Supported in part by

Energy dependence of triangular flow for identified hadrons in Au+Au collisions at $\sqrt{s_{NN}}$ = 14.5 - 62.4 GeV from the STAR experiment

Alexey Povarov
for the STAR Collaboration

National Research Nuclear University MEPhI

LXXII International Conference "Nucleus-2022: Fundamental problems and applications"

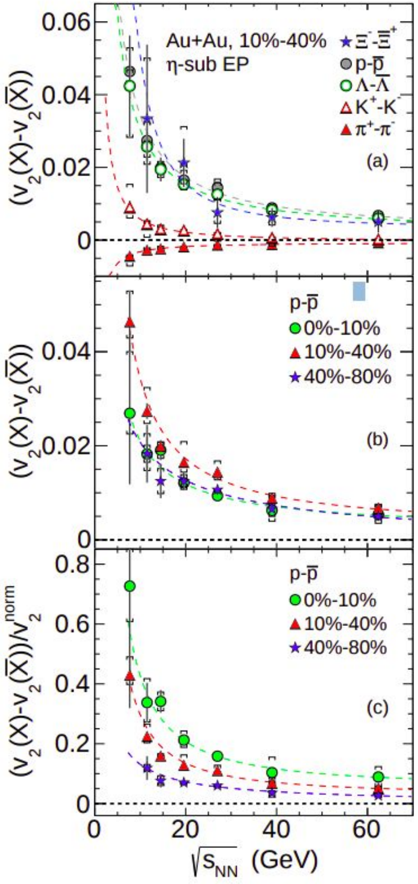
Moscow (Russia), July 11-16, 2022

Outline

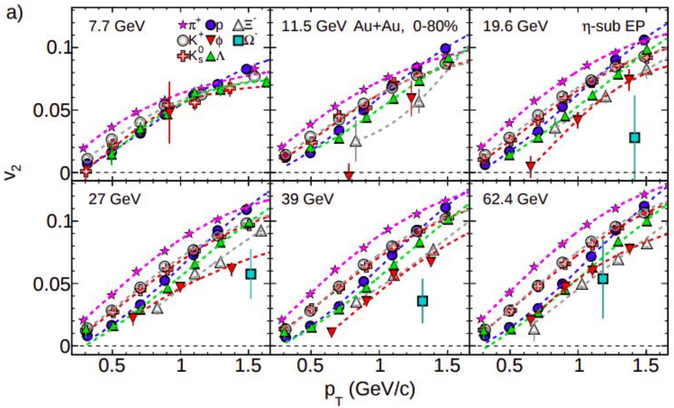
- Introduction
- Anisotropic flow at RHIC
- The STAR detector at RHIC
- Analysis methods
- Results
- Summary and Outlook

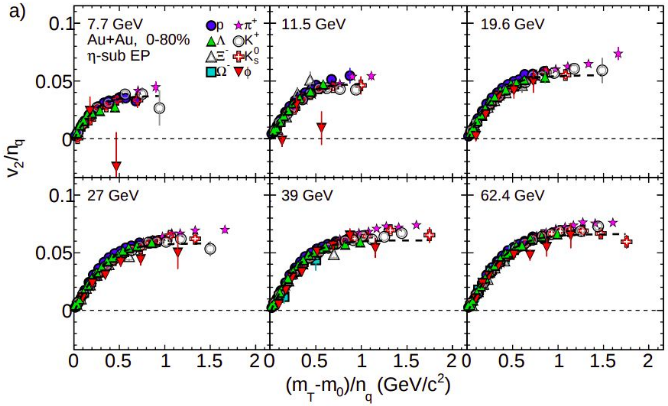
Anisotropic collective flow at RHIC

L. Adamczyk *et al.* Phys. Rev. C **93**, 014907



L. Adamczyk *et al.* Phys. Rev. C **88**, 014902

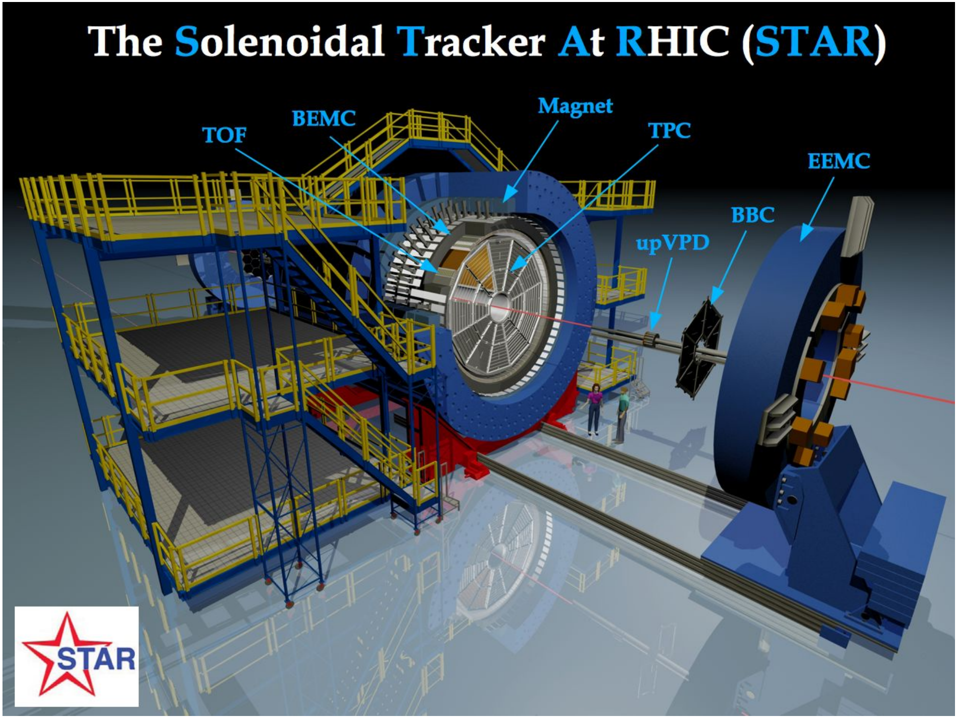




- v_n**(p_T, centrality)** - sensitive to the early stages of collision.
- Important constraint on transport properties: EOS, η/s, ζ/s, etc.
- **Mass ordering** at p_T < 2 GeV/c (hydrodynamic flow, hadron rescattering)
- **Baryon/meson grouping** at p_T > 2 GeV/c (recombination/coalescence)
- v_2 **difference** of particles and antiparticles is larger for baryons than mesons

The main goal is to study $v_3(\sqrt{s_{NN}}$, centrality, PID, $p_T)$ because it is sensitive to initial state fluctuations and viscosity

The STAR detector at RHIC



Time Projection Chamber (TPC):

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

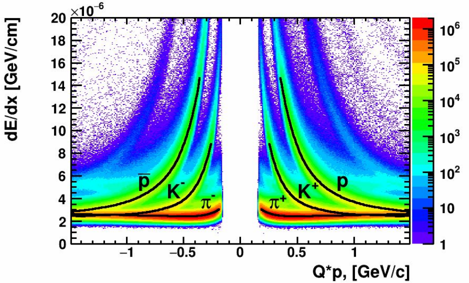
Time-Of-Flight (TOF):

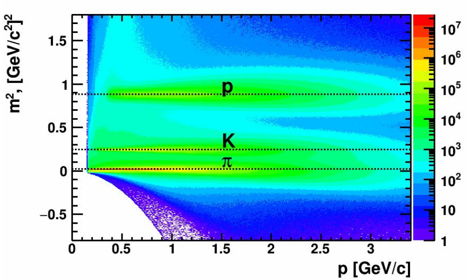
- $|\eta| < 0.9$, 2π in φ
- PID using time-of-flight information

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

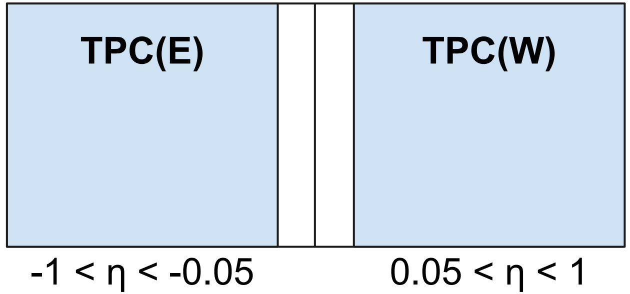
Data set: Au+Au at $\sqrt{s_{NN}}$ = 11.5 - 62.4 GeV

27 GeV from RHIC beam energy scan phase two (BES-II) and other energies from BES-I





Analysis technique: Event Plane Method (EP)



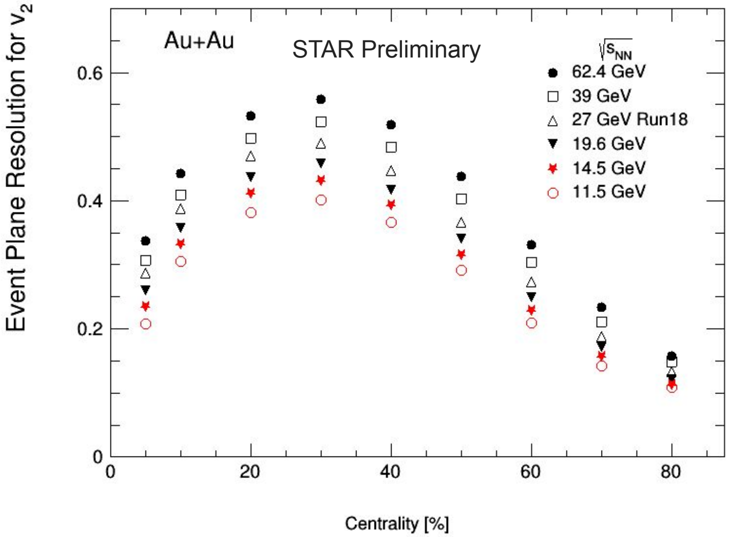
TPC (E) half $(-1 < \eta < -0.05) \rightarrow \eta_{-}$

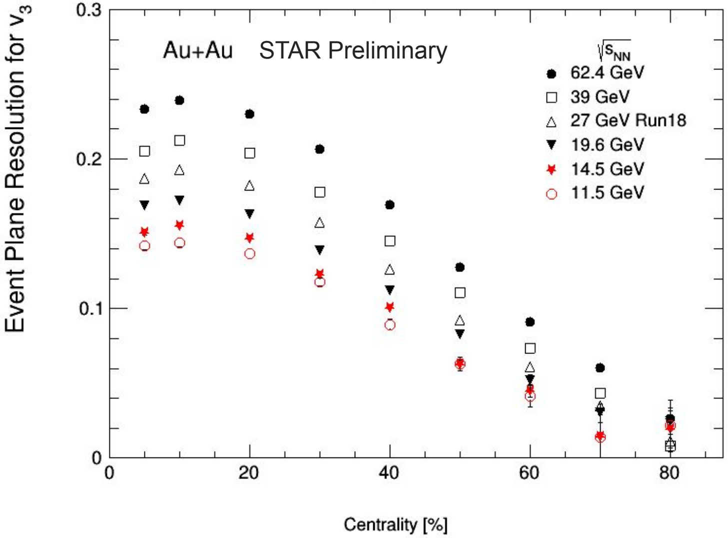
TPC (W) half $(0.05 < \eta < 1) \rightarrow \eta_{+}$

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

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

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

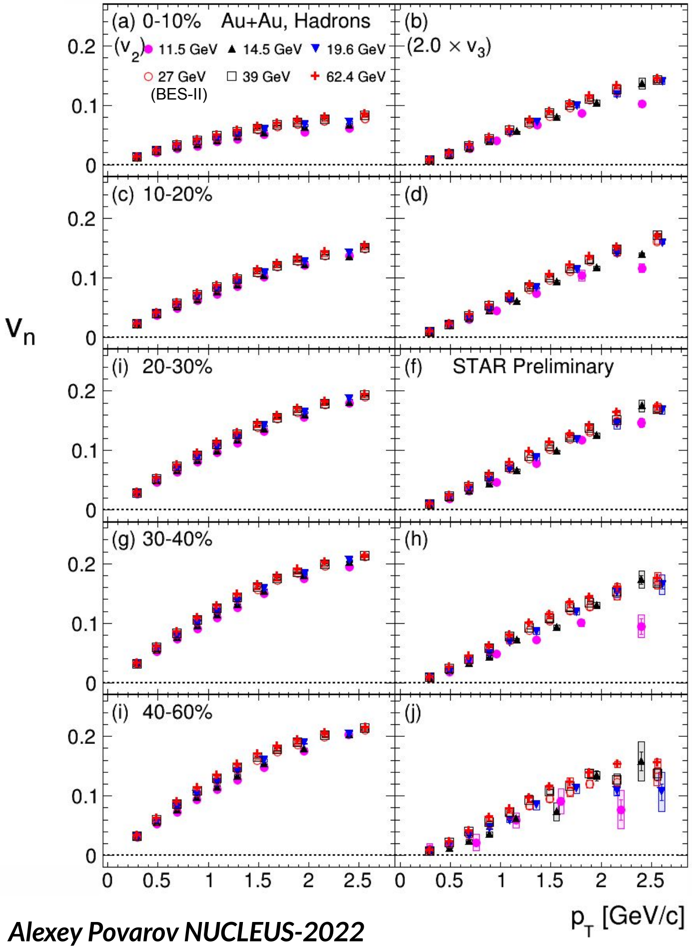


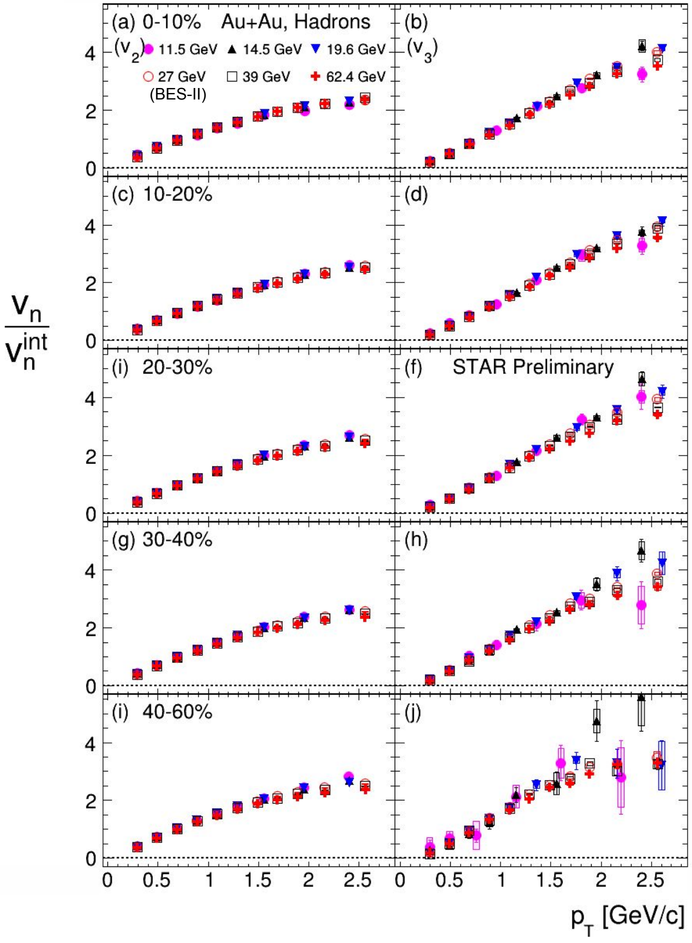


Note: 27 GeV from RHIC beam energy scan phase two (BES-II) and other energies from BES-I

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 a function of p_T





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

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

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

Note: 27 GeV from RHIC beam energy scan phase two (BES-II) and other energies from BES-I

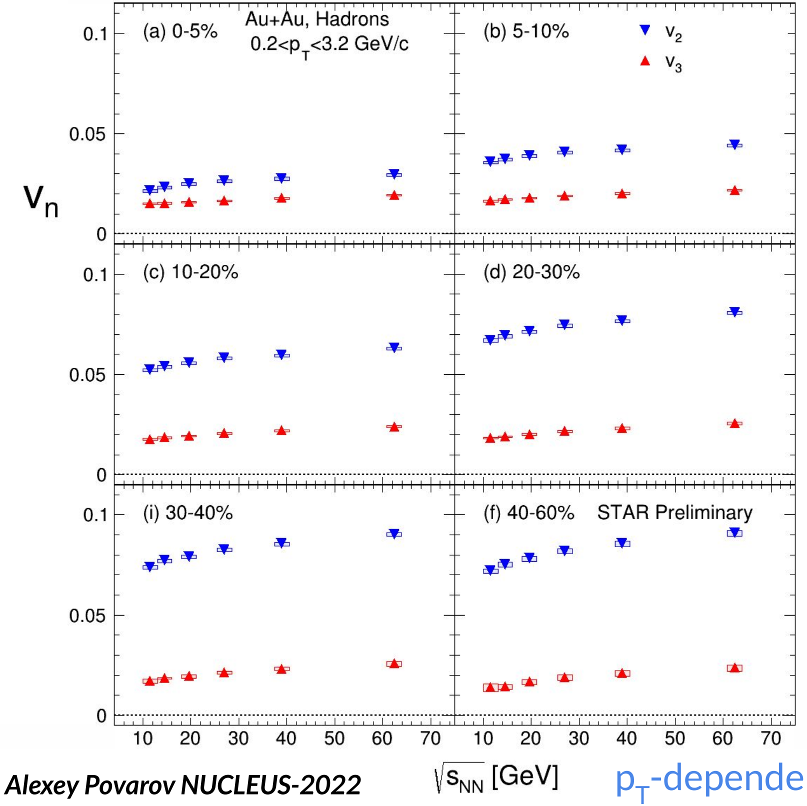
Beam-energy dependence of v_2 and v_3

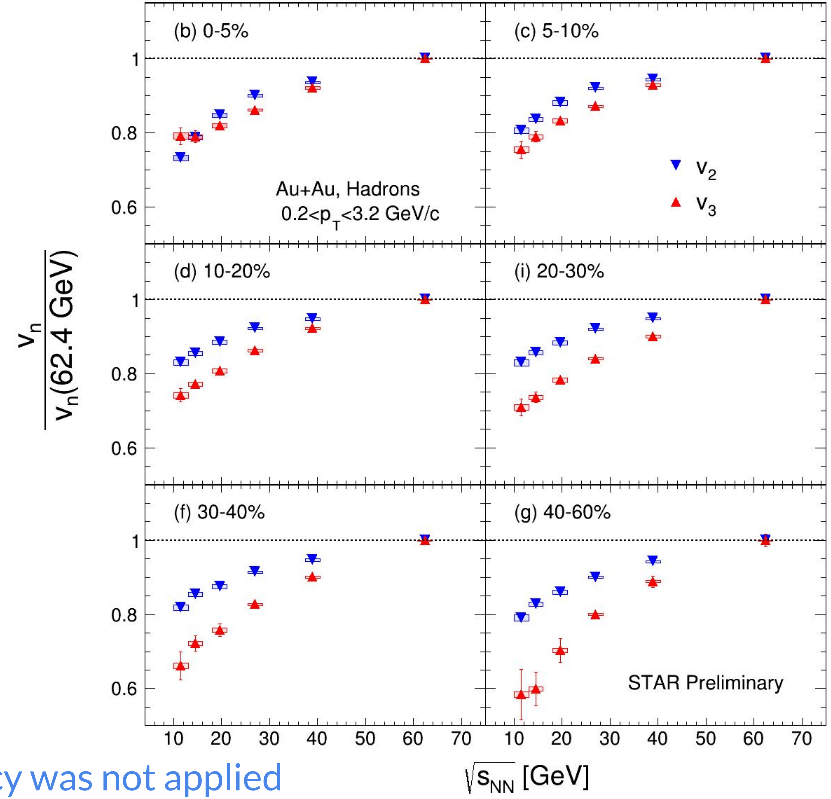
Integrated v_2 and v_3 increase with increasing collision energy

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

Note: 27 GeV from RHIC beam energy scan phase two (BES-II) and other energies from BES-I

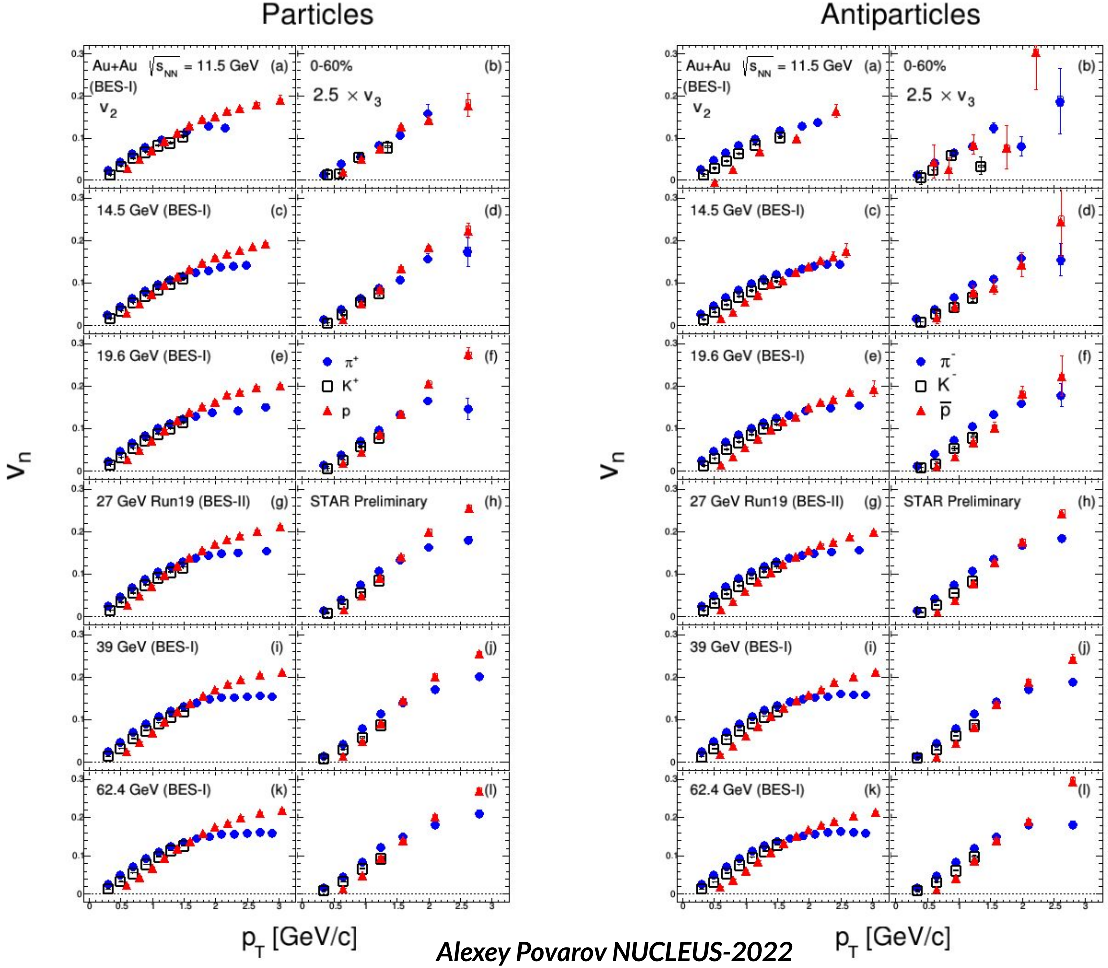
$$0.2 < \mathrm{p_T} < 3.2 \text{ GeV/c}$$

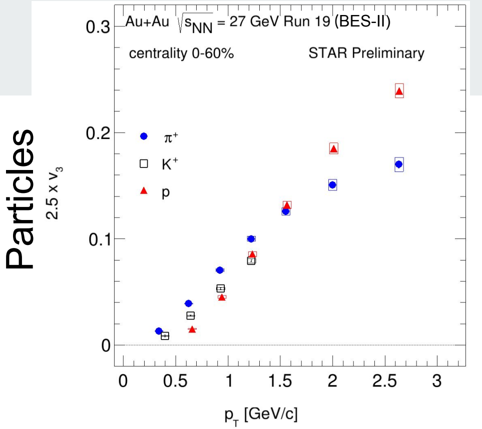


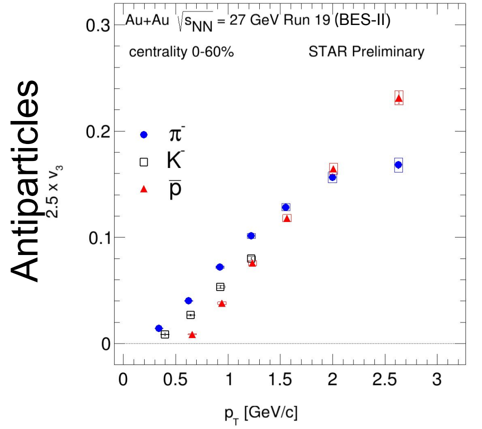


$\mathrm{p_T}$-dependent efficiency was not applied

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



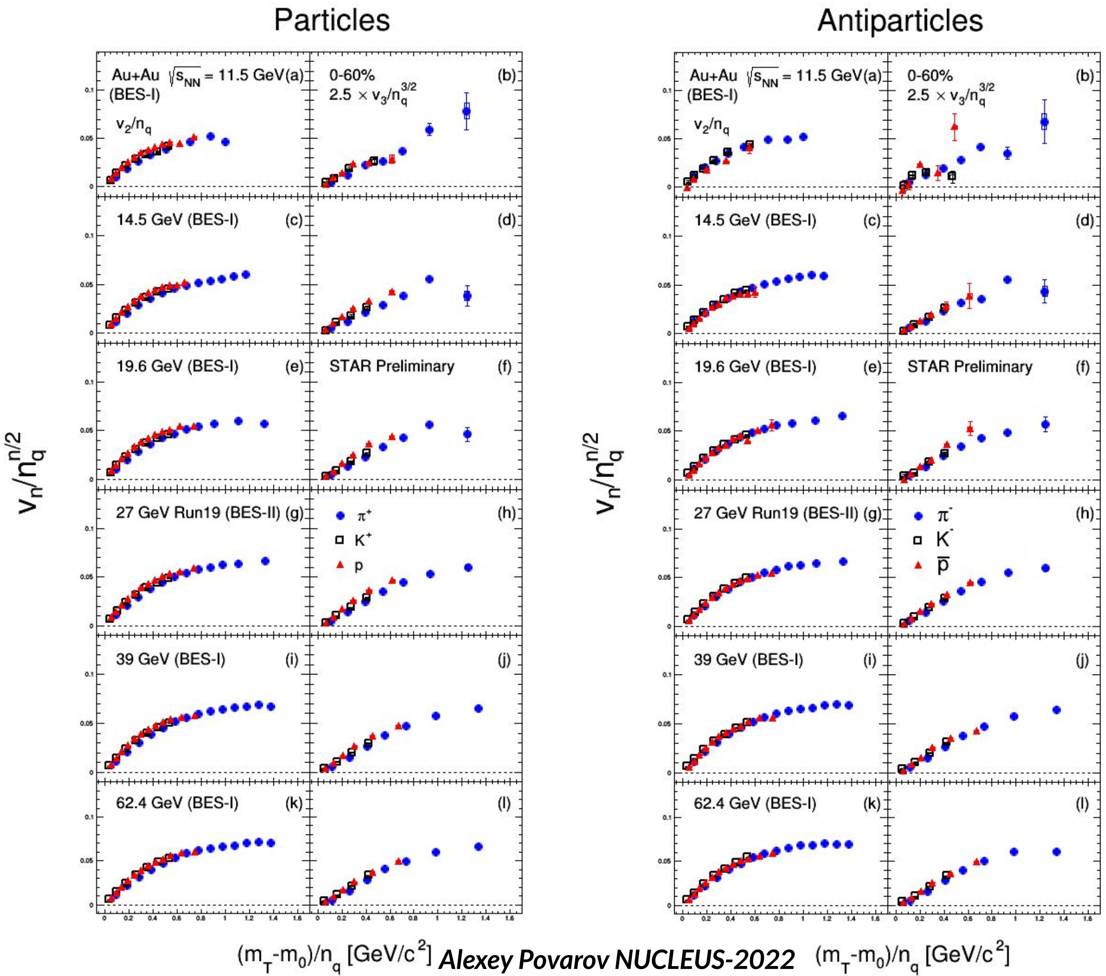




Mass ordering for p_T<1.5 GeV/c
Baryon/meson grouping for p_T>2 GeV/c
First measurement of identified particle v_3 at BES energies

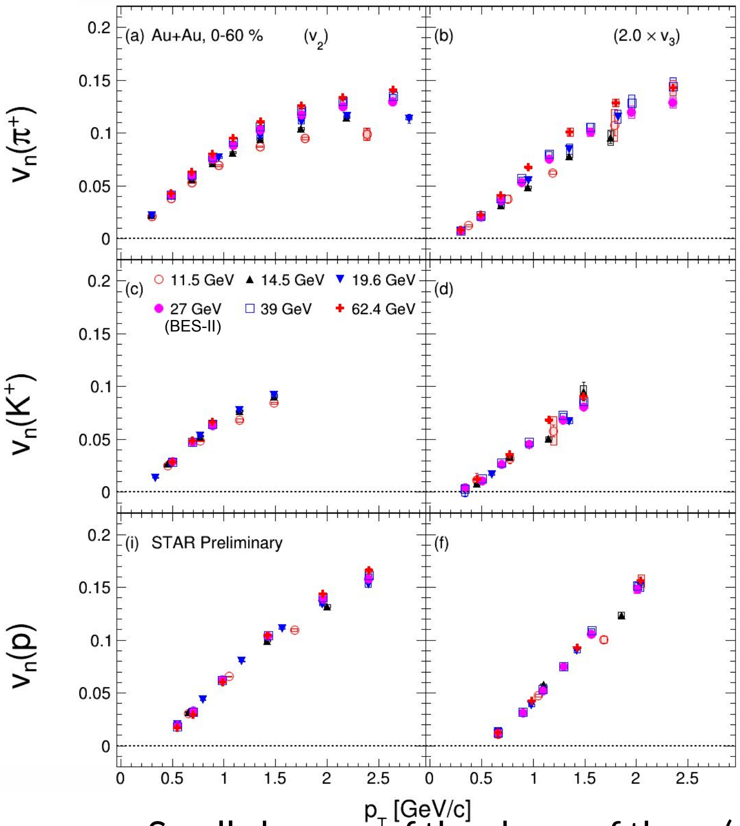
Alexey Povarov NUCLEUS-2022

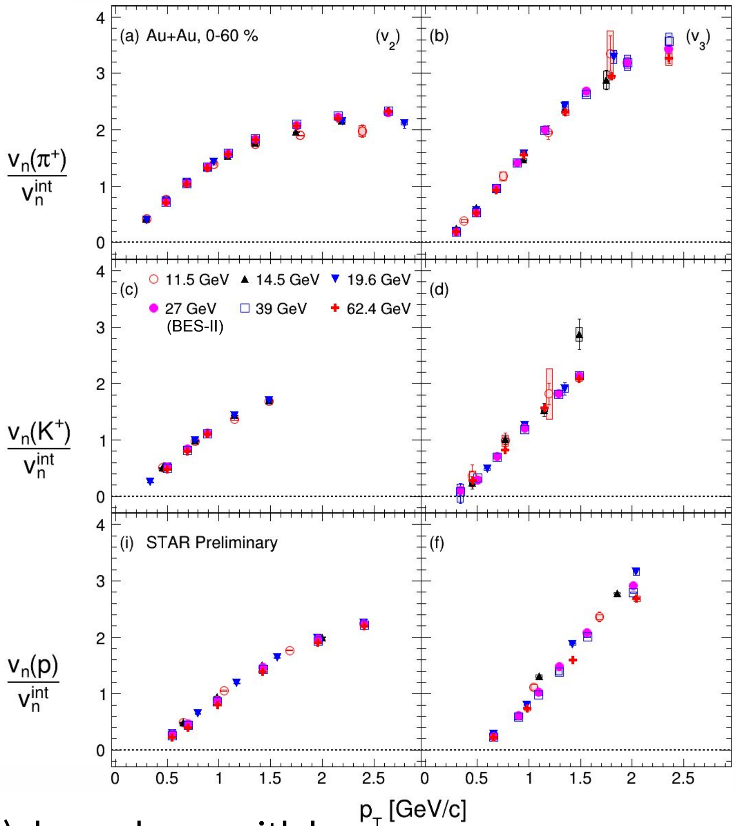
NCQ scaling of v_2 and v_3



- NCQ scaling tests were performed for v_2 and v_3 of particles and antiparticles
- Scaling holds better for higher energies
- Scaling holds better for particles than antiparticles
- Quantification of the baryon and meson splitting and the scaling with the number of constituent quarks (NCQ) is ongoing

$v_2(p_T)$ and $v_3(p_T)$ for positively charged particle species

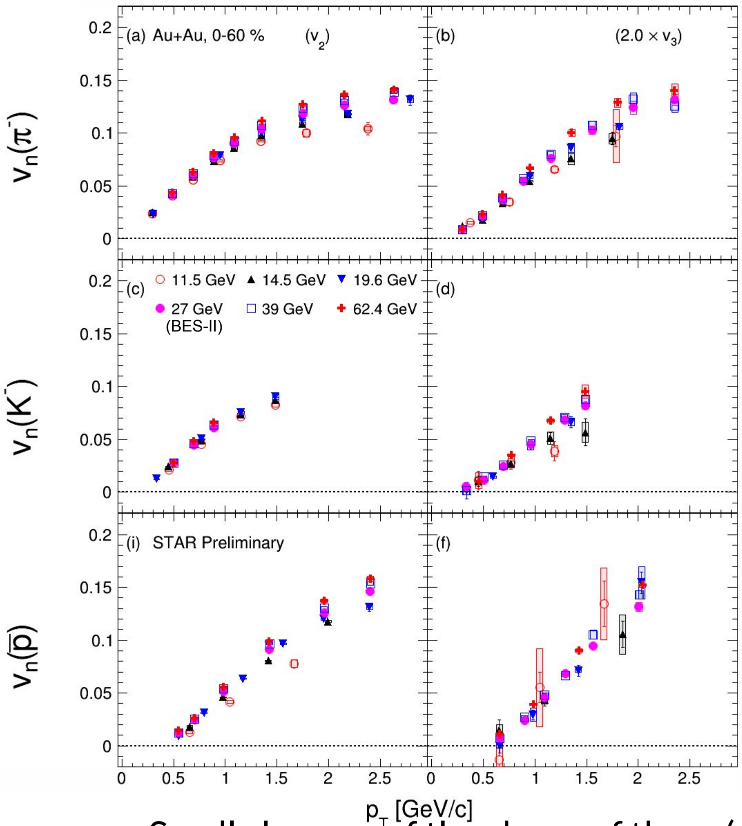


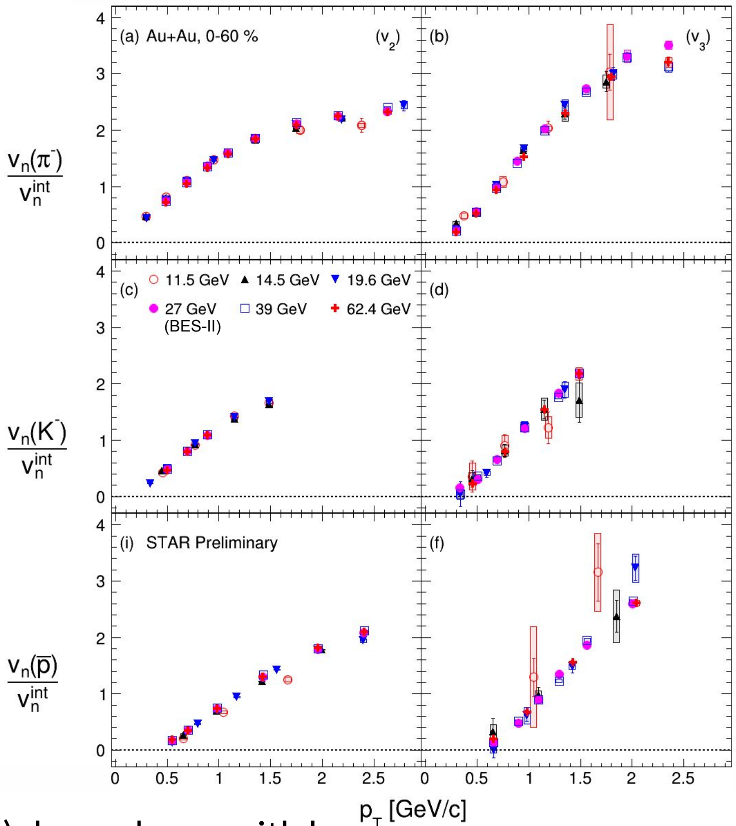


Note: 27 GeV from RHIC beam energy scan phase two (BES-II) and other energies from BES-I

- 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 positively charged particle species

$v_2(p_T)$ and $v_3(p_T)$ for negatively charged particle species



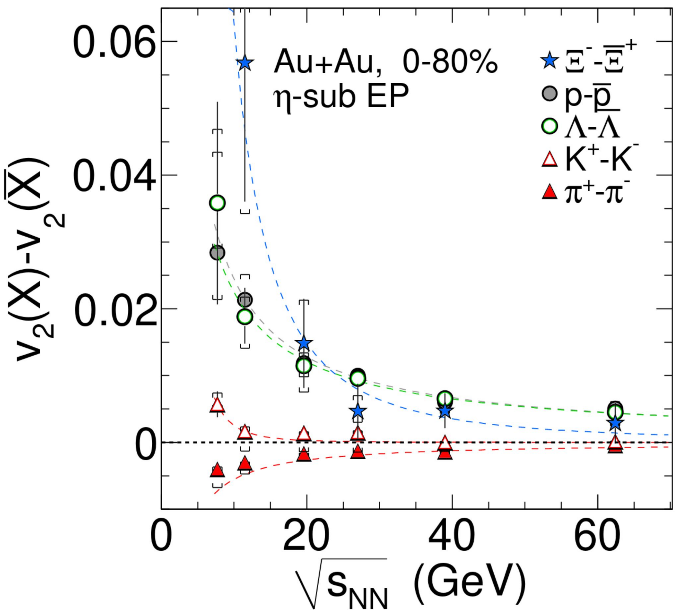


Note: 27 GeV from RHIC beam energy scan phase two (BES-II) and other energies from BES-I

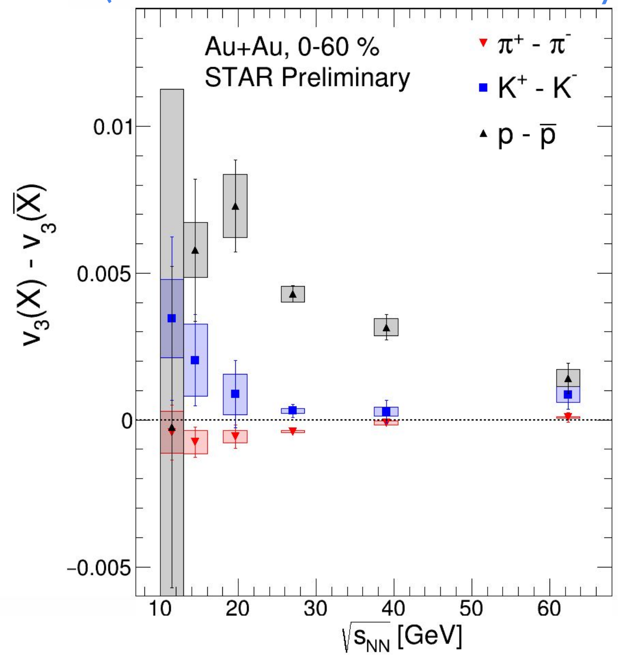
- Small changes of the shape of the $v_n(p_T)$ dependence with beam energy
- Similar shape for p_T dependence of normalized v_2 and v_3 for negatively charged particle species

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

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



New v_3 results
(not corrected for efficiency)



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 $\pi^{\pm}$, $K^{\pm}$.

Note: 27 GeV from RHIC beam energy scan phase two (BES-II) and other energies from BES-I

Summary

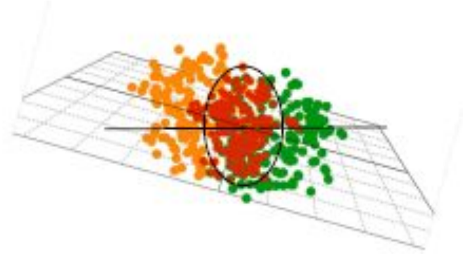
Results of v_2 and v_3 in Au+Au collisions at BES energies $\sqrt{s_{NN}}$ = 11.5 - 62.4 GeV are presented.

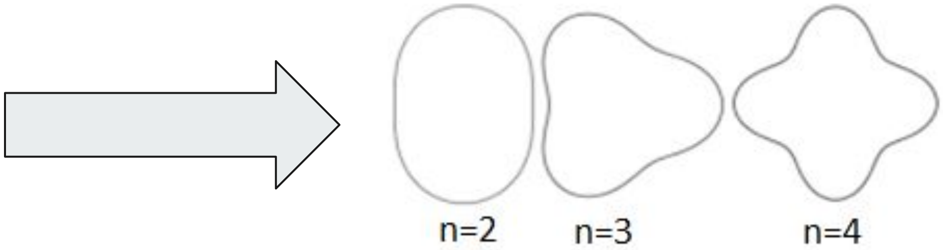
($\sqrt{s_{NN}}$,centrality,PID,p_T)-dependence of v_2 and v_3:

- 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 particles than antiparticles and for or higher energies
- The difference of particles and antiparticles 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



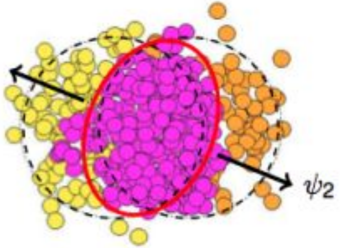


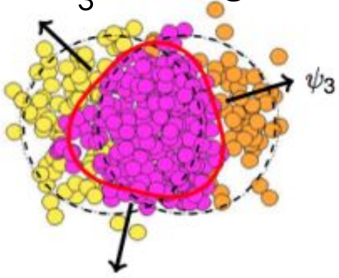
$$\epsilon_n = \sqrt{\frac{\langle r^n \cos n\phi\rangle + \langle r^n \sin n\phi\rangle}{\langle r^n\rangle}}$$

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

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

Tracks selection and particle identification

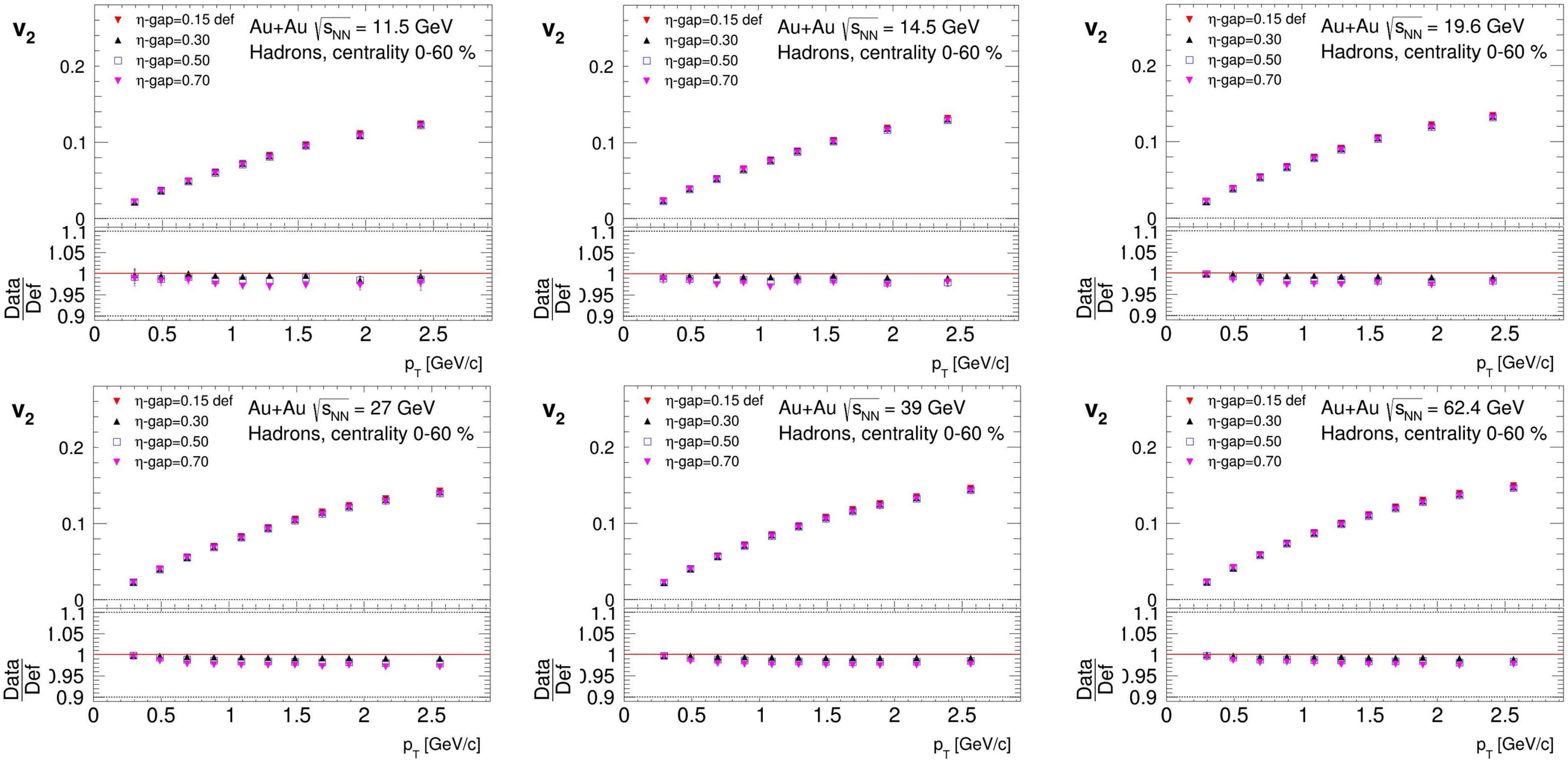
Tracks selection:

- Primary tracks
- $|\eta| < 1.0$
- DCA < 2 cm ($h^{\pm}$)
- DCA < 1 cm ($\pi^{\pm}$, $K^{\pm}$, p, pbar)
- NHits > 15
- NHits/NHitsPoss > 0.52

Particle identification:

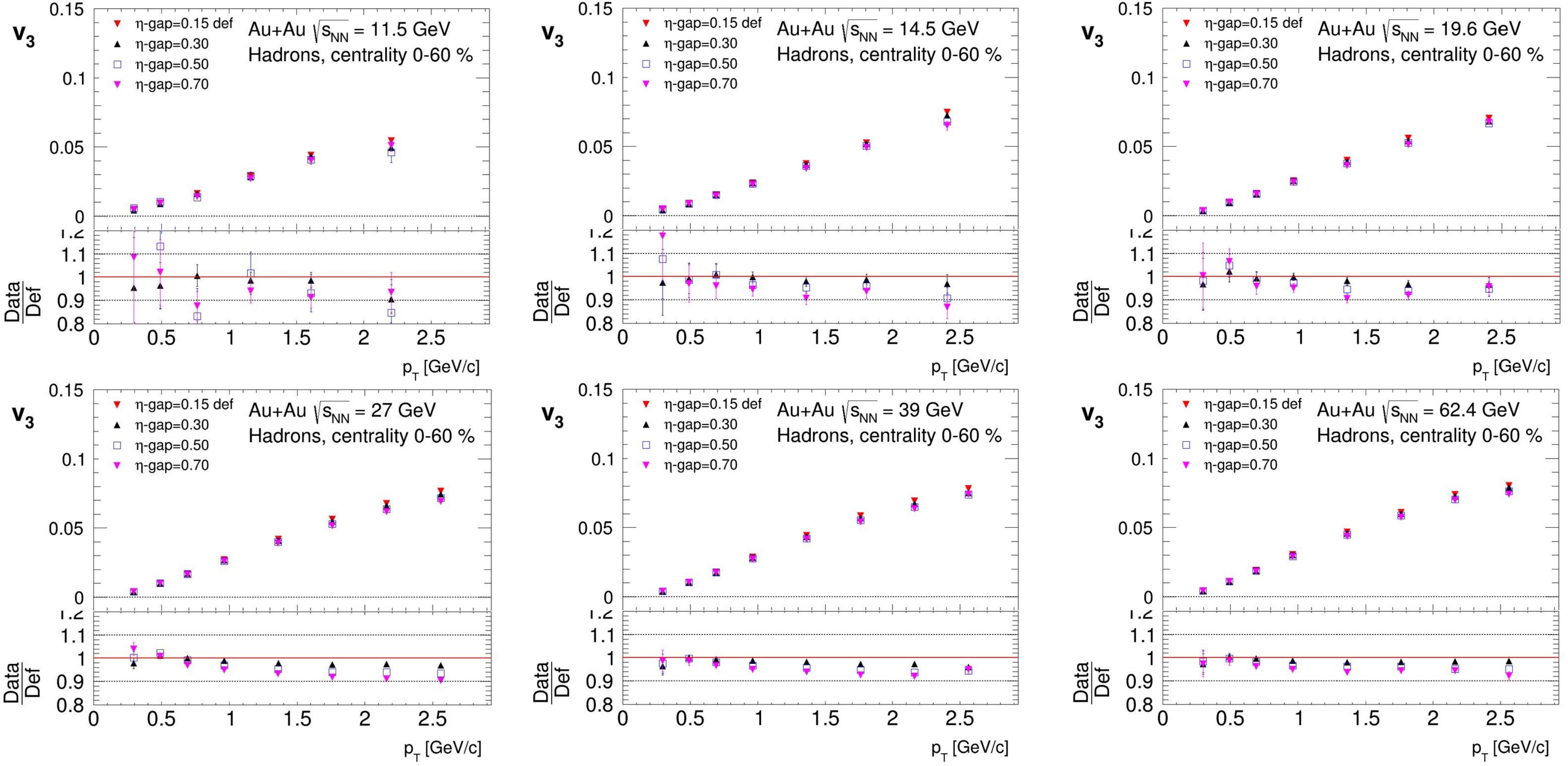
- dE/dx (TPC):
  - $|n\sigma| < 1.5$ for 27 and 62.4 GeV
  - $|n\sigma| < 3.0$ for other energies
- TOF identification:
  - $-0.15 < m_{\pi}^2 < 0.1$ GeV/c^2
  - $0.2 < m_K^2 < 0.32$ GeV/c^2
  - $0.74 < m_P^2 < 1.2$ GeV/c^2

Systematic uncertainties for v_2: different Δη-gap



Differences are within 1-5% for all beam energies

Systematic uncertainties for v_3: different Δη-gap



Differences are within 1-5% for all beam energies