CHARM CONTENT OF A PROTON IN COLLINEAR PARTON MODEL AND IN $K_T$–FACTORIZATION APPROACH *

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March 25, 2022

Abstract

It is shown that the difference between the c-quark proton SF’s calculated in the $k_T$-factorization approach using different unintegrated gluon distribution functions is the same order as the difference between results obtained in the parton model and in the $k_T$-factorization approach.

1 Introduction

The result of a study for the internal structure of a proton in the process of the lepton deep inelastic scattering (DIS) can be presented in terms of a

*This work is supported by the RFBR under Grant 02-02-16253
proton structure function (SF) $F_2^p(x_B,Q^2)$ as a function of $Q^2 = -q^2$ and $x_B = Q^2/(pq)$, where $q$ is the exchange photon 4-momentum and $p$ is the proton 4-momentum. In a process of the charmed quark lepton production the charmed content of the proton structure function $F_2^p(x_B,Q^2)$ is probed. The recent relevant measurements by the H1 [1] and the ZEUS [2] Collaborations at the HERA ep-collider include the following kinematic region: $1.8 < Q^2 < 130$ GeV$^2$ and $5 \cdot 10^{-5} < x_B < 2 \cdot 10^{-2}$.

The charmed quark SF has been studied in the framework of DGLAP [3] and BFKL [4] dynamics. Usually, the c-quark SF $F_2^p(x_B,Q^2)$ is calculated via the amplitude which described by the quark box diagrams. This type of a calculation for the $F_2^p(x_B,Q^2)$ is presented in the talk by A.Kotikov [5].

Here we use another method which is based on a direct calculation of the total $c\bar{c}$–production cross section in the electron DIS. In a such way, we have obtained the c-quark distribution function $C_p(x_B,Q^2)$ which is connected with the c-quark SF as follows:

$$F_2^p(x_B,Q^2) = 2e_c^2 x_B C_p(x_B,Q^2).$$

(1)

## 2 Electroproduction cross section

In the framework of the parton model and the one photon exchange approximation the charmed quark production cross section in the electron DIS can be presented as a convolution of the c-quark proton distribution function and the electron – c-quark partonic cross section:

$$d\sigma(ep \to ecX) = \int d\sigma(ec \to ec) C_p(x_B,Q^2).$$

(2)

The doubly differential cross section can be presented as follows:

$$\frac{d\sigma}{d\sigma(dp)dp} = \frac{M(ec \to ec)}{16\pi(x_Bs)^2}.$$

(3)
where \( s = (p_e + p)^2 \), \( p \) is the proton 4-momentum, \( p_e \) is the electron 4-momentum. The squared amplitude of an elastic \( ec \)-scattering has the following form:

\[
|M(ec \rightarrow ec)|^2 = 2 e^4 e_c^2 (x_B s)^2 \left( y^2 - 2y + 2 - \frac{2m_e y^2}{Q^2} \right),
\]

where \( y = Q^2/(x_B s) \). From (1), (3) and (4) we can obtain the master formula

\[
F_{2e}(x_B, Q^2) = x_B Q^4 \frac{d\sigma}{dx_B dQ^2}(ep \rightarrow ecX)/\left( \pi \alpha^2 y^2 - 2y + 2 - \frac{2m_e y^2}{Q^2} \right).
\]

At the high energy the dominant mechanism of the c-quark electroproduction on a proton is the photon-gluon fusion. In the leading order approximation for the QCD running constant \( \alpha_s \) the relevant subprocess is \( e + g \rightarrow e + c + \bar{c} \).

In the conventional collinear parton model it is suggested that hadronic cross section, in our case \( \sigma(ep \rightarrow ecX, s) \), and the relevant partonic cross section \( \hat{\sigma}(eg \rightarrow ec\bar{c}, \hat{s}) \) are connected as follows:

\[
\sigma^{PM}(ep \rightarrow ecX, s) = \int dx G(x, \mu^2) \hat{\sigma}(eg \rightarrow ec\bar{c}, \hat{s}),
\]

where \( \hat{s} = xs \), \( G(x, \mu^2) \) is the collinear gluon distribution function in a proton, \( x \) is the gluon fraction of a proton momentum, \( \mu^2 \) is the typical scale of a hard process. The \( \mu^2 \) evolution of the gluon distribution \( G(x, \mu^2) \) is described by DGLAP evolution equation \([3]\). In the \( k_T \)-factorization approach hadronic and partonic cross sections are related by the following condition \([3]\):

\[
\sigma^{KT}(ep \rightarrow ecX) = \int \frac{dx}{x} \int d\vec{k}_T^2 \int \frac{d\phi}{2\pi} \Phi(x, \vec{k}_T^2, \mu^2) \hat{\sigma}(eg^* \rightarrow ec\bar{c}, \hat{s})
\]

where \( \hat{\sigma}(eg^* \rightarrow ec\bar{c}, \hat{s}) \) is the c-quark production cross section on the off mass-shell ("reggeized") gluon, \( k^2 = -\vec{k}_T^2 \), \( \hat{s} = xs-\vec{k}_T^2 \), \( \phi \) is the azimuthal angle in the
transverse $XOY$ plane between vectors $\vec{k}_T$ and the fixed $OX$ axis ($\vec{p}_c$ and $\vec{p}_c' \in XOZ$).

The unintegrated gluon distribution function $\Phi(x, \vec{k}_T^2, \mu^2)$ satisfies the BFKL evolution equation [4]. At the $x \ll 1$ the off mass-shell gluon has dominant longitudinal polarization along a proton momentum and the gluon polarization four-vector is written as follows [6]: $\varepsilon^\mu(k) = k_T^\mu/|\vec{k}_T|$.

Our calculation in the parton model was done using the GRV [7] and the CTEQ5L [8] parameterizations for a collinear gluon distribution function $G(x, \mu^2)$. In case of the $k_T$-factorization approach we use the following parameterizations for an unintegrated gluon distribution function $\Phi(x, \vec{k}_T^2, \mu^2)$: JB by Bluemlein [9], JS by Jung and Salam [10], KMR by Kimber, Martin and Ryskin [11]. We compared these parameterizations directly in our recent paper [12].

Finally, in the $k_T$-factorization formalism the doubly differential cross section for the process $ep \rightarrow ecX$ can be written as follows:

$$\frac{d\sigma^{KT}}{dx_B dQ^2} = \frac{y}{x_B} \int dp_c d\phi_c d\eta_c d\vec{k}_T^2 \frac{d\phi}{2\pi} \frac{p_c p_{cT}}{E_c} \frac{|M(eg^* \rightarrow ec\bar{c})|^2}{256\pi^4(y - a_1)(xs)^2} \Phi(x, \vec{k}_T^2, \mu^2),$$  \hspace{1cm} (8)

where $p_c = (E_c, \vec{p}_c)$ is the $c$-quark 4-momentum, $\eta_c$ is the $c$-quark pseudorapidity, $\phi_c$ is the azimuthal angle between $OX$ axis and vector $\vec{p}_{cT}$, $a_1 = 2(pp_c)/s$, $b_1 = 2(p_c p_c)/s$ and

$$x = (\vec{k}_T^2 + Q^2 + yb_1 s + 2(\vec{q}_{cT} \vec{k}_T) - 2(\vec{p}_{cT} \vec{k}_T) - 2(\vec{q}_{cT} \vec{p}_{cT}))/((y - a_1)s).$$  \hspace{1cm} (9)

We use the following approximations for gluon 4-momentum $k^\mu = xp^\mu + k_T^\mu$, where $k_T^\mu = (0, \vec{k}_T, 0)$.

In the parton model one has $\vec{k}_T = 0$ and

$$\frac{d\sigma^{PM}}{dx_B dQ^2} = \frac{y}{x_B} \int dp_c d\phi_c d\eta_c \left( \frac{p_c p_{cT}}{E_c} \right) \frac{|M(eg \rightarrow ec\bar{c})|^2}{256\pi^4(y - a_1)(xs)^2} xG(x, \mu^2),$$  \hspace{1cm} (10)
where
\[ x = \frac{(Q^2 + yb_1s - 2(\bar{q}T\bar{p}_c T))/(y - a_1)s}{(y - a_1)s}. \] (11)

The obtained results (Fig. 1) demonstrate agreement between our predictions and the recent data for the \( F_{2c}(x_B, Q^2) \) from HERA [2]. However, we see that the difference between the c-quark proton SF’s calculated in the \( k_T \)-factorization approach using different unintegrated gluon distribution functions is the same order as than the difference between results obtained in the parton model and in the \( k_T \)-factorization approach.

The authors would like to thank B. Kniehl, A. Kotikov and H. Jung for discussion of the obtained results, L. Lipatov and V. Kim for kind hospitality during Workshop DIS-2003.

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Figure 1: The SF $F_{2e}(x_B, Q^2)$ as a function of $x_B$ at the $Q^2=4, 18, 60$ and $130$ GeV$^2$ compared to ZEUS data
