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Scaling of collective flow of charged and identified hadrons in Au+Au collisions at $\sqrt{s_{NN}}$ = 11.5 - 62.4 GeV from the STAR experiment

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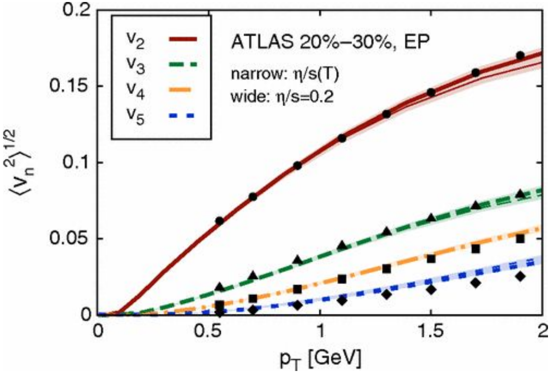
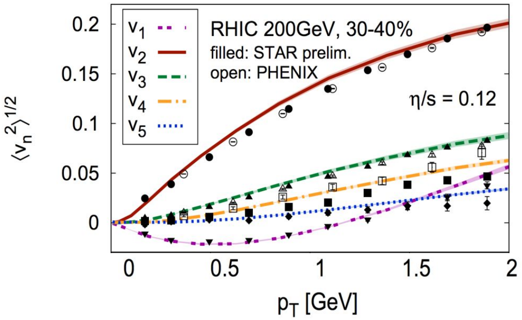
Outline

- Introduction
- Anisotropic flow at RHIC
- The STAR detector at RHIC
- Analysis methods
- Results
- Summary and Outlook

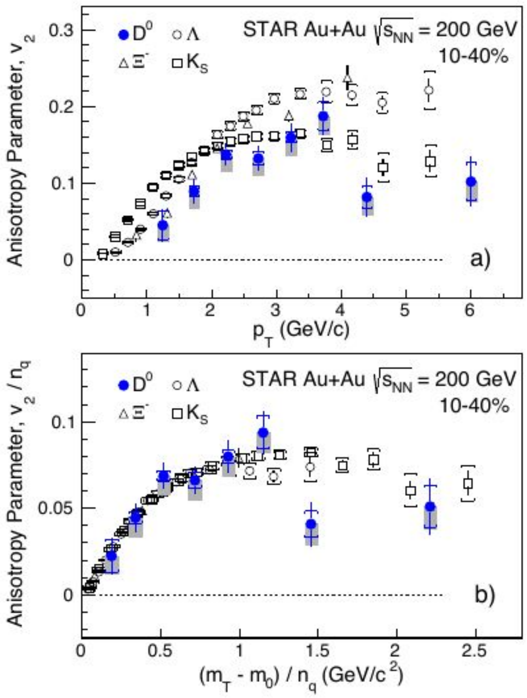
Anisotropic collective flow at RHIC/LHC

Gale et al., Phys. Rev. Lett. 110, 012302 (2013)





STAR PRL118 (2017) 212301



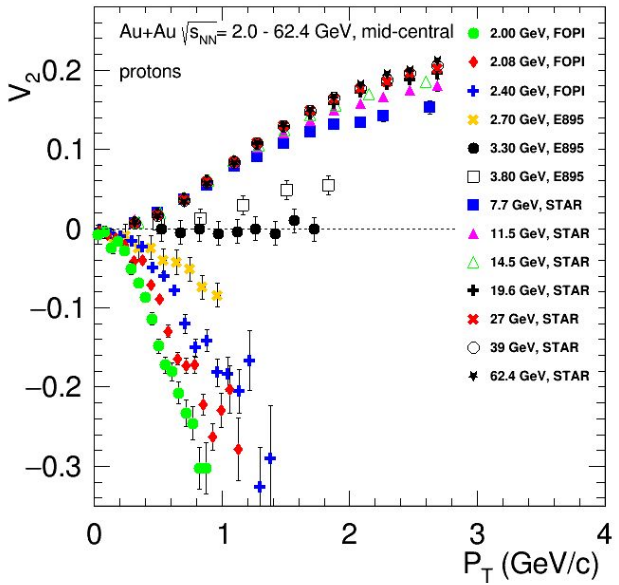
v_n**(p_T, centrality)** - sensitive to the early stage of nuclear collisions. Important constraints for transport properties: EOS, η/s, ζ/s, etc.

Mass ordering at p_T < 2 GeV/c (hydrodynamic flow, hadron rescattering)

Baryon/meson grouping at p_T > 2 GeV/c (recombination/coalescence), Number of constituent quark (NCQ) scaling

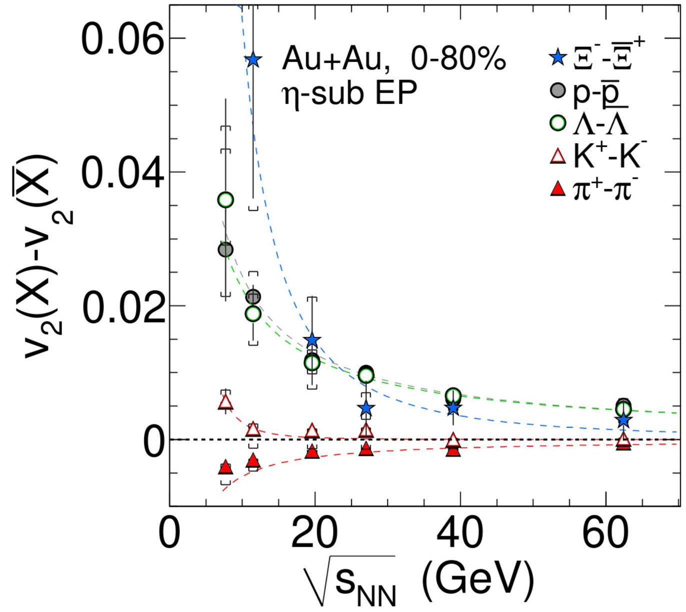
Anisotropic collective flow at RHIC Beam Energy Scan

Taranenko, EPJ Web Conf. 204 (2019) 03009



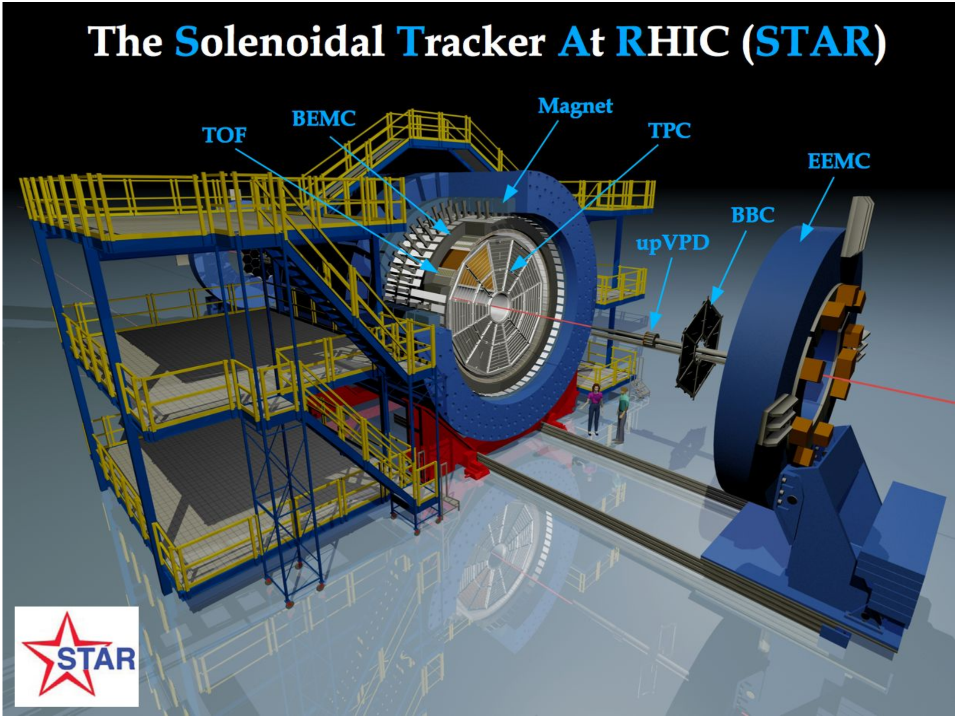
FOPI(15-29%) E895(12-25%) STAR(10-40%)

STAR Collaboration, Phys. Rev. C 88 (2013) 14902



- Small change in $v_2(p_T)$ in Au+Au collisions above $\sqrt{s_{NN}}$ = 7.7 GeV
- Strong energy dependence of the difference in v_2 of particles and antiparticles
- **Our aim is to measure and study the systematics of $v_3(\sqrt{s_{NN}}$, centrality, PID, $p_T)$**

The STAR detector at RHIC



Time Projection Chamber (TPC):

- Tracking of charged particles with $|\eta| < 1$, 2π in φ.
- PID using dE/dx measurements

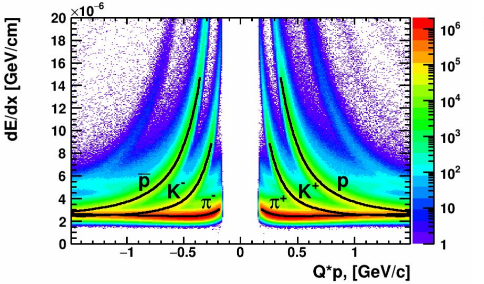
Time-Of-Flight (TOF):

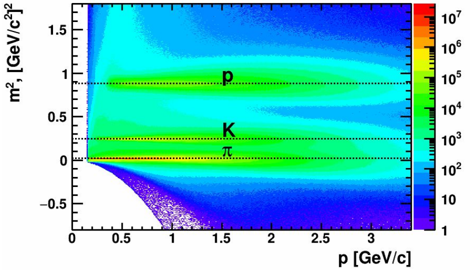
- $|\eta| < 0.9$, 2π in φ
- PID using time-of-flight information

Event planes: TPC ($|\eta| < 1$)

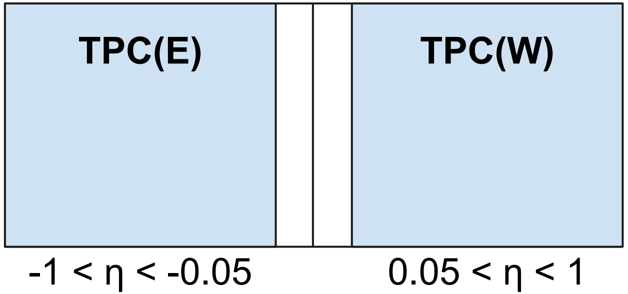
Data set: Au+Au at $\sqrt{s_{NN}}$ = 11.5 - 62.4 GeV

RHIC beam energy scan phase one





Analysis technique: Event Plane Method (EP)



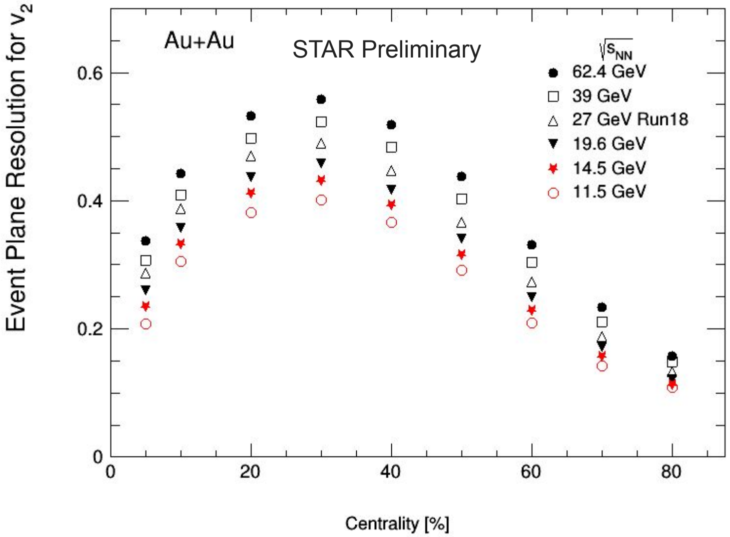
TPC (E) half $(-1 < \eta < -0.05) \rightarrow \eta_-$

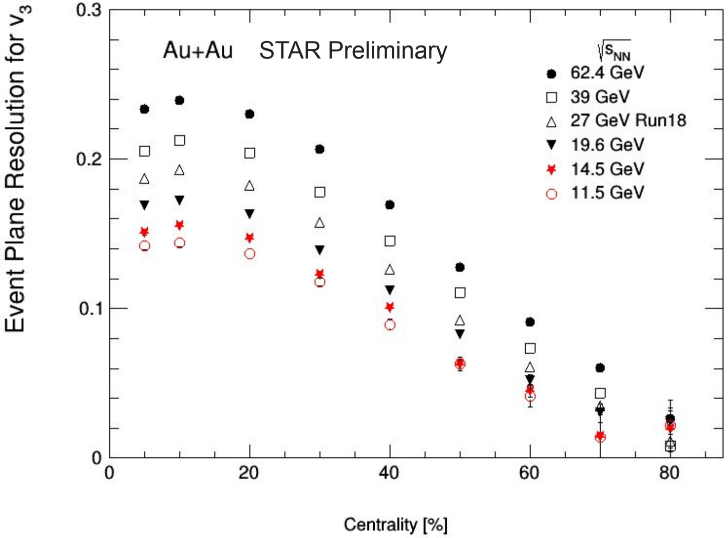
TPC (W) half $(0.05 < \eta < 1) \rightarrow \eta_+$

$$Res\{\Psi_n\} = \sqrt{\langle \cos[n(\Psi_{n,\eta+} - \Psi_{n,\eta-})] \rangle}$$

$$v_n = \frac{\langle \cos[n(\phi_{\eta\pm} - \Psi_{n,\eta\mp})] \rangle}{Res\{\Psi_n\}}$$

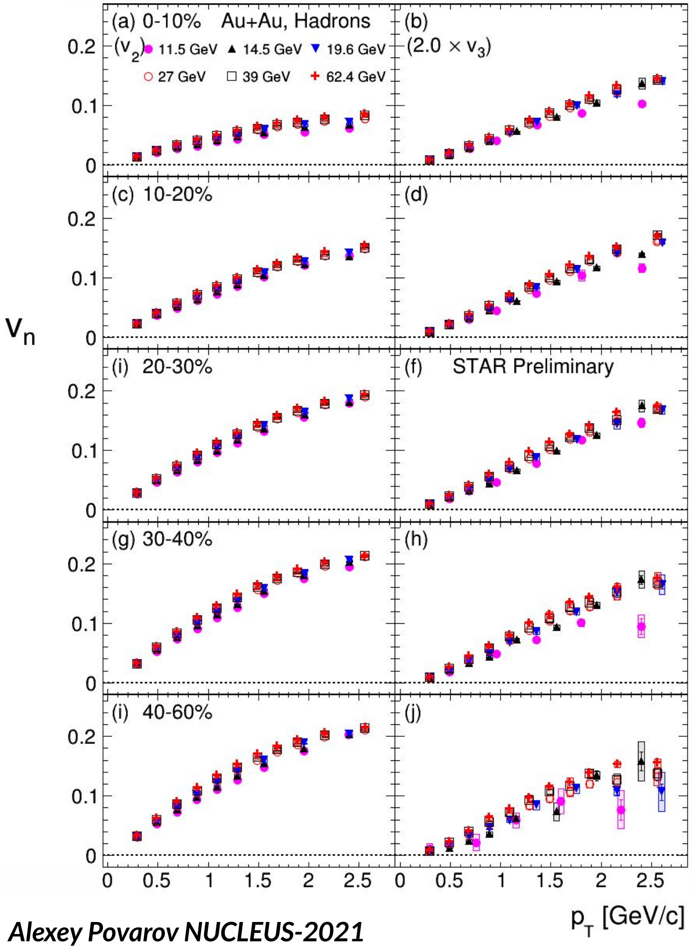
In the end we take average $v_n(\eta<0)$ and $v_n(\eta>0)$

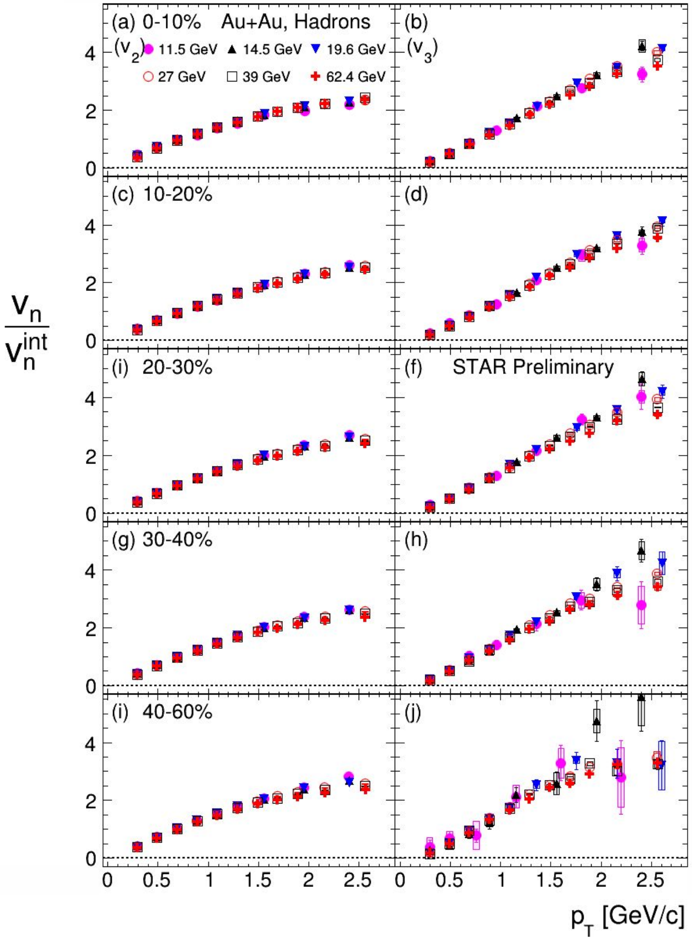




Used the same method as in Phys. Rev. C 88 (2013) 14902

$v_2(p_T)$ and $v_3(p_T)$ of charged hadrons as p_T function





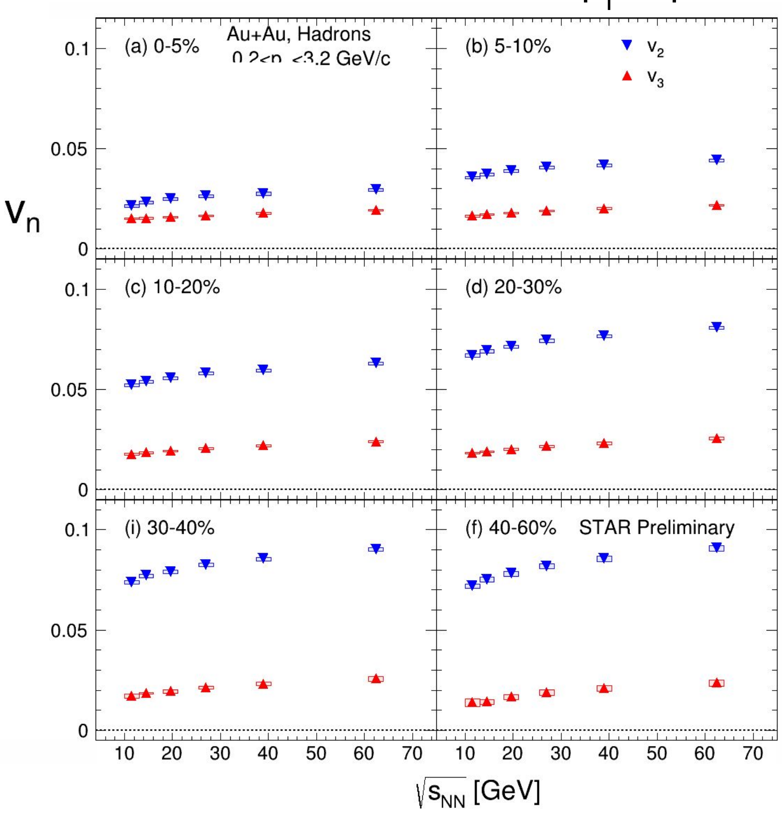
$$v_n^{\mathrm{int}} = \int v_n(\mathrm{p_T})\mathrm{dp_T}$$

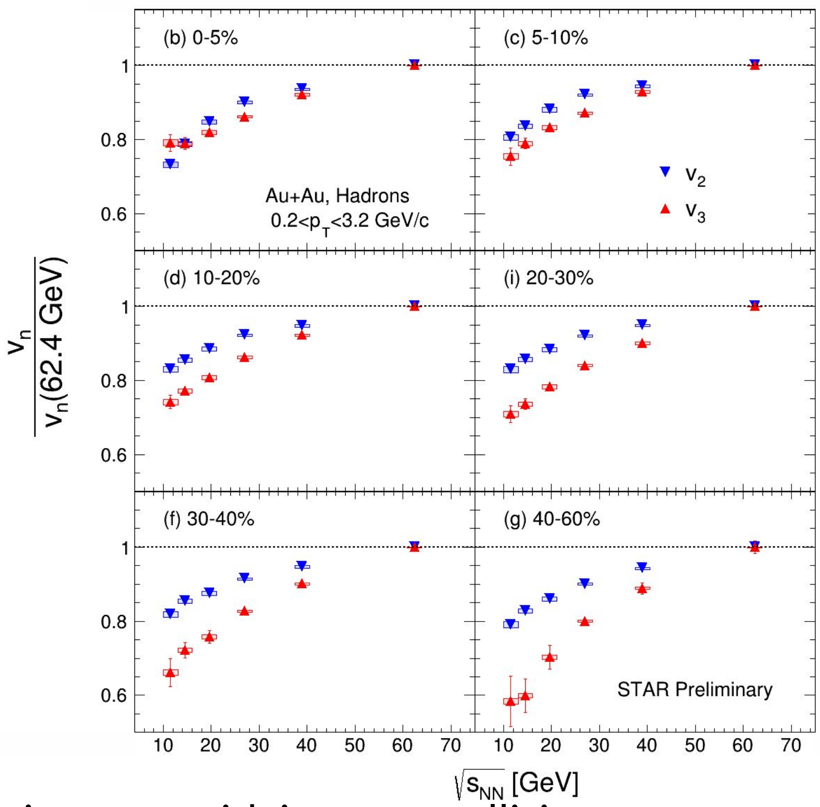
$$0.2 < \mathrm{p_T} < 3.2\ \mathrm{GeV/c}$$

- Elliptic flow is more dependent on centrality than triangular flow
- Similar shape of p_T dependence of normalized v_2 and v_3 for all centralities and beam energies

Beam-energy dependence of v_2 and v_3

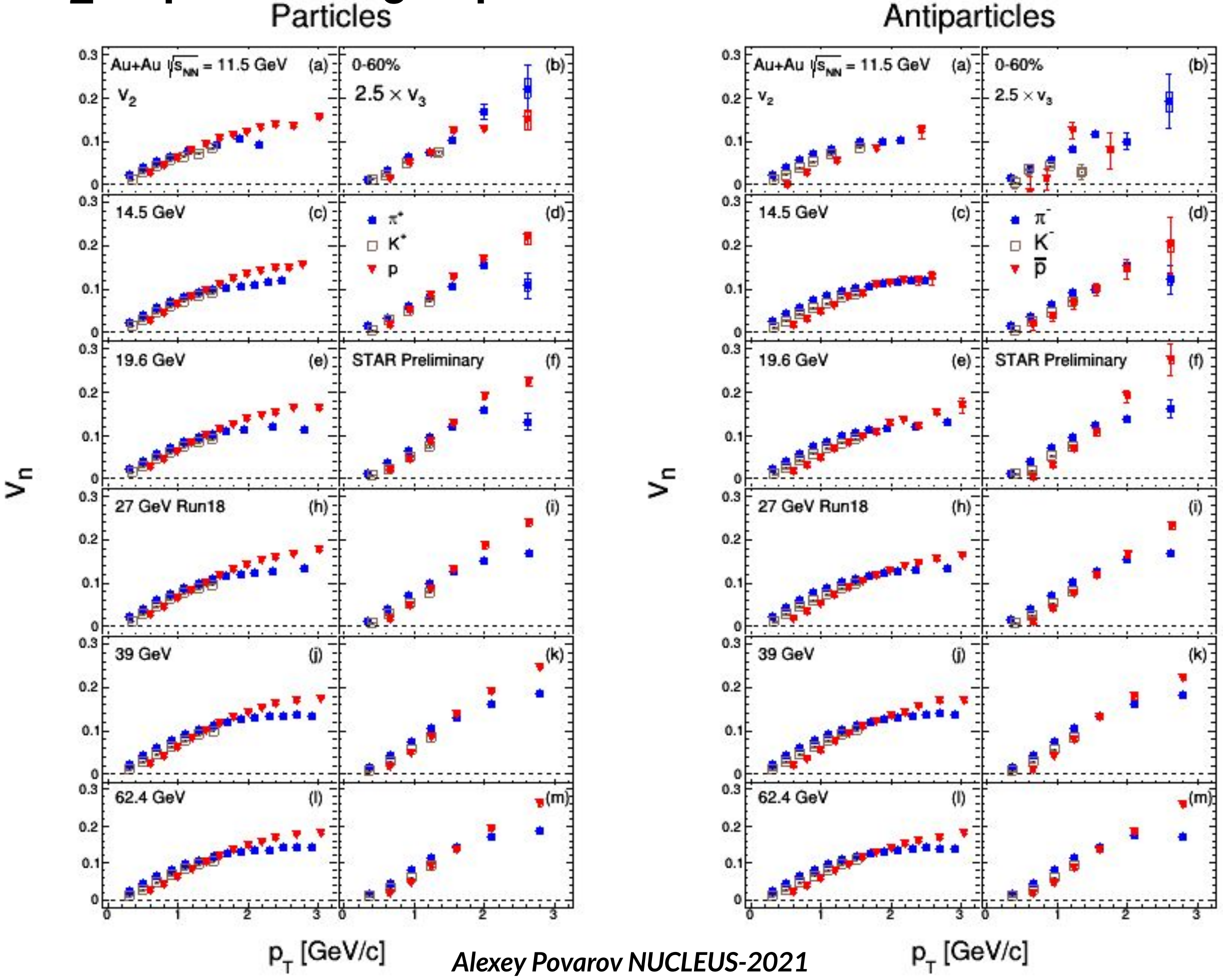
p_T-dependent efficiency was not applied

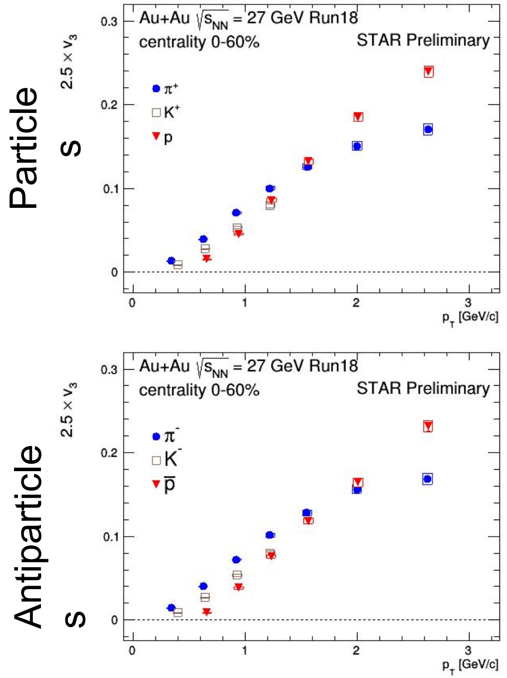




Transverse momentum integrated v_2 and v_3 increase with increase collision energy

$v_2(p_T)$ and $v_3(p_T)$ of identified hadrons

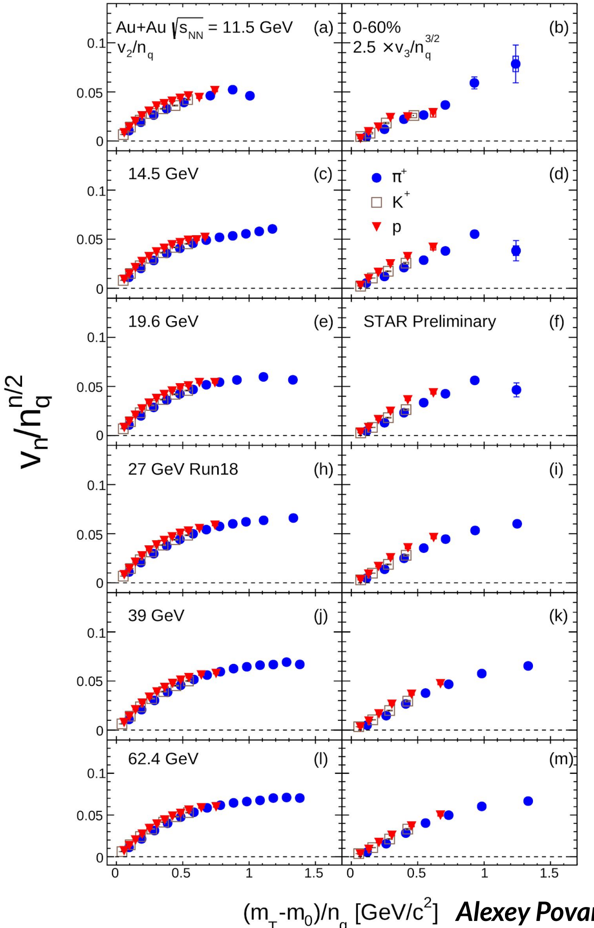




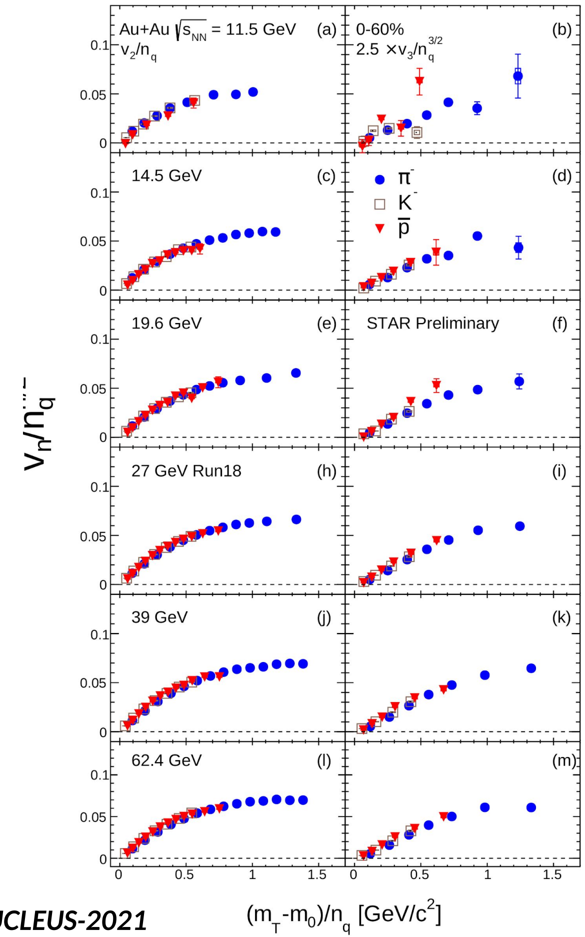
Mass ordering for p_T<1.5 GeV/c
Baryon/meson grouping for p_T>2 GeV/c

NCQ scaling of v_2 and v_3

Particles

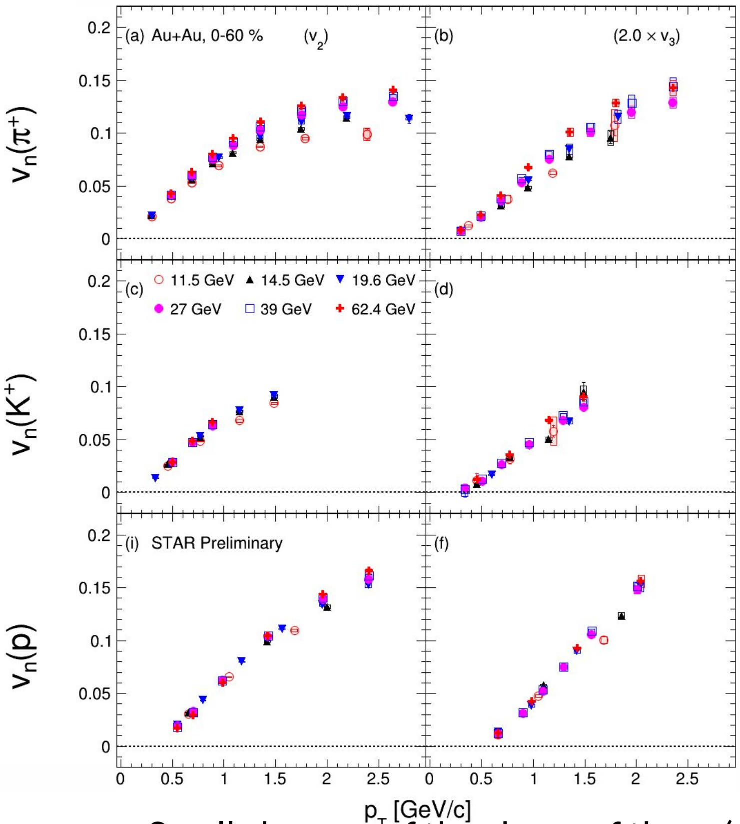


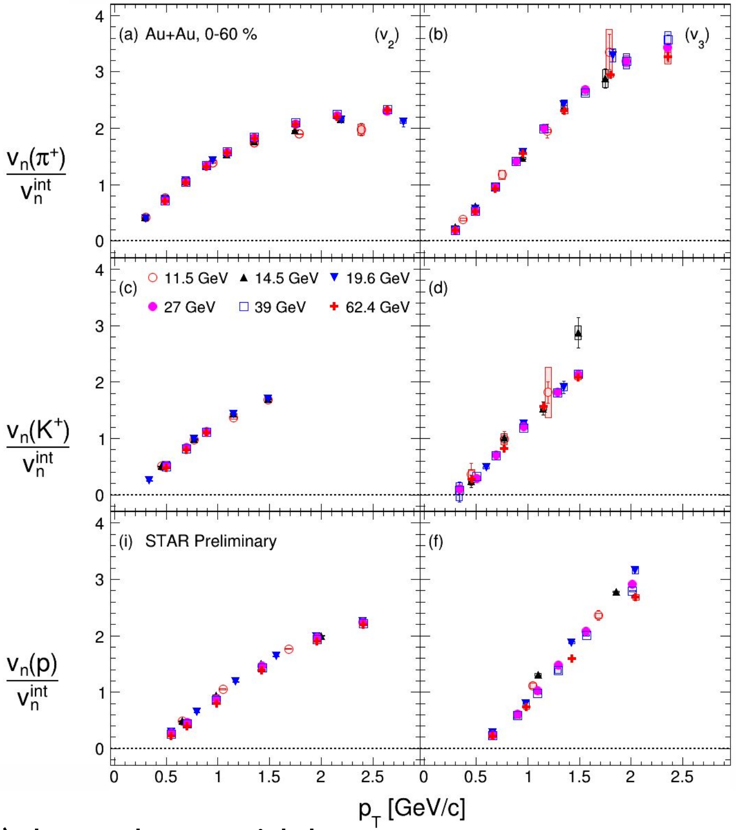
Antiparticles



- NCQ scaling tests were performed for v_2 and v_3 for particles and antiparticles
- Scaling holds better at higher energies

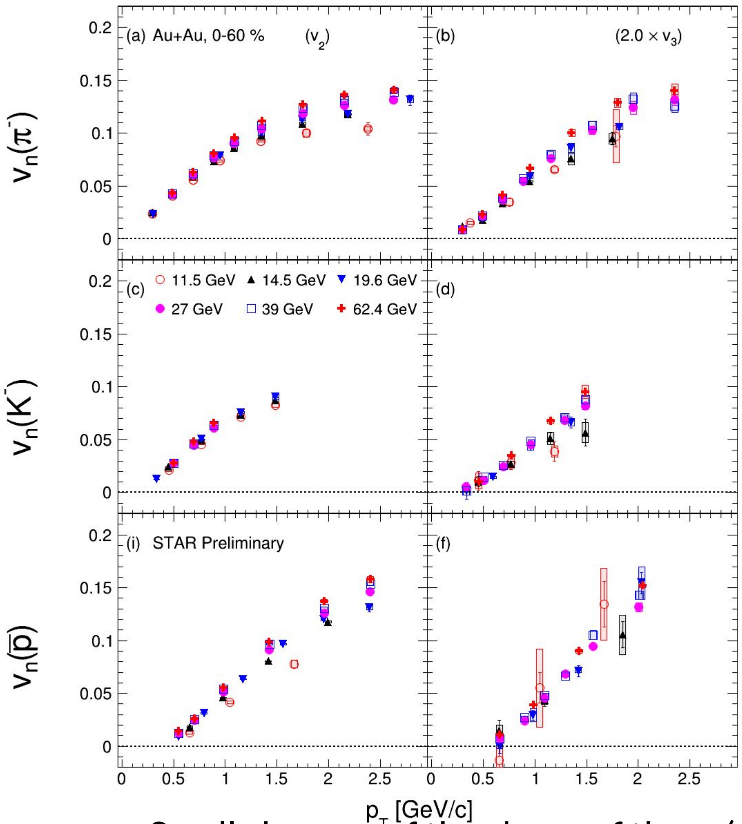
$v_2(p_T)$ and $v_3(p_T)$ of identified hadrons: positive

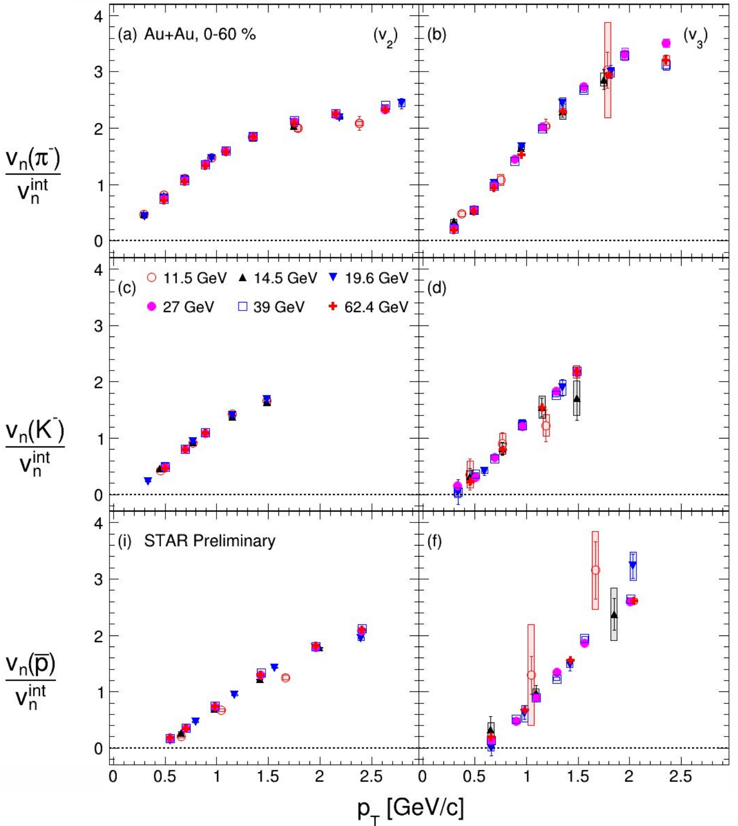




- Small changes of the shape of the $v_n(p_T)$ dependence with beam energy
- Similar shape for p_T dependence of normalized v_2 and v_3 for positive particle species

$v_2(p_T)$ and $v_3(p_T)$ of identified hadrons: negative





- Small changes of the shape of the $v_n(p_T)$ dependence with beam energy
- Similar shape for p_T dependence of normalized v_2 and v_3 for negative particle species

Beam-energy dependence of v_2 and v_3 particle-antiparticle difference

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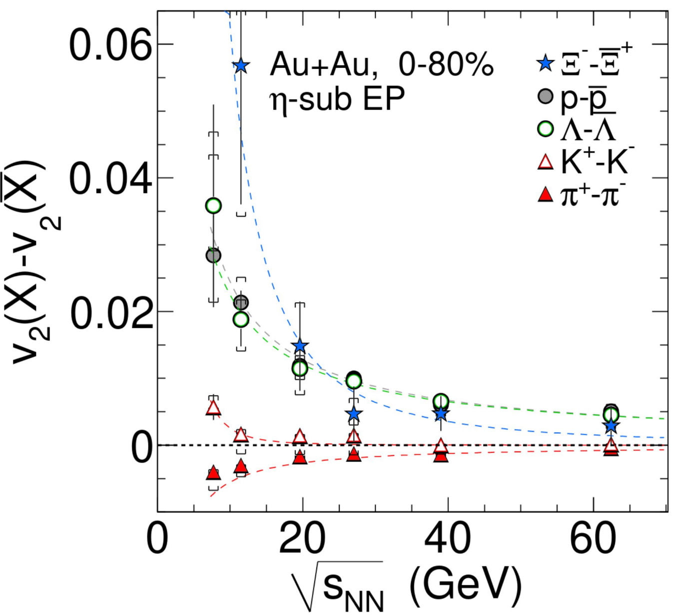
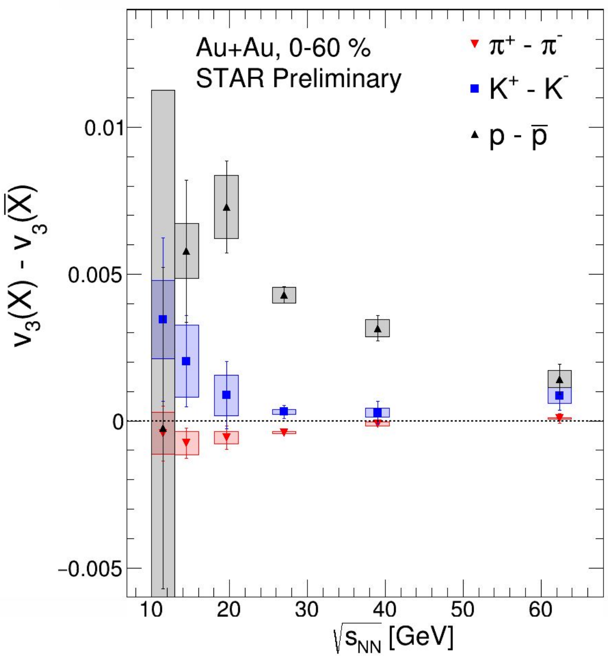


New results



- Differences for v_2 and v_3 between particles and antiparticles increase with decreasing beam energy
- Absolute value of particle-antiparticle difference is larger for proton and antiproton than for $\pi^{\pm}$, $K^{\pm}$

Summary

Results of v_2 and v_3 in Au+Au collisions at BES energies $\sqrt{s_{NN}}$ = 11.5 - 62.4 GeV are presented.

Systematics of of v_2 and v_3 with $\sqrt{s_{NN}}$, centrality, PID and pT :

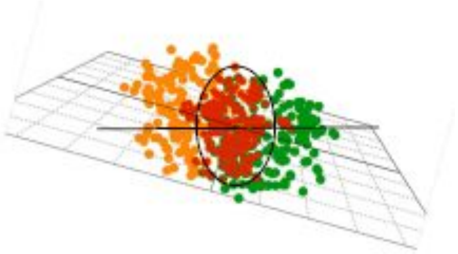
- Normalized v_2 and v_3 have similar p_T shape for all centralities and beam energies for each particle species
- Mass ordering for p_T < 1.5 GeV/c and baryon/meson grouping for p_T > 2 GeV/c
- NCQ scaling holds better for higher energies

$v_n(X) - v_n(\bar{X})$:

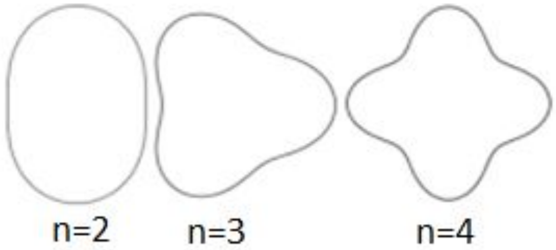
- The difference increases with decreasing collision energy
- Absolute value of $v_n(X) - v_n(\bar{X})$ is larger for $(p, \bar{p})$ than for $\pi^{\pm}, K^{\pm}$

Backup slides

Anisotropic collective flow



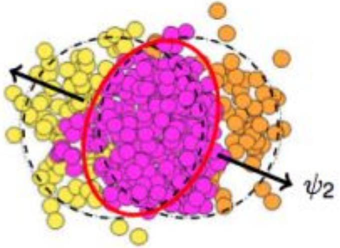
$$\epsilon_n = \sqrt{\frac{\langle r^n \cos n\phi\rangle + \langle r^n \sin n\phi\rangle}{\langle r^n\rangle}}$$



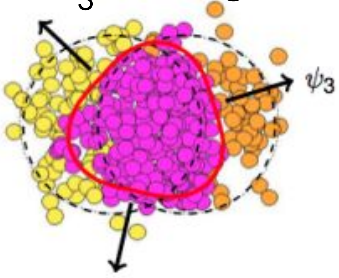
$$\frac{dN}{d\phi} \approx (1 + 2\sum_{n=1} v_n cos[n(\phi - \Psi_n)])$$

Initial eccentricity (and its attendant fluctuations), ε_n, drives momentum anisotropy, v_n, with specific viscous modulation

v_2 - elliptic flow



v_3 - triangular flow



Events selection

Au+Au	|Vz|, cm	|Vr|, cm	ΔVy, см	Before cuts	After cuts
Run10 11.5 GeV	< 50	< 2	0.0	12M	10M
Run14 14.5 GeV	< 70	< 1	-0.89	28M	24M
Run11 19.6 GeV	< 70	< 2	0.0	25M	21M
Run10 27 GeV	< 70	< 2	0.0	74M	62M
Run18 27GeV	< 70	< 2	0.0	550M	460M
Run10 39 GeV	< 40	< 2	0.0	126M	105M
Run10 62.4 GeV	< 40	< 2	0.0	56M	47M