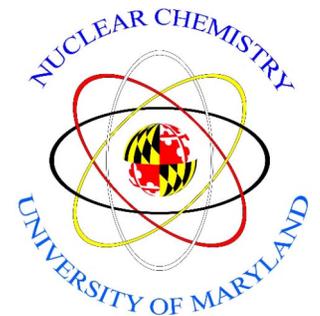
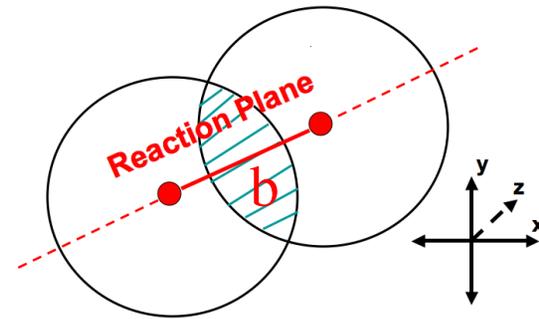


The Latest Flow Results From PHENIX at RHIC

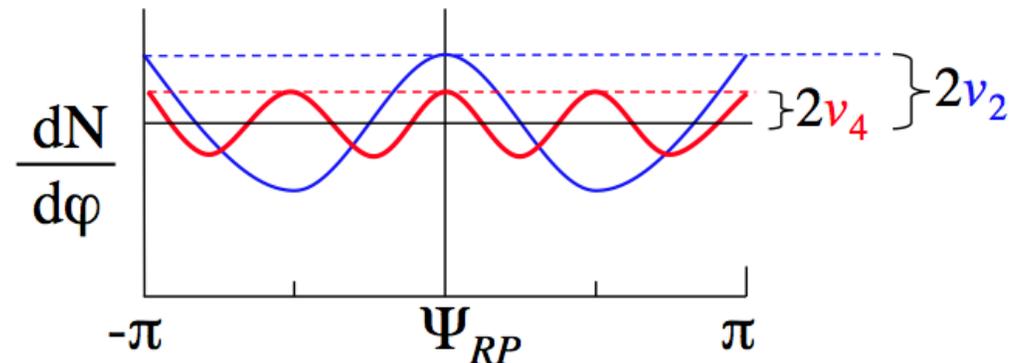
Eric Richardson
University of Maryland
For the PHENIX Collaboration
PANIC11, MIT
July 24-29, 2011



Flow



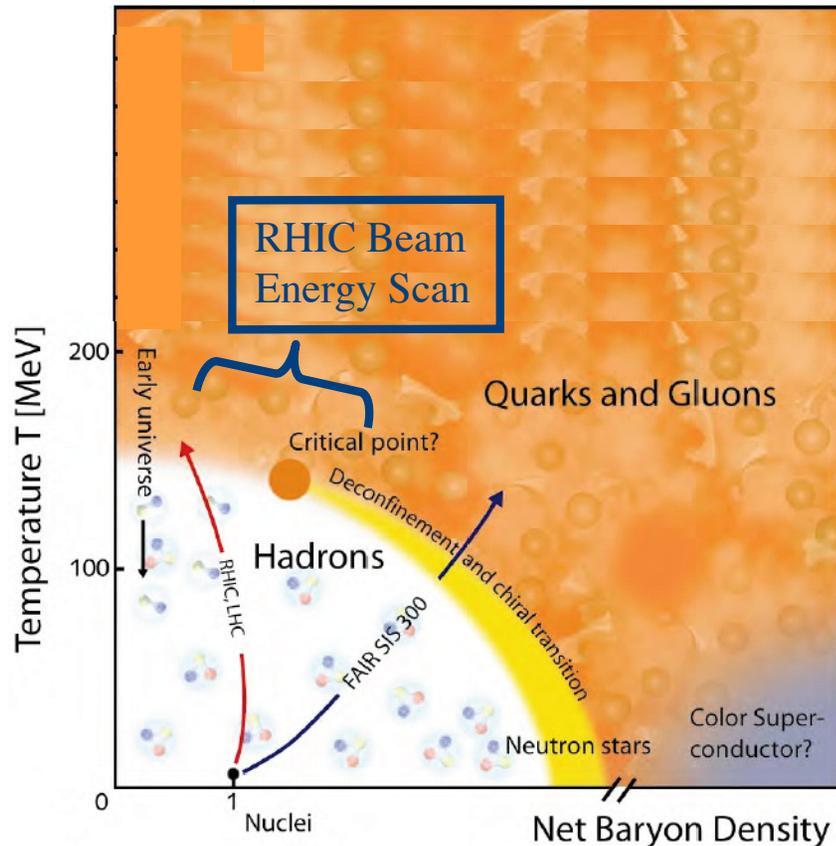
- A key measurement in making discoveries at RHIC has been measuring the asymmetry of the emitted particles ϕ distribution w.r.t. the Reaction Plane angle (Ψ_{RP}), which is referred to as “flow”.



$$\frac{dN}{d\phi} \propto 1 + \sum_{n=1} 2v_n \cos[2(\phi - \Psi_{RP})]$$

$$v_n = \langle \cos[n(\phi - \Psi_{RP})] \rangle, n = 1, 2, 3, \dots$$

Beam Energy Scan

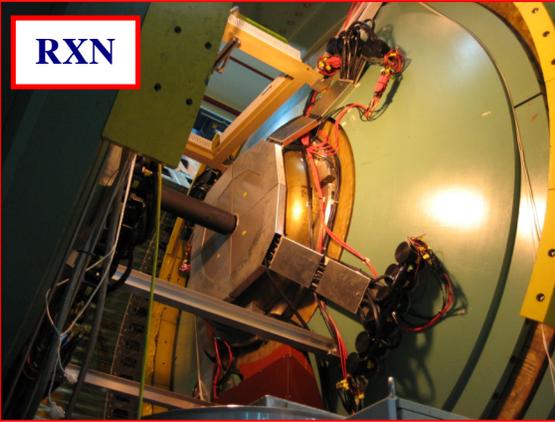


- Expanding upon the knowledge gained from RHIC's 200 GeV Au+Au collisions a beam energy scan is being undertaken to:
 - probe the nuclear phase diagram
 - further study the fundamental properties of the QGP (T , η , etc...)
 - determine at what collision energy partonic level behavior stops
 - study how initial geometry effects change with beam energy
 - find the critical point
- Measuring flow can help us investigate these issues.

Detectors

Reaction Plane Detector

Scintillator Paddles
 Inner Ring: $1.5 < |\eta| < 2.8$
 Outer Ring: $1.0 < |\eta| < 1.5$



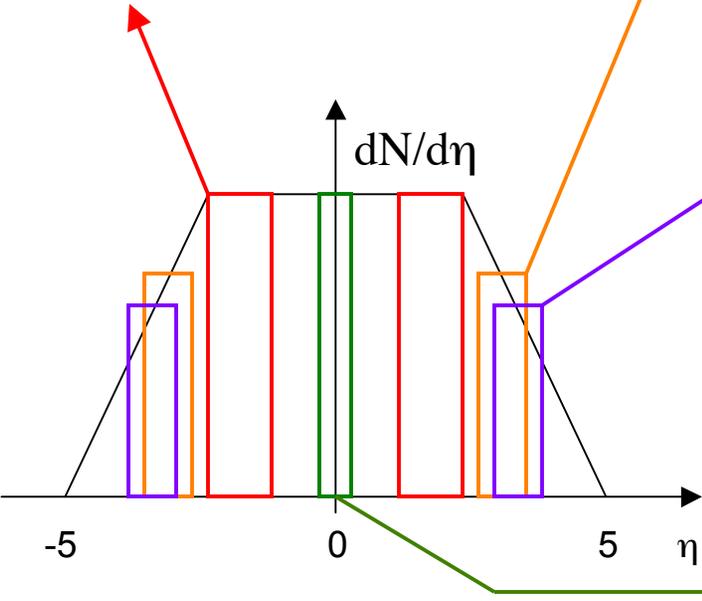
Muon Piston Calorimeter

PbWO₄ Calorimeter
 $3.1 < |\eta| < 3.9$



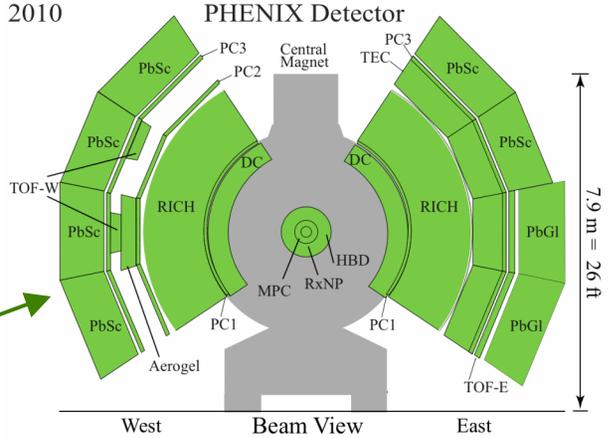
Beam Beam Counter

Quartz Cherenkov
 $3.1 < |\eta| < 3.9$

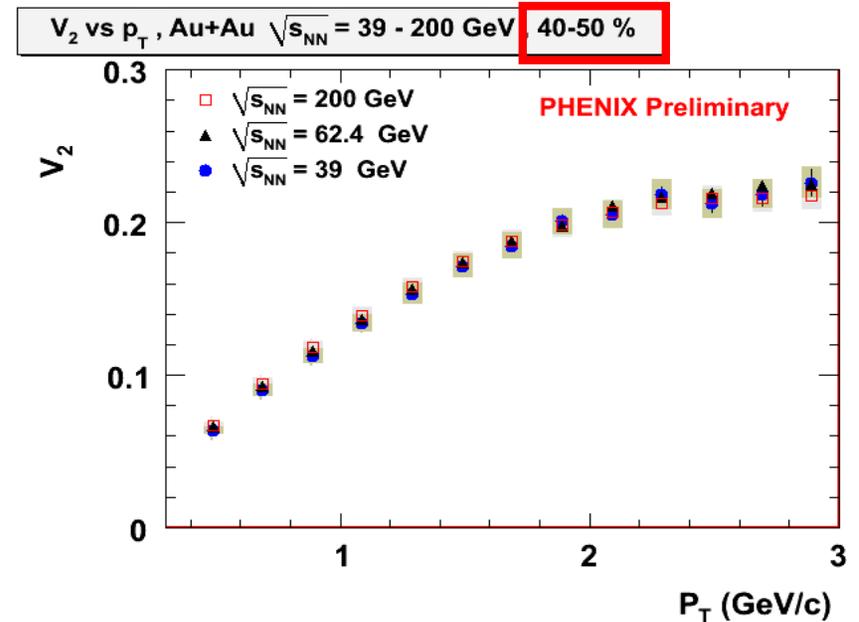
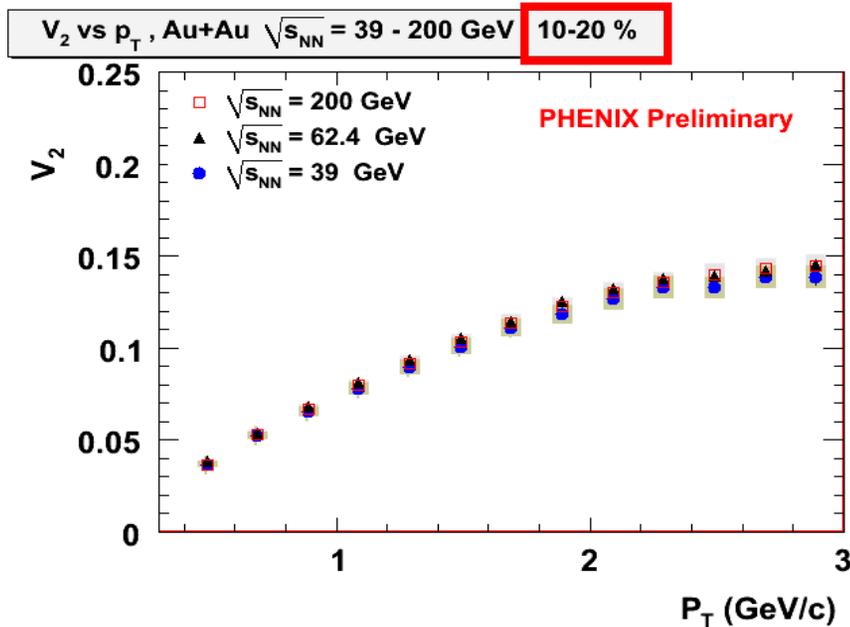


Central Arm Tracking

$|\eta| < 0.35$

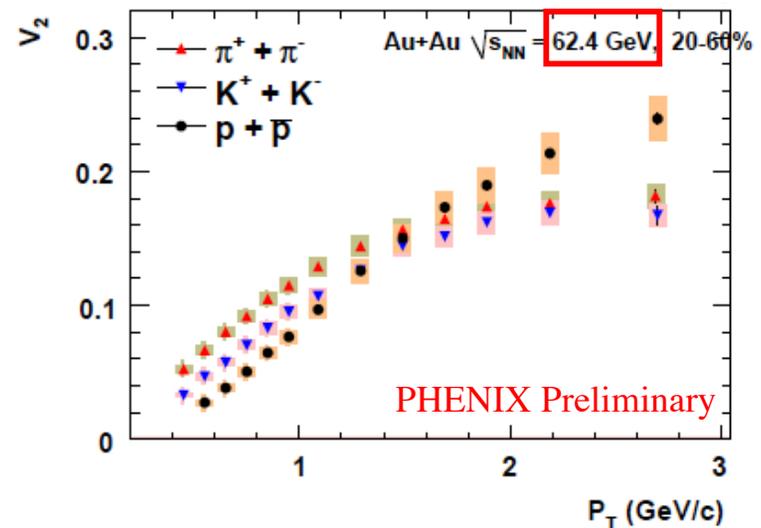
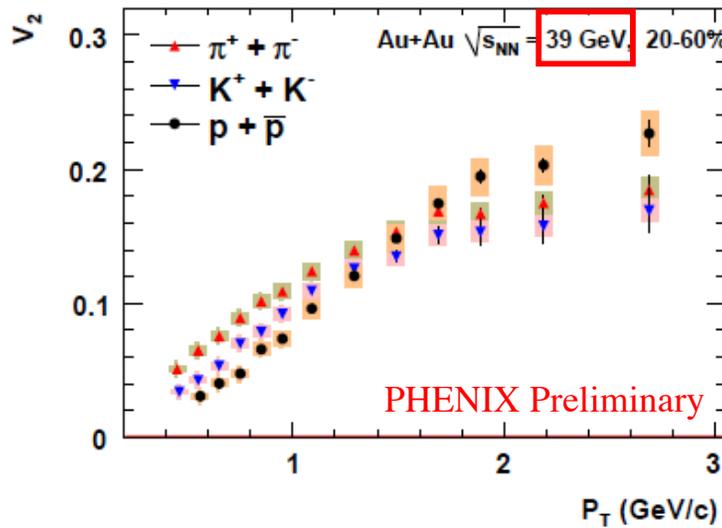


v_2 for $\sqrt{s_{NN}} = 39, 62.4$ and 200 GeV

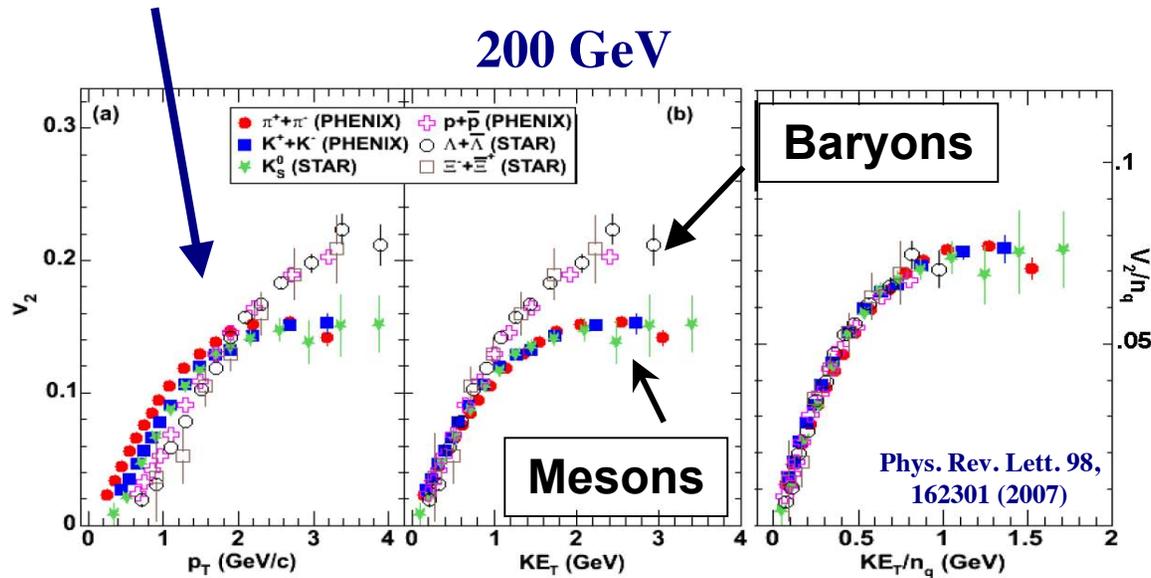


- v_2 signal is consistent between 39 \rightarrow 200 GeV.
- v_2 shows saturation down to at least 39 GeV collisions.

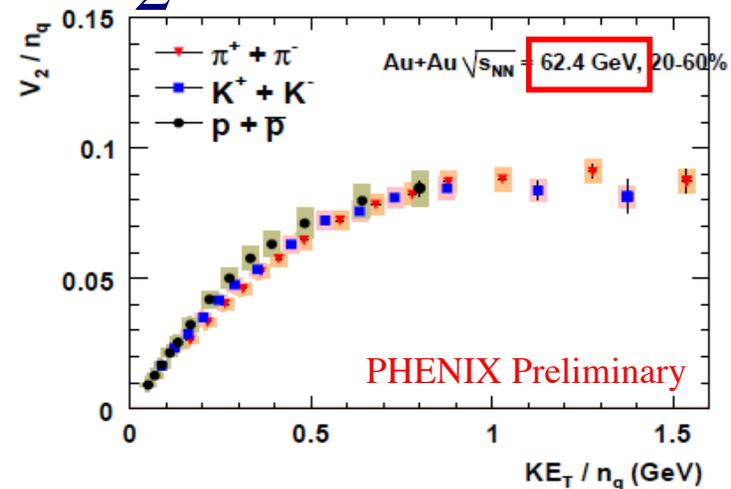
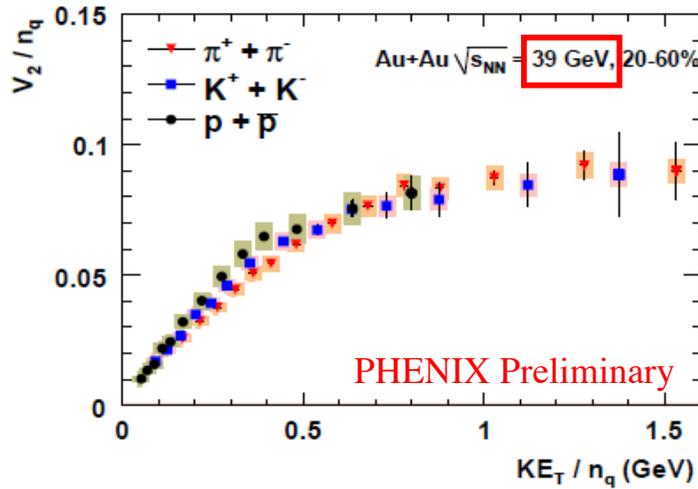
PID v_2



- Same mass scaling pattern as seen in 200 GeV collisions.

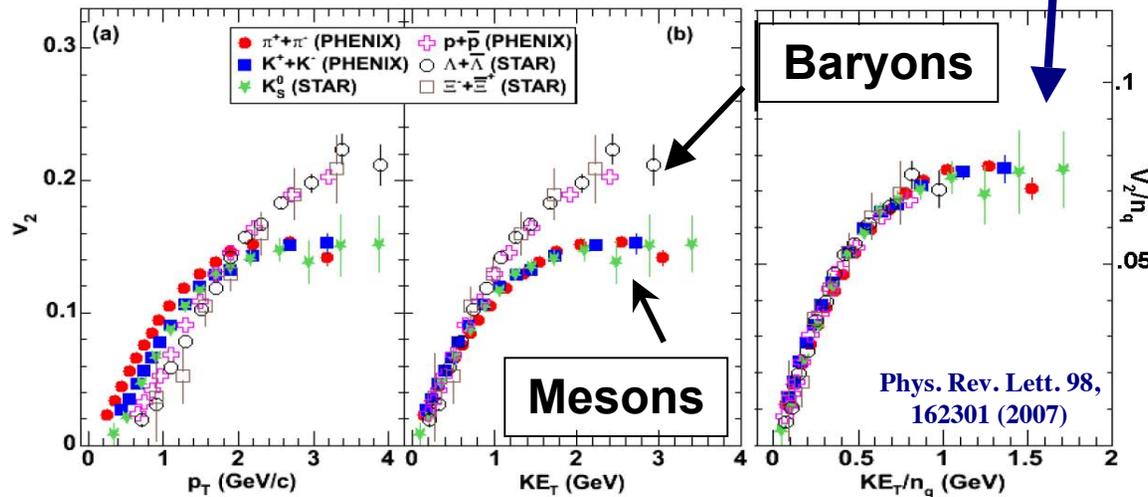


PID v_2



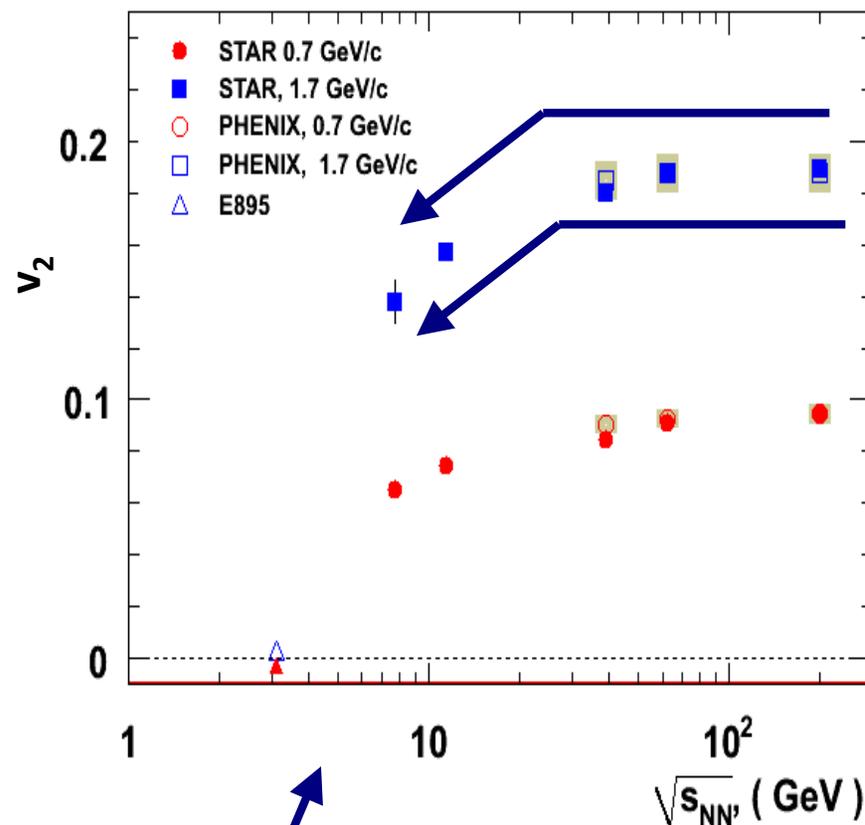
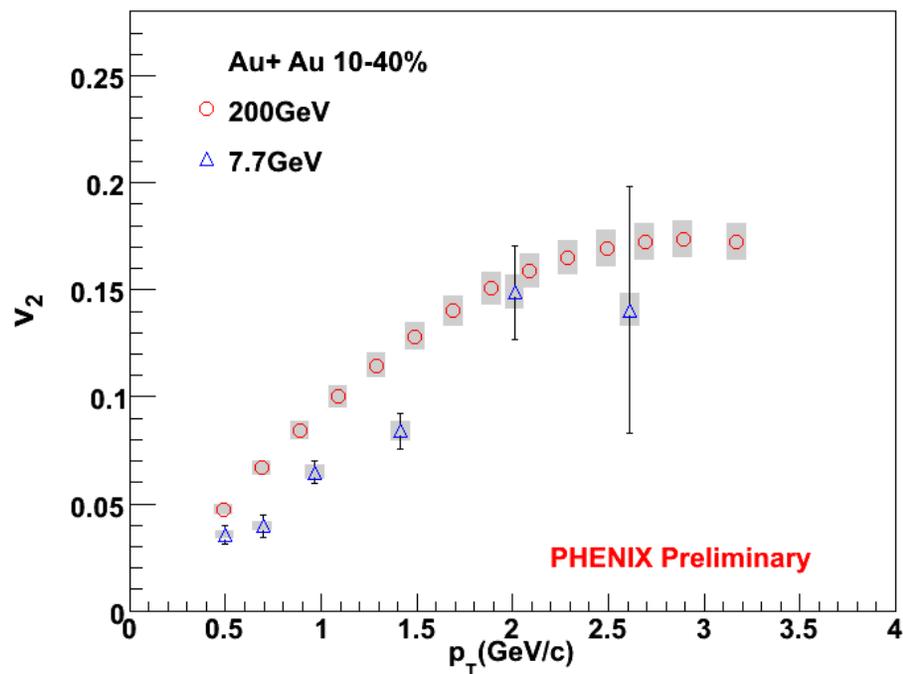
- Although small discrepancy at $KE_T/n_q \sim 0.4$ GeV, scaling indicates partonic collective flow down to 39 GeV.
- Likely due to increase prominence of (anti)protons.

200 GeV



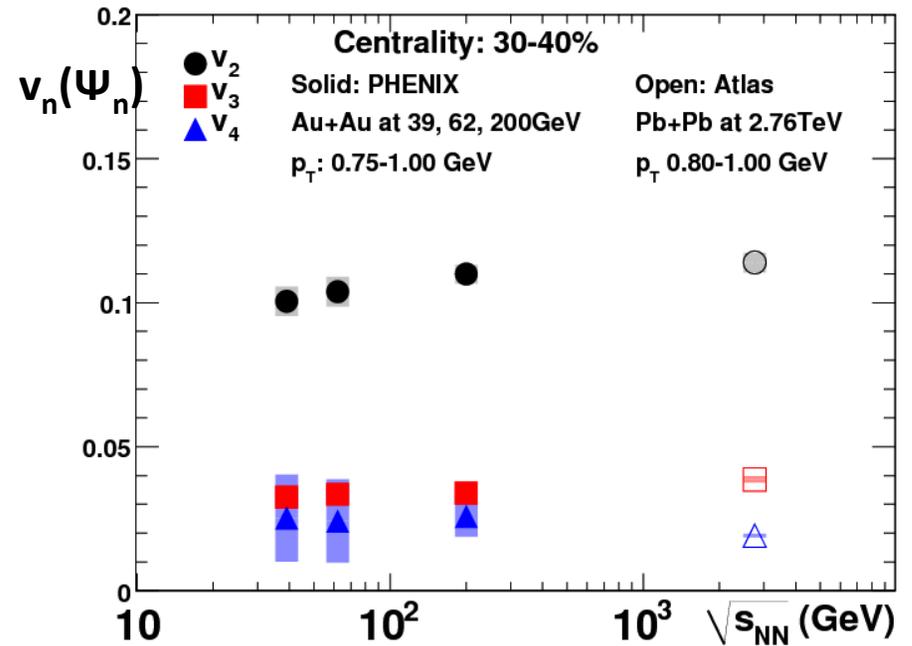
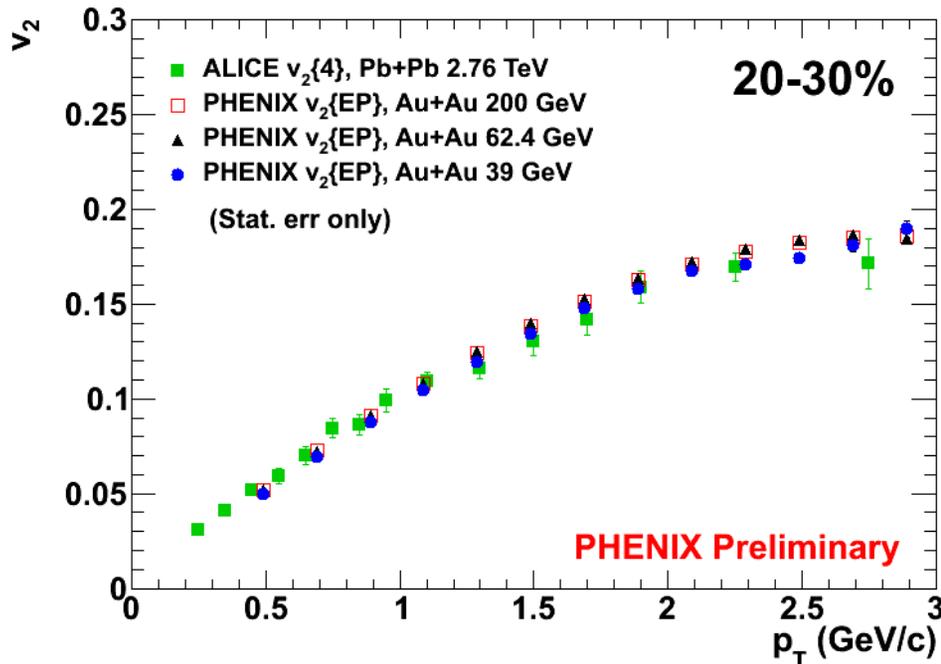
Beam Energies < 39 GeV

Preliminary, STAR, PHENIX and E895 data



- v_2 at 7.7 GeV is lower than 39, 62 and 200 GeV collisions.
- v_2 flattens at 39 GeV and above, but starts decreasing somewhere below 39 GeV
- Change from partonic to hadronic flow between 39 GeV \rightarrow 7.7 GeV?

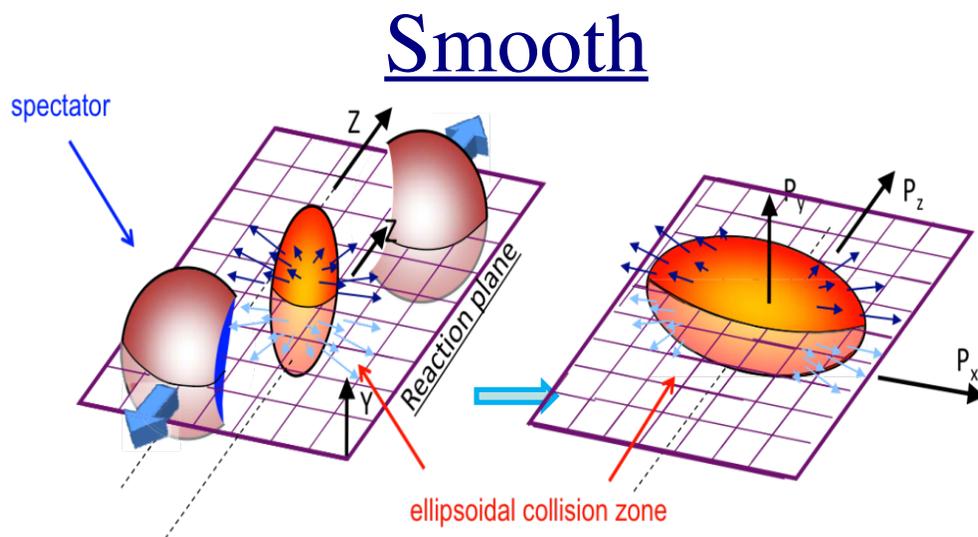
Comparison with LHC



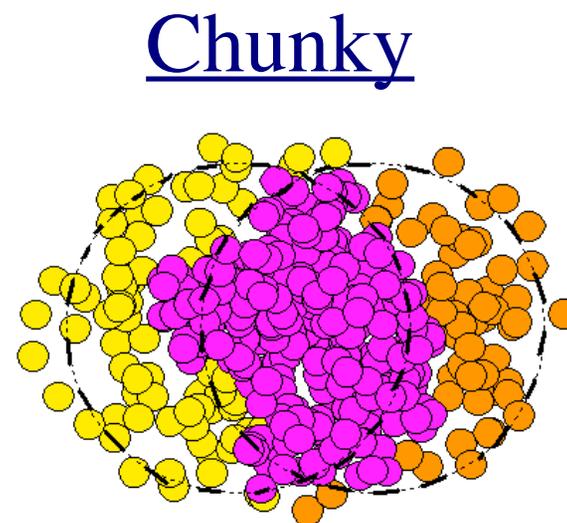
Caution: PHENIX & ALICE use different flow methods.

- Similar v_n signal at LHC energy, $\sqrt{s_{NN}} = 2.76$ TeV
- Similar hydrodynamic behavior seen from 0.039 \rightarrow 2.76 TeV

Higher Order Harmonics: v_3 & v_4



Odd harmonics **cancel**

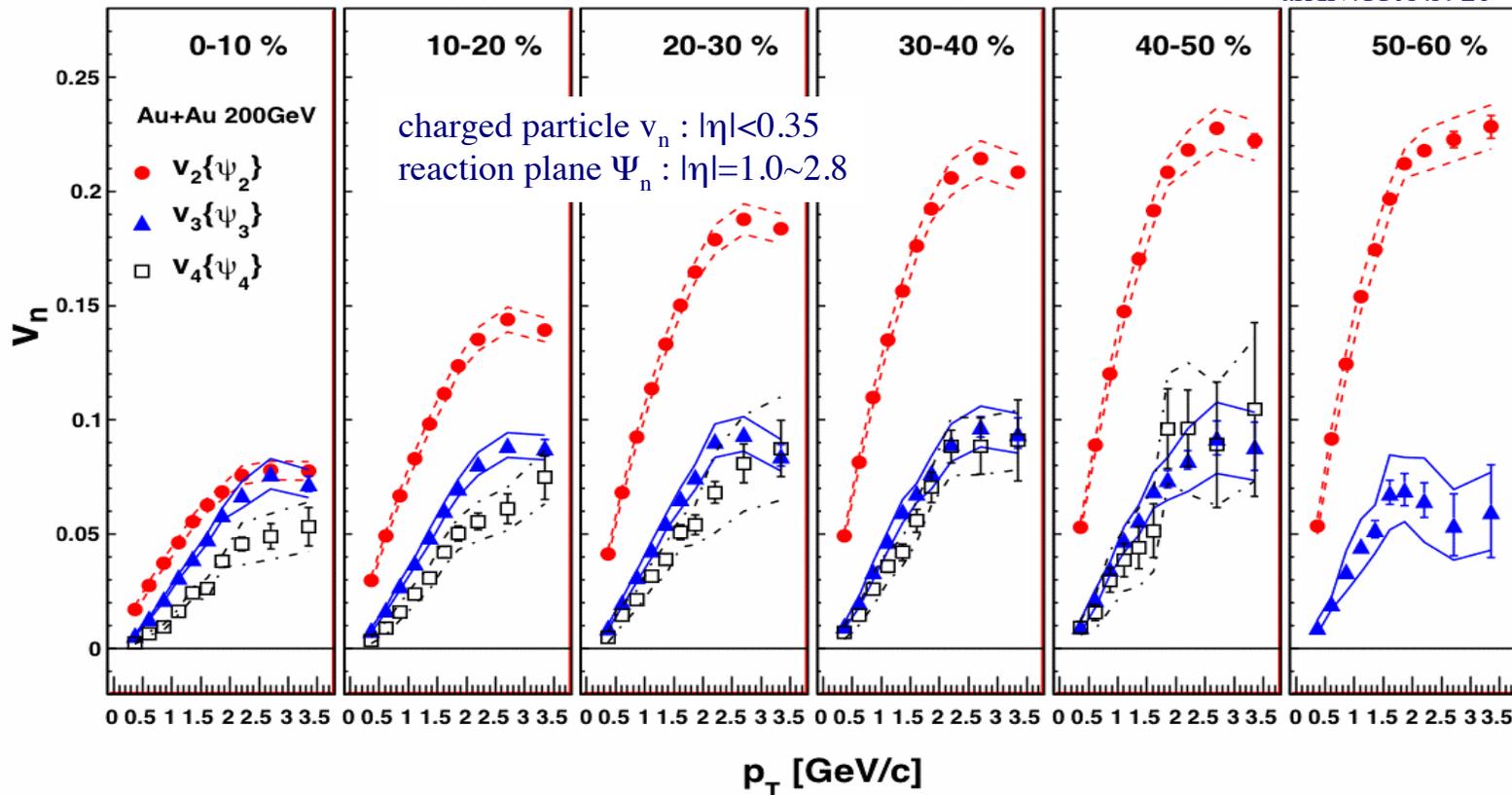


Odd harmonics **persist**

- Higher order harmonics could provide additional constraints on initial geometry models (smooth or chunky?).
- Do v_3 and v_4 saturate at 62 and 39 GeV as v_2 did?

$v_n\{\Psi_n\}$ at 200 GeV Au+Au

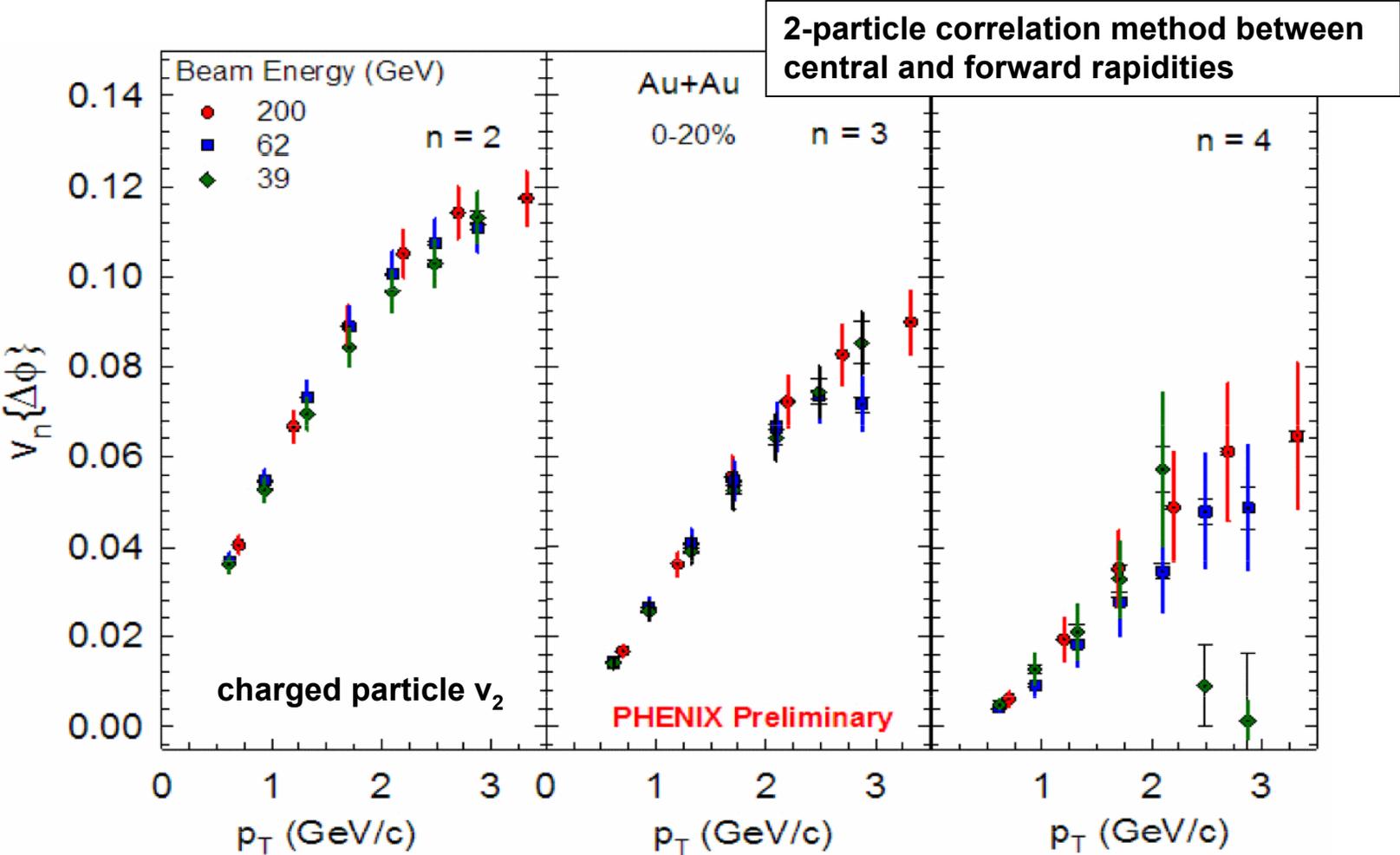
arXiv:1105.3928



- (1) Significant v_3 signal - indicates “chunky” origins
- (2) v_3 comparable to v_2 at 0~10%, but increasingly deviates with decreasing centrality.
- (3) Weak centrality dependence on v_3
- (4) $v_4\{\Psi_4\} \sim 2 \times v_4\{\Psi_2\}$

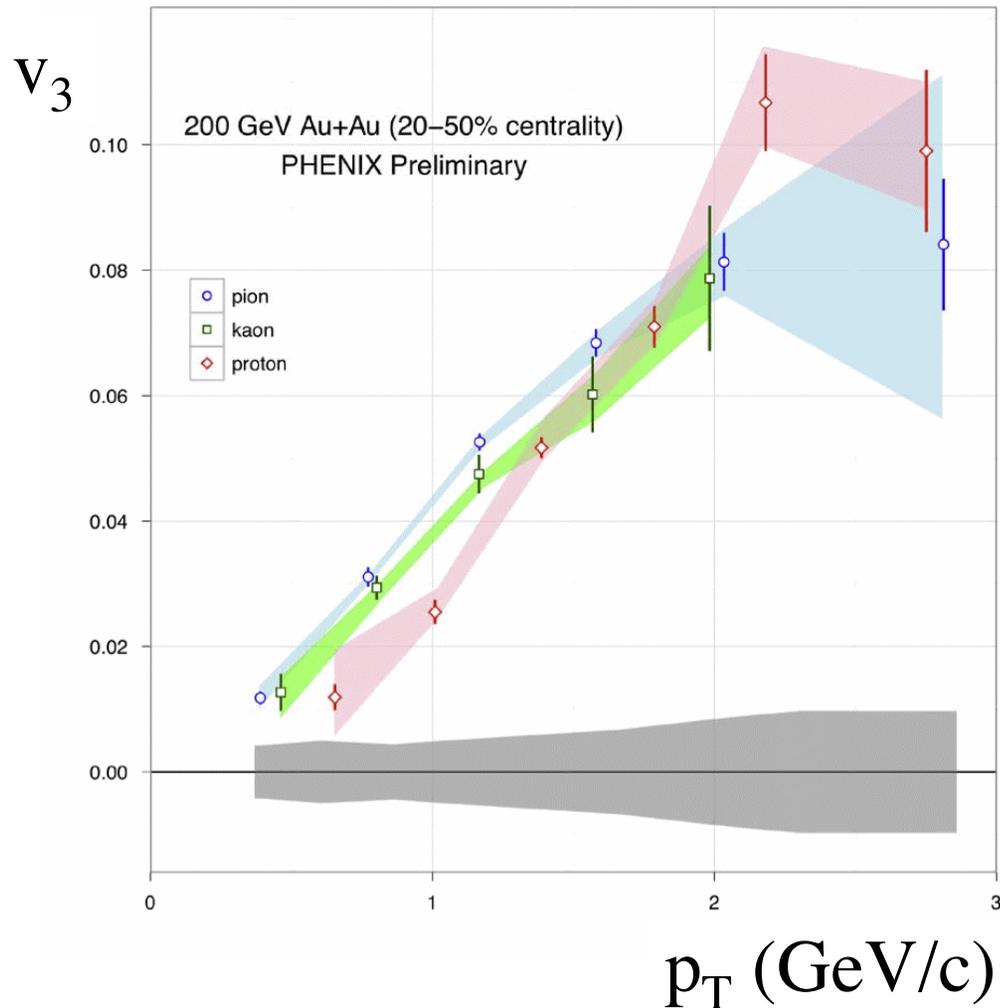
All of these are consistent with $n = 3, 4$ signal originating from initial fluctuation.

Beam Energy Dependence for Different Harmonics

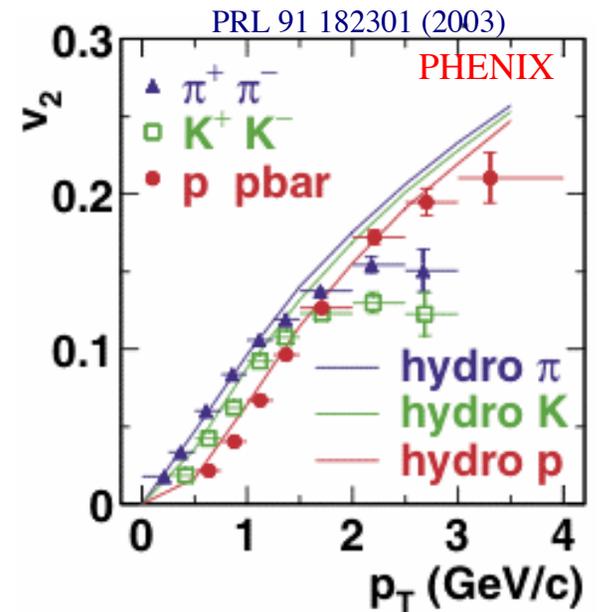


Similar hydro properties down to 39 GeV

PID v_3 @ $\sqrt{s_{NN}} = 200$ GeV

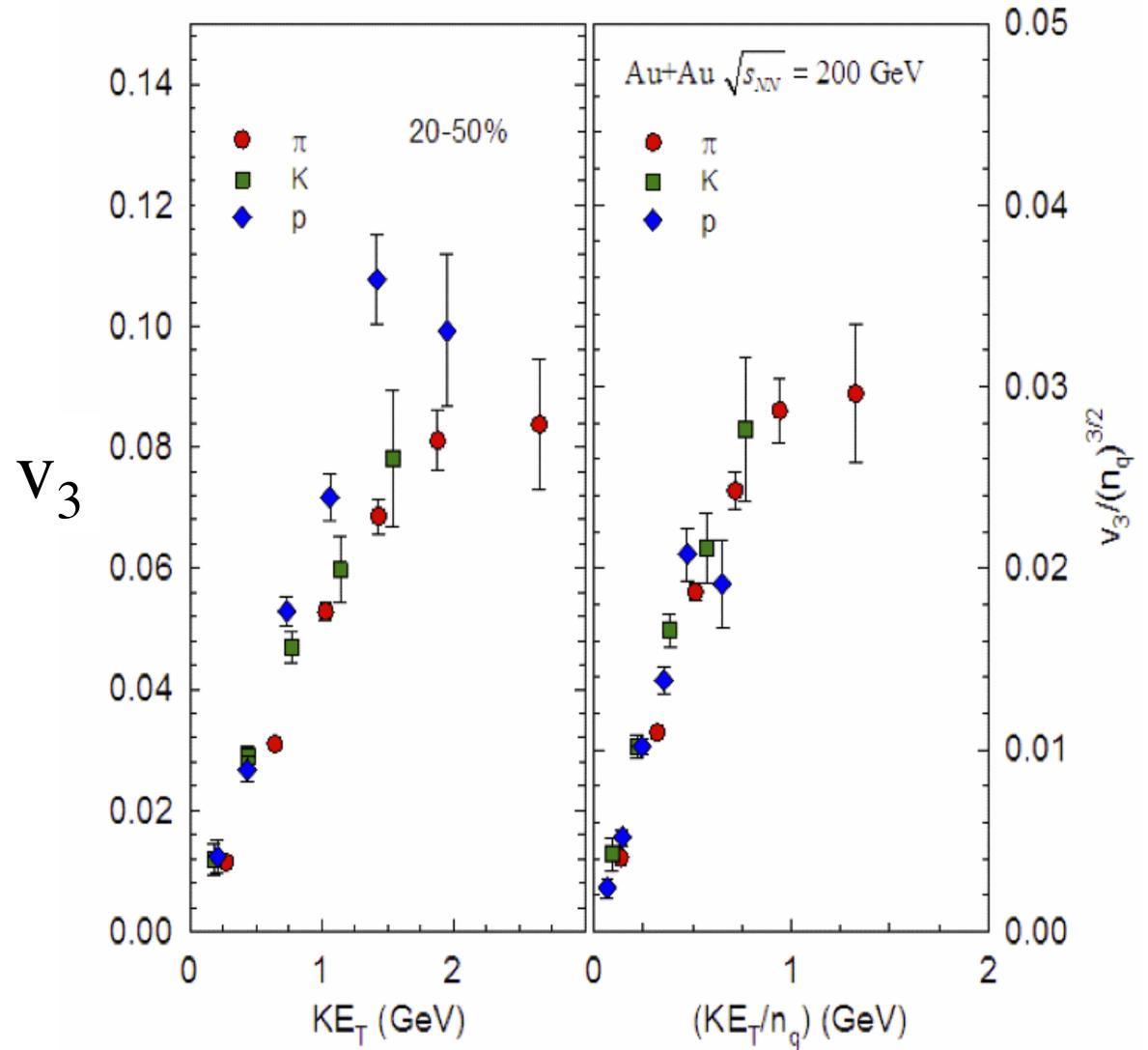


As with v_2 , mass ordering is observed with v_3 , confirming hydrodynamic behavior.



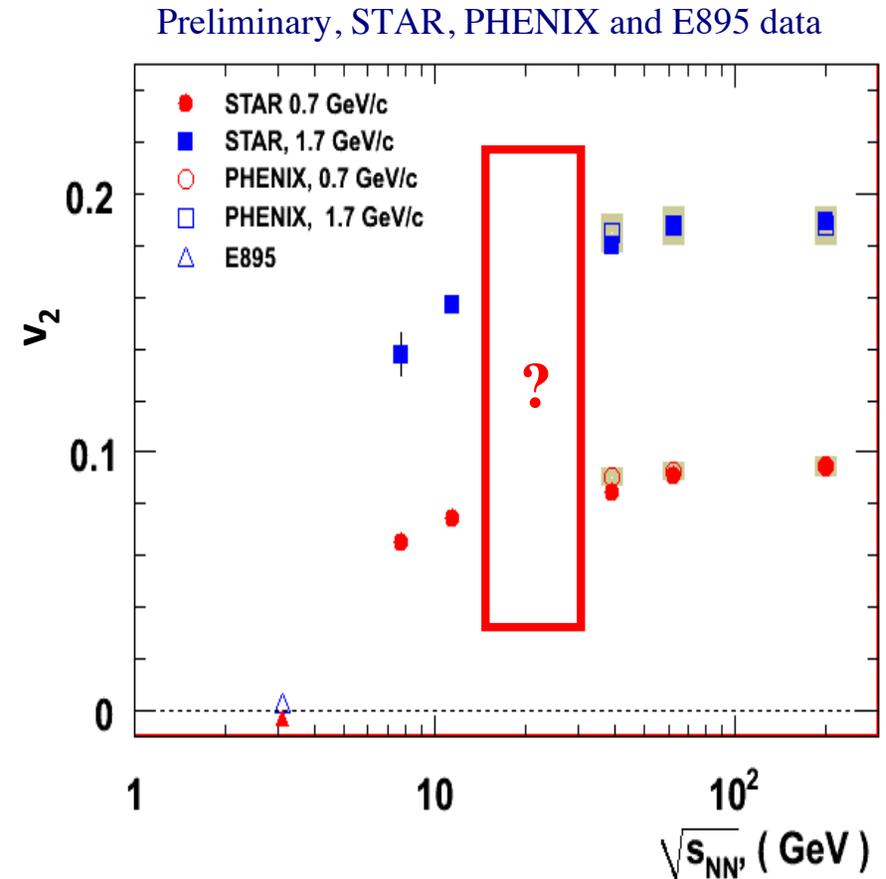
v_3 PID Scaling

- Like v_2 , constituent quark scaling is seen with v_3 .
- Evidence of partonic flow.



Summary

- PHENIX has measured v_2 , v_3 , v_4 from 39→200 GeV where measurements appear independent of beam energy within this range and even up to 2.76 TeV @ LHC.
- However, at 7.7 GeV v_2 is noticeably lower than at 39 GeV. No longer a QGP?
- v_3 & v_4 measurements appear to originate from fluctuations which should aid in better understanding initial geometry and medium conditions.

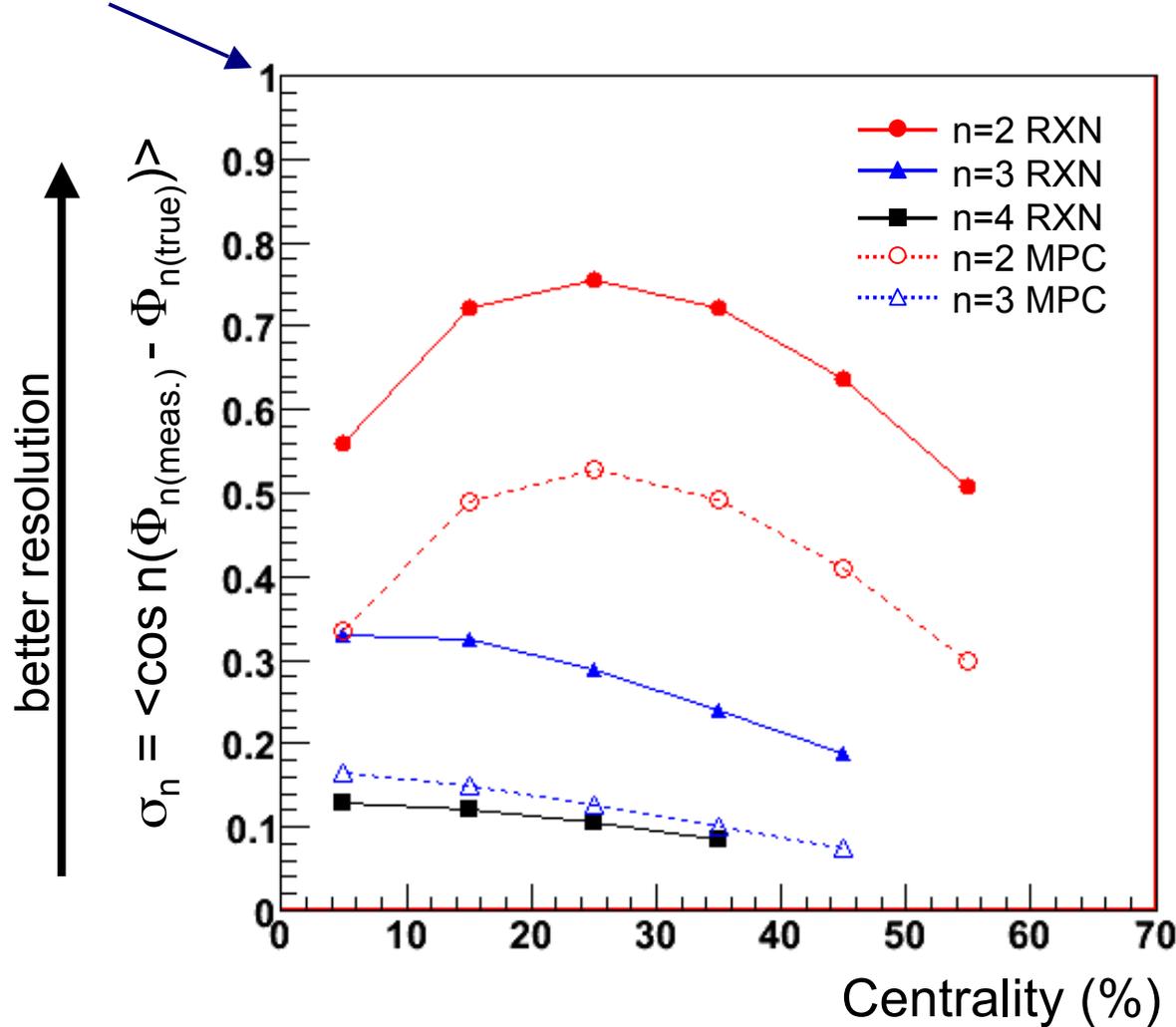


- Latest RHIC run collected data at 19.6 and 27 GeV to help fill gap in transition region.

Backup

Reaction Plane Resolution

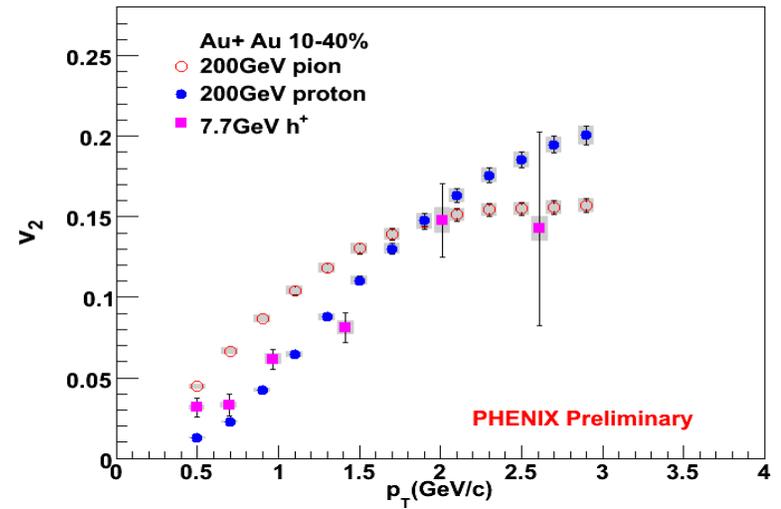
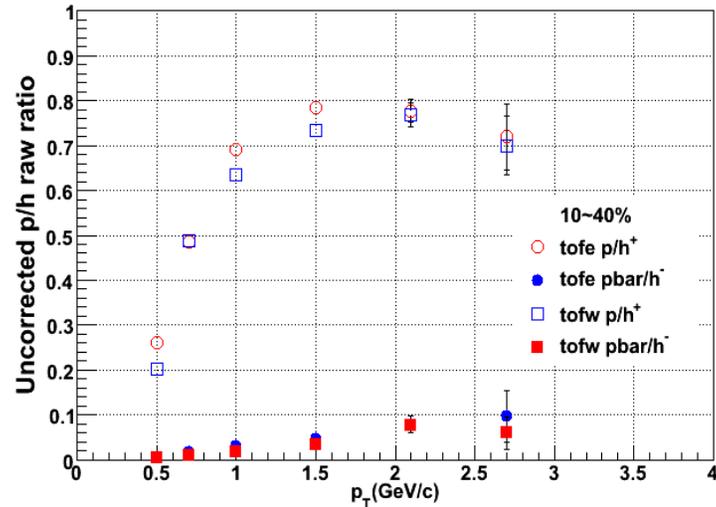
Perfect Resolution



RXN $|\eta| = 1.0 \sim 2.8$
 MPC $|\eta| = 3.1 \sim 3.7$

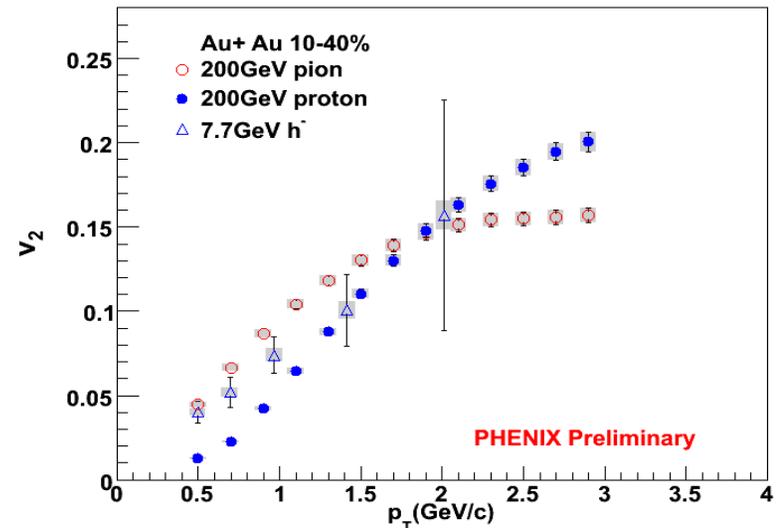
$$v_n = \frac{v_n^{meas}}{\sigma_n}$$

The Baryon contribution

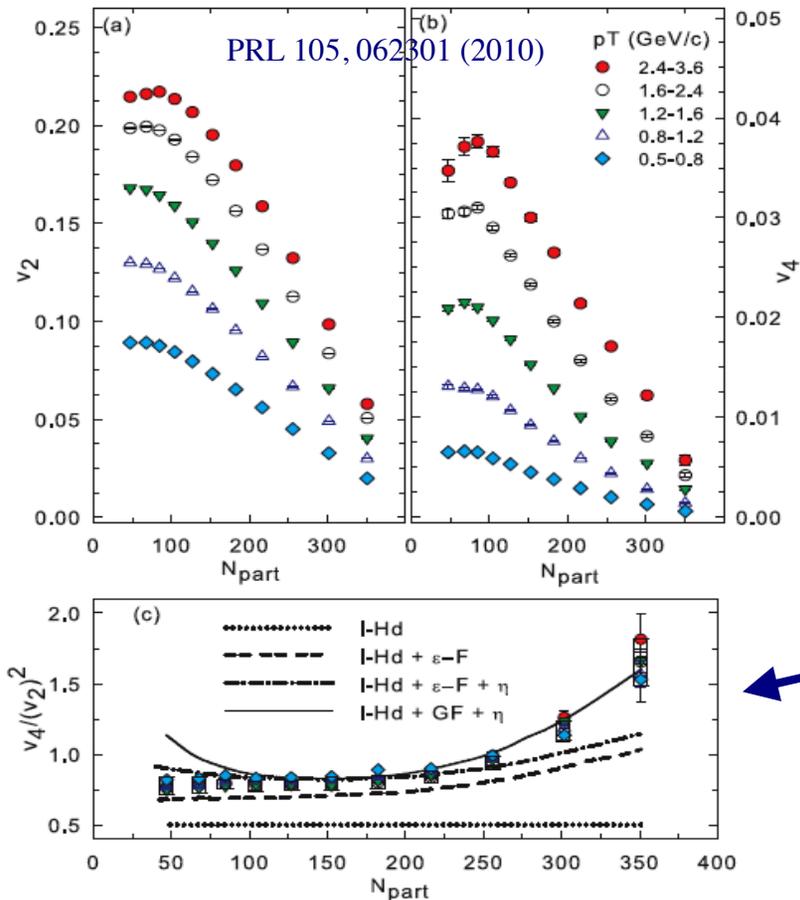


Proton yield dominates in the positive hadrons, while pion yield dominates in the negative hadrons

The v_2 of negative hadrons at 7.7 GeV Au+Au is lower than v_2 of pions at 200 GeV AuAu

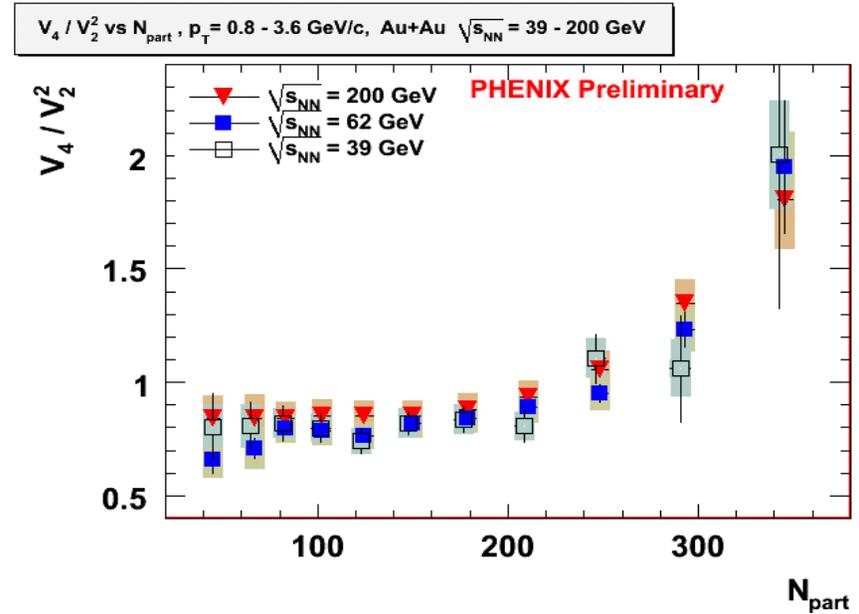
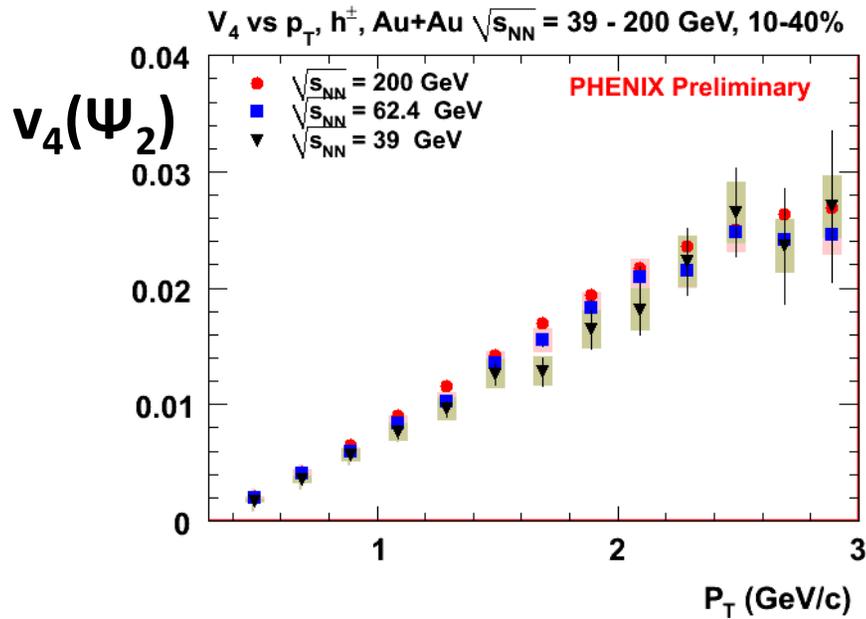


$$v_4(\Psi_2)/v_2^2 @ \sqrt{s_{NN}} = 200 \text{ GeV}$$

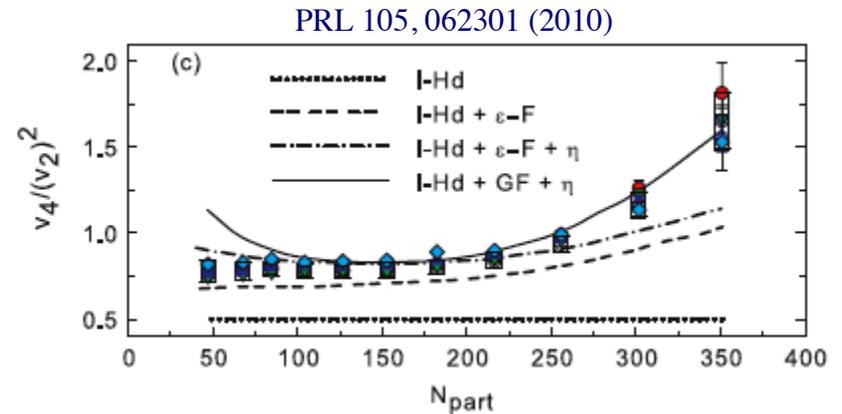


- v_4/v_2^2 (both w.r.t. Ψ_2) could be used to constrain initial geometric fluctuations and specific viscosity.
- Adding fluctuations and viscosity to hydrodynamic model improves agreement with data.

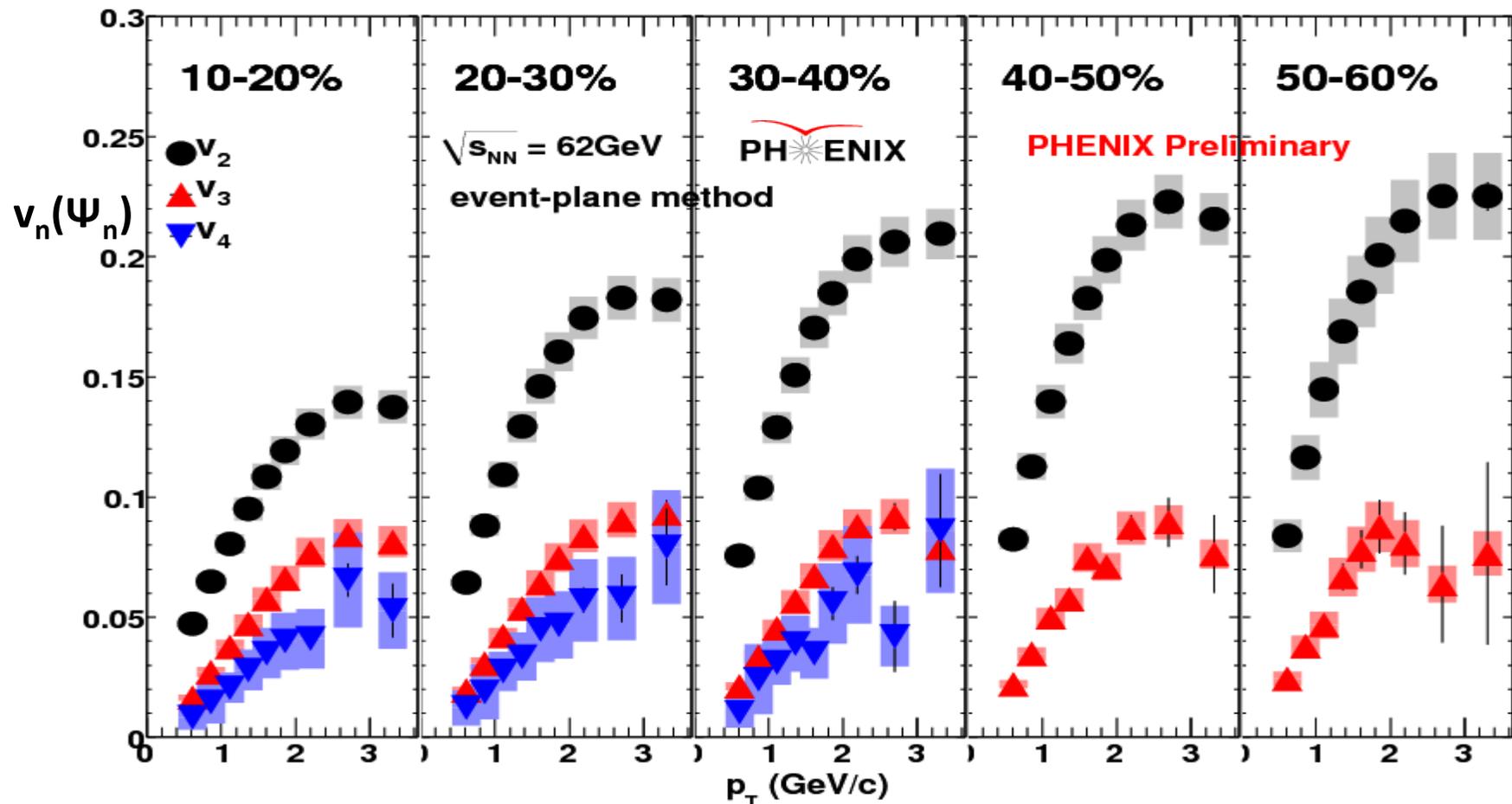
Beam Energy Dependence of $v_4(\Psi_2)$



See similar behavior with 62 and 39 GeV collisions

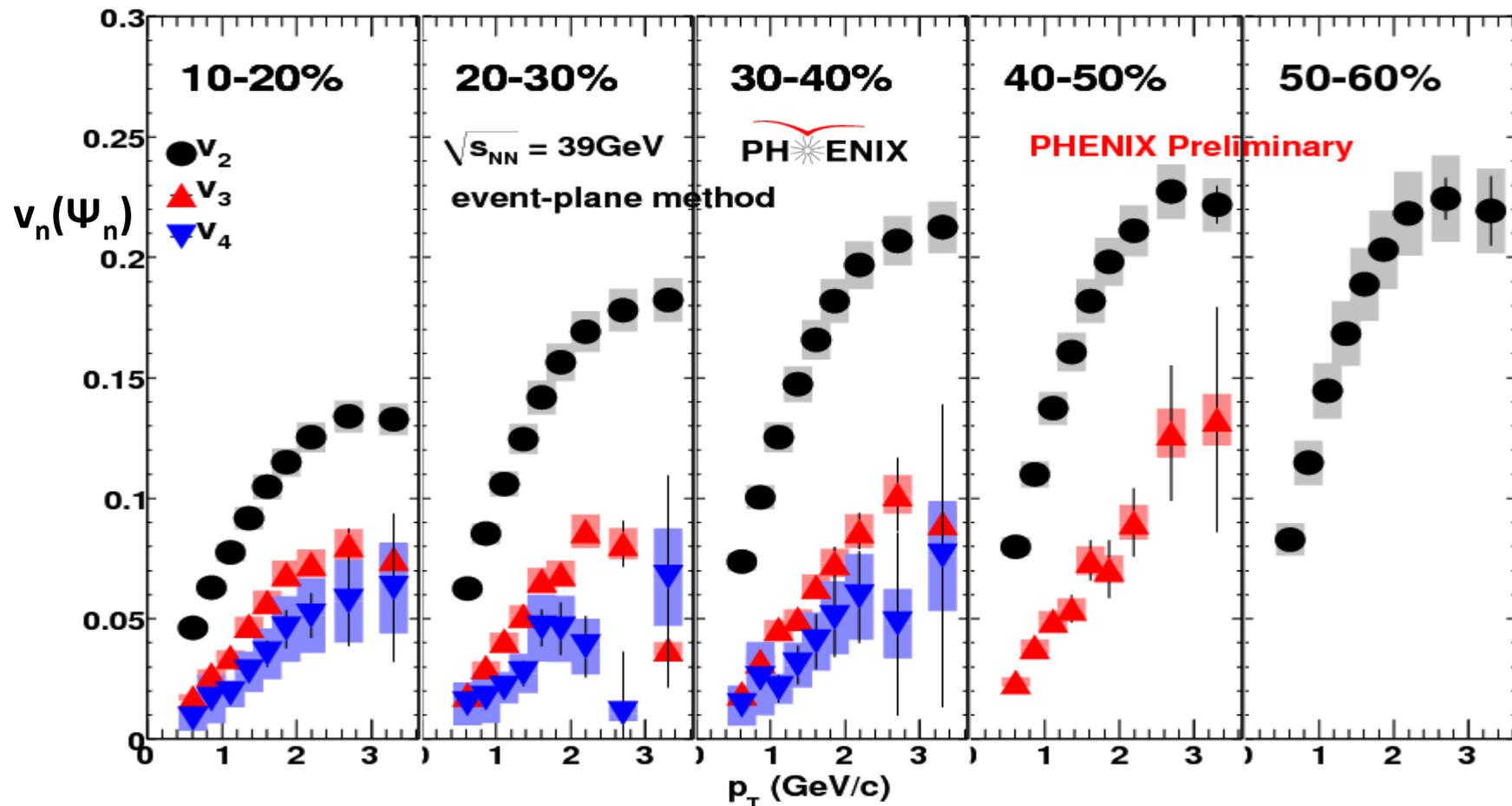


Charged Hadron $v_n(\Psi_n)$ @ 62.4 GeV



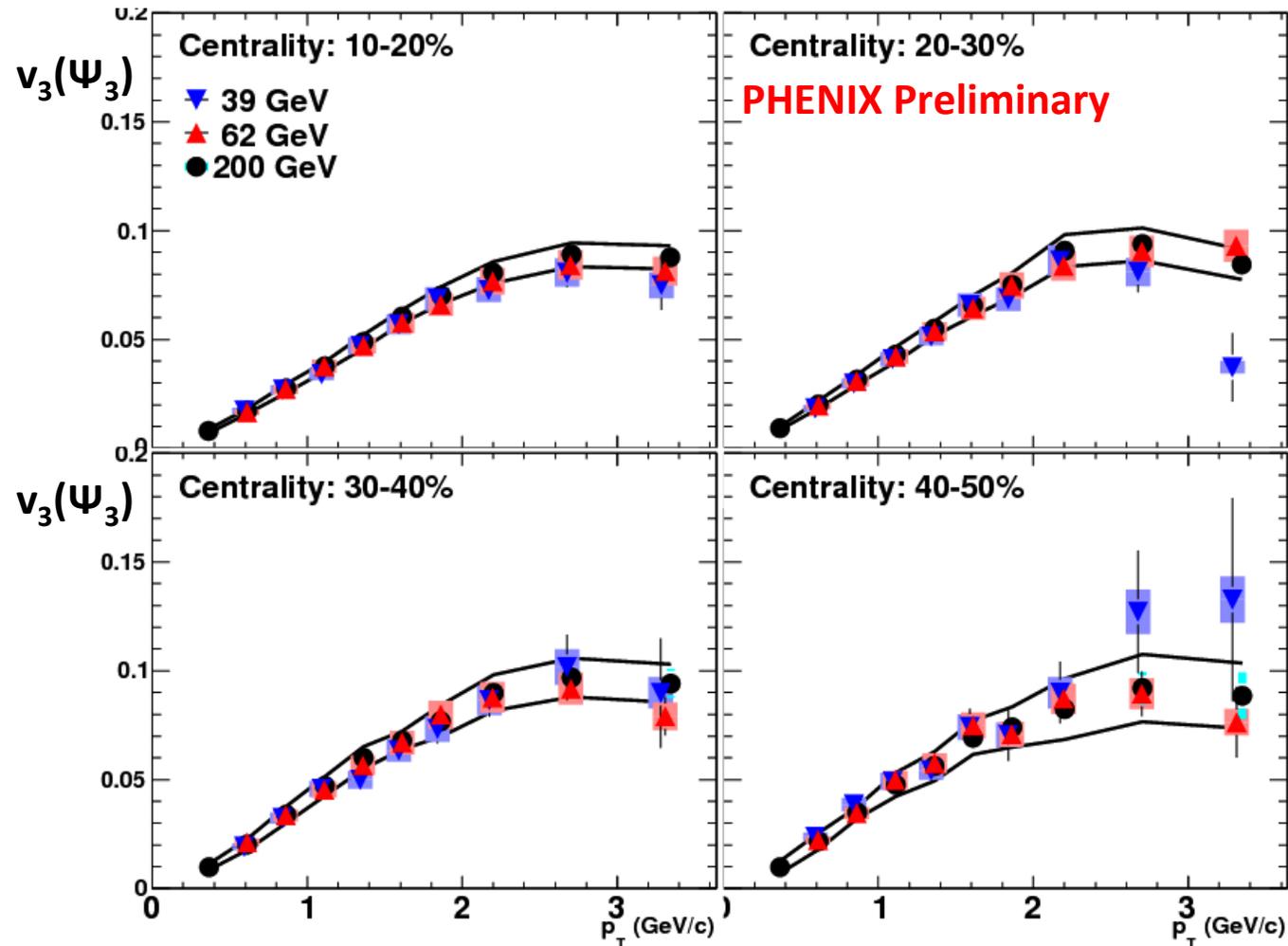
- v_3 has very little centrality dependence. This is consistent with “chunky” origin in fluctuations.
- v_4 slightly increases with centrality.

Charged Hadron $v_n(\Psi_n)$ @ 39 GeV



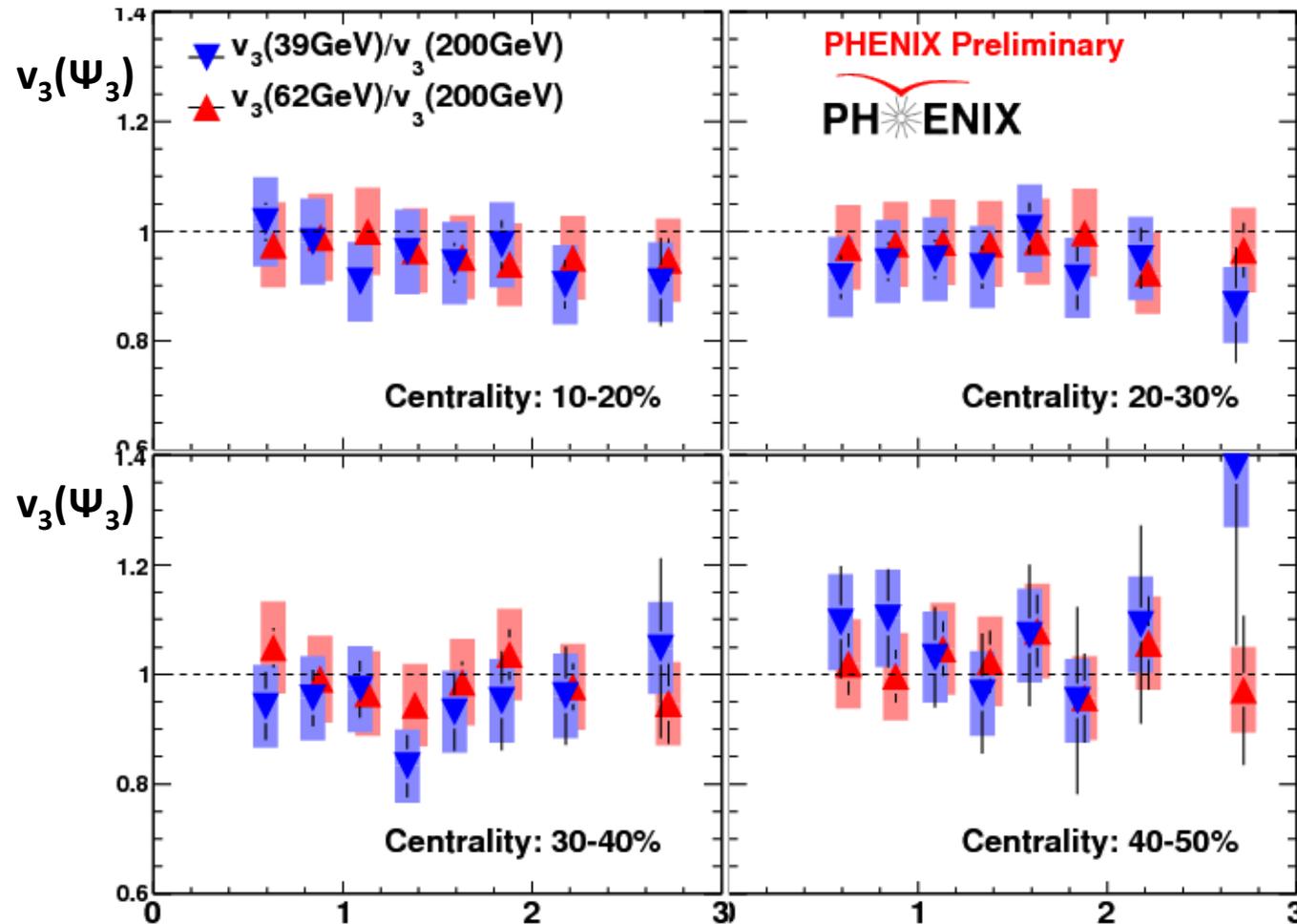
- Similar behavior at 39 GeV.

Beam Energy Dependence on v_3 (Ψ_3)



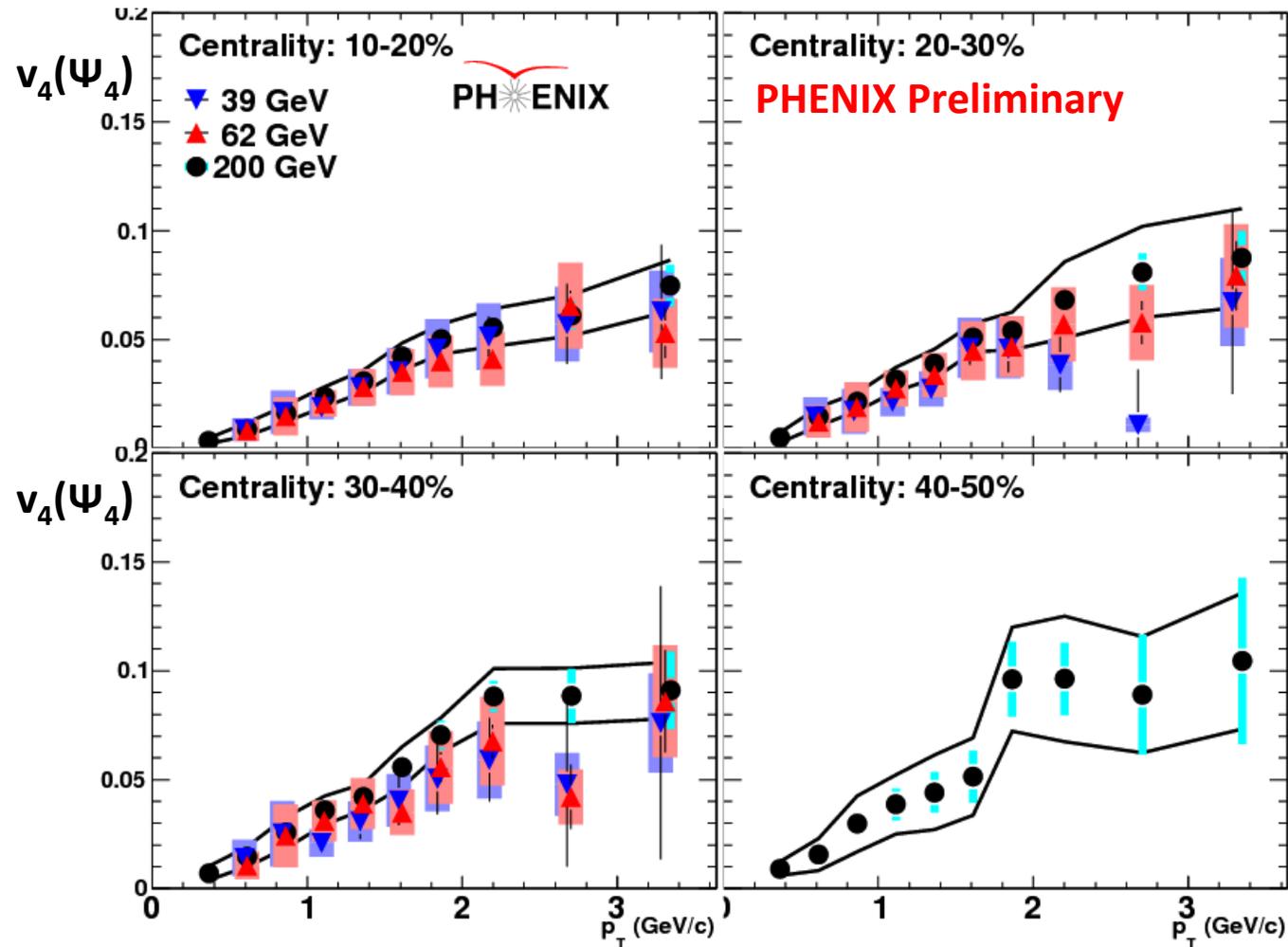
- Like v_2 , v_3 also shows saturation from 39→200 GeV.

Beam Energy Dependence on $v_3(\Psi_3)$



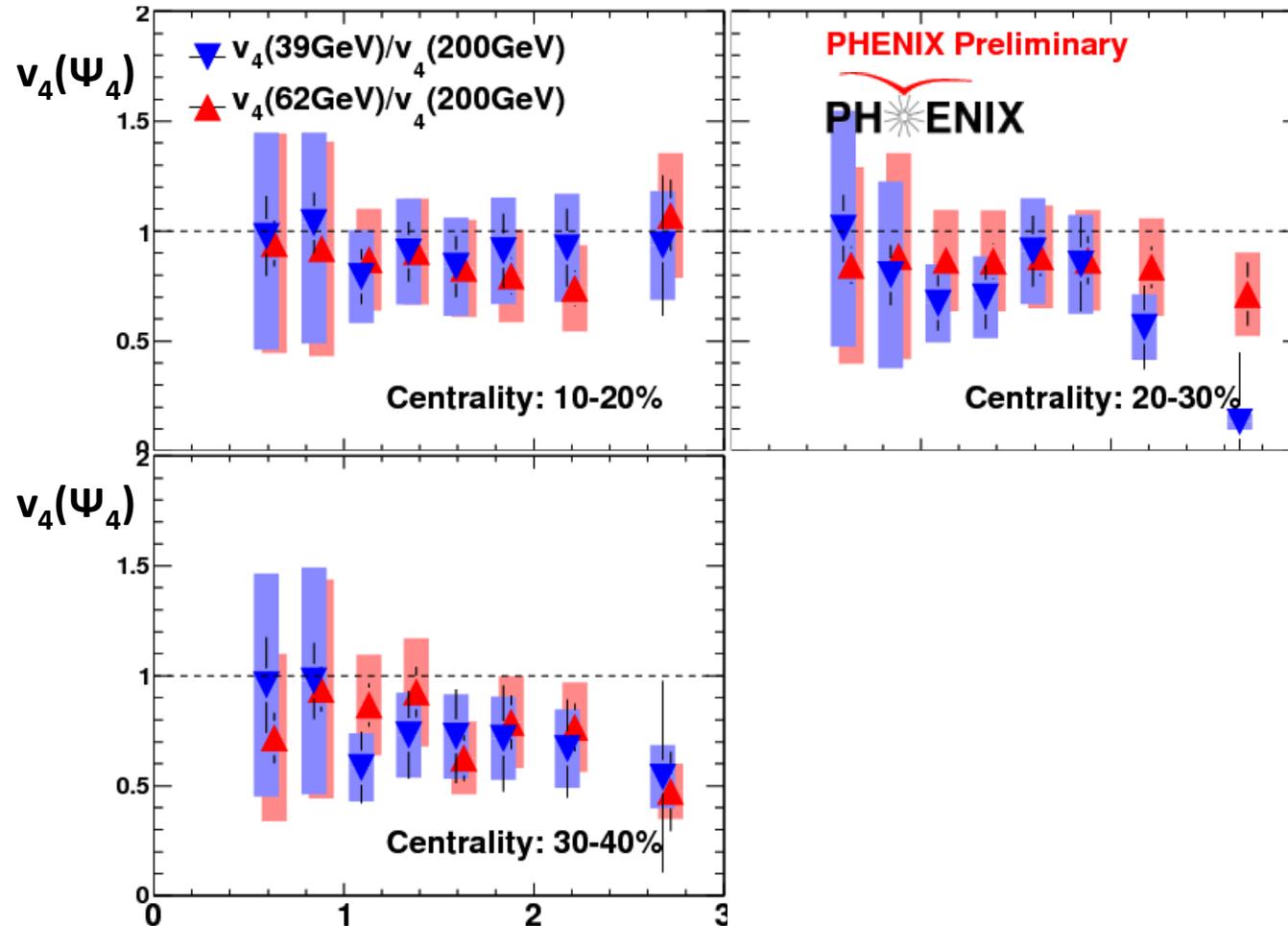
- Ratio of 39 & 64 GeV with 200 GeV is consistent with unity within errors.

Beam Energy Dependence on $v_4(\Psi_4)$



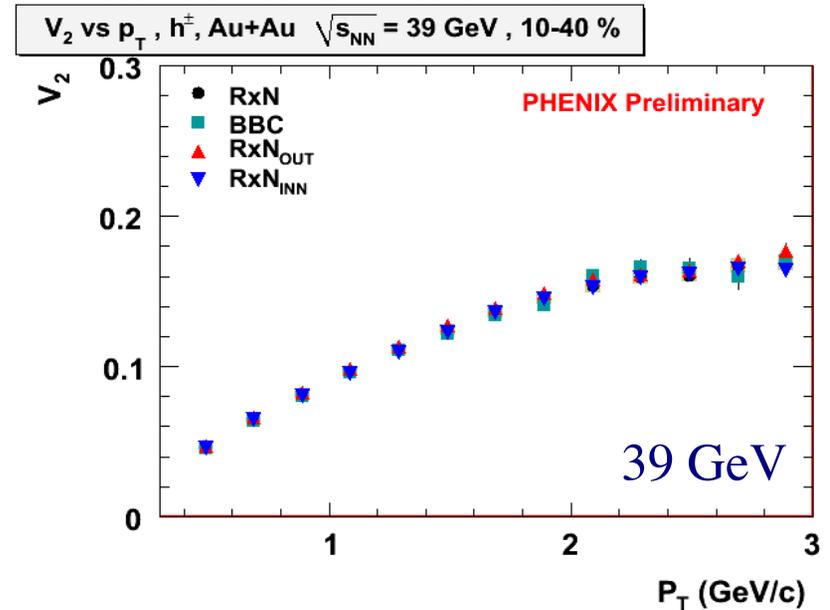
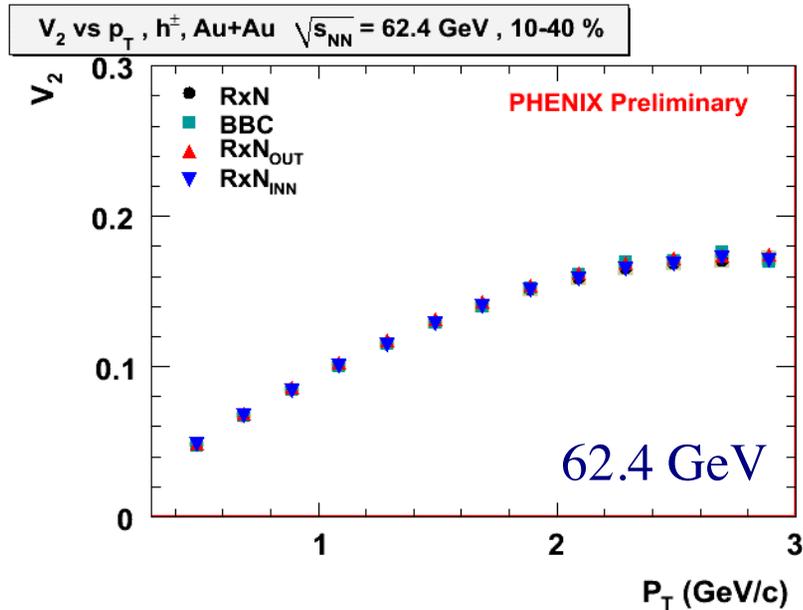
- Similar to v_2 & v_3 , v_4 also saturates within errors from 39→200 GeV.

Beam Energy Dependence on $v_4(\Psi_4)$



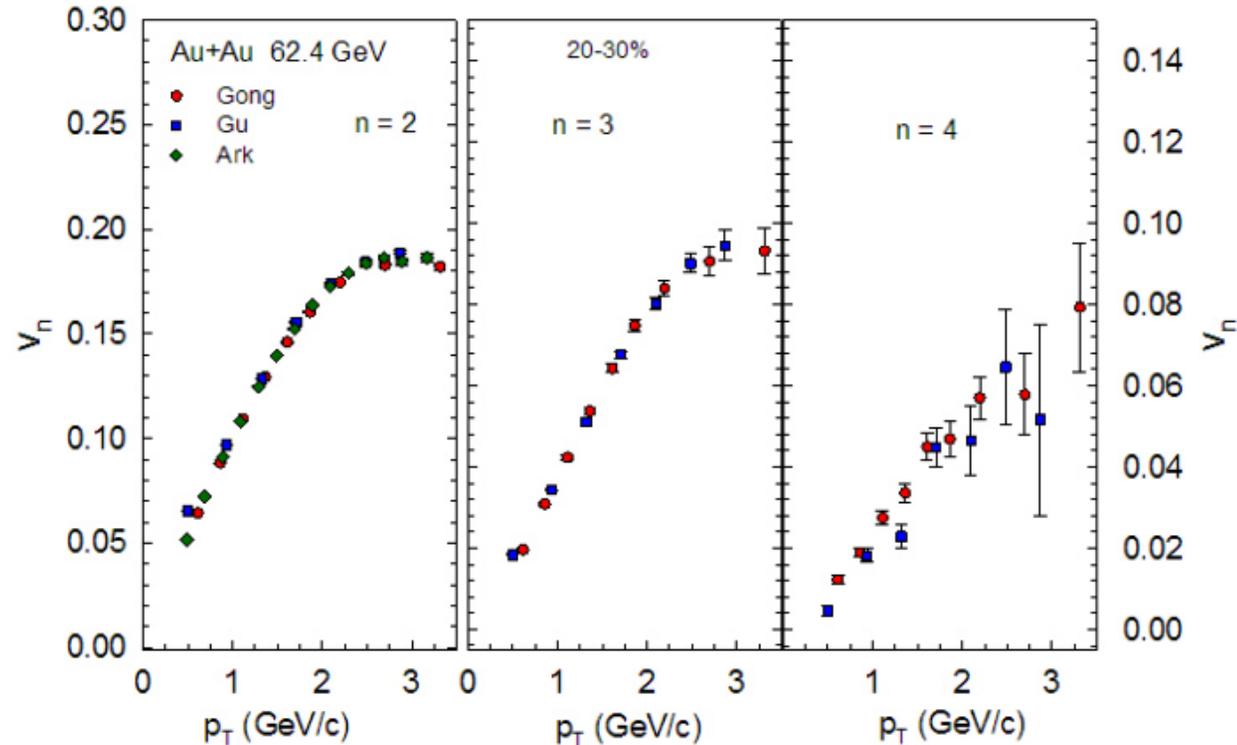
- Again, ratio of 39 & 64 GeV with 200 GeV is consistent with unity within errors.

Measurement Consistency



- Similar v_2 signal using detectors with different size η gaps with central arms.
- v_2 not dependent on detector.

Measurement Consistency



- ❑ **Gong** and **Ark** use event-plane method: reconstruct event planes in the **forward detectors**; measure **central arm** particle azimuthal distributions relative to event plane.
- ❑ **Gu** uses long-range correlation method: Fourier decomposition of correlation functions built with one particle from **central arm** and the other from **forward detectors**.

Different methods agree very well!

Beam Energy Scan PID v_2

