REGGEONS IN DIFFRACTIVE INTERACTIONS IN DEEP INELASTIC SCATTERING AT HERA

K. GOLEC-BIERNAT\textsuperscript{a,b}, J. KWIĘCİŃSKI\textsuperscript{a} and A. SZCZUREK\textsuperscript{b}

\textsuperscript{a}Department of Physics, University of Durham, Durham DH1 3LE, England
\textsuperscript{b}Institute of Nuclear Physics, Radzikowskiego 152, Kraków 30-342, Poland

The "triple-Regge" analysis of subleading Reggeon contributions to the diffractive structure function in DIS at HERA is presented. The recently published data allow to determine the only free parameter of the analysis related to the ratio of the $\text{RRI}_P$ and $\text{PP}_P$ couplings. The large value of this ratio is preferred which is in agreement with analyses of soft hadronic interactions. The role of the subleading Reggeons as well as pions for the fast forward neutron production in diffractive processes is estimated. The forward $\pi N$ state production is also discussed.

1 Introduction

The new diffractive DIS data from HERA, published by the H1 collaboration\textsuperscript{1}, indicate breaking of the Regge factorization of the diffractive structure function. The physical picture which lies behind this factorization is the "soft" Pomeron emission from the proton and a subsequent hard scattering of the virtual photon on a parton in the Pomeron\textsuperscript{2,3,4} (for the alternative description see\textsuperscript{5,6}).

In order to describe the breaking of the factorization it was recently proposed to include the contribution coming from subleading Reggeons\textsuperscript{1,7,8}. In the approach presented here the diffractive structure function is written as:

$$
\frac{dF_D}{dx^2 x_\gamma^2 dt}(x, Q^2, x_\gamma, t) = f^P(x_\gamma, t) F^P_2(\beta, Q^2) + \sum_R f^R(x_\gamma, t) F^R_2(\beta, Q^2),
$$

where $\beta = x/x_\gamma$, and $f^P$ and $f^R$ are the Pomeron and Reggeon flux factors respectively, and $F^P_2$ and $F^R_2$ are their DIS structure functions. The details of the Pomeron contribution can be found in\textsuperscript{4} and we shall concentrate in this presentation on the Reggeon part of (1).

The Reggeon flux factors are parametrized in analogy to the Pomeron case

$$
 f^R(x_\gamma, t) = \frac{N}{16\pi} x^{1-2\alpha_R(t)} B_R^2(t) |\eta_R(t)|^2,
$$

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$^b$The term "diffractive processes" applies only to processes described by the Pomeron exchange. For simplicity we shall use the same terminology for the Reggeon exchanges.
where $\alpha_R(t)$ is the Reggeon trajectory, $B_R(0) = B_R(0) \exp(t/(2\Lambda_R^2))$ with $\Lambda_R = 0.65$ GeV, as known from the Reggeon phenomenology of hadronic reactions, describes the coupling of the Reggeon to the proton. The function $\eta_R(t)$ is the signature factor $|\eta_R(t)|^2 = 4 \cos^2(\pi \alpha_R(t)/2)$ or $4 \sin^2(\pi \alpha_R(t)/2)$ for even and odd signature Reggeons, respectively.

The exchange (emission) of the isoscalar Reggeons ($f_2, \omega$) dominates the Reggeon contribution to (1), and the isovector subleading Reggeons ($a_2, \rho$) can be neglected. However, they become important for the processes with leading neutron in the final state. Therefore we include them in our analysis and show that for small values of $x$, the isovector Reggeons give the dominant contribution to the leading neutron production.

The size of the Reggeon contributions is determined by the Reggeon-proton couplings $B_R(0)$. They can be estimated from the energy dependence of the total hadronic cross section, see (4) for the description of the method. As a result we obtain that $B_{f_2}^2(0) = 75.49$ mb, $B_{\omega}^2(0) = 20.06$ mb, $B_{a_2}^2(0) = 1.75$ mb and $B_{\rho}^2(0) = 1.09$ mb, where the same Reggeon trajectory, $\alpha_R(t) = 0.55 + 1.0 t$, was assumed for the four Reggeons. One clearly sees the following ordering

$$B_{f_2}^2(0) > B_{\omega}^2(0) \gg B_{a_2}^2(0) \approx B_{\rho}^2(0) ,$$

which confirms the dominance of the isoscalar Reggeons.

We are interested in the Reggeon structure function $F_R^2$ for small $\beta$, since we expect that in this kinematical limit the Reggeon contribution to (3) is most important. In that limit we can apply the "triple-Regge" analysis to our problem, (see (4) for more details), in which both the Pomeron and Reggeon structure functions are of the form

$$F_2^{g,R}(\beta) = A_{g,R} \beta^{-0.08} ,$$

for small $\beta$, where the ratio

$$C_{enh} = \frac{A_R}{A_g}$$

is related to the ratio of the "triple-Regge" $RRP$ and $PPRP$ couplings, and should be much bigger than one, as suggested by the analysis of soft hadronic interactions.

Indeed the new data from HERA, presented in terms of the structure function (3) integrated over $t$ and denoted by $F_2^{D(3)}$, prefer $C_{enh} \approx 10$ in which case a reasonable agreement of our description with the data is obtained for $\beta \leq 0.4$. This is illustrated in Fig.1 where the pure Pomeron contribution from (solid lines) and the effect of the Reggeon terms (dashed lines) is shown.
| $Q^2$ (GeV$^2$) | $\beta$ | $x_P$ | $F^D_2(x)$ |
|--------------|-------|------|----------------|
| 4.5          | 0.04  | 0    |                |
| 7.5          | 0.04  | 0    |                |
| 9            | 0.04  | 0    |                |
| 12           | 0.04  | 0    |                |
| 18           | 0.04  | 0    |                |
| 28           | 0.04  | 0    |                |
| 45           | 0.04  | 0    |                |
| 75           | 0.04  | 0    |                |
| 75           | 0.1   | 0    |                |
| 9            | 0.1   | 0    |                |
| 12           | 0.1   | 0    |                |
| 18           | 0.1   | 0    |                |
| 28           | 0.1   | 0    |                |
| 45           | 0.1   | 0    |                |
| 75           | 0.1   | 0    |                |
| 75           | 0.2   | 0    |                |
| 9            | 0.2   | 0    |                |
| 12           | 0.2   | 0    |                |
| 18           | 0.2   | 0    |                |
| 28           | 0.2   | 0    |                |
| 45           | 0.2   | 0    |                |
| 75           | 0.2   | 0    |                |
| 75           | 0.4   | 0    |                |
| 9            | 0.4   | 0    |                |
| 12           | 0.4   | 0    |                |
| 18           | 0.4   | 0    |                |
| 28           | 0.4   | 0    |                |
| 45           | 0.4   | 0    |                |
| 75           | 0.4   | 0    |                |
| 75           | 0.65  | 0    |                |
| 9            | 0.65  | 0    |                |
| 12           | 0.65  | 0    |                |
| 18           | 0.65  | 0    |                |
| 28           | 0.65  | 0    |                |
| 45           | 0.65  | 0    |                |
| 75           | 0.65  | 0    |                |
| 75           | 0.9   | 0    |                |
| 9            | 0.9   | 0    |                |
| 12           | 0.9   | 0    |                |
| 18           | 0.9   | 0    |                |
| 28           | 0.9   | 0    |                |
| 45           | 0.9   | 0    |                |
| 75           | 0.9   | 0    |                |

Figure 1: The comparison of the structure function $x_P F^D_2(x)$ measured at HERA and the results of the presented analysis. The solid lines correspond to the pure Pomeron contribution while the dashed lines show the effect of the Reggeon exchanges for $C_{enK} = 10$. 
The model presented here allows to separate the diffractive structure function $F_2^{D(3)}$ into two distinct contributions $\Delta^{(p)}$ and $\Delta^{(n)}$ with the leading proton or neutron observed in the final state, respectively

$$F_2^{D(3)}(\beta, x_{IP}, Q^2) = \Delta^{(p)}(\beta, x_{IP}, Q^2) + \Delta^{(n)}(\beta, x_{IP}, Q^2).$$

Additionally, we add pions to our model. Their contribution has the same form as the Reggeon contribution, but now the one-pion exchange model was assumed for the form of the pion flux factor $f^\pi(x_{IP}, t)$ and the GRV parametrization of the pion structure function $F_2^\pi(\beta, Q^2)$ was used.

In Fig.2 we show $\Delta^{(p)}$ and $\Delta^{(n)}$ marked by the solid lines. As expected, the proton contribution dominates over the neutron one almost in the whole range of $x_{IP}$ because of the Pomeron contribution present in $\Delta^{(p)}$ but absent in $\Delta^{(n)}$. The ratio $\Delta^{(n)}/\Delta^{(p)}$ becomes significant ($\sim 0.1$) only for $x_{IP} > 0.1$, where the Pomeron exchange is suppressed. In this case the Reggeon and pion contributions come into play. However, this region needs a careful treatment since it might already be unsuitable for the Regge analysis.

The lower curves in Fig.2 show different contributions to the fast forward neutron production. For large values of $x_{IP}$, the $\pi^+$ exchange process, marked
by the dash-dotted line, is the dominant effect. The situation changes when \(x_P\) is getting smaller and the Reggeon exchanges (shown by the dashed lines) are almost entirely responsible for the fast neutron production.

Is it possible to identify these contributions experimentally? We suggest studies with the help of the Monte Carlo models which are supposed to describe diffractive interaction in DIS at HERA with the Reggeon contribution included.

3 Diffractive \(\pi N\) production

In the presented analysis we have neglected the contribution of diffractively produced \(\pi N\) and \(\pi\pi N\) states. For small values of \(x_P\) relevant here only the \(\pi N\) contribution is of interest\(^\text{18}\). The analysis of the \(\pi N\) contribution to the structure function \(^\text{12}\) is performed using the Deck mechanism\(^\text{14}\). The dominant process is the emission of the virtual pion from the proton which couples to the Pomeron. In the simplest approximation the corresponding contribution can be written as a product of the pion flux factor \(f_\pi\) and the effective structure function

\[
F_2^{\pi/\pi}(\beta, Q^2) = \int^{1}_{\beta} \int_{-\infty}^{t^{\prime\max}} dz \, dt' \, f_{\pi/\pi}(z, t') F_2^{\pi}(\tilde{\beta}, Q^2),
\]

where \(\tilde{\beta} \equiv \beta/z\) and \(f_{\pi/\pi} = 2/3 \, f_P\) is the Pomeron flux in the pion. The \(\pi N\) contribution to \(\Delta^{(n)}\) is shown in Fig.2 as the dotted line and it can safely be neglected for the forward nucleon production, especially for large \(\beta\).

An interesting feature of the Deck mechanism is that it contributes to the rapidity gap events for large \(x_P\), while the pion exchange (Sullivan process) is not expected to give rapidity gaps. Since in the description of both processes the same pion flux factor is present, the Deck mechanism can explain an approximately constant ratio in \(x_P\) of the number of events with and without the rapidity gap and the forward nucleon, observed by the ZEUS Collaboration\(^\text{17}\).

4 Conclusions

The isoscalar Reggeon \((f_2, \omega)\) exchanges can describe the Regge factorization breaking in the inclusive DIS diffractive processes observed at HERA. The size of this contribution, determined by the HERA data, is in agreement with soft hadronic reaction analyses. The isovector Reggeons \((a_2, \rho)\) dominate the fast forward neutron production at small \(x_P\), while for large \(x_P\), the \(\pi^+\) exchange is equally important or even dominates. The \(\pi N\) production estimated from the Deck mechanism is small for the forward nucleon production but it can explain
an approximately constant ratio of the number of the fast nucleon events with
and without the rapidity gap.

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