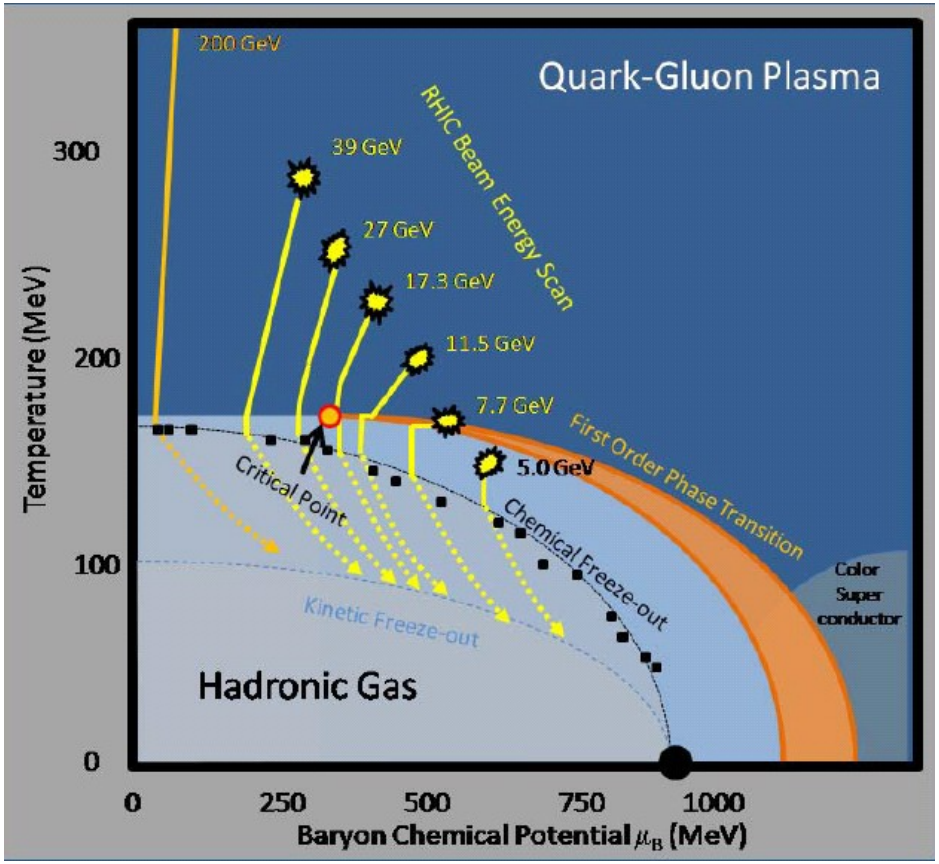
PHENIX v_2 vs. Beam Energy

SUNY Stony Brook, Chemistry Department
Damian Reynolds
June 20, 2011

Outline

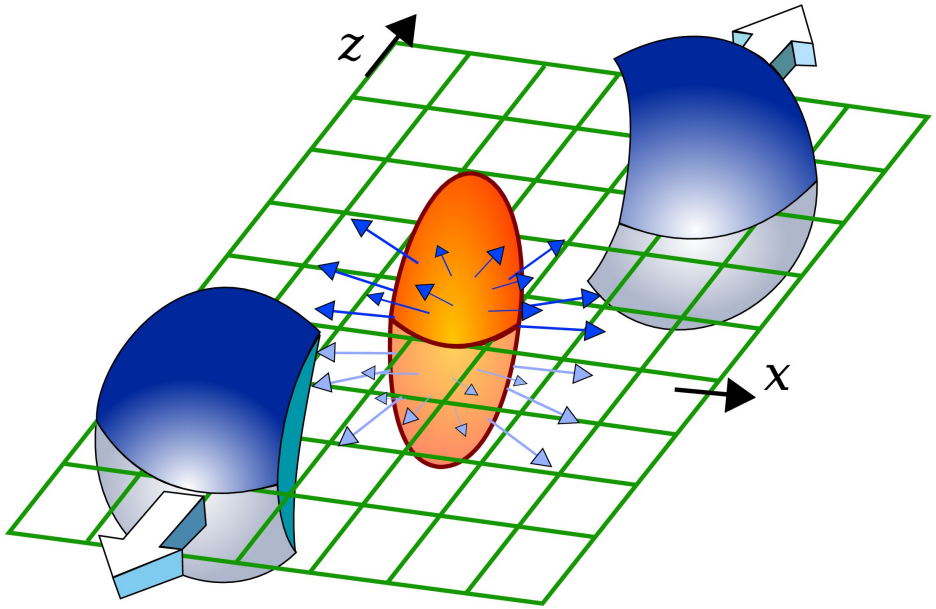
- Charged Hadron Flow
- Model Constraints and Viscosity
- Direct Photon Elliptic Flow

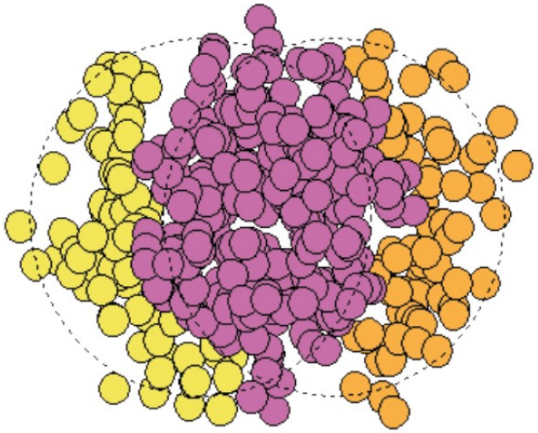
Beam Energy Scan at RHIC

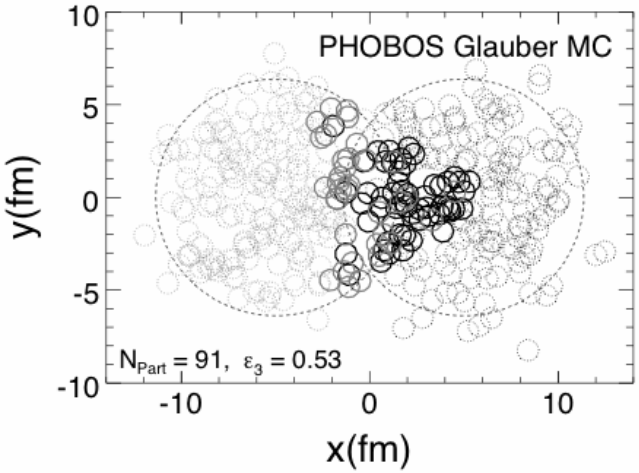


- Will there be any changes to the specific viscosity depending on the beam energy?
- Will we see changes in the initial geometry?
- Will flow develop at a different time at lower energies?
- Can we find the critical point?

Initial Conditions







The old picture
Smooth profile means v3 = 0

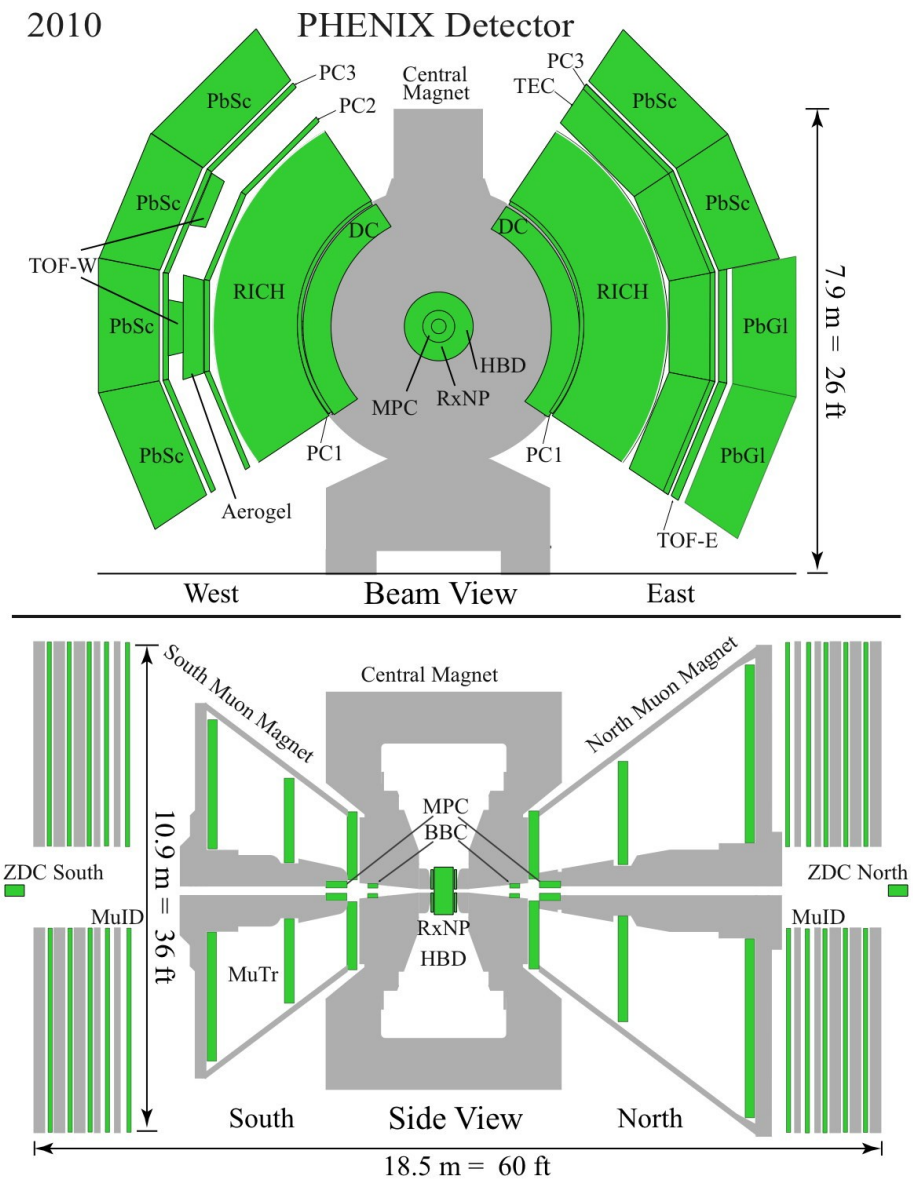
$$dN/d\phi \propto 1+2\Sigma v_n \cos[n(\phi-\psi_n)]$$

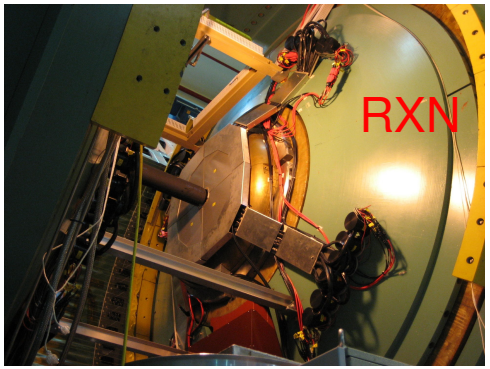
$$v_n = \langle\cos[n(\Phi-\Psi_n)]\rangle$$

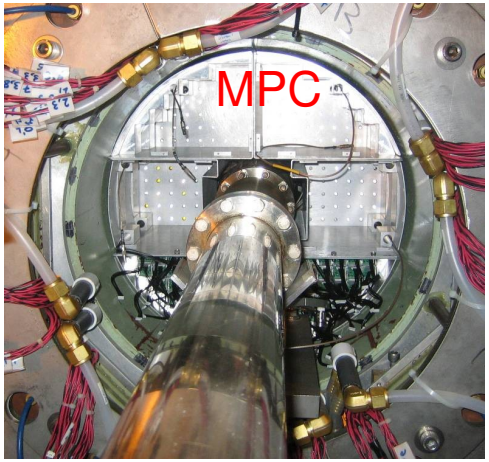
The new picture
The nucleons participating may not be as smooth v3 != 0

Alver, Roland, Phys.Rev.C81, 054905

Reaction Plane Detectors

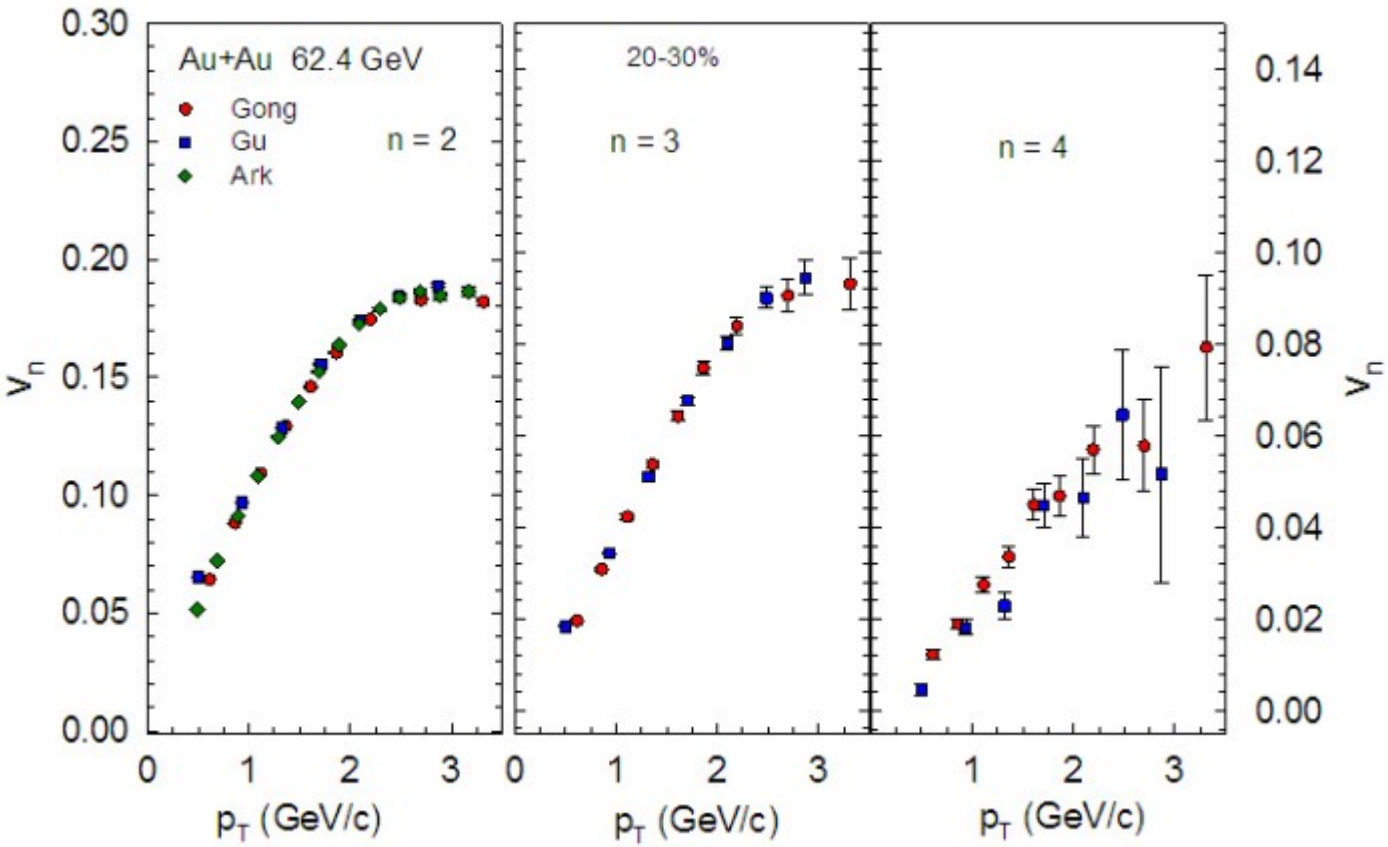






- BBC $3.1 < |\eta| < 3.9$
- MPC $3.1 < |\eta| < 3.9$
- RXNIn $1.5 < |\eta| < 2.8$
- RXNOut $1.0 < |\eta| < 1.5$

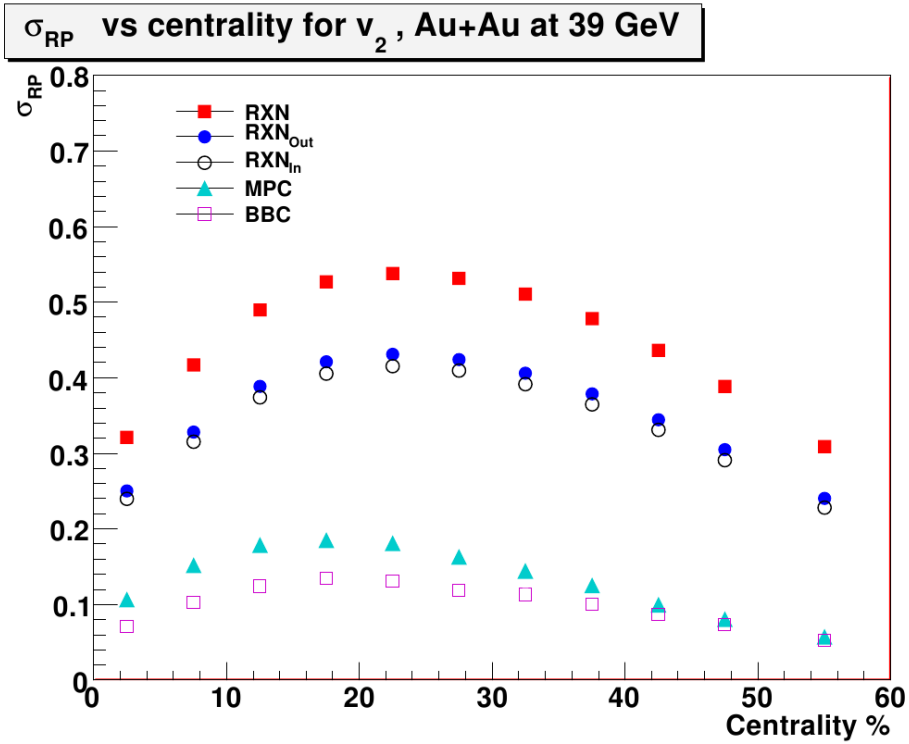
Flow Measurements with Different Methods

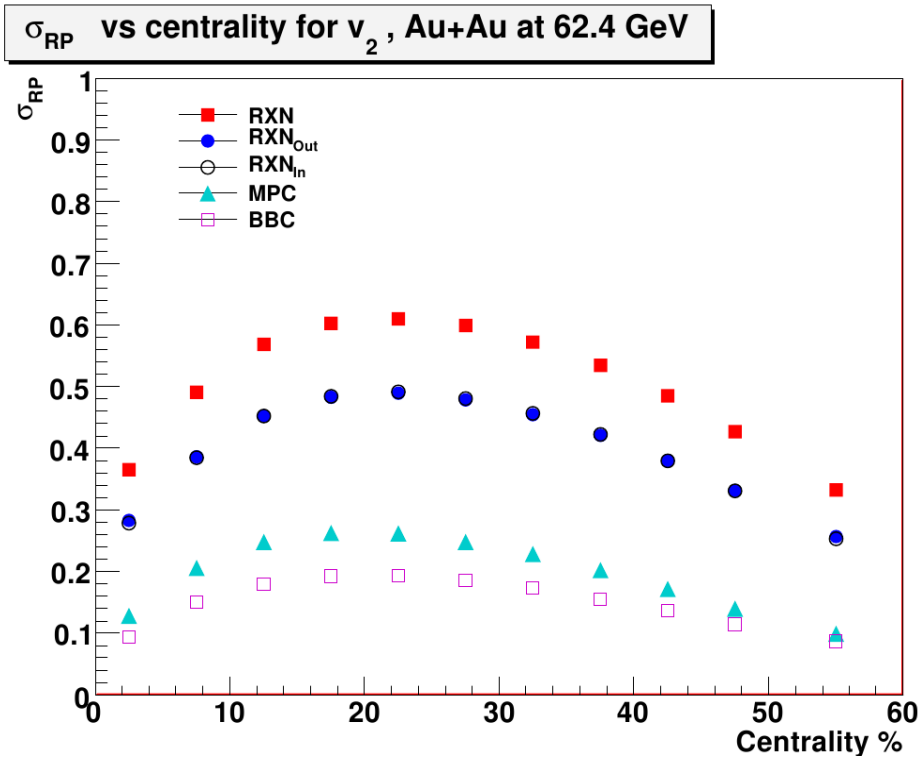


Gong and Ark are the results of the event plane method: A Fourier decomposition of the azimuthal distribution between a particle in the central arm and its reconstructed event plane.

Gu is a long range correlation method: A Fourier decomposition of a particle in the central arm with another from a forward detector.

Event Plane Resolution

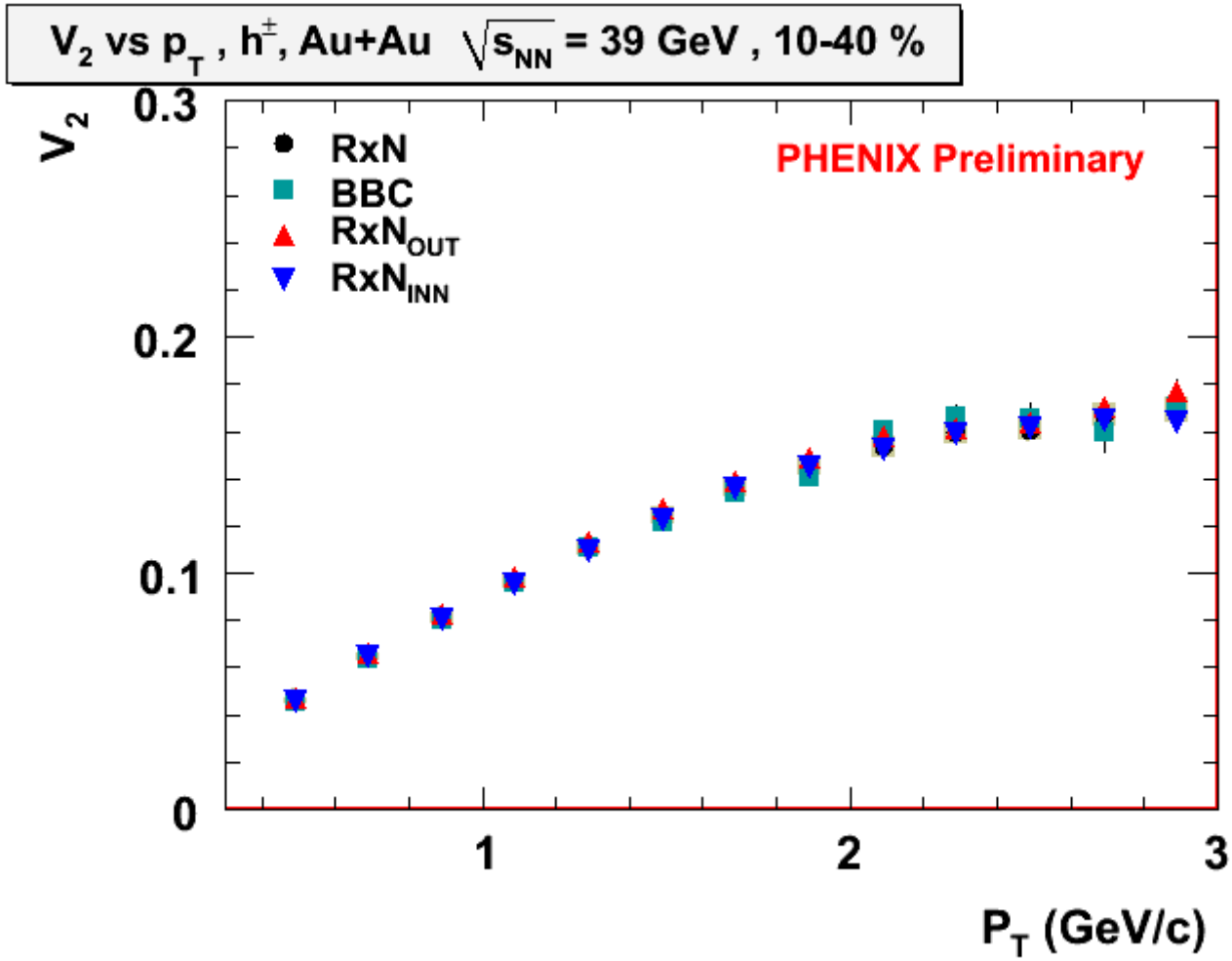




The event plane resolution is a measure of how well we can measure a particular event plane. (i.e. $\psi_1, \ldots, \psi_n$).

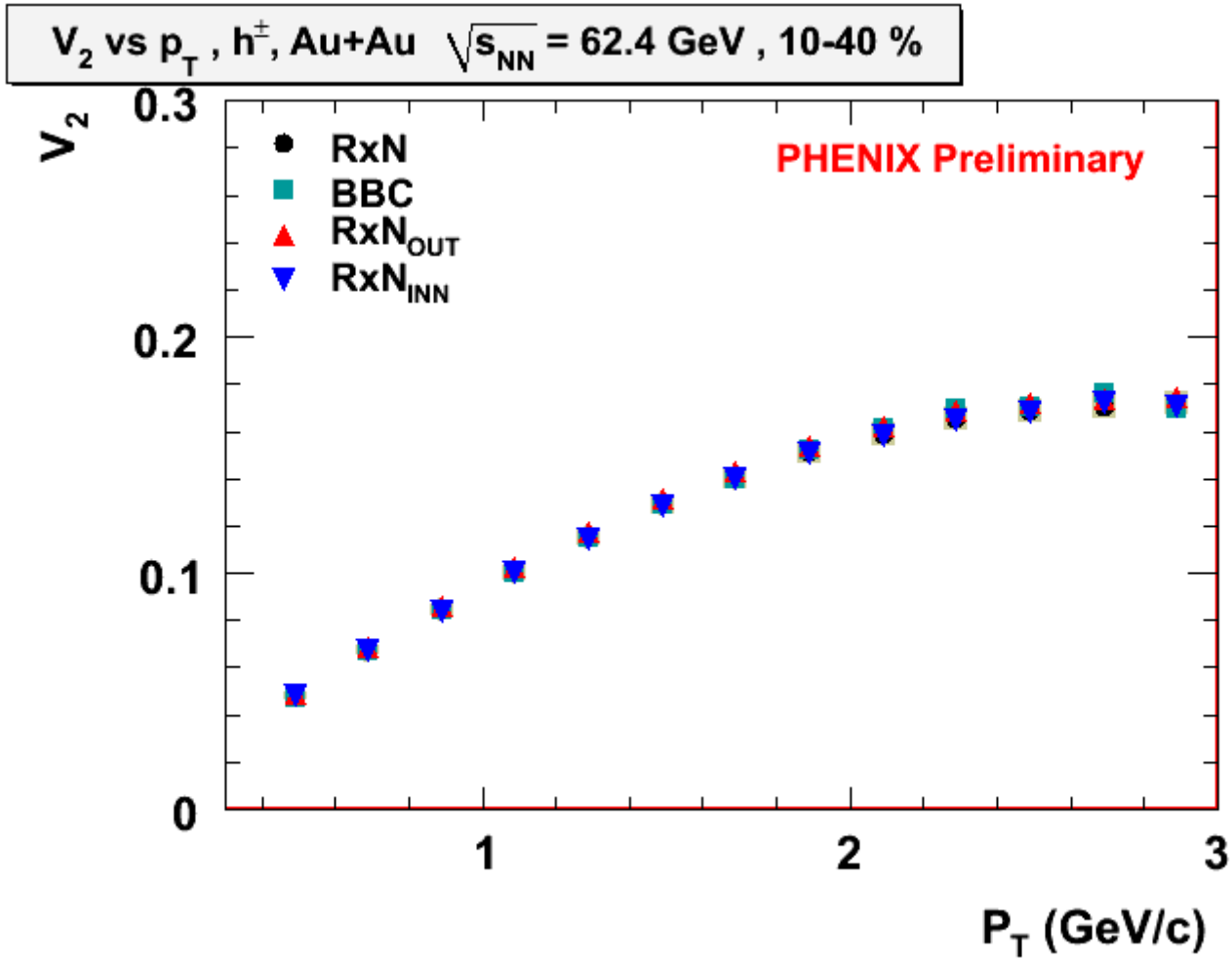
$v_2 = v_2^{raw}/\text{resolution}$

v_2 Event Plane 39 GeV



There wasn't a large difference between different event plane detectors. This is good because the v_2 shouldn't depend on the detector.

v_2 Event Plane 62.4 GeV



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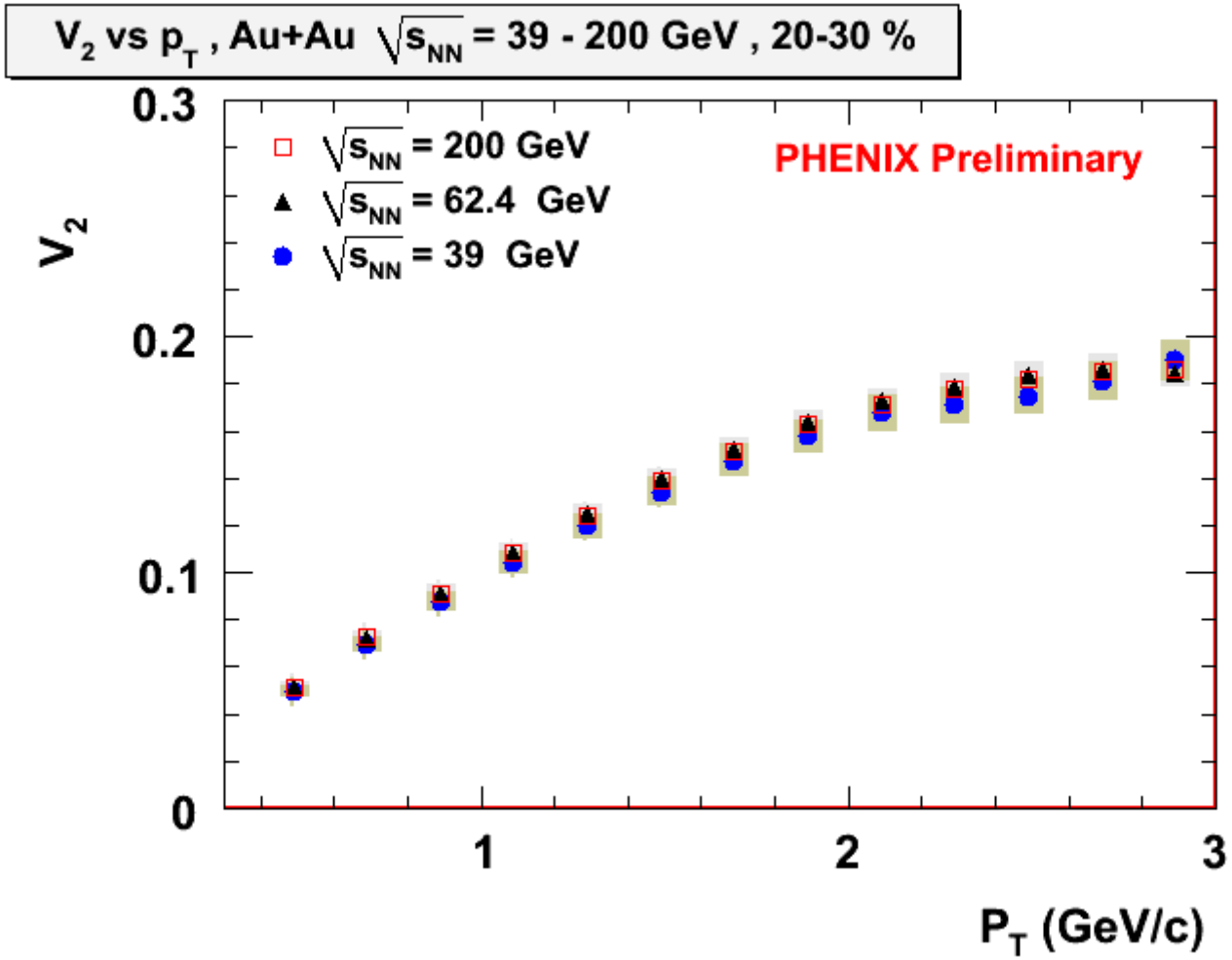
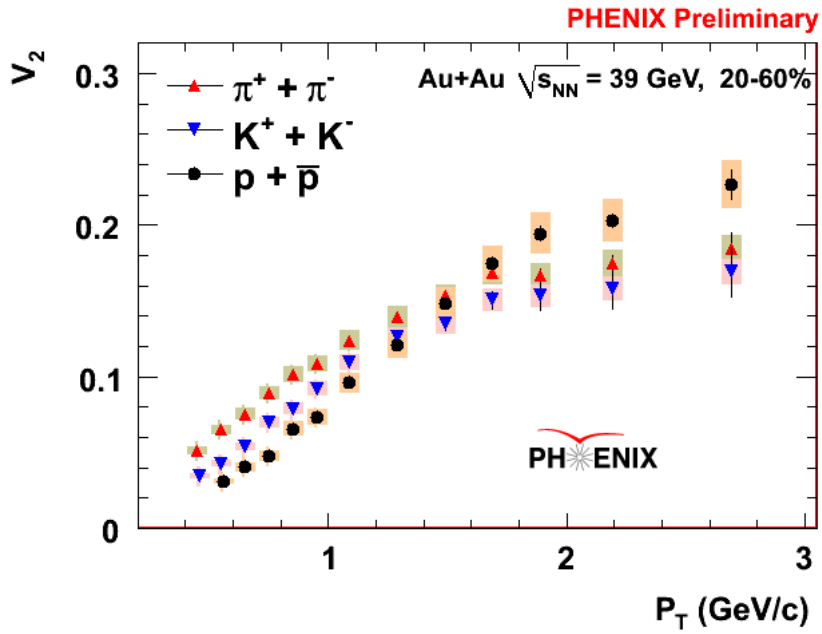
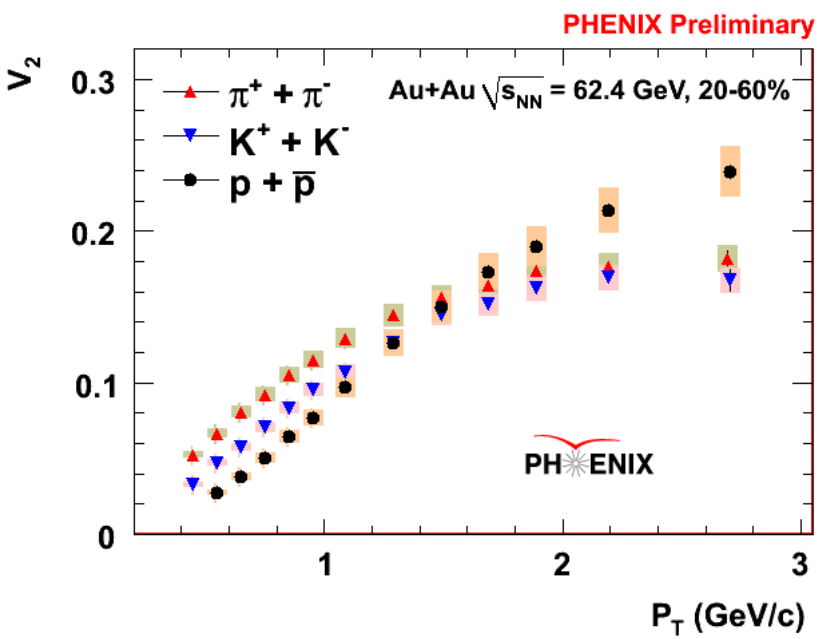
v_2 Across Different Energies



The v_2 of the three energies lie atop eachother within error.

Elliptic Flow of Identified Particles





- Quark number scaling works better at higher energies than at lower energies suggesting that flow might be developing differently though primarily during the partonic phase.
- This breaks down at higher p_T where non-flow contributions start appearing.

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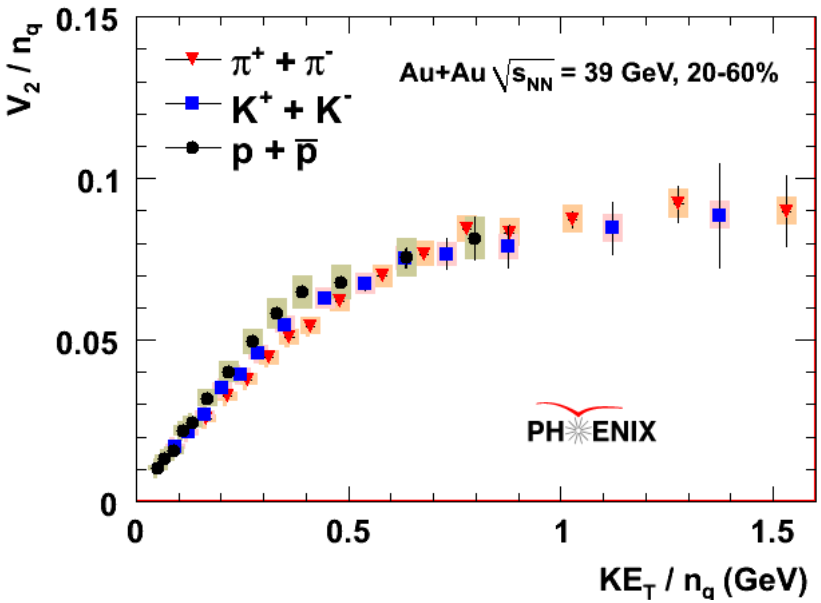

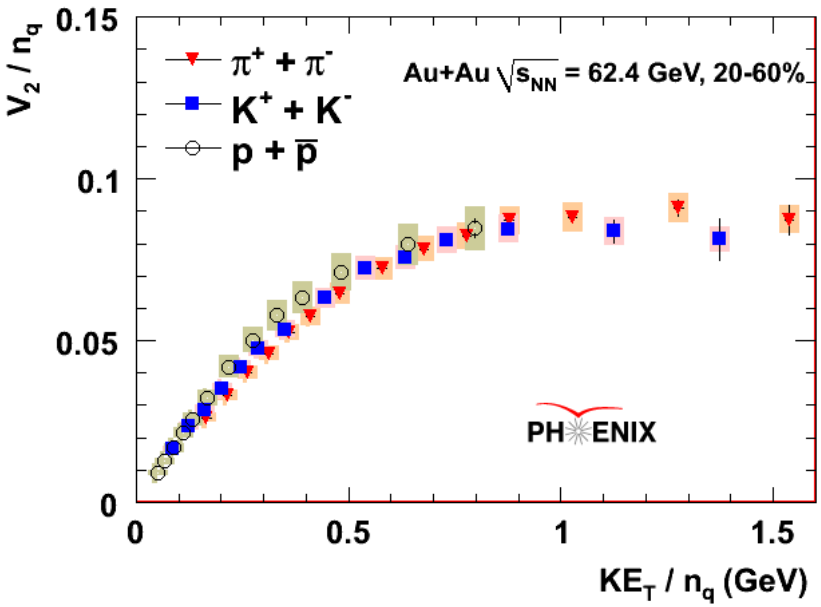

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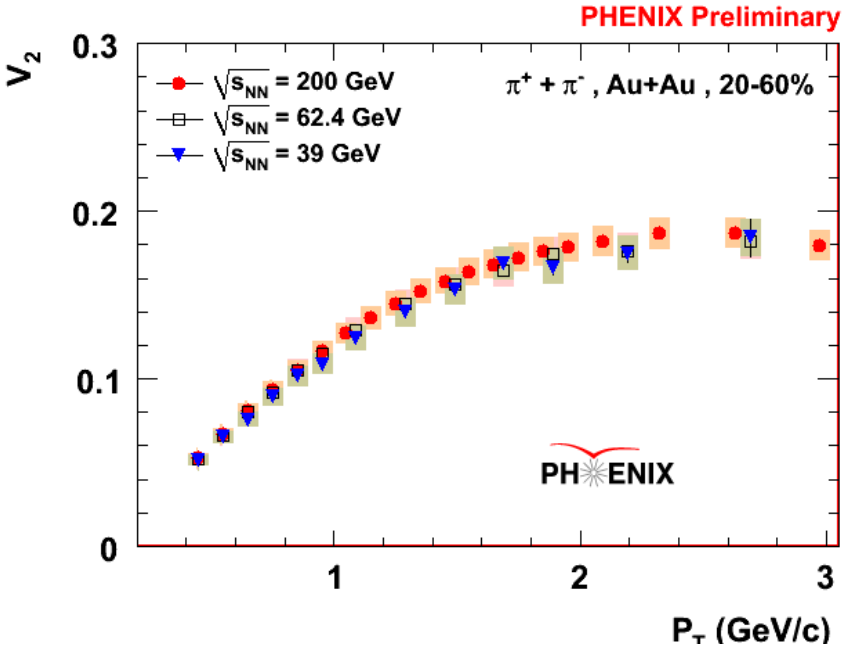
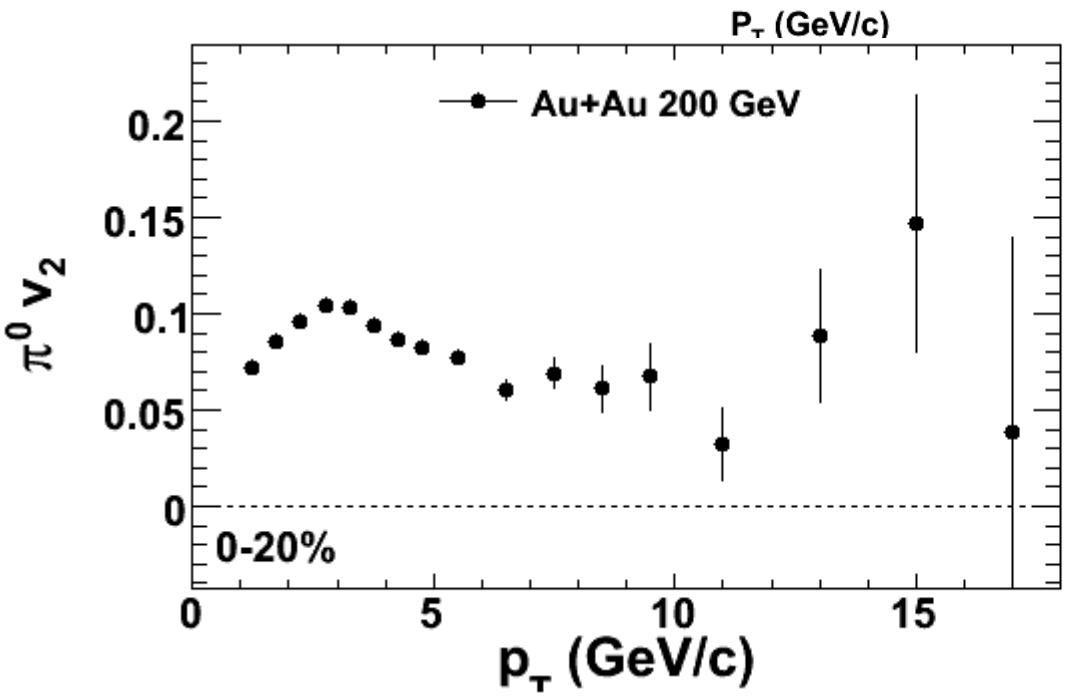
Pion v_2

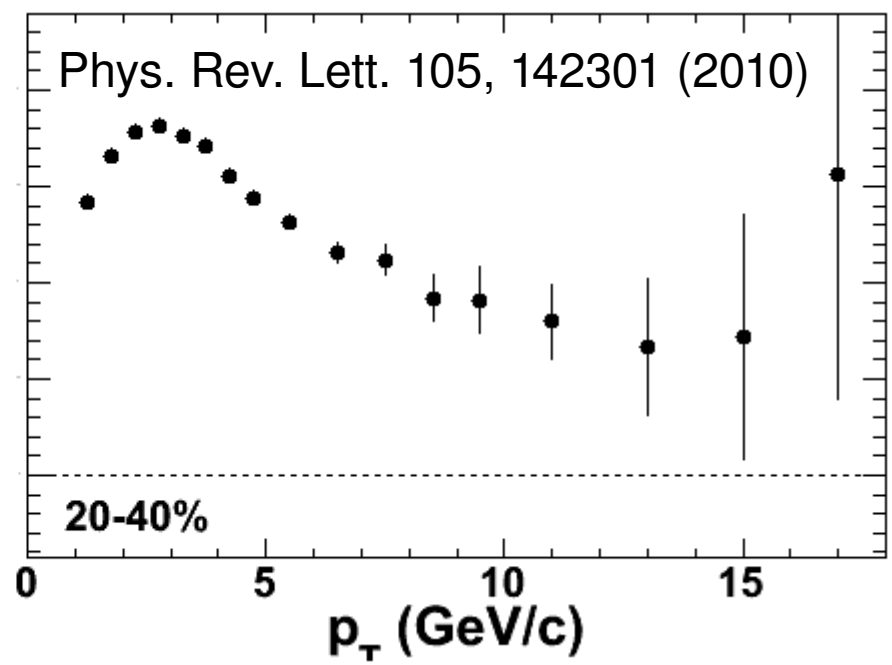


Both neutral and charged pions have been measured at different energies.

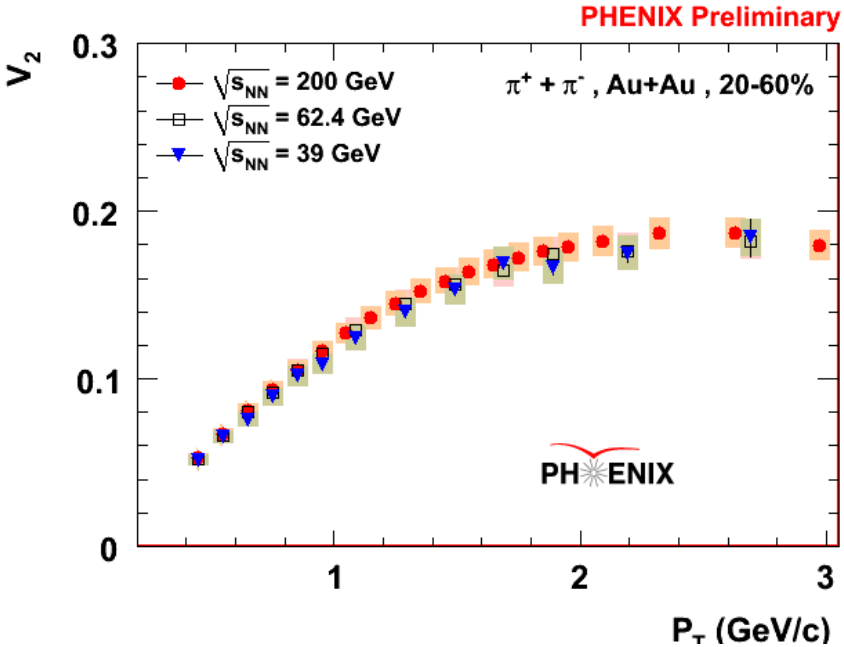
Statistics is a greater problem at lower energies.

π^0 v_2 is important when analyzing direct photon v_2.





Pion v_2



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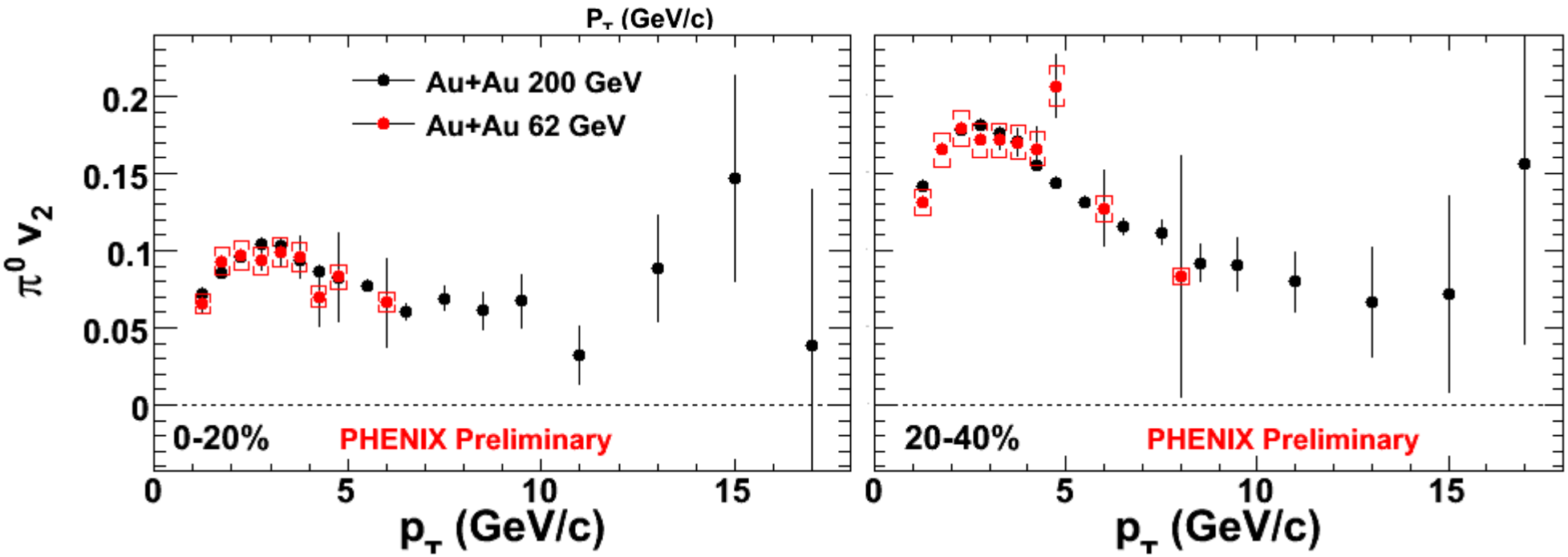

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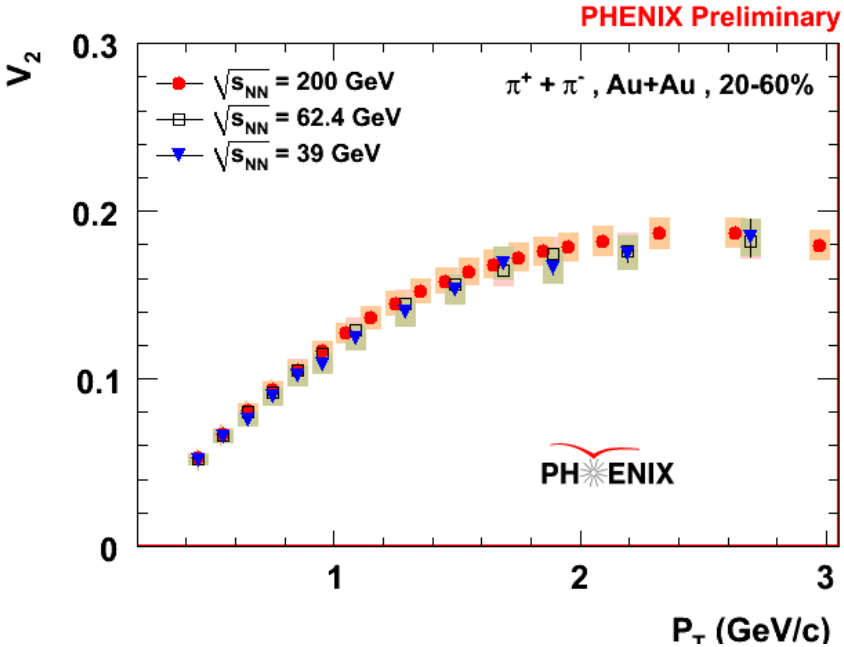

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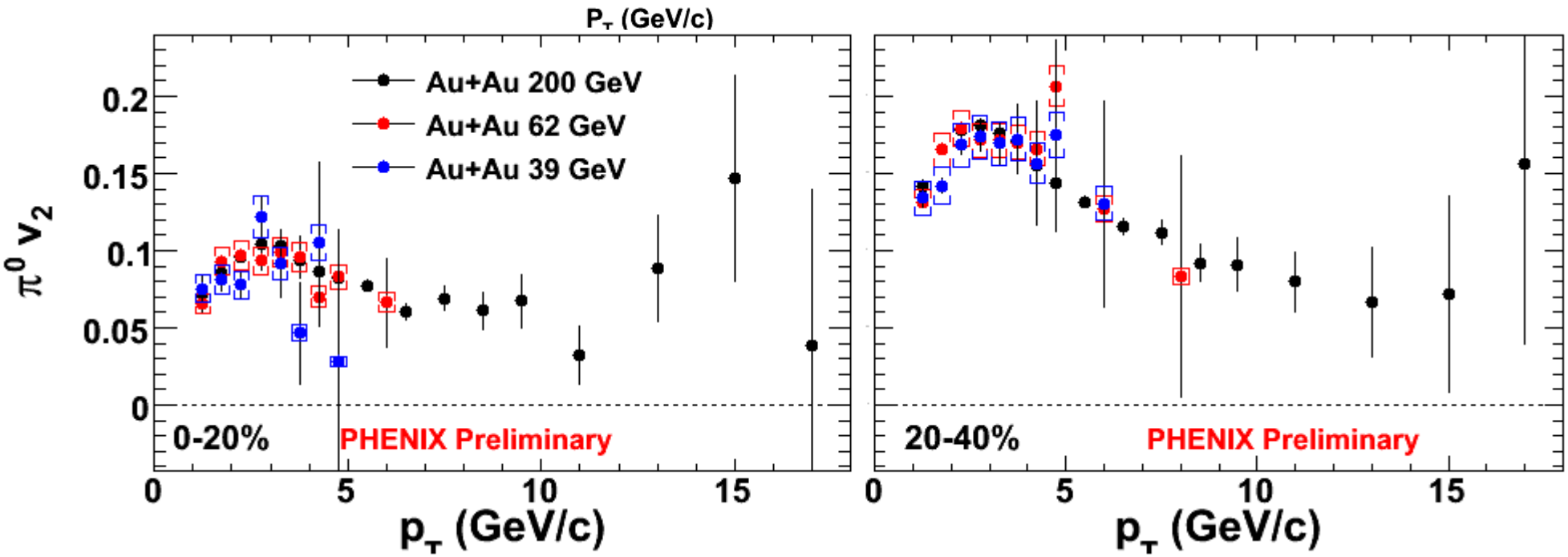


Eccentricity and Triangularity

B. ALVER AND G. ROLAND PHYSICAL REVIEW C **81**, 054905 (2010)

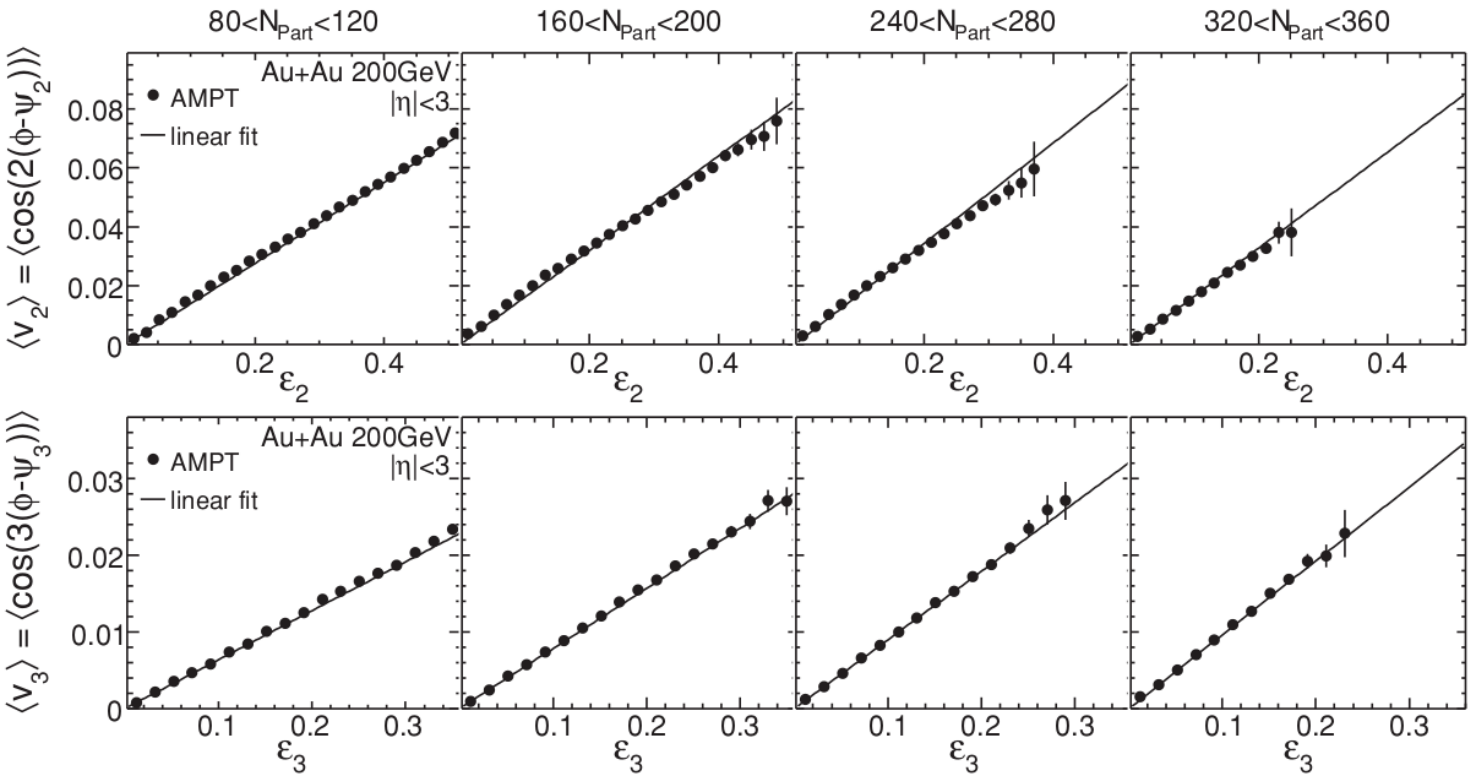
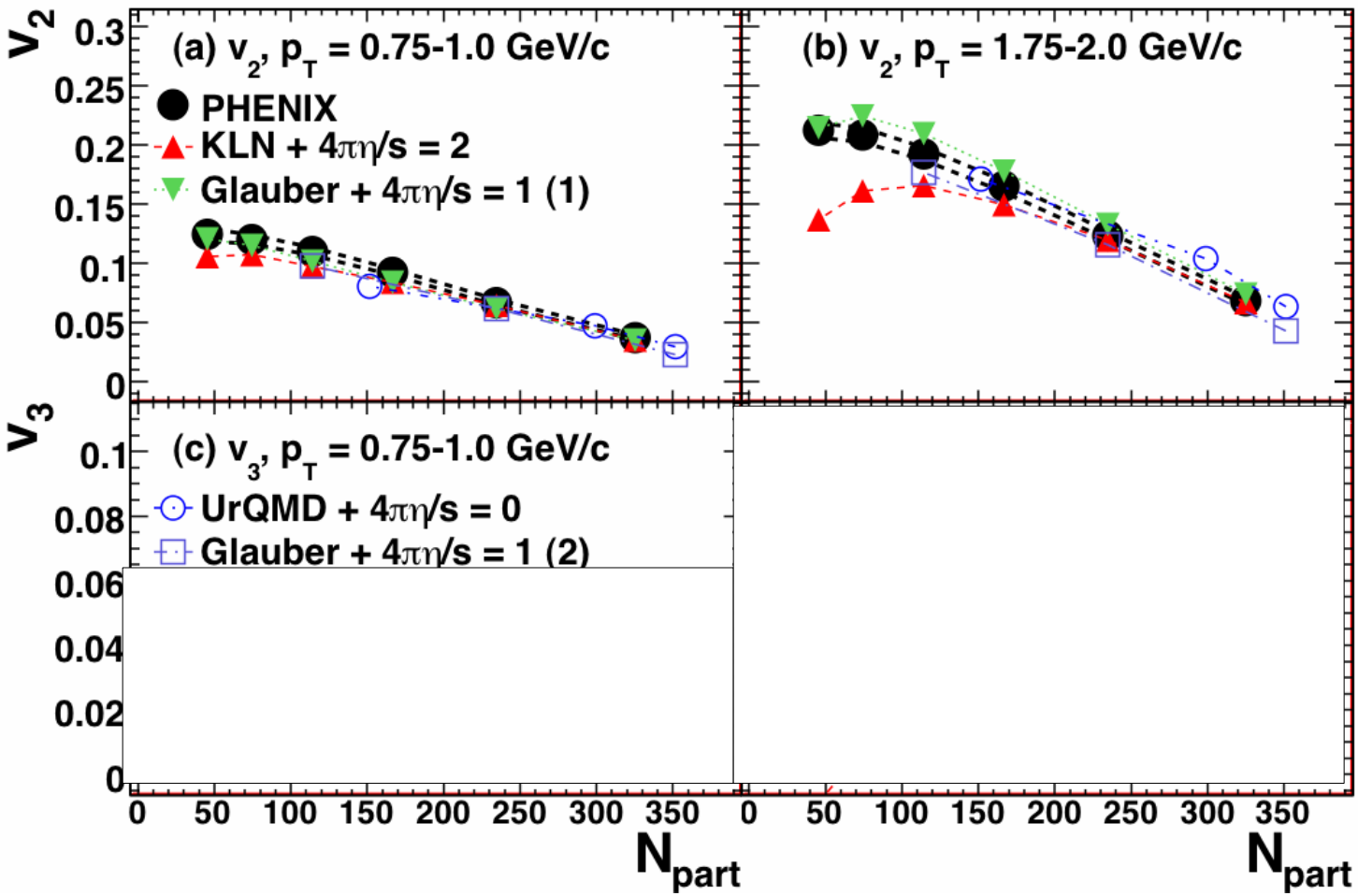


FIG. 4. (Top) Average elliptic flow, $\langle v_2 \rangle$, as a function of eccentricity, ε_2; (bottom) average triangular flow, $\langle v_3 \rangle$, as a function of triangularity, ε_3, in $\sqrt{s_{NN}} = 200$ GeV Au + Au collisions from the AMPT model in bins of number of participating nucleons. Error bars indicate statistical errors. A linear fit to the data is shown.

$$\varepsilon_2 = \frac{\sqrt{\langle r^2 \cos(2\phi_{\text{part}})\rangle^2 + \langle r^2 \sin(2\phi_{\text{part}})\rangle^2}}{\langle r^2 \rangle} \qquad \varepsilon_3 \equiv \frac{\sqrt{\langle r^2 \cos(3\phi_{\text{part}})\rangle^2 + \langle r^2 \sin(3\phi_{\text{part}})\rangle^2}}{\langle r^2 \rangle}$$

Constraining Theoretical Models and Viscosity



At 200 GeV, v_2 has shaped models, but hasn't been able to fully separate some.

Arxiv:1105.3928

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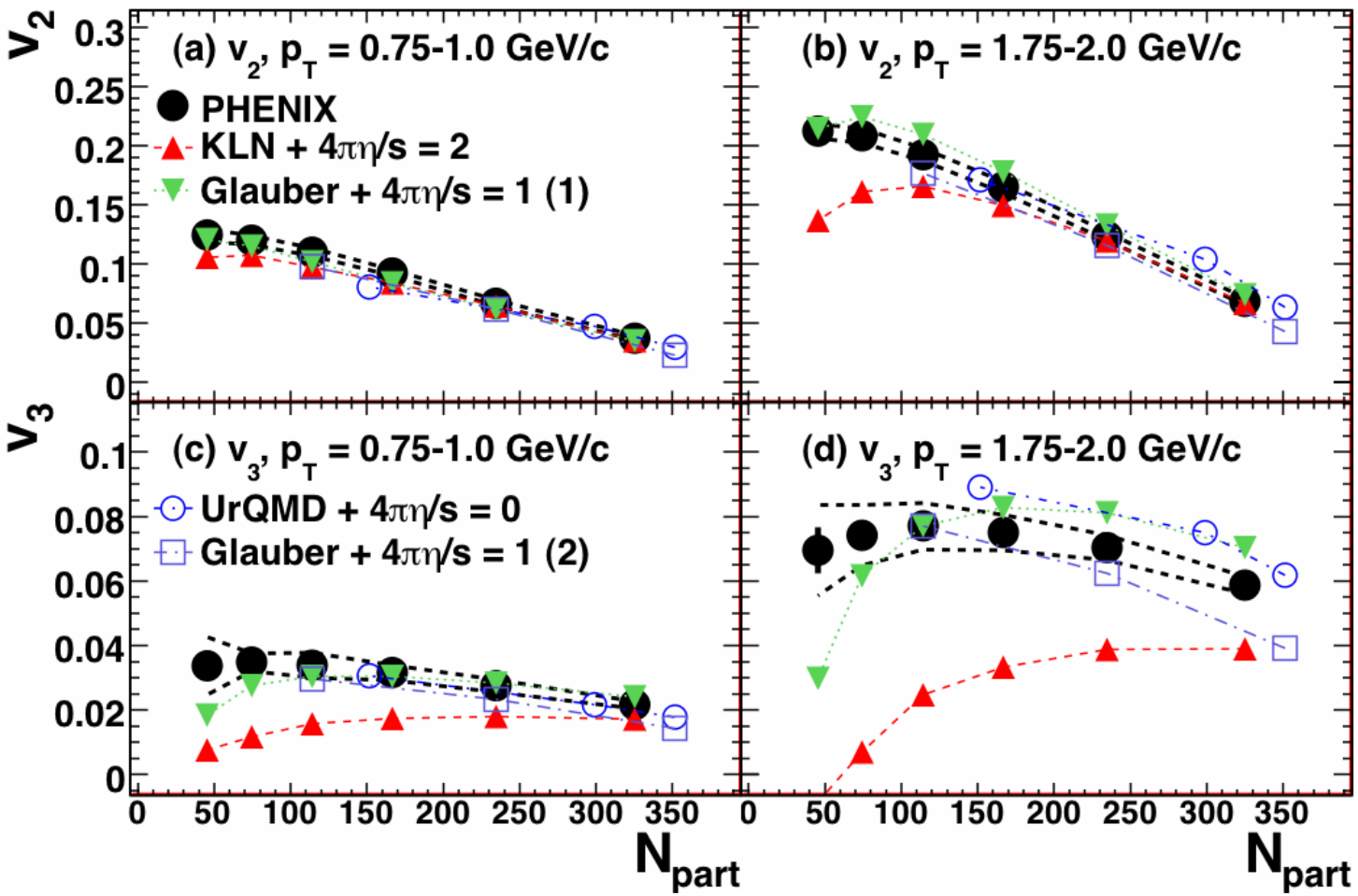
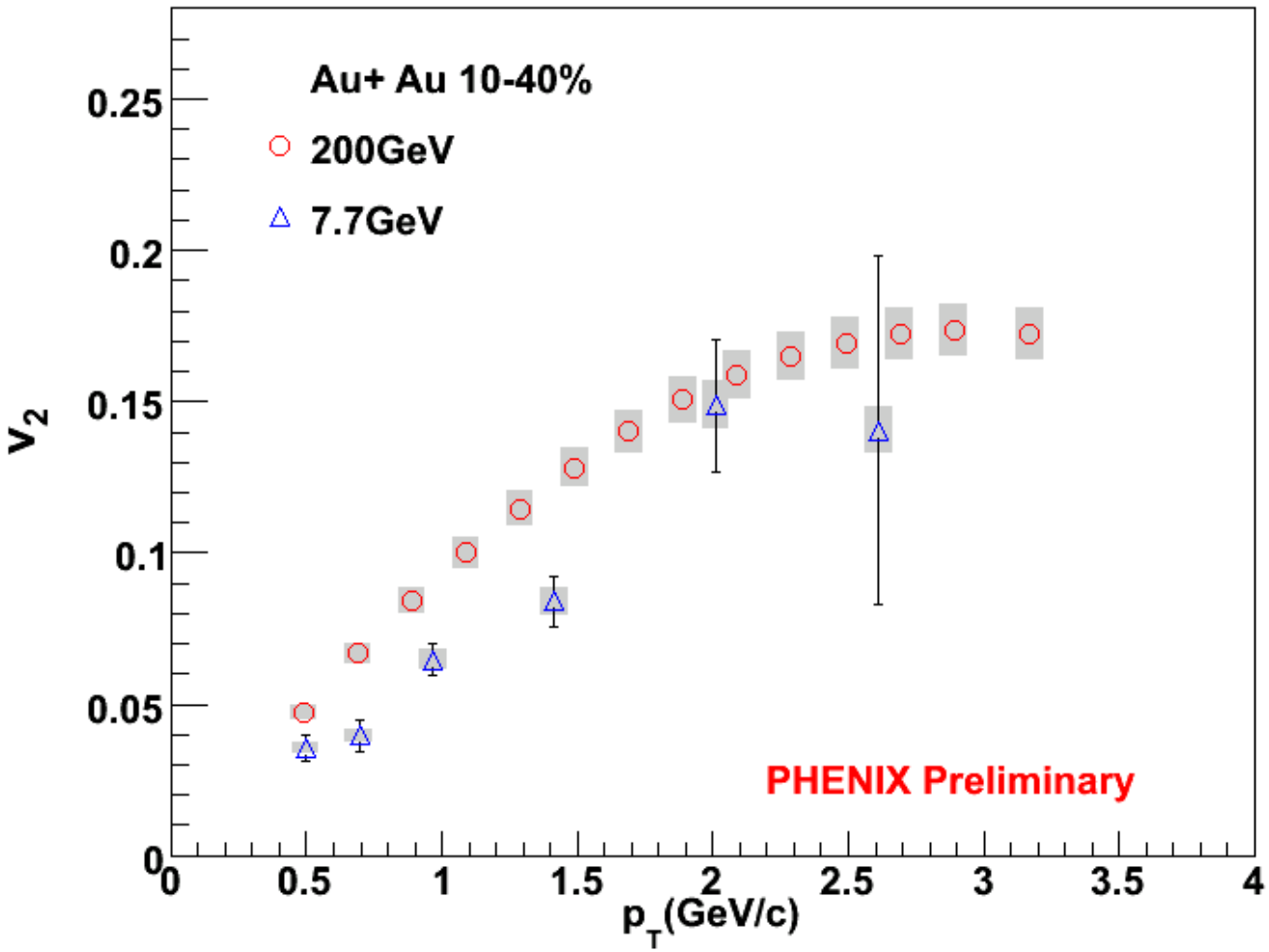


Now with v_3, Glauber + 4πη/s = 1 is favored over the KLN model.

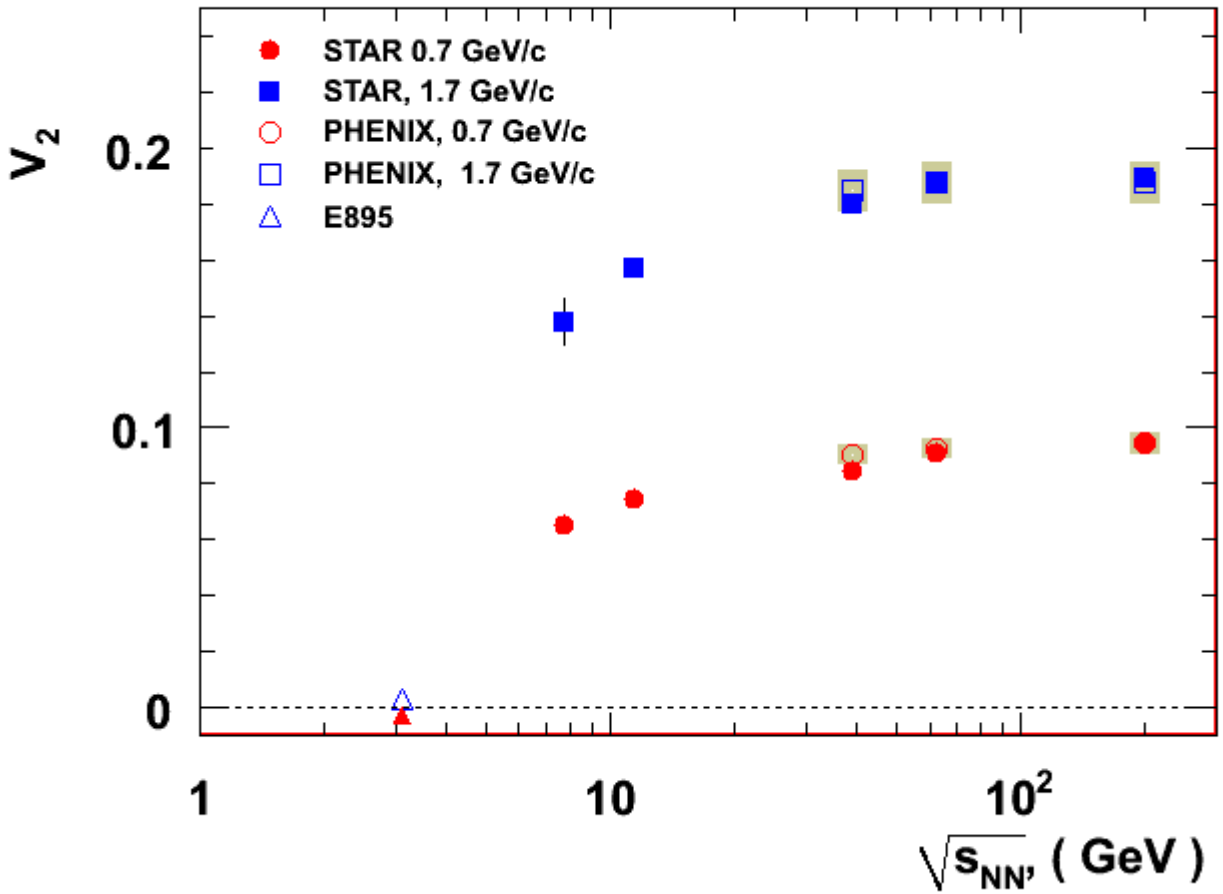
Arxiv:1105.3928

v_2 at 7.7 GeV



Elliptic flow seems to no longer saturate at low energies.

Lower Energies

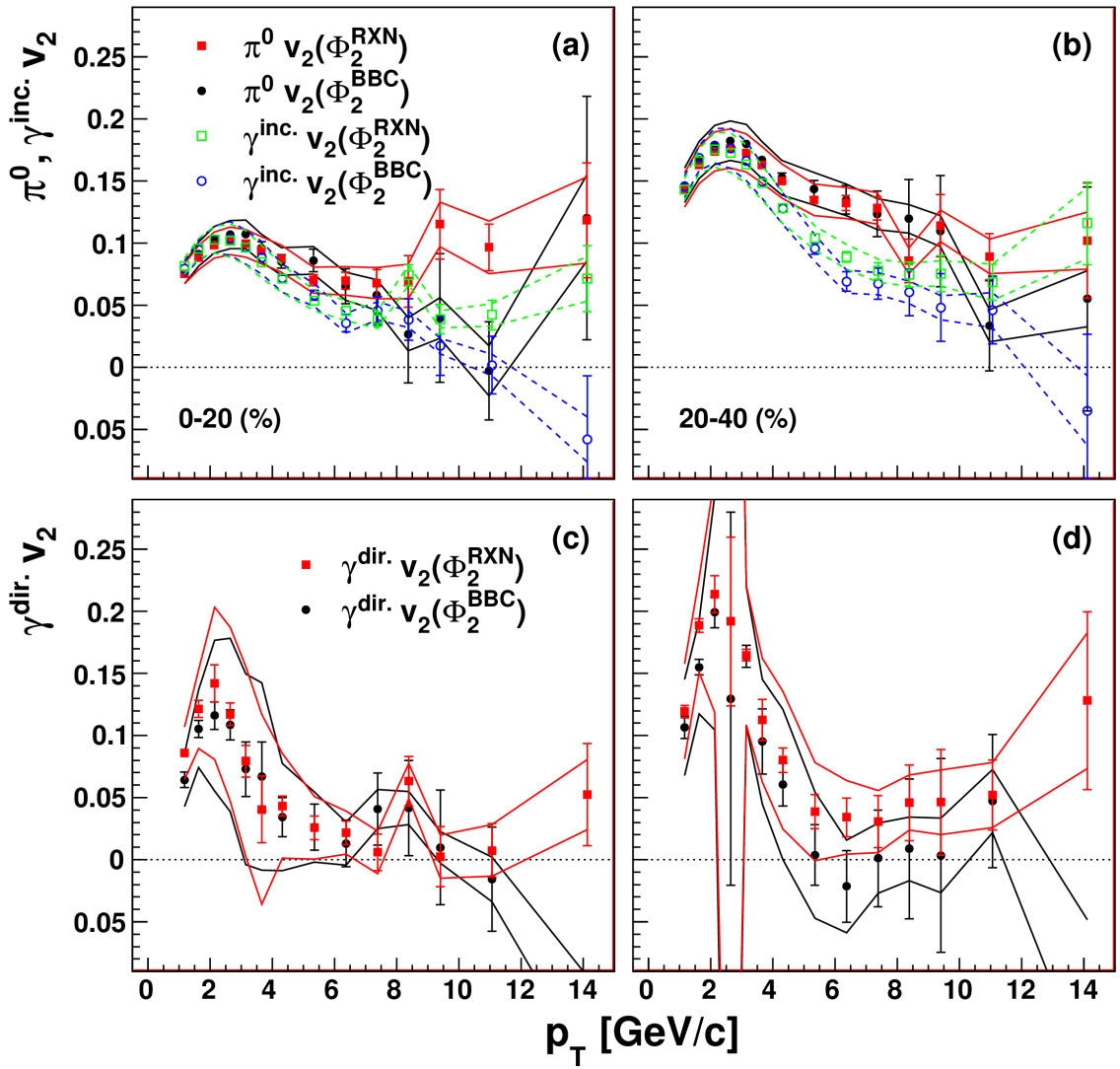


The Beam Energy Scan can help us see what is happening in the gaps.
At 39 GeV and above, it looks to have saturated.

Direct Photon Measurements

- What can the elliptic flow of direct photons tell us?
  - It can help constrain models about photon production which has been used in the past to determine the initial temperature of the medium.
  - Low $p_T < 4$ GeV/c
    - Thermal photons produced by the medium and should have positive v_2.
  - High $p_T >$ GeV/c (Path length dependence tells us geometric information)
    - $v_2 = 0$: Gluon Compton scattering $(qg \rightarrow q\gamma)$
    - $v_2 > 0$: Jet fragmentation photons.
      - There is less energy lost in the event plane.
    - $v_2 < 0$: Jet-conversion photons.
      - A hard scattered quark interacts with thermal gluon in medium.
    - $v_2 < 0$: Bremmstrahlung photons
      - Emitted preferentially where medium is thicker.

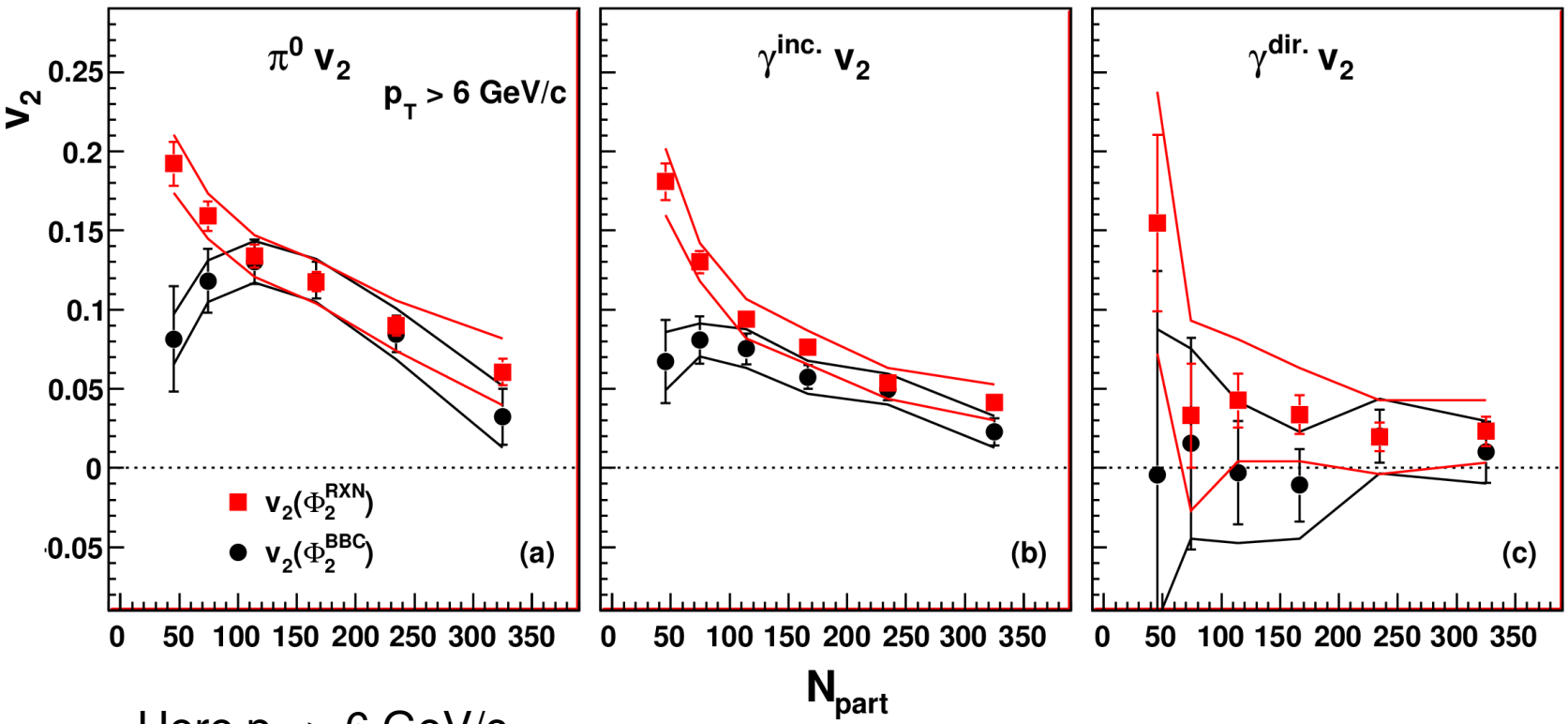
Direct Photon v_2



arxiv:1105.4126v1

v_2 in 0-20% and 20-40% centrality bins for the π^0, inclusive and direct photons using either the RXN or BBC

Direct Photon v_2



Here p_T > 6 GeV/c.

The low N_{part} difference is due to the η difference of detectors.

There should be little v_2 contribution from thermal photons.

v_2 = 0 if only initial hard scattering

v_2 = -0.02 If only jet-conversion

v_2 < 0.01 If only jet fragmentation

Contributions cannot be resolved within errors, but Initial hard scattering looks to play a major role.

arxiv:1105.4126v1

Conclusions

- At 39, 62.4, 200 Gev the elliptic flow was very similar suggesting saturation.
- At lower energies, v_2 dropped off.
- Identified hadron v_2 shows early flow development.
- Simulations can tell us how initial geometry and fluctuations influence flow.
- Using v_3, Glauber + $4\pi\eta/s = 1$ is favored.
- Low p_T direct photon v_2 is higher than current theories have predicted.
- High p_T direct photon v_2 suggests initial hard scattering seems to play a major role.

Thank you!