Constraining shear viscosity of QCD matter at forward rapidity†

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The quark-gluon plasma (QGP) is a high-temperature phase of QCD. Its materialization at BNL Relativistic Heavy Ion Collider and LHC Large Hadron Collider has opened up a possibility to observe the QCD medium quantitatively. One of the goals of heavy-ion phenomenology is to constrain the microscopic properties of the QGP, namely, the equation of state (EoS) and the transport coefficients. With the advent of lattice QCD techniques, we have a good understanding of the EoS near the vanishing chemical potential; however speculations still surround the transport coefficients. One such conjecture is the *lower boundary* of shear viscosity, $\eta/s = 1/4\pi$, derived from the framework of the Anti-de Sitter/conformal field theory (AdS/CFT) correspondence[1)].

We use a full three-dimensional viscous hydrodynamic model MUSIC[2)] to explore *forward rapidity* regions. In particular, we show in our description of the experimental data that the AdS/CFT-conjectured minimum boundary would not hold in QCD.

The input to the hydrodynamic model are chosen as follows[3)]. The fluctuating initial conditions for the entropy and the net baryon distribution are calculated using the Monte-Carlo Glauber model with rapidity dependence implemented by the modified Lexus model. The EoS is that of (2+1)-flavor lattice QCD with the Taylor expansion method, connected to that of hadron resonance gas in low-temperature regions at a connecting temperature T_c. Since the hadron gas at low T and the perturbative QCD gas at high T are known to have large viscosity, we can parametrize the shear viscosity as

$$\begin{aligned}(\eta T/(\epsilon + P))(T) &= (\eta T/(\epsilon + P))_{\min} \\ &+ a \times (T_c - T)\theta(T_c - T) \\ &+ b \times (T - T_c)\theta(T - T_c), \qquad (1)\end{aligned}$$

where $(\epsilon + P)/T$ replaces s in the finite density system considered in this study. The four scenarios are plotted in Fig. 1. Hydrodynamic and initial condition parameters are independently chosen for each scenario so that rapidity distribution is reproduced.

Figure 2 shows the numerical results on the rapidity dependence of elliptic flow v_2 in Au-Au collisions at $\sqrt{s_{NN}} = 200$ GeV for four different sets of a and b. We see that $(\eta T/(\epsilon+P))_{\min} = 0.04$ with large hadronic viscosity is favored by the PHOBOS Collaboration data[4)]. Similarly, our calculation of triangular flow v_3 indicates that the $b = 2$ scenario is better than the $b = 0$ one. It is worth noting that (i) the temperature-independent $\eta T/(\epsilon + P) = 0.12$, which has been known to work well at mid-rapidity, is not preferred at forward rapidity, and (ii) this is an experimental indication that the AdS/CFT minimum boundary $\eta/s = 1/4\pi \simeq 0.08$ can be crossed near the quark-hadron crossover. It can be interpreted that one needs a much smaller minimum than what was conventionally used for the whole temperature range when temperature dependence is introduced because of the effects of large shear viscosity at lower and higher temperatures.

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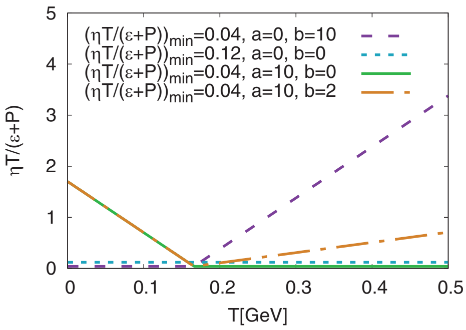

Fig. 1. (Color online) Four models of temperature-dependent shear viscosity.

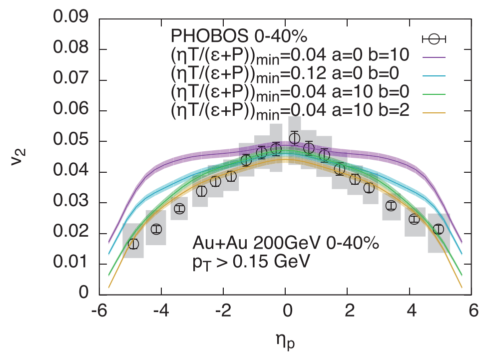

Fig. 2. (Color online) Rapidity dependence of v_2 for different $\eta T/(\epsilon + P)$ parameterizations.

References

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