Inclusive diffraction in DIS at HERA

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Abstract. Measurements of the diffractive deep inelastic scattering processes $ep \rightarrow eXY$ and $ep \rightarrow eXP$ at HERA are presented. Events with a measured leading proton, as well as events with a large rapidity gap (LRG) between X and the outgoing proton were analysed. Moreover, the difference in the shape of the $M_X$ distribution of diffractive and non-diffractive events was utilised to extract the diffractive component. Diffractive parton distribution functions and their uncertainties were determined from a next-to-leading order DGLAP QCD analysis. The results are presented in terms of the diffractive structure functions, $F_D^{(3)}$ and $F_D^{(4)}$, and the diffractive reduced cross sections, $\sigma_D^{(3)}$ and $\sigma_D^{(4)}$.

1. Introduction

The diagram of the diffractive Deep Inelastic $ep$ Scattering (DIS) is shown in the Fig. 1. This process is characterised by the fact that proton loses a small fraction of its energy and emerges from the scattering intact or dissociated into a low-mass state with a transverse momentum squared typically much smaller than $1 \text{ GeV}^2$. The diffractive DIS events can be described, in addition to standard DIS variables, by the four-momentum transfer at proton vertex squared, $t$ and invariant mass of $\gamma^* IP$ system, $M_X$, which is the mass of the system resulting from virtual photon dissociation. If also proton dissociates into higher mass state it will be denoted by $Y$. Moreover, the diffractive structure functions are often expressed in terms of $x_P$ and $\beta$ variables.

In a model with Pomeron exchange in the $t$ channel $x_P$ is the fraction of the proton momentum carried by the Pomeron, while $\beta$ corresponds to the momentum fraction of the struck quark within the Pomeron.

There are three different experimental approaches to select the inclusive diffractive events:

- proton tagging methods which consist in measurement of the final state proton; it can be done by means of a H1 Forward Proton Spectrometer (FPS) [1] or using ZEUS Leading Proton Spectrometer (LPS) [2],
- exploit the different shape of the $M_X$ distribution for diffractive and non-diffractive events ($M_X$ method) [4, 9],

On behalf of the ZEUS Collaboration.
• a large rapidity gap in the forward direction requirement (LRG method) [3, 7].

The published and also preliminary results obtained by the H1 and ZEUS Collaborations will be presented briefly in the following.

2. Results
The data are presented in terms of the diffractive structure functions, $F_{2}^{D(3)}$ and $F_{2}^{D(4)}$. The results are also presented in terms of the diffractive reduced cross sections [5], $\sigma_{r}^{D(3)}$ and $\sigma_{r}^{D(4)}$, which are equal to the $F_{2}^{D(3)}$ and $F_{2}^{D(4)}$ respectively up to corrections due to the longitudinal structure function. The results from LRG and $M_{X}$ methods are given for $M_{Y} < 1.6$ GeV in H1 case and for $M_{Y} < 2.3$ GeV for the measurements from the ZEUS Collaboration.

![Figure 2](image_url)

**Figure 2.** The diffractive reduced cross section multiplied by $x_{IP} \times F_{2}^{D(4)}$, shown as a function of $x_{IP}$ for $|t| = 0.25$ GeV$^{2}$ at different values of $\beta$ and $Q^{2}$. An overall normalisation uncertainty of 10.1% is not shown.

2.1. Results from the proton tagging methods
In the Fig. 2 the diffractive reduced cross section is shown in terms of the $x_{IP} \sigma_{r}^{D(4)}$ as a function of $x_{IP}$ for $|t| = 0.25$ GeV$^{2}$ at different values of $\beta$ and $Q^{2}$. In this measurement H1 Collaboration used the data corresponding to an integrated luminosity of 28.4 pb$^{-1}$ and were collected in the years 1999 and 2000 when the HERA collider was operated at electron and proton beam energies of $E_{e} = 27.6$ GeV and $E_{p} = 920$ GeV [6].

The ZEUS Collaboration made the similar measurement on the data collected in the year 2000, which correspond to integrated luminosity of 32.6 pb$^{-1}$. Figure 3 shows the measured structure function $x_{IP} F_{2}^{D(4)}$.

2 From now on in each plot the inner error bars will indicate the statistical uncertainties, the outer bars the statistical and systematic uncertainties summed in quadrature.
Figure 3. The diffractive structure function multiplied by $x_{IP} F_{D(4)}^{2}$, in two $t$ bins as a function of $x_{IP}$ for different values of $Q^2$ and $\beta$. The normalisation uncertainty of 10% is not shown. The continuous lines are the result of the Regge fit described in the text.

In both results (from H1 and from ZEUS) measured functions rise with decreasing $x_{IP}$ for $x_{IP} < 0.01$. For higher values of $x_{IP}$ they start to rise with increasing $x_{IP}$. This latter effect is attributed to the contributions from Regge trajectory exchanges [8]. A sum of two contributions was fitted to these data according to

$$F_{D(4)}^{2} = f_{IP}(x_{IP}, t) \cdot F_{D(4)}^{P}(\beta, Q^2) + n_{IR} \cdot f_{IR}(x_{IP}, t) \cdot F_{D(4)}^{IR}(\beta, Q^2).$$

The first term of this sum is the contribution from Pomeron exchange and the second one, from the exchanges of the Reggeon trajectories. Results of the fits are shown in the Figs. 2 and 3.

2.2. Results from the LRG method

The ZEUS Collaboration used 2000 data sample, corresponding to integrated luminosity of 45.4 pb$^{-1}$, to study the inclusive diffraction with the LRG method. Data were selected by requiring the maximum pseudorapidity to be $\eta_{max} < 3$ outside the Forward Plug Calorimeter (FPC). In addition events with energies in the FPC larger than 1 GeV were rejected. The resulting diffractive structure function $x_{IP} F_{D(3)}^{2}$ is shown in Fig. 4 for low values of $Q^2$. The result of a Regge fit, performed in the same way as described previously in Sect. 2.1, is shown as the continuous lines. It gives a good description of the data. No rise of $x_{IP} F_{D(3)}^{2}$ coming from Regge-exchanges can be seen because the LRG data end essentially at $x_{IP} = 0.01$.

The H1 Collaboration measured the diffractive reduced cross section using different event samples for different $Q^2$ ranges from 1997, 1999 and 2000 data taking periods. The diffractive
2.3. Diffractive Parton Distributions (DPDFs)

DPDFs and their uncertainties are determined by H1 Collaboration from a next-to-leading order DGLAP QCD analysis of the $Q^2$ and $\beta$ dependences of the cross section. This analysis was performed on H1 LRG data. The fits (‘2006 DPDF fit A/B’) are based on the QCD hard scale scattering collinear factorisation, they assume the proton vertex factorisation and include a sub-leading exchange contribution. These two fits differ in the parametrisation chosen for the gluon density at the starting scale for QCD evolution [7].

The diffractive quark singlet and gluon distributions from ‘Fit A’ and ‘Fit B’ are compared and shown together with their uncertainties in Fig. 5. A good description of the data is obtained throughout the fitted range by both ‘Fit A’ and ‘Fit B’. The resulting gluon distribution carries an integrated fraction of around 70% of the exchanged momentum in the $Q^2$ range studied.

2.4. Results from the $M_X$ method

The recent preliminary results of the $x_F F_D^{D(3)}$ from the ZEUS Collaboration extend the published measurement [9] to higher $Q^2$ values (25 < $Q^2$ < 320 GeV$^2$). The comparison of the ZEUS preliminary results from the $M_X$ and LRG methods shows reasonable agreement concerning the shape of the distributions below $x_F = 0.01$. Above $x_F = 0.01$ one can expect
Figure 5. Comparison between the total quark singlet and gluon distributions obtained from the ‘H1 2006 DPDF Fit A’ and the ‘H1 2006 DPDF Fit B’. The DPDFs are shown at four different values of $Q^2$ for the range $0.0043 < z < 0.8$, corresponding approximately to that of the measurement. For ‘Fit A’, the central result is shown as a light coloured central line, which is surrounded by inner error bands corresponding to the experimental uncertainties and outer error bands corresponding to the experimental and theoretical uncertainties added in quadrature. For ‘Fit B’, only the total uncertainty is shown.

contributions from Regge exchanges in the LRG data. Indications of such contributions might be seen in some kinematic bins.

The H1 Collaboration also compared their preliminary measurement of the $xgD^{(3)}_{\sigma_F}$ from $M_X$ method with the H1 LRG preliminary results (done for 1999–2000 data samples) and with the ZEUS published measurements [9]. The good agreement between both approaches in the kinematic range accessed by this analysis was observed.

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