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CHARMONIUM DISSOCIATION BY PION AND ρ MESON

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We analyze the open charm production in binary $\pi(\rho)\,J/\psi$ reactions within the Regge approach including the final state interactions. The calculations show that the total cross section of all these binary reactions is a few millibarns at an energy close to the threshold, then it is decreasing when the energy increases, according to the true Regge asymptotics.

Проводится анализ открытого рождения чарма в парных $\pi(\rho)\,J/\psi$-реакциях в рамках приближения Редже с учетом взаимодействия в конечном состоянии. Расчеты показывают, что полное сечение всех этих реакций составляет несколько миллибарн при энергии, близкой к порогу, а далее оно уменьшается с увеличением энергии в соответствии с истинной редже-асимптотикой.

In the last decade the problem of searching for a quark-gluon plasma (QGP) has been rising along with the development of new experimental facilities [1]. For instance, the J/ψ meson plays a key role in the context of a phase transition to the QGP [2], where charmonium ($c\bar{c}$) states should be no longer formed due to color screening [3,4]. However, the suppression of J/ψ and ψ' mesons in the high density phase of nucleus–nucleus collisions [5,6] might also be attributed to inelastic comover scattering (see, for example, [7–10] and references therein) provided that the corresponding J/ψ-hadron cross sections are of the order of a few mb [11–15]. Present theoretical estimates here differ by more than an order of magnitude [16] especially with respect to J/ψ-meson scattering, so that the question of charmonium suppression is not yet settled. More over, the calculation of these cross sections within the chiral Lagrangian approach results in either a constant or a slow increasing of their energy dependence [11–14,17] which contradicts the true Regge asymptotics predicting the decreasing one when the energy increases. The inclusion of the meson structure and the introduction of the meson form factors into this Lagrangian model leads to a big uncertainty for the shape and the magnitude of the J/ψ-dissociation cross sections by mesons.

The amplitude of the reaction considered has to be satisfied by the Regge asymptotics at large s. For the elastic and the total hadron–proton cross section the relation of their true Regge energy asymptotics to the hadron form factors has been analyzed in [19]. Here we will find such relation for the discussed $\bar{D}D^*$ production in $\pi(\rho)\,J/\psi$ collisions. In Refs. [20,21] the cross section of the reaction $\pi N \to \bar{D}(\bar{D}^*)\Lambda_c$ was estimated in the framework of the Quark-Gluon String Model (QGSM) developed in Ref. [22]. The QGSM is a nonperturbative approach based on the ideas of a topological $1/N$ expansion in QCD and on the Regge theory.

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This approach can be considered as a microscopic model describing Regge phenomenology in terms of quark degrees of freedom. It provides the possibility of establishing relations between many soft hadronic reactions as well as masses and partial widths of resonances with different quark content (see, e.g., review [23]).

We apply such an approach to the analysis of the processes of type $\pi(\rho)J/\psi \to \to \bar{D}D^*(\bar{D}D, \bar{D}^*D^*)$ because they are due to the same D^* exchange Regge trajectory as in the reaction $\pi N \to \bar{D}\Lambda_c$. The amplitude for such reactions corresponding to the planar graph with u- and $\bar{c}$-quark exchange in the t channel can be written as (see Refs. [20,21])

$$\mathcal{M}_{\pi(\rho)J/\psi}(s,t) \;=\; C_I\, g_0^2\, F(t)\,(s/s_0)^{\alpha_{u\bar{c}}(t)-1}\,(s/\bar{s})\,, \tag{1}$$

where the isotopic factor $C_I = \sqrt{2}$ for $\pi^{\pm}(\rho)^{\pm}J/\psi$ and $C_I = 1$ for $\pi^0(\rho^0)J/\psi$ reactions, respectively; $g_0^2/4\pi = 2.7$ is determined from the width of the ρ meson [20]; $\alpha_{u\bar{c}}(t) = \alpha_{\mathcal{D}^*}(t)$ is the $\mathcal{D}^*$-Regge trajectory; $\bar{s} = 1$ GeV^2 is a universal dimensional factor; $s_0 = 4.0$ GeV^2 is the flavor-dependent scale factor which is determined by the mean transverse mass and the average momentum fraction of quarks in colliding hadrons [20]; and $F(t)$ is the form factor describing the t dependence of the residue. We assume as in Refs. [20,21] that the $\mathcal{D}^*$-Regge trajectory is linear and therefore can be expanded over the transfer t:

$$\alpha_{\mathcal{D}^*}(t) \;=\; \alpha_{\mathcal{D}^*}(0) \;+\; \alpha'_{\mathcal{D}^*}(0)\,t, \tag{2}$$

where the intercept $\alpha_{\mathcal{D}^*}(0) = -0.86$ and its derivative $\alpha'_{\mathcal{D}^*}(0) = 0.5$ GeV^{-2} are found from their relations to the same quantities for the J/ψ and ρ trajectories which are known [20]:

$$\alpha_{u\bar{c}}(0) \;=\; \frac{1}{2}\left(\alpha_{c\bar{c}}(0) \;+\; \alpha_{u\bar{u}}(0)\right), \tag{3}$$

$$(\alpha'_{u\bar{c}})^{-1} \;=\; \frac{1}{2}\left((\alpha'_{c\bar{c}})^{-1} \;+\; (\alpha'_{u\bar{u}})^{-1}\right), \tag{4}$$

where the intercept $\alpha_{u\bar{u}}(0) = 0.5$ and the derivative $\alpha'_{u\bar{u}}(0) = 0.9$ GeV^{-2} of the ρ-Regge trajectory are known very well; $\alpha_{c\bar{c}}(0) = -2.18$ and $\alpha'_{c\bar{c}}(0) = 0.5$ GeV^{-2} are determined by drawing the trajectory through the ψ-meson mass $m_\psi = 3.097$ GeV and the χ mass $m_\chi = 3.554$ GeV. The form factor $F(t)$ determining the t dependence of the residue was presented in Ref. [20] as follows:

$$F(t) \;=\; \Gamma\left(1 - \alpha_{\mathcal{D}^*}(t)\right), \tag{5}$$

where $\Gamma(x)$ is the gamma function.

As has been shown in Ref. [24], at intermediate energies the absorption corrections due to the elastic and inelastic rescattering of final hadrons produced in binary reactions can be very sizable. They can reduce the magnitude of the cross section at energies especially close to the threshold so much. This is the reason why we have to include these effects. We estimate these absorption corrections using the standard method of Reggeon calculus [25] and the quasi-eikonal approximation [26]. The amplitude of the binary reaction in the impact parameter space is presented in the following form [24]:

$$\mathcal{M}(s,b) \;=\; \mathcal{M}_R(s,b)\exp\left(-\chi(s,b)\right), \tag{6}$$

where $\mathcal{M}_R(s,b)$ is the b-space representation of the simple Regge-pole exchange amplitude

$$\mathcal{M}_R(s,b) \;=\; \int \frac{d^2\mathbf{q}_\perp}{2\pi} \mathcal{M}_R(s,\mathbf{q}_\perp^2)\exp\left(i\mathbf{b}\mathbf{q}_\perp\right), \tag{7}$$

and the amplitude $\mathcal{M}_R(s,\mathbf{q}_\perp^2)$ in our case is given by Eq. (1). The function $\chi(s,b)$ in Eq. (6) includes the possible elastic and inelastic rescattering of the final charmed mesons. The elastic $\bar{D}D$ scattering is determined mainly by the one-Pomeron exchange graph at $s > s_{\text{thr}}$, therefore [24]

$$\chi(s,b) \;=\; -2i\,\delta(s,b), \tag{8}$$

where

$$\delta(s,b) \;=\; C\int \frac{d^2\mathbf{q}}{2\pi} \mathcal{T}_P(s,\mathbf{q}^2)\exp\left(i\mathbf{b}\mathbf{q}\right). \tag{9}$$

$\mathcal{T}_P(s,\mathbf{q}^2)$ is the one-Pomeron exchange elastic $\bar{D}D$ amplitude having the following normalization:

$$8\pi\,\Im\left[\mathcal{T}_P(s,\mathbf{q}^2=0)\right] = \sigma^{\text{tot}}_{D\bar{D}}, \tag{10}$$

and C is the so-called «enhancement factor» including a possible inelastic diffractive rescattering [24]. Eq. (8) can be represented also in the following form:

$$\chi(s,b) \;=\; \frac{C\,\sigma^{\text{tot}}_{\bar{D}D}}{4\pi\Lambda(s)}\,\exp\left(-\frac{b^2}{2\Lambda(s)}\right), \tag{11}$$

where $\Lambda(s)$ is the slope of the differential cross section of $\bar{D}D^*(\bar{D}D, \bar{D}^*D^*)$ elastic scattering. For the one-Pomeron exchange graph

$$\Lambda_{\mathcal{P}}(s) = 2\alpha'_{\mathcal{P}}(0)\,\ln\left(s/s_0\right), \tag{12}$$

where $\alpha'_{\mathcal{P}}(0) \simeq 0.2\ (\text{GeV}/c)^{-2}$ is the slope of the Pomeron trajectory. Returning from the b representation of the scattering amplitude, given by Eq. (6), to the momentum space we can calculate the $\mathcal{M}_{\pi(\rho)J/\psi}(s,t)$ including the absorption corrections. The «enhancement factor» $C \simeq 1.5$ has been found (Refs. [24, 27, 28]) to be in good agreement with the experiment for elastic $\pi p, Kp, \bar{p}p$ scatterings. So, in our calculations we have taken the same value for C entering Eq. (11). The total $\bar{D}D$ cross sections at $s > s_{\text{thr}}$ can be calculated within the one-Pomeron exchange graph. According to [19], it is proportional to the average radius square of D meson. Taking $\langle r_\pi^2\rangle = 0.64\ \text{fm}^2$ at $\sqrt{s} = 16$ GeV [19] and $\langle r_D^2\rangle = 0.36\ \text{fm}^2$ at $\sqrt{s} = 20$ GeV [29] one can estimate $\sigma^{\text{tot}}_{\bar{D}D}$ assuming that $\sigma^{\text{tot}}_{\bar{D}D}/\sigma^{\text{tot}}_{\pi p} = \langle r_D^2\rangle/\sqrt{\langle r_\pi^2\rangle\langle r_p^2\rangle}$. Including the energy dependence of these values, according to [19] we can finally find $\sigma^{\text{tot}}_{\bar{D}D} \simeq 10 \div 12$ mb at $4.0 < \sqrt{s} < 5.5$ GeV.

Referring to the procedure of inclusion of the absorption correction mentioned above we have the following form for the scattering amplitude:

$$\begin{aligned}\mathcal{M}_{\pi(\rho)J/\psi}(s,t) \;=\; C_I\,g_0^2\,F(0)\,&\frac{(s/s_0)^{\alpha_{\mathcal{D}^*}(0)-1}\,(s/\bar{s})}{\Lambda_{\mathcal{D}^*}(s)}\left(\frac{s}{s_0}\right)^{\alpha'_{\mathcal{D}^*}(0)(q_0^2-q_z^2)}\times\\ &\times\int_0^\infty f_{\mathcal{D}^*}(s,b)\,C_A(s)^{f_{\mathcal{P}}(s,b)}\,j_0(bq_\perp)\,bdb,\end{aligned} \tag{13}$$

where $t = q^2 = q_0^2 - q_z^2 - q_\perp^2$; $j_0(x)$ is the Bessel function of the zero order; $C_A(s) = \exp\left(-\chi(s,0)\right)$ and $f_R(b) = \exp\left(-b^2/(2\Lambda_R(s))\right)$. Simplifying the calculation we moved out of the integral the form factor $F(t)$ at $t = 0$ as it has been done in Refs. [20,21]. The integral above can be re-expressed as a power series:

$$\begin{aligned}\mathcal{M}_{\pi(\rho)J/\psi}(s,t) \;=\; & C_I\, g_0^2\, F(0) \left(\frac{s}{s_0}\right)^{\alpha_{\mathcal{D}^*}(0)-1} \left(\frac{s}{\bar{s}}\right) \left(\frac{s}{s_0}\right)^{\alpha'_{\mathcal{D}^*}(0)(q_0^2-q_z^2)} \times \\ & \times \sum_{k=0}^{\infty} \frac{(-\chi_{\mathcal{P}}(s,0))^k}{k!\,(1+k/a)} \left(\frac{s}{s_0}\right)^{-\frac{\alpha'_{\mathcal{D}^*}(0) q_\perp^2}{1+k/a}}, \qquad (14)\end{aligned}$$

where $a = \alpha'_{\mathcal{P}}(0)/\alpha'_{\mathcal{D}^*}(0) \sim 0.4$.

The differential cross section for the reactions $\pi(\rho)\, J/\psi \to \bar{D}D^*\ (\bar{D}D, \bar{D}^*D^*)$ then is

$$\frac{d\sigma_{\pi(\rho)J/\psi}}{dt} \;=\; \frac{1}{64\pi s\, p^2_{\pi(\rho),\text{cm}}} \sum_{\text{isospin}} \frac{2J_{\text{tot}}+1}{(2J_{\pi(\rho)}+1)(2J_{J/\psi}+1)} \left|\mathcal{M}_{\pi(\rho)J/\psi}(s,t)\right|^2, \qquad (15)$$

where p_{cm} is the initial momentum in the c.m.s.; $J_{\pi(\rho)}$ and $J_{J/\psi}$ are the spins of $\pi(\rho)$ and J/ψ, respectively. The total cross section of the discussed process is the integral from Eq. (15).

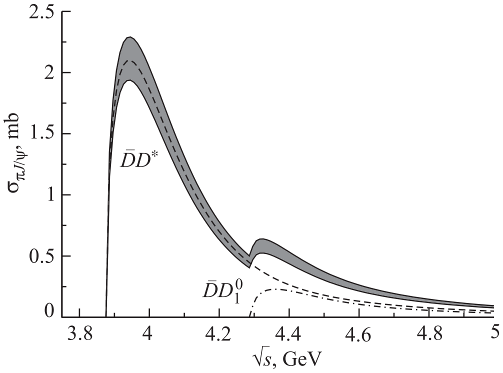

Fig. 1. The energy dependence of the total $\pi J/\psi$ cross sections in the Regge model including the absorption corrections. The figure shows also all significant partial cross sections open to $\sqrt{s} = 5$ GeV. The total cross section includes charge conjugation final states where appropriate. The estimated range of uncertainty, due to parameter variation, is shown as a shaded band

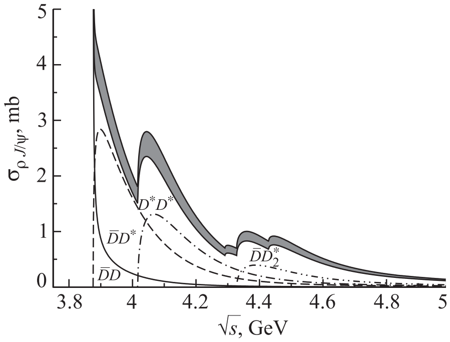

Fig. 2. The same as in Fig. 1, but for $\rho J/\psi$ cross sections

The results on the D-meson production cross sections in the binary $\pi\, J/\psi$ and $\rho\, J/\psi$ reactions obtained within the Regge theory including the absorption corrections are presented in Figs. 1 and 2. One can see that the energy dependence of the cross section is decreasing. At energies close to the threshold, the simple Regge-pole approximation results in the cross sections, which are few times larger than the ones presented in these figures. The inclusion of the absorption corrections related to the final state interaction of the produced charmed mesons modifies the form of the cross section so much at energies close to the threshold and decreases the slope of its energy dependence. One can see from Fig. 1 that the total yield of the charmed mesons produced from the dissociation of J/ψ by all the π mesons has the maximum value about $1.9 \div 2.3$ mb at the energy close to the threshold. The dashed line in Fig. 1 corresponds to the calculations using $\sigma_{\bar{D}D}^{\rm tot} = 11$ mb. Note, that these results are close to the ones obtained in Ref. [37] within the relativistic quark model. Figure 2 shows that the maximum value of the J/ψ-dissociation cross section from all the ρ mesons is about $4 \div 5$ mb.

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