On the Character of Leading Asymmetry in the Hadroproduction of Charmed Mesons and Baryons.

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The character of asymmetry between the spectra of Λ_c and ¯Λ_c, obtained recently in the E781 experiment (FNAL) is discussed on the basis of the Quark Gluon String Model (QGSM). As it was shown in the description of the asymmetry between the spectra of leading and nonleading charmed mesons measured in Σ−A interactions at p_L = 340 GeV/c in the WA89 experiment in previous studies, the asymmetries between D− and D+ meson spectra and between D_s− and D_s+ mesons are fitted by QGSM curves obtained with the same parameter of string fragmentation, a_1 = 10, as well as the asymmetry between the D-meson spectra in π−A collisions at the E791 experiment. The forms of Λ_c/ ¯Λ_c asymmetry dependences measured in Σ−A and p−A collisions at p_L = 600 GeV/c in the E781 experiment are different. It is shown in the framework of QGSM that they depend on whether the diquarks of beam and target particles took part in charmed baryon formation or not. The QGSM results are compared with the calculations carried out by the other authors.

1. INTRODUCTION

The difference in x spectra (x = x_F = 2pII/√s) of leading and nonleading particles has been discussed recently and several theoretical models explained successfully the asymmetry as an effect of an interplay between the quark contents of the projectile and of the produced hadron. The charmed particles of leading type (LP) containing at least one ordinary quark of the same type as the beam particle have higher average x value than the particles (NLP) of the same sort having no one quark in common with the projectile.

The asymmetry A(x) is usually defined as:

\[ A(x) = \frac{dN_{LP}}{dx} - \frac{dN_{NLP}}{dx} \]

Two experiments have measured recently the asymmetries between the spectra of D− and D+, D_s− and D_s+ mesons as well as between Λ_c and ¯Λ_c in Σ−A interactions: WA89 [1] (CERN) at p_L = 340 GeV/c and E781 [2] (FNAL) at p_L = 600 GeV/c. It seems to be interesting to consider these results from the point of view of Quark Gluon String Model (QGSM) and to compare with x_F asymmetry dependences obtained in the π−A experiments [3,4] in order to understand the influence of quark composition of beam particle on the features of heavy flavored particle production.

The nonperturbative approach accepted in our QGSM model [5] exploits the properties of fragmentation functions in order to insert the asymmetry.

2. QUARK-GLUON STRING MODEL

2.1. The Quark Distributions in QGSM

The process of multiparticle production can be illustrated in QGSM with the cut n-pomeron diagram. The inclusive production cross section of hadrons H is written as a sum over n-pomeron cylinder diagrams:

\[ f_1 = \int E d^3p \frac{d^2\sigma_H}{d^2p} = \sum_{n=0}^{\infty} \sigma_n(s) \varphi_n^H(s, x) \]

where function \( \varphi_n^H(s, x) \) is a particle distribution in the configuration of n cut cylinders and \( \sigma_n \) is the probability of this process. The parameter of the supercritical Pomeron used here is \( \Delta_P = \alpha_P(0) - 1 = 0.12 \).

The distribution functions are described in previous papers [3,4]. It should be mentioned here that a structure function of i-th quark which has a fraction of energy x_1 in the interacting hadron, f_i(x_1), and \( D_i^H(z) \), a fragmentation function of this quark into the considered type of produced hadrons H, are constructed according to
the Regge asymptotic rules proposed in [3]. In the case of the hyperon beam they depend on the parameter of the Regge trajectory of \(\varphi\)-mesons \((s\bar{s})\) because of s-quark contained in \(\Sigma^-\).

2.2. The Fragmentation Functions.

The following favored fragmentation function into \(D^-\) mesons was written, for instance, for the strange valence quark fragmentation:

\[
D_s^{D^-}(z) = \frac{1}{z}(1 - z)^{-\alpha_s(0) + \lambda + a_1^{D^-} z^2),
\]

where \(\lambda = 2 \alpha_f D_d(0) z^2\). An additional factor \((1 + a_1^{D^-} z^2)\) provides the parametrization of the probability of heavy quark production in the interval \(z = 0 \to z \to 1\). The function for the nonleading fragmentation of d-quark chain into \(D^+\) has an additional \((1 - z)^{2(1 - \alpha_R(0))}\) according to the same rules:

\[
D_d^{D^+}(z) = \frac{1}{z}(1 - z)^{-\alpha_R(0) + \lambda + 2(1 - \alpha_R(0)) + \Delta_\psi},
\]

where \(\Delta_\psi = \alpha_R(0) - \alpha_s(0)\).

The dd-diquark fragmentation includes the constant \(a_f\) which could be interpreted as "leading" parameter, but this value is fixed due to baryon number sum rule and should be approximately equal to \(a_f\) taken for \(\Lambda_c\) spectra in our previous calculations [11].

\[
D_{fdd}(z) = \frac{a_f}{a_0 z} z^{2 \alpha_R(0) - 2 \alpha_s(0)}
\]

\[
(1 - z)^{-\alpha_s(0) + \lambda + 2(1 - \alpha_R(0))},
\]

where the term \(z^{2 \alpha_R(0) - 2 \alpha_s(0)}\) means the probability for initial diquark to have \(z\) close to 0.

2.3. The Distributions and the Fragmentation Functions of Sea Quarks.

Some fractions of sea quark pairs in hyperon, \(d\bar{d}\) and \(s\bar{s}\), are to be taken into account as far as they suppress the leading/nonleading asymmetry. The structure functions of ordinary quark pairs in the quark sea of hyperon can be written by the same way as the valence quark distributions.

As soon as we accounted \(d\bar{d}\) and \(s\bar{s}\) fraction in the quark sea of hyperon some fraction of charmed sea quark are to be considered as well. This small heavy quark admixture plays an important role due to its strong impact on the difference between leading and nonleading charmed meson spectra.

The charmed sea quark structure function is similar to the distribution of strange sea quarks [12]:

\[
f_{\Sigma^{-}}^{c,\bar{c}}(x_1) = C_c^{(n)} \delta_{c,\bar{c}} x_1^{-\alpha_c(0)} (1 - x_1)^{\alpha_c(0) - 2 \alpha_N(0) + \Delta_c + \Delta_\psi + n - 1 + 2(1 - \alpha_R(0))}
\]

where \(\delta_{c,\bar{c}}\) is the weight of charm admixture in the quark sea of hyperon. In fact it is not necessarily to be equal to the charmed quark fraction in quark sea of pion. This is only one parameter we can vary for \(\Sigma^-\) interaction after the best fit of pion experimental data which had been done before. The value of \(\delta_{c,\bar{c}}\) can be estimated in the description of the WA89 data on \(D_s^-\) and \(D^-\) meson asymmetries.

Fragmentation functions into \(D\) mesons are the following:

\[
D_{c,\bar{c}}^{D^-}(z) = \frac{1}{z} z^{1 - \alpha_s(0)} (1 - z)^{-\alpha_R(0) + \lambda}.
\]

3. EXPERIMENTAL DATA ON ASYMMETRY

3.1. \(D^-/D^+\) and \(D_s^-/D_s^+\) asymmetries.

The main parameter of QGSM scheme which is responsible for leading/nonleading charm asymmetry is \(a_1\), defined above. The fraction of charmed sea quarks, \(\delta_{(c,\bar{c})}\), is the second parameter in this calculations which makes the asymmetry lower because of the equal amounts of \(D^+\) and \(D^-\) mesons produced by each sea charmed quark pair. Two sets of this couple of parameters were chosen in the description of \(\pi^-A\) reaction data: \(a_1 = 4\), \(\delta_{(c,\bar{c})} = 0\) and \(a_1 = 10\), \(\delta_{(c,\bar{c})} = 0.05\sqrt{a_0}\).

We consider here these two values of \(a_1\) taking the \(\delta_{(c,\bar{c})}\) as more or less free parameter.

The two curves provided the fits of E791 and WA92 pion beam experiment data [12] are presented in Fig.1 with two sets of parameters discussed above as well as the results of two other approaches [11,12].

It should be mentioned that the smaller fraction of charmed sea quarks was taken into account \((\delta_{(c,\bar{c})} = 0.01\sqrt{a_0})\) for to describe both \(D^-/D^+\) and \(D_s^-/D_s^+\) asymmetries in \(\Sigma^-A\) reac-
Figure 1. $D^-/D^+$ asymmetry measured in WA89 and theoretical calculations: solid line corresponds to the following set of QGSM parameters $a_1 = 10, \delta(c, \bar{c}) = 0.01$; dashed line is a result of QGSM fit with $a_1 = 4, \delta(c, \bar{c}) = 0$; dashed-dotted line is the result of [11] and dotted line corresponds to $A(x)$ predicted in [12].

3.2. The $\Lambda_c/\bar{\Lambda}_c$ Asymmetry.

The asymmetry between the spectra of $\Lambda_c$ and $\bar{\Lambda}_c$ measured in $\Sigma^-A$ collisions can be easily obtained practically in the same calculations described here. What is important, the leading $\Lambda_c$ baryon is formed from single d-quark of projectile particle. No diquark from $\Sigma^-$ hyperon takes part in leading charm baryon production. It allows us to take the results of our calculation for D-meson production at $p_L = 600$ GeV/c and to compare with the $\Lambda_c/\bar{\Lambda}_c$ asymmetry measured in $\Sigma^-A$ collisions in the E781 experiment [2]. The parameter $a_1$ means in this case a parameterization parameter for the density of uc-diquark in the string fragmentation, it can be different than $a_1$ taken for D-meson production. The energy of interaction has to be also changed. The parameter of the fraction of sea charm quarks, $\delta(c, \bar{c})$, must be of the same value as for D-meson calculations because it doesn’t know what leading particle is produced.

The asymmetry between the spectra of $\Lambda_c$ and $\bar{\Lambda}_c$ measured in $\Sigma^-A$ collisions at $p_L = 600$ GeV/c is shown in Fig.2.

Figure 2. Asymmetry between $\Lambda_c$ and $\bar{\Lambda}_c$ spectra obtained in the E781 experiment (empty circles) [2] and in the WA89 experiment (black stars) [1]; the preliminary QGSM curve (solid line) corresponds to the following set of parameters $a_1 = 25, \delta(c, \bar{c}) = 0.01$; dashed-dotted line is the result of [11] and dotted line corresponds to $A(x)$ predicted in [13].

The complete calculations carried out with the fragmentation function written for $\Lambda_c$ and $\bar{\Lambda}_c$ production with proton beam give the good description of data with the value of diquark fragmentation parameter $a_1^{f_{\Lambda_c}} = 0.008$ (see Fig.3).

4. CONCLUSIONS

We can conclude here only that the data of the WA89 experiment on leading asymmetry in
Figure 3. Asymmetry between $\Lambda_c$ and $\bar{\Lambda}_c$ spectra obtained in the E781 experiment with the proton beam (black circles); the complete QGSM calculation (solid line).

Charmed meson production at $\Sigma^- A$ interactions can be described within the framework of Quark-Gluon String Model with the same asymmetry parameter $a_1 = 10$ as E791 data for $\pi^- A$ reaction. Good statistics on $D^-/D^+$ and $D_s^-/D_s^+$ production is needed to estimate the comparable influence of light, strange and charmed sea quark fractions for different beams. $D^-/D^+$ and $D_s^-/D_s^+$ asymmetries measured with $\Sigma^-$ beam are discribed with the different weight of charmed quark sea of interacting hyperon ($\delta(c,\bar{c})=0.01$) than it was done for $\pi^- A$ beam interaction ($\delta(c,\bar{c})=0.05$). $D_s^-/D_s^+$ asymmetry is higher than $D^-/D^+$ asymmetry because strange quark pairs suppressing the asymmetry at $D_s$ production have lower weight in quark sea of hyperon than ordinary $d\bar{d}$ pairs which cause the suppression of $D^-/D^+$ meson asymmetry. Data of the E781 experiment on charmed baryon production asymmetry measured in $\Sigma^- A$ collisions can be also described within the framework of Quark-Gluon String Model with the asymmetry parameter $a_1 = 25$ for uc-diquark density in d-quark string fragmentation. The asymmetry between the spectra of $\Lambda_c$ and $\bar{\Lambda}_c$ doesn’t grow so rapidly with $x_F$ as it was predicted in other approaches. The rapid growing of asymmetry in the case of proton beam can be explained by the important role of ud-diquark fragmentation into $\Lambda_c$.

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