New structure function results at low x and high Q^2 from HERA

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A precise proton structure function F_2 at low x is measured. The data is interpreted in the framework of QCD with an extraction of gluon density xg. The charm contribution to F_2 is determined in an extended kinematic range. Neutral and charged current cross-sections at high Q^2 are also measured and compared with the Standard Model predictions.

1. INTRODUCTION

The deep inelastic scattering (DIS) experiments have played an important role in establishing and developing the quantum chromodynamics (QCD) and electroweak (EW) sector of the Standard Model (SM). At HERA, the first $e^{\pm}p$ collider operating at a centre-of-mass energy of $\sqrt{s} = 300 - 320\,\mathrm{GeV}$, the neutral current (NC) and charged current (CC) DIS processes are being studied since 1992 with increasing precision by the H1 and ZEUS experiments in a largely new kinematic domain at low x and high Q^2. The experimentally measurable kinematic variable x stands for the momentum fraction carried by the struck parton in the quark-parton model, and Q^2 the negative of the four-momentum transfer squared of the exchanged bosons.

2. SELECTED RECENT MEASUREMENTS AT LOW x AND HIGH Q^2

In this talk, a few recent measurements at low x and high Q^2 are reported[2]: precision proton structure function F_2, gluon density xg from a next-to-leading-order (NLO) QCD analysis of F_2, charm contribution to F_2, longitudinal structure function F_L, and NC and CC cross-sections at high Q^2.

What is measured experimentally is the cross-section. For the NC process, the cross-section can be expressed in terms of F_2, F_L, and parity violating term xF_3:

$$\frac{d^2\sigma^{\pm}_{\mathrm{NC}}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^2}\left[Y_+F_2(x,Q^2) - y^2F_L(x,Q^2) \mp Y_-xF_3(x,Q^2)\right] \tag{1}$$

where $Y_\pm = 1 \pm (1-y)^2$ is the helicity function with $y = Q^2/sx$ and $F_2 = F_2^{\mathrm{em}}(1+\delta_Z)$. The dominant contribution F_2^{em} arises from the photon exchange and the term δ_Z accounts for contributions from the γZ interference and the Z exchange. At Q^2 well below M_Z^2,

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[2]Due to the space limitation, a further selection has been made from what have actually been shown during the conference.

both δ_Z and xF_3 are negligible. The second term in Eq.(1) is also negligible if y is not too large ($y \leq 0.6$). Similarly for the CC process, the cross-section can also be related to the corresponding structure functions. In the leading-order approximation this is given by:

$$\frac{d^2\sigma^+_{\rm CC}}{dxdQ^2} = \frac{G_F^2}{4\pi x}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2 \left[x(\overline{u}+\overline{c})+(1-y)^2x(d+s)\right] , \quad (2)$$

$$\frac{d^2\sigma^-_{\rm CC}}{dxdQ^2} = \frac{G_F^2}{4\pi x}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2 \left[x(u+c)+(1-y)^2x(\overline{d}+\overline{s})\right] . \quad (3)$$

where G_F is the Fermi coupling constant. Contrary to the NC process, where $F_2^{\rm em}$ is independent of the lepton beam polarity, the $e^\pm p$ CC processes probe different quark types.

The most precisely measured reduced cross-section[3] σ_r so far at HERA is shown in Fig.1 as a function of x for a fixed Q^2 value ranging from $1.5\,{\rm GeV}^2$ to $150\,{\rm GeV}^2$. The H1 measurement is based on their $18\,{\rm pb}^{-1}$ e^+p data taken in 1996 and 1997 for $Q^2 > 10\,{\rm GeV}^2$ and a dedicated run of $2\,{\rm pb}^{-1}$ for $Q^2 < 10\,{\rm GeV}^2$. The statistical precision at $Q^2 < 100\,{\rm GeV}^2$ is now better than 1% with a typical systematic precision of $3-4\%$. The H1 data at $y \leq 0.6$ together with fixed target data [1] at high x have been analysed using the NLO DGLAP evolution equations [2] to provide predictions (H1 QCD fit) for σ_r (full curves) and $F_2^{\rm em}$ (dashed curves). The data at high y, which do not enter the fit, agree well with the predicted σ_r but deviate from $F_2^{\rm em}$ showing the sensitivity to F_L. This sensitivity has been exploited by H1 with an extracted F_L as shown in Fig.2.

The HERA data at low x are unique as they can be used to extract the gluon density xg. The results of the ZEUS analysis are presented in Fig.3 based on their previous F_2 data [3]. The relative magnitudes show that the rise of F_2 at low x for Q^2 around $1\,{\rm GeV}^2$ is actually dominated by the quark singlet distribution $x\Sigma \equiv \sum_{i=u,d,s}[xq_i(x)+x\overline{q}_i(x)]$ while the rise for Q^2 at higher values can be attributed to the dominant gluon distribution xg.

The charm production mechanism can be tested experimentally using tagged D^* decaying via $D^* \to D^0\pi \to (K\pi)\pi$. The measured inclusive D^* production cross-section [4] can be described by NLO prediction [5] for charm produced via photon-gluon fusion. Extrapolating the measured cross-section into the full phase space, the open charm contribution to F_2, $F_2^{c\overline{c}}$, has been determined. The results reported here are from ZEUS using their 1996-1997 data ($37\,{\rm pb}^{-1}$), a more than tenfold increase compared to the previous studies [6]. The ratio of $F_2^{c\overline{c}}$ over F_2 is shown in Fig.4. The $F_2^{c\overline{c}}$, which contributes about 20% to F_2, increases as Q^2 grows and as x falls, and agrees well with the NLO prediction. The charm production data have further been used by H1 to determine in an alternative way the gluon density xg [4]. These results, though less precise, provide a powerful check of the xg determined from the QCD analysis of the F_2 data.

The NC cross-sections at high Q^2 have been obtained by the H1 and ZEUS collaborations using fully available $e^\pm p$ data [7]. The H1 results cover $150\,{\rm GeV}^2 \leq Q^2 \leq 30000\,{\rm GeV}^2$ and $0.0032 \leq x \leq 0.65$. The results at high x are shown in Fig.5. The data are compared with predictions derived from a slightly different fit [7] from the one mentioned earlier but using also only low Q^2 e^+p data. The data, though limited in statistical precision, agree

[3]The reduced cross-section is defined so that the (x, Q^2) dependence on the kinematic factor is removed, e.g. $\sigma_r = \tilde{\sigma}_{\rm NC} = F_2(x,Q^2) - y^2/Y_+F_L(x,Q^2) \mp Y_-/Y_+xF_3(x,Q^2)$.

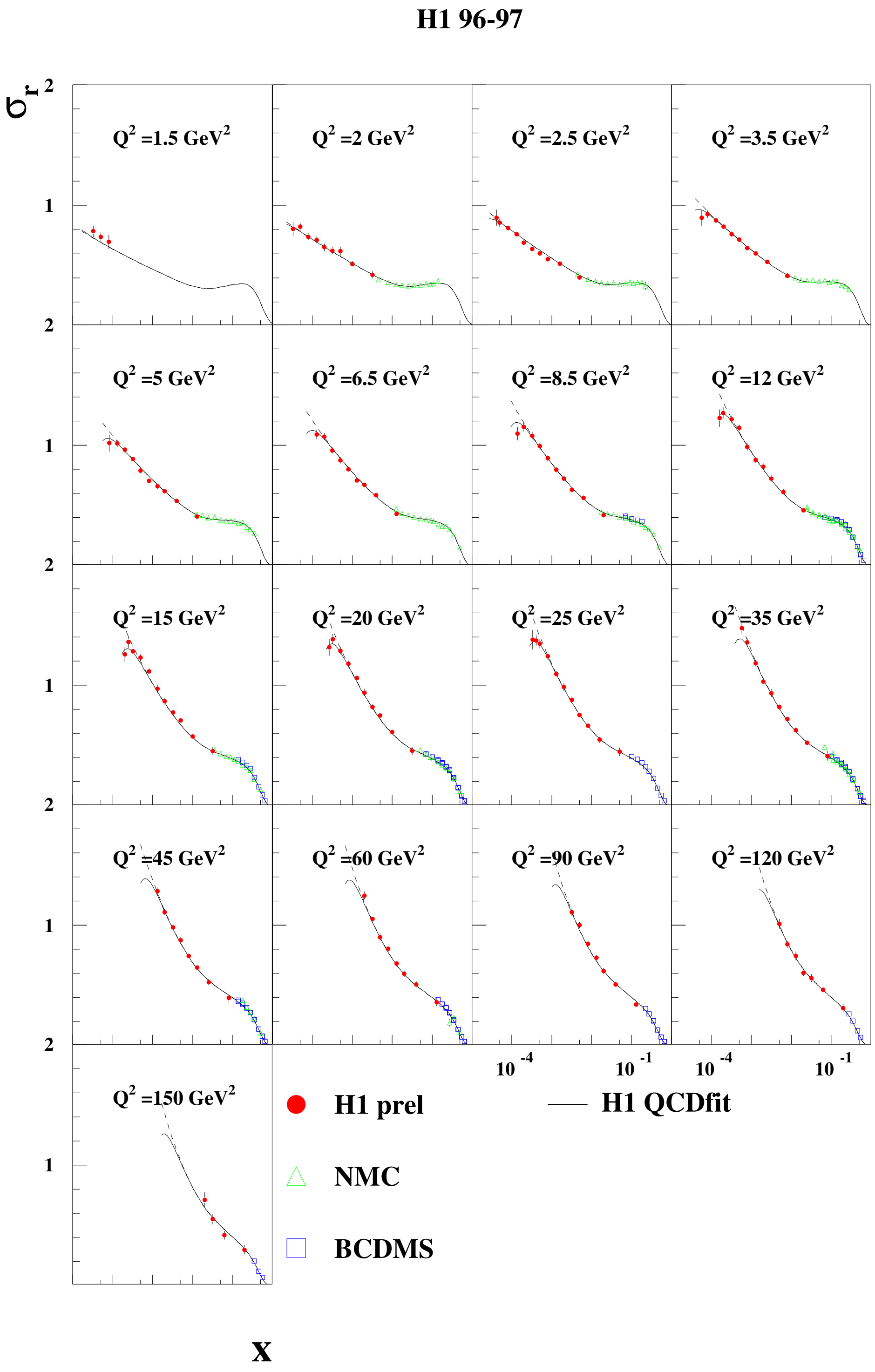

Figure 1. H1 preliminary reduced cross-section compared with the H1 QCD fit (full curves) and with F_2^{em} (dashed curves).

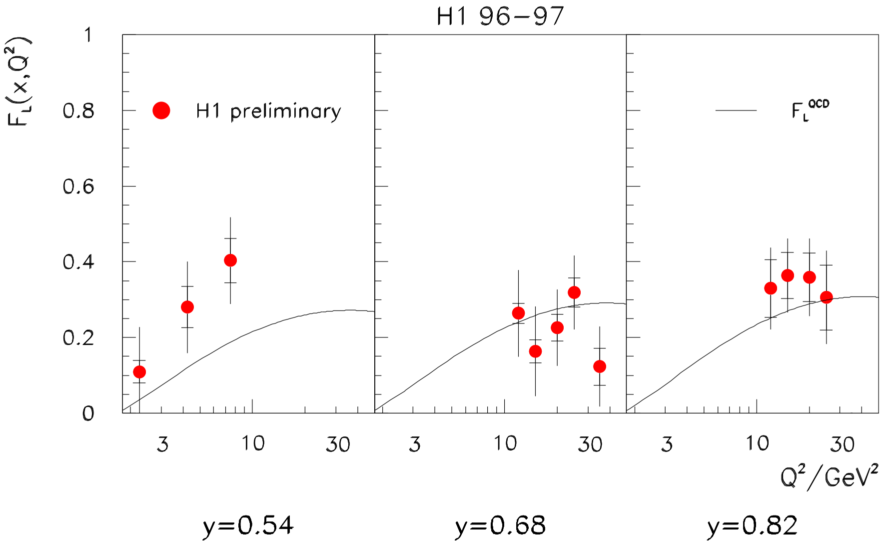

Figure 2. A determination of F_L (H1 preliminary) compared with the QCD prediction.

fairly well with the predictions except for a systematic excess of the e^+p data at $x = 0.4$ and $Q^2 > 15000\,\mathrm{GeV}^2$ and a step behaviour at $x = 0.65$ between the H1 and the fixed target data. The excess, though less significant with respect to what has been reported earlier based on 1994-1996 e^+p data [8], remains to be clarified. The data also present a clear evidence for the EW effect associated with the Z exchange at high Q^2 in the NC process.

The CC cross-sections have also been measured [9]. The difference in the e^+p and e^-p scatterings shows the large selectivity in the lepton quark coupling and the potential to constrain u and d flavours in a region that is free of nuclear binding effects.

3. SUMMARY AND OUTLOOK

To summarise, the structure function F_2 measured by the HERA experiments at low x and Q^2 has now reached a precision comparable with that of fixed target experiments. The gluon density determined from a NLO QCD analysis of F_2 data agrees well with that determination based on the tagged D^* samples. The charm contribution to F_2 has been measured in an extended kinematic ranges with improved precision. Experimental uncertainties of these measurements are expected to be further reduced when all available data will have been analysed. Both NC and CC cross-sections from e^+p and e^-p collisions at high Q^2 are measured. The electroweak effect has been observed for the first time at HERA in the $e^{\pm}p$ NC cross-sections. The different quark contributions to the CC cross-sections have been experimentally established providing potential for constraining the valence quark densities in the future with more precise measurements.

HERA is currently running with e^+p collisions and will be upgraded in 2000 with a factor of 5 increase in its peak luminosity and the possibility of having polarised beams. These data provide an exciting opportunity both in further precision tests of the Standard Model and in searching for new physics beyond it.

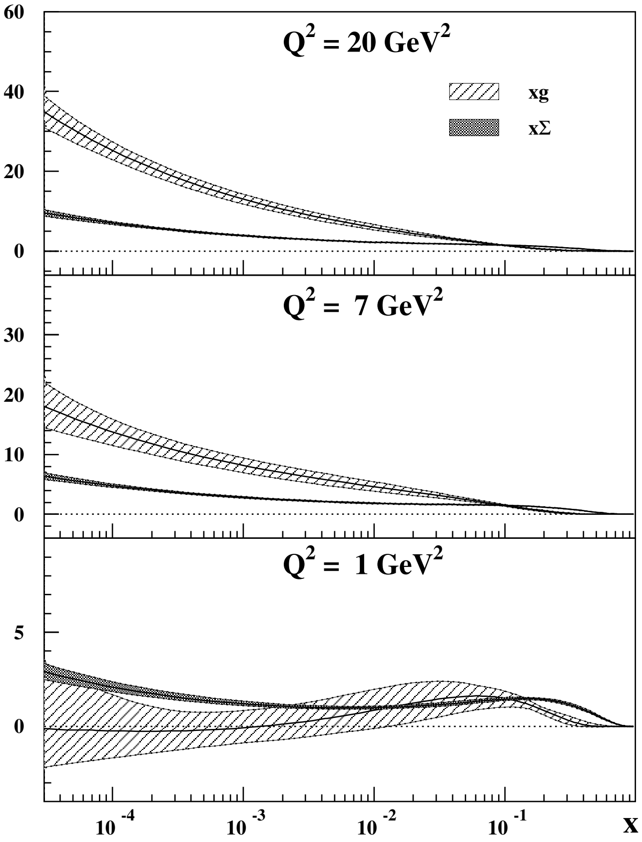

Figure 3. The results of the ZEUS QCD fit: the gluon momentum distribution xg and the quark singlet momentum distribution $x\Sigma$ as a function of x.

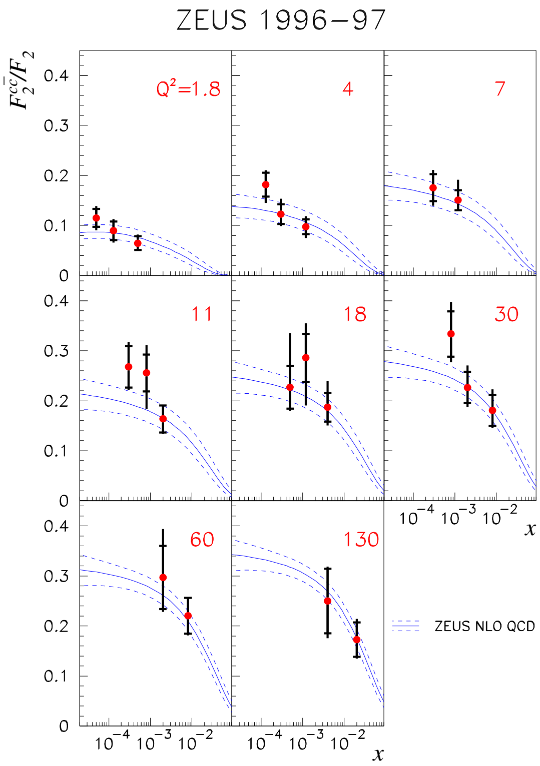

Figure 4. The ratio of the measured charm contribution $F_2^{c\bar{c}}$ over F_2 compared with the QCD prediction.

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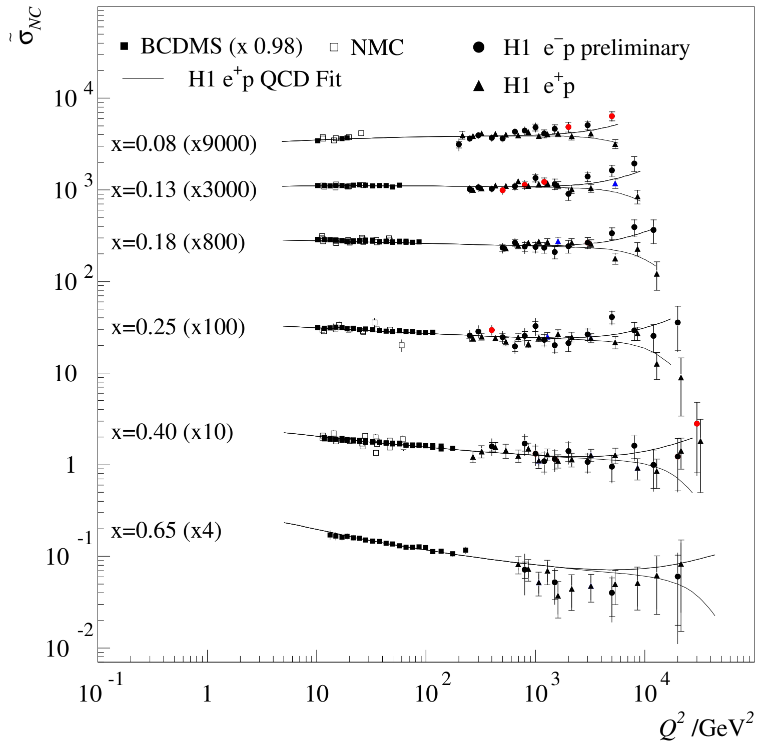

Figure 5. H1 reduced e^+p NC cross-section and preliminary reduced e^-p NC cross-section compared with H1 e^+p QCD fit.

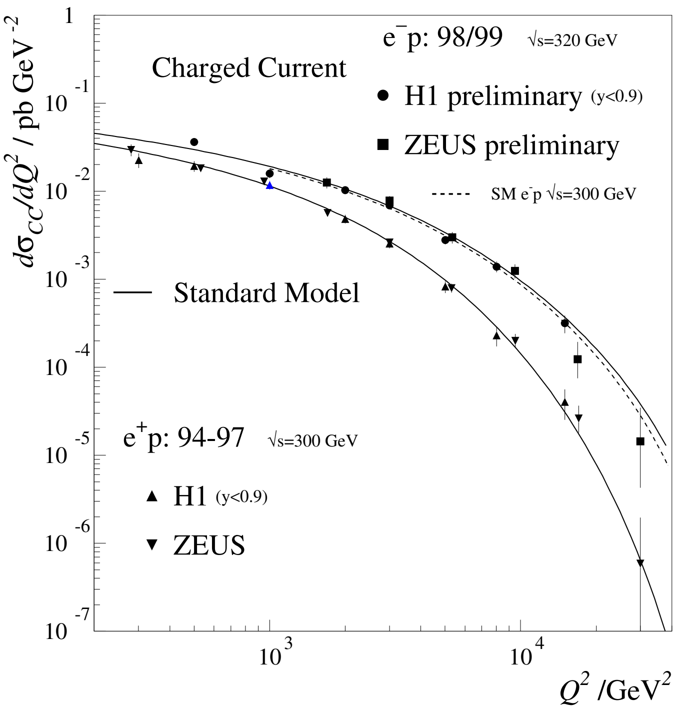

Figure 6. H1 and ZEUS e^+p CC cross-sections and preliminary e^-p CC cross-sections compared with SM predictions.