Charm contribution to the structure function in diffractive deep inelastic scattering

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The charm contribution to structure functions of diffractive deep inelastic scattering is considered here within the context of the Ingelman-Schlein model. Numerical estimations of this contribution are made from parametrizations of the DESY HERA data. The influence of the Pomeron flux factor is analyzed as well as the effect of the shape of the initial parton distribution employed in the calculations. The obtained results indicate that the charm contribution to diffractive deep inelastic processes might be large enough to be measured in the HERA experiments. [S0556-2821(99)04921-8]

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I. INTRODUCTION

The DESY ep collider HERA data of deep inelastic scattering (DIS) measured in the last few years contain a sizable fraction of events with a large rapidity gap in the forward region [1,2]. This phenomenon is present even at high Q^2 and results from a color-singlet exchange between the dissociated virtual photon and the recoiling proton (or proton remnant), characterizing what is usually called *diffractive* DIS (DDIS). The measurement of DDIS at HERA provides a unique opportunity to study diffraction in regions in which perturbative QCD is applicable.

Open heavy quark production at HERA is also a subject of major interest in QCD phenomenology. Both the H1 and ZEUS Collaborations have found the charm component of the structure function, $F_2^{(c)}(x,Q^2)$, to be a large fraction of $F_2(x,Q^2)$ at small x [3,4]. Recently the first measurements of the $b\bar{b}$-cross section have been reported [5]. Because of the higher mass of the b quark, it is two orders of magnitude smaller than the $c\bar{c}$-cross section [5].

For the moment most of the experimental data is for the neutral current structure function $F_2(x,Q^2)$. A number of theoretical estimates of $F_2^{(c)}(x,Q^2)$ has recently been obtained [6,7] (see also a review in Ref. [5], and references therein). In the present paper we consider DDIS with open charm production and calculate a charm contribution to the diffractive structure function $F_2^D(\beta,Q^2,x_{\mathrm{P}})$.

There are two different approaches to treatment of the charm component in structure functions. In one approach [8–10] the charm is an active flavor which undergoes massless renormalization group (RG) evolution. We will follow the other approach, in which only light (u, d, s) quarks and gluons are active partons and no initial state heavy quark lines show up in any diagram [11]. It involves the calculation of the photon-gluon fusion process and thus is quite sensitive to the gluon distribution.

For the time being, the gluon distributions inside the Pomeron predicted by a number of models are dramatically different and they have different shapes. The diffractive production of open charm at HERA will, therefore, provide us with the possibility for a direct test of the models.

The present analysis is partially based on a previous study on the Pomeron structure function [12] in which charm contribution was not considered. This study was mostly concerned with effects of the Pomeron flux factor on the evaluation of the diffractive structure fuction. Such effects are a central issue also in the present analysis.

This paper is organized as follows. In Sec. II, we describe how to take into account the charm content of the Pomeron. The charm contribution to the diffractive structure function is evaluated in Sec. III, where the comparison with other models is also given. Our main conclusions are summarized in Sec. IV.

II. THE CHARM CONTENT OF THE POMERON

After integration over the entire t range, the DDIS inclusive cross section can be written as

$$\frac{d^3\sigma^D}{d\beta\, dQ^2 dx_{\mathrm{P}}} = \frac{2\pi\alpha^2}{\beta Q^4}[1+(1-y)^2]F_2^{D(3)}(\beta,Q^2,x_{\mathrm{P}}), \quad (1)$$

where the contribution due to longitudinal structure function, $F_L^{D(3)}$, has been neglected since it is expected to be small. Here the following kinematic variables are used to describe DDIS (in addition to usual DIS variables x, Q^2, y, and W):

$$x_{\mathrm{P}} \simeq \frac{M_X^2+Q^2}{W^2+Q^2} \quad (2)$$

and

$$\beta \simeq \frac{Q^2}{M_X^2+Q^2}, \quad (3)$$

where M_X is the invariant mass of the diffractive system. The kinematical variable x_{P} defined in Eq. (2) can be interpreted as the fraction of the proton momentum transfered to the Pomeron, while β, given by Eq. (3), may be interpreted as the momentum fraction of the Pomeron carried by the

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quark coupling to the photon. To simplify the notation, in what follows we will often write F_2^D instead of $F_2^{D(3)}(\beta,Q^2,x_{\mathbb{P}})$.

In a fit to the full data sample, H1 Collaboration has found that a description of F_2^D that considers only diffractive exchange requires a β-dependent Pomeron intercept. However, this factorization breaking may be explained by introducing secondary trajectories [1]. So we suggest that, in the region where Pomeron exchange is the dominant process, the diffractive structure function could be expressed in a factorized form:

$$F_2^D(\beta,Q^2,x_{\mathbb{P}})=f_{\mathbb{P}/\mathrm{p}}(x_{\mathbb{P}})F_{\mathbb{P}}^D(\beta,Q^2), \tag{4}$$

where $f_{\mathbb{P}/\mathrm{p}}(x_{\mathbb{P}})$ is the integrated Pomeron flux factor, and $F_{\mathbb{P}}^D(\beta,Q^2)$ is the Pomeron structure function [12,13].

The contribution of b quarks to F_2^D is expected to be negligible due to the large mass of the bottom quark (as it takes place for DIS). Thus, we can omit this contribution and write

$$F_{\mathbb{P}}^D(\beta,Q^2)=\beta\sum_a e_a^2\tilde{F}_{\mathbb{P}}^{(a)}(\beta,Q^2), \tag{5}$$

e_a being the electric charge of the quark a $(a=u,d,s,c)$.

For $Q^2\gg m_c^2$, where m_c is the charm-quark mass, we can regard u, d, and s quarks to be massless [both the quark and antiquark are included in the distribution $q_{\mathbb{P}}(\beta,Q^2)$] and put

$$\tilde{F}_{\mathbb{P}}^{(u)}(\beta,Q^2)=\tilde{F}_{\mathbb{P}}^{(d)}(\beta,Q^2)=\tilde{F}_{\mathbb{P}}^{(s)}(\beta,Q^2)=q_{\mathbb{P}}(\beta,Q^2), \tag{6}$$

which results in

$$F_{\mathbb{P}}^D(\beta,Q^2)=\frac{2}{3}\beta q_{\mathbb{P}}(\beta,Q^2)+\frac{4}{9}\beta\tilde{F}_{\mathbb{P}}^{(c)}(\beta,Q^2,m_c^2). \tag{7}$$

Recently, a factorization theorem has been proved for diffractive lepton scattering off nucleons [14] from which structure functions of DDIS coincide with DIS structure functions. Therefore, quark and gluon distributions inside the Pomeron, $q_{\mathbb{P}}(\beta,Q^2)$ and $g_{\mathbb{P}}(\beta,Q^2)$, obey the same set of RG evolution equations as quark and gluon distributions inside the proton do. As the observed values of β are not too small, Dokshitzer-Gribov-Lipatov-Altavelli-Parisi (DGLAP) equations [15] can be used to perform such an evolution.

In the present analysis, we suppose that charm quarks are mainly produced by virtual photon-gluon fusion and do not take part in the evolution of the light quarks. In such a case, by analogy with charm contribution to F_2 [6], we get the following equation for the charm contribution to DDIS structure function F_2^D:

$$\tilde{F}_{\mathbb{P}}^{(c)}(\beta,Q^2,m_c^2)=\int_{Q_0^2}^{Q^2}\frac{dk^2}{k^2}\int_\beta^1\frac{dz}{z}C_g(z,Q^2,k^2,m_c^2)\frac{\partial}{\partial\ln k^2}g_{\mathbb{P}}\left(\frac{\beta}{z},k^2\right), \tag{8}$$

in which $Q_0=2$ GeV is assumed.

Now we isolate a similar term in $q_{\mathbb{P}}(\beta,Q^2)$ and call the rest of $q_{\mathbb{P}}(\beta,Q^2)$ ''direct contribution,'' that is

$$q_{\mathbb{P}}(\beta,Q^2)=q_{\mathbb{P}}^{dir}(\beta,Q^2)+\int_{Q_0^2}^{Q^2}\frac{dk^2}{k^2}\times\int_\beta^1\frac{dz}{z}C_g(z,Q^2,k^2,0)\frac{\partial}{\partial\ln k^2}g_{\mathbb{P}}\left(\frac{\beta}{z},k^2\right). \tag{9}$$

Let us define the quantity

$$\Delta\tilde{F}_{\mathbb{P}}^{(c)}(\beta,Q^2,m_c^2)=\int_{Q_0^2}^{Q^2}\frac{dk^2}{k^2}\int_\beta^1\frac{dz}{z}[C_g(z,Q^2,k^2,0)-C_g(z,Q^2,k^2,m_c^2)]\frac{\partial}{\partial\ln k^2}g_{\mathbb{P}}\left(\frac{\beta}{z},k^2\right). \tag{10}$$

By using these definitions, from Eqs. (7)–(10) we obtain

$$\begin{aligned}F_{\mathbb{P}}^D(\beta,Q^2)&=\frac{2}{3}\beta\left[q_{\mathbb{P}}^{dir}(\beta,Q^2)+\int_{Q_0^2}^{Q^2}\frac{dk^2}{k^2}\int_\beta^1\frac{dz}{z}C_g(z,Q^2,k^2,0)\frac{\partial}{\partial\ln k^2}g_{\mathbb{P}}\left(\frac{\beta}{z},k^2\right)\right]\\&\quad+\frac{4}{9}\beta\int_{Q_0^2}^{Q^2}\frac{dk^2}{k^2}\int_\beta^1\frac{dz}{z}C_g(z,Q^2,k^2,m_c^2)\frac{\partial}{\partial\ln k^2}g_{\mathbb{P}}\left(\frac{\beta}{z},k^2\right)\\&=\frac{2}{3}\beta q_{\mathbb{P}}^{dir}(\beta,Q^2)+\frac{10}{9}\beta\int_{Q_0^2}^{Q^2}\frac{dk^2}{k^2}\int_\beta^1\frac{dz}{z}C_g(z,Q^2,k^2,m_c^2)\frac{\partial}{\partial\ln k^2}g_{\mathbb{P}}\left(\frac{\beta}{z},k^2\right)+\frac{2}{3}\beta\Delta\tilde{F}_{\mathbb{P}}^{(c)}(\beta,Q^2,m_c^2)\\&=\frac{2}{3}\beta q_{\mathbb{P}}^{dir}(\beta,Q^2)+\frac{5}{2}F_{\mathbb{P}}^{(c)}(\beta,Q^2,m_c^2)+\frac{2}{3}\beta\Delta\tilde{F}_{\mathbb{P}}^{(c)}(\beta,Q^2,m_c^2).\end{aligned} \tag{11}$$

It follows from Eq. (11) that

$$F_{\mathbb{P}}^{(c)}(\beta,Q^2,m_c^2)=\frac{2}{5}\left[F_{\mathbb{P}}^{D}(\beta,Q^2)-\frac{2}{3}\beta q_{\mathbb{P}}^{dir}(\beta,Q^2)-\frac{2}{3}\beta\Delta\tilde{F}_{\mathbb{P}}^{(c)}(\beta,Q^2,m_c^2)\right]. \tag{12}$$

An analogous difference between DIS structure functions with and without charm contribution, $\Delta F_2(x,Q^2,m_c^2)$, was calculated in Ref. [6], where it was shown that it scales at high Q^2. The generalization for DDIS is straightforward and the result [up to corrections $O(m_c^2/Q^2)$] reads

$$\Delta\tilde{F}_{\mathbb{P}}^{(c)}=\Delta\tilde{F}_{\mathbb{P}}^{(c)}(\beta,m_c^2)=\int_{Q_0^2}^{\infty}\frac{dk^2}{k^2}\int_{\beta}^{1}\frac{dz}{z}\Delta C\left(\frac{m_c^2}{k^2},z\right)\frac{\partial}{\partial\ln k^2}g_{\mathbb{P}}\left(\frac{\beta}{z},k^2\right). \tag{13}$$

In α_s order the expression for ΔC is of the form[1] [6]

$$\Delta C(v,u)=\frac{\alpha_s}{\pi}\left\{P_{qg}(u)\ln\left[1+\frac{v}{u(1-u)}\right]-\frac{1}{2}(1-2u)^2\frac{v}{v+u(1-u)}\right\}. \tag{14}$$

Formula (13) does not contradict the factorization theorem for DDIS [14]. Namely, if we put $k^2=0$ in $C_g(\beta,Q^2,k^2,m_c^2)$ as it is usually done, the main contribution in Eq. (8) is due to the region $k^2\sim Q^2$, and one obtains

$$\tilde{F}_{\mathbb{P}}^{(c)}(\beta,Q^2,m_c^2)\simeq\int_{\beta}^{1}\frac{dz}{z}C_g\left(\frac{m_c^2}{Q^2},z\right)g_{\mathbb{P}}\left(\frac{\beta}{z},Q^2\right). \tag{15}$$

On the other hand, in the difference of the diffractive structure functions, $\Delta\tilde{F}_{\mathbb{P}}^{(c)}(\beta,m_c^2)$, Eq. (13), the leading contributions cancel out. The quantity ΔC has the asymptotic behavior

$$\Delta C\left(\frac{m_c^2}{k^2},\beta\right)\Big|_{|k^2|\to\infty}\sim\frac{m_c^2}{k^2}, \tag{16}$$

and the main contribution to the integral in k^2 in Eq. (13) comes from the region $k^2\sim m_c^2$ [6].

As can be seen from Eq. (12), $F_{\mathbb{P}}^{(c)}$ is defined via $\Delta\tilde{F}_{\mathbb{P}}^{(c)}$. In its turn, $\Delta\tilde{F}_{\mathbb{P}}^{(c)}$ is given by formula (13) which contains a derivative of $g_{\mathbb{P}}$ in $\ln k^2$. This is related to the fact that we started from an exact expression for the coefficient function C_g [6] depending on both m_c^2 and k^2. Thus, one can expect that the charm contribution to the DDIS structure function should significantly be dependent on both the form and evolution of the gluon distribution inside the Pomeron.

For numerical estimates we shall use the quark and gluon distribution functions which have been obtained in Ref. [12] by fitting the data on $F_2^{D(3)}$ from H1 and ZEUS Collaborations [16,17]. Since in this analysis it was assumed $N_f=3$ (N_f being the number of flavors), we have to rewrite Eq. (12) in terms of corresponding parton distributions, $q_{\mathbb{P}}^{(3)}$ and $g_{\mathbb{P}}^{(3)}$. Let us also define $q_{\mathbb{P}}^{(4)}$ ($g_{\mathbb{P}}^{(4)}$) to be a quark (gluon) distribution for the case $N_f=4$.

It is useful to introduce the quantities

$$\Delta q_{\mathbb{P}}=q_{\mathbb{P}}^{(4)}-q_{\mathbb{P}}^{(3)} \tag{17}$$

and

$$\Delta g_{\mathbb{P}}=g_{\mathbb{P}}^{(4)}-g_{\mathbb{P}}^{(3)}. \tag{18}$$

It should be noted that

$$\Delta q_{\mathbb{P}}=-\frac{3}{2}F_{\mathbb{P}}^{(c)}. \tag{19}$$

From Eq. (12), one obtains

$$F_{\mathbb{P}}^{(c)}(\beta,Q^2,m_c^2)=\frac{2}{3}F_{\mathbb{P}}^{D}(\beta,Q^2)-\frac{4}{9}\beta[q_{\mathbb{P}}^{dir}(\beta,Q^2)+\Delta\tilde{F}_{\mathbb{P}}^{(c)}(\beta,m_c^2)]\big|_{N_f=3}+\frac{4}{9}\int_{Q_0^2}^{Q^2}\frac{dk^2}{k^2}\frac{\alpha_s}{\pi}\times\int_{\beta}^{1}dzP_{cg}(z)\frac{\beta}{z}\Delta g_{\mathbb{P}}\left(\frac{\beta}{z},k^2\right), \tag{20}$$

where the subscript $|_{N_f=3}$ means that the corresponding quantities on the right-hand side (RHS) of Eq. (20) should be calculated with the use of the distributions $q_{\mathbb{P}}^{(3)}$ and $g_{\mathbb{P}}^{(3)}$.

The next step is to estimate the quantity $\Delta g_{\mathbb{P}}$ which enters into Eq. (20). Because of our assumption (no charm in light quark evolution), $q_{\mathbb{P}}^{(3)}$ and $q_{\mathbb{P}}^{(4)}$ obey one and the same DGLAP evolution equation [15]:

$$q_{\mathbb{P}}^{(n)}(\beta,Q^2)=q_{\mathbb{P}}^{(n)}(\beta,Q_0^2)+3\int_{Q_0^2}^{Q^2}\frac{dk^2}{k^2}\frac{\alpha_s}{2\pi}\int_{\beta}^{1}\frac{dz}{z}P_{qq}(z)q_{\mathbb{P}}^{(n)}\left(\frac{\beta}{z},k^2\right)+\int_{Q_0^2}^{Q^2}\frac{dk^2}{k^2}\frac{\alpha_s}{\pi}\int_{\beta}^{1}\frac{dz}{z}P_{qg}(z)g_{\mathbb{P}}^{(n)}\left(\frac{\beta}{z},k^2\right), \tag{21}$$

for $n=3,4$. The factor 3 in front of the first integral on the RHS of Eq. (21) is related to the number of light flavors.

As for initial quark and gluon distributions inside the Pomeron, we have $g_{\mathbb{P}}^{(4)}(\beta,Q_0^2)\neq g_{\mathbb{P}}^{(3)}(\beta,Q_0^2)$, while

$$\Delta q_{\mathbb{P}}(\beta,Q_0^2)=0. \tag{22}$$

[1]There are two misprints in formula (40) of Ref. [6] that were corrected in Eq. (14): the expression $P_{qg}(y)=1/2[(1-y)^2+y^2]$ should be put within the curly brackets and the factor $\alpha_s/4\pi$ should be replaced by $\alpha_s/2\pi$.

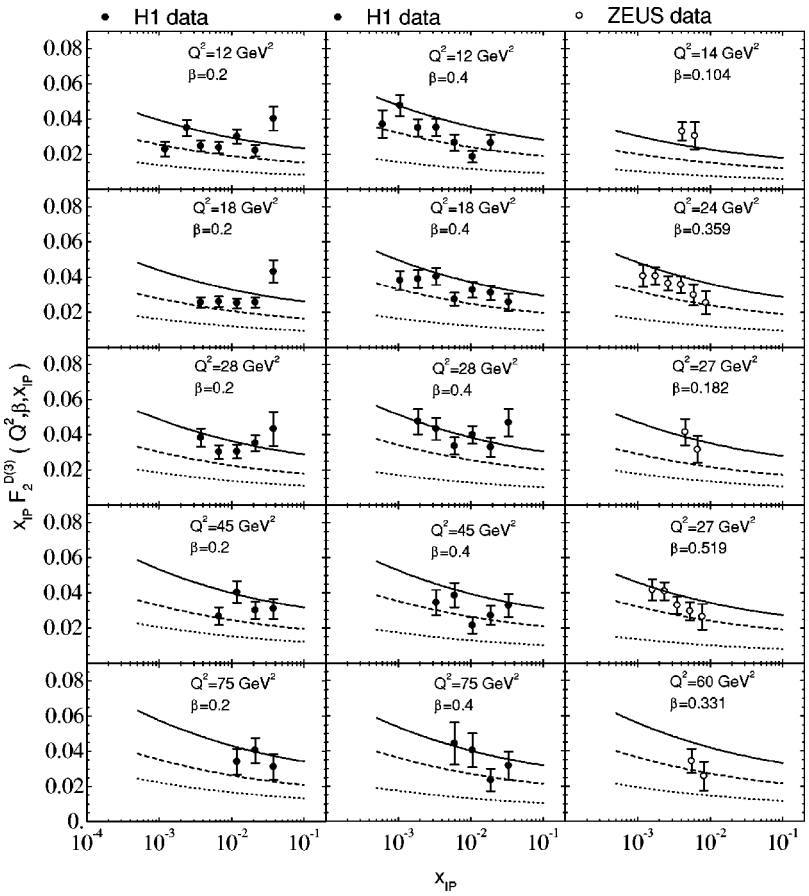

FIG. 1. Theoretical estimations of diffractive DIS structure functions in comparison with HERA data. The curves correspond to the total diffractive structure function, $x_{\mathbb{P}}F_2^D$ (solid curves), its charm component, $x_{\mathbb{P}}F_2^{(c)}$ (dotted curves), and the difference $x_{\mathbb{P}}(F_2^D - F_2^{(c)})$ (dashed curves). In the theoretical calculations employed, the flux factor and initial parton distributions of the Pomeron were described as Fit 1 (see text). The experimental data are from H1 [1] (filled circles) and ZEUS [2] (open circles) Collaborations.

There is no intrinsic charm in the Pomeron. If we neglect the variation of α_s with the change of the flavor number from $N_f=3$ to $N_f=4$, from Eq. (21) we obtain

$$\Delta q_{\mathbb{P}}(\beta,Q^2) = 3\int_{Q_0^2}^{Q^2}\frac{dk^2}{k^2}\,\frac{\alpha_s}{2\pi}\int_\beta^1\frac{dz}{z}P_{qq}(z)\Delta q_{\mathbb{P}}\left(\frac{\beta}{z},k^2\right) + \int_{Q_0^2}^{Q^2}\frac{dk^2}{k^2}\,\frac{\alpha_s}{\pi}\int_\beta^1\frac{dz}{z}P_{qg}(z)\Delta g_{\mathbb{P}}\left(\frac{\beta}{z},k^2\right). \tag{23}$$

The QCD-evolution parameter

$$\xi(Q^2) = \frac{1}{2\pi b}\ln\left(\frac{\ln(Q^2/\Lambda^2)}{\ln(Q_0^2/\Lambda^2)}\right), \tag{24}$$

where $12\pi b = 33 - 2N_f$, rises slowly in Q^2 and is numerically small even at rather high values of Q^2. For instance, for $Q_0=2$ GeV and $\Lambda=0.2$ GeV we find $\xi(10^2\text{GeV}^2)\simeq 0.13$, $\xi(10^3\text{GeV}^2)\simeq 0.24$. In particular, it enables one to solve the DGLAP equations by using an expansion in the parameter ξ [18].

From the above, we obtain [up to small corrections $O(\xi^2)$]

$$\Delta q_{\mathbb{P}}(\beta,Q^2) \simeq \int_{Q_0^2}^{Q^2}\frac{dk^2}{k^2}\,\frac{\alpha_s}{\pi}\int_\beta^1\frac{dz}{z}P_{qg}(z)\Delta g_{\mathbb{P}}\left(\frac{\beta}{z},k^2\right). \tag{25}$$

Due to the fact that $C_g(z,Q^2,k^2,m_c^2)$ has no large logarithms, at $k^2\simeq Q^2$ [see an explicit expression for $C_g(z,Q^2,k^2,m_c^2)$ in Ref. [6]], from Eq. (8) we obtain in the leading logarithmic approximation (LLA) the expression

$$F_{\mathbb{P}}^{(c)}(\beta,Q^2,m_c^2) \simeq \int_{Q_0^2}^{Q^2}\frac{dk^2}{k^2}\,\frac{\alpha_s}{\pi}\int_\beta^1 dz\,P_{cg}\left(z,\frac{m_c^2}{Q^2}\right)\frac{\beta}{z}g_{\mathbb{P}}^{(4)}\left(\frac{\beta}{z},k^2\right), \tag{26}$$

where $P_{cg}(z,m_c^2/Q^2) = -\partial C_g(z,Q^2,k^2,m_c^2)/\partial\ln k^2|_{k^2=Q^2}$ is the modified form of the P_{qg} splitting function for the charm quark [19].

Now let us define

$$\int_\beta^1\frac{dz}{z}P_{qg}(z)\Delta g_{\mathbb{P}}\left(\frac{\beta}{z},Q^2\right) = r_q\int_\beta^1\frac{dz}{z}P_{qg}(z)g_{\mathbb{P}}^{(3)}\left(\frac{\beta}{z},Q^2\right) \tag{27}$$

and

$$\int_\beta^1\frac{dz}{z}P_{cg}(z)\Delta g_{\mathbb{P}}\left(\frac{\beta}{z},Q^2\right) = r_c\int_\beta^1\frac{dz}{z}P_{cg}(z)g_{\mathbb{P}}^{(3)}\left(\frac{\beta}{z},Q^2\right), \tag{28}$$

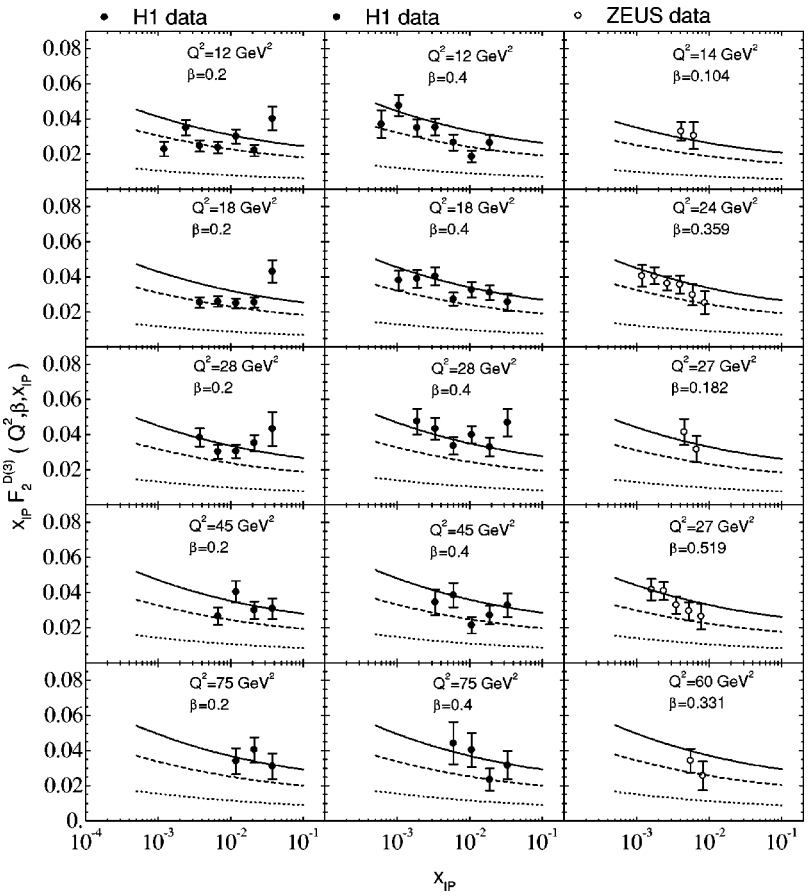

FIG. 2. The same as Fig. 1, but with theoretical curves calculated from the formulas of Fit 2 (see text).

and put $r_c \simeq r_q = r$. This means that we ignore additional subleading m_c^2-dependent terms in P_{cg} with respect to P_{qg}. The quantity r may in principle depend on both β and Q^2. Numerical estimates have shown, however, that it is weakly dependent on variable Q^2.

From Eqs. (19), (25)–(28), we calculate r and rewrite $F_{\mathbb{P}}^{(c)}$ in the following form:

$$F_{\mathbb{P}}^{(c)}(\beta,Q^2,m_c^2)=\frac{2}{3}\frac{AB}{A+B}, \tag{29}$$

where

$$A=F_{\mathbb{P}}^{D}(\beta,Q^2)-\frac{2}{3}\beta[q_{\mathbb{P}}^{dir}(\beta,Q^2)+\Delta\tilde{F}_{\mathbb{P}}^{(c)}(\beta,m_c^2)]\big|_{N_f=3} \tag{30}$$

and

$$B=\int_{Q_0^2}^{Q^2}\frac{dk^2}{k^2}\frac{\alpha_s}{\pi}\int_{\beta}^{1}dz\,P_{qg}(z)\frac{\beta}{z}g_{\mathbb{P}}^{(3)}\left(\frac{\beta}{z},k^2\right). \tag{31}$$

Here $F_{\mathbb{P}}^{D}$ is the Pomeron structure function, while $q_{\mathbb{P}}^{dir}$ and $\Delta\tilde{F}_{\mathbb{P}}^{(c)}$ are defined in Eqs. (9) and (13).

III. THE CHARM CONTRIBUTION TO THE DIFFRACTIVE STRUCTURE FUNCTION

In this section, we present quantitative results obtained in the present analysis as well as some comparison with other models.

A. Results of the present analysis

Our concern now is the calculation of the charm contribution to $F_2^{D(3)}(\beta,Q^2,x_{\mathbb{P}})$ in two different approaches and for different shapes of the quark and gluon distributions inside the Pomeron. In one approach the *standard* flux factor is employed, whereas in the other the *renormalized* flux factor is used (for brevity, we will refer to these quantities hereafter as STD and REN flux factors, respectively). For the former, the Donnachie-Landshoff expression [20] was assumed,

$$f_{STD}(x_{\mathbb{P}},t)=\frac{9\beta_0^2}{4\pi^2}[F_1(t)]^2 x_{\mathbb{P}}^{1-2\alpha(t)} \tag{32}$$

while the latter is determined from the procedure prescribed in [21], that is

$$f_{REN}(x_{\mathbb{P}},t)=\frac{f_{STD}(x_{\mathbb{P}},t)}{N(x_{\mathbb{P}_{\min}})}, \tag{33}$$

where

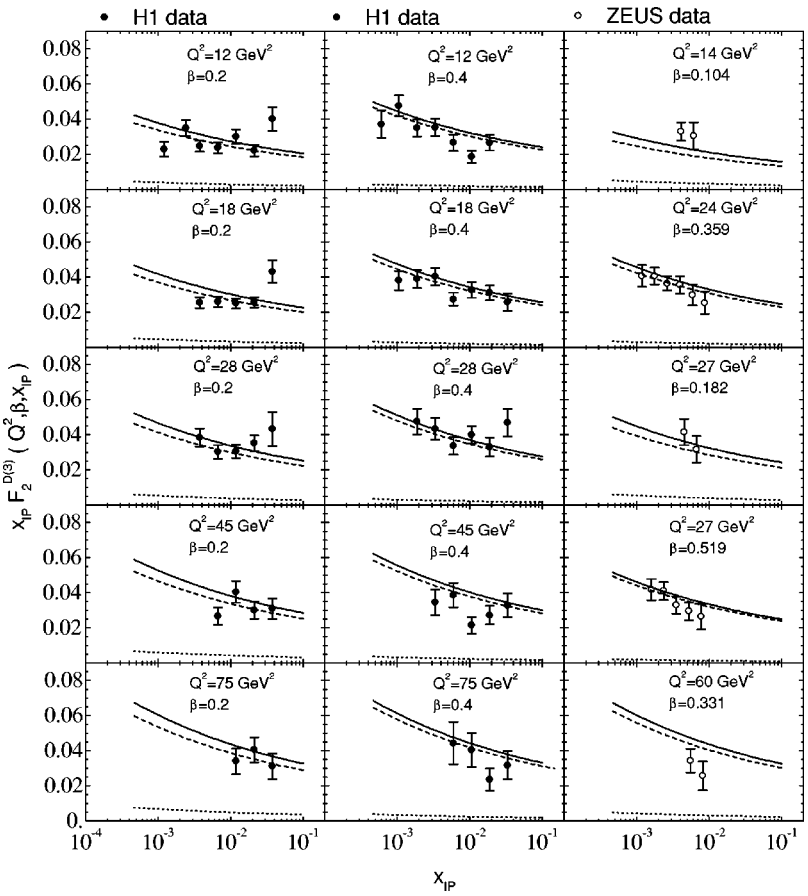

FIG. 3. The same as Fig. 1, but with theoretical curves calculated from the formulas of Fit 3 (see text).

$$N(x_{\mathrm{P}_{\min}}) = \int_{x_{\mathrm{P}_{\min}}}^{x_{\mathrm{P}_{max}}} dx_{\mathrm{P}} \int_{t=-\infty}^{0} f_{STD}(x_{\mathrm{P}},t)\,dt. \tag{34}$$

By introducing Eq. (32) into Eq. (34) and assuming an exponential approximation for the form factor, $F_1^2(t) \simeq e^{b_0(t)}$, one obtains

$$N(x_{\mathrm{P}_{\min}}) = K\frac{e^{-\gamma}}{2\alpha'}[E_i(\gamma - 2\epsilon \ln x_{\mathrm{P}_{\min}}) - E_i(\gamma - 2\epsilon \ln x_{\mathrm{P}_{\max}})], \tag{35}$$

where $E_i(x)$ is the exponential integral, $K = 9\beta_0^2/4\pi^2$, and $\gamma = b_0\epsilon/\alpha'$. The minimum value of x_{P} is $x_{\mathrm{P}_{\min}} = (m_p + m_\pi)^2/s$ for soft diffractive dissociation and $x_{\mathrm{P}_{\min}} = Q^2/\beta s$ for DDIS [21].

The distributions of the quarks and gluons inside the Pomeron, $q_{\mathrm{P}}^{(3)}$ and $g_{\mathrm{P}}^{(3)}$, were obtained from HERA data [16,17] in Ref. [12] (we refer the reader to this paper for details). The parametrizations for each flux factor are described below. No sum rules were imposed on them to perform the fitting.

Fit 1: Parametrizations obtained with STD flux in which both quark and gluon distributions have a hard shape at the initial scale of evolution:

$$3\beta q_{\mathrm{P}}^{(3)}(\beta,Q_0^2) = 2.55\beta(1-\beta),$$
$$\beta g_{\mathrm{P}}^{(3)}(\beta,Q_0^2) = 12.08\beta(1-\beta). \tag{36}$$

Fit 2: Parametrizations obtained with the STD flux; the initial distributions correspond to a super-hard profile imposed to gluons by a delta function while quarks were left free to change according to the data:

$$3\beta q_{\mathrm{P}}^{(3)}(\beta,Q_0^2) = 1.51\beta^{0.51}(1-\beta)^{0.84},$$
$$\beta g_{\mathrm{P}}^{(3)}(\beta,Q_0^2) = 2.06\delta(1-\beta). \tag{37}$$

Fit 3: Parametrizations obtained with the REN flux factor and an initial combination of the *hard-hard* type:

$$3\beta q_{\mathrm{P}}^{(3)}(\beta,Q_0^2) = 5.02\beta(1-\beta),$$
$$\beta g_{\mathrm{P}}^{(3)}(\beta,Q_0^2) = 0.98\beta(1-\beta). \tag{38}$$

All three combinations of flux factors and parton distributions of the Pomeron were applied in the calculation of the charm contribution to DDIS structure function. This quantity is given by the formula

$$F_2^{(c)}(\beta,Q^2,x_{\mathrm{P}}) = f_{\mathrm{P/p}}(x_{\mathrm{P}})F_{\mathrm{P}}^{(c)}(\beta,Q^2), \tag{39}$$

where $f_{\mathrm{P/p}}(x_{\mathrm{P}})$ stands for the integrated (over t) flux factors mentioned above and the charm structure function of the Pomeron is defined by Eqs. (29)–(31).

The results of our calculations are shown in Figs. 1–3. The upper curve in each figure corresponds to the total diffractive structure function, $x_{\mathrm{P}}F_2^D$, while the lowest one describes its charm component, $x_{\mathrm{P}}F_2^{(c)}$. The difference $x_{\mathrm{P}}(F_2^D - F_2^{(c)})$ is also shown.

In these figures, the theoretical results are presented together with recent H1 and ZEUS data on F_2^D [1,2] which were not used in the fitting procedure mentioned above. The idea is not providing a precise description for these data, but giving the reader a possibility to compare the net charm contribution to the precision of present day data.

As one can see in Figs. 1 and 2, the charm contribution to the diffractive structure function obtained with the STD flux factor amounts to 30–40 %, depending on the values of β, x_{P}, and Q^2. To compare, the nondiffractive structure function F_2 contains between 10% (low Q^2) and 30% (high Q^2) of charm at small x. From these figures, we see that the charm contribution to F_2^D grows with the decrease of x_{P} and is a little bit larger for the hard gluon distribution (Fig. 1) than it is for the superhard gluons (Fig. 2). However, for both parametrizations (Figs. 1 and 2) it is comparable with the experimental errors[2] of the H1 and ZEUS data and, consequently, can likely be measured in forthcoming HERA experiments on diffractive dissociation processes.

On the other hand, for the renormalized flux factor the charm component is very small in the full range of β and Q^2 presented in Fig. 3. The reason is that the initial gluon distribution for this case, Eq. (38), is much smaller compared to the initial gluon distribution with the same form for the standard flux factor, Eq. (36).

Another way of comparing these results is shown in Fig. 4 in terms of $F_{\mathrm{P}}^{(c)}(\beta,Q^2)$, which is calculated for the three combinations of Pomeron flux factors with the respective structure functions considered here.

Two main features that characterize our predictions for $F_{\mathrm{P}}^{(c)}(\beta,Q^2)$ are evident in this figure: (1) the shape of the β distributions are quite similar (they are moderately hard at the initial scale) and change similarly with Q^2 evolution; (2) the amount of charm is different in each case with the proportions seen in the figure.

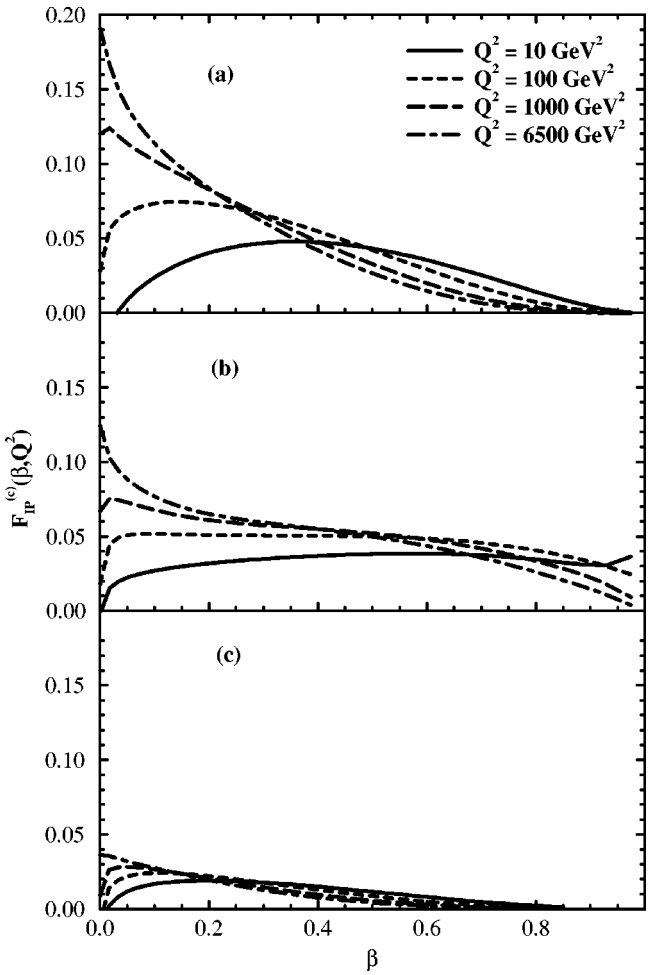

FIG. 4. Predictions for the charm structure function in diffractive DIS as obtained with the parametrizations of Fit 1 (a), Fit 2 (b), and Fit 3 (c) and their respective Q^2 evolution.

B. Comparison with other models

The diffractive production of the open charm in DIS has been studied in the framework of perturbative two-gluon exchange between the $c\bar{c}$-pair and the proton in Refs. [22]. In Refs. [23], nonperturbative approaches were used to calculate cross sections and spectra for charm quark pair production.

One common aspect of some of these models (the first two of Refs. [22] and the first one of Ref. [23]) is that their predictions for the charm contribution practically do not change at low β with Q^2 evolution, which is in contrast with the results of our analysis shown in Fig. 4. Another distinctive feature of these models in respect to ours is that the β distributions are generally peaked at some intermediate β value that becomes larger with increasing Q^2. This last aspect is also observed in the analysis by Levin *et al.* [22], although in this case the low β behavior does not follow the others.

Another general observation is that the obtained steep rise of the charm component towards small x_{P} is in qualitative accordance with the results of Refs. [22]. In Fig. 5, we present a quantitative comparison of our results for the charm contribution to $F_2^{D(3)}(x_{\mathrm{P}},\beta,Q^2)$ with those obtained by Lotter [22] for two Q^2 values and $x_{\mathrm{P}}=0.001$. It is seen that, in terms of the amount of charm, Lotter's predictions are comparable only to our renormalized case (Fit 3), although in terms of shape these distributions are quite different. Let us note, however, that Lotter's model is not adequate to describe diffraction in the complete β range as was mentioned by the author [22].

Now let us consider other models, remembering that our analysis was performed in the context of the Ingelman-

[2]Statistical and systematic errors have been added in quadrature.

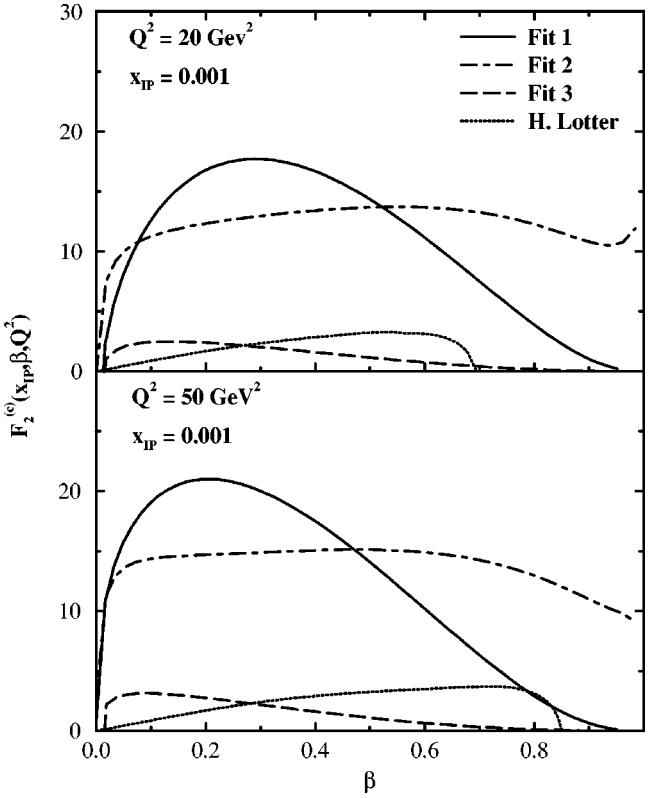

FIG. 5. Comparison of the charm contribution to $F_2^{D(3)}(x_{\mathbb{P}},\beta,Q^2)$, obtained in the present analysis (Fits 1, 2, and 3) with the predictions by Lotter [22] for two Q^2 values and for $x_{\mathbb{P}}=0.001$.

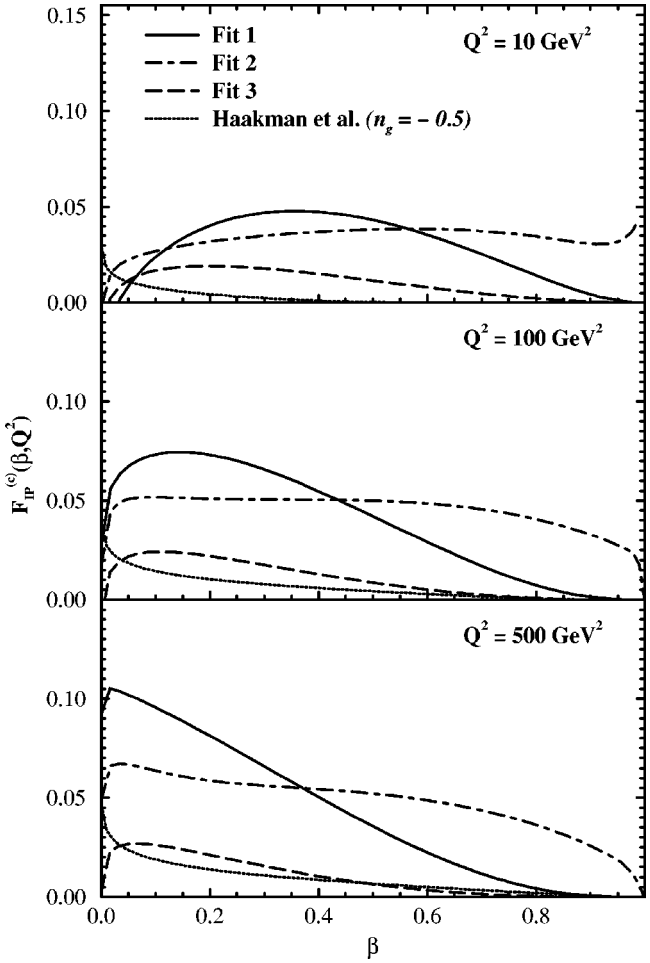

FIG. 6. Comparison of the charm structure function obtained in the present analysis (Fits 1, 2, and 3) with the predictions by Haakman *et al.* [24].

Schlein model. Predictions for the charm contribution to the Pomeron structure function have been made by using the same scheme in Refs. [24]. However, no estimates of the charm contribution to the diffractive structure function $F_2^{D(3)}$ have been presented.

In Fig. 6, we present a comparison of our predictions for $F_{\mathbb{P}}^{(c)}(\beta,Q^2)$ with those obtained by Haakman *et al.* [24]. We see that in their analysis the charm structure function is pretty soft even at low Q^2 where our results are predominantely hard. In terms of the amount of charm, their results are comparable only to our Fit 3.

IV. CONCLUDING REMARKS

In this paper we have considered the charm content of the Pomeron and its effects on the structure function measured in diffractive deep inelastic scattering. In the present analysis, the formulas are derived to define this contribution from the quark and gluon distributions inside the Pomeron obtained previously by fitting HERA data on DDIS. Two parametrizations have been chosen for the standard Pomeron flux factor corresponding to the hard and superhard gluon components of the Pomeron, whereas for the renormalized flux factor the hard parton parametrization has been analyzed.

Numerical calculations show that the results critically depend on the Pomeron flux factor. In particular, the charm content of the Pomeron is expected to be very small for the renormalized flux factor. As for charm contribution corresponding to the standard flux factor, the estimates obtained allow us to think that it could be extracted from diffractive deep inelastic process with open charm production, taking into account the planned upgrades of the HERA experiment [25].

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