Measurement of directed flow in the high-baryon density region at RHIC-STAR

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Introduction

Anisotropic flow parameters provide valuable insights into the collective hydrodynamic expansion and transport characteristics of the produced medium [1]. Moreover, these parameters are sensitive indicators of the compressibility of the nuclear matter and the nuclear equation of state, particularly at lower collision energies [2]. At these lower energies, the transit time of the colliding nuclei, $2R/\gamma\beta$, is comparable to the particle production time [3]. This results in a significant influence of the shadowing effect, where passing spectator nucleons obstruct the interaction region, thereby affecting the measured flow observables.
Directed flow (v_1) is an important probe to study the in-medium dynamics as it is predicted to be sensitive to the equation of state (EoS) of the produced medium [4]. Hydrodynamic calculations suggest that a minimum in directed flow could serve as a signature of a first-order phase transition between hadronic matter and QGP (Quark-Gluon Plasma) [5].
We report the systematic measurement of v_1 for π, K, p, net-kaon, net-proton, d, and t in Au+Au collisions at $\sqrt{s_{NN}} = 3.2$, 3.5, 3.9, and 4.5 GeV taken in fixed-target (FXT) mode from the BES-II program at RHIC-STAR. The results are compared with the JAM transport model to explore the underlying physics mechanisms.

Analysis Details

The identification of charged particles in STAR is done by the combination of Time Projection Chamber (TPC) and Time of Flight (TOF) detectors. The TPC uses the specific ionisation energy loss (dE/dx) in a large volume of gas to identify the charged particle. Moreover, mass-squared (m^2) information from the TOF is used to increase the purity of the signal. The event plane angle, a proxy for the reaction plane angle, is reconstructed using the Event Plane Detector (EPD), which has coverage within $5.3 < \eta < 2.6$ [6].

Results

Net particle refers to the excess yield of particle over its antiparticle. To highlight the contribution of transported quarks over those produced in collisions, $v_{1,net}$ is calculated and is defined as $v_{1,net} = v_{1,p}$ - $rv_{1,\bar{p}}/(1$ - $r)$, where $v_{1,p}$, $v_{1,\bar{p}}$ are the v_1 of the particle and antiparticle, and r is the ratio of antiparticles to particles [1]. Figure 1 illustrates the rapidity (y) dependence of v_1 for identified hadrons, net-particles, and light nuclei in Au+Au collisions at $\sqrt{s_{NN}} = 3.2$ GeV in $10 - 40\%$ centrality. The magnitude of v_1 increases with rapidity for all particles, with $v_1(y)$ for π^+ being positive, likely due to strong spectator shadowing. Figure 2 shows the collision energy dependence of the slope of v_1, $dv_1/dy|_{y=0}$, for identified hadrons, net-particle, and light nuclei (scaled by mass number, A) in 10 - 40% centrality. The magnitude of $dv_1/dy|_{y=0}$ decreases with increasing collision energy for all particle species. The net-kaon $dv_1/dy|_{y=0}$ shows a minimum between $\sqrt{s_{\rm NN}} = 4.5$ and 7.7 GeV, at lower collision energies than for net-protons, where the minimum is found between $\sqrt{s_{\rm NN}} = 11.5$ and 19.6 GeV [1]. The light nuclei v_1 slope shows approximate A scaling, consistent with the nucleon coalescence mechanism for their production. A detailed comparison of expereimental data with the JAM model will be presented to emphasize the significant impact of mean-field effects and spectator nucleons at low collision energies.

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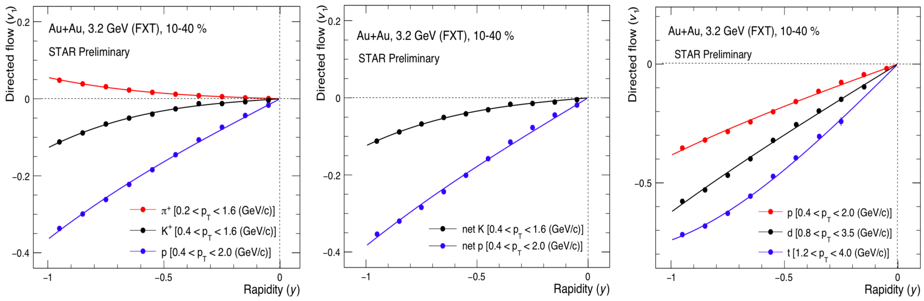

FIG. 1: v_1 as a function of y in $10-40\%$ centrality for identified hadrons (left panel), net particles (middle panel) and light nuclei (right panel) in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 3.2 GeV. The line represents 3$^{\rm rd}$ order polynomial fit. Statistical and systematic errors are within the marker size.

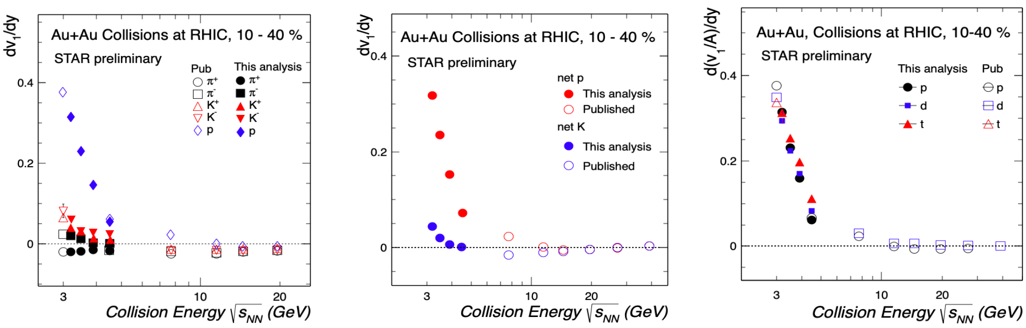

FIG. 2: Collision energy dependence of $\mathrm{d}v_1/\mathrm{d}y|_{y=0}$ for identified hadrons (left panel), net particles (middle panel) and light nuclei (right panel) in Au+Au collisions at RHIC for 10-40% centrality. The published data are shown in open markers [1].

Summary

In summary, we have studied v_1 of identified hadrons, net-particle, and light nuclei in Au+Au collisions at $\sqrt{s_{NN}} = 3.2 - 4.5$ GeV. The slope of identified hadrons, net-particles, and light nuclei exhibits a decreasing trend with increasing collision energy. The trend of net-kaon $dv_1/dy|_{y=0}$ suggests a minimum at lower collision energy range compared to that of net-proton. $dv_1/dy|_{y=0}$ of light nuclei exhibits an approximate mass number scaling consistent with the nucleon coalescence mechanism for the production of light nuclei.

Acknowledgments

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