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D_{sJ} (2317) meson production at RHIC

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Abstract : We study the production of D_{sJ} (2317) mesons in relativistic heavy ion collisions using the quark coalescence model. The predicted D_{sJ} (2317) abundance depends sensitively on the quark structure of the D_{sJ} (2317) meson. We have also evaluated the absorption cross sections of the D_{sJ} (2317) meson by π, ρ, kaon and K^* in a phenomenological hadronic model. We find that the final yield of D_{sJ} (2317) mesons remains sensitive to its initial number produced from the quark-gluon plasma, providing thus the possibility of studying the quark structure of the D_{sJ} (2317) meson and its production mechanism in relativistic heavy ion collisions.

Keyword : Heavy flavor

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1. Introduction

A narrow D_{sJ} (2317) meson was recently observed by the BABAR Collaboration [1] in the inclusive $D_s^+\pi^0$ invariant mass distribution. This meson has spin-parity $J^P = 0^+$ and a mass below what was predicted by quark model calculations [2] for a normal two-quark state $c\bar{s}$. The D_{sJ} (2317) meson has thus been considered as a possible candidate for the exotic four-quark state or a *DK* molecule.

Studying the mechanism for D_{sJ} (2317) meson production in nuclear reactions is useful for understanding its quark structure. In [3], a coupled-channel quark model has been used to study the production of a two-quark D_{sJ} (2317) meson and its radial excitations in hadronic reactions. Production of D_{sJ} (2317) in relativistic heavy ion collisions has also been studied [4]. It was found that for a four-quark D_{sJ} (2317) meson, a much large yield

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is obtained if one takes into account the diquark-diquark interactions in the produced quark-gluon plasma. Since the D_{sJ} (2317) meson is not expected to survive in the quark-gluon plasma, it is more likely to be produced at hadronization of the quark-gluon plasma either statistically or *via* quark coalescence. Its final abundance in a heavy ion collision depends, however, also on its absorption and production probability in the subsequent hadronic matter. Here, we study D_{sJ} (2317) meson production in central heavy ion collisions at the Relativistic Heavy Ion Collider (RHIC) in a kinetic model that starts from the final stage of the quark-gluon plasma, goes through a mixed phase of quark-gluon and hadronic matters, and finally undergoes the hadronic expansion.

2. The model

In the coalescence model, the number of D_{sJ} (2317) mesons that are produced from the quark-gluon plasma is given by

$$N_{D_sJ}^{coal} = g_{D_sJ} \int_{\sigma_C} \prod_{i=1}^{n} \frac{p_i \cdot d\sigma_i d^3 p_i}{(2\pi)^3 E_i} f_q\left(x_i, p_i\right) f_{D_sJ}^{W}\left(x_1..x_n; p_1..p_n\right)$$

where g_{D_sJ} is the probability of combining $c\overline{s}$ or $c\overline{s}q\overline{q}$ quarks to form the D_{sJ} (2317) meson, $f_q(x_i, p_i)$ is the overlap of the quark phase-space distribution function in the fire-cylinder with the Wigner distribution function $f_{D_sJ}^{W}$, with n = 2 or 4 for a two-quark or four-quark D_{sJ} (2317). Using a Monte Carlo method to evaluate the integral we get : $N_{D_sJ}^{(2)}$ = 9.8 × 10^{-3} and $N_{D_sJ}^{(4)}$ = 4.2 × 10^{-4} per unit rapidity.

The abundance of D_{sJ} (2317) mesons can change during the expansion of the hadronic matter as a result of absorption by π, ρ, kaons and K^* mesons, according to the reactions

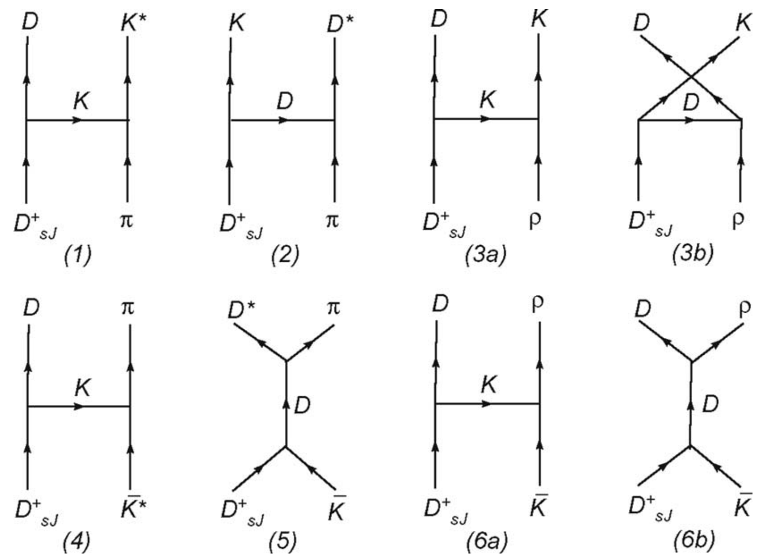

Figure 1. Diagrams for D_{sJ} (2317) absorption by mesons.

in Fig. 1. The cross sections for these reactions can be evaluated using interaction effective Lagrangians [7]. The coupling constant g_{DsJDk} has been studied in the QCD sum rules, and its value depends strongly on the quark structure of D_{sJ} (2317) meson. The predicted values are $g^{(2)}_{D_sJDK}$ = 9.2 GeV and $g^{(4)}_{D_sJDK}$ = 3.15 GeV for a two-quark [5] or four-quark state [6]. The thermally averaged absorption cross sections of the D_{sJ} (2317), considered as a four-quark meson, are shown in Fig. 2. The thermally averaged cross section of the dominant reaction $\pi D_{sJ} \to K^* D$ has values less than 0.6 mb. This value is about ten times larger if the D_{sJ} (2317) is a two-quark meson, due to the differences in the coupling constant.

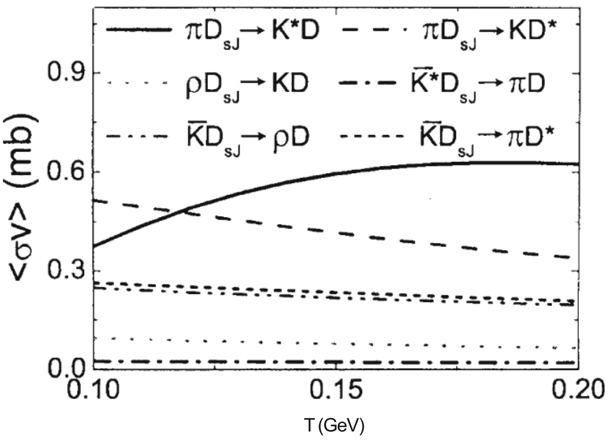

Figure 2. Thermally averaged cross sections for the absorption of a four-quark D_{sJ} (2317) meson by π, ρ, $\bar{K}$, and $\bar{K}^*$ mesons.

3. Time evolution of the D_{sJ} (2317) abundance

In terms of thermally averaged cross sections and the densities of π, ρ, K, and K^* mesons, the time evolution of the D_{sJ} (2317) meson abundance in the hadronic matter is determined by the kinetic equation

$$\frac{dN_{D_{sJ}}(\tau)}{d\tau} = R_{QGP}(\tau) + \sum_{a,b,c} \left\langle \sigma_a D_{sJ\to bc} v_a D_{sJ} \right\rangle n_a^{(0)}(\tau) \left[N_{D_sJ}^{(0)}(\tau) \frac{n_c(\tau)}{n_c^{(0)}(\tau)} - N_{D_sJ}(\tau) \right],$$

where $n_a(\tau)$, $n_c^{(0)}(\tau)$, and $N_{D_sJ}^{(0)}(\tau)$ are the equilibrium densities of light meson type a, charmed meson type c, and D_{sJ} (2317) meson in the hadronic matter at proper time τ when its temperature is T . D_{sJ} (2317) mesons are also produced from the quark-gluon plasma in the mixed phase, with a rate proportional to the volume of the quark-gluon plasma. This is included in the above equation through the term R_{QGP} (τ).

In Fig. 3 we show the abundance of D_{sJ} (2317)mesons in central Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. The final number of D_{sJ} (2317) mesons is about 3.0 × 10^{-2} if the D_{sJ}

(2317) meson is a two-quark state and is about 6.0 × 10^{-3} if it is a four-quark meson. Although the ratio (~ 5) between the final numbers for the two and four-quark D_{sJ} (2317) mesons is smaller than that (~ 20) for initially produced D_{sJ} (2317) mesons, it is still appreciable. This result differs significantly from the predictions of the statistical model, as can also be seen in Fig. 3. In this case, the D_{sJ} (2317) meson number decreases slightly to 3.8 × 10^{-2} during the hadronic evolution if it is a two-quark meson as shown by the dash-dotted line, and it remains essentially unchanged during hadronic evolution if it is a four-quark meson as shown by the dotted line. Since the final yield of D_{sJ} (2317) mesons in the coalescence model is much smaller for a four-quark state than for a two-quark state, studying D_{sJ} (2317) meson production in relativistic heavy ion collisions thus provides the possibility of understanding not only its production mechanism but also its quark structure.

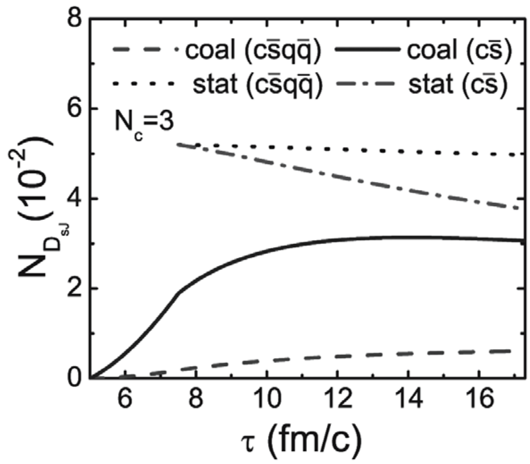

Figure 3. Time evolution of the D_{sJ} (2317) meson abundance in central Au+Au collisions.

4. Summary

Using the quark coalescence model, we have predicted the yield of D_{sJ} (2317) mesons in central Au+Au collisions at RHIC. Contrary to the prediction of the statistical model, the initial number of D_{sJ} (2317) meson produced at the end of the quark-gluon stage of heavy ion collisions depends sensitively on whether it is a two-quark or a four-quark meson, with the former giving an order of magnitude larger number than the latter. To take into account the effects of absorption and production during subsequent hadronic evolution, we have used a hadronic model to evaluate the cross sections for the absorption of the D_{sJ} (2317) meson by comovers. If the D_{sJ} (2317) is a conventional two-quark meson, these cross sections are about ten times larger than the cross sections obtained considering the D_{sJ} (2317) as a four-quark meson. Therefore, studying D_{sJ} (2317) production at RHIC and also at the forthcoming LHC thus offers the possibility to understand its quark structure and production mechanism.

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