Inclusive Measurement of Diffractive Deep Inelastic Scattering at HERA

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The diffractive process $ep \to eXY$, where Y denotes a proton or its low mass excitation having $M_Y < 1.6$ GeV, is studied with the H1 experiment at HERA. Triple differential cross sections are measured as a function of the photon virtuality Q^2, the longitudinal momentum fraction of the incident proton carried by the colourless exchange $x_{I\!P}$ and $\beta = x/x_{I\!P}$, where x is the Bjorken scaling variable. These measurements are made after selecting diffractive events by demanding a large empty rapidity interval separating the final state hadronic systems X and Y. High statistics measurements covering the data taking periods 1999-2000 and 2004-2007 are combined with previously published results. The combined data represent a factor between three and thirty increase in statistics with respect to the previously published results. The measurements are compared with predictions from NLO QCD calculations based on diffractive parton densities and from a dipole model. The proton vertex factorisation hypothesis is tested.

1 Introduction

At low x in deep inelastic scattering (DIS) at HERA, approximately 10% of the events are of the type $ep \to eXp$, where the final state proton carries more than 95% of the proton beam energy. For these processes, a photon virtuality Q^2, coupled to the incoming lepton, undergoes a strong interaction with the proton to form an hadronic final state system X of mass M_X separated by a large rapidity gap (LRG) from the leading proton. In such a reaction no net quantum number are exchanged and a fraction $x_{I\!P}$ of the proton longitudinal momentum is transferred to the system X. In addition the virtual photon couples to a quark carrying a fraction $\beta = x/x_{I\!P}$ of the exchanged momentum. The study and interpretation of diffraction at HERA provides essential inputs for the understanding of quantum chromodynamics (QCD) at high parton densities.

2 Large rapidity gap measurements and combination

High statistics data with an integrated luminosity of up to 366 pb^{-1} recorded with the H1 detector in the years 1999-2000 and 2004-2007, when HERA collided protons of 920 GeV energy with 27.6 GeV electrons and positrons have been analysed [1]. Diffractive neutral current DIS events are selected by requiring an absence of hadronic activity in a large rapidity region extending close to the outgoing proton beam direction. The measurement is integrated over the region $M_Y < 1.6$ GeV, $|t| < 1$ GeV^2. Triple differential reduced cross sections are measured, as defined by $\sigma_r^{D(3)}(Q^2,\beta,x_{I\!P}) = \frac{\beta Q^4}{4\pi\alpha_{em}^2}\frac{1}{(1-y-\frac{y^2}{2})}\frac{d^3\sigma^{ep\to eXY}}{dQ^2\,d\beta\,dx_{I\!P}} = F_2^{D(3)} - \frac{y^2}{1+(1-y)^2}F_L^{D(3)}$, where $F_2^{D(3)}$ and $F_L^{D(3)}$ are diffractive structure functions, $F_L^{D(3)}$ corresponding to longitudinal polarisation of the virtual photon.

A combination with previous measurements obtained by H1, also using LRG events and based on low and medium Q^2 data from 1997 and high Q^2 data from 1999-2000 [2], is performed in order to provide a single set of diffractive cross sections from all H1 data. The combination is performed taking into account correlated systematic uncertainties by using the χ^2 minimisation method developed for the combination of inclusive DIS cross sections [3, 4, 5]. A reasonable consistency of the different data sets is found, confirming with a larger statistic previous H1 measurements. The combined data span more than two orders of magnitude in Q^2 from 3.5 GeV^2 to 1600 GeV^2 and cover the range $0.0017 \leq \beta \leq 0.8$ for five fixed values of $x_{I\!P}$ in the range $0.0003 \leq x_{I\!P} \leq 0.03$. A significant reduction of statistical errors is observed. In the best measured region for $Q^2 \geq 12$ GeV^2, the statistical and systematic uncertainties are at the level of 1% and 5%, respectively, with an additional overall normalisation uncertainty of 4%. An example of the β dependence of the reduced cross section $\sigma_r^{D(3)}$ from combined H1 data is presented in Fig. 1 at a fixed $x_{I\!P} = 0.003$ value. It is compared to previous published H1 results [2] and to predictions from the H1 2006 DPDF Fit B [2]. Similar figures for other $x_{I\!P}$ bins and for Q^2 dependences can be found in [1].

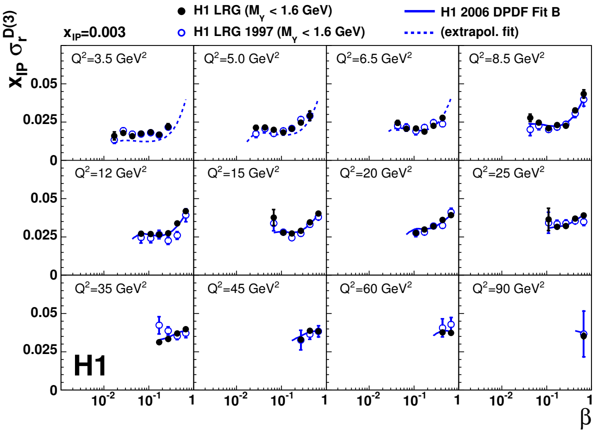

Figure 1: The β dependence of the reduced diffractive cross section, multiplied by $x_{I\!P}$, for $x_{I\!P} = 0.003$, for combined H1 data, compared to previously published H1 measurements [2]. Overall normalisation uncertainties of 4% and 6.2% on the combined and previous data, respectively, are not shown.

The combined reduced cross section $\sigma_r^{D(3)}$ can be compared with other H1 measurements obtained by a direct measurement of the outgoing proton using the H1 Forward Proton Spectrometer (FPS) [6]. The cross section $ep \to eXY$ measured here with the LRG data includes proton dissociation to any system Y with a mass in the range $M_Y < 1.6$ GeV, whereas in the cross section measured with the FPS the system Y is defined to be a proton. Therefore, the cross section ratio LRG/FPS provides an experimental determination of the fraction of proton dissociative events, $ep \to eXY$, where the proton dissociation system has a small mass M_Y, in LRG events. The global weighted average of the cross section ratio LRG/FPS is found to be $\frac{\sigma(M_Y<1.6\,\mathrm{GeV})}{\sigma(Y=p)} = 1.203 \pm 0.019(\mathrm{exp.}) \pm 0.087(\mathrm{norm.})$.

The combined H1 LRG cross section are also compared with the most recent measurements by the ZEUS experiment using a similar LRG selection [7]. These ZEUS diffractive data have been determined for identical β and $x_{I\!P}$ values, but at different Q^2 values to H1. In order to match the $M_Y < 1.6$ GeV range of the H1 data, a global factor of 0.91 ± 0.07 is applied to the ZEUS LRG data [7]. The comparison for $M_Y < 1.6$ GeV between the H1 data and the rescaled

ZEUS data is shown in Fig. 2. The ZEUS data tend to remain higher than those of H1 by $\sim 10\%$ on average. Deviations are observed between the β dependence of the two measurements at the highest and lowest β values. However a good agreement of the Q^2 dependence is observed throughout most of the phase space.

3 Comparison with models

In Fig. 2 the data are compared also with predictions of the H1 2006 DPDF Fit B [2] and of a dipole model [8]. As the dipole model predictions correspond to the process $ep \to eXp$, they are rescaled by a factor of 1.20 according to the comparison of FPS and LRG H1 data. Both approaches give a good overall description of the measurements. In the low Q^2 range, for $Q^2 < 8.5$ GeV^2, the dipole model, which includes saturation effects, seems to better describe the data, whereas for larger β and for $x_{\mathbb{P}} = 0.01$ it tends to underestimate the measured cross section.

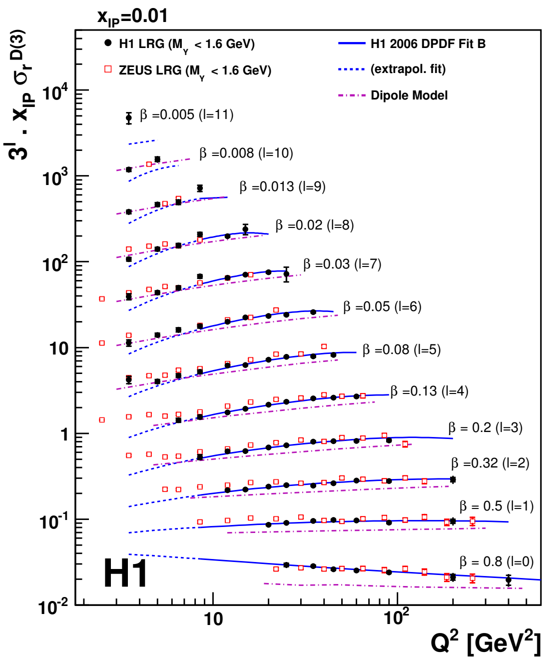

Figure 2: The Q^2 dependence of the reduced diffractive cross section from combined H1 data, multiplied by $x_{\mathbb{P}}$, for $x_{\mathbb{P}}= 0.01$. The overall normalisation uncertainties of H1 and ZEUS data are not shown. Predictions from the H1 2006 DPDF Fit B and dipole model are displayed.

The diffractive structure function can also be investigated in the framework of Regge phenomenology and is usually expressed as a sum of two factorised contributions corresponding to Pomeron and secondary Reggeon trajectories $F_2^{D(3)}(Q^2, \beta, x_{\mathbb{P}}) = f_{\mathbb{P}/p}(x_{\mathbb{P}})\, F_2^{\mathbb{P}}(Q^2, \beta) + n_{\mathbb{R}}\, f_{\mathbb{R}/p}(x_{\mathbb{P}})\, F_2^{\mathbb{R}}(Q^2, \beta)$. In this parametrisation, $F_2^{\mathbb{P}}$ can be interpreted as the Pomeron structure function and $F_2^{\mathbb{R}}$ as an effective Reggeon structure function. The Pomeron and Reggeon fluxes are assumed to follow a Regge behaviour with linear trajectories $\alpha_{\mathbb{P},\mathbb{R}}(t) = \alpha_{\mathbb{P},\mathbb{R}}(0) + \alpha'_{\mathbb{P},\mathbb{R}}t$, such that $f_{\mathbb{P}/p,\mathbb{R}/p}(x_{\mathbb{P}}) = \int_{t_{cut}}^{t_{min}} \frac{e^{B_{\mathbb{P},\mathbb{R}}t}}{x_{\mathbb{P}}^{2\alpha_{\mathbb{P},\mathbb{R}}(t)-1}} \mathrm{d}t$. In previous publications [6, 7, 9, 10], it has already been shown that fits of this form provide a good description of the data. This supports the proton vertex factorisation hypothesis whereby the $x_{\mathbb{P}}$ and t dependences are decoupled from the Q^2 and β dependences for each of the Pomeron and sub-leading contributions. This global conclusion can be refined using the advantage of the improved statistical precision of the new data, by dividing the full range in Q^2 into six intervals. For each interval i, a free Pomeron intercept $\alpha_{\mathbb{P}}(0)[Q_i^2]$ is introduced, allowing thus to test differentially in Q^2 the factorisation assumption. The fit performed in such a way provides a good description of the data and results on the Pomeron intercept are presented in Fig. 3. No significant Q^2 dependence of the Pomeron intercept is observed, which supports the pro-

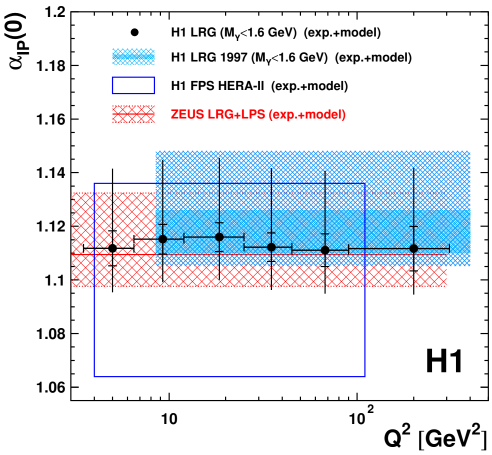

Figure 3: Pomeron intercept values obtained from Regge fits in different Q^2 bins (dots). The inner error bars represent the statistical and systematic errors added in quadrature and the outer error bars include model uncertainties in addition. Previous determinations of the Pomeron intercept [2, 6, 7, 10] are also displayed for comparison. For these previous results the bands or boxes represent the combination of experimental and model uncertainties, always dominated by the model error.

ton vertex factorisation hypothesis, as discussed above. The average value is found to be $\alpha_{I\!P}(0) = 1.113\ \pm 0.002\ \text{(exp.)}\ ^{+0.029}_{-0.015}\ \text{(model)}$.

4 Conclusion

A measurement of the reduced inclusive diffractive cross section $\sigma_r^{D(3)}(Q^2, \beta, x_{I\!P})$ for the process $ep \to eXY$ with $M_Y < 1.6$ GeV and $|t| < 1$ GeV^2 is presented. New results obtained from the selection of LRG events using high statistics data taken from 1999 to 2007 by the H1 detector at HERA are combined with previous H1 results obtained with the same technique. By comparison to proton-tagged cross section, a contribution of 20% of proton dissociation is found to be present in LRG data. The combined H1 LRG data are compared with predictions from the dipole and DPDF approaches and a reasonable description of the data is achieved by both models. The $x_{I\!P}$ dependence of $\sigma_r^{D(3)}$ is described using a model motivated by Regge phenomenology, in which a leading Pomeron and a sub-leading exchange contribute. A possible Q^2 dependence of the Pomeron intercept was tested with increased sensitivity. The result is compatible with previous determinations and do not exhibit any dependence on Q^2, which supports the proton vertex factorisation hypothesis.

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