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QCD fits to ZEUS and fixed target structure function data

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Abstract

Preliminary results are presented on the gluon density at low x obtained from a QCD analysis of ZEUS 1994 F_2 structure function data combined with those from NMC. Also given are estimates of the experimental error on the e^+p NC Born cross section at large x and Q^2. This estimate is obtained from propagation of the statistical and systematic errors on fixed target structure functions.

Introduction

In perturbative QCD the scaling violations of the F_2 structure functions are caused by gluon bremsstrahlung from quarks and quark pair creation from gluons. In the low x domain accessible at HERA the latter process dominates the scaling violations. In this report I present preliminary results on the gluon momentum density extracted from a NLO QCD anlysis of F_2 structure functions measured by ZEUS in 1994.

With the present integrated luminosity of about 20 pb^{-1} at HERA the region of large x (~ 0.5) and Q^2 ($\sim 10^4$ GeV^2) becomes accessible. Both ZEUS [1] and H1 [2] have observed an excess of events compared to the standard model predictions in this hitherto unexplored region. The uncertainty in these predictions is dominated by that on the parton distributions in the proton. I will summarise the results of a QCD analysis by ZEUS of fixed target structure function data at high x (> 0.1) yielding an estimate of the experimental error on the NC Born cross section of e^+p deep inelastic scattering at HERA.

QCD analysis of ZEUS 1994 data

The data used in the fit were the ZEUS 1994 nominal vertex data [3] which cover a kinematic range of $6.3\times10^{-5} < x < 0.5$ and $3.5 < Q^2 < 5000$ GeV^2 together with the low Q^2 measurements (shifted vertex, ISR) [4]. The latter datasets extend the kinematic range down to $x = 3.5\times10^{-5}$ and $Q^2 = 1.5$ GeV^2 albeit with larger statistical and systematic errors. NMC data on F_2^p and F_2^d [5] constrain the fit at high x. To remove possible contributions from higher twist effects at large x the NMC data below $Q^2 = 4$ GeV^2 were discarded.

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At the input scale $Q_0^2 = 7$ GeV^2 the gluon distribution (xg), the singlet quark distribution ($x\Sigma$) and the difference of up and down quarks in the proton ($x\Delta_{ud}$) were parametrised as

$$
\begin{aligned}
xg(x,Q_0^2) &= A_g x^{\delta_g}(1-x)^{\eta_g}(1+\gamma_g x) \\
x\Sigma(x,Q_0^2) &= A_s x^{\delta_s}(1-x)^{\eta_s}(1+\varepsilon_s\sqrt{x}+\gamma_s x) \\
x\Delta_{ud}(x,Q_0^2) &= A_{ns} x^{\delta_{ns}}(1-x)^{\eta_{ns}}
\end{aligned}
\tag{1}
$$

The strange quark distribution was assumed to be 20% of the sea at $Q^2 = 4$ GeV^2 [6]. The sea quark density was otained by subtracting the valence (taken from MRSD$'_-$) from the singlet distribution. The gluon normalisation, A_g, was fixed by the momentum sumrule. The input value for the strong coupling constant was set to the result of ref. [7]: $\alpha_s(M_Z^2) = 0.113$.

The input parton distributions were evolved in NLO in the $\overline{\mathrm{MS}}$ scheme with $f = 3$ light flavours. The charm contribution to the F_2 structure function was calculated in NLO from the evolved distributions as described in [8] with the charm mass set to 1.5 GeV. Contributions from bottom are estimated to be small and were neglected.

In addition to the 11 parameters describing the parton distributions one (two) normalisation parameters for the ZEUS (NMC) data were left free in the fit. In the computation of the χ^2 only statistical errors were taken into account. For each dataset the quantity $[(N-1)/\Delta N]^2$ was added where ΔN is the quoted normalisation error of the dataset.

The fit yielded a good description of the data as shown in Fig. 1. Adding the statistical and systematic errors in quadrature the $\chi^2 = 463$ for 408 datapoints and 13 free parameters. The

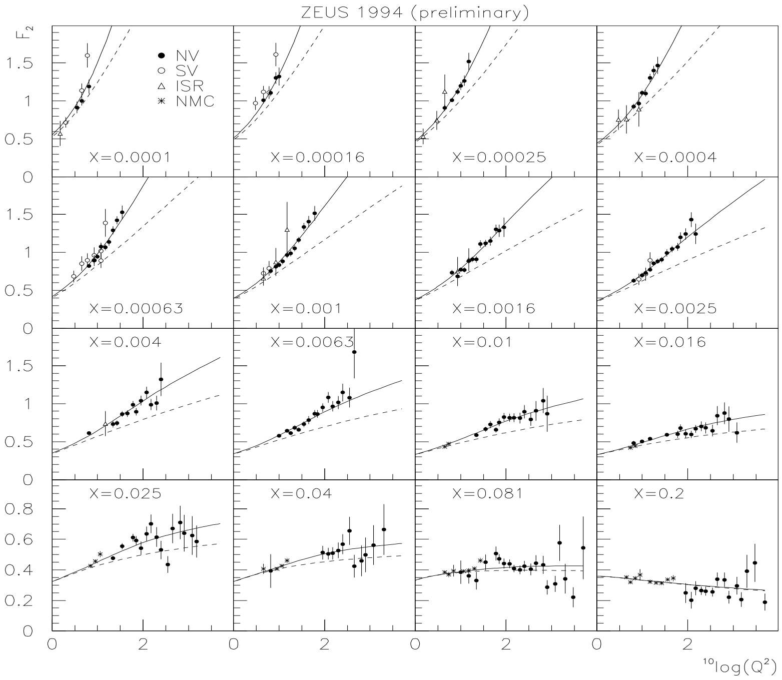

Figure 1: The F_2^p structure function versus Q^2 for fixed values of x. The errors shown are the statistical and systematic errors added in quadradure. The solid curves correspond to the NLO QCD fit described in the text. The dashed curves show F_2 without the contribution from charm.

fitted normalisation parameters were 97.4% for ZEUS and (99.3%,98.9%) for the NMC 90 GeV and 280 GeV datasets respectively which is well within the quoted normalisation errors.

Fig. 2a shows the gluon momentum denstity obtained from the fit at the input scale $Q_0^2 = 7$ GeV^2. The inner (outer) shaded band indicate the statistical and the statistical and systematic error added in quadrature. It is seen that at the lowest value of $x = 3 \times 10^{-5}$ the gluon is determined with an accuracy of about 20%. At $x = 4 \times 10^{-4}$ the total error is $\sim$12% which is a large improvement compared to the $\sim$50% error on the gluon distribution obtained from the QCD analysis of the ZEUS 1993 F_2 data [9]. At the input scale the momentum fraction carried by quarks (gluons) was found to be 0.555 (0.445). The fitted values of the parameters describing the low x behaviour of the quark singlet and the gluon distributions are $\delta_s = -0.23 \pm 0.01 \pm 0.02$ and $\delta_g = -0.24 \pm 0.02 \pm 0.05$ where the first error is statistical and the second systematic.

The gluon distribution evolved to $Q^2 = 20$ GeV^2 is shown as the shaded (total) error band in Fig. 2b. Also plotted are the gluon densities from the recent parton distribution sets MRS(R1) [10], CTEQ4M [11] and from GRV(HO) [12]. Whereas the agreement with MRS and CTEQ at low x is excellent, the steep gluon obtained from the dynamical evolution by GRV is inconsistent with the result of this analysis.

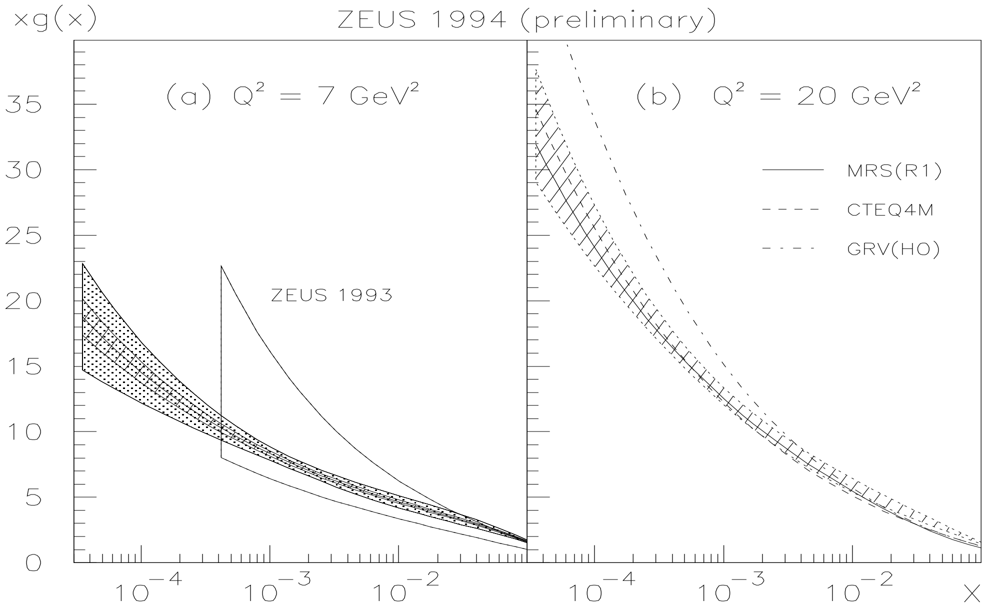

Figure 2: The gluon distribution as function of x for a fixed value of $Q^2 = 7$ GeV^2. The inner (outer) shaded band corresponds to the statistical (total) error. Also shown is the gluon distribution obtained from the ZEUS 1993 analysis. (b) The gluon distribution from this analysis (shaded band) at $Q^2 = 20$ GeV^2 compared to those from MRS(R1), CTEQ4M and GRV(HO).

Extrapolation of high x structure functions to large Q^2

In this section we describe a QCD analysis of high x structure function data. The aim of this analysis is to estimate the experimental uncertainty on the ep neutral current (NC) cross-section at large $x \sim 0.5$ and $Q^2 \sim 3 \times 10^4$. This error estimate is used in [1] to judge the significance of a possible excess of events observed at HERA in this region [1, 2].

The data used in the fit were the proton and deuteron F_2 data from SLAC [13], BCDMS [14] and NMC [15] together with $xF_3^{\nu N}$ from CCFR [16]. Since we are only interested in the high x domain, data below $x = 0.1$ were discarded. Also applied were the cuts $Q^2 > 4$ GeV^2 and $W^2 > 10$ GeV^2 to remove target mass and higher twist effects. F_2^d data above $x = 0.7$ were discarded to eliminate possible contributions from Fermi motion in deuterium.

The QCD analysis of these data is similar to that presented in the previous section except (i) the charm (bottom) quark distribution was generated dynamically from the threshold $Q^2_{c(b)} = 4$ (25) GeV^2 (ii) no momentum sumrule was imposed (iii) all normalisations were kept fixed to unity and (iv) the valence quark distribution, constrained by the CCFR xF_3 data, was left free in the fit with a functional form identical to that of $x\Delta_{ud}$ in Eq. (1). From the evolved quark distributions the F_2, F_L and xF_3 structure functions in ep scattering were calculated in NLO including contributions from Z_0 exchange and γZ interference [17].

The experimental systematic errors were propagated to the covariance matrix of the fitted parameters using the technique described in [18]. In total 24 independent sources of systematic error were included taking properly into account the correlations between the systematic errors of the NMC datasets.

It is convenient to express the NC cross section for e$^\pm$p scattering as

$$\tilde{\sigma}^\pm \equiv \frac{xQ^4}{2\pi\alpha^2 Y_+} \frac{d^2\sigma^\pm_{NC}}{dxdQ^2} = F_2 - \frac{y^2}{Y_+} F_L \mp \frac{Y_-}{Y_+} xF_3 \tag{2}$$

where $y = Q^2/xs$, $s \approx 4E_eE_p$ is the square of the ep centre of mass energy and $Y_\pm = 1 \pm (1-y)^2$.

In Fig. 3a we show the cross section for e^+p scattering at HERA energies ($E_e = 27.5$ $E_p = 820$ GeV) as a function of Q^2 for fixed values of x. The strong decrease in the cross section above $Q^2 \sim 5000$ GeV^2 is due to the contribution from xF_3. At high $x \sim 0.5$ and $Q^2 \sim 3 \times 10^4$ GeV^2 the error on $\tilde{\sigma}^+$ is estimated to be about 9%, see Table . The estimated errors include (small) contributions from an assumed uncertainty of $\Delta\alpha_s(M_Z^2) = 0.005$ and an error of 50% on the strange quark content of the proton.

In Fig. 3b the cross sections obtained from this analysis are compared to those calculated from the parton distribution sets MRSA [19] and CTEQ3M [20]. It is seen that the differences are much smaller than the experimental errors: comparison of results obtained from different parton distribution sets do not yield a reliable estimate of the uncertainty in the cross sections.

Q^2 (GeV^2)	$x \rightarrow$	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1000		4	4	4	4	4	5	8	15	31
30000					11	9	8	9	14	30

Table 1: The relative uncertainty in σ^+_{NC} in percent.

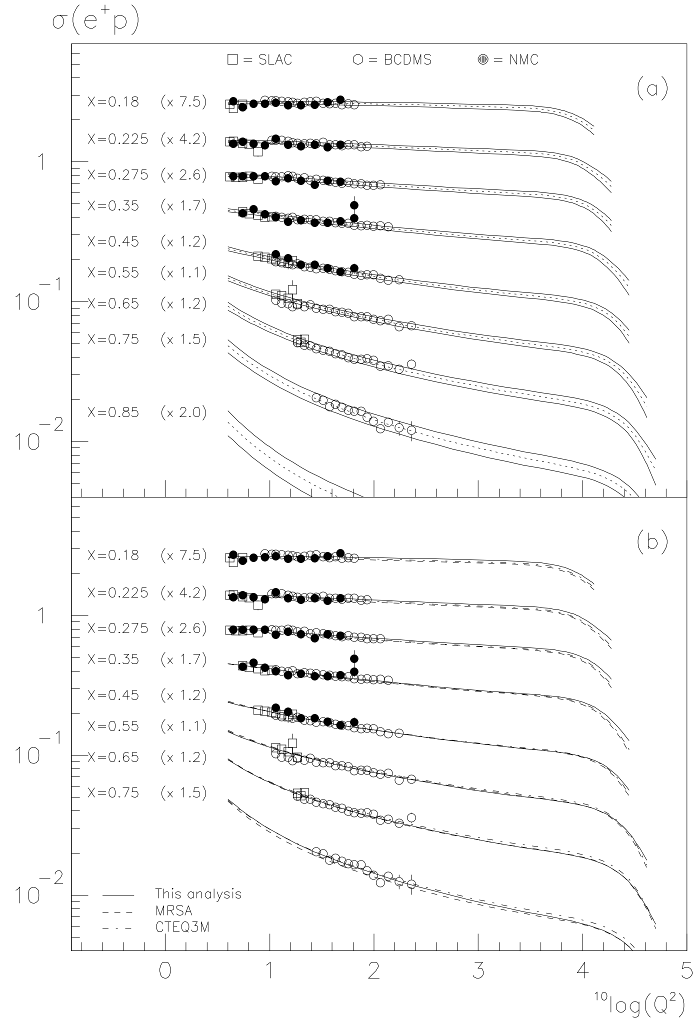

Figure 3: (a) The cross-section $\tilde{\sigma}$ (see text) for e^+p scattering at Hera energies. (b) The result of this analysis compared to cross sections calculated with the parton distribution sets MRSA and CTEQ3M.

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