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Observation of a Dependence on p_t^{thrust} of Factorisation Breaking in Diffractive Deep-inelastic ep Scattering

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Abstract

An analysis is presented of the semi-inclusive cross section $ep \rightarrow eXY$ with the H1 detector at HERA. The data are decomposed into intervals of Q^2, β, $x_{\mathbb{P}}$ and the transverse momentum p_t^{thrust}, which is obtained from a thrust analysis of the hadronic final state. In fits to the $x_{\mathbb{P}}$ dependence of the data at fixed Q^2, β and p_t^{thrust} of the form ${x_{\mathbb{P}}}^{-n}$, the previously reported dependence of n on β is found to vary with p_t^{thrust}; no dependence with Q^2 is observed within the limits of the present sensitivity. The $n(\beta)$ and $n(p_t^{thrust})$ dependences are understood in terms of the interplay between pomeron and reggeon exchanges and of the partonic substructure of each.

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1 Introduction

Measurements of the semi-inclusive deep inelastic scattering process $ep \to eXY$, where X and Y are hadronic systems distinguished by a large rapidity interval devoid of hadron production and where Y has low mass, have demonstrated that the dominant interaction mechanism can be understood in terms of the exchange of leading (pomeron) and sub-leading (reggeon) Regge trajectories and their partonic structure [1]. A QCD analysis using the DGLAP evolution equations also shows that the parton content of the pomeron is dominated by gluons carrying a large fraction of the exchange momentum.

The interplay between pomeron and reggeon exchanges is reflected in the $x_{\mathbb{P}}$ dependence of the differential structure function $F_2^{D(3)}(Q^2, \beta, x_{\mathbb{P}})$, which is integrated over t, the square of the exchange four-momentum; $-Q^2$ is the photon's four momentum squared and the variables $x_{\mathbb{P}}$ and β can be interpreted respectively as the fraction of the proton momentum carried by the pomeron and the fraction of the pomeron momentum carried by the quark interacting with the photon.

Parameterising the $x_{\mathbb{P}}$ dependence of $F_2^{D(3)}$ in the form ${x_{\mathbb{P}}}^{-n}$, it was found [2] that, in order to fit the data, n has to depend on β; n is however independent of Q^2 within the experimental resolution. The $n(\beta)$ dependence is understood because, in a Regge approach, a pomeron (reggeon) flux in the proton corresponds to a contribution of the form ${x_{\mathbb{P}}}^{-n_{\mathbb{P}}}$ (${x_{\mathbb{P}}}^{-n_{\mathbb{R}}}$), where the exponent is related to the exchanged trajectory: $n_{\mathbb{P}} = \langle 2\alpha_{\mathbb{P}}(t) - 1\rangle$ (and similarly for the reggeon). An increase of n with β thus results from the characteristics of both trajectories: the pomeron trajectory, with $\alpha_{\mathbb{P}}(0) \approx 1.20$, which dominates at small $x_{\mathbb{P}}$ and large β values, and the reggeon trajectory, with $\alpha_{\mathbb{R}}(0) \approx 0.50$ [1].

It is interesting at this point to investigate whether factorisation breaking in any other variable than β is manifest in the data, in particular, whether there is any dependence of n on a scale such as p_t. To this end, the p_t^{thrust} variable has been chosen, with p_t^{thrust} defined as the transverse momentum of the thrust jets with respect to the γ^* direction in the rest frame of X ($\gamma^* - \mathbb{P}$ centre-of-mass system). An analysis [3] applied to the diffractive final state has shown that the value of p_t^{thrust} is related to the partonic process underlying the diffractive interaction.

The present paper outlines an analysis [4] of the diffractive structure function in terms of the variables Q^2, β, $x_{\mathbb{P}}$ and p_t^{thrust} with the main emphasis on the flux factor dependence $n = n(Q^2, \beta, p_t^{thrust})$.

2 Event selection and final state reconstruction

The DIS event sample, collected in 1994 using the H1 detector at the HERA ep collider, corresponds to an integrated luminosity of $\approx$ 2 pb^{-1}. The H1 detector is described in detail in ref. [5]. The fine grained liquid argon calorimeter and the backward electromagnetic calorimeter (BEMC) cover the pseudo-rapidity range $-3.5 \lesssim \eta \lesssim 3.5$ and the full azimuthal angle [1]. The tracking detector is used in order to improve the reconstruction of the kinematic quantities relevant for this analysis.

The basic event trigger required a minimum energy deposition in the BEMC ($E_{e'} \geq 4$ GeV). The following selection criteria are applied. The energy of the electron shower in the BEMC must be greater than 14 GeV and the shower is required to lie within the angular range $156^\circ \leq \theta \leq 173^\circ$. The energy deposition must also be associated with a hit in the backward

[1]The $+z$ axis is taken along the proton beam direction, which defines the "forward" direction.

proportional chamber, located immediately in front of the BEMC. The electron kinematic range is restricted to $0.05 \leq y \leq 0.5$ and $Q^2 \geq 10.0$ GeV^2. Events containing a large rapidity gap are identified by the absence of signal in the forward H1 detectors [6]: events are rejected if there is more than 7.5 GeV in the plug calorimeter, more than one pair of hits in the first half of the forward muon detector or any hit in the proton remnant tagger. The most forward cluster in the liquid argon calorimeter with energy larger than 400 MeV is required to have a maximum pseudorapidity of 3.2. Also included in the kinematic range definition is the requirement that $x_{\mathbb{P}} \leq 0.05$ (see below).

The events studied are of the type $ep \to eXY$ where the forward produced system Y is not detected. Events in which the proton elastically scattered or dissociated in a low mass state ($M_Y \leq 1.6$ GeV) are also included in the sample. The forward detector selection imposes an upper $|t|$ value of 1 GeV^2.

The use of the Σ-method [7] in the calculation of the kinematic variables Q^2 and y reduces effects due to initial state radiation to the few percent level.

The diffractive final state mass M_X, is calculated as

$$M_X^2 = 2E_e y_e (E_h + p_{z,h}) - (\sum p_{t,h})^2$$

where E_h, $p_{z,h}$, $p_{t,h}$ are the energy, the longitudinal and the transverse momentum of the hadrons in the final state with respect to the beam direction and E_e is the energy of the incident electron beam. This formula makes the M_X calculation less dependent on possible hadronic energy loss in the backward direction. In the M_X calculation, calorimeter energy clusters and track information are combined [3].

From M_X and the kinematic DIS quantities, the variables $x_{\mathbb{P}}$ and β can be computed:

$$x_{\mathbb{P}} = \frac{q.\mathbb{P}}{P.\mathbb{P}} \approx \frac{Q^2 + M_X^2}{Q^2 + W^2} \qquad \beta = \frac{Q^2}{2q.\mathbb{P}} \approx \frac{Q^2}{Q^2 + M_X^2},$$

where P, $\mathbb{P}$ and q are the four momenta of the proton, pomeron and photon.

A detailed account of the procedure used to calculate the value of p_t^{thrust} in the $\gamma^* - \mathbb{P}$ cms can be found in [3]. To obtain a meaningful p_t^{thrust} determination, the selected event sample was restricted to events with at least three particles in the final state, with values of $M_X \geq 3$ GeV.

3 Monte Carlo Model

The Monte Carlo simulations used in this analysis, to correct for detector effects as well as to assist in the interpretation of the results, are based on the RAPGAP generator [8]. In this generator the electron is assumed to undergo deep inelastic scattering either off a pomeron or off a reggeon, which are emitted from the proton with flux factors, respectively, $\propto {x_{\mathbb{P}}}^{-n_{\mathbb{P}}}$ and $\propto {x_{\mathbb{P}}}^{-n_{\mathbb{R}}}$, following the results of the Regge analysis of the $F_2^{D(3)}$ structure function [1], and the $|t|$ dependence is exponentially decreasing. The pomeron is attributed a partonic content, obtained from a DGLAP QCD analysis of the measured diffractive structure function [2]. For the reggeon, the parameterisation [9] of the pion is used. Whereas the pomeron contains a small quark component and its structure is dominated by a hard gluon component, the meson structure is dominated by quarks with a softer β dependence than that of the pomeron.

At the parton level, the photon can interact either directly with a quark in the pomeron (or reggeon) or with a gluon. The p_t involved in $\gamma^* q$ interactions is typically small, unless a QCD Compton (QCDC) emission process takes place. In contrast, $\gamma^* g$ interactions occur only via the boson gluon fusion mechanism (BGF). The relative contributions of the QCDC and BGF processes, which both induce a large p_t^{thrust}, is thus controlled by the quark and gluon contents of the exchanged object. The gluon dominance in the pomeron implies that the BGF mechanism dominates for pomeron exchange, in contrast to the reggeon case. A harder p_t distribution is therefore expected for $\gamma^*\mathbb{P}$ interactions than for $\gamma^*\mathbb{R}$ interactions.

Parton showers are used to simulate the QCD effects on the final state partons, and the subsequent hadronisation of the partons is performed by the Lund string fragmentation model [10].

4 Results

The semi-inclusive cross section for the process $ep \to eXY$ has been measured in intervals of Q^2, β, $x_{\mathbb{P}}$ and p_t^{thrust} for $M_Y \leq 1.6$ GeV and $|t| \leq 1$ GeV^2 (see Table 1). For the variables Q^2, β and $x_{\mathbb{P}}$, the bin limits are the same as those used for the $F_2^{D(3)}(Q^2, \beta, x_{\mathbb{P}})$ structure function analysis [2]. For p_t^{thrust}, the number of bins was chosen to be 3 since the event sample covers a p_t^{thrust} range of [0,4] GeV, with a p_t^{thrust} resolution of $\approx 0.5 - 0.8$ GeV.

variable	kinematic range	no. of bins
Q^2 (GeV^2)	10.0 – 48.7	3
β	0.023 – 0.800	5
$x_{\mathbb{P}}$	2.0×10^{-4} – 5.0×10^{-2}	8
p_t^{thrust} (GeV)	0.0 – 4.0	3

Table 1: Kinematic range and number of bins for the four variables Q^2, β, $x_{\mathbb{P}}$ and p_t^{thrust}.

The raw data distributions were corrected for detector acceptance and resolution effects using the RAPGAP Monte Carlo. Bin volume corrections in the four dimensional phase space due to kinematic cuts have been applied, and the data points in each $x_{\mathbb{P}}$ bin were corrected to the bin center according to the ${x_{\mathbb{P}}}^{-n}$ dependence. For a given interval in any of the three variables (Q^2, β, p_t^{thrust}), the averages of the other two variables are the same within statistical errors; hence bin centre corrections have not been applied.

In each of the (Q^2, β, p_t^{thrust}) bins, the $x_{\mathbb{P}}$ dependence of the data was fitted to the form ${x_{\mathbb{P}}}^{-n(Q^2, \beta, p_t^{thrust})}$. Only the $x_{\mathbb{P}}$ bins with more than 3 events were considered, and fits were performed only in the (Q^2, β, p_t^{thrust}) bins where measurements were made at more than 3 values of $x_{\mathbb{P}}$. Within the precision of the present data, no dependence of n on Q^2 is found. In the following, n is thus considered to be a function of β and p_t^{thrust} only.

Fig. 1 shows the n values obtained from the data for the different β and p_t^{thrust} intervals. One of the important results of the $F_2^{D(3)}$ analysis [2] was the observation that n varied from a value of 0.85 at low β to a value 1.2 at high β. The present analysis, which reproduces the results of [2] when no p_t^{thrust} decomposition is performed, shows that this dependence of n on β is different for each of the considered bins in p_t^{thrust}; the n value tends to increase with p_t^{thrust} at fixed β.

In order to ensure that the n-dependence on p_t^{thrust} is not an artefact of the acceptance corrections, a Monte Carlo simulation containing only a pomeron component, i.e. with a flat behaviour for $n(p_t^{thrust})$, has also been used to correct the data, – although this simulation reproduces the data poorly. The differences in n obtained after correction with the two different simulations have been used as an estimate of systematic uncertainties. All other systematic uncertainties, including an uncertainty of 4% in the LAr energy scale, are found to be less than the statistical error. In Fig. 1, the inner error bars represent the statistical errors only, whereas the full error bars represent the statistical and systematic uncertainties added in quadrature. With the present conservative errors, which were treated as uncorrelated between the data points, the evaluation of a Student-t test on the n values of highest and lowest p_t^{thrust} intervals shows that the probability is less than 2 % that these points are sample means from a common population.

As established by the previous analysis [2], the dependence of $n(\beta)$ at fixed p_t^{thrust} can be attributed to the addition of a pomeron and a reggeon component, with different flux factors (different n values) and different β dependences of the cross sections. The pomeron has a harder structure function than the meson, and the effective n value is therefore closest to that expected for the pomeron at large β values. The increasingly rich reggeon admixture lowers n as β decreases.

The observed changes in the $n(\beta)$ relationship in different p_t^{thrust} intervals can be understood in terms of the partonic composition of the pomeron and the reggeon. The gluon-dominated pomeron interacts dominantly via the $\gamma^* g \rightarrow q\bar{q}$ BGF mechanism, whereas the quark-dominated subleading exchange interacts dominantly via the lower p_t $\gamma^* q \rightarrow q$ process. The differences in dynamics naturally lead to an increasingly high proportion of pomeron exchange induced events as p_t^{thrust} increases. The result is that the value of n becomes closer to that expected for the pomeron exchange as p_t^{thrust} increases at fixed β.

Fig. 2a presents the predictions of the RAPGAP Monte Carlo, containing both the pomeron and reggeon components. A comparison with Fig. 1 shows that the features exhibited by the data are qualitatively well reproduced by the RAPGAP calculations. It should be stressed that there is no explicit p_t flux factor dependence in this model.

The conclusion that the observed p_t^{thrust} dependence can be interpreted as resulting solely from the pomeron-reggeon mixture has been investigated by performing the analysis with a Monte Carlo simulation based on pomeron exchange only. The results are shown in Fig. 2b, indicating the expected constant behaviour of n with β and p_t^{thrust}.

5 Conclusion

An analysis has been presented of the semi-inclusive diffractive cross section $ep \rightarrow eXY$ with the H1 detector at HERA. When fits of the $x_{\mathbb{P}}$ dependence of the diffractive structure function are performed to the form $x_{\mathbb{P}}{}^{-n}$, it is found that n has to depend on p_t^{thrust} as well as on β in order to fit the data, with n increasing with p_t^{thrust} at fixed β. No dependence with Q^2 is observed within the limits of the present sensitivity.

The behaviour of the data can be understood as a consequence solely of an interplay between pomeron and reggeon exchanges. These exchanges are characterised by different flux factor parameters n, which in Regge theory are related to the slope of the exchanged trajectory. The dependence of n on β can be understood as due to the difference in the quark distributions, whereas the dependence of n on p_t^{thrust} is related to the hard process composition involved, and in particular to the difference in the gluonic contents of the exchanges. The dominance of pomeron exchange in events with large p_t^{thrust} values, evidenced by the observation of large effective n values, is attributed to the dominant role of the BGF process and the dominance of hard gluons in the pomeron.

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Figures

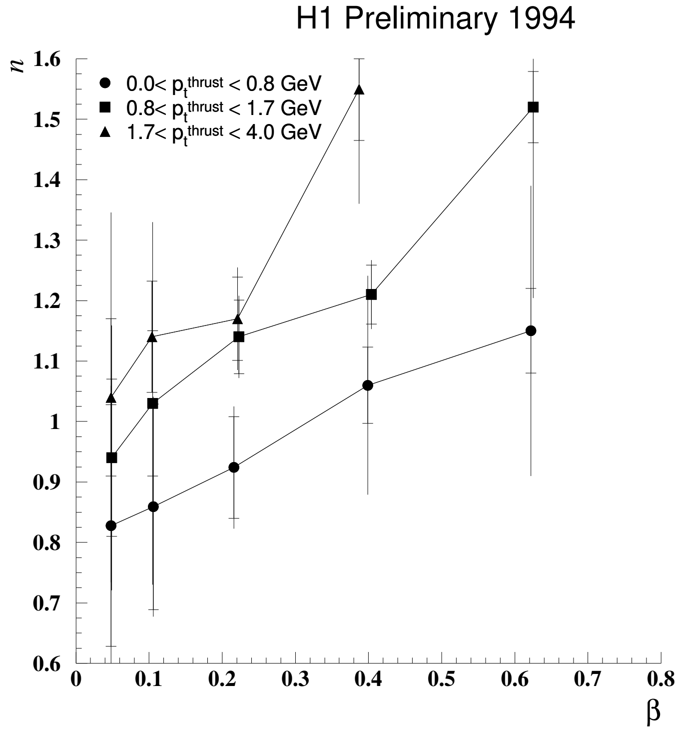
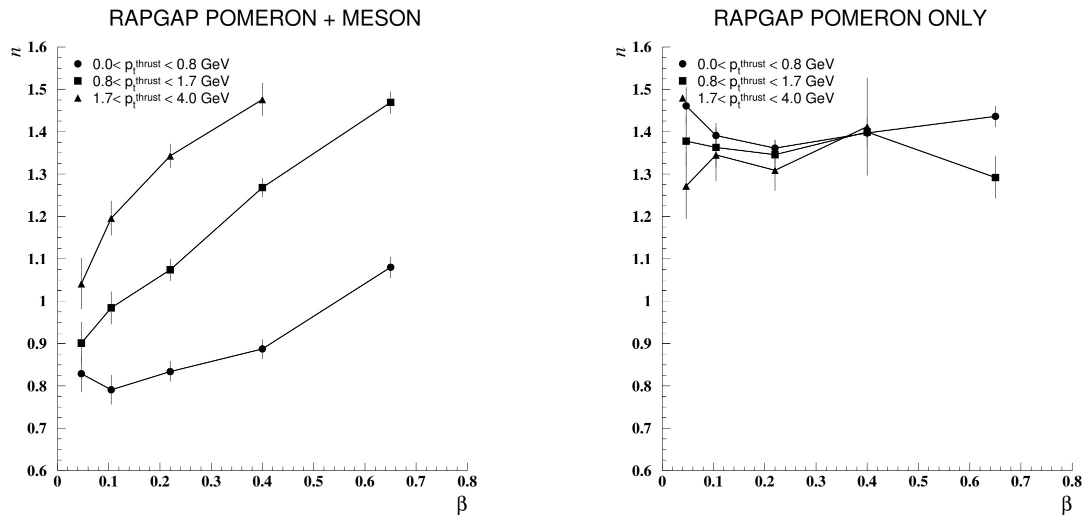


Figure 1: Values of n as a function of β for three different intervals in p_t^{thrust} for the data. The inner error bars correspond to the statistical errors only, and the full error bars correspond to the statistical and systematic uncertainties added in quadrature; the latter include the effect of the use of a Monte Carlo simulation with constant n for the data correction for detector acceptance and resolution.



(a) (b)

Figure 2: Values of n as a function of β for three different intervals in p_t^{thrust}: a) predictions of the RAPGAP Monte Carlo model, containing a pomeron and a reggeon component; b) predictions of a RAPGAP Monte Carlo simulation containing only a pomeron component, with constant n.