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Excitation of open charm and factorization breaking in rapidity gap events at HERA

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Abstract

We develop the pQCD description of diffraction excitation of heavy flavours in DIS and we derive the analytic formulas for the mass spectrum in leading $\log m_f^2$. The result illustrates nicely non-factorization properties of the QCD pomeron. We predict a very steep rise of the charm content of diffraction dissociation of photons at small $x_{\mathbf{P}}$. We evaluate the contribution of open charm to scaling violations in the structure function of the pomeron.

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Following Ingelman and Schlein [1], Regge factorization [2] is often applied to diffraction dissociation (DD) of (virtual) photons $\gamma^* + p \rightarrow X + p'$ into states X of mass M (large rapidity gap (LRG) events), which are reinterpreted as a deep inelastic scattering (DIS) on pomerons radiated by the target proton, endowing the pomeron with the usual attributes of a particle such as the partonic structure function $F_{2\mathbf{P}}(\beta, Q^2)$ and the flux of pomerons $\phi_{\mathbf{P}}(x_{\mathbf{P}})/x_{\mathbf{P}}$ in the proton ([1, 3]:

$$(M^2 + Q^2) \frac{d\sigma_D(\gamma^* \rightarrow X)}{dt dM^2} \Big|_{t=0} = \frac{\sigma_{tot}(pp)}{16\pi} \frac{4\pi^2 \alpha_{em}}{Q^2} \phi_{\mathbf{P}}(x_{\mathbf{P}}) F_{2\mathbf{P}}(\beta, Q^2). \quad (1)$$

Here Q^2 is the virtuality of the photon, W and M are c.m.s. energy in the photon-proton and photon-pomeron collision, $\beta = Q^2/(Q^2 + M^2)$ is the Bjorken variable for the lepton-pomeron DIS and $x_{\mathbf{P}} = (Q^2 + M^2)/(Q^2 + W^2) = x/\beta$ is interpreted as the fraction of the momentum of the proton carried away by the pomeron.

The Ingelman-Schlein model has never been derived from a QCD analysis. Quite to the contrary, the unequivocal conclusion from the QCD approach to DD is the non-factorization of the QCD pomeron [4]: the $x_{\mathbf{P}}$ dependence of $d\sigma_D$ *can not* be reabsorbed entirely in the Q^2, β and flavour independent pomeron flux function $\phi_{\mathbf{P}}(x_{\mathbf{P}})$, whereas the β, Q^2 and flavour dependence of $d\sigma_D$ *can not* be contained entirely in the $f\bar{f}$ structure function of the pomeron. Different aspects of the non-factorization in DD have been discussed in [4, 5, 6, 7, 8]; the non-factorizable colour dipole approach to DD [4, 7] is well known to provide very good quantitative description of the HERA data on LRG events [9, 10]. Regarding the applicability of pQCD, the crucial observation [4] is that in DD of transverse photons, the $q\bar{q}$ pairs have a, Q^2 -independent, typical transverse size $\sim 1/m_f$. This allows to quantify the factorization breaking in DD into heavy flavours on a more quantitative basis than for the (predominantly nonperturbative) DD into light flavours. The demonstration of this factorization breaking is the subject of the present paper.

One of the main points of the present communication is a derivation of the β dependence of the pQCD factorization scale,

$$q_0^2 \sim m_f^2 \left(1 + \frac{Q^2}{M^2}\right) = \frac{m_f^2}{1 - \beta}. \quad (2)$$

This β, m_f dependence of the pQCD factorization scale drives the flavour and β dependence of the flux of pQCD pomerons in the proton and nicely illustrates the breaking of Regge

factorization for the QCD pomeron: each and every flavour brings in a new, and explicitly β -dependent, flux function into the menagerie of pomeron fluxes in the proton. We predict a very steep rise of the charm abundance in DD towards small $x_{\mathbf{P}}$, which is a distinctive feature of the QCD approach to DD as compared to the Regge factorization models. We present also an evaluation of the contribution of open charm excitation to the counterintuitive rise with Q^2 of the pomeron structure function at large values of β . Finally, we comment on the even more dramatic factorization breaking in DD of longitudinal photons, where the pQCD factorization scale $q_0^2 \sim \frac{1}{4}Q^2$ entails the Q^2 -dependent "flux of pomerons" which can be related to the Q^2 dependence of the gluon structure function of the proton (for the similar situation in DD into dijets see [6]).

DD into open heavy flavour, $X = q\bar{q}$, is described by diagrams of Fig. 1. It dominates at $M^2 \sim Q^2$ considered here. The relevant formalism is described in detail in [4, 6]. The mass of the state X is given by $M^2 = (m_f^2 + k^2)/z(1-z)$, where m_f is the quark mass, \vec{k} is the transverse momentum of the quark with respect to the γ^* -pomeron collision axis and z is the fraction of light-cone momentum of the photon carried by the (anti)quark. Other useful kinematical variables are $\varepsilon^2 = z(1-z)Q^2 + m_f^2$ and

$$q^2 = k^2 + \varepsilon^2 = (k^2 + m_f^2) \frac{M^2 + Q^2}{M^2} \quad (3)$$

After the standard leading $\log\kappa^2$ resummation, the cross sections of the forward ($t = 0$) DD of (T) transverse and (L) longitudinal photons takes the compact form [4, 6]

$$\left. \frac{d\sigma_T}{dM^2 dk^2 dt} \right|_{t=0} = \frac{\pi^2}{6} e_f^2 \alpha_{em} \alpha_S^2(q^2) \cdot \frac{m_f^2 + k^2}{M^3 \cos\theta \sqrt{M^2 - 4m_f^2}} \left\{ \left(1 - 2 \frac{k^2 + m_f^2}{M^2} \right) \Phi_1^2 + m_f^2 \Phi_2^2 \right\}, \quad (4)$$

$$\left. \frac{d\sigma_L}{dM^2 dk^2 dt} \right|_{t=0} = \frac{\pi^2}{6} e_f^2 \alpha_{em} Q^2 \alpha_S^2(q^2) \cdot \frac{(m_f^2 + k^2)^3}{M^7 \cos\theta \sqrt{M^2 - 4m_f^2}} \Phi_2^2. \quad (5)$$

Here θ is the quark production angle with respect to the γ^* -pomeron collision axis,

$$\Phi_1 = \int \frac{d\kappa^2}{\kappa^4} f(x_{\mathbf{P}}, \kappa^2) \left[\frac{k}{k^2 + \varepsilon^2} - \frac{k}{\sqrt{a^2 - b^2}} + \frac{2k\kappa^2}{a^2 - b^2 + a\sqrt{a^2 - b^2}} \right], \quad (6)$$

$$\Phi_2 = \int \frac{d\kappa^2}{\kappa^4} f(x_{\mathbf{P}}, \kappa^2) \left[\frac{1}{\sqrt{a^2 - b^2}} - \frac{1}{k^2 + \varepsilon^2} \right], \quad (7)$$

$a = \varepsilon^2 + k^2 + \kappa^2$, $b = 2k\kappa$ and $f(x_{\mathbf{P}}, \kappa^2) = \partial G(x_{\mathbf{P}}, \kappa^2)/\partial \log \kappa^2$ is the unintegrated gluon structure function of the target proton. In the derivation of the pQCD factorization scale we follow the analysis [6]: At small $\kappa^2 \lesssim q^2$ the expression in the square brackets in the integrand of (6) equals $2k\varepsilon^2\kappa^2/q^6$ and tends to a constant value at $\kappa^2 \gtrsim q^2$. Then, in (6) and (7) one has a logarithmic κ^2 integration with q^2 being the upper limit of integration. Consequently, q^2 emerges as the pQCD factorization scale (it has already been used as such in the running strong coupling $\alpha_S(q^2)$ in (4) and (5)) and to the leading $\log q^2$,

$$\Phi_1 = \frac{2kM^4[Q^2(k^2 + m_f^2) + M^2m_f^2]}{(Q^2 + M^2)^3(k^2 + m_f^2)^3} G(x_{\mathbf{P}}, q^2) \quad (8)$$

$$\Phi_2 = \frac{M^4[(k^2 + m_f^2)(M^2 - Q^2) - 2m_f^2M^2]}{(Q^2 + M^2)^3(k^2 + m_f^2)^3} G(x_{\mathbf{P}}, q^2). \quad (9)$$

Notice a zero of the $d\sigma_L$ at $(k^2 + m_f^2)(M^2 - Q^2) = 2m_f^2M^2$. Equations (3), (8) and (9) exhaust the derivation of the mass spectrum.

Subtleties of DD in QCD are clearly seen already for real photons ($Q^2 = 0$), where

$$\begin{aligned} \left. \frac{d\sigma_T}{dM^2 dk^2 dt} \right|_{t=0} &= \frac{1}{6} \pi^2 e_f^2 \alpha_{em} \alpha_S^2 (m_f^2 + k^2) G^2(x_{\mathbf{P}}, m_f^2 + k^2) m_f^2 \\ &\times \left[(k^2 + m_f^2) \left(1 - \frac{8m_f^2}{M^2}\right) + \frac{8m_f^4}{M^2} \right] \frac{1}{M^3 (k^2 + m_f^2)^4 \cos \theta \sqrt{M^2 - 4m_f^2}}. \end{aligned} \quad (10)$$

Evidently, the k^2 -integrated $d\sigma_T/dm^2$ is dominated by the contribution from $k^2 \lesssim m_f^2$. Consequently, to the leading $\log m_f^2$ one can take the k^2 -independent factorization scale $q_0^2 = m_f^2$. (The dominance of the contribution from $k^2 \lesssim m_f^2$ in σ_T holds also at large Q^2 , entailing the pQCD factorization scale q_0^2 of Eq. (2)). We find

$$\left. \frac{d\sigma_T}{dM^2 dt} \right|_{t=0} = \pi^2 e_f^2 \alpha_{em} \alpha_S^2 (m_f^2) G^2(x_{\mathbf{P}}, m_f^2) \times \begin{cases} \frac{\sqrt{M^2 - 4m_f^2}}{96m_f^7}, & \text{if } M^2 - 4m_f^2 \lesssim m_f^2 \\ \frac{1}{12m_f^2 M^4}, & \text{if } M^2 \gg 4m_f^2 \end{cases}. \quad (11)$$

The M^2 and $x_{\mathbf{P}}$ dependence in (11) do factor and one may try to reinterpret the $x_{\mathbf{P}}$ dependent factor as the pomeron flux function

$$\phi_{\mathbf{P}}^{(f\bar{f})}(x_{\mathbf{P}}) = \left(\frac{G(x_{\mathbf{P}}, m_f^2)}{G(x_0, m_f^2)} \right)^2, \quad (12)$$

subject to the normalization $\phi_{\mathbf{P}}^{(f\bar{f})}(x_0 = 0.03) = 1$ [7]. The explicit flavour dependence in (12) breaks the Regge factorization, hence the universal flux of QCD pomerons does not exist.

Consider now the DIS regime of large Q^2 . For transverse photons, the expression in the curly braces in Eq. (4) is a function of only β and Q^2 and can be a basis for the definition of the $f\bar{f}$ pomeron structure function $F_{\mathbf{P}}^{(f\bar{f})}(\beta, Q^2)$. The factor $\alpha_S^2(q_0^2) = \alpha_S^2(m_f^2(1-\beta)^{-1})$ also is a function of β only and as such can be reabsorbed into the $F_{\mathbf{P}}^{(f\bar{f})}(\beta, Q^2)$. The $x_{\mathbf{P}}$ dependence comes entirely from $G^2(x_{\mathbf{P}}, q_0^2) = G^2(x_{\mathbf{P}}, m_f^2(1-\beta)^{-1})$ and here by virtue of the QCD scaling violations the $x_{\mathbf{P}}$ and β dependences are inextricably entangled, which breaks the Regge factorization (1) explicitly. One can think of a generalized factorization at best, leaving the pomeron flux factor to depend explicitly on β and on flavour:

$$\phi_{\mathbf{P}}^{(f\bar{f})}(x_{\mathbf{P}}, \beta) = \left(\frac{G(x_{\mathbf{P}}, m_f^2(1-\beta)^{-1})}{G(x_0, m_f^2(1-\beta)^{-1})} \right)^2. \quad (13)$$

Because q_0^2 rises with β , the pQCD is applicable better at smaller M ; for the specific case of exclusive vector meson production see [11].

At this point, a brief digression on the still more striking, and different, Regge factorization breaking in the longitudinal cross section is in order [12]. Substituting (8) into (5), one readily finds

$$\begin{aligned} \left. \frac{d\sigma_L}{dM^2 dk^2 dt} \right|_{t=0} &= \frac{1}{6} \pi^2 e_f^2 \alpha_{em} Q^2 \alpha_S^2(k^2 + \varepsilon^2) G^2(x, k^2 + \varepsilon^2) \\ &\times \frac{M[(k^2 + m_f^2)(M^2 - Q^2) - 2m_f^2 M^2]^2}{\cos \theta (Q^2 + M^2)^6 (k^2 + m_f^2)^3 \sqrt{M^2 - 4m_f^2}} \end{aligned} \quad (14)$$

which decreases with k^2 only as k^{-2} . While σ_T is dominated by the contribution from $k^2 \lesssim m_f^2$, for σ_L the dominant contribution comes from large $k^2 \sim \frac{1}{4}M^2 - m_f^2$. This has two major implications: First, σ_L has the higher twist Q^2 dependence $\sigma_L \propto \sigma_T/Q^2 \propto 1/Q^4$ [8]. Second, in σ_L the factorization scale $q_0^2 \sim \frac{1}{4}Q^2$, the $x_{\mathbf{P}}$ and Q^2 dependence in $d\sigma_L$ are inextricably entangled and the generalized flux of pomerons does explicitly depend on Q^2 , $\phi_{\mathbf{P}}^L(x_{\mathbf{P}}) \propto G^2(x_{\mathbf{P}}, \frac{1}{4}Q^2)$, rather than on β and flavour in the case of $d\sigma_T$.

The exceptional case is the triple pomeron region of $\beta \ll 1$ dominated by DD into the $q\bar{q}g..$ states, where the conditions of the Regge factorization are fulfilled at $Q^2 \gtrsim 3 \text{ GeV}^2$ for all the flavours simultaneously and the corresponding flux function $f_{\mathbf{P}}(x_{\mathbf{P}})$ is flavour blind. This conclusion readily follows from an analysis of the colour dipole content of the triple-pomeron coupling in ref. [13].

Hereafter we focus on DD of transverse photons into $c\bar{c}$ states, which dominates the open charm excitation in LRG events at $\beta \gtrsim 0.1-0.2$. For open charm the factorization scale (2) is still not large, we evaluate the open charm cross section in the colour dipole gBFKL formalism described in detail in [4, 5, 7]. In Fig. 2 we show our results for the total cross section of diffraction excitation of $c\bar{c}$ pairs. The evaluation of this cross section requires the t -integration; one can argue that for the heavy flavour excitation the diffraction slope B is smaller than the light flavours one ($B_{el} \approx 10 \text{ GeV}^{-2}$). In the following we use $B_{c\bar{c}} = 6 \text{ GeV}^{-2}$ (for instance, see [14]). The closer analysis of Eqs. (4) suggests a simple interpolation $\sigma_T \propto 1/(Q^2 + 4m_f^2)$ between the real photoproduction ($Q^2 = 0$) and DIS ($Q^2 \gg 4m_f^2$) at fixed value of the natural variable $x_{Pom} = (Q^2 + 4m_c^2)/(W^2 + Q^2)$. This scaling is demonstrated in Fig. 2 where we plot $(Q^2 + 4m_c^2)\sigma_T^{(c\bar{c})}$ as a function of the Bjorken variable x and x_{Pom} .

Notice the very steep rise, $\sigma_T \propto x_{Pom}^{-\epsilon}$, at $x_{Pom} \lesssim 10^{-3}$, with the exponent $\epsilon \approx 0.72$ which is very close to the asymptotic gBFKL prediction $\epsilon = 2\Delta_{\mathbf{P}} = 0.8$ (for the prediction of the precocious onset of the BFKL behaviour in the charm structure function of the proton see [15]). In Fig. 3 we show the flux function $\phi_{\mathbf{P}}^{(c\bar{c})}(x_{\mathbf{P}})$ defined for the above integrated $c\bar{c}$ excitation cross section at large Q^2 , which is dominated by the contribution from $\beta \sim 0.5$. For the region $0.1 \lesssim x_{\mathbf{P}} \lesssim 10^{-4}$ accessible at HERA, the convenient parameterization is

$$\phi_{\mathbf{P}}^{(c\bar{c})}(x_{\mathbf{P}}) = \left(\frac{x_o}{x_{\mathbf{P}}}\right)^{p_1} \left(\frac{x_{\mathbf{P}} + p_3}{x_o + p_3}\right)^{p_2} \quad (15)$$

with $p_1 = 0.7233, p_2 = 0.3939, p_3 = 2.377 \cdot 10^{-3}$, which is different from the flux function $\phi_{\mathbf{P}}(x_{\mathbf{P}})$ for the valence light-flavour component of the pomeron ($p_1 = 0.569, p_2 = 0.4895, p_3 = 0.153 \cdot 10^{-3}$) and the flux function $f_{\mathbf{P}}(x_{\mathbf{P}})$ for the sea (triple-pomeron) component of the pomeron ($p_1 = 0.741, p_2 = 0.586, p_3 = 0.8 \cdot 10^{-3}$) [7]. The charm content of DD is predicted to rise by one order of magnitude from $x_{\mathbf{P}} = 0.01$ to $x_{\mathbf{P}} = 0.0001$ (see also Fig. 6).

Now we focus on the Q^2 and β dependence of the open charm excitation. The variation of the factorization scale (2) at $\beta \lesssim 0.5$ is marginal, but at $1 - \beta \ll 1$ the factorization-breaking β dependence of the generalized flux function (15) is quite strong. The distortion

factor

$$\Gamma(\beta) = \frac{\phi_{\mathbf{P}}^{(c\bar{c})}(x_{\mathbf{P}}, \beta)}{\phi_{\mathbf{P}}^{(c\bar{c})}(x_{\mathbf{P}}, \beta = 0.5)} \quad (16)$$

presented in Fig. 4, shows how the shape of the β distribution varies with $x_{\mathbf{P}}$ in defiance of the Regge factorization. Here we have evaluated $\Gamma(\beta)$ using the GRV gluon structure function [16], for other parameterizations of parton densities the results for the factorization breaking will be very similar.

Despite having discredited the very concept of the pomeron structure function, we can not help but use this language to make the contact with what has unfortunately become a common presentation of the experimental data on DD. The t -integrated cross section measured at HERA can be represented as

$$(M^2 + Q^2) \frac{d\sigma_D(\gamma^* \rightarrow X)}{dM^2} = \frac{\sigma_{tot}(pp)}{16\pi B_{el}} \frac{4\pi^2 \alpha_{em}}{Q^2} F_D(x_{\mathbf{P}}, \beta, Q^2) \quad (17)$$

with the valence light ($q\bar{q}$) and valence charm ($c\bar{c}$) decomposition of the non-factorizing "diffractive structure function" (we omit the negligible $b\bar{b}$ contribution, neglect the marginal difference between fluxes for the $s\bar{s}$ and $u\bar{u}$, $d\bar{d}$ excitation and limit ourselves to the transverse structure function.)

$$F_D(x_{\mathbf{P}}, \beta, Q^2) = \phi_{\mathbf{P}}(x_{\mathbf{P}}) F_{\mathbf{P}}^{(q\bar{q})}(\beta, Q^2) + \phi_{\mathbf{P}}^{(c\bar{c})}(x_{\mathbf{P}}, \beta) F_{\mathbf{P}}^{(c\bar{c})}(\beta, Q^2) + f_{\mathbf{P}}(x_{\mathbf{P}}) F_{\mathbf{P}}^{(sea)}(\beta, Q^2). \quad (18)$$

The result [7] for light flavours, $F_{\mathbf{P}}^{(q\bar{q})}(\beta) \approx 0.27\beta(1 - \beta)$, evaluated with the diffraction slope $B_{el} = 10 \text{ GeV}^{-2}$, provides an excellent description of the experimental data [9, 10]. In Fig. 5 we show our predictions for the β dependence of the $c\bar{c}$ component of $F_D(x_{\mathbf{P}}, \beta, Q^2)$ at $x_{\mathbf{P}} = 0.001$. Because $M^2 \gtrsim 4m_c^2$, the $F_D^{(c\bar{c})}(x_{\mathbf{P}}, \beta, Q^2)$ vanishes at $\beta > \beta_c = \frac{Q^2}{Q^2 + 4m_c^2}$. The impact of this threshold effect on $F_D^{(c\bar{c})}(\beta, Q^2)$ was for the first time discussed in [4]. Fig. 5 updates Fig. 10 of ref. [4]; in the present calculation we use the more modern gBFKL dipole cross section of [17, 11].

In Fig. 6 we show the threshold effect due to opening of the charm production in $F_D(x_{\mathbf{P}}, \beta, Q^2)$ considered as a function of Q^2 at different values of β . Here we neglect the possible scaling violations in the light flavour contribution $F_D^{(q\bar{q})}(x_{\mathbf{P}}, \beta, Q^2)$ (see below). In the domain of $0.35 \lesssim \beta \lesssim 0.8$ and $5 \lesssim Q^2 \lesssim 200 \text{ GeV}^2$ of the current HERA experiments,

the predicted threshold rise of $F_D(x_{\mathbf{P}}, \beta, Q^2)$ is quite strong and must be observable. The error bars of the presently available HERA data [9, 10] on $F_D(x_{\mathbf{P}}, \beta, Q^2)$ are still too large for the observation of the charm threshold effect. Fig. 6 clearly demonstrates the rise of the charm content of DD towards small $x_{\mathbf{P}}$: at the typical $\beta \sim 0.5$ and $x_{\mathbf{P}} = 10^{-2}$ not shown here the charm contribution and the threshold effect are $\sim 3\%$, which rises to $\sim 9\%$ at $x_{\mathbf{P}} = 10^{-3}$ and $\sim 25\%$ at $x_{\mathbf{P}} = 10^{-4}$, cf. different fluxes in Fig. 3. At even smaller $x_{\mathbf{P}}$, not accessible at HERA, the charm content of DD levels off. The strong $x_{\mathbf{P}}$ -dependence of the charm content of DD is a non-negotiable consequence of pQCD; such a $x_{\mathbf{P}}$ -dependence is absent in Regge models [18, 19, 20]. Neither works [18, 19] discuss the strong impact of the charm threshold on the Q^2 dependence of DD at large β . One of the two models of DD into open heavy flavour discussed in [20] assumes a pointlike pomeron-quark coupling; in this model too the charm content does not depend on $x_{\mathbf{P}}$. Such a pointlike pomeron-quark coupling is not born out in our pQCD approach.

Several more comments on our results are in order:

First, for heavy flavours the results for the β distribution are exact in contrast to the nonperturbative DD into light flavours, where the β dependence is not pQCD calculable. Fig. 5 shows that at very large $Q^2 \gg 4m_c^2$, in a broad range of β , the β dependence of $F_D^{(c\bar{c})}(x_{\mathbf{P}}, \beta, Q^2)$ follows the approximation $\propto \beta(1 - \beta)$ fairly well. In terms of the mass spectrum, it corresponds to $d\sigma_D^{(c\bar{c})}/dM^2 \sim M^2/(Q^2 + M^2)^3$. The departures from this law were noticed already in [4] (see Fig. 3 in [4]). Indeed, in a very narrow region of $\beta \rightarrow 1$, i.e., $4m_c^2 \ll M^2 \ll Q^2$, from Eqs. (4),(8),(9) one readily finds (modulo to the pQCD scaling violations) $d\sigma_D^{c\bar{c}}/dM^2 \sim M^4/(Q^2 + M^2)^4$ and $F_D^{c\bar{c}}(x_{\mathbf{P}}, \beta, Q^2) \propto (1 - \beta)^2$. Although this observation is hardly of practical significance, the law $F_D(x_{\mathbf{P}}, \beta, Q^2) \propto (1 - \beta)^2$ will be applicable also to the light flavour excitation in a very narrow domain for $\beta \rightarrow 1$, in which the factorization scale (2) is sufficiently large for the pQCD applicability (for a hint at such a β dependence see also Fig. 3 in [4]).

Second, the factorization breaking and the β -dependent pQCD factorization scale have certain implications for the Q^2 -evolution of $F_D^{c\bar{c}}(x_{\mathbf{P}}, \beta, Q^2)$, which remains one of the open issues in the theory of DD. In [5] it was shown that an approximate GLDAP evolution

is recovered in the double leading-log Q^2 , leading-log $\frac{1}{\beta}$ approximation. Here we wish to comment that Eq. (2) implies that DD at large β is dominated by excitation of $q\bar{q}$ pairs with the transverse size $r_{q\bar{q}}$ which decreases with β ,

$$r_{q\bar{q}}^2 \propto \frac{1}{m_f^2}(1 - \beta). \quad (19)$$

At large values of the Bjorken variable β the parton distributions decrease with Q^2 for the radiation of gluons. Evidently, the radiation of gluons by a colour singlet system of size $r_{q\bar{q}}$ requires the condition $Q^2 r_{q\bar{q}}^2 \gg 1$. Then, Eqs. (2),(19) hint at the possibility that the larger β the larger $Q_0^2 \propto (1 - \beta)^{-1}$ is needed for the onset of the conventional pattern of the Q^2 evolution of $F_D^{c\bar{c}}(x_{\mathbf{P}}, \beta, Q^2)$ at $Q^2 > Q_0^2$.

Third, the predicted steep rise of the charm excitation cross section has a non-negligible impact on the $x_{\mathbf{P}}$ dependence of $F_D(x_{\mathbf{P}}, \beta, Q^2)$. Consider the $x_{\mathbf{P}}^{-\epsilon}$ approximation of this quantity in the vicinity of $x_{\mathbf{P}} \sim 10^{-3}$ typical for the current HERA experiments. For excitation of light flavours $q = u, d, s$, our prediction [7] for the flux function $\phi_{\mathbf{P}}(x_{\mathbf{P}})$ corresponds to $\epsilon(uds) \approx 0.15$, which is close to the soft pomeron model predictions [3, 18, 19, 20]. For the charm excitation we predict $\epsilon(c) \approx 0.72$ at $x_{\mathbf{P}} \lesssim 10^{-3}$. Although the abundance of charm is numerically small, the steeply rising contribution of the charm to $F_D(x_{\mathbf{P}}, \beta, Q^2)$ substantially renormalizes upwards the exponent ϵ for the total DD cross section: at $\beta \sim 0.5$ and Q^2 above the charm threshold our crude estimate is $\epsilon(uds+c) \approx 0.20$. For comparison, in the triple pomeron region of $\beta \ll 1$ our prediction [7] for the flux function $f_{\mathbf{P}}(x_{\mathbf{P}})$ corresponds to $\epsilon \approx 0.32$. Evidently, the estimates for these exponents depend on β and on the range of $x_{\mathbf{P}}$ considered, see Figs. 3 and 4.

To summarize, we have presented the pQCD derivation of the mass spectrum and cross section of DD into open charm in DIS at HERA. Our results unequivocally demonstrate strong breaking of the Regge factorization in diffraction dissociation of photons, which has already been advocated by two of the authors in a previous work [4]. We predict a very steep rise of the charm content of DD towards small $x_{\mathbf{P}}$, which is a distinctive consequence of pQCD and can be tested at HERA. We predict strong $x_{\mathbf{P}}$ dependence of the β distribution in open charm production at $\beta \rightarrow 1$, which also can be tested in the HERA experiments. We have found a substantial charm threshold effects in the Q^2 dependence of

the diffractive structure function at large β which must be observable with higher statistics data at HERA. This charm threshold effect leads to a counterintuitive rise of the large- β diffractive structure function with Q^2 , which is stronger at smaller $x_{\mathbf{P}}$. Our finding of the β -dependent pQCD factorization scale casts shadow on the GLDAP description of the Q^2 -evolution of the diffractive structure function at large β .

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