Directed and triangular flow of identified hadrons and light nuclei from fixed-target energies at RHIC-STAR

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Abstract

The anisotropic flow parameters (v_n) offer insights into collective hydrodynamic expansion and transport properties of the produced medium at higher collision energies, while they are sensitive to the compressibility of the nuclear matter and nuclear equation of state at lower collision energies. Among them directed flow (v_1) describes the collective sideward motion of produced particles in heavy-ion collisions. It is an important probe to study the in-medium dynamics as it is sensitive to the equation of state (EoS) of the produced medium. The triangular flow (v_3) typically arises from the initial condition fluctuations and is expected to be uncorrelated to the reaction plane. However, recent measurements at lower collision energies show a correlation between v_3 and the first-order event plane angle (Ψ_1).

In this poster, we report the first measurements of v_1 and v_3 for π, K, p, d, and t in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 3.2, 3.5, and 3.9 GeV in fixed-target mode from the second phase of beam energy scan (BES-II) program at RHIC-STAR. The rapidity, centrality, and collision energy dependence of v_1 and v_3 have been studied to understand the underlying physics mechanism at high baryon density regions.

1. Motivation

Azimuthal distribution of particles can be written in the form of a Fourier series,

$$E\frac{d^3N}{dp^3} = \frac{d^2N}{2\pi p_T dp_T dy}\left\{1 + \sum_{n\geq 1} 2\, v_n \cos\left[n\left(\phi - \Psi_n\right)\right]\right\} \quad (1)$$

where p_T, y, ϕ are transverse momentum, rapidity and azimuthal angle of the particle, respectively and Ψ_n is the n^{th} harmonic plane angle.

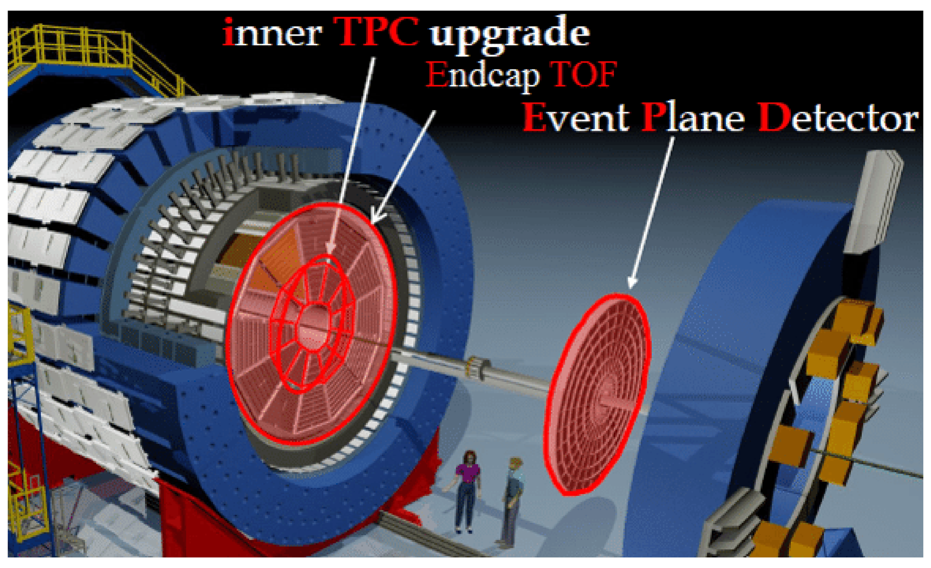
The n^{th} order flow coefficient (v_n) in the expansion is defined as:

$$v_n = \langle \cos\left[n\left(\phi - \Psi_n\right)\right]\rangle \quad (2)$$

- Minimum in the slope of baryons v_1 (dv_1/dy) as a function of collision energy has been proposed as a signature of the first-order phase transition between hadronic matter and quark-gluon plasma.
- v_3 is driven by the shape fluctuations of the initial collision geometry and is expected to be uncorrelated to the reaction plane. However, recent measurements at lower collision energies show a correlation between v_3 and the first-order event plane angle (Ψ_1).

2. The STAR Experiment

The data presented was collected in fixed-target mode during the second phase of the Beam Energy Scan (BES-II) program, conducted by the STAR experiment at RHIC.



- Time Projection Chamber (TPC) and Time of Flight (TOF) used for tracking, momentum measurement and particle identification at STAR.
- Dataset: Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 3.2, 3.5 and 3.9 GeV in fixed target mode.

3. Methodology

- Event plane (EP) reconstruction using Event Plane Detector (EPD) and TPC : Flow vector ($\vec{Q}$) is constructed from particles azimuthal angle and is used to determine the first order event plane angle (Ψ_1)

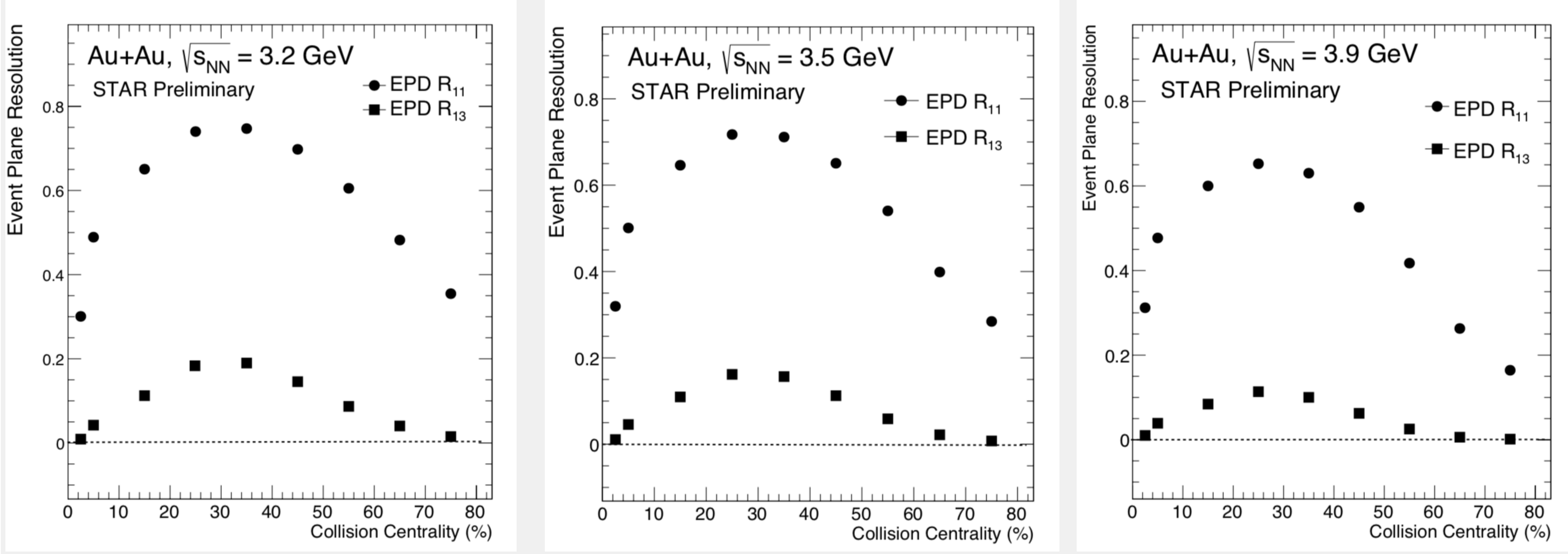
$$\vec{Q} = (Q_x, Q_y) = \left(\sum_i w_i \cos(\phi_i), \sum_i w_i \sin(\phi_i)\right) \quad (3)$$

$$\Psi_1 = \tan^{-1}(Q_y/Q_x) \quad (4)$$

w_i is weight factor for the i^{th} particle.
Three sub-event plane method is used to determine the resolution

$$\langle\cos\left(\Psi_1^a - \Psi_r\right)\rangle = \sqrt{\frac{\langle\cos\left(\Psi_1^a - \Psi_1^b\right)\rangle\,\langle\cos\left(\Psi_1^a - \Psi_1^c\right)\rangle}{\langle\cos\left(\Psi_1^b - \Psi_1^c\right)\rangle}} \quad (5)$$

For EP reconstruction, we used EPD-AB ($-5.3 < \eta < -3.3$).
For resolution calculation, we considered EPD-C ($-3.3 < \eta < -2.9$) and TPC B ($-1.0 < \eta < 0$).



- TPC and TOF detectors are used for particle identification.

$$z_X = \ln\frac{\langle dE/dx\rangle^{\mathrm{measured}}}{\langle dE/dx\rangle_X^{\mathrm{Bichsel}}} \quad \text{and} \quad m^2 = p^2\left[\left(\frac{c\,\Delta T}{\Delta L}\right)^2 - 1\right] \quad (6)$$

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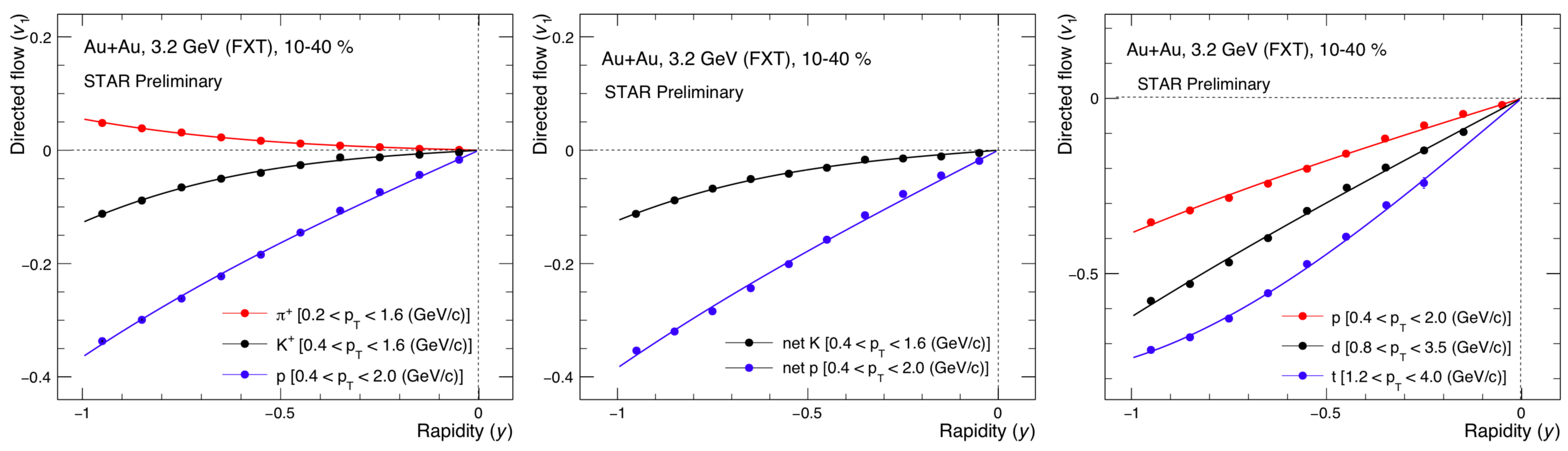
4. Results and discussion

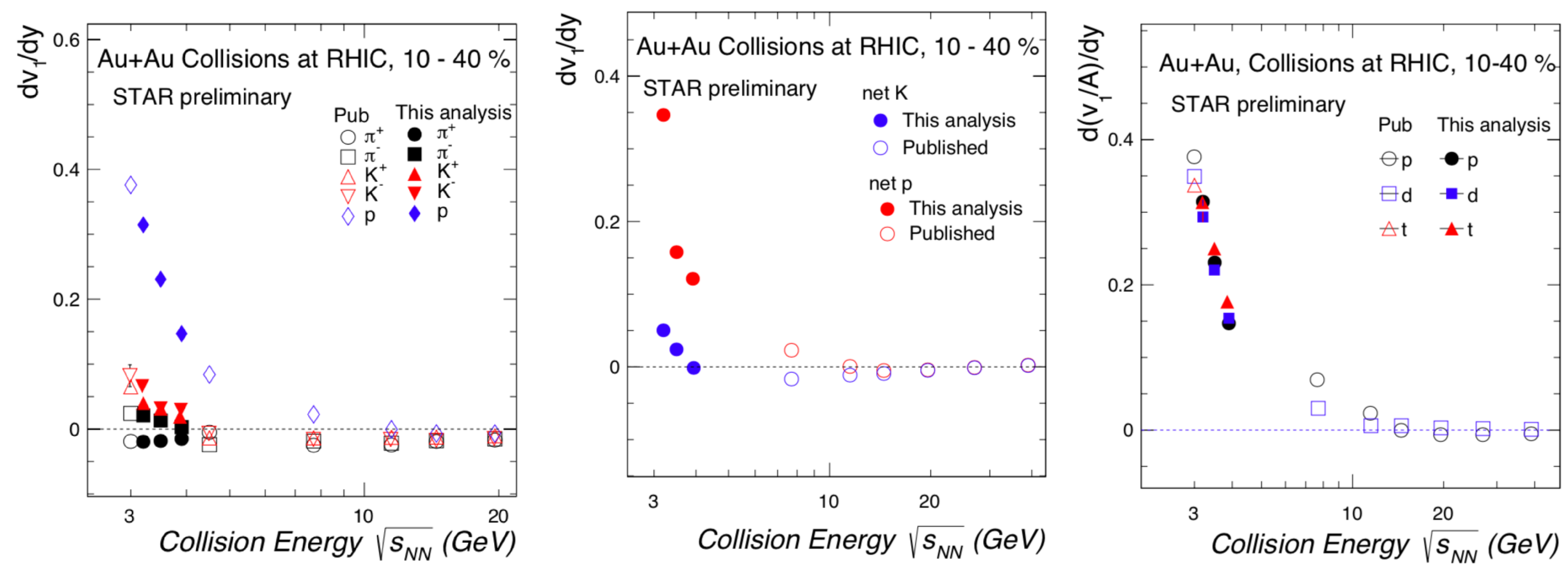
Directed flow (v_1)



- Magnitude of v_1 increases with increasing rapidity for all the particles.
- Net particle represents the excess yield of a particle species over its antiparticle. In order to enhance the contribution of transported quarks relative to those produced in the collision

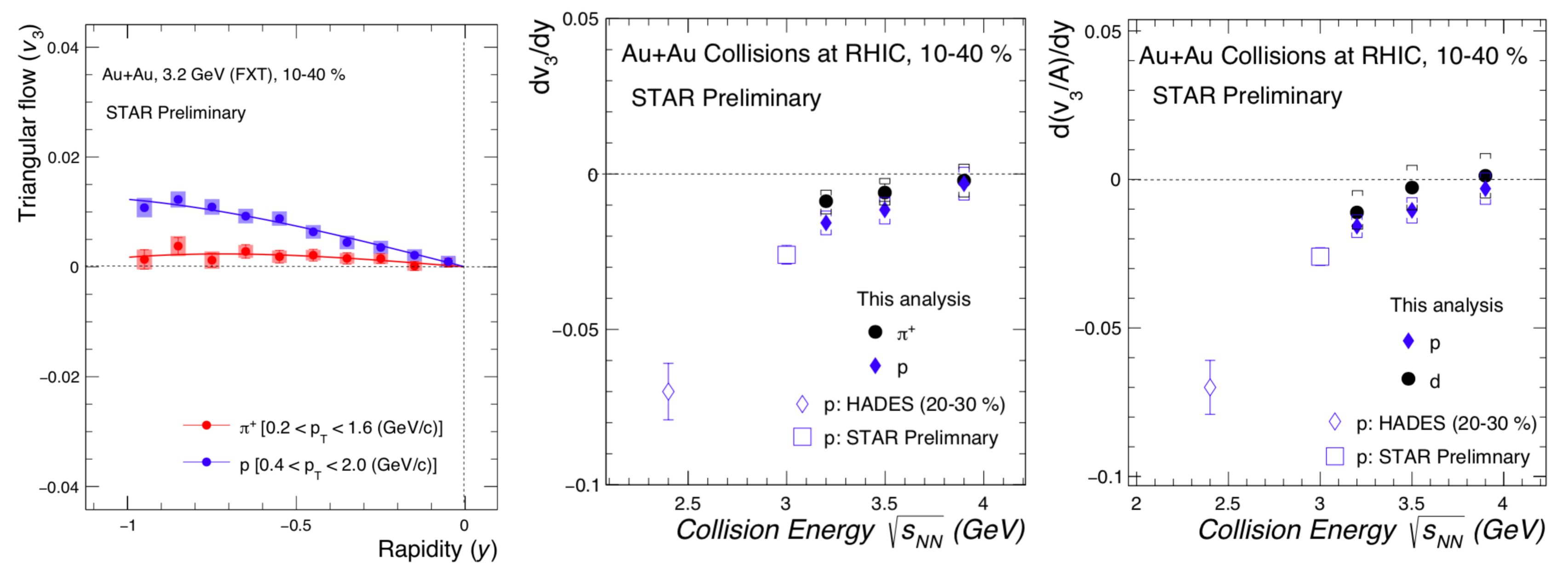
$$v_{1,net} = \frac{v_{1,p} - r\, v_{1,\bar{p}}}{1 - r} \quad (7)$$

where $v_{1,p}$, $v_{1,\bar{p}}$ and r are particle, anti-particle v_1 and the anti-particle to particle ratio respectively.
- $v_1(y)$ for all the particles is fitted with third order polynomial of form $ay + by^3$ to extract the slope value (dv_1/dy).



- dv_1/dy for all particles decreases with increasing collision energy.
- $d(v_1/A)/dy$ for light nuclei seem to follow approximate mass number scaling.

Triangular flow (v_3)



- Magnitude of v_3 increases with increasing rapidity for proton and weaker dependence for pions.
- $v_3(y)$ for all the particles is fitted with third order polynomial of form $ay + by^3$ to extract the slope value (dv_3/dy).
- dv_3/dy for all particles decreases in magnitude with increasing collision energy.

5. Summary

- Magnitude of v_1 and v_3 increases with increasing rapidity for all the particles.
- Slope of v_1 (dv_1/dy) decreases with increasing collision energy for all particles.
- Magnitude of v_3 slope (dv_3/dy) decreases with increasing collision energy.
- Approximate mass number scaling is observed for light nuclei v_1

6. References

- A. M. Poskanzer & S. A. Voloshin, Phys. Rev. C 58, 1671 (1998).
- L. Adamczyk et al. (STAR Collaboration), Phys. Rev. Lett. 112, 162301 (2014).
- L. Adamczyk et al. (STAR Collaboration), Phys. Rev. Lett. 120, 062301 (2018).
- M. S. Abdallah et al. (STAR Collaboration), Phys. Rev. Lett. 827, 137003 (2022).
- J. Adamczewski-Musch et al. (HADES Collaboration), Phys. Rev. Lett. 125, 262301 (2020).

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