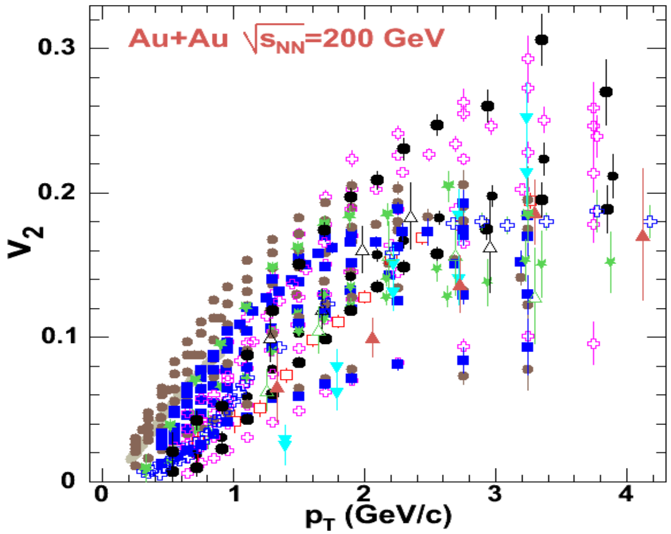
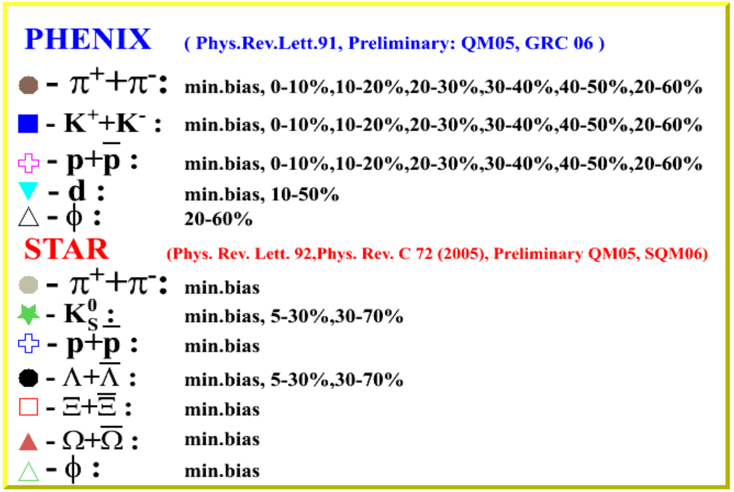
Alexander Zaytsev
National Research Nuclear University MEPhI

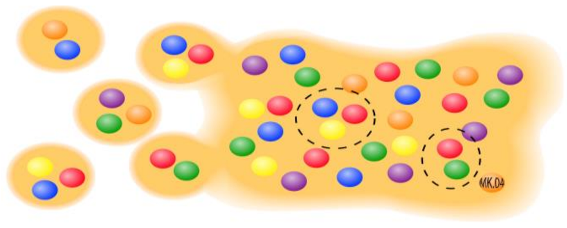
Scaling properties of collective effects at RHIC

INTERNATIONAL CONFERENCE ON PARTICLE PHYSICS AND ASTROPHYSICS – MEPHI 2015

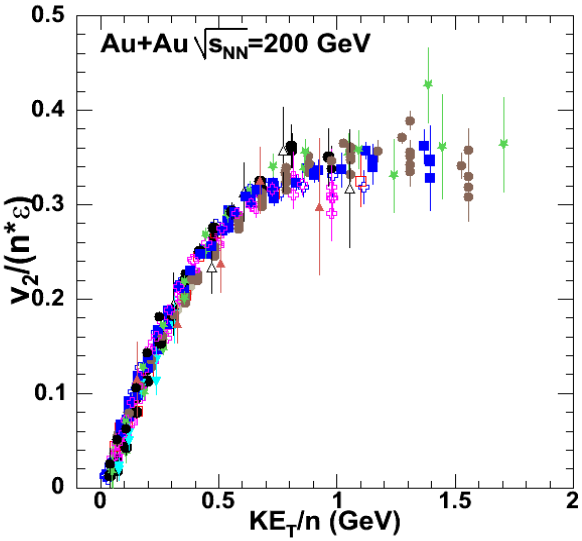
Collective flow at RHIC: 2005







n=3 for baryons and *n*=2 for mesons

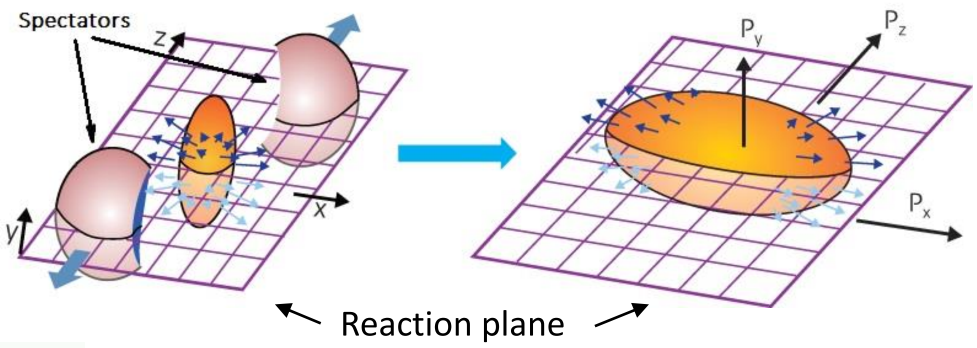


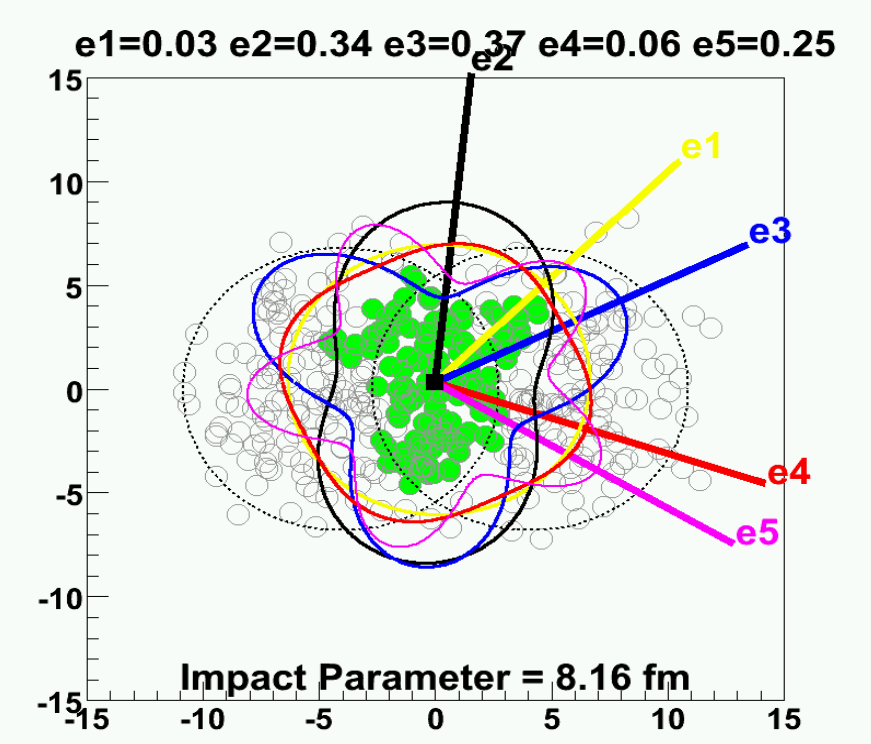
Collective flow

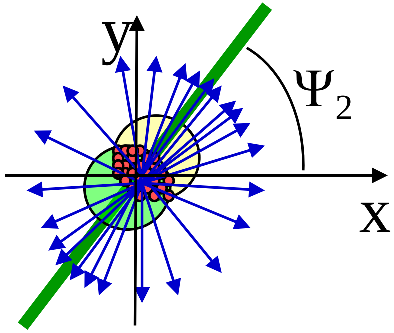
Fourier coefficients:

$$\frac{dN}{d\phi} \propto \left(1 + \sum_{n=1} v_n \cos(n\phi - n\Psi_n)\right)$$

$$v_n = \langle \cos n(\phi - \Psi_n) \rangle$$

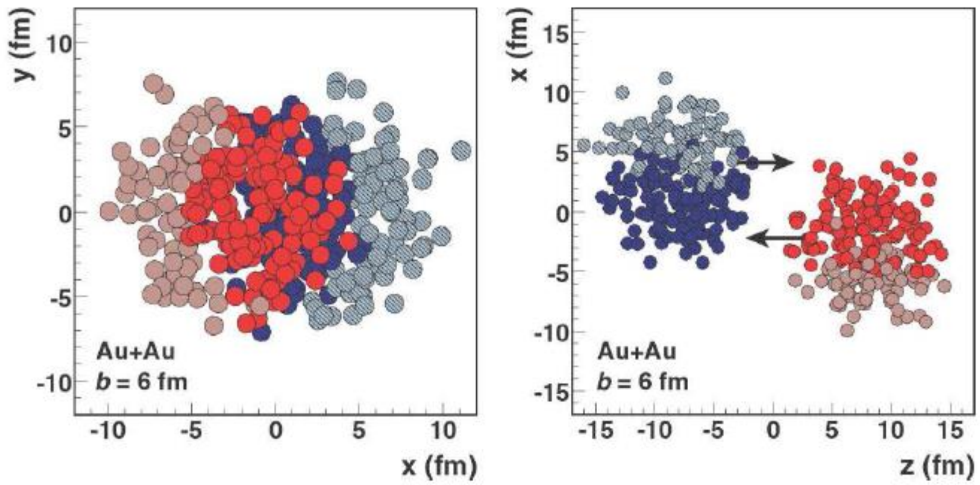






Event plane – an estimate of the reaction plane

Glauber model



Glauber Monte Carlo event
Au+Au at $\sqrt{S_{NN}}$=200 GeV

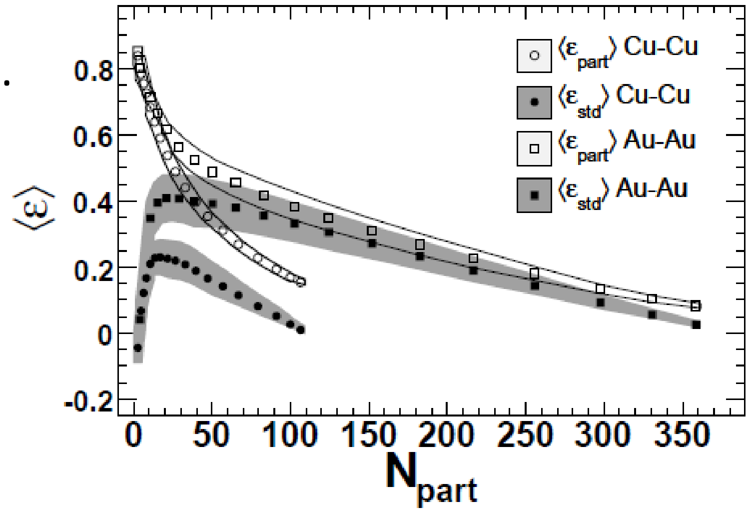
$$\frac{1}{\bar{R}} = \sqrt{\frac{1}{\sigma_x^2} + \frac{1}{\sigma_y^2}}$$

$$\epsilon_n = \sqrt{\frac{\langle r^n \cos n\phi\rangle + \langle r^n \sin n\phi\rangle}{\langle r^n\rangle}}$$

$$\varepsilon = \frac{\langle Y^2 - X^2\rangle}{\langle Y^2 + X^2\rangle}$$

$$\varepsilon_{\text{part}} = \frac{\sqrt{(\sigma_x^2 - \sigma_y^2)^2 + 4(\sigma_{xy}^2)^2}}{\sigma_x^2 - \sigma_y^2}$$

Eccentricity vs. number of participants



Miller M L *et al.* 2007 *Ann. Rev. Nucl. Part. Sci.* **57** 205-243

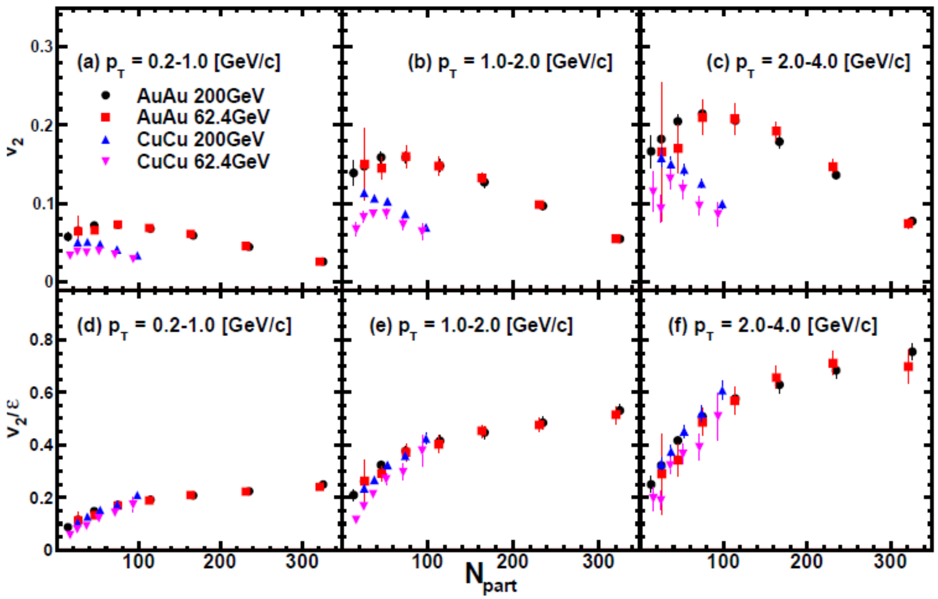
Is QGP a perfect fluid?
Not quite

For perfect fluids v_2/ε should be independent on N_{part}, but for nonperfect fluids it also shoud depends on the Knudsen number:

$$K = \lambda / \overline{R}$$

(λ is the mean free path)

PHENIX data



Adare A *et al.* (PHENIX collaboration) 2014 *arXiv*:1412.1043

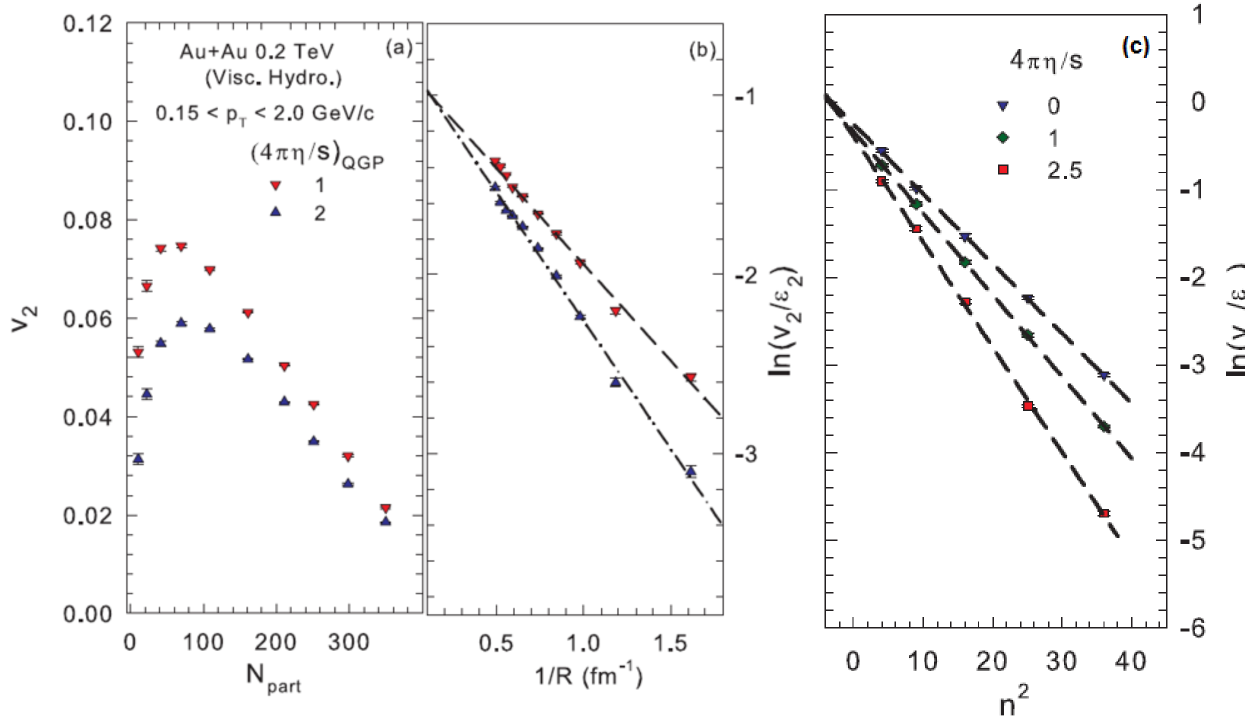
Applying viscous hydrodynamics

One effects of viscosity on sounds is damping of their amplitude. Assumption of the acoustic nature of collective flow leads to following dependencies:

$$\frac{A(t)}{A(0)} = \exp\left(-\frac{2}{3}\frac{\eta}{s}\frac{k^2 t}{T}\right)$$

$$\frac{v_n}{\varepsilon_n} \sim \exp\left[-Cn^2 \frac{\eta}{s}\frac{1}{T\bar{R}}\right]$$

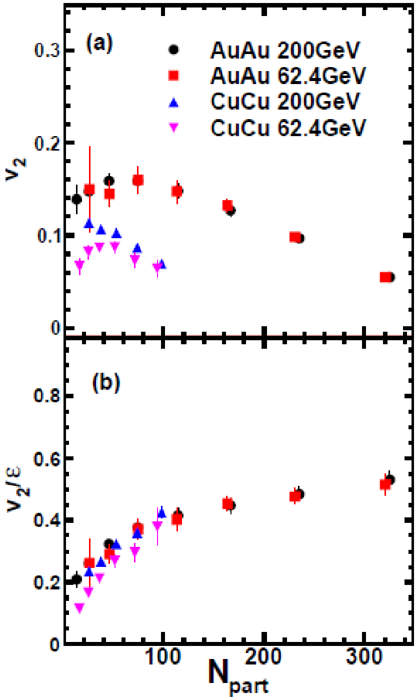
where $\bar{R}$ is the transverse size of the collision zone



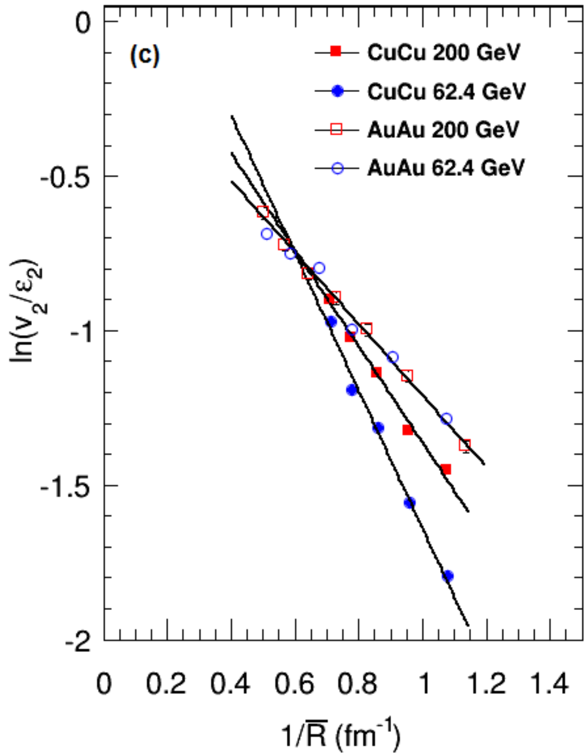
Shuryak E 2014 *arXiv*:1412.8393

Song H *et al.* 2011 *Phys.Rev.* C **83** 054910
Lacey R A *et al.* 2014 *Phys. Rev. Lett.* **112** 082302

Acoustic scaling for the PHENIX data



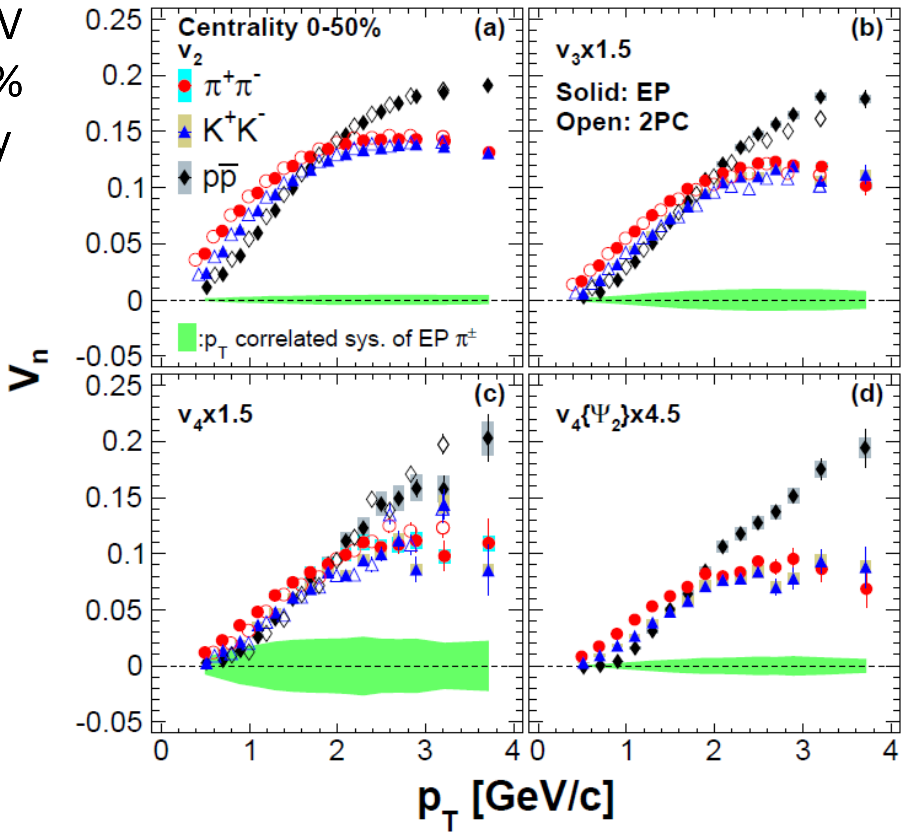
Adare A *et al.* (PHENIX collaboration) 2014 *arXiv*:1412.1043



- The slopes are the same for Au+Au collisions at $\sqrt{s_{NN}}$ = 62.4 and 200 GeV.
- The slopes are different for Au+Au and Cu+Cu at $\sqrt{s_{NN}}$ = 200 GeV
- The slope is larger for Cu+Cu at 62.4 GeV than for 200 GeV.

Collective flow for identified hadrons

Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV
Centrality 0 – 50 %
Midrapidity

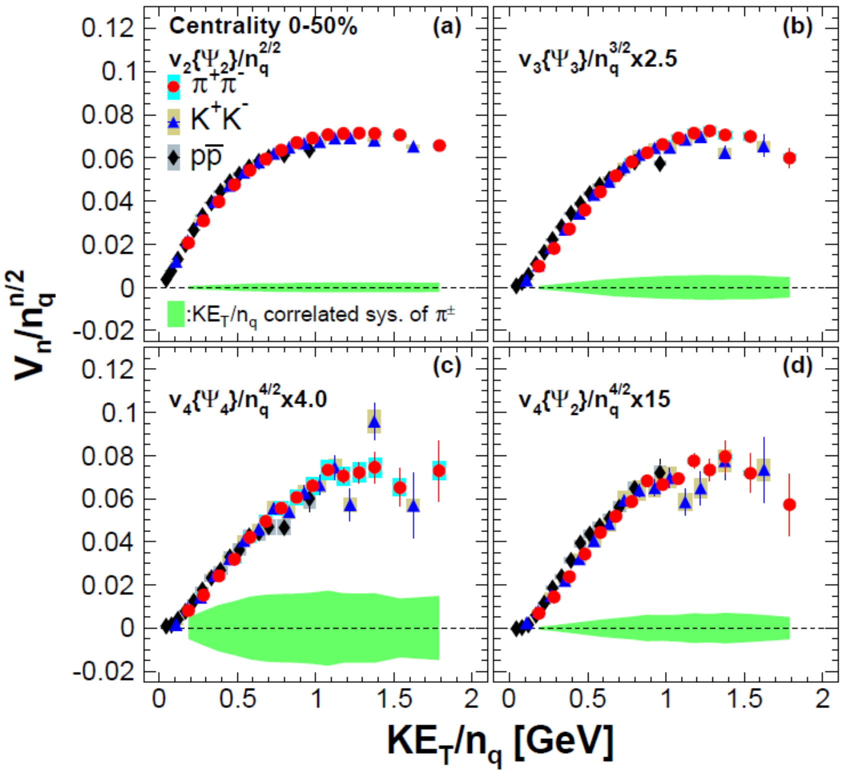


- At low p_T: the anisotropy is the highest for the lightest hadrons
- At high p_T: anisotropy is greater for the (anti-)baryons than for the mesons

quark scaling?

Adare A *et al.* (PHENIX collaboration) 2014 *arXiv*:1412.1038

Constituent quark scaling



Previously observed:

1) $v_n(p_T) \propto (v_2)^{n/2}$

2) Quark scaling in the dependence v_2/n_q vs. KE_T/n_q, where KE_T is transverse kinetic energy:

$$KE_T = \sqrt{p_T^2 + m^2} - m$$

Combination of these properties leads to scaling of $v_n / n_q^{n/2}$ vs. KE_T/n_q

Adare A *et al.* (PHENIX collaboration) 2014 *arXiv*:1412.1038