EXPERIMENTAL TESTS OF QCD AT LOW X

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The electron-proton collider HERA has allowed the study of the partonic content of the proton in regions of Q^2 up to 50,000 GeV^2 and values of Bjorken-x down to 10^{-5}. This paper presents the most recent measurements of the proton structure functions F_2 and its behaviour at low x. A QCD interpretation of this work is provided by next-to-leading order DGLAP calculations which also allow the extraction of the gluon momentum distribution in the proton $xg(x)$.

1 Introduction

Deep-inelastic lepton-nucleon scattering experiments have traditionally shed light on the nature of the partons within the proton and the strong QCD interactions between them[1].

The ep scattering experiments H1 and ZEUS at the HERA facility at DESY have continued this tradition and have made precision measurements of both the inclusive ep scattering cross-section and features of the ep-induced hadronic final state. The theory of perturbative QCD, as implemented in the DGLAP[2] parton evolution equations, has been successful in describing these measurement at higher values of Q^2 (above $\approx$ 100 GeV^2). However, the DGLAP equations resum terms in $ln(Q^2)$ and ignore terms in $ln(1/x)$ which are expected to become important in the lower Q^2, low x domain ($x \leq 10^{-3}$)[3]. Furthermore, gluon recombination effects may also be visible in the low x domain[4].

This paper presents precision low-x measurements of the proton structure F_2 and its local derivatives. Next to leading order (NLO) DGLAP calculations are tested against the data and the gluon momentum distribution of the proton $xg(x)$ is inferred.

2 The Proton Structure Function F_2 and the Gluon Momentum Distribution $xg(x)$ of the Proton

The reduced ep scattering cross-section σ_r can be written as a function of F_2 and F_L.

$$\sigma_r = \frac{d\sigma}{dxdQ^2} \cdot \frac{Q^4 x}{2\pi\alpha^2 Y_+} = F_2(x,Q^2) - \frac{y^2 F_L(x,Q^2)}{Y+}$$

This quantity is dominated by the contribution from F_2 and F_L only plays an important role at large values of the inelasticity $y = \frac{Q^2}{sx}$.

Precision measurements of $F_2(x, Q^2)$ have been made by the H1[5] and ZEUS[6] collaborations. The ZEUS results are shown in figure 1 and compared with earlier fixed target data. The classic scaling violations of F_2 are exhibited via the strong dependence on Q^2 for a range of fixed x values. The low x behaviour of F_2 is dominated by quark anti-quark pair production arising from the gluon content $g(x)$ of the proton which, within the DGLAP formalism, is given by $F_2 \propto \alpha_s \cdot g(x)$. QCD fits based on DGLAP evolution using the HERA data and the fixed target data are also shown. The fit describes the data well over several orders of magnitude in x and Q^2. In the region of kinematic overlap the independent measurements from fixed target experiments and the ZEUS data agree well.

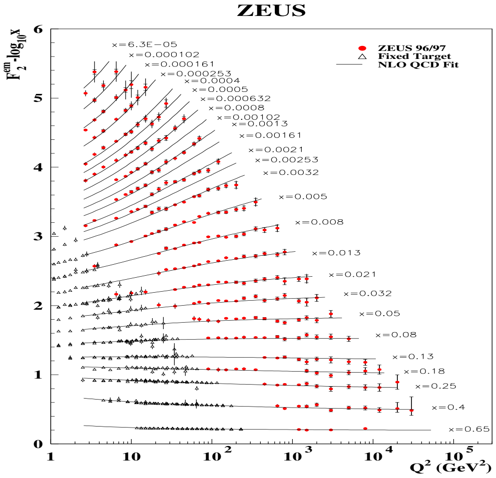

Figure 1. The proton structure function $F_2(x, Q^2)$ shown as a function of Q^2 for fixed values of x. QCD fits and results from fixed target experiments are also shown.

Using these precision measurements of the ep scattering cross-section and within the DGLAP formalism the gluon momentum distribution $xg(x)$ has been derived[7]. The dependence of $xg(x)$ on x for different values of Q^2 is shown in figure 2. There is a strong rise towards low x for values of Q^2 down to about 5 GeV^2. Below this, the gluon distribution tends to flatten off, approaching valence quark-like behaviour.

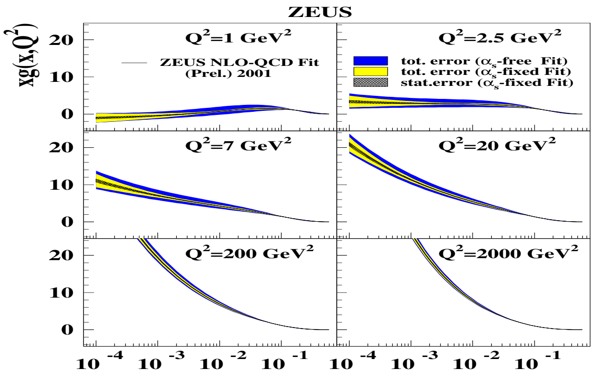

Figure 2. The gluon momentum distribution $xg(x)$ shown as a function of x at different values of Q^2.

3 The Longitudinal Structure Function F_L

At high values of y the contribution from the longitudinal structure function F_L becomes significant. In figure 3, measurements of F_L from the H1 collaboration are presented as a function of x at different values of Q^2.

The values of $F_L(x, Q^2)$ increase towards low x, consistent with the QCD calculation which reflects the rise of the gluon momentum distribution.

The values of F_L were experimentally determined for $Q^2 < 10$ GeV^2 following a procedure involving fitting straight lines in lny to the derivative $\frac{\partial \sigma_r}{\partial lny}$ in order to estimate the contribution from the behaviour of F_2 to the reduced cross-section. For $Q^2 > 10$ GeV^2, the NLO QCD fit in the low y domain ($y < 0.35$) is used to estimate F_2 in the high y region and thus extract F_L.

4 The Rise of F_2 Towards Low x

As mentioned in the introduction, the low x dependence of F_2 may be directly sensitive to any new physics which may be evident in this region of high partonic density[4].

Fits of the form $F_2(x, Q^2) = c(Q^2)x^{-\lambda(Q^2)}$ were made to the H1 structure function data[8].

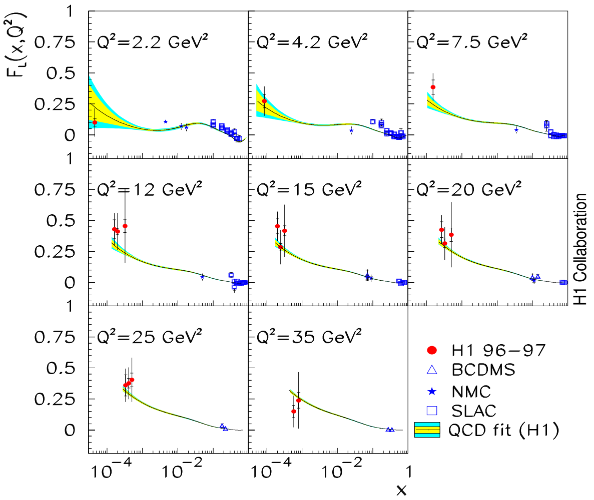

Figure 3. The longitudinal structure function F_L shown as a function of x at different values of Q^2.

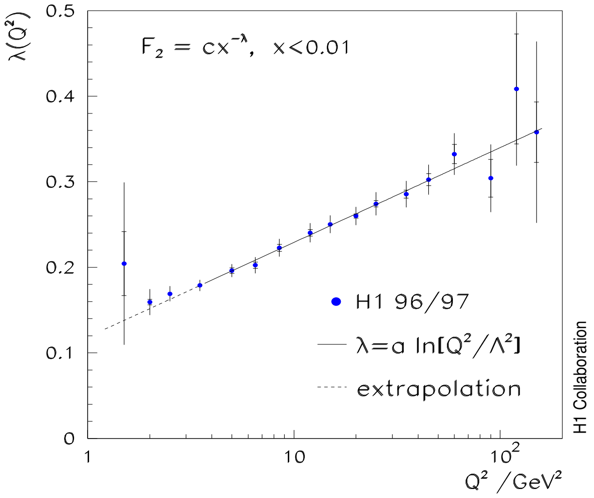

Figure 4. The dependence of λ on Q^2.

The co-efficients $c(Q^2)$ were found to be approximately independent of Q^2 and, as shown in figure 4, $\lambda(Q^2)$ rises approximately linearly with lnQ^2 and can be represented as $\lambda(Q^2) = a \cdot ln[\frac{Q^2}{\Lambda^2}]$ with co-efficients $a = 0.0481 \pm 0.0013(stat) \pm 0.0037(syst)$ and $\Lambda = 292 \pm 20(stat) \pm 51(syst)$ MeV.

Below the deep-inelastic scattering region, for fixed $Q^2 < 1$ GeV^2, the simplest Regge phenomenology predicts that $F_2(x, Q^2) \propto x^{-\lambda}$ where $\lambda = \alpha_{pom(0)} - 1 \approx 0.08$[9]. An extrapolation of the function $\lambda(Q^2)$ from the QCD fit gives a value of 0.08 at $Q^2 = 0.45$ GeV^2.

5 Summary

Results on deep-inelastic ep scattering cross-sections in the low x regime at HERA have been presented. Perturbative QCD calculations based on DGLAP evolution have been tested against precision results on proton structure functions and found to describe the data over many orders of magnitude in the kinematic variables x and Q^2.

References

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