Charmonium Production from Hot Hadronic Matter

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One of the signals proposed for identifying the existence of a quark-gluon plasma in ultra-relativistic heavy-ion collisions is the suppression of J/ψ production compared to that expected from the superposition of nucleon-nucleon collisions [1]. The suppression is due to the dissolution of J/Ψ in the quark-gluon plasma as a result of Debye screening and vanishing string tension between c and $\bar{c}$. However, J/ψ can be regenerated from the hadronic matter via interactions of charm mesons with hadrons. These reactions are apparently unimportant at SPS energies but may become significant at RHIC and LHC [2].

To model heavy-ion collisions at such high energies, we use the results from the HIJING calculation [3], which shows that at an initial proper time τ_0 a thermally equilibrated although chemically non-equilibrated quark-gluon plasma of temperature T_0 is formed. For Au+Au collisions, HIJING predicts that $\tau_0 \sim 0.7$ and 0.5 fm/c, $T_0 \sim 0.57$ and 0.83 GeV at RHIC and LHC energies, respectively. The quark-gluon plasma then cools due to expansion and production of additional partons. It reaches the critical temperature $T_c \sim 200$ MeV at about $\tau_c \sim 3$ fm/c at RHIC and 6 fm/c at LHC, when the quark-gluon plasma starts to make a transition to a hadron gas, consisting mostly of pions and rho mesons. We assume that the proper time at which the quark-gluon plasma is completely converted to a hadron gas is $\tau_h \sim 2\tau_c$. Neglecting transverse expansion in this early phase, the initial volume of the hadronic matter at midrapidity is simply $V_h \sim \pi R_0^2 \tau_h$, where R_0 is the radius of the colliding nuclei.

For transverse expansion of the hadron gas, we introduce an acceleration $a \sim 0.1\ c^2$/fm such that its transverse radius increases quadratically with time until the velocity reaches the velocity of light, when it increases linearly with time. Assuming that the hadron gas expands isentropically, its temperature then decreases according to the inverse of the cubic root of volume until the freeze out temperature of $T_f \sim 120$ MeV.

According to the HIJING model, the initial number of $c\bar{c}$ pairs at midrapidity in Au+Au collisions is about 1.65 at RHIC and 53 at LHC, which we take as the initial number of $D\bar{D}$ pairs in the hadronic phase as thermal charm production from the quark-gluon plasma is small [3]. The initial J/ψ number at midrapidity is 0.0189 at RHIC and 0.48 at LHC.

For the J/ψ production cross section, we use the one calculated either from an effective Lagrangian [5] or from the quark-exchange model [6]. In Fig. 1, we show the temperature dependence of the thermally averaged J/ψ production and absorption cross sections from the effective Lagrangian model. In the quark-exchange model, the values are order of magnitude larger.

The total number of produced J/ψ from heavy ion collisions is obtained by mul-

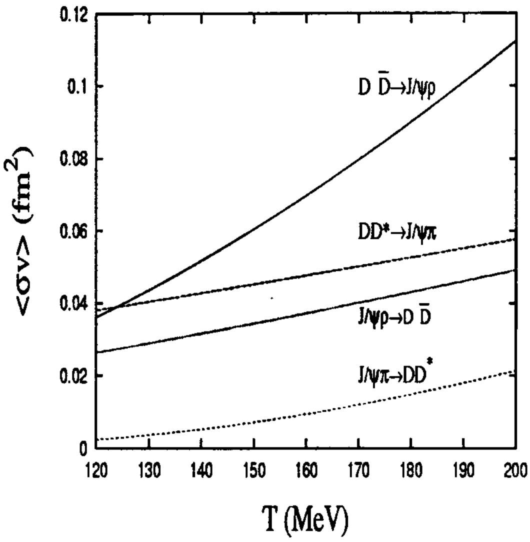

Figure 1: Temperature dependence of the thermally averaged J/ψ absorption and production cross sections from the effective Lagrangian model [5].

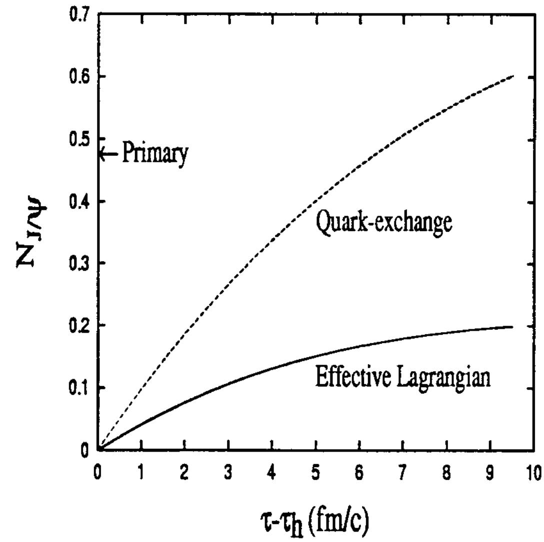

Figure 2: Time evolution of the abundance of J/ψ from Au+Au collisions at LHC using cross sections from the effective Lagrangian [6] and the quark-exchange model [5]. The initial J/ψ number is denoted by the arrow on the left.

tiplying the rate by the volume of the hadron gas and then integrating over time. At RHIC the number of J/ψ produced from $D\bar{D}$ annihilation is 3.0×10^{-4} and 9.6×10^{-4} using cross sections from the effective Lagrangian and the quark-exchange model, respectively. These are almost two orders of magnitude smaller than the number of primary J/ψ. At LHC, where the number of $D\bar{D}$ present in the hadron gas is much larger, the J/Ψ number is 0.2 in the effective Lagrangian model and 0.6 in the quark-exchange model. As shown in Fig. 2, both are comparable to the number of primary J/ψ, shown by the arrow on the left.

Our results thus indicate that in heavy ion collisions at LHC a good understanding of J/Ψ production from the hadron gas is required before one can use it as a signal for the quark-gluon plasma.

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