Azimuthal anisotropy of the identified charged hadrons in Au+Au collisions at $\sqrt{s_{NN}}$= 39 - 200 GeV at RHIC

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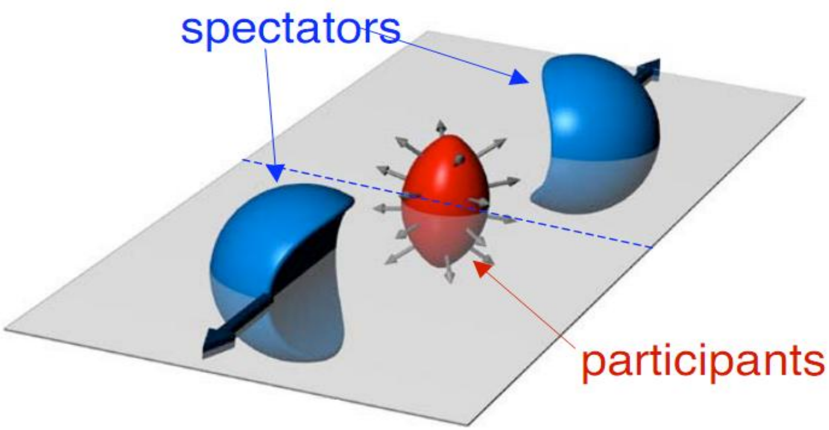
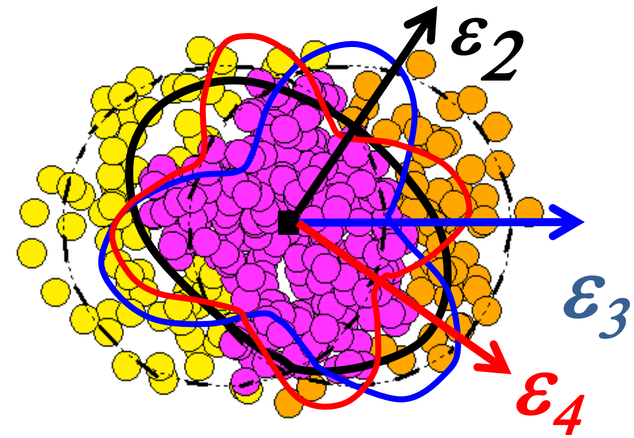
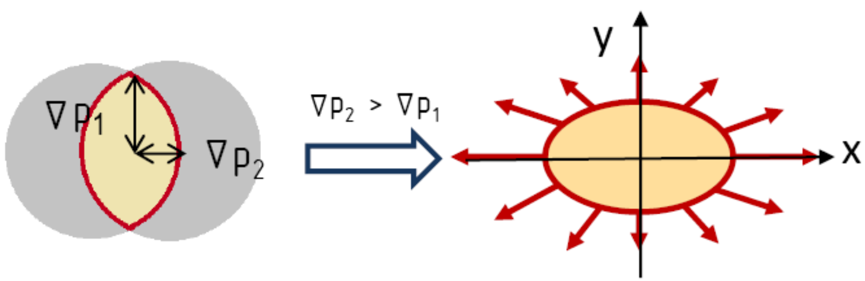
What is collective flow?



Event-by-event fluctuations:





Spatial anisotropy → Azimuthal anisotropy

ϵ_n → v_n

Fourier series expansion : $$\frac{dN}{d(\phi-\psi_k)} \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos(n(\phi-\psi_k))$$

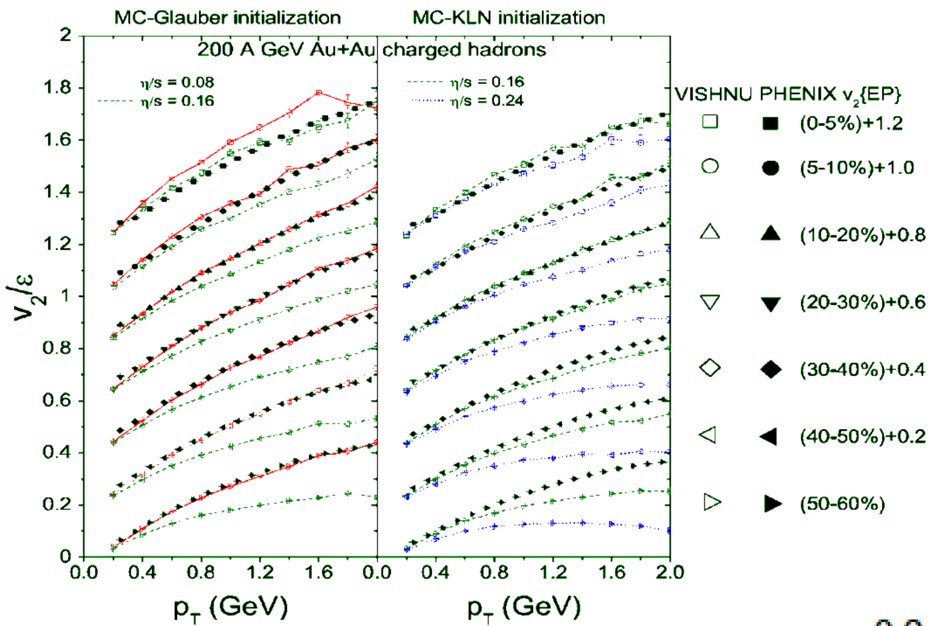
n-th flow harmonic

Motivation

Collective flow allows to study properties of the ***quark-gluon plasma.***

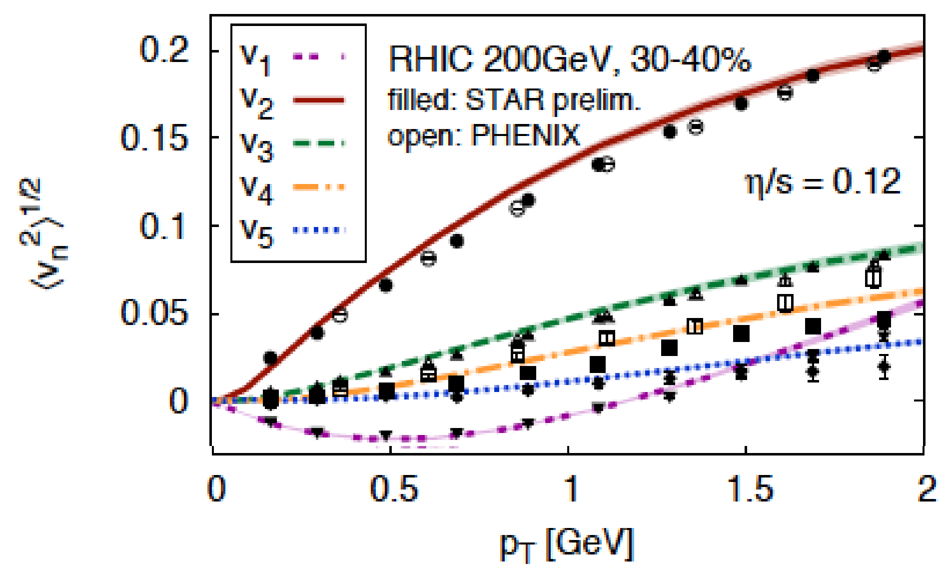
- ✓ Evaluation of the initial state geometry and transport properties
- ✓ High flow harmonics are more sensitive to transport properties
- ✓ The flow of identified particles → hadronization mechanism
- ✓ Scaling properties can give insights on flow nature

Highlights from highest energy at RHIC – 200 GeV

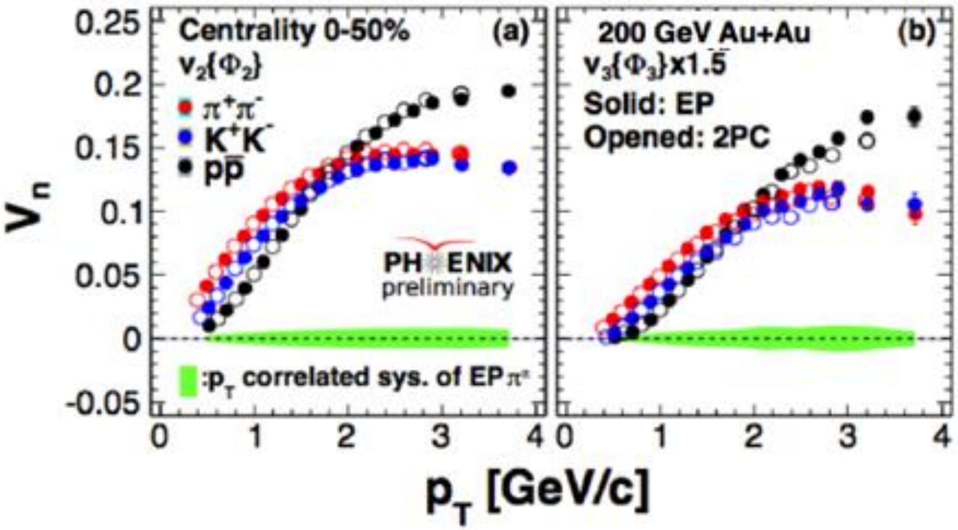


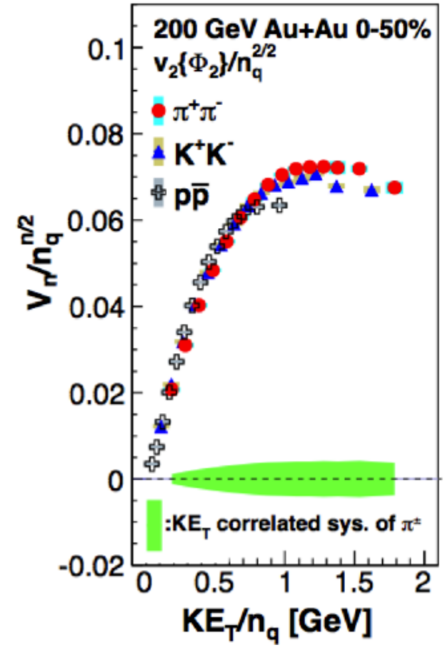
Comparison to hydrodynamic models is a way to evaluate value of viscosity

Higher harmonics put stronger constraints on η/s value



Highlights from highest energy at RHIC – 200 GeV





Mass ordering is observed for $p_T < 2$ GeV/c. Particles with the lowest mass (pions) have the highest flow

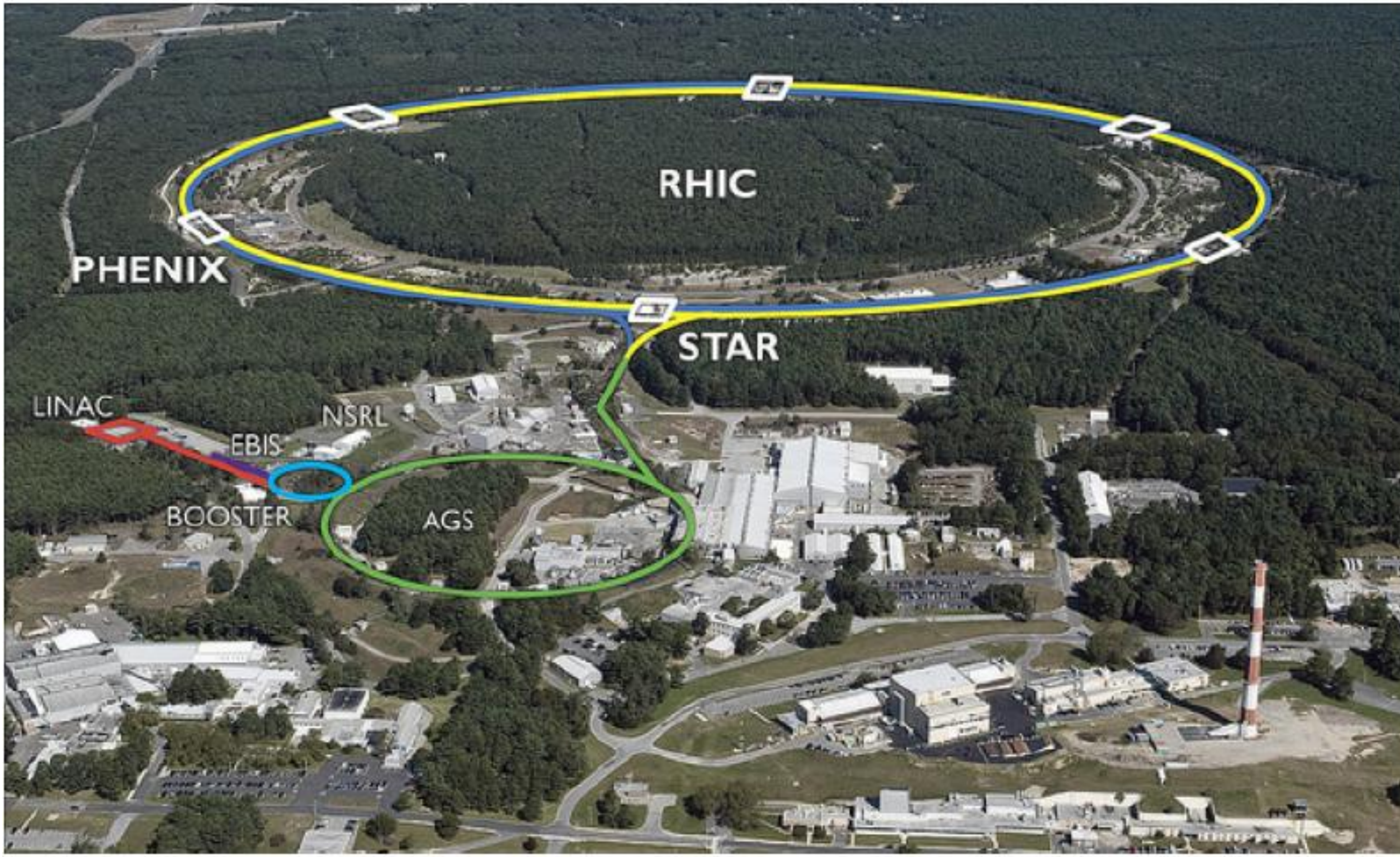
For the higher p_T the meson-baryon splitting is observed

$KE_T = m_T – m_0$

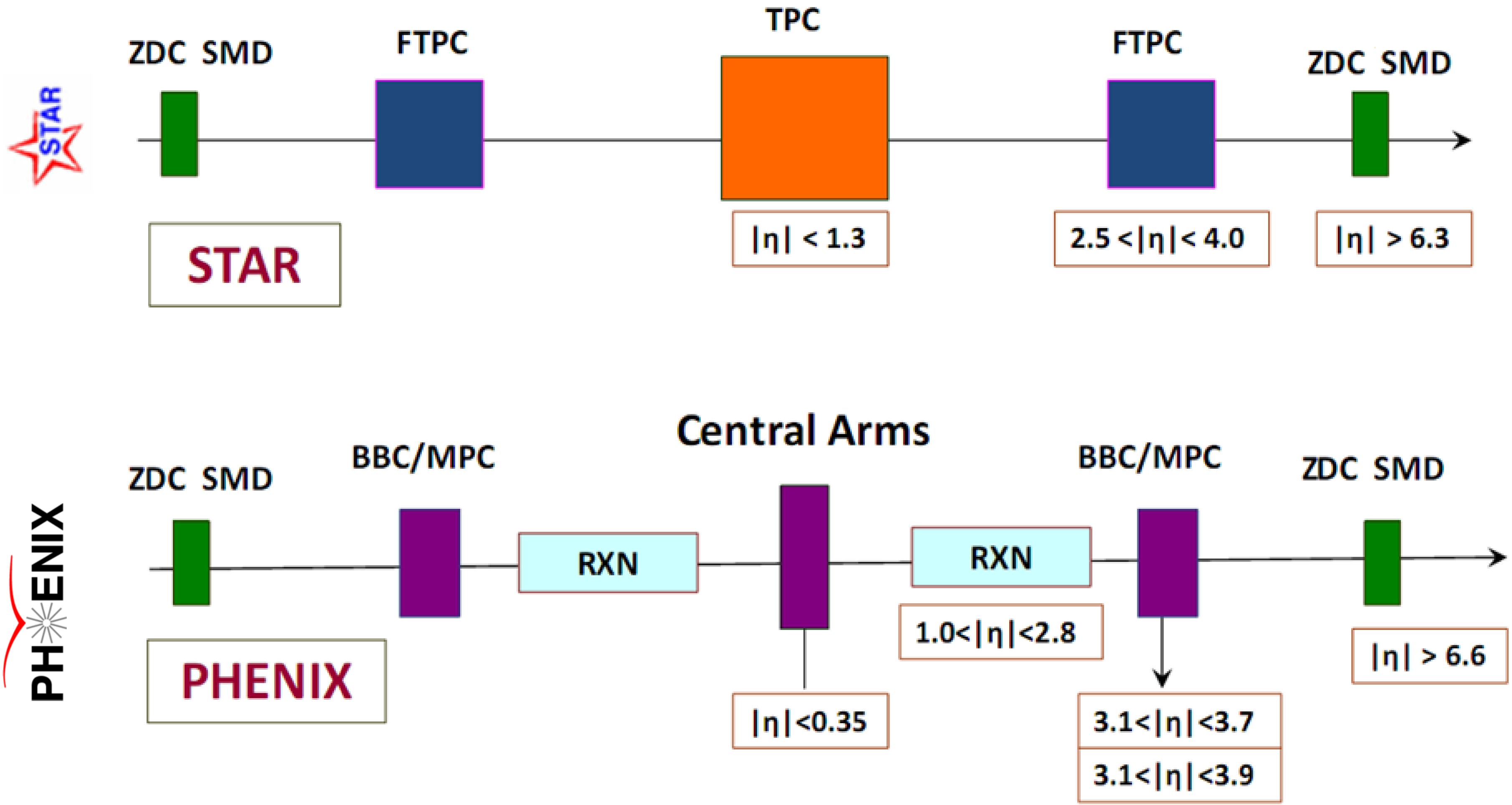
Scaling of the flow - different particles species follow the same curve

arXiv:1211.4009

RHIC collider, BNL



PHENIX and STAR



STAR has wide azimuthal coverage (2π), while PHENIX does not (two arms of π/2)
PHENIX have variety of detectors with big enough η-gap to central arms.

Event Plane Method (EP)

$$\frac{dN}{d(\phi-\psi_n)} \propto 1 + 2\sum_{k=1}^{\infty} v_k \cos(k(\phi-\psi_n))$$

Evaluation of the event plane Φ_n → Calculation of the observed value $v_n^{obs} = \langle \cos[n(\phi - \Phi_n)]\rangle$ → Determination of the real value $v_n = \frac{v_n^{obs}}{Res\{\Phi_n\}}$

$$Q_{nx} = \sum w_i \cos n\phi_i$$

$$Q_{ny} = \sum w_i \sin n\phi_i$$

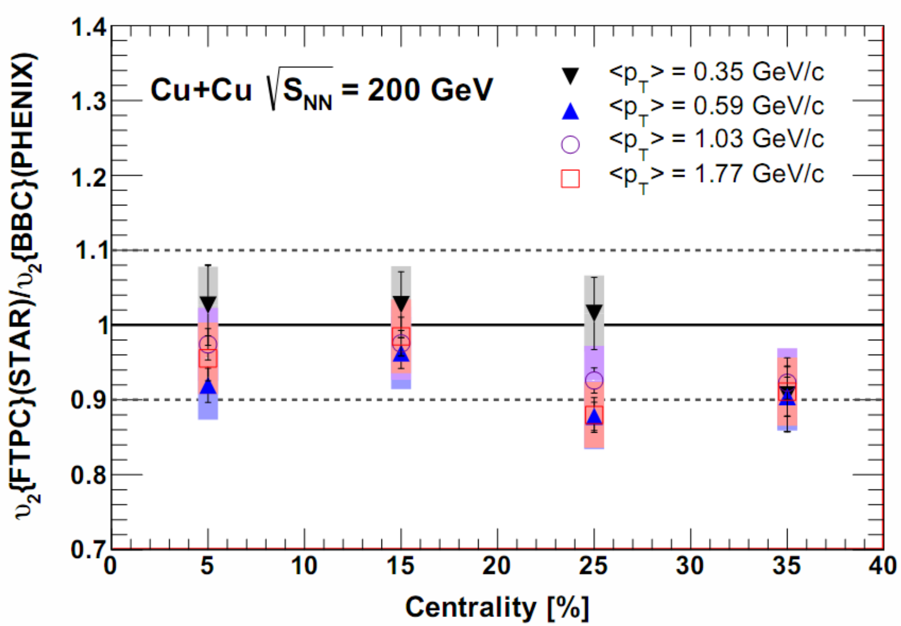
$$\Phi_n = \tan^{-1}\left(\frac{Q_{ny}}{Q_{nx}}\right)/n$$

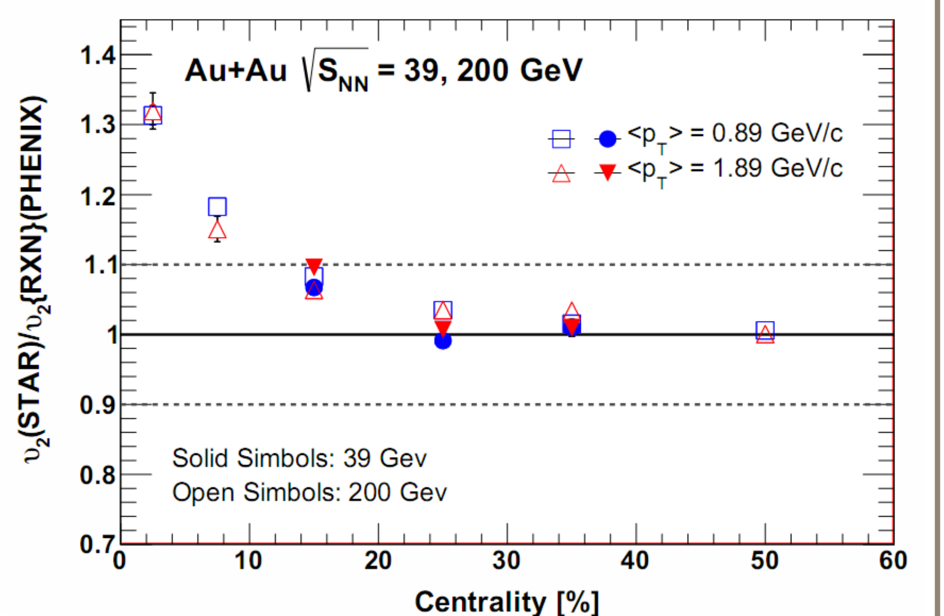
Between detectors which measure ϕ and Φ_n should be Δη gap.

Res{Φ_n} comes from fluctuations of Φ_n since Φ_n is an estimation of a real symmetry angle Ψ_n

$$Res\{\Phi_n\} = \langle \cos[n(\Phi_n - \Psi_n)]\rangle$$

Difference in the results (v_2)





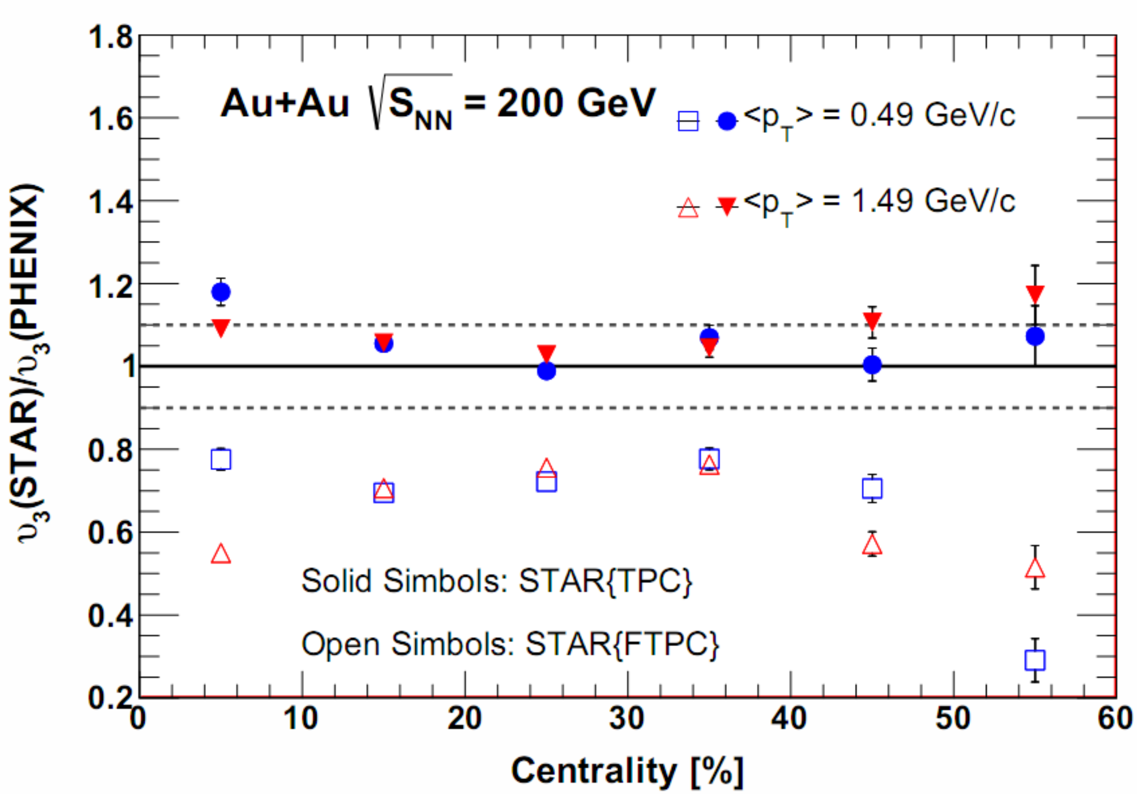
FTPC(STAR) and BBC(PHENIX) the only measurements with similar η-gap!

Same behavior pattern for both 39 and 200 GeV energies → difference can't come from non-flow only.

The difference between two data sets are less than 5-10%

STAR: Charged and strange hadron elliptic flow in Cu+Cu collisions at 62.4 and 200 GeV, Phys. Rev. C 81 (2010) 44902
PHENIX: Scaling properties of azimuthal anisotropy in Au+Au and Cu+Cu collisions at s(NN) = 200-GeV, Phys.Rev.Lett. 98 (2007) 162301

Difference in the results (v_3)



Less than 10% difference between STAR(TPC) to PHENIX(RXN) results on the other hand

A huge difference (40-50%) between STAR TPC and FTPC data.

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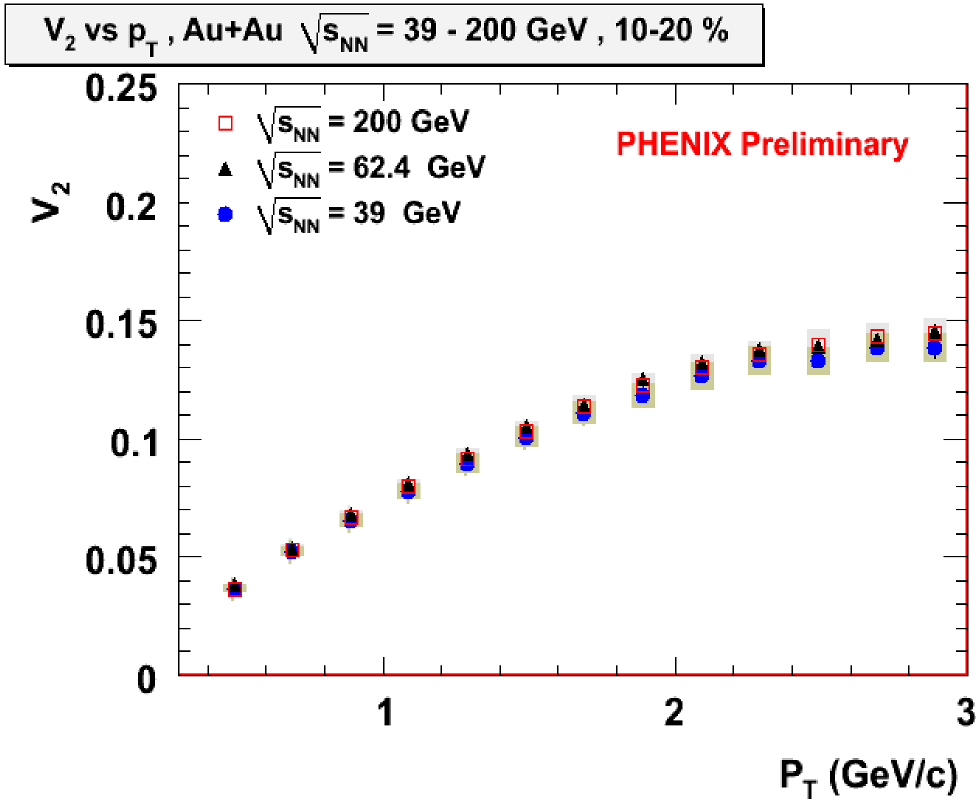
STAR: Third Harmonic Flow of Charged Particles in Au+Au Collisions at 200 GeV, Phys. Rev. C 88 (2013) 14904

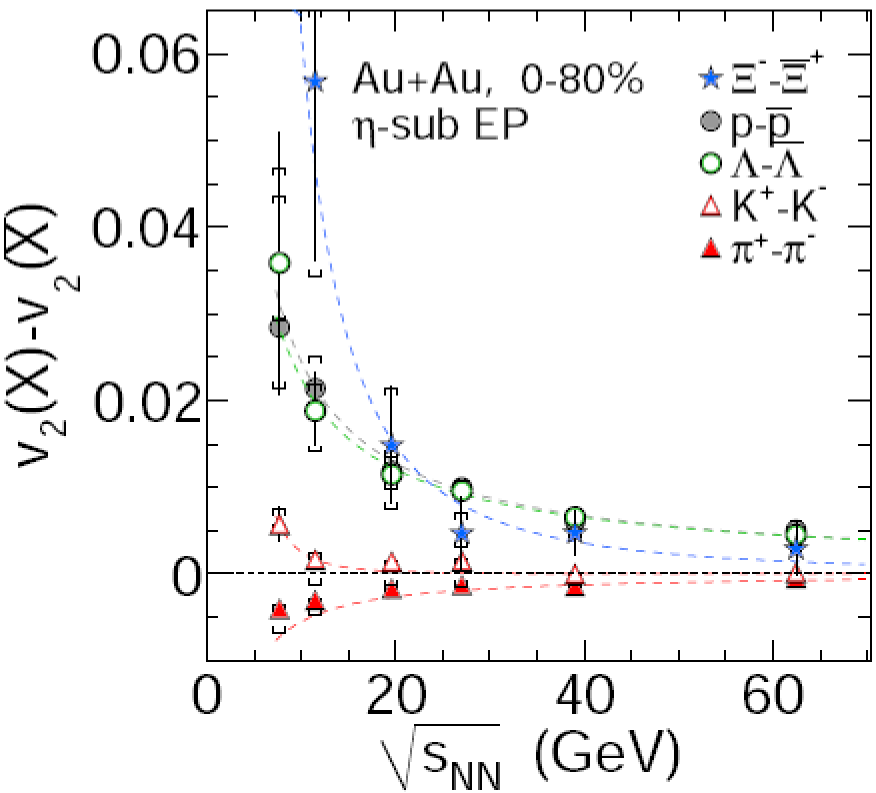
PHENIX: Scaling properties of azimuthal anisotropy in Au+Au and Cu+Cu collisions at s(NN) = 200 GeV, Phys.Rev.Lett. 98 (2007) 162301

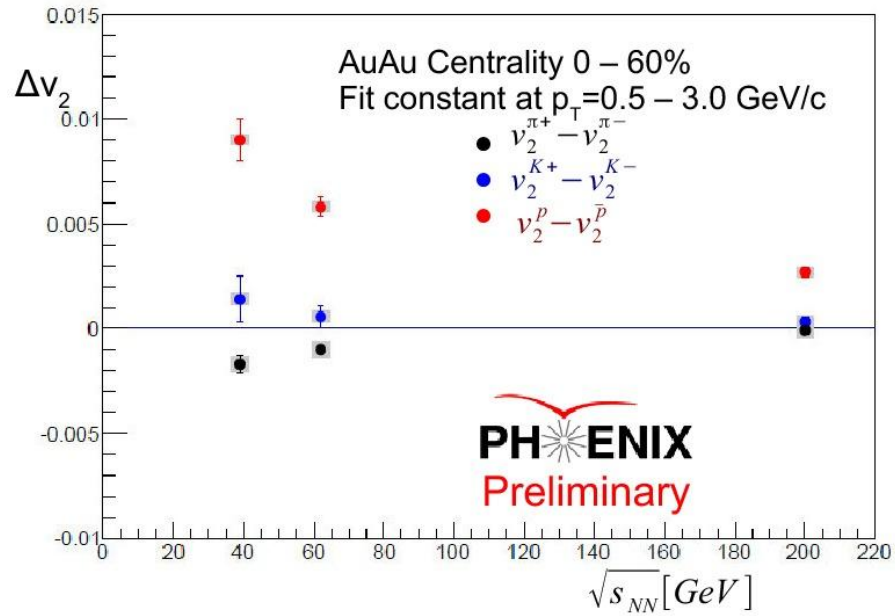
v_2 at lower RHIC energies. Charged hadrons



No significant change of the flow at lower energies for charged hadrons

v_2 particle-antiparticle difference.



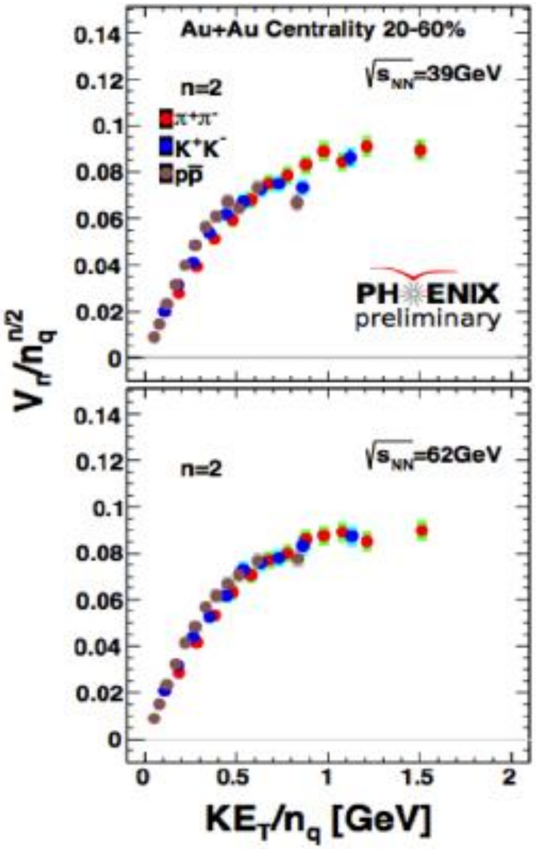


The difference between flow of particles and antiparticles is increasing with energy decreasing. That cause the scaling violation at low energies.

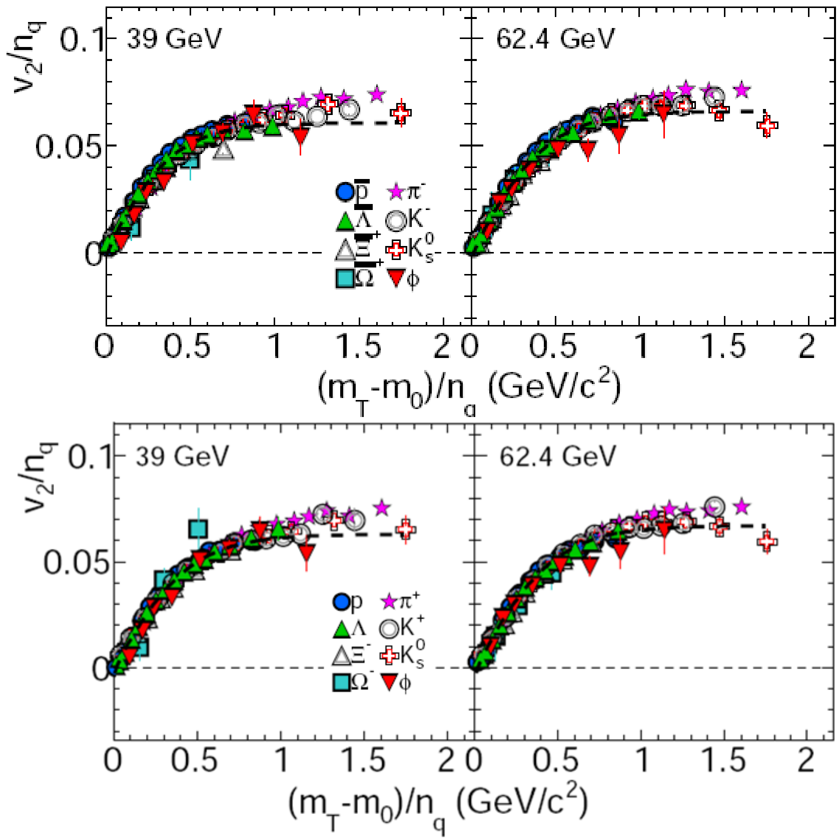
arXiv:1509.08397 (2015)

Scaling of elliptic flow v_2

PHENIX

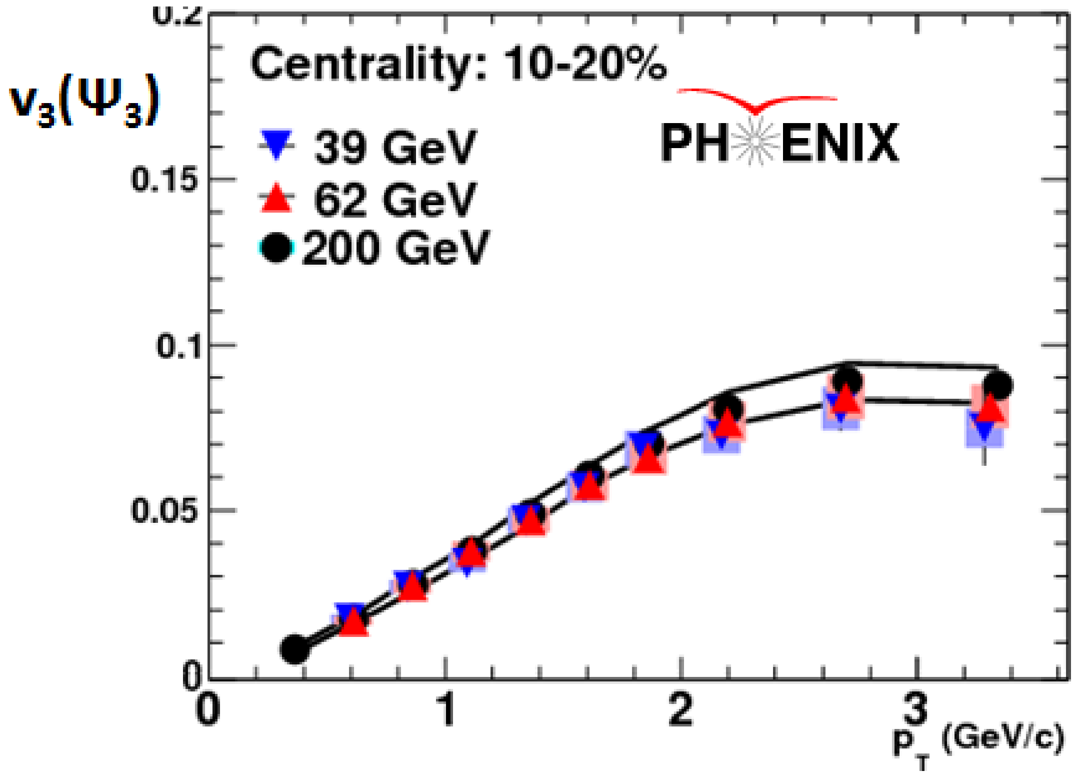


STAR



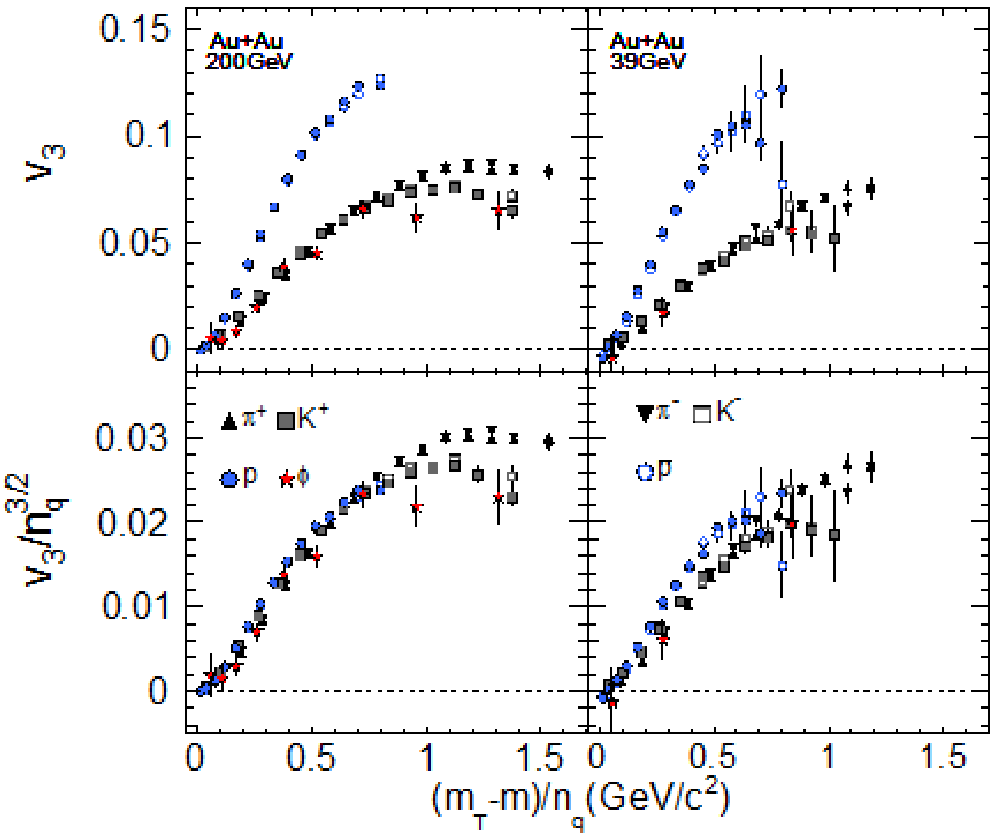
Elliptic flow scales with number of quarks – different particle species have the similar trend. But agreement is worse for lower energies. The presence of scaling ($v_n^{hadron} = n_q v_n^{quarks}$) shows that the flow is formed on the quarks level.

v_3 at lower RHIC energies. Charged hadrons



No significant changing of the flow at lower energies for charged hadrons

Scaling of triangular flow v_3



Scaling is also observed for v_3 at 200 GeV and breaks at lower energies

J. Phys. G: Nucl. Part. Phys. 38 (2011) 124048

Conclusions

A detailed comparison of RHIC experimental data for anisotropic flow harmonics has been presented:

- KE_T and NCQ scaling of v_2 and v_3 is observed at 200 GeV and broken at lower energies

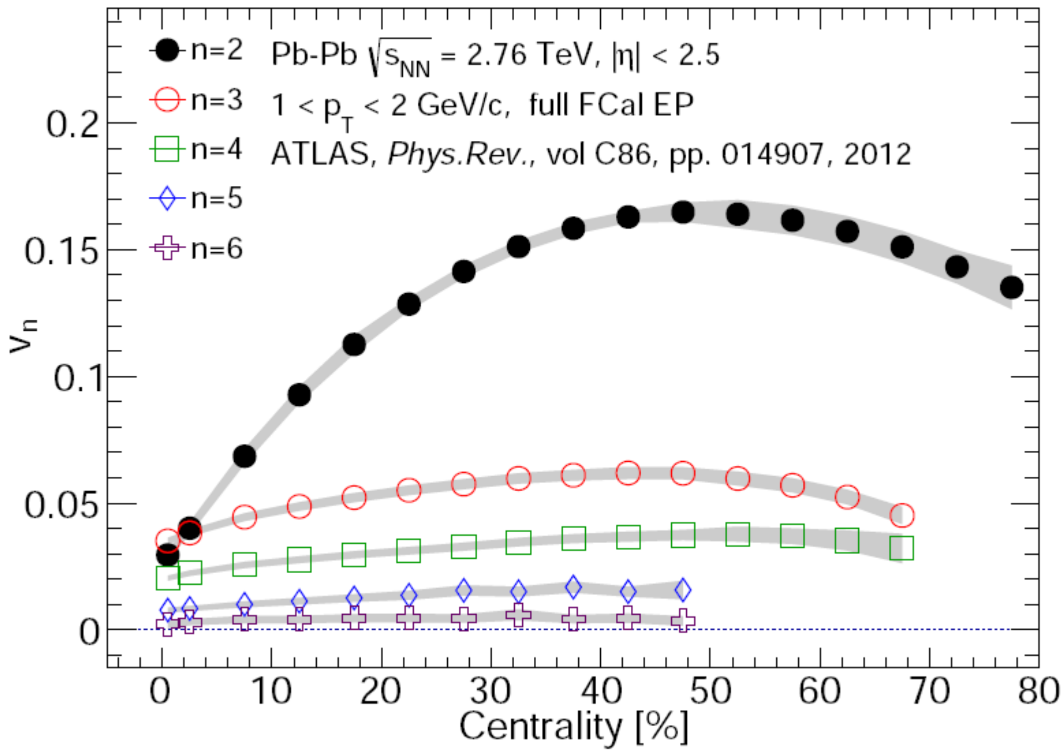
- The difference of elliptic flow between particles and antiparticles is increasing at lower energy

- STAR and PHENIX have slightly different results for v_2 and v_3

Thank you for your attention!

Backup Slides

Centrality dependence of flow harmonics



Since overlapping region is mostly elliptic shape, the second harmonic – v_2 – is the highest one

Baryon chemical potential