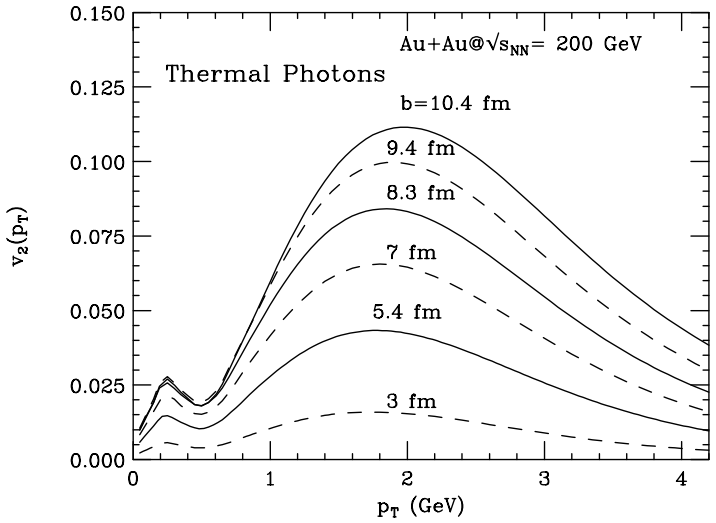
PHENIX arXiv:1105.4126

Data

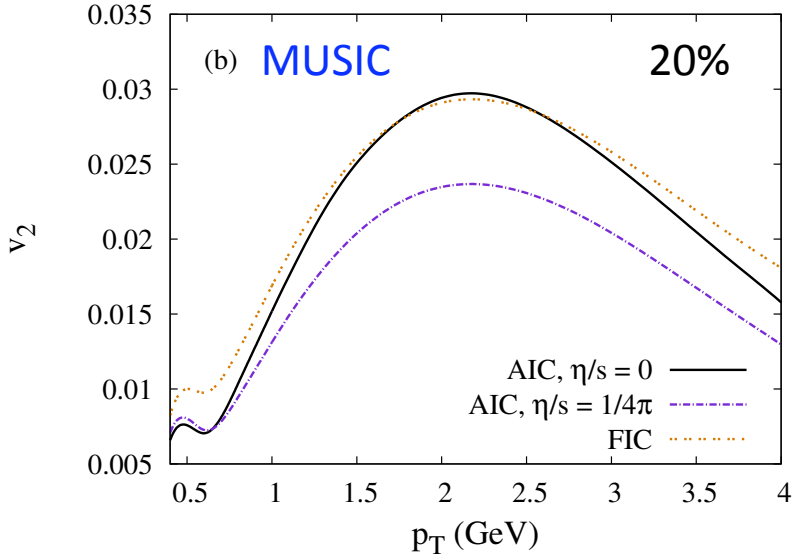


PHENIX arXiv:1105.4126

Theory
(mostly underpredicts)



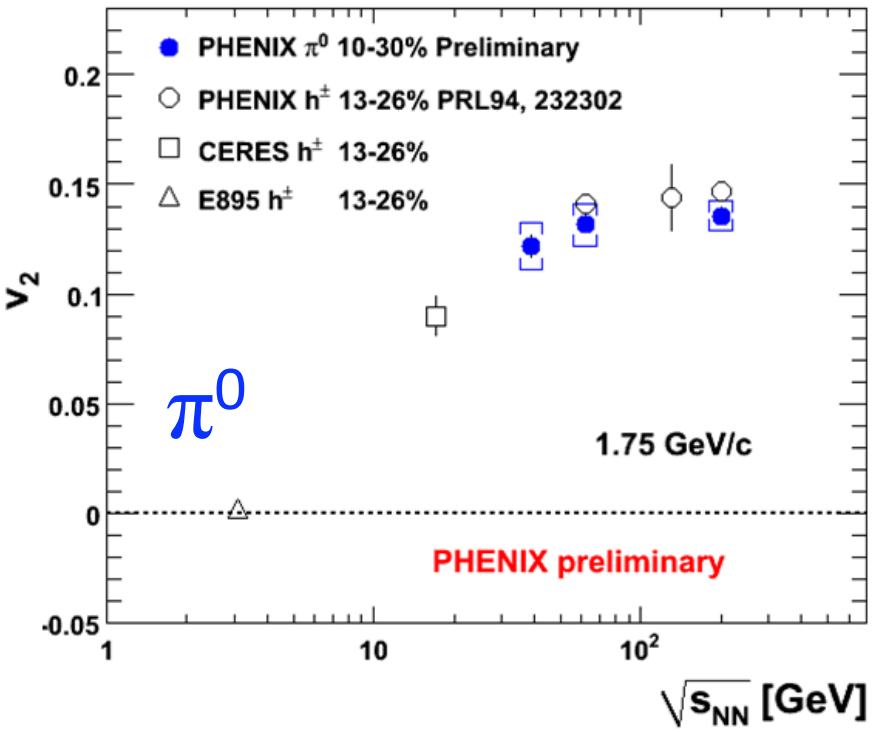
Chatterjee, et.al., Phys. Rev. Lett. 96, 202302 (2006)

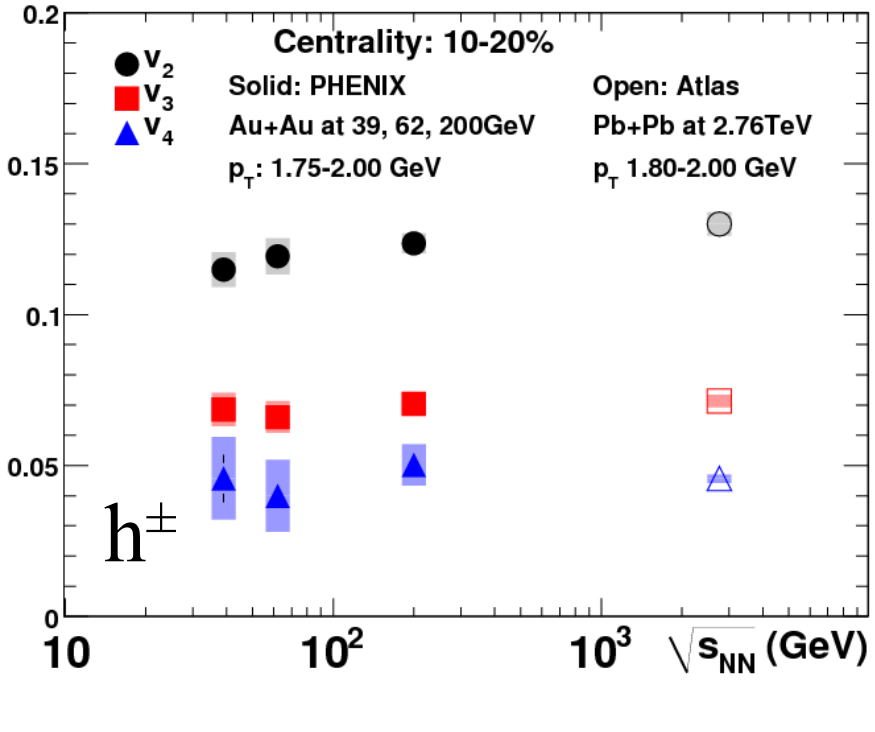


Dion, et.al., Phys. Rev. C 84, 064901 (2011)

Saturation with Beam Energy

Observe that v_2, v_3, v_4 all saturate as √s enters RHIC regime



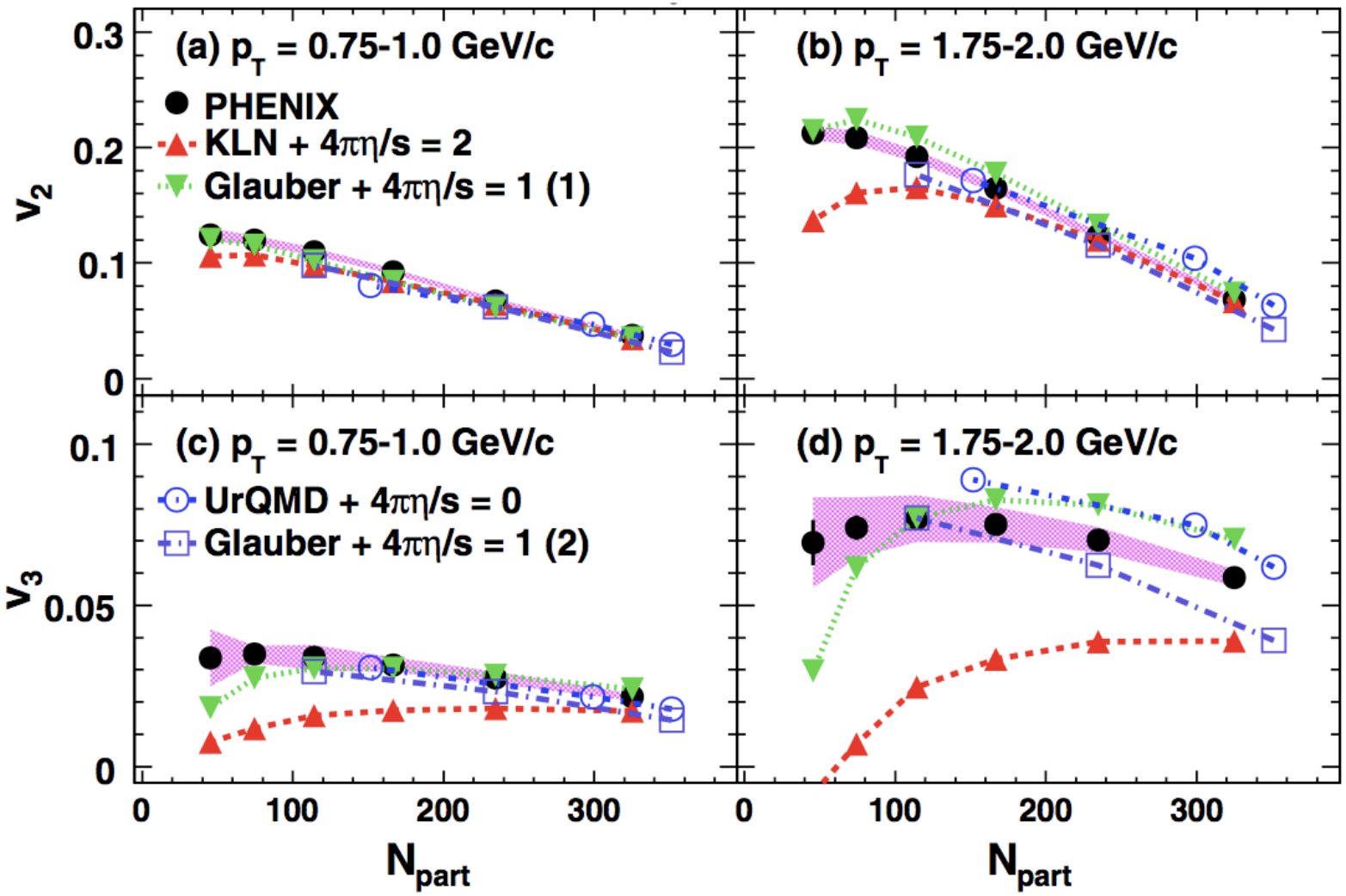


NB: A (uncontroversial) refutation of Hagedorn-style hadron gas models, where P/ε would *decrease* with beam energy.

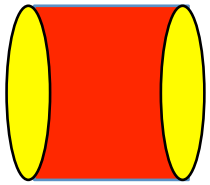
The η/s Cottage Industry

The PHENIX v3 results provide additional discrimination between flow scenarios.

PHENIX Phys. Rev. Lett. 107, 252301 (2011)



The Initial Deposition of Energy

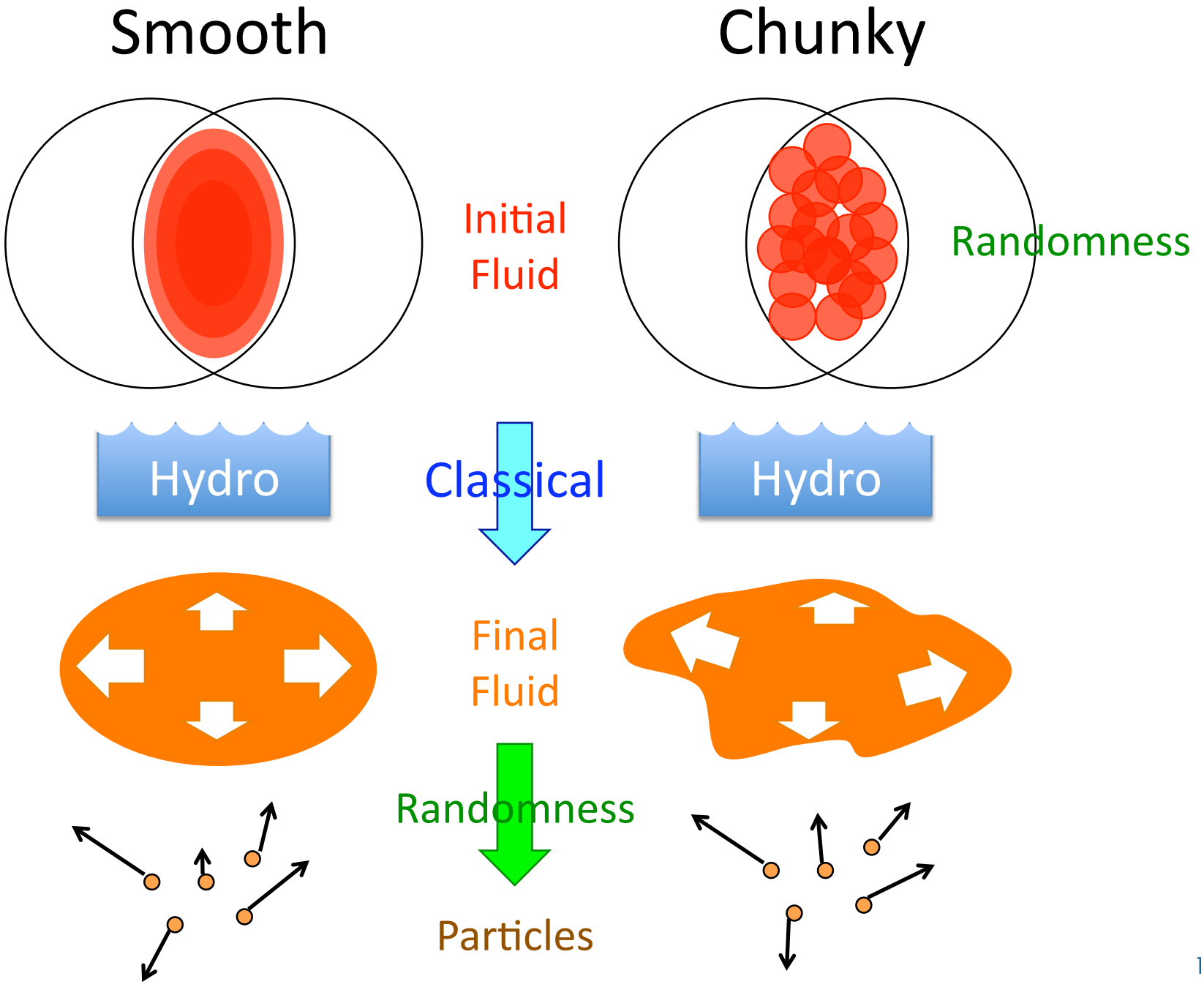


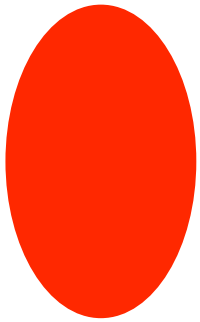
An eternal question:

OR

Smooth?

Chunky?

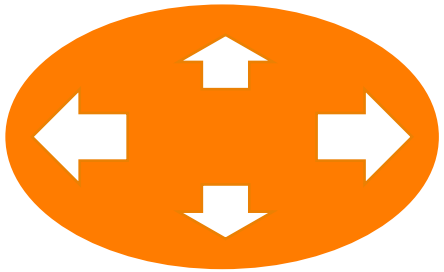

Smooth
Chunky
Initial
Fluid
Randomness
Hydro
Classical
Hydro
Final
Fluid
Randomness
Particles

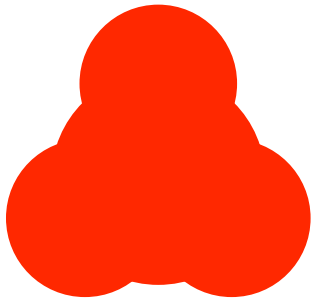


ε_2

Clear

v_2, v_4, v_6

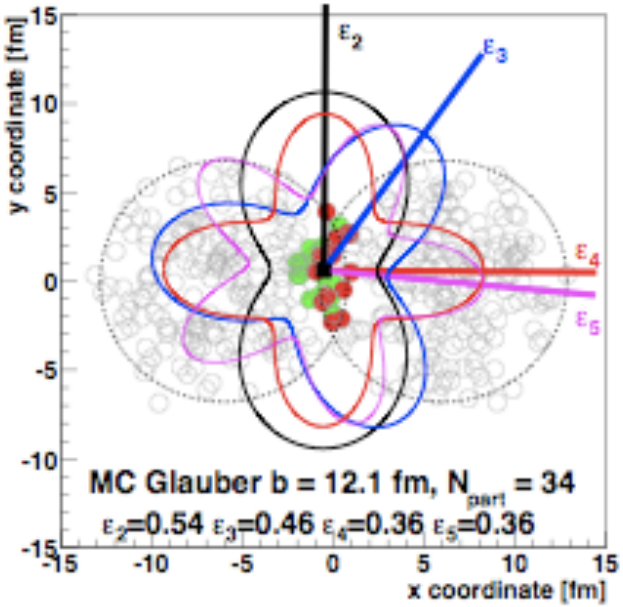




ε_3

Clear

v_3, v_6, v_9



Nagle, McCumber arXiv:1011.1853

ε_2, ε_3, ε_4, ε_5…

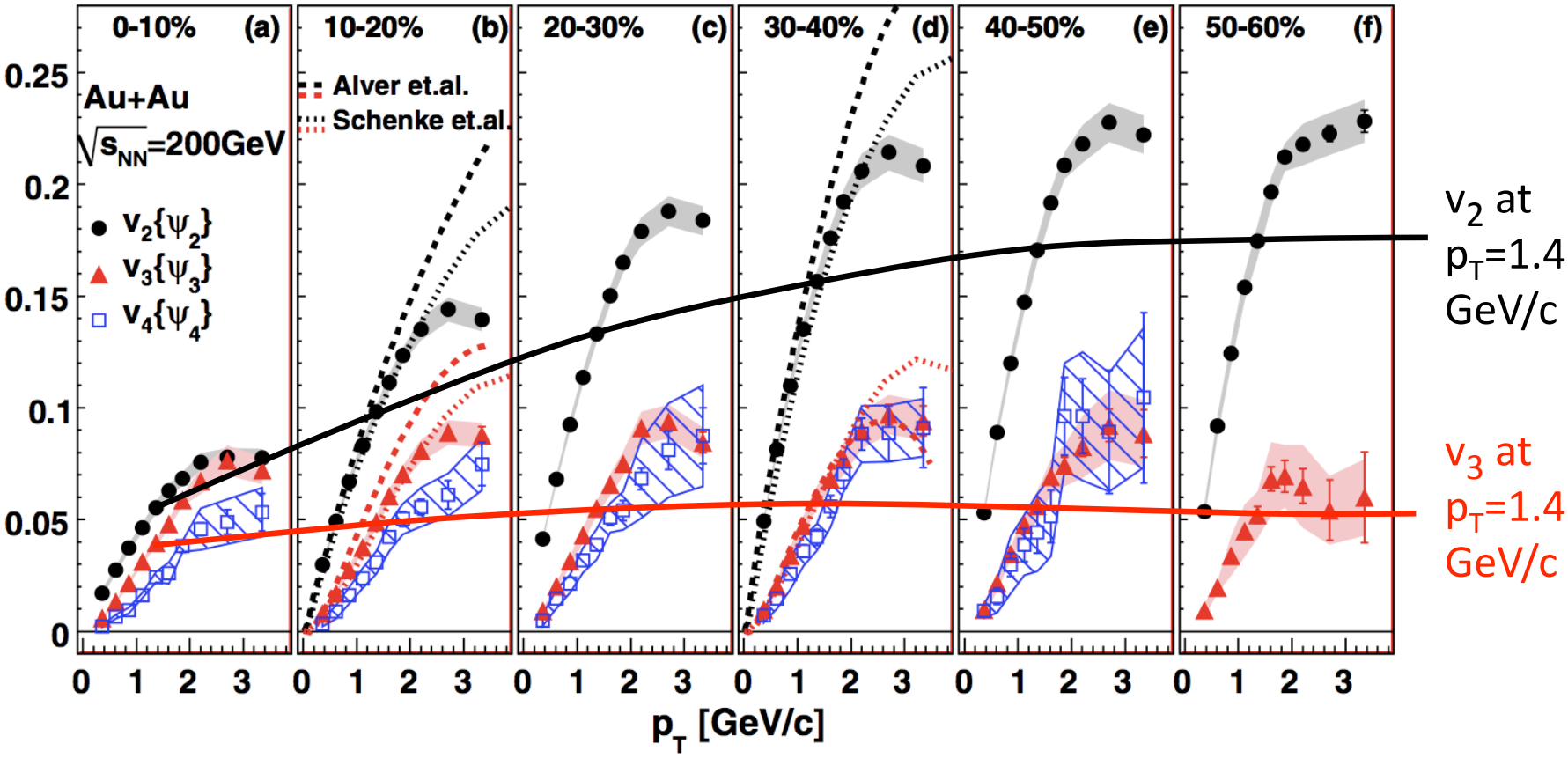
Unclear!

v_2, v_3, v_4, v_5…

?

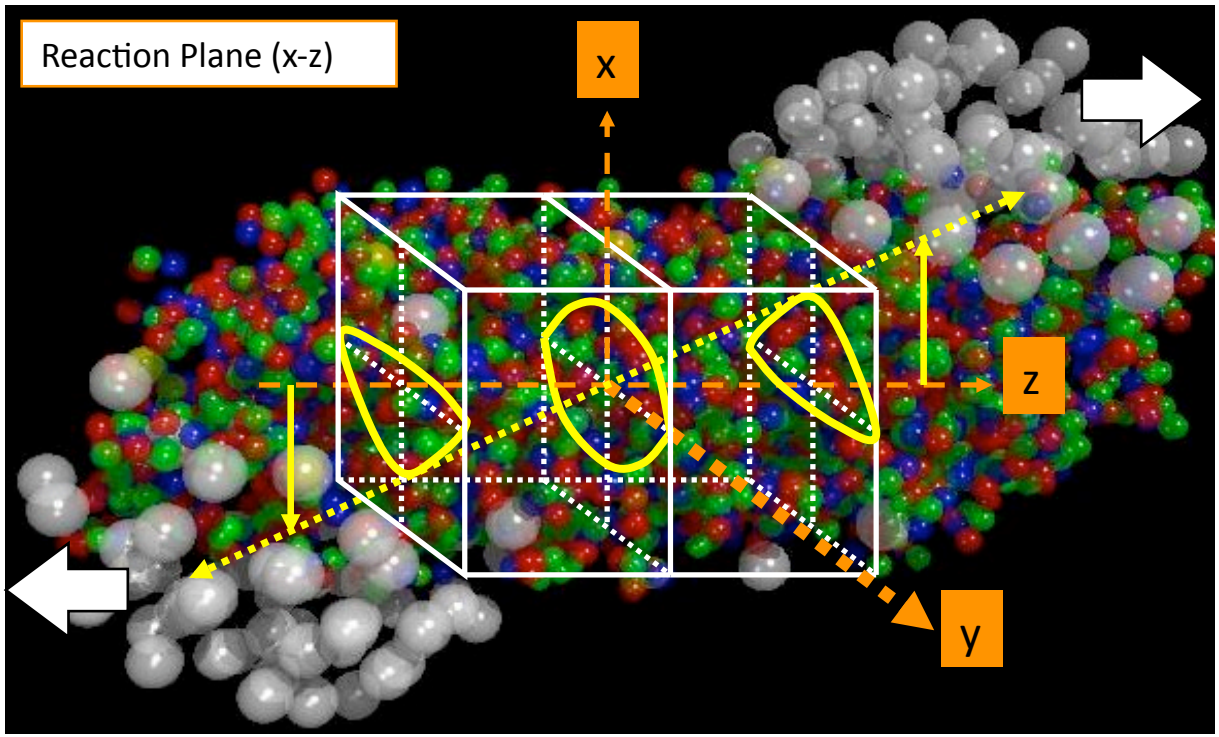
Signature of Initial Fluctuations

Observe "normal" geometry dependence of v_2, but almost no geometry dependence of v_3 → qualitatively consistent with v_3 being driven mainly by initial-state transverse-plane fluctuations.



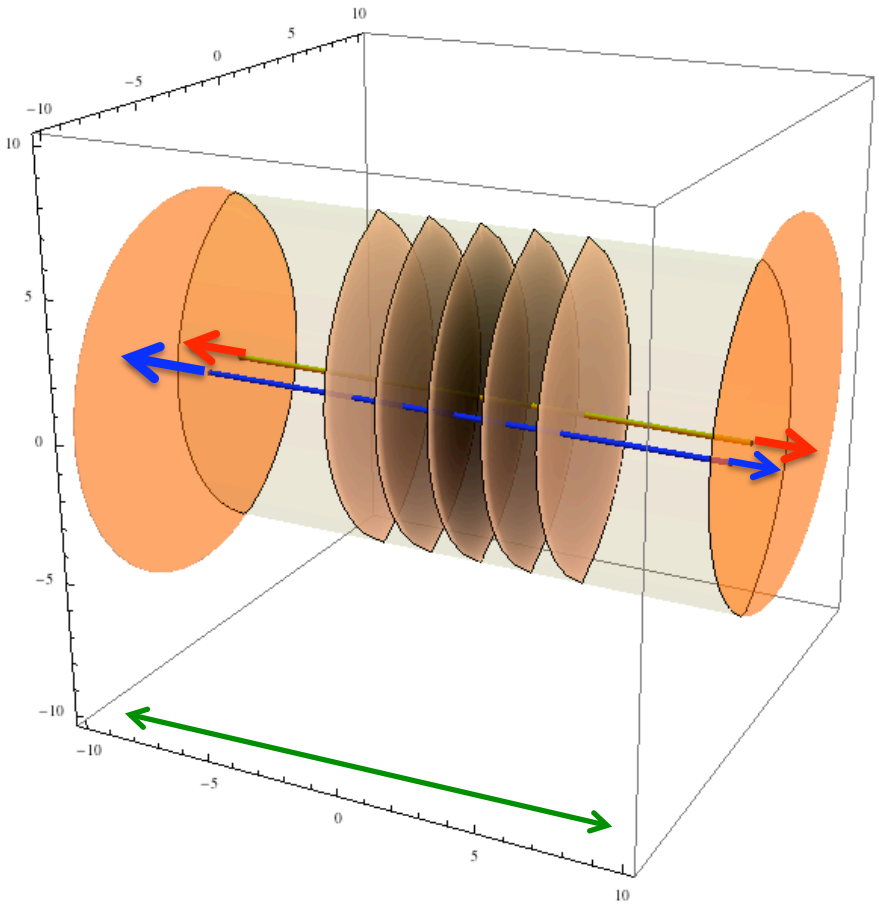
PHENIX Phys. Rev. Lett. 107, 252301 (2011)

Think outside the mid-plane



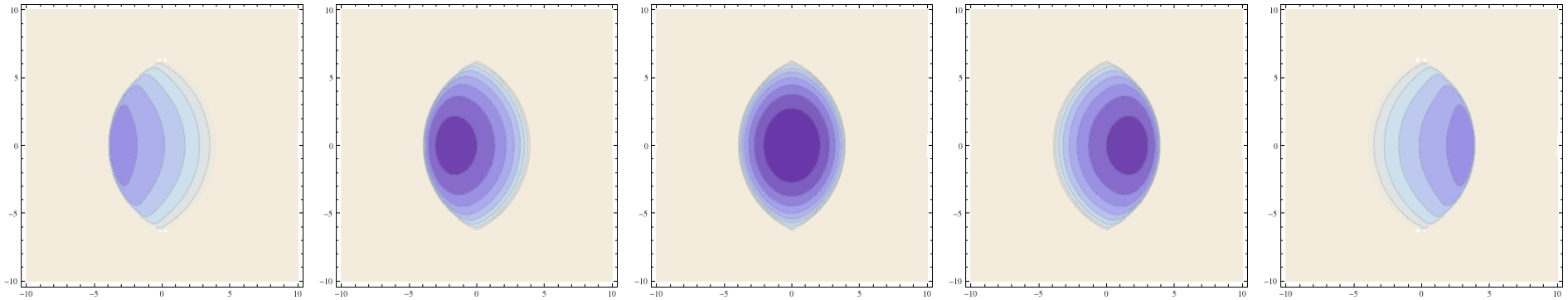
PR Cartoon of a mid-central A+A collision, with a 3-D initial state space superimposed

In the event-averaged geometry of a mid-central collision, we expect the ε_3 orientations to be *opposite* at forward vs backward rapidities



In a marginally less cartoonish toy model, longitudinal momentum conservation "twists" the initial 3-D energy distribution, leading to oppositely-signed odd moments in the spatial anisotropies.

Rapidity or Longitudinal
Initial Hydro Space



Event Plane Correlations

PHENIX Phys. Rev. Lett. 107, 252301 (2011)

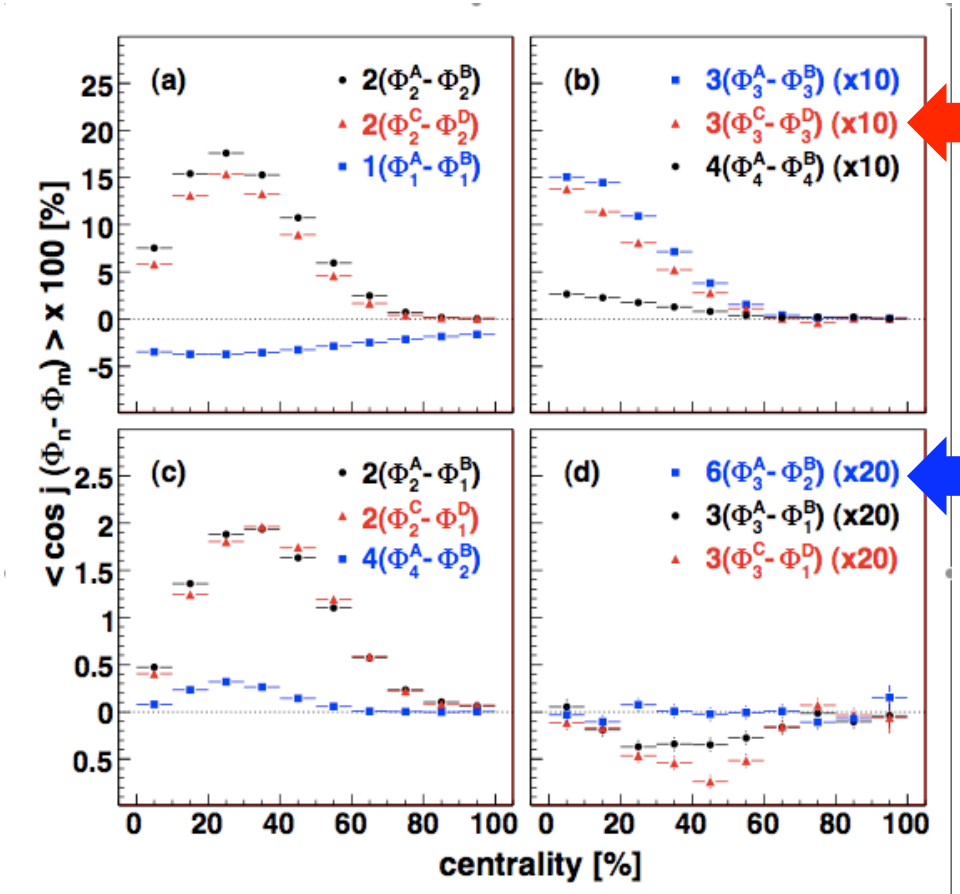


FIG. 1: (color online) Raw correlation strengths (see text) of the event planes for various detector combinations as a function of collision centrality. The detectors in which the event plane is measured are: (a) RXN North, (b) BBC South, (c) MPC North, and (d) MPC South.

North ϕ_3 positively correlated with South ϕ_3; indicates dominance of long-$\Delta\eta$ fluctuations.

No visible correlation between ϕ_2 and ϕ_3 event planes; direct test of fluctuation models

PHENIX Forward 2π Detectors

RXN: $1.0<|\eta|<2.8$

MPC: $3.1<|\eta|<3.7$

BBC: $3.1<|\eta|<3.9$

Points to Take Home

• PHENIX has a new wealth of flow (=low-p_T anisotropy) results, including PID hadron v_2 to high p_T, inclusive hadron v_3 and v_4, and direct photon v_2 -- plus more coming soon! incl. PID v_3, v_4

• The hydrodynamical picture of the final-state is generally supported, but the hadronization process is still unclear; quark number scaling of v_2 is broken above $KE_T/n > 0.7$ GeV

• Low-pT direct photon v_2 provides intermediate-stage information on how flow is built up; new ingredient, early flow?

• Both higher-order moments and forward-backward event plane correlations indicate dominance of initial-state fluctuations in driving the flow; requires modeling fundamentally new physics