D, D∗(2010) and D∗(2460) charmed meson production in hadron–hadron collisions

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Abstract. A recently developed generalization of the Quark Gluon String Model to the case of bosonic resonance production in hadron–hadron collisions is used for the calculation of inclusive production of charmed mesons D, D∗(2010) and D∗(2460). A simple relation which determines the dependence of the charmed meson production cross sections on their spin J is obtained. It is shown that the theoretical predictions for the inclusive spectra and production cross sections of these charmed mesons are confirmed experimentally with a reasonable accuracy.

1 Introduction

Hadroproduction of charmed particles is now being investigated in many experiments at different energies of colliding hadrons. Usually the heavy flavour production processes in hadron–hadron interactions at high energies are considered in the framework of perturbative QCD [1, 2]. However these processes can also be considered in the framework of the phenomenological Quark Gluon String Model (QGSM) [3–7], which is one of the nonperturbative approaches to the description of hadron production processes.

The QGSM considers the inelastic hadron–hadron collision as a two step process: an interaction which breaks the hadron into coloured constituents followed by a fragmentation of these constituents via formation of strings or chains. The QGSM treatment of string formation is based on the 1/N expansion of QCD in the framework of the Dual Topological Unitarization (DTU) scheme [8]. In the leading order of 1/N expansion, the particles are produced in two chains or strings (one-pomeron exchange) which are linked between constituents of different hadrons. Each of these two chains has a planar topology. The contribution of several pomeron exchange is also significant.

In the QGSM the properties of the fragmentation functions of a quark $G_q(z)$ and a diquark $G_{qg}(z)$ are determined directly from an analysis of the planar diagrams on the basis of the reggeon diagram technique. This approach allows one to express the behavior of the fragmentation functions at $z \to 0$ and $z \to 1$ in terms of intercepts of the known Regge trajectories. The comparison of the QGSM predictions with the experimental data shows that the model describes quite reasonably the inclusive production of the pseudoscalar mesons [9–11].

Recently the QGSM was generalized [12] to the case of bosonic resonance production for which the resonances are lying on the leading trajectories of the vector-tensor (V–T) group ($\rho$, $a_2$, $K^*$, $\cdots$), and the functions of quark and diquark fragmentation $G'_{qg}(z)$ into bosonic resonances with arbitrary spin $J$ were considered. The functions $G'_{qg}(z)$ at $z \to 1$ can be expressed in terms of the residues of secondary Regge trajectories which correspond in the framework of the DTU approach to the contribution of planar diagrams. Using the predictions of the model for the spin structure of planar diagrams ([13]), the relations between the residues of leading trajectories of the (V–T) group were obtained. According to these predictions, the interaction of a V–T group reggeon with hadrons has an universal form similar to the case of electromagnetic interaction. The hypothesis of the dominance of electromagnetic type interaction in the planar part of hadronic amplitudes (reggeon-photon analogy) [12, 13] together with the predictions of the dual Veneziano model [14] for the reggeon-particle couplings allows one to fix the quantities $G'_{qg}(z)$ at $z \to 1$. As a result, the simple relation which determines the dependence of the production cross sections on the spin $J$ of resonances can be obtained. The analysis given in [12] shows that the model reproduces correctly the available data on the high energy Feynman–x spectra of bosonic resonances with arbitrary spins lying on $\rho$- and $K^*$-trajectories.

In the present paper we apply this approach to the cross sections of high spin charmed meson $D^*(2010)$ and $D^*_2(2460)$ production using the QGSM description of
$D$ meson production cross section in $pp$ and $\pi p$ collisions [4, 6]. We describe the data on inclusive spectra and production cross sections for the $D^*(2010) (\frac{1}{2}^+ 1^-)$-meson in $\pi p$ [15, 16] and $pp$ [17] collision. The predictions for the $D^*_s (2460)$-meson production cross section and inclusive spectra are presented.

2 Model description

The inclusive spectrum of a secondary hadron $h$ in the framework of the QGSM has the form [6, 9]:

$$\frac{x_E \, d\sigma^h}{\sigma_{\text{in}}} = \sum_{n=1}^{\infty} w_n(s) \phi_n^h(x) + V^D_D \phi^D_D(x) + V^D_P \phi^D_P(x). \quad (1)$$

Here $x_E = E/F_{\text{max}}$, $w_n(s) = \sigma_n(s)/\sum_{n=1}^{\infty} \sigma_n(s)$ is the probability of cutting precisely $n$ pomerons, $\sigma_n(x)$ is the cross section of $n$-pomeron shower production and $\phi_n^h(x)$ determines the contribution of a diagram with $n$ cut pomerons. The two last terms in (1) correspond to the diffraction dissociation contribution which is negligibly small in the case of charmed meson production.

The expressions for $w_n(s)$ and the corresponding parameter values for $pp$ and $\pi p$ collisions are given in [9–11]. The function $\phi_n^h(x)$ determines the diffraction dissociation contribution which is negligibly small in the case of charmed meson production.

The function $\phi_n^h(x)$ for $\pi p$ interaction can be written in the form $[9–11]$: $\phi_n^h(x) = f_n^h(x, +, n)f_n^h(x, -, n) + f_n^h(x, +, n)f_n^h(x, -, n) + 2(n - 1)f_n^h(x, +, n)f_n^h(x, -, n)$ (3)

and for baryon-proton interaction $\phi_n^h(x) = f_n^h(x, +, n)f_n^h(x, -, n) + f_n^h(x, +, n)f_n^h(x, -, n) + 2(n - 1)f_n^h(x, +, n)f_n^h(x, -, n)$ (4)

where $x = \frac{1}{2}(\sqrt{x^2 + x_1^2} \pm \chi)$. The functions $f_n^h(x, n)$ in (3) and (4) describe the contributions of the valence/sea quarks, antiquarks and diquarks, respectively. They represent a convolution of quark/diquark momentum distribution functions $u_i(x, n)$ in the colliding hadrons with the fragmentation functions of quark/diquark into a secondary hadron $h$, $G_i^h(x, n)$:

$$f_i(x, n) = \int x u_i(x_1, n)G_i(x/x_1)dx_1.$$

The projectile (target) contribution depends only on the variable $x$. The functions $f_i^h(x, n)(i = q, \bar{q}, qg, q_{\text{sea}})$ for $D$-mesons production in $\pi p$ and $pp$ collision together with the full list of the distributions $u_i(x, n)$ and the fragmentation $G_i(x, n)$ functions are presented in [6].

Some general properties of fragmentation functions were discussed in [12]. In the two limits, $z \to 0$ and $z \to 1$, the behaviour of the fragmentation functions $G_{q(\bar{q})}^h(z)$ can be found from their Regge asymptotics:

$$G_{q(\bar{q})}^h(z) = a^h(1 - z)^{\gamma}.$$ (6)

Here $\gamma$ is determined by the intercepts of corresponding Regge trajectories. For our purpose it is most important to consider the constant $a^h$, which is the value of the function $G_{q(\bar{q})}^h(z)$ at $z \to 0$ and does not depend on the type of initial quark $q$ (diquark $qq$). The constants $a^h$ are determined by the dynamics of the fragmentation of the string when a $q\bar{q}$ pair is produced from the vacuum. For instance, the SU(3)-flavour symmetry requires that $a^h = a^h = a^h = a^h$, and $a^h = a^h = a^h = a^h$. A direct calculation of these constants cannot be done in the framework of QGSM. In [12] the ratios of the constants concerning light and strange mesons were estimated. As an approximation it was assumed that the shapes of the $x_T$-spectra of resonances produced in the quark-gluon string do not depend on their spins $J$. In the considered approximation, the functions of quark fragmentation into different resonances of the $\rho$ and $K^*$ families can be expressed via functions of quark fragmentation into $\rho^-$ or $K^*$-mesons [12]:

$$G_{q(\bar{q})}^h(z) = R_J G_{q(\bar{q})}^{\rho,K^*}(z),$$ (7)

where the quantity $R_J$ does not depend on he variable $z$. Analogously the relation for the resonances of the $D^*$ family with spin $J$, can be written in a similar form:

$$G_{q(\bar{q})}^h(z) = R_J G_{q(\bar{q})}^{\rho,K^*}(z).$$ (8)

The quantities $R_J$ can be expressed in terms of constants $a^J, R_J = (a^J/a^\rho)^2$. Following [12] it is possible to express the quantities $a^J$ in terms of $z_T(0)$ of the trajectory to which a resonance $J$ belongs:

$$R_J = (a^J/a^\rho)^2 = a^J/a^\rho = \frac{(J + 1)!}{(J - z_T(0)^J + 1)^J}.$$ (9)

According to the results ([12]) for light and strange mesons we estimate the relation between the $D^*_s (2460) \equiv D^{**}$ and the $D^*(2010) \equiv D^*$ residues as follows:

$$(a^D)^2 \approx 0.84(a^\rho)^2.$$ (10)

Using the predictions of the resonance decay model ([18]), in [12] the relations were obtained for the probabilities of the production of the light and strange pseudoscalar and vector mesons. In the case of the charmed meson production the relation has the form

$$(a^D)^2 \approx \frac{<k^2>/n}{4m_q^2},$$ (11)

where $m_q$ is the transverse mass of the constituent quark. The value $m_q = 0.415 \pm 0.015$ GeV which was used in [18] for light and strange mesons leads for $D$-mesons to the wrong predictions, namely the multiplicity of produced $D$-mesons is predicted to be smaller than the multiplicity of $D^*(2010)$ that is impossible because all $D^*(2010)$ should decay into $D$. We found the value of the parameter $m_q$ from the comparison with the data on $D$ and $D^*(2010)$