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INCLUSIVE DIFFRACTIVE DIS AT HERA

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Recent precision measurements of diffractive neutral current deep inelastic ep scattering are performed by the H1 and ZEUS Collaborations at the HERA collider in a wide range of photon virtuality Q^2. The first measurements of the large rapidity gap cross sections in charged current processes at high Q^2 are also presented. The results are compared with model predictions based on parton density functions obtained from a DGLAP QCD fit to the data.

1 Introduction

Diffractive processes in deep-inelastic ep scattering (DIS) at HERA are characterized by the presence of a large rapidity gap (LRG) between the leading proton (or the proton dissociation system Y) and the rest of the hadronic final state X (Fig. 1). Here the variables W, M_X and M_Y denote the CMS energy of the virtual photon and the proton and the effective masses of the systems X and Y, respectively. Within Regge phenomenology, diffractive processes are described by the exchange of the Pomeron trajectory. As a result the Pomeron intercept can be extracted through a Regge fit to the data. The presence of a hard scale - the photon virtuality Q^2 - enables perturbative QCD to be applied to the data. Within the QCD framework the diffractive events can be interpreted as processes in which a colour singlet combination of partons is exchanged.

The structure of the colour singlet can be studied using a QCD approach based on the hard scattering factorization theorem and parton density functions (PDFs) [1]. In the charged current

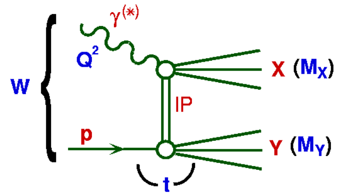

Figure 1: The diffractive process $\gamma^* p \to XY$ at HERA.

processes the structure of the color singlet could be probed by its coupling to the W boson.

The diffractive reduced cross section is defined by

$$\frac{d^4\sigma^{ep\to eXp}}{dx_{I\!P}dtd\beta dQ^2} = \frac{4\pi\alpha^2}{\beta Q^4}\left(1 - y + \frac{y^2}{2}\right)\cdot\sigma_r^{D(4)}(x_{I\!P}, t, \beta, Q^2), \tag{1}$$

where y is the inelasticity, t is the 4-momentum transfer squared at the proton vertex, $x_{I\!P}$ is the longitudinal momentum fraction of the incident proton carried be the colour singlet ($I\!P$) and $\beta = x/x_{I\!P}$ is the longitudinal momentum fraction of the colour singlet carried by the struck quark. The β variable for diffractive DIS processes is analogous to the Bjorken scaling variable x for inclusive DIS.

σ_r^D is related to the diffractive structure functions F_2^D and F_L^D by:

$$\sigma_r^D = F_2^D - \frac{y^2}{1+(1-y)^2}F_L^D. \tag{2}$$

Thus $\sigma_r^D \simeq F_2^D$ is a good approximation except at the highest y. The measurements are integrated over $|t| < 1$ GeV^2 because the leading proton is not detected: $\sigma_r^{D(3)} = \int \sigma_r^{D(4)}dt$.

2 Factorization properties of diffractive DIS

The validity of the QCD hard scattering factorization for diffractive DIS was proven by Collins [1]. It states that at fixed $x_{I\!P}$ and t the diffractive cross section is a product of diffractive proton parton density functions f_i^D and partonic hard scattering cross sections $\sigma^{\gamma^* i}$:

$$\sigma_r^{D(4)} \sim \sum \sigma^{\gamma^* i}(x, Q^2) \otimes f_i^D(x, Q^2, x_{I\!P}, t). \tag{3}$$

f_i^D are universal for diffractive ep DIS processes (inclusive, dijet and charm production) and obey the DGLAP evolution equations. $\sigma^{\gamma^* i}$ are the same as for inclusive DIS. This approach allows us to test the diffractive exchange within the perturbative QCD framework and extract diffractive parton density functions. A NLO DGLAP QCD fit can be applied to diffractive DIS in analogy with inclusive DIS.

An additional assumption is made in the present analysis, that is, that the $x_{I\!P}$ and t dependences of diffractive parton densities factorise from the $\beta = x/x_{I\!P}$ and Q^2 dependences (Regge factorisation) [2]:

$$f_i^D(x_{I\!P}, t, x, Q^2) = f_{I\!P}(x_{I\!P}, t)\cdot f_i^{I\!P}(\beta, Q^2). \tag{4}$$

Here $f_{I\!P}$ is the Pomeron flux factor and $f_i^{I\!P}$ are Pomeron PDFs. Although there is no firm proof in QCD for this assumption it is approximately consistent with the present data. The $x_{I\!P}$ dependence of the Pomeron flux factor was parameterized using a Regge motivated form:

$$f_{\mathbb{P}}(x_{\mathbb{P}}) = \int x_{\mathbb{P}}^{1-2\alpha_{\mathbb{P}}(t)} e^{B_{\mathbb{P}}t} dt, \tag{5}$$

where $\alpha_{\mathbb{P}}(t) = \alpha_{\mathbb{P}}(0) + \alpha'_{\mathbb{P}}t$ is the Pomeron trajectory with the intercept $\alpha_{\mathbb{P}}(0)$.

3 Diffractive DIS cross sections

3.1 W dependence of the diffractive cross section

ZEUS measured the W dependence of the diffractive cross section $d\sigma/dM_X^2$ [3]. Using a new Forward Plug Calorimeter the acceptance was extended to higher M_X and lower W values in comparison with the previous measurement [4]. The results are presented in the kinematic range $2.2 < Q^2 < 80$ GeV^2, $37 < W < 245$ GeV, $M_X < 35$ GeV and $M_Y < 2.3$ GeV. The Pomeron intercept $\alpha_{\mathbb{P}}$ was extracted using a Regge motivated power-like fit $d\sigma/dM_X^2 \sim (W^2)^{2\alpha_{\mathbb{P}}(0)-2}$. For $M_X < 2$ GeV the diffractive cross section shows a weak W dependence and a strong decrease with Q^2 consistent with a higher twist behaviour. For larger M_X values, a strong rise with W and a weaker dependence on Q^2 are found. According to the optical theorem the total γ^*p cross section is also characterized by a power-like dependence on W: $\sigma_{tot}^{\gamma^*p} \sim (W^2)^{\alpha_{\mathbb{P}}^{tot}(0)-1}$. The fit shows that the Pomeron intercept extracted from the diffractive cross section is smaller than that from the total γ^*p cross section (Fig. 2), but that the W dependences of the cross sections are similar: $2\alpha_{\mathbb{P}} - 2 \approx \alpha_{\mathbb{P}}^{tot} - 1$. The diffractive data are consistent with a "soft Pomeron" [6] at low Q^2, but also suggest the increase of the Pomeron intercept with Q^2, indicating possible Regge factorization breaking.

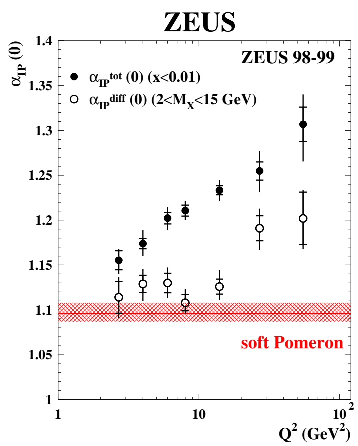

Figure 2: The Pomeron intercept as a function of Q^2 obtained from the W dependence of the total γ^*p cross section and the diffractive cross section $d\sigma/dM_X^2$.

3.2 Diffractive reduced cross sections at medium and high Q^2

Recent H1 and ZEUS measurements in which the leading proton is detected in proton spectrometers are described in [7]. The selection of diffractive events containing a large rapidity gap (LRG) yields better statistical precision. In these events the leading proton is not detected and the kinematics are reconstructed from the hadronic system X. Figure 3 shows a compilation of the H1 and ZEUS measurements based on the selection of either a leading proton or a large rapidity gap in the final state. Good agreement between the two methods and the experiments points to a small contribution from proton dissociation processes to the LRG data.

The H1 LRG data measured in the range of $6.5 < Q^2 < 120$GeV^2 [8] were used to perform a NLO QCD fit [9]. In the fit the diffractive exchange is parameterized by light quark singlet and

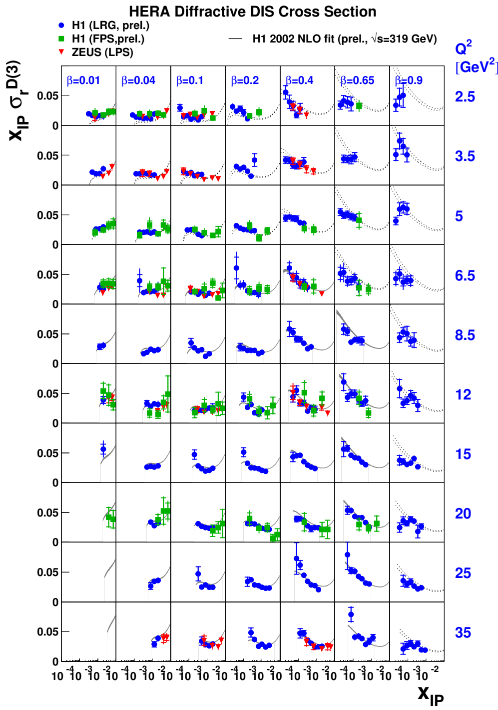

Figure 3: The diffractive reduced cross section measured in DIS processes with either a leading proton or a large rapidity gap in the final state.

gluon density functions at a starting scale $Q_0^2 = 3\mathrm{GeV}^2$ which are evolved according to the NLO DGLAP equations. The $x_{\mathbb{P}}$ dependence is assumed to factorise from the β and Q^2 dependences and is described by a phenomenological Regge flux factor (5).

The momentum fraction carried by gluons is estimated to be $75 \pm 15\%$. This result is consistent with the result of the NLO QCD fit to the leading proton data performed recently by ZEUS [5]. PDFs extracted from the QCD fit to the diffractive cross sections can be used to test QCD factorization in the production of charm and dijets in ep DIS at HERA and $p\bar{p}$ scattering at the TEVATRON[10].

The H1 Collaboration has also measured the diffractive reduced cross section at high Q^2. The results are presented in Fig. 4. The QCD prediction based on the PDFs extracted from the H1 NLO QCD fit to the medium Q^2 data [8,9] gives a good description of the high Q^2 measurements, even though the NLO DGLAP evolution was performed over one order of magnitude in Q^2. The data show that the contribution of a sub-leading trajectory is needed at high $x_{\mathbb{P}}$ and low β.

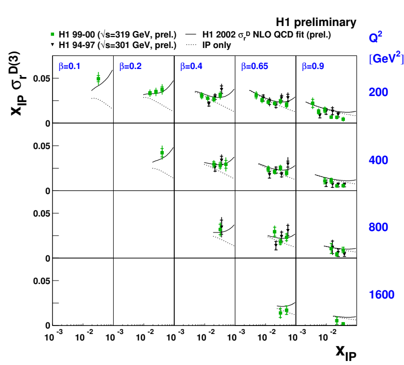

Figure 4: The diffractive reduced cross section as a function of $x_{\mathbb{P}}$ with the predictions based on the H1 NLO QCD fit.

4 Charged current cross sections

The charged current process $ep \to \nu XY$ with a large rapidity gap in the final state has also been studied by H1 and ZEUS. In the diffractive CC process the W boson probes the partonic structure of the colour singlet exchange. The LRG CC events were selected in the kinematic range: $Q^2 > 200\text{GeV}^2, y < 0.9, x_{I\!P} < 0.05$.

The LRG CC cross sections and their ratios to the inclusive CC cross section measured by H1 and ZEUS in the range $Q^2 > 200\text{GeV}^2, y < 0.9, x < 0.05$ are:

ZEUS: $0.49 \pm 0.20(\text{st}) \pm 0.13(\text{sys})$ pb
H1: $0.42 \pm 0.13(\text{st}) \pm 0.09(\text{sys})$ pb

ZEUS: $2.9 \pm 1.2(\text{st}) \pm 0.8(\text{sys})\%$
H1: $2.5 \pm 0.8(\text{st}) \pm 0.6(\text{sys})\%$

The results from the two experiments are in good agreement.

The data were used to test predictions based on PDFs extracted from the diffractive NC DIS. A model based on PDFs extracted from the H1 LO QCD fit [11] gives reasonable description of the ZEUS LRG CC data after statistical subtraction of the non-diffractive background. The data are also consistent within the experimental errors with the non-diffractive distribution alone.

The H1 LRG CC cross sections are in good agreement with predictions of the recent H1 NLO QCD fit [9] assuming an additional contribution from a sub-leading reggeon trajectory.

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