Directed flow of identified hadrons in Au+Au collisions with the STAR experiment at RHIC

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Abstract. Rapidity-odd component of the directed flow (v_1) is considered to be sensitive to the early collision dynamics and the equation of state (EoS) of the QCD matter formed in heavy-ion collisions. Hydrodynamic models predict that the double sign change of v_1 slope at mid-rapidity (dv_1/dy) of net-baryon is a signature of the first-order phase transition. The STAR experiment at RHIC shows that the collision energy dependences of dv_1/dy of net-proton and net-Λ reach a minimum at $\sqrt{s_{\rm NN}}$ = 14.5 GeV, implying the possible softening of the EoS. We further explore such observations with new measurements. A comprehensive transverse momentum ($p_{\rm T}$) dependent v_1 measurement of identified light hadrons (π^+, π^-, K^+, K^-, p, $\overline{p}$) enables us to test the constituent quark number scaling and provides a better understanding of the coalescence mechanism of particle production. In this proceeding, new results of $p_{\rm T}$ and rapidity dependent v_1 for identified hadrons in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 19.6, 27, and 54.4 GeV are presented. These results are compared to AMPT model calculations.

Keywords: Directed flow, QCD phase structure, Quark-gluon plasma

1 Introduction

The beam energy scan program of the STAR experiment at RHIC aims to understand the QCD phase diagram of strongly interacting matter produced by the ultra-relativistic heavy-ion collisions [1]. The first-order coefficient of Fourier expansion of emitted particles in the momentum space is called directed flow (v_1). The rapidity-odd, $v_1(y)$ = -$v_1(-y)$, component of the directed flow is a sensitive probe of the bulk to study the collective phenomenon in the early stage of the collisions dynamics. A first-order phase transition is predicted by various transport and hydrodynamics models [2, 3]. The model calculations show a sign change in the v_1-slope (dv_1/dy) as function of beam energy for baryons. The QCD lattice calculations also predict the first-order phase transition [4].

The number of constituent quark (NCQ) of elliptic flow (v_2) of identified hadrons in BES energies suggests that the flow is developed in the early stage of collisions and also the hadrons are formed via quarks coalescence [5–7]. However, at lower energies hadronic matter dominates. For the first time a comprehensive

p_{T} dependent study of identified hadrons directed flow at different energies are reported here. The rapidity dependence study in BES energies has been published by the STAR Collaboration [8].

2 Directed flow of identified hadrons

The p_{T} dependent v_1 of $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ in the rapidity region $0.5 < |y| < 1$ for 10-40% centrality in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 27$ GeV along with different tunes of AMPT model calculations are shown in Fig. 1. For all the measured hadrons (except proton), the v_1 values are found to be negative (anti-flow) for p_{T} below 2.5 GeV/c (1.8 GeV/c for proton). The negative v_1 at low p_{T} region suggests that the produced bulk matter and formed hadrons move opposite to each other [9–12]. However, one can not rule out the effect of shadowing in the low p_{T} region [13]. The AMPT calculations are also compared with the corresponding hadrons. The AMPT-Default configuration qualitatively well describes the hadrons ($\pi^{\pm}$, K^{+}, p) formed by quarks (anti-quarks) contributed from both transported and produced quarks [14]. The produced hadrons such as K^{-}, $\bar{p}$ are formed from the produced quark and anti-quark. These hadrons are qualitatively well described by AMPT-SM with hadronic interaction time, $t_{\max} = 0.4$ and 30 fm/c.

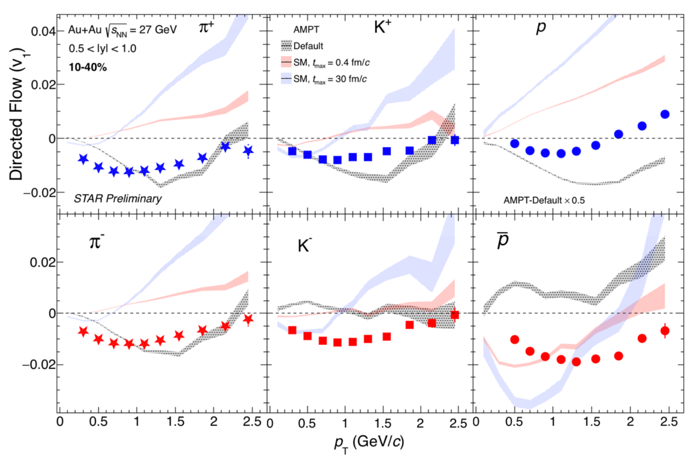

Fig. 1. v_1 as a function of p_{T} for $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ in the rapidity region $0.5 < |y| < 1$ for 10-40% centrality Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 27$ GeV. The black, red and blue shaded bands represents AMPT-Default, AMPT-SM with hadronic interaction time $t_{max} = 0.4$ fm/c and 15 fm/c, respectively [15].

Figure 2 shows the v_1/n_{q} as a function of $(m_{\mathrm{T}} - m_0)/n_{\mathrm{q}}$ for π^{+}, K^{+}, p (upper row) and π^{-}, K^{-}, $\bar{p}$ (lower row) in the rapidity $0.5 < |y| < 1$ for 10-40%

centrality in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 19.6 (left panel), 27 (middle panel) and 54.4 (right panel) GeV. It is observed that NCQ scaling does not hold well for the particles (π^+, K^+ and p) in all the measured energies. The magnitude of the violation also increases with decrease in energy as the transported quark contribution to the form hadrons increases. However, the NCQ scaling holds better for produced hadrons like K^- and $\overline{p}$ as these are formed via coalescence for quarks and anti-quarks [16].

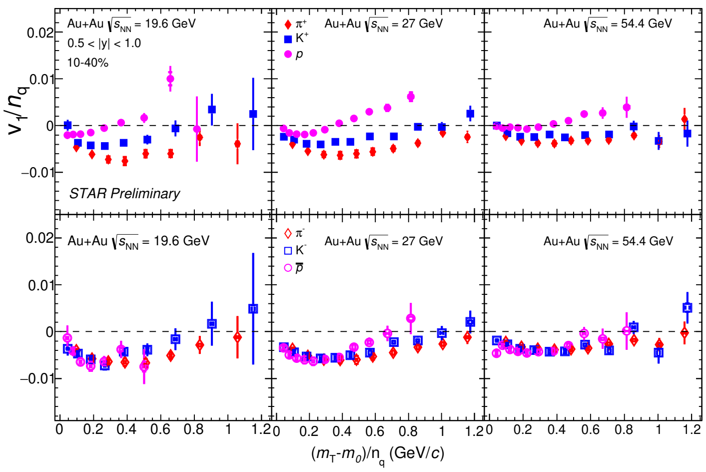

Fig. 2. $v_1/n_{\rm q}$ vs $(m_{\rm T} - m_0)/n_{\rm q}$ for π^+, K^+, p (upper row) and π^-, K^-, $\bar{p}$ (lower row) in the rapidity $0.5 < |y| < 1$ for 10-40% centrality in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 19.6, 27 and 54.4 GeV in the left, middle and right column, respectively.

Figure 3 shows the centrality dependence of $v_1/n_{\rm q}$ as a function of $(m_{\rm T} - m_0)/n_{\rm q}$ for π^-, K^-, $\overline{p}$ in 40-80% (left), 10-40% (middle) and 0-10% (right) panel in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 27 GeV (upper row) and 54.4 GeV (lower row). The NCQ scaling holds better for produced hadrons such as K^- annd $\overline{p}$ in all three centralities in the low-$m_{\rm T}$ region.

3 Conclusion

First comprehensive measurements of $p_{\rm T}$ dependence directed flow of identified hadrons ($\pi^\pm$, $K^\pm$, p and $\overline{p}$) in the rapidity region of $0.5 < |y| < 1.0$ for various collision centralities in Au+Au at $\sqrt{s_{\rm NN}}$ = 19.6, 27 and 54.4 GeV are reported. In the low-$p_{\rm T}$ region, anti-flow is observed in the measured rapidity region 0.5 $< |y| <$ 1 for all hadrons in these energies. The NCQ scaling is observed for produced hadrons (K^- and $\overline{p}$) which suggests that coalescence is the dominant mechanism of particle formation for these hadrons. For other hadrons such as $\pi^\pm$, K^+ and p, the NCQ scaling is violated as they also receive contribution from

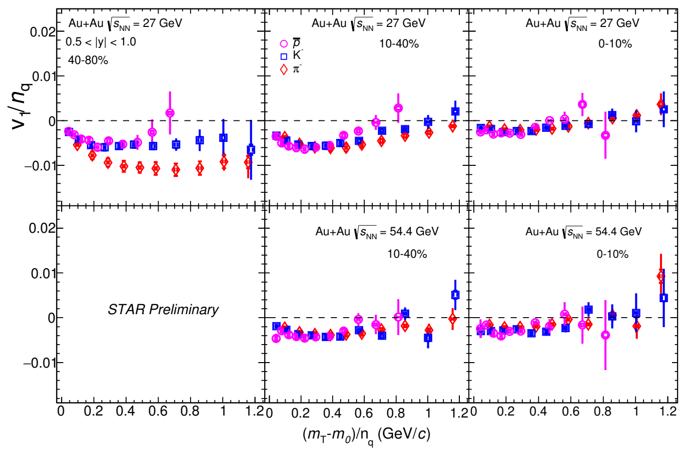

Fig. 3. $m_{\rm T}$ scaling for π^-, K^-, $\overline{p}$ in $0.5 < |y| < 1$ for 40-80% (left), 10-40% (middle) and 0-10% (right) centrality in Au+Au at 27 (upper row) and 54.4 (lower row) GeV.

transported quarks along with the primary produced quarks. The contribution of transported quarks increases with decrease in energy and hence deviation from the NCQ scaling increases.

4 Acknowledgments

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