INELASTIC ep SCATTERING AT LOW x AND Q^2

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A brief summary is presented of recent deeply inelastic positron-proton scattering measurements at HERA of the structure of the proton at low Bjorken x and of the strong interaction coupling constant α_s.

1 Introduction

The exploration of low-x physics in deeply inelastic lepton-proton scattering at HERA revealed a strong increase in the proton structure function F_2 with decreasing Bjorken x and with increasing momentum transfer squared, Q^2; a domain of high quark and gluon densities was discovered. Since the initial discovery, precision measurements and new theoretical insights have led to important tests of perturbative QCD, to the development of strong interaction theory for high density matter and to predictions of high energy interaction rates relevant for cosmic neutrinos and the LHC. This paper briefly presents results available in Spring 2001 on the structure functions F_2 and F_L , on the contribution charm makes to proton structure at low x, F_2^c . A new accurate measurement of α_s is discussed which is based on the scaling violations of $F_2(x, Q^2)$.

2 The Proton Structure Function F_2

Recent measurements of the inclusive DIS cross section

$$\sigma_r = \frac{d\sigma}{dxdQ^2} \cdot \frac{Q^4 x}{2\pi\alpha^2 Y_+} = F_2(x, Q^2) - \frac{y^2 F_L(x, Q^2)}{Y_+} \qquad (1)$$

by the H1 [1] and ZEUS [2] Collaborations have reached an accuracy of a few per cent at low $Q^2 \sim 5 - 50\,\mathrm{GeV}^2$. Here, F_L is the longitudinal structure function, which at large inelasticities $y = Q^2/sx$ influences the behaviour of the reduced cross section σ_r. The event kinematics

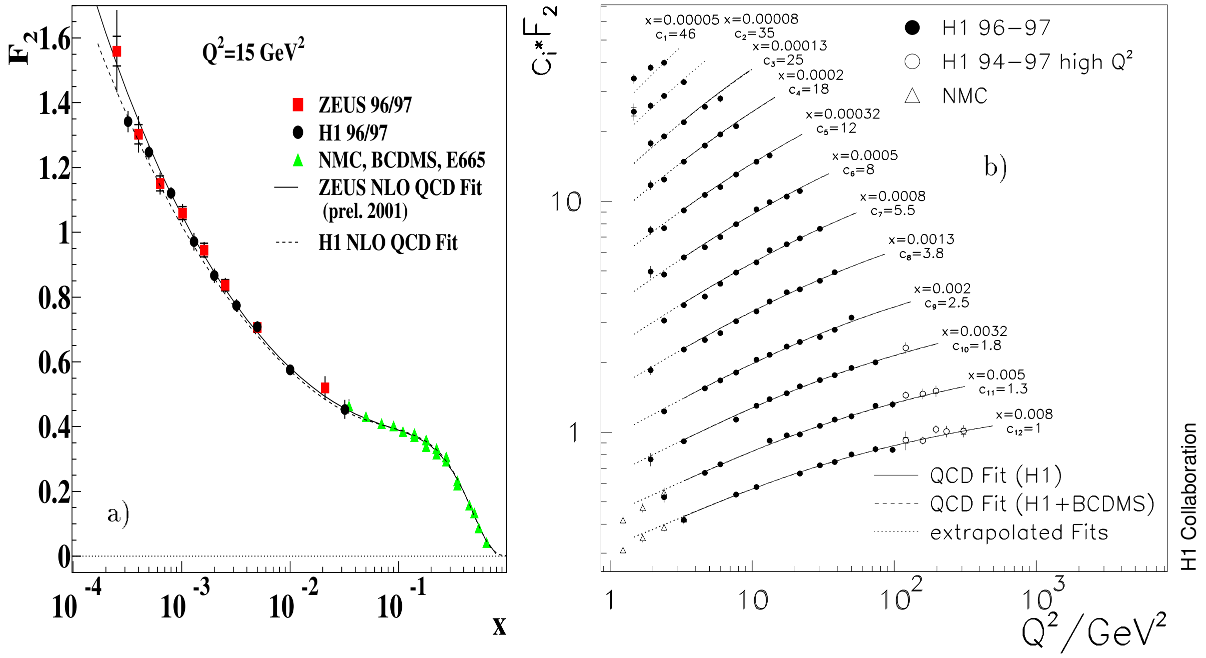

Figure 1: Measurements of the proton structure function $F_2(x,Q^2)$ at HERA extending into the region of fixed target data. The rise towards low x is described by NLO QCD fits (a). The Q^2 dependence is compared with a NLO QCD fit to H1 and BCDMS cross section data (b).

can be reconstructed from the measurements of the energies and angles both of the scattered positron and of the hadronic final state. This overconstraint has been a major reason for the wide kinematic coverage and the reliability of the HERA structure function data. Figure 1(a) illustrates the high precision and the compatibility of the recent F_2 measurements. The proton structure function $F_2(x,Q^2)$ rises towards low x and also strongly with Q^2, Figure 1(b) . Standard QCD evolution attributes this rise to the gluon distribution, i.e. $(\partial F_2/\partial \ln Q^2)_x \propto \alpha_s \cdot xg$ for $Q^2 > 3\,\mathrm{GeV}^2$. Photon-gluon fusion into quark-antiquark pairs dominates the interaction cross section at low x. The gluon momentum distribution has been determined in NLO QCD from the observed scaling violations [1], to within a few per cent accuracy at $Q^2 \sim 20\,\mathrm{GeV}^2$.

3 The Longitudinal and the Charm Structure Functions

Complementary information on the behaviour of the gluon distribution at low x can be obtained from the measurements both of F_L and of F_2^c, now performed with increased accuracy. Assumptions about the behaviour of F_2 at high y allow measurements of F_L to be obtained from reduced cross section data in this region. Combining high resolution calorimetry with tracking information in front of the calorimeter, the H1 Collaboration has presented data up to $y = 0.89$ which requires an understanding of the positron identification and photoproduction background problems for scattered electron energies down to 3 GeV. The F_L data [1] are shown in Figure 2 (left). They are well described by a NLO QCD fit to the F_2 data only, i.e. within the current uncertainty the observed behaviour of F_L is consistent with the measured scaling violations described by NLO QCD. Also shown is a dipole model prediction of F_L from a fit to F_2 , which at lowest Q^2 seems to prefer the exact solution over the leading twist prediction [3].

The charm structure function is mainly determined from the observation of photon-gluon fusion into $c\bar{c}$ pairs leading to the production and decay of D mesons, $D^* \to D^0\pi_s \to K\pi\pi_s$. This reaction is identified by utilising the small $D^* - D$ mass difference, ΔM. Recent results on F_2^c from the ZEUS Collaboration, using the ΔM technique and semi-inclusive charm data [4], and from the H1 Collaboration, using ΔM data [5], are shown in Figure 2 (right). $F_2^c(x,Q^2)$ is

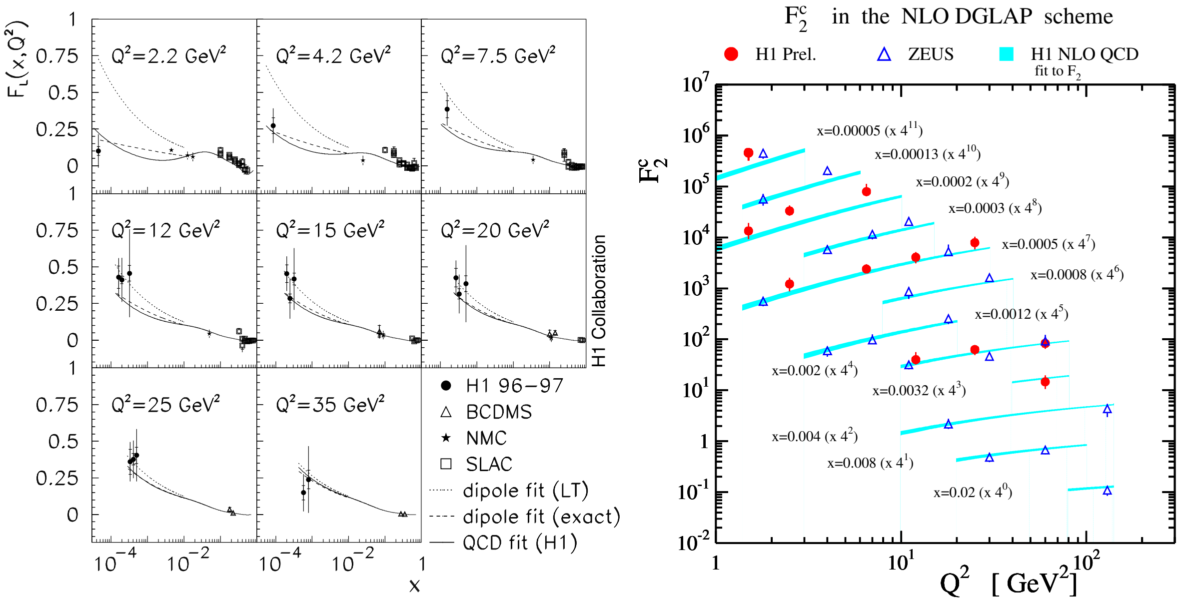

Figure 2: Left: Determination of the longitudinal proton structure function at low x by the H1 Collaboration compared to fixed target data at larger x. Right: Measurements of the charm structure function by the ZEUS and the H1 Collaborations compared with a NLO QCD fit to inclusive cross section data by H1.

observed to rise with Q^2 and is consistently described by NLO QCD fits to the F_2 data. At low x, charm production represents about 10 to 30% of the inclusive cross section for Q^2 between 2 and 50 GeV^2, respectively, see Figure 3(left). Heavy flavour physics at HERA has become a central field of theoretical activity with the challenge of consistently describing both the charm and a surprisingly large beauty [6] production cross section [7].

4 Strong Coupling Constant α_s

The strong interaction coupling constant is known much less accurately than either the Fermi constant or the electroweak mixing angle, yet is equally important with regard to investigations of the unification of the particle interactions. Inclusive DIS measurements, coupled with high-order QCD calculations, provide an ideal laboratory for α_s measurements. The H1 Collaboration obtained a new result [1] on α_s. The combination of the low-x H1 data with the large-x BCDMS data [8] resolves the correlation of α_s and xg yielding in NLO QCD $\alpha_s(M_Z^2) = 0.1150 \pm 0.0017\ (exp)^{+0.0009}_{-0.0005}\ (model)$. The correlated systematic errors are part of the minimisation. By a disputable convention, the effect of the uncertainty of the factorisation and renormalisation scales is estimated with variations between $Q^2/4$ and $4Q^2$. This determines an additional theoretical uncertainty $\alpha_s(M_Z^2)$ of about ± 0.005, mainly due to the renormalisation scale. The analysis leads also to the first determination of α_s with H1 data alone, $\alpha_s(M_Z^2) = 0.115 \pm 0.005\ (exp)$.

H1 were able to restrict the analysis to lepton-proton data alone by introducing a novel flavour decomposition of F_2. The two functions necessary to describe the evolution are chosen so as to allow the quark counting rules to be imposed and the measured asymmetry of the proton sea to be considered. In a conventional analysis of lp and ld data, a consistent result is obtained, namely $\alpha_s(M_Z^2) = 0.1158 \pm 0.0016\ (exp)$. This, however, is subject to nuclear binding correction uncertainties. The result obtained by H1 is independent of the choice of the minimum Q^2 and x, i.e. it is not affected by any possible departure from NLO QCD in the low x region. Higher twist effects at larger x are suppressed by the inherent cut at $Q^2 > 6.5\,\mathrm{GeV}^2$

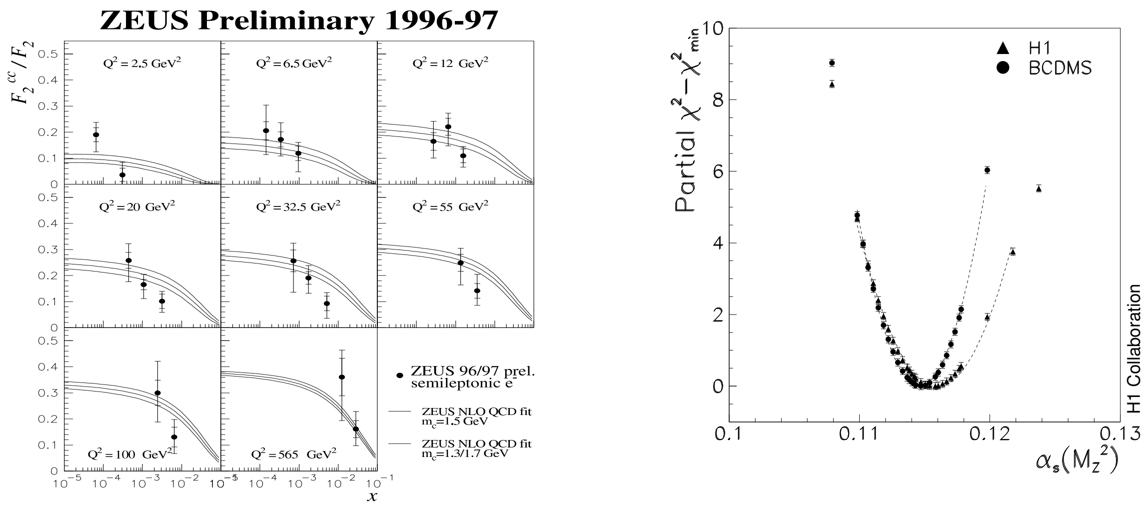

Figure 3: Left: The ration F_2^c to F_2 as a function of x at different Q^2 values; Right: The contributions to the χ^2 in the NLO QCD fit due to the H1 and BCDMS data as a function of α_s.

in the BCDMS data. With such a Q^2 requirement, the NMC data lead to a consistent result, $\alpha_s(M_Z^2) = 0.116 \pm 0.003$ (exp), without any higher twist term. This result, however, is of lower accuracy, which justifies the restriction of the analysis to a minimum set of data easing the systematic error treatment. With a detailed analysis of systematic effects, the BCDMS data are shown to lead to a larger value of α_s than hitherto believed [9] if the region of largest uncertainty and discrepancy with SLAC data is excluded from the analysis. This leads to a remarkable consistency of the H1 and the BCDMS data, expressed in the partial χ^2 contributions shown in Figure 3(right). The result obtained is consistent with recent analyses of DIS data [10,11] which include contributions beyond NLO.

5 Summary

Progress in the exploration of the low-x domain of deeply inelastic scattering has been impressive. With the start of the high luminosity phase of HERA, with upgraded detectors and improved calibration and alignment accuracy, this field will undoubtedly become a high precision testing ground for proton structure and strong interaction theory.

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