Hadroproduction of particle with open charm

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Abstract

In the framework of Quark–Gluon–String Model (QGSM) we calculate the inclusive spectra of meson and baryons with open charm in hadron–hadron collisions, obtained by SELEX and BEATRICE collaborations, taking into account the decays of corresponding \( S \)–wave resonances.

In the papers \cite{1, 2, 3, 4} in the framework of the QGSM the inclusive spectra of stable charmed particles (\( \Lambda_c, \Xi_c, \Omega_c, D, D_s \)) were reanalyzed taking into account the contributions from decays of corresponding \( S \)–wave resonances, like \( 1^- \) mesons (\( D^* \) and \( D_s^* \)), \( 1/2^+ \) (\( \Sigma_c \) and \( \Xi_c' \)) and \( 3/2^+ \) (\( \Sigma_c^*, \Xi_c^* \) and \( \Omega_c^* \)) hyperons. \( S \)–wave charmed resonances decay into stable charmed particles with emission of \( \pi \)–meson or \( \gamma \)–quantum \cite{5}. The kinematics of this decays was used according to \cite{6}. In this report our predictions are compared with latest experimental data of WA89 collaboration \cite{7} on \( \Lambda_c \) charmed hyperon production asymmetry on \( \Sigma^- \) beam and preliminary measurements of \( \Lambda_c \) charmed hyperon cross section and production asymmetry in \( \pi^- p, pp \) and \( \Sigma^- p \) collisions of SELEX collaborations \cite{8, 9, 10, 11}. We also present the comparision of model calculation with the experimental data on vector \( D^{*+/-} \) meson production on \( \pi^- \)– beam measured by Beatrice (WA92) collaboration \cite{12}. All formulae for inclusive spectra of hadrons together with a full list of the quark/diquark distribution functions and corresponding fragmentation functions into charmed hadrons used in this work were given in \cite{1, 2, 3, 4}. We present here only the main features of our approach.

The invariant cross section of hadron \( h \) production has the form:

\footnote{Talk presented at XXXIV Recontres de Moriond "QCD and High Energy Hadronic Interactions", Les Arcs, France, March 20-27, 1999}
\[ x \frac{d\sigma^h}{dx} = x \frac{d\sigma^{h \text{dir}}}{dx} + \int_{x^-}^{x^+} x_R \frac{d\sigma^R}{dx_R} \Phi(x_R) dx_R. \quad (1) \]

Here, \( x \frac{d\sigma^{h \text{dir}}}{dx} \) is the direct production cross section of hadron \( h \), and \( x \frac{d\sigma^R}{dx_R} \) is the production cross section of \( R \)-resonance. Function \( \Phi(x_R) \) describes two–body decay of resonance \( R \) into hadron \( h \). After integration over transverse momenta of both hadron \( h \) and resonance \( R \), the function \( \Phi(x_R) \) has the form

\[ \Phi(x_R) = \frac{M_R}{2p^* x^2_R}. \quad (2) \]

In eqs. (1) and (2), \( x_R \) is the Feynman variable of resonance \( R \)

\[ x^*_+ = \frac{M_R \tilde{x}}{E^* - p^*}, \quad x^*_- = \frac{M_R \tilde{x}}{E^* + p^*}, \quad \tilde{x} = \sqrt{x^2 + x^2_{\perp}}, \quad x_{\perp} = \frac{2\sqrt{<p^2_{\perp}>} + m^2}{\sqrt{s}}, \]

\( m \) is the mass of produced hadron \( h \), \( M_R \) is the mass of resonance, \( E^* \) and \( p^* \) are energy and 3–momentum of hadron \( h \) in the resonance rest frame, \( <p^2_{\perp}> \) is the average transverse momentum squared of hadron \( h \).

The hadron \( h \) inclusive spectrum in the framework of the QGSM has the form

\[ x \frac{d\sigma^h}{dx} = \sum_{n=0}^{\infty} \sigma_n(s) \varphi_n^h(x), \quad (3) \]

where \( \sigma_n(x) \) is the cross section of \( n \)-pomeron shower production and function \( \varphi_n^h(x) \) determines the contribution of diagram with \( n \) cut pomerons.

The expressions for \( \sigma_n(s) \) and values of corresponding parameters for \( pp \) and \( \pi p \) collisions are given elsewhere (see [1] for citations). For \( \Sigma^-p \) interaction in the framework of additive quark model we calculate the relation between pomeron residues in \( \Sigma^-p \) and \( pp \) collisions \( \gamma_{\Sigma p} = 0.92 \gamma_{pp} \).

The functions \( \varphi_n^h(x) \) (\( n > 1 \)) for \( \pi p \) interaction can be written in the form

\[ \varphi_n^h(x) = f^h_q(x_+,n) f^h_q(x_-,n) + f^h_q(x_+,n) f^h_q(x_-,n) + 2(n-1) f^h_s(x_+,n) f^h_s(x_-,n), \quad (4) \]

and for baryon–proton interaction

\[ \varphi_n^h(x) = f^h_{qq}(x_+,n) f^h_{qq}(x_-,n) + f^h_q(x_+,n) f^h_{qq}(x_-,n) + 2(n-1) f^h_{\text{sea}}(x_+,n) f^h_{\text{sea}}(x_-,n), \quad (5) \]
where \( x_\pm = \frac{1}{2}[\sqrt{x^2 + x_\perp^2} \pm x] \).

The functions \( f^h_i(x,n)(i = q,q,q_{sea}) \) in (4) and (5) describe the contributions of the valence/sea quarks, antiquarks and diquarks, respectively. They can be expressed as a convolution of quark/diquark momentum distribution functions \( u_i(x,n) \) in the colliding hadrons with the function of quark/diquark fragmentation into hadron \( h \), \( G^h_i(x,n) \):

\[
f^h_i(x,n) = \int_x^1 u_i(x_1,n) G^h_i(x/x_1) dx_1 .
\]

The projectile (target) contribution depends on the variable \( x_+ (x_-) \).

For the \( \Sigma^- \) beam functions \( f^h_q(x,n) \) are expressed in terms of corresponding \( s^- (f^h_s(x,n)) \) and \( d^- \)quark \( (f^h_d(x,n)) \) functions in the following form

\[
f^h_q(\Sigma^-)(x,n) = \frac{1}{3} f^h_s(\Sigma^-)(x,n) + \frac{2}{3} f^h_d(\Sigma^-)(x,n)
\]

In the framework of the additive quark model diquarks in \( S^- \)wave baryons may have spin (isospin) 0 and 1. Thus the diquark functions \( f^h_{qq}(x) \) are expressed in terms of scalar (0) and vector (1) diquark functions with the weights determined by \( SU(6) \) symmetric functions

\[
f^h_{qq}(p) = \frac{1}{3} f^h_{uu}(p)(x,n) + \frac{1}{2} f^h_{(ud)_0}(x,n) + \frac{1}{6} f^h_{(ud)_1}(x,n)
\]

\[
f^h_{qq}(\Sigma^-) = \frac{1}{3} f^h_{dd}(\Sigma^-)(x,n) + \frac{1}{2} f^h_{(ds)_0}(\Sigma^-)(x,n) + \frac{1}{6} f^h_{(ds)_1}(\Sigma^-)(x,n).
\]

In what follows, we will assume that the distribution functions of scalar and vector diquarks \( u_{qq}(x,n) \) are the same. Certainly, different diquarks fragment into baryons in different ways: for instance, the direct production of \( \Lambda_c \) in \( pp \) collision is determined by scalar (and isoscalar) diquark function \( f_{(ud)_0} \) and direct production of \( \Sigma_c \) and \( \Sigma^*_c \) hyperons is determined by the vector diquark function \( f_{(ud)_1} \).

Further, we will assume that the fragmentation functions of quarks and diquarks do not depend on spin of the picked up quark (or diquark). In particular this means that functions for fragmentation into \( \Sigma_c \) and \( \Sigma^*_c \), \( D \) and \( D^* \) mesons are equal.

Let now turn to the consideration of the experimental data on \( L_c \) production measured by SELEX collaboration on different hadron beams.
The unnormalized inclusive spectra of $\Lambda_c$-baryon in $\pi^-p$, $pp$ and $\Sigma^-p$ collisions at $P_L = 600 GeV/c$ were compared with model calculations on Fig.1a-c respectively. We present here two set of the data: full circles – the first publication of SELEX data [8] and full squares – the new one, presented by K.Stenson on this conference [9] and also published in [10]. The theoretical curves are calculated taking into account both direct $\Lambda_c$ production and the one which is due to the contribution of $\Lambda_c$ produced in decays $\Sigma_c \rightarrow \Lambda_c\pi$ and $\Sigma^*_c \rightarrow \Lambda_c\pi$ with free parameters, given in [1] except the parameter, standing for $\bar{\Lambda}_c$ contribution. The value $a4 = 0.1$ was taken to have a satisfactory description of $A(L_C, \bar{L}_c)$ production asymmetry(see below). As one can see the model reproduce the shape of the inclusive spectra rather well. Concerning the data on $\Sigma^-p$ collisions (Fig.1c) the disagreement at small $x_F$ in the first set of the data [8] may be due to experimental uncertainty and as we can see from Fig.1c the new set of the data [9, 10] do not have such strong decrease at small $x_F$. Note, that as in [1] the theoretical curves were calculated without taking into account the charmed sea contribution.

In Fig.2 we plotted the experimental points of the $L_c$ and $\bar{L}_c$ production asymmetry measured by two collaborations WA89 at $P_L = 340 GeV/c$ [7](full circles) and SELEX [11] at $P_L = 600 GeV/c$ (stars) in $\Sigma^-p$ collisions together with QGSM prediction. Both experimental data of WA89 [7] and SELEX [11] shows rather large production asymmetry even at $x_F > 0.2$. Two curves were calculated for momenta $P_L = 340 GeV/c$ (full line) and $P_L = 600 GeV/c$ (dashed line). The difference at small $x_F$ has a kinematical reason. At large value of $x_F$ the theoretical curves are energy independent. As we can see the modified QGSM calculations reproduce the experimental behavior both inclusive cross sections and production asymmetry on different hadron beams.

Let now turn to the description of the charmed vector meson production.

It is important for the model under consideration to compare our predictions with spectra of resonances. The data on inclusive differential cross section $1/\sigma d\sigma/dx$ of the reactions $\pi^-p \rightarrow D^*/D^-X$ and production asymmetry $A(D^*/D^+)$ at 350 GeV/c [12] together with theoretical predictions are shown in Figs.3a,b and Fig.4 respectively.

The theoretical calculations were perform with taking into account the charmed sea contribution described in [3]. All formulae for the parametrisations of the $c$-sea in the initial pion and the $c$ quark fragmentation functions into $D^*$ mesons were given in [3].
The full line (1) corresponds to calculations without taking into account charmed sea contribution, dashed (2) and dashed-dotted (3) lines stands for different parametrisations of leading fragmentation functions into \( D^{*-} \) meson as described in [3] (formulae (14) and (15) correspondingly).

It seems that the agreement for the shape of the sum of spectra of \( D^{*+} \) and \( D^{*-} \) mesons is quite satisfactory.

The production asymmetry of the leading \((D^{*-}, \bar{D}^{*0})\) and nonleading \((D^{*+}, D^{*0})\) vector resonances with open charm in \(\pi^-p^-\) collisions, integrated over the \(x_F > 0\) region was measured in [13]. The experimental value of asymmetry was obtained equal \(A(L, NL) = 0.09 \pm 0.06\).

The calculations of the model give the following values for all parametrizations used in work [3]: Varients 1, 2 and 3 corresponds to the different parametrisation of the fragmentation functions as described above. The behaviour of production asymmetry for \(D^{*+/}\) vector mesons presented on Fig.4 look like that for the pseudoscalar \(D\) mesons. It is important to note that the measurements of the integrated cross section of \(D^{*+}\) and \(D^{*-}\) mesons are about twice lower than data [14] measured on hydrogen target at the same momenta.

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Figure captions

Fig.1 Comparison of QGSM calculations with preliminary experimental data on $\Lambda_c$ spectra measured by SELEX collaboration [8, 9, 10] for:
a) $\pi^- p$, b) $pp$ and c) $\Sigma^- p$ collision at $P_L = 600\text{GeV}/c$.

Fig.2 The $x_F$–dependence of $L_c, L_c$–production asymmetry in $\Sigma^- p$ collision. The experimental data from WA89 [7] (full circles) at $P_L = 340\text{GeV}/c$ and SELEX [11] (open circles) at $P_L = 600\text{GeV}/c$. The theoretical curves were calculated for $350\text{GeV}/c$ (full line) and $600\text{GeV}/c$ (dashed line).

Fig.3 The $x_F$–dependence of $D^*$–meson cross section $1/\sigma d\sigma/dx$ in $\pi^- p$ interaction at $350\text{GeV}/c$ [12].

Fig.4 Comparison of the model calculations with experimental data on leading ($D^{*-}$) and nonleading ($D^{*+}$) charmed vector mesons production asymmetry in $\pi^- p$ interaction at $P_L = 350\text{GeV}/c$ [12].
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\[ \Sigma^- p \rightarrow \Lambda_c X \]
WA92  $\pi^- p \rightarrow D^{+/0} X$, 350 GeV/c

Fig. 3

$\frac{1}{\sigma} \frac{d\sigma}{dx}$ vs $x_r$
$\pi^- p \rightarrow D' X, 350 \text{ GeV/c}$