Photon 01

# DIFFRACTION AT HIGH AND LOW $Q^2$ AT HERA

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Recent measurements of the diffractive cross section in deep-inelastic scattering (DIS) at HERA are presented. The data are used to investigate the factorisation properties of diffractive DIS and to examine its quantum chromodynamic (QCD) structure.

## 1 Diffractive Deep Inelastic Scattering

At low $x$ in DIS at HERA, approximately 10% of the events are of the type $ep \rightarrow eXp$, where the final state proton carries in excess of 95% of the proton beam energy [1,2]. The kinematics of these processes are illustrated in figure 1. A photon of virtuality $Q^2$, coupled to the electron, undergoes a strong interaction with the proton to form a final state hadronic system $X$ (mass $M_X$) separated by a large rapidity gap from the leading proton. No net quantum numbers are exchanged. A fraction $x_{I\!P}$ of the proton longitudinal momentum is transferred to the system $X$. The virtual photon couples to a quark carrying a fraction $\beta$ of the exchanged momentum. The squared four-momentum transfer at the proton vertex is denoted $t$.

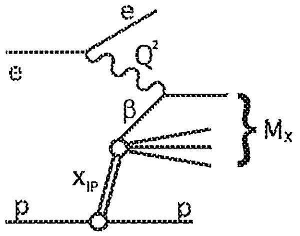

Figure 1. Illustration of the kinematic variables used to describe diffractive DIS.

Events with this 'diffractive' topology are interpreted in Regge models in terms of pomeron trajectory exchange between the proton and the virtual photon. The large photon virtualities encourage a perturbative QCD treatment of the process. However, the parton level interpretation is not obvious. In order to generate an exchange with net vacuum quantum numbers, a minimum of two partons must be exchanged in the $t$ channel.

The differential cross section for diffractive DIS is often presented in terms of a diffractive structure function $F_2^{D(4)}(\beta, Q^2, x_{I\!P}, t)$, defined analogously to the inclusive proton structure function $F_2$. Experimentally, diffractive events have been selected using two complementary methods; measuring the scattered proton directly in proton spectrometers (the H1 forward proton spectrometer FPS or the ZEUS leading proton spectrometer LPS) or requiring an absence of particles in the forward region (large rapidity gap method). The first method provides a clean selection of diffractive events, independent of the hadronic final state and free from proton dissociation background, and allows a direct measurement of $t$. However, due to the limited acceptance of the proton spectrometers the second method yields the better statistical precision. In rapidity gap analyses, where $t$ is not directly measured, the results are presented in the form of a structure function $F_2^{D(3)}(\beta, Q^2, x_{I\!P})$, corresponding to an integral of $F_2^{D(4)}$ over $t$.

## 2 $t$-dependence

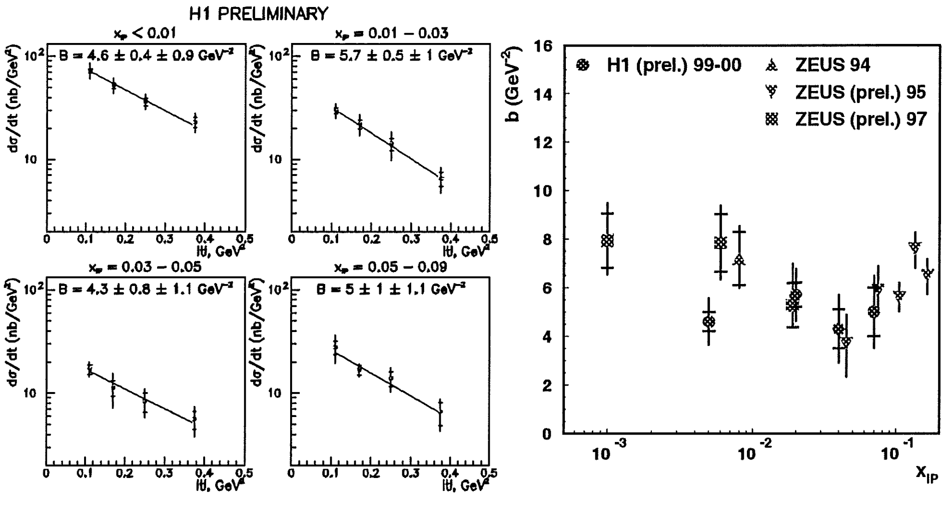

Figure 2. *Left:* The differential cross section $d\sigma/dt$ measured with the H1 FPS in four different $x_{I\!P}$ bins. Results of the fit with a function $d\sigma/dt \propto e^{bt}$ are shown. *Right:* The slope parameter $b$ is plotted as a function of $x_{I\!P}$. Results obtained with the H1 FPS and ZEUS LPS are shown.

Recent measurements in which the leading proton is measured in proton spectrometers have been made [3,4]. A typical feature of diffractive events is an exponential fall of the differential cross section with $|t|$. In Fig.2, the cross section is parameterised as $d\sigma/dt \propto e^{b|t|}$ in bins of $x_{I\!P}$, and the slope parameter $b$ is plotted as a function of $x_{I\!P}$. The results of H1 and ZEUS are consistent within the experimental uncertainties and no significant dependence on $x_{I\!P}$ is visible.

## 3 Factorisation Properties and Diffractive Parton Densities

The H1 collaboration recently released new preliminary $F_2^{D(3)}$ data [5] (see figure 3) based on a factor of 5 more luminosity than previous measurements. In this section, these data are used to test the factorisation properties of diffractive DIS.

In figure 3, the data are compared with the results of a fit in which the ($\beta$, $Q^2$) dependence is obtained by parameterising the diffractive light quark and gluon densities at $Q_0^2 = 2$ GeV$^2$ and evolving to higher $Q^2$ using the leading order DGLAP equations. The $x_{I\!P}$ dependence is assumed to factorise from the $(\beta, Q^2)$ dependence and is described by a Regge phenomenological flux factor such that

$$x_{I\!P} F_2^{D(3)} = A(\beta, Q^2)\, x_{I\!P}^{2-2\langle\alpha_{I\!P}(t)\rangle}, \tag{1}$$

where $\alpha_{I\!P}(t)$ is the effective pomeron trajectory. The fit describes the data well and results in diffractive parton densities dominated by the gluon density, which extends to large fractional momenta.

The hard scattering factorisation proof [6] makes no prediction for the ($x_{I\!P}$, $t$) dependence. From the QCD perspective, the diffractive parton densities could vary in both shape and normalisation with these variables. However, the success of Regge phenomenology in describing soft hadronic cross sections with a universal pomeron trajectory suggests that there may be an extended 'Regge' factorisation property whereby the $x_{I\!P}$ dependence is driven by Regge asymptotics and is completely decoupled from the ($\beta$, $Q^2$) dependence. The dependence on ($\beta$, $Q^2$) then represents a structure function for the exchanged pomeron [7].

In [5], the Regge factorisation hypothesis is tested by measuring the data at a larger number of $x_{I\!P}$ values and performing a fit to equation (1) with free parameters for the effective pomeron intercept $\alpha_{I\!P}(0)$ and $A(\beta, Q^2)$ at each ($\beta$, $Q^2$) point. The fit yields $\alpha_{I\!P}(0) = 1.173 \pm 0.018$ (stat.) $\pm$ 0.017 (syst.) $^{+0.063}_{-0.035}$ (model), the dominant upward model dependence uncertainty arising from the unknown contribution of the cross section for lon-

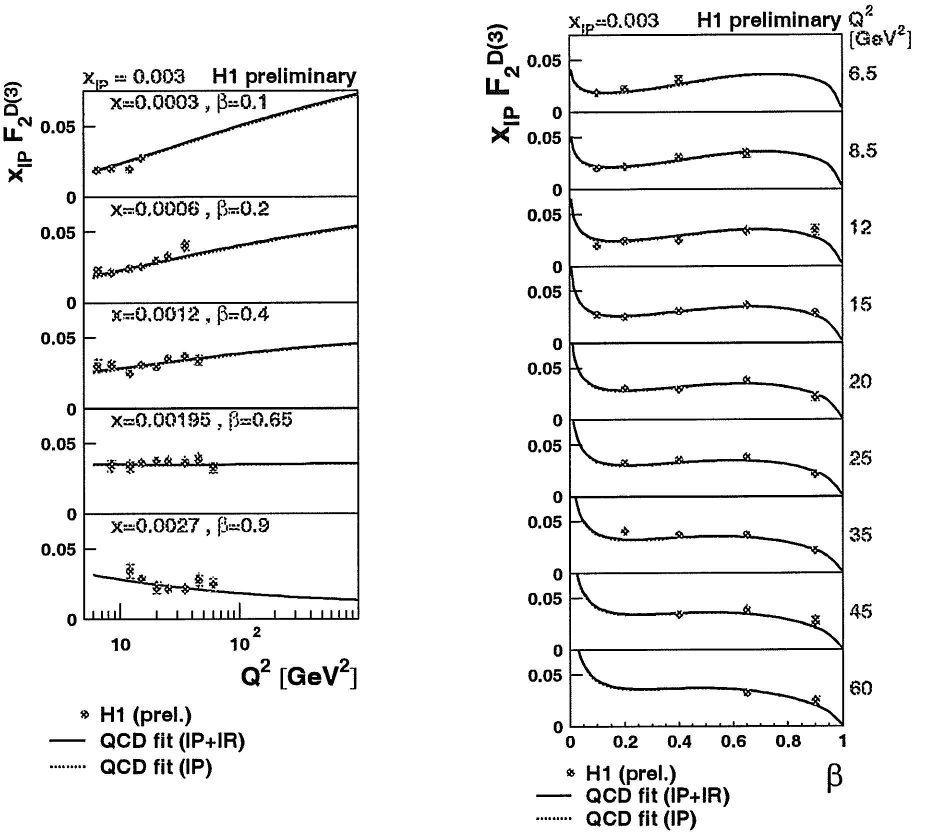

Figure 3. *Left:* Dependence of $x_{IP} F_2^D$ on $Q^2$ for different $\beta$ values, with fixed $x_{IP} = 0.003$. The data are compared with the DGLAP QCD fit described in the text. *Right:* Dependence of $x_{IP} F_2^D$ on $\beta$ for different $Q^2$ values, with fixed $x_{IP} = 0.003$. The data are compared with the DGLAP QCD fit described in the text.

gitudinally polarised photons. The Regge factorisation hypothesis works well within the kinematic range measured in [5], with no significant variation of the effective $\alpha_{IP}(0)$ with $\beta$ or $Q^2$. There is thus no experimental evidence at the present level of precision for a variation of the diffractive parton densities with $x_{IP}$.

## 4 Comparisons with Dipole Models

The hard scattering factorisation proof for diffractive DIS does not specify the relationship between the diffractive and the inclusive parton densities. Specific models [8,9] have been developed for this relationship. A popular approach is to consider the interaction in the proton rest frame, in terms of the elastic and total cross sections for the scattering on the target of $q\bar{q}$ and $q\bar{q}g$ fluctuations of the virtual photon, treated as colour dipoles. Using ideas such as the optical theorem, the same 'dipole cross section' can be used to describe total, elastic and dissociative cross sections, thus unifying the description of $F_2$ and $F_2^D$.

In the "saturation" model [9], the $q\bar{q}$ dipole cross section is obtained from a 3 parameter fit to $F_2$ data and is then used to predict $F_2^D$, under the assumption that the diffractive cross section is driven by 2-gluon exchange. A contribution from $q\bar{q}g$ fluctuations is added in the diffractive case. Figure 4 shows a comparison of the "saturation" model with various diffractive data from ZEUS [2,10]. The description is good for $Q^2 \geq 4$ GeV$^2$. The $q\bar{q}g$ contribution is clearly needed at large $M_X$. As yet, the model is not able to describe the low $Q^2$ region.

## References

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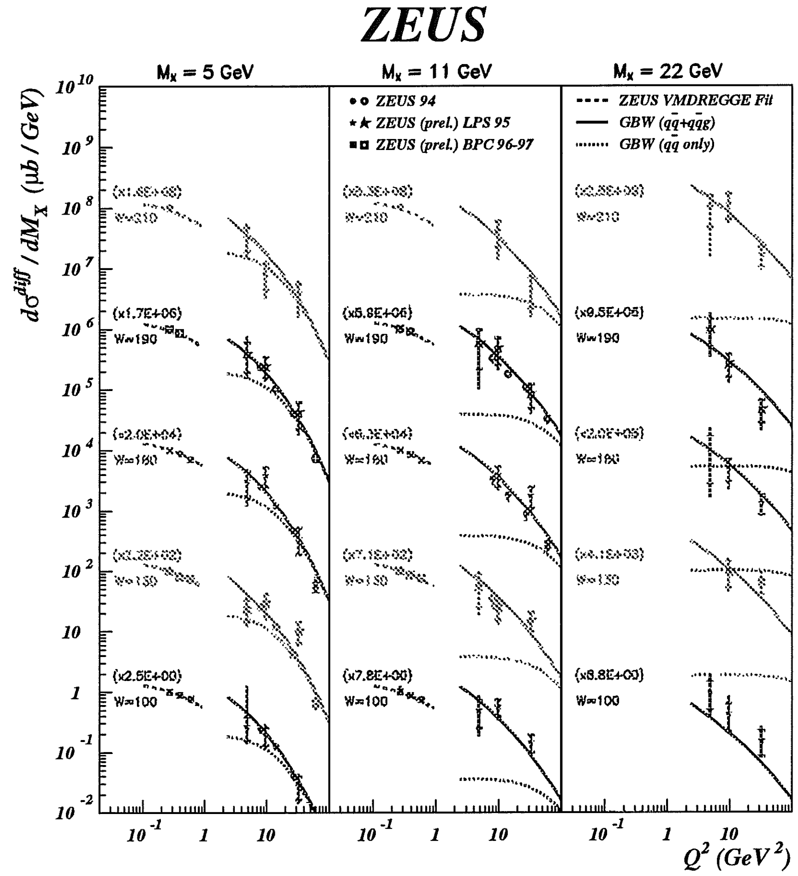

Figure 4. Compilation of ZEUS $F_2^D$ data, presented in the form $d\sigma^{\rm diff}/dM_X$ for different $W$ and $M_X$ values as a function of $Q^2$. The data are compared at high $Q^2$ ($Q^2 > 4{\rm GeV}^2$) with the "saturation" model and at low $Q^2$ with a Regge motivated parameterisation.