Strongly Interacting Quark Gluon Plasma and Longitudinal expansion of Quark Gluon Plasma

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Introduction

Two different phenomenological models of quark gluon plasma, quasi-particle model and strongly coupled quark gluon plasma model,both explain the non-ideal behavior seen in lattice simulation of quantum chromodynamics and relativistic heavy ion collisions.It should be noted that SCQGP [1] is different from popularly known sQGP. sQGP means strongly interacting QGP in the sense that the coupling constant α_s is not very small or weak and hence leads to non-perturbative effects like the existence of hadrons, mostly colored hadrons. First we use an equation of state (EoS) which should reproduce the lattice results verifying the strongly-interacting nature of QGP. Then we study hydrodynamic boost-invariant Bjorken expansion in $(1+1)$ dimension with the EoS.In addition we explore the effects of dissipative terms on the hydrodynamic expansion by considering the shear viscosity η up to first-order in the stress-tensor.

Strongly-interacting and Longitudinal expansion of QGP

In the presence of viscous forces the energy-momentum tensor is written as,

$$T^{\mu\nu} = (\epsilon + p)u^\mu u^\nu + g^{\mu\nu} p + \pi^{\mu\nu}, \qquad (1)$$

where $\pi^{\mu\nu}$ is the stress-energy tensor. In this case the equation of motion reads,

$$\partial_\tau \epsilon = -\frac{\epsilon + p}{\tau} + \frac{4\eta}{3\tau^2} \, . \qquad (2)$$

The solution of the above equation in the case of constant value of η/s is known analytically [2] and is given by,

$$T(\tau) = T_i \left(\frac{\tau_i}{\tau}\right)^{1/3} \left[1 + \frac{2\eta}{3s\tau_i T_i}\left(1 - \left(\frac{\tau_i}{\tau}\right)^{2/3}\right)\right] . \qquad (3)$$

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The first term in the RHS is the same as in the case of zeroth-order (non-viscous) hydrodynamics and the second term is the correction arising from constant η/s. The solution of Eq.(2) is obtained as,

$$\begin{aligned} \epsilon(\tau)\tau^{(1+c_s^2)} + \frac{4a}{3\tilde{\tau}^2}\tau^{(1+c_s^2)} &= \epsilon(\tau_i)\tau_i^{(1+c_s^2)} + \frac{4a}{3\tilde{\tau_i}^2} \\ &= \text{const} \, , \end{aligned} \qquad (4)$$

where $a = \left(\frac{\eta}{s}\right) T_i^3 \tau_i$ and $\tilde{\tau}^2$ and $\tilde{\tau}_i^2$ are given by $(1-c_s^2)\tau^2$ and $(1-c_s^2)\tau_i^2$, respectively. The first term in both LHS and RHS accounts for the contributions coming from the zeroth-order expansion and the second term is the first-order viscous corrections. We consider three values of the η/s to see the effects of nonzero values of the shear viscosity on the expansion.

Survival probability

Let us take a simple parametrization for the initial energy-density profile on any transverse plane :

$$\epsilon(\tau_i, r) = \epsilon_i A_T(r); A_T(r) = \left(1 - \frac{r^2}{R_T^2}\right)^\beta \theta(R_T - r) \qquad (5)$$

where r is the transverse co-ordinate and R_T is the transverse radius of the nucleus. The experimental measurement of survival probability at a given number of participants $(N_{\rm part})$ whose theoretical expression would be

$$\langle S(p_T)\rangle = \frac{\int_{p_T^{\rm min}}^{p_T^{\rm max}} dp_T S(p_T)}{\int_{p_T^{\rm min}}^{p_T^{\rm max}} dp_T} \qquad (6)$$

In nucleus-nucleus collisions, it is known that only about 60% of the observed J/ψ originate directly in hard collisions while 30% of them come from the decay of χ_c and 10% from the

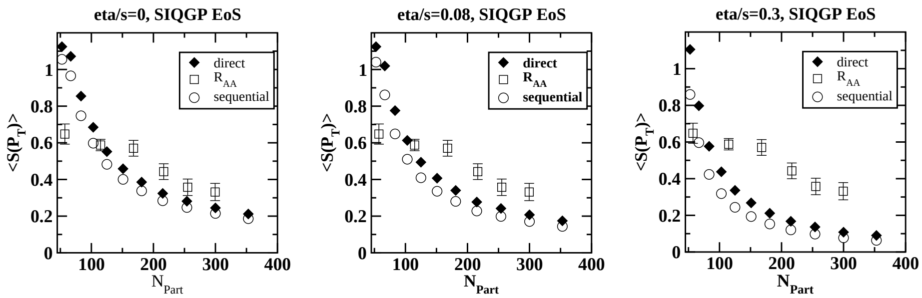

FIG. 1: The variation of p_T integrated survival probability versus number of participants at mid-rapidity.The experimental data (the nuclear-modification factor R_{AA}) are shown by the squares with error bars whereas circles and diamonds represent with ($\langle S^{\rm incl}\rangle$) without ($\langle S^{\rm dir}\rangle$) sequential melting using the values of T_D's [3] and related parameters from Table I using SIQGP equation of state.

decay of ψ'. Hence, the p_T-integrated inclusive survival probability of J/ψ in the QGP becomes [4].

$$\langle S^{\rm incl}\rangle = 0.6\langle S^{\rm dir}\rangle_{\psi} + 0.3\langle S^{\rm dir}\rangle_{\chi_c} + 0.1\langle S^{\rm dir}\rangle_{\psi'} \tag{7}$$

The hierarchy of dissociation temperatures in lattice correlator studies [5] thus leads to sequential suppression pattern with an early suppression of ψ' and χ_c decay products and much later one for the direct J/ψ production.

TABLE I: Formation time (fm), dissociation temperature T_D with the Debye mass in the leading-order,the speed of sound c_s^2 and the screening energy density ϵ_s (GeV/fm^3) calculated in SIQGP and ideal EoS for J/ψ, ψ', χ_c states [3], respectively.

State	τ_F	T_D	c_s^2(SIQGP)	c_s^2(Id)	ϵ_s (SIQGP)	ϵ_s(Id)
J/ψ	0.89	1.61	0.26	1/3	17.65	21.77
ψ'	1.50	1.16	0.24	1/3	04.51	06.53
χ_c	2.00	1.25	0.24	1/3	06.15	08.47

Results and discussions

We study the dissociation phenomenon of J/ψ by studying the in-medium modifications to the heavy quark potential and its suppression in a longitudinally expanding QGP. In Fig.1. we have shown the variation of p_T-integrated survival probability with $N_{\rm Part}$ at mid-rapidity. And the survival probability of directly produced J/ψ is slightly higher than $\langle S^{\rm incl}\rangle$ and is closer to the the experimental results [7]. For the lower value of η/s our predictions are closer to the experimental ones. As the ratio η/s is increased, the expansion of the system becomes slower leading to the higher values for the screening time and hence lower values of $\langle S(p_T)\rangle$ i.e., J/ψ's will be suppressed more.The matching is almost perfect for η/s=0.

However, with our recent results [3] (Table I) employing medium modification to the full Cornell potential and also results from potential model studies [6] on dissociation temperatures,all three species will show essentially almost the same suppression pattern.

References

[1] V. M. Bannur, J. Phys. G: Nucl. part. Phys.**32** 993 (2006); Phys. Lett. **B 362**, 7 (1995).

[2] H. Kouno, M. Maruyama, F. Takagi, and K. Saito, Phys. Rev. D **41**, 2903 (1990).

[3] V. Agotiya, V. Chandra and B. K. Patra, Phys. Rev. C **80**, 025210 (2009).

[4] D. Pal, B. K. Patra and D. K. Srivastava, Euro. Phys. J. **C 17**, 179 (2000).

[5] S. Datta, F. Karsch, P. Petreczky, and I.Wetzorke, Phys. Rev. D **69**, 094507 (2004).

[6] A. Mocsy and P. Petreczky, Phys. Rev. Lett. **99**, 211602 (2007).

[7] J. Adams, *et al*,Phys. Rev. Lett. **92**, 112301 (2004); A. Adare *et al.*, (PHENIX Collaboration),Phys. Rev. Lett. **98**, 232301 (2007).