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$F_2^{D(3)}$ MEASUREMENTS AT LOW, MEDIUM AND HIGH Q^2

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Recent high precision measurements of diffractive deep inelastic ep scattering are performed by the H1 collaboration in a wide range of photon virtuality Q^2. Diffractive parton density functions are extracted using a NLO DGLAP QCD fit to the data. The results are also compared with models of diffractive deep inelastic scattering.

1 Introduction

Diffractive processes in deep-inelastic ep scattering (DIS) at HERA are characterized by presence of a large rapidity gap between the leading proton p' and the rest of the hadronic final state. Within Regge phenomenology, diffractive processes are described by the exchange of the Pomeron trajectory. As a result the Pomeron intercept is 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 are interpreted as processes with the exchange of a colour singlet combination of partons. The structure of the colour singlet could be studied using a QCD approach based on the hard scattering factorization theorem and parton density functions.

2 Diffractive reduced cross section

The diffractive reduced cross section is defined using:

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

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 exchange 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:

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

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

3 Factorization properties of diffractive DIS

The validity of 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 (PDF's) f_i^D and partonic hard scattering cross sections $\sigma^{\gamma^* i}$:

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

The f_i^D are universal for diffractive *ep* DIS processes (inclusive, di-jet, 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 analogous to inclusive DIS.

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

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

Here $f_{I\!P}$ is a Pomeron flux factor and $f_i^{I\!P}$ are Pomeron PDF's. 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:

$$f_{I\!P}(x_{I\!P}) = \int x_{I\!P}^{1-2\alpha_{I\!P}(t)} e^{B_{I\!P} t} dt; \quad \alpha_{I\!P}(t) = \alpha_{I\!P}(0) + \alpha'_{I\!P} t.$$

Figure 1 shows the recent measurement of the diffractive reduced cross section at low Q^2 [3] with the results of the Regge fit overlaid. Both the Pomeron and a sub-leading Reggeon contribution at high $x_{I\!P}$ were taken into account. The Pomeron

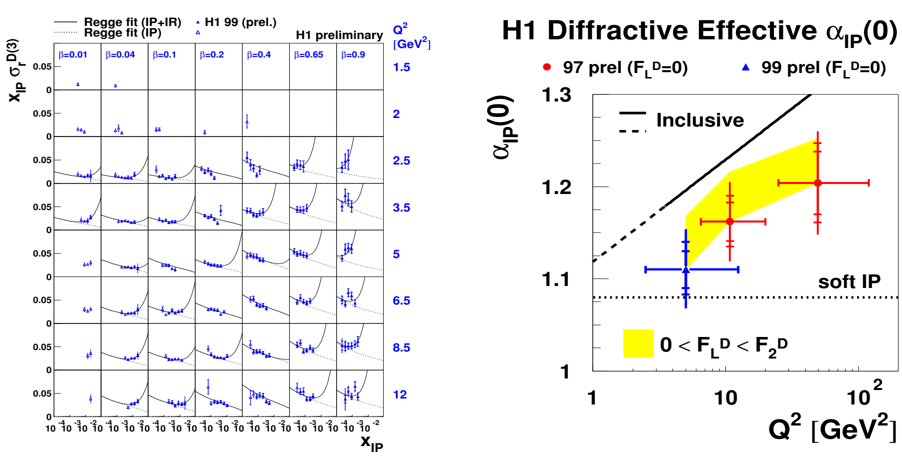

Figure 1. The diffractive reduced cross section at low Q^2 compared with the results of the Regge fit. The dependence on Q^2 of the Pomeron intercept extracted from the Regge fit.

intercept $\alpha_{I\!P}(0)$ extracted from the fit of the low and medium Q^2 data is shown as a function of Q^2. Although the data suggest an increase of $\alpha_{I\!P}(0)$ with Q^2 the results from different Q^2 values are still consistent within the errors. The effective Pomeron intercept for the diffractive DIS cross section is above the soft Pomeron intercept extracted from hadron-hadron scattering [4] and lower than that extracted from the inclusive DIS cross section [5] assuming: $F_2 \sim Bx^{1-\alpha(Q^2)}$.

4 NLO QCD fit to the experimental data

In the NLO DGLAP QCD fit the diffractive exchange is parameterized by a light quark singlet and a gluon distribution at a starting scale $Q_0^2 = 3\text{GeV}^2$ using Chebychev polynomials. Charm quarks are treated in the massive scheme with $m_c = 1.5 \pm 0.1$ GeV. The strong coupling is set via $\Lambda_{QCD}^{\bar{MS}} = 200 \pm 30$ MeV. A sub-leading exchange contribution parameterized using pion PDF's is non-negligible only at the highest $x_{I\!P}$. The fit is based on the medium Q^2 data measured in the range of $6.5 < Q^2 < 120\text{GeV}^2$ [6]. Full propagation of the correlated experimental systematic and theoretical uncertainties is done in the fit.

The fit reproduces the β and Q^2 dependences of the cross section scaled by the Pomeron flux factor (Fig.2). No dependence of the scaled cross section on $x_{I\!P}$ is visible, consistent with the Regge factorization assumption. Figure 2 also shows PDF's for the singlet quark and gluon extracted from the NLO fit. The momentum fraction carried by gluons is estimated to be $75 \pm 15\%$. The parton distributions extend to large fractional momenta z. The results of the LO QCD fit are also presented for comparison. The extracted PDF's could be applied to test QCD factorization in the production of charm and di-jets in ep DIS at HERA and $p\bar{p}$ scattering at the TEVATRON [7,8].

To quantify the scaling violations a logarithmic Q^2 derivative of the cross section

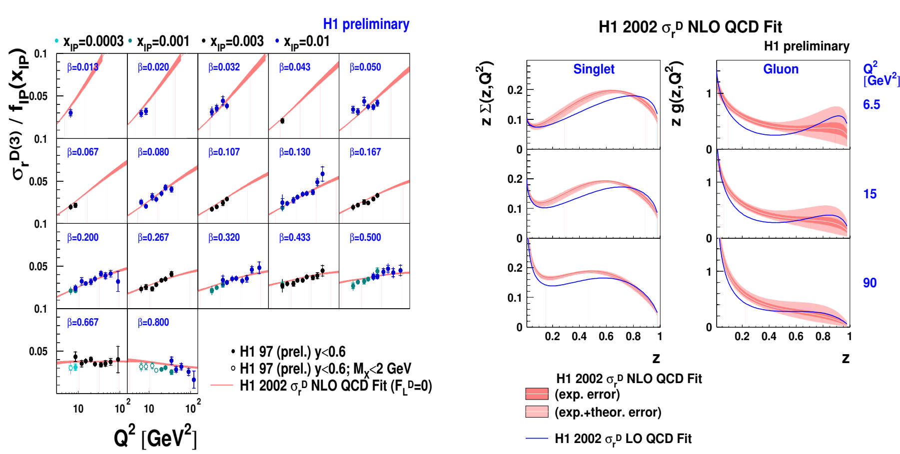

Figure 2. The diffractive reduced cross section as a function of Q^2 for different β and $x_{I\!P}$ bins. Diffractive quark singlet and gluon density functions extracted from the NLO QCD fit.

is plotted as a function of β in Fig.3. Positive scaling violations are observed in most of the β range up to $\beta \sim 0.6$, supporting a large gluon content of the diffractive exchange. The ratio of the diffractive to the inclusive DIS cross section is found to be reasonably flat at fixed x as a function of Q^2 over most of the kinematic range, suggesting that the same dynamics take place in both processes. The logarithmic Q^2 derivative of the cross section ratio, shown in Fig.3, is consistent with zero except where $\beta \to 1$ where it becomes negative suggesting the presence of Q^2 suppressed higher twist contributions to the diffractive cross section.

In Fig.4 the prediction of the QCD fit for low and high Q^2 is compared with the recent H1 measurements which are not used in the fit. Good agreement is observed between the fit extrapolation over one order of magnitude and the high Q^2 data [9]. The fit is also consistent with the data at low Q^2 except for the lowest β and Q^2. The low and high Q^2 data will provide additional constraints on the singlet quark and gluon distributions in future fits.

5 Comparison with DIS models

Figure 5 shows a comparison of the H1 diffractive data with the predictions of the colour dipole saturation model [10] and the soft colour interaction model [11]. In the saturation model the virtual photon fluctuates into $q\bar{q}$ or $q\bar{q}g$ colour dipole configurations long before the interaction with the proton. A phenomenological parameterization of the dipole-proton cross section is developed including colour transparency for small dipole sizes and saturation at low x/Q^2. In the soft colour interaction model large rapidity gap events occur through non-perturbative soft gluon exchanges between the outgoing partons without significant momentum transfer. The proability of the colour rearrangement is fixed by the fit to the experimental data. The saturation model consistently undershoots the low and medium Q^2 data. The soft colour interaction model based on generalized area law [12] describes the data except at low β.

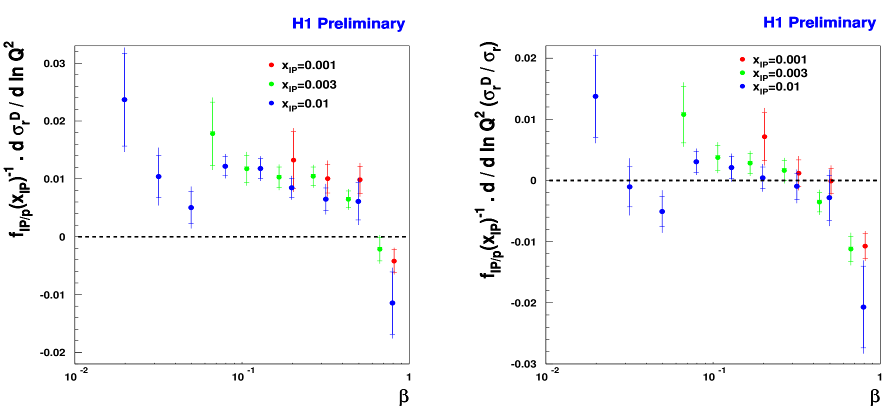

Figure 3. The logarithmic $Q2$ derivative of σ_r^D and the ratio σ_r^D/σ_r

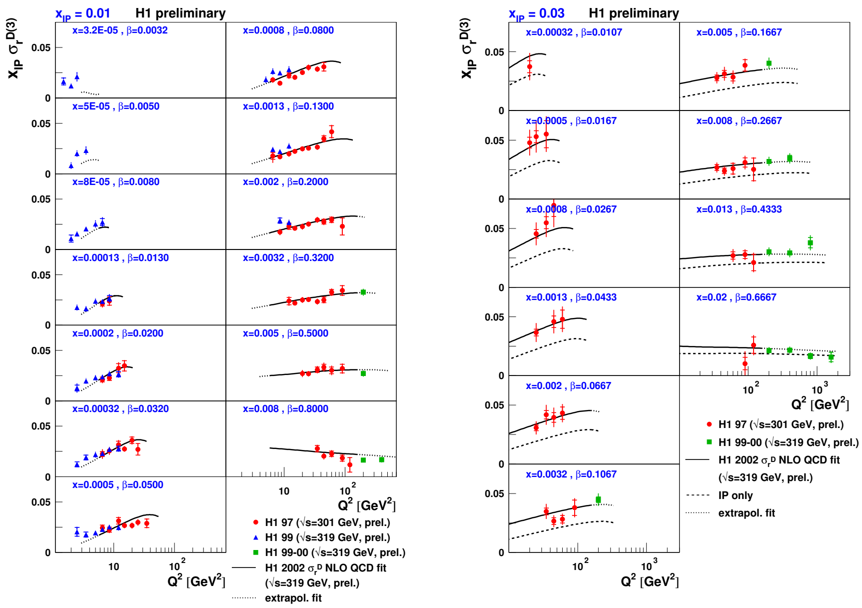

Figure 4. The diffractive reduced cross section measured at low, medium and high Q^2. The results of the NLO QCD fit are also shown.

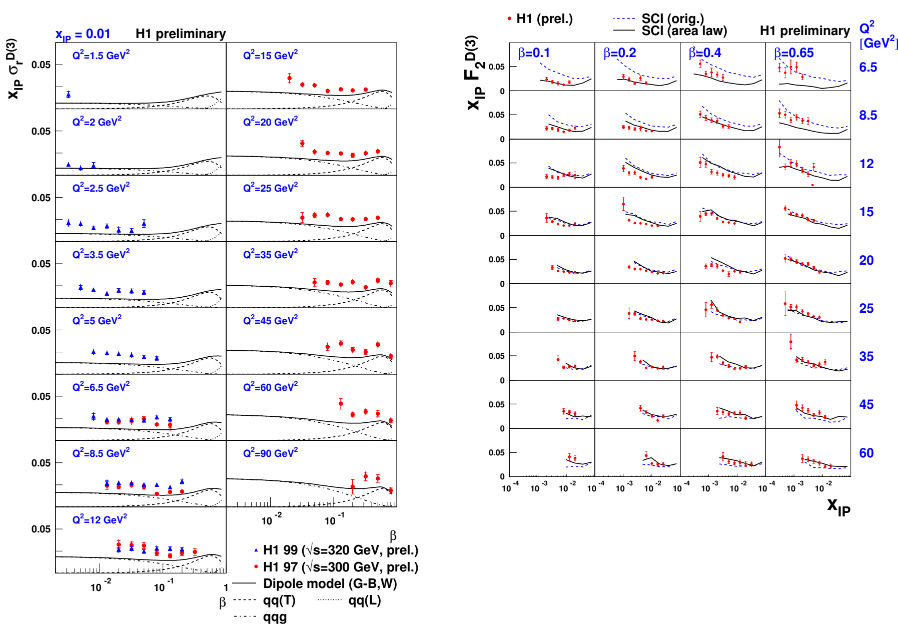

Figure 5. The low and medium Q^2 data compared with the predictions of the colour dipole saturation model. The medium Q^2 data compared with the predictions of the SCI model.

6 Conclusions

High precision measurements of the diffractive cross section have been performed by the H1 experiment in a wide range of Q^2. The data are consistent with Regge factorization assuming an additional contribution from sub-leading Reggeon trajectory. Diffractive DIS shows similar Q^2 dynamics to inclusive DIS at medium β. The medium Q^2 diffractive data are used to perform a NLO DGLAP fit based on QCD hard scattering factorization. Diffractive parton density functions for the quark singlet and gluon densities have been extracted from the fit. The extrapolation of the fit is in good agreement with the recent H1 measurements at low and high Q^2.

The parton density functions could be used to test QCD factorization properties in *ep* final states and hadron-hadron scattering. The colour dipole saturation model undershoots the low and medium Q^2 data. The soft colour interaction model describes the measurements except at low β.

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