

The physics mechanisms of light and heavy flavor v_2 and mass ordering in AMPT

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Abstract. A Multi-Phase Transport (AMPT) model has been shown to describe fairly well experimental data including the bulk properties of particle spectra and elliptic anisotropy (v_2) in heavy ion collisions. Recent studies have shown that AMPT describes the v_2 measurements in small system collisions as well. In these proceedings, we first investigate the origin of the mass ordering of identified hadrons v_2 in heavy ion as well as small system collisions. We then study the production mechanism of the charm v_2 in light of the escape mechanism for the light quark v_2 .

1. Introduction

Relativistic heavy ion collisions aim to create the quark-gluon plasma (QGP) and study its properties at extreme conditions of high temperature and energy density [1, 2]. Collective flow is often used in experimental and theoretical investigations to study the QGP properties. Both hydrodynamics [3, 4] and transport theory [5] can describe the bulk data in heavy ion collisions. For example, the string melting version of A Multi-Phase Transport (AMPT) model [5, 6] reasonably reproduces particle yields, p_T spectra, and v_2 of low- p_T pions and kaons in central and mid-central Au+Au collisions at 200A GeV and Pb+Pb collisions at 2760A GeV [7]. Similar measurements in small systems can also be satisfactorily described by AMPT [8].

Recent studies have shown that light parton v_2 is mainly generated by the anisotropic parton escape from the collision zone and hydrodynamics may play only a minor role [9, 10]. It suggests that the mass ordering of v_2 , commonly considered as a signature of hydrodynamic expansion of the system, may arise from other mechanisms. In these proceedings, we first investigate the physics mechanisms of this mass ordering in AMPT [11, 12]. We then study the production mechanism of the charm v_2 in light of the escape mechanism for the light quark v_2 .

2. Model details and analysis method

We employ the string melting version of AMPT [5, 6] in our study. The model consists of four components: fluctuating initial conditions, parton elastic scatterings, quark coalescence for hadronization, and hadronic interactions. The parton interactions are modeled by Zhang's parton cascade (ZPC) [13]. We use Debye screened differential cross-section $d\sigma/dt \propto \alpha_s^2/(t - \mu_D^2)^2$ [5], with strong coupling constant $\alpha_s = 0.33$ and Debye screening mass $\mu_D = 2.265/\text{fm}$ (the

total cross section is then $\sigma = 3$ mb) for all AMPT simulation in our work. Once partons stop interacting, a simple quark coalescence model is applied to combine two (three) nearest partons into a meson (baryon or antibaryon). The subsequent hadronic interactions are described by an extended ART model [5, 14]. We terminate the hadronic interactions at a cutoff time, when the observables of interest are stable with time; a cutoff time of 30 fm/c is used in this study.

We simulate three collision systems: Au+Au collisions with $b = 6.6$ -8.1 fm at the nucleon-nucleon center-of-mass energy $\sqrt{s_{\text{NN}}} = 200$ GeV, d +Au collisions with $b = 0$ fm at $\sqrt{s_{\text{NN}}} = 200$ GeV, and p +Pb collisions with $b = 0$ fm at $\sqrt{s_{\text{NN}}} = 5$ TeV. We analyze the momentum-space azimuthal anisotropy of partons in the final state before hadronization, of hadrons right after hadronization but before hadronic rescattering takes place, and of freeze-out hadrons in the final state. The momentum anisotropy is characterized by the Fourier coefficients [15] according to $v_2 = \langle \cos 2(\phi - \psi_2^{(r)}) \rangle$, where ϕ is the azimuthal angle of a particle (parton or hadron). The $\psi_2^{(r)}$ is the harmonic plane of each event from its initial spatial configuration of all partons. All results shown are for particles within the pseudo-rapidity window $|\eta| < 1$.

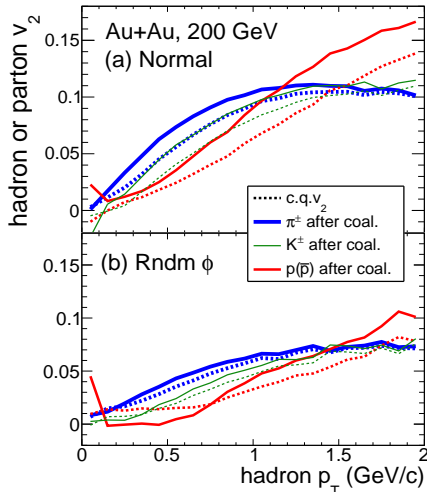


Figure 1. Mass splitting from coalescence. Constituent quark (c.q., dashed curves) and primordial hadron (solid curves) v_2 as a function of hadron p_T in Au+Au collisions by normal (a) and ϕ -randomized (b) AMPT.

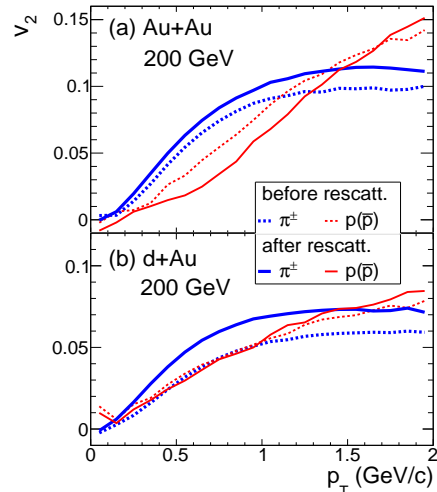


Figure 2. Effects of hadronic rescatterings. Pion and (anti) proton v_2 before (dashed) and after (solid) hadronic rescatterings in Au+Au (a) and d +Au (b) collisions by AMPT.

3. Mass ordering of v_2

We have found almost identical $v_2(p_T)$ values after parton cascade for up and down quarks and for quarks and antiquarks of the same flavor. Considering that pions and protons are made of only light constituent quarks, the difference between their v_2 should come from the hadronization process and/or hadronic rescatterings. Thus we first study the primordial hadrons (i.e. hadrons formed directly from quark coalescence before any decays or hadronic rescatterings take place). Figure 1(a) shows the v_2 of primordial charged pion, kaon, and (anti)proton as a function of p_T (solid curves). It demonstrates that the mass ordering of v_2 at low p_T in AMPT comes from the kinematics in coalescence such as the constituent quark number in a hadron and the finite opening angle between coalescence partners [11, 12]. The dynamical “selections” of constituent

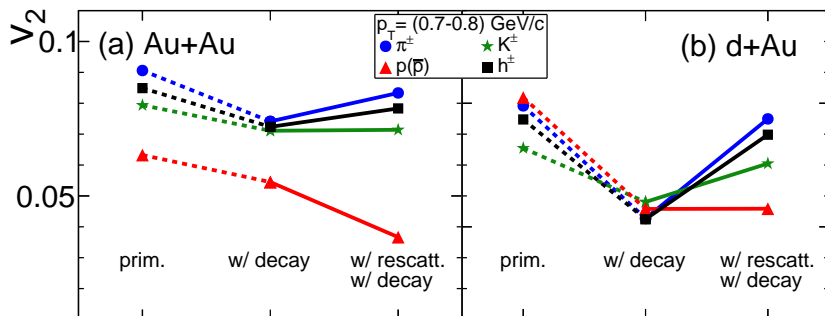


Figure 3. (Color online) Mid-rapidity ($|\eta| < 1$) v_2 of π , K, $p(\bar{p})$ and charged hadrons (h^\pm) at $0.7 < p_T < 0.8$ GeV/ c at different stages of system evolution in $b = 6.6-8.1$ fm Au+Au (left) and $b = 0$ fm d +Au (right) collisions at $\sqrt{s_{NN}}=200$ GeV by AMPT: initial v_2 of primordial hadrons (right after coalescence hadronization and before hadronic rescatterings), initial v_2 of all hadrons (including decays), and final v_2 of all hadrons (after hadronic rescatterings and decays).

quarks into pions, kaons, and protons are manifest in the constituent quark v_2 distributions shown by the dashed curves in Fig. 1(a), plotted at the respective *hadron* p_T .

Figure 1(b) shows the v_2 results by ϕ -randomized AMPT [9] for primordial hadrons right after the coalescence hadronization at the corresponding hadron p_T . No hydrodynamic anisotropic flow is present in the ϕ -randomized case [9], however, mass ordering is still present. This observation implies that the mass ordering is mainly due to the kinematics in the coalescence process. It is therefore not a unique signature of collective anisotropic flow or hydrodynamics.

After hadronization, particles undergo decays and rescatterings. We evaluate the v_2 of hadrons before hadronic rescatterings but including resonance decays. The results are represented in Fig. 2(a) by the dashed curves. The decay product v_2 is usually smaller than their parent v_2 [12]. By including decay products, the hadron v_2 is reduced from that of primordial hadrons (solid curves in Fig. 1(a)).

The v_2 values before hadronic rescatterings (but including resonance decay effects) can be considered as the initial v_2 for the hadronic evolution stage. The final-stage freezeout hadron v_2 's (also including decay daughters) are shown in Fig. 2(a) by the solid curves. Pion v_2 increases while proton v_2 decreases after the hadronic rescattering phase. This may be due to interactions between pions and protons, after which they tend to flow together at the same velocity. Thus, the same-velocity pions and protons (i.e. small p_T pions and large p_T protons) will tend to have the same anisotropy. This will yield lower v_2 for protons and higher v_2 for pions at the same p_T value. This should happen regardless of the net change in the overall charged hadron v_2 , which depends on the initial configuration geometry from which the hadronic evolution begins [12]. Similar results in d +Au collisions as shown in Fig. 2(b) [12].

To summarize the origin of v_2 mass splitting, we plot the v_2 of pions, kaons, and protons within $0.7 < p_T < 0.8$ GeV/ c for different stages of the collision system evolution as shown in Fig. 3. The evolution stages contain: (i) right after coalescence hadronization including only primordial hadrons (labeled “prim.”); (ii) right after coalescence hadronization but including decay products (labeled “w/ decay”); and (iii) at final freezeout (labeled “w/ rescatt. w/ decay”). We can see the mass ordering actually comes from the interplay of several physics effects: coalescence, and more importantly, from the hadronic rescattering process.

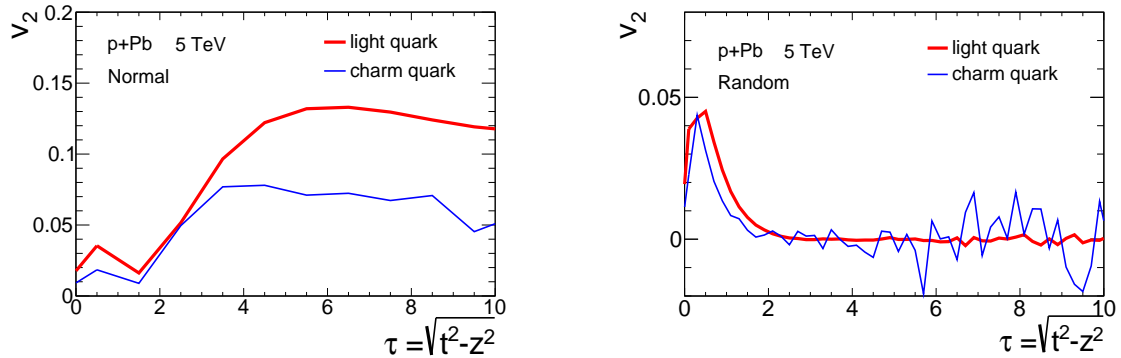


Figure 4. (Color online) The charm and light quark v_2 as a function of the freezeout proper time $\tau = \sqrt{t^2 - z^2}$ in p+Pb collisions with $b = 0$ fm. Both the normal (left) and ϕ -randomized (right) AMPT results are shown.

4. Charm v_2 mechanism

In this section we discuss the production mechanism of charm quark flow in pPb. We compare the light and charm quark v_2 at freezeout, integrated over all p_T , versus the freezeout proper time. This is shown in the left panel of Fig. 4. The charm v_2 is systematically lower than light quark v_2 . This suggests that quark mass significantly affects the elliptic flow. The right panel of Fig. 4 shows the ϕ -randomized results. The charm and light quark v_2 are similar suggesting a common escape mechanism.

5. Summary

In these proceedings, we investigate the origin of mass splitting of identified hadron v_2 . The mass splitting is due to coalescence and, more importantly, hadronic rescatterings. It is therefore not a unique signature of hydrodynamics. We also study the development of charm v_2 in pPb and found the escape mechanism to be the major contribution similar to light quarks.

Acknowledgments

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