Subleading Reggeons in Deep Inelastic Diffractive Scattering
at HERA

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Abstract

The contribution of subleading reggeons to the diffractive structure function $dF^D_2/dx dt$ is estimated from the soft physics data. This contribution leads in a natural way to the violation of the factorization property of the diffractive structure function.
The diffractive processes in deep inelastic scattering, observed at the ep collider HERA by the H1 and Zeus collaboration [1, 2], were interpreted in terms of the exchange of the leading Regge trajectory corresponding to the soft pomeron with a partonic substructure [3, 4, 5, 6]. In this interpretation the diffractive interaction is treated as a two step process: an emission of the soft pomeron from a proton and a hard scattering of a virtual photon on a partonic constituent of the pomeron. In this case the diffractive structure function (DSF) is given in the factorizable form

\[
\frac{dF_2^D}{dx d^2t}(x, Q^2, x_F, t) = f^P(x_F, t) F_2^P(\beta, Q^2) .
\]  

Here \( x \) is the Bjorken variable, \( Q^2 \) is the virtuality of the photon, \( x_F \) is the fraction of the momentum of the proton carried away by the pomeron, \( t \) is the pomeron virtuality and \( \beta = x/x_F \). The function \( f^P(x_F, t) \) is the "pomeron flux" describing the pomeron emission and \( F_2^P(\beta, Q^2) \) is the pomeron structure function.

The "pomeron flux" has the following form [6]

\[
f^P(x_F, t) = N x^{1-2\alpha_P(t)/16\pi},
\]

where \( \alpha_P(t) = 1.1 + (0.25 \text{ GeV}^{-2}) \cdot t \) is the pomeron trajectory (with slightly increased value of the intercept \( \alpha_P(0) \)) and \( B_P(t) \) is the pomeron coupling to a proton. The normalization factor \( N \) was set to be equal to \( 2/\pi \).

The pomeron structure function \( F_2^P(\beta, Q^2) \) is related to the parton distributions in the pomeron in the same way as for the proton. The partonic structure of the pomeron was estimated in [4, 5, 6] and independently fitted to the diffractive HERA data [1, 2] using the QCD evolution equations [7, 8, 9]. Contrary to the proton case a large gluonic component of the pomeron was found at \( \beta \to 1 \).

In view of a new preliminary data, shown for the first time by the H1 collaboration during the 1996 Eilat conference [10], which suggest breaking of the factorization property (1) of the DSF, it is interesting to estimate the contribution of the subleading reggeons to the factorization breaking of the DSF. This idea appeared for the first time among other possibilities in the H1 Collaboration talk in Eilat [10].

We add to the DSF (1) the "Regge" contribution

\[
\frac{dF_2^R}{dx d^2t}(x, Q^2, x_F, t) = f^R(x_F, t) F_2^R(\beta, Q^2) ,
\]  

where in this case \( f^R(x_F, t) \) is the "reggeon flux" and \( F_2^R(\beta, Q^2) \) is the reggeon structure function. In principle we should sum over the different Regge pole contribution and include interference terms. As a first approximation, we assume that the reggeon structure functions \( F_2^R(\beta, Q^2) \) are the same for all reggeons and we also neglect the interference terms between different reggeons as well as between reggeons and the pomeron. In this case

\[
f^R(x_F, t) = \sum_{R_i} f^{R_i}(x_F, t) ,
\]

where each term \( f^{R_i}(x_F, t) \) represents the contribution of a single reggeon.
\[ f^{R_i}(x_P, t) = N x_P^{1-2\alpha_i(t)} \frac{B_i^2(t)}{16\pi} C_i(t) , \]  

where \( C_i(t) = 4\cos^2(\pi\alpha_i(t)/2) \) or \( C_i(t) = 4\sin^2(\pi\alpha_i(t)/2) \) for even signature reggeons \( (f_2, a_2) \) or odd signature reggeons \( (\rho, \omega) \) respectively. The functions \( \alpha_i(t) \) are the reggeon trajectories, \( B_i(t) \) denote the reggeon couplings to a proton and \( N = 2/\pi \).

The dominant contribution to sum (4) comes from the isoscalar exchanges of \( f_2 \) and \( \omega \) mesons which approximately lie on the same Regge trajectory
\[ \alpha(t) \approx 0.5 + (1.0 \text{ GeV}^{-2}) \cdot t . \]  

The corresponding couplings \( B_i(0) \) can be deduced from the total cross section data. The \( f_2 \) and \( \omega \) exchanges give the following contribution to the total \( pp \) and \( p\bar{p} \) cross sections
\[ \sigma_{pp}^R = \sin(\pi\alpha(0)) \left( B_{f_2}^2 - B_{\omega}^2 \right) \left( \frac{s}{s_0} \right)^{\alpha(0)-1} , \]  
\[ \sigma_{p\bar{p}}^R = \sin(\pi\alpha(0)) \left( B_{f_2}^2 + B_{\omega}^2 \right) \left( \frac{s}{s_0} \right)^{\alpha(0)-1} , \]  
where \( s_0 = 1\text{GeV}^2 \). Using Donnachie and Landshoff parametrization \([11]\), we obtain the following values of the couplings
\[ B_{f_2}^2 = \frac{98.39 + 56.08}{2} \text{mb} \approx 77.3 \text{mb} , \]  
\[ B_{\omega}^2 = \frac{98.39 - 56.08}{2} \text{mb} \approx 21.1 \text{mb} . \]  

We neglect the \( t \) dependence of the couplings in our analysis.

The analytical form of the reggeon and pomeron structure function \( F_2^{R(P)}(\beta, Q^2) \) at small \( \beta \) can be estimated from the triple Regge analysis of the diffractive scattering, valid for a large mass \( M_X \) of a diffractive system \( (\beta \to 0) \). In this limit the pomeron structure function is determined by the triple pomeron \( (\Pi\Pi\Pi) \) coupling, while the reggeon-reggeon-pomeron \( (RR\Pi) \) coupling determines the reggeon structure function. In both cases the structure functions have the same analytical form at small \( \beta \)
\[ F_2^{R(P)}(\beta, Q^2) = A_{R(P)}(Q^2) \beta^{-0.08} . \]  

Due to the Regge factorization, the coefficient \( A_{R(P)}(Q^2) \) is a product of the \( RR\Pi \) \( (\Pi\Pi\Pi) \) coupling and the \( Q^2 \) dependent coupling of the pomeron to the virtual photons. For the pomeron case the coefficient \( A_P \) was estimated in \([1]\) to be \( A_P = 0.03 \) at the scale \( Q_0^2 = 4\text{GeV}^2 \). This relatively small value is a direct consequence of the small magnitude of the triple pomeron coupling. The effective coupling controlling the \( RR\Pi \) contribution to inclusive hadronic cross sections in the triple Regge region is about one order of magnitude bigger than that in the triple pomeron term \([12]\). We do therefore expect that the \( RR\Pi \) coupling should also be significantly bigger than the triple pomeron one. Thus, in our estimate we vary the coefficient \( A_R \) in formula \([11]\) within the limits \( A_R = 0.1 - 1.0 \).
Finally, we extrapolated the parametrization of $F_{2}^{R}$ to the region of moderate and large values of $\beta$ by multiplying the r.h.s of formula (11) by $(1 - \beta)$.

We have also checked how the QCD evolution in $Q^2$ of the reggeon structure function $F_{2}^{R}$ influences the results, and found that it is not important, especially in view of the above uncertainties.

In Fig.1 we show the DSF integrated over $t$, denoted by $F_{2}^{D(3)}(x_{F}, \beta, Q^2)$, as a function of $x_{F}$. The values of $\beta$ and $Q^2$ are those used in the H1 collaboration analysis \cite{13}. The solid lines correspond to the soft pomeron contribution (1) found in analysis \cite{9} of the published diffractive data \cite{1, 2}. The dotted, dashed and dot-dashed lines correspond to the sum of the pomeron and reggeon contributions with the coefficient $A_{R}$ equal to 0.1, 0.5 and 1.0 respectively.

The DSF is now the sum of the two terms

$$\frac{dF_{2}^{D}}{dx_{F}dt}(x, Q^2, x_{F}, t) = f^{P}(x_{F}, t) F_{2}^{P}(\beta, Q^2) + f^{R}(x_{F}, t) F_{2}^{R}(\beta, Q^2),$$

where $f^{P}(x_{F}, t) \neq f^{R}(x_{F}, t)$. This fact leads to a violation of the factorization property of the DSF, i.e. the DSF is no longer a product of the $x_{F}$ dependent “flux factor” and $\beta$ dependent structure function.

To summarize, we estimated the subleading reggeon contribution to the DSF, based on the triple Regge limit of diffractive scattering. These corrections are important for small values of $\beta$ and for $x_{F}$ bigger then $10^{-2}$, however, the precise value of the size of these corrections is difficult to estimate. The subleading corrections lead in a natural way to the violation of the factorization property of the DSF

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| $Q^2$ | $F_2^{D(3)}(x_P, \beta, Q^2)$ | $\beta$ | $Q^2$ | $F_2^{D(3)}(x_P, \beta, Q^2)$ | $\beta$ | $Q^2$ | $F_2^{D(3)}(x_P, \beta, Q^2)$ | $\beta$ | $Q^2$ | $F_2^{D(3)}(x_P, \beta, Q^2)$ |
|------|-----------------------------|-------|------|-----------------------------|-------|------|-----------------------------|-------|------|-----------------------------|
| 2.5  | $\beta=0.01$               | 0.1   | 3.5  | $\beta=0.01$               | 0.1   | 5    | $\beta=0.01$               | 0.1   | 8.5  | $\beta=0.01$               | 0.1   |
| 3.5  | $\beta=0.04$               | 0.1   | 5    | $\beta=0.04$               | 0.1   | 8.5  | $\beta=0.04$               | 0.1   | 12   | $\beta=0.04$               | 0.1   |
| 5    | $\beta=0.1$                | 0.1   | 8.5  | $\beta=0.1$                | 0.1   | 12   | $\beta=0.1$                | 0.1   | 20   | $\beta=0.1$                | 0.1   |
| 8.5  | $\beta=0.2$                | 0.1   | 12   | $\beta=0.2$                | 0.1   | 20   | $\beta=0.2$                | 0.1   | 35   | $\beta=0.2$                | 0.1   |
| 12   | $\beta=0.4$                | 0.1   | 20   | $\beta=0.4$                | 0.1   | 35   | $\beta=0.4$                | 0.1   | 65   | $\beta=0.4$                | 0.1   |
| 20   | $\beta=0.65$               | 0.1   | 35   | $\beta=0.65$               | 0.1   | 65   | $\beta=0.65$               | 0.1   |      | $\beta=0.65$               | 0.1   |
| 35   | $\beta=0.9$                | 0.1   |      | $\beta=0.9$                | 0.1   |      | $\beta=0.9$                | 0.1   |      | $\beta=0.9$                | 0.1   |

Figure 1: $F_2^{D(3)}(x_P, \beta, Q^2)$ as a function of $x_P$ for different $\beta$ and $Q^2$ values (given in $GeV^2$). The solid lines correspond to the soft pomeron contribution. The dotted, dashed and dot-dashed lines show the sum of the pomeron and reggeon contributions with the coefficient $A_R$ equal to 0.1, 0.5 and 1.0 respectively.