LOW X AND DIFFRACTION AT HERA

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ON BEHALF OF THE H1 AND ZEUS COLLABORATIONS
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Recent results from H1 and ZEUS on low x and diffraction are reviewed. The rôle of gluons and the consistency of the results with predictions using DGLAP evolution are explored.

1 Introduction

HERA collides electrons (positrons) with protons at a centre of mass energy $\sqrt{s} \sim 300$ GeV. In the low x regime, only the neutral current exchange of a photon is important. Two kinematic variables used to describe the exchange are Q^2, the virtuality of the photon, and x, the fraction of the proton's momentum carried by the struck parton. The kinematic region accessed at HERA spans six orders of magnitude in x and Q^2.

The cross section factorises into a non-perturbative part, the parton densities in the proton ($f_p(Q^2,x)$), and a partonic cross section ($\hat{\sigma}$), calculable in perturbative QCD (pQCD). The cross section can be expressed as

$$\frac{d^2\sigma^{e^\pm p}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}(Y_+F_2 - y^2F_L \pm Y_-xF_3) \text{ with } Y_\pm = 1 \pm (1-y)^2 \qquad (1)$$

where F_2 is the proton structure function, F_L is the longitudinal structure function and xF_3 is the γ-Z interference term. At leading order (LO), F_2 can be related to the individual quark densities

$$F_2(x,Q^2) = \Sigma_i e_i^2(xq_i(x,Q^2) + x\overline{q}_i(x,Q^2)). \qquad (2)$$

Structure functions are not calculable perturbatively, so they must be measured, and perturbative QCD can be used to predict how they vary with Q^2. In particular, the DGLAP equations describe parton splitting (P):

$$\frac{\delta f(x,Q^2)}{\delta \ln(Q^2)} = f(x,Q^2) \otimes P. \qquad (3)$$

The fact that DGLAP evolution uses an expansion in $\ln(Q^2)$, indicates two areas where evidence for non-DGLAP evolution can be sought in the data. Firstly, how low in Q^2 does DGLAP continue to describe the measured

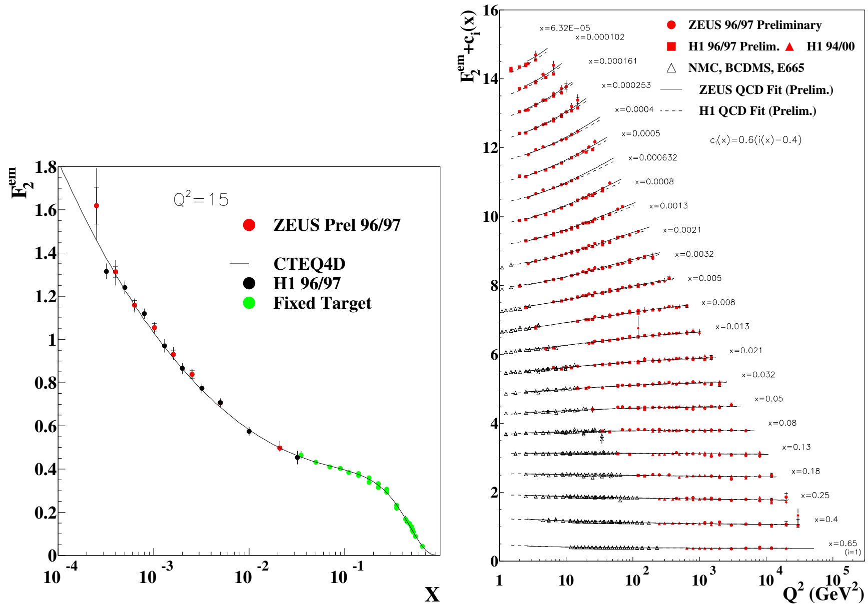

Figure 1. Data from HERA and fixed target experiments on F_2. The left hand plot shows F_2 versus x at Q^2=15 GeV^2. The right hand plot shows F_2 versus Q^2 at fixed x.

data? Secondly at low x, where $ln\frac{1}{x}$ terms are large (neglected in DGLAP evolution), does DGLAP describe the data? Note that by kinematics low x always implies low Q^2 at HERA.

Diffractive scattering is often thought of as a *"soft"* process. However, results will be presented where DGLAP evolution has been applied to diffraction, where a *"hard"* scale (Q^2) is present.

2 Results at Low x

2.1 Inclusive Measurements

Recent data[1,2] on the structure function F_2 are shown in figure 1. The steep rise of F_2 observed at small x indicates rising parton densities. The line is a NLO DGLAP fit by the CTEQ group[3]. The DGLAP fit shows good agreement with the data down to Q^2 of a few GeV^2.

From figure 1, when F_2 is plotted at constant x, F_2 is independent of

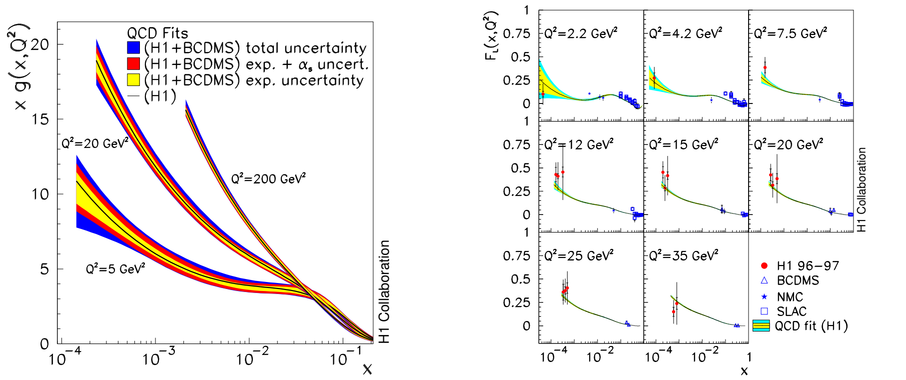

Figure 2. The gluon distribution (left) and F_L (right) extracted by H1.

Q^2 for $x \sim 0.1$. As x decreases, the deviations from this scaling increase. At leading order, these scaling violations can be directly related to the gluon density,

$$\frac{\delta f(x,Q^2)}{\delta \ln(Q^2)} \sim xg(x,Q^2). \tag{4}$$

The NLO picture is less trivial, but both H1 and ZEUS have done NLO fits to the data to extract the gluon density, as shown from H1[2] in figure 2. Here the gluon density rises strongly at small x. However the QCD fits by both H1 and ZEUS lead at $Q^2 \sim 1$ to a gluon density close to 0. Thus, the meaning of a gluon density here is unclear, and it is also questionable whether the DGLAP evolution used in the fit to extract the gluon density is applicable at such low values of Q^2.

H1 have extracted F_L from cross section data, by comparing data with a DGLAP fit, with F_L set to 0. The deviations of the measured data from this fit give the value of F_L. These values of F_L (shown in figure 2) give vastly improved knowledge of the behaviour of F_L from the previous fixed target data, and are consistent with the H1 DGLAP fit. A rise in F_L is also seen at low x, which is again indicative of the rise in the gluon density at low x.

2.2 Charm Production

One final state which is particularly sensitive to the gluon distribution is charm production, where the leading order contribution is directly sensitive to the gluon density. Figure 3 shows results from H1[5] on $D^\star$ production, compared

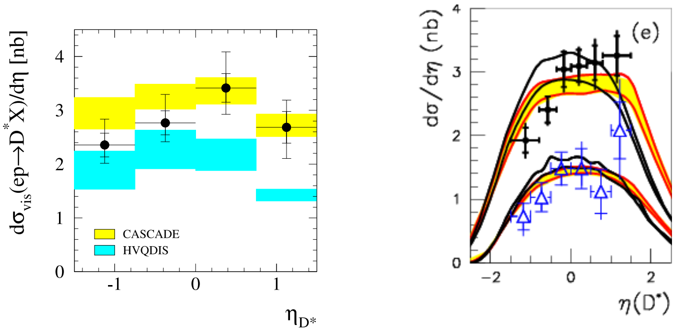

Figure 3. H1 (left) and ZEUS (right) $D^{\star}$ differential cross sections versus the pseudorapidity of the $D^{\star}$, $\eta(D^{\star})$.

to two models - HVQDIS, which uses DGLAP evolution, and CASCADE, which uses non-DGLAP (CCFM) evolution, including $\ln\frac{1}{x}$ terms. It appears that DGLAP evolution is disfavoured for charm production, as the predicted cross sections undershoot the data in the forward region. ZEUS, however, found agreement between data and HVQDIS after adding a more realistic model of the charm hadronisation (which affected only the shape of the η distribution and not the normalisation). Therefore it is too early to say that the behaviour observed here is indicative of non-DGLAP evolution. However, results on forward jet production[7,8] have found similar indications of non-DGLAP evolution.

2.3 Very Low x and Q^2

ZEUS[9] has also measured F_2 at very low values of Q^2. Very low Q^2 implies very small x, due to kinematics. At low Q^2 there is no *"hard"* scale for pQCD calculation, and therefore DGLAP evolution is expected to fail here. This transition to *"soft"* physics can clearly be seen from figure 4. At $Q^2 \sim 1$ GeV^2 the DGLAP fit gives a good description of data . For $Q^2 < 1$ GeV^2 a Regge-type phenomenological fit gives a good description of the data. As $Q^2 \to 0$, $F_2 \to k\,Q^2$ from current conservation.

3 Diffraction

One of the early surprises from HERA data was that about 10% of the DIS events at HERA have little or no activity in the forward (proton) direction -

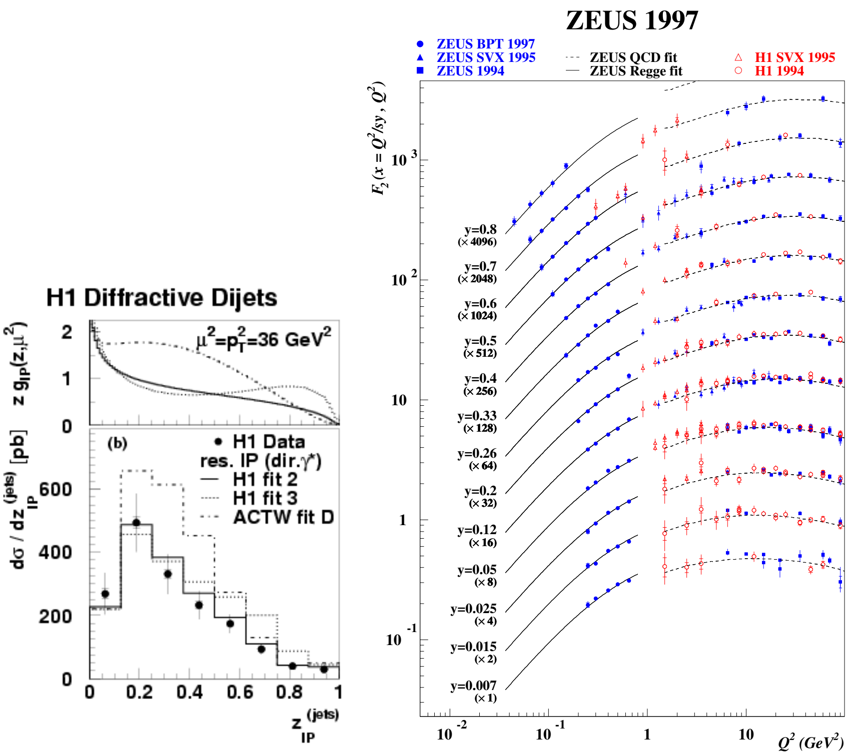

Figure 4. Diffractive dijets differential cross sections against $z_{I\!P}$ from H1 (left). $z_{I\!P}$ is the fraction of energy of system X contained within the dijets. F_2 as a function of Q^2 at low Q^2 from ZEUS (right).

these are termed diffractive events. To describe these events, the exchange of a colourless object, called the pomeron ($I\!P$), is often used.

3.1 Resolved Pomeron Approach

The resolved pomeron approach describes the diffractive scatter in terms of a partonic pomeron, where a parton within the pomeron scatters off the photon. To describe this extra vertex, two new variables are needed - $x_{I\!P}$, which is the fraction of the proton's momentum carried by the pomeron, and β, which is the fraction of the pomeron's momentum which the struck parton carries. The diffractive cross section can be written in terms of a diffractive structure function, $F_2^{D(3)}$,

$$\frac{d^3\sigma^D}{d\beta dQ^2 dx_{I\!P}} = \frac{4\pi\alpha^2}{\beta Q^2}(1 - y + \frac{y^2}{2})F_2^{D(3)}(\beta, Q^2, x_{I\!P}) \tag{5}$$

Analogous to the inclusive case, the cross section factorises[10] into the universal diffractive parton densities and the pQCD partonic cross section, $F_2^D \sim f^D \otimes \hat{\sigma}$. Assuming Regge factorisation,

$$F_2^D \sim f(x_{I\!P}, t) \cdot F_2^{I\!P}(\beta, Q^2). \tag{6}$$

The pomeron flux factor, $f(x_{I\!P}, t) is \sim \frac{1}{x_{I\!P}}$. Therefore it is possible to make a DGLAP analysis of $F_2^{I\!P}$ in an analogous way to F_2.

3.2 Inclusive Diffraction

Both H1 and ZEUS have published results on $F_2^{D(3)}$[12]. Scaling violations are observed in the data also at large values of beta, indicating that gluons are important in diffraction. NLO DGLAP fits to diffractive data have been made, and the diffractive parton densities extracted. A gluon-dominated pomeron is highly favoured by the fits.

ZEUS has also released diffractive data at very low Q^2, for both $F_2^{D(3)}$ and $F_2^{D(4)}$[11]. The behaviour is again analogous to the inclusive data, with a clear transition at low Q^2 ($Q^2 < 1$ GeV^2).

3.3 Diffractive Final States

It is interesting to see whether the data for diffractive final states form a consistent picture with the resolved pomeron model. The parton densities extracted from the DGLAP fits to diffractive data can be fed into calculations for particular diffractive final states, and compared to the measured data.

One final state for which this has been done is the diffractive dijet production - this process is sensitive to the gluon distribution at LO. Results from H1[13] are shown in figure 4. The diffractive gluon content of the pomeron is tightly constrained by the dijet data. The data favour a large gluon component in the pomeron. Overall, the agreement between the predictions from the resolved pomeron model and the data indicate consistency in the resolved pomeron approach.

4 Summary

There are many new precise results in low x and diffraction at HERA of which only a small selection is shown here. The results emphasise the importance of the gluon distribution in the low x regime. DGLAP evolution seems to describe the measured data across most of the kinematic range down to $Q^2 \sim 1$ GeV^2 There are some indications of non-DGLAP parton dynamics in charm and forward jet production, although neither of these is conclusive yet. For $Q^2 < 1$ GeV^2, where DGLAP evolution is not applicable, a Regge-type phenomenological approach fits the data.

Diffractive data can be fitted to give diffractive parton densities, using DGLAP evolution, giving a consistent picture for a range of results. A gluon-dominated pomeron is favoured. The transition to the low Q^2 regime in diffraction is qualitatively similar to the inclusive case.

Overall, these results show that HERA is an ideal place to study evolution schemes and the transition between *"soft"* and *"hard"* physics.

Acknowledgments

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