Combined Electroweak and QCD analysis of ZEUS data including DIS cross sections with longitudinally polarised leptons.
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Abstract
A NLO QCD analysis on ZEUS jet-production data and inclusive cross-section data, including data with polarised lepton beams, is presented. The analysis is used to extract the parton distribution functions of the proton and is extended to fit electroweak parameters.

1 Introduction

The kinematics of deep inelastic lepton hadron scattering (DIS) is described in terms of the variables Q^2, the invariant mass of the exchanged vector boson, Bjorken x, the fraction of the momentum of the incoming nucleon taken by the struck quark (in the quark-parton model), and y which measures the energy transfer between the lepton and hadron systems. The double differential cross-sections for the neutral current (NC) process with lepton polarization P are given by,

$$\frac{d^2\sigma(e^{\pm}p)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[H_0^{\pm} + PH_P^{\pm}\right], H_{0,P}^{\pm} = Y_+ F_2^{0,P} - y^2 F_L^{0,P} \mp Y_- xF_3^{0,P} \tag{1}$$

where the tsructure functions $F_2^{0,P}$ and $xF_3^{0,P}$ are directly related to quark distributions by

$$F_2^{0,P} = \sum_i x(q_i + \bar{q}_i)A_i^{0,P}, xF_3^{0,P} = \sum_i x(q_i - \bar{q}_i)B_i^{0,P} \tag{2}$$

The coefficients A_i^0, B_i^0 for unpolarised beams are given to LO by

$$A_i^0(Q^2) = e_i^2 - 2e_i v_i v_e P_Z + (v_e^2 + a_e^2)(v_i^2 + a_i^2)P_Z^2 \tag{3}$$

$$B_i^0(Q^2) = -2e_i a_i a_e P_Z + 4a_i v_i v_e a_e P_Z^2 \tag{4}$$

The coefficients for the polarisation terms are given by

$$A_i^P = 2e_i a_e v_i P_Z - 2a_e v_e(v_i^2 + a_i^2)P_Z^2, \tag{5}$$

$$B_i^P = 2e_i a_i v_e P_Z - 2a_i v_i(v_e^2 + a_e^2)P_Z^2. \tag{6}$$

The term in P_Z arises from γZ^0 interference and the term in P_Z^2 arises purely from Z^0 exchange, where P_Z accounts for the effect of the Z^0 propagator relative to that of the virtual photon, and is given by

$$P_Z = \frac{Q^2}{Q^2 + M_Z^2}\frac{1}{\sin^2 2\theta_W}. \tag{7}$$

The other factors in the expression for A and B are the charge, e_i, NC electroweak vector, v_i, and axial-vector, a_i, couplings of quark i and the corresponding NC electroweak couplings of the electron, v_e, a_e. Equations 5,6 show that polarization effects are only important at high Q^2.

Unpolarized HERA data have been used in fits to determine Parton Distribution Functions (PDFs). For low x, $x \leq 10^{-2}$, F_2^0 is sea quark dominated and its Q^2 evolution, as predicted by QCD, is controlled by the gluon contribution, such that HERA data provide crucial information on low-x sea-quark and gluon distributions. At high Q^2, the structure function xF_3^0 becomes increasingly important, and gives information on valence quark distributions. The charged current (CC) interactions also enable us to separate the flavour of the valence distributions at high-x, since their (LO) cross-sections are given by,

$$\frac{d^2\sigma(e^+p)}{dxdQ^2} = (1+P)\frac{G_F^2 M_W^4}{(Q^2+M_W^2)^2 2\pi x} x\left[(\bar{u}+\bar{c}) + (1-y)^2(d+s)\right],$$
$$\frac{d^2\sigma(e^-p)}{dxdQ^2} = (1-P)\frac{G_F^2 M_W^4}{(Q^2+M_W^2)^2 2\pi x} x\left[(u+c) + (1-y)^2(\bar{d}+\bar{s})\right].$$

Parton Density Function (PDF) determinations are usually global fits [1–3], which use fixed target DIS data as well as HERA data. In such analyses, the high statistics HERA NC e^+p data have determined the low-x sea and gluon distributions, whereas the fixed target data have determined the valence distributions. Now that high-Q^2 HERA data on NC and CC e^+p and e^-p inclusive double differential cross-sections are available, PDF fits can be made to HERA data alone, since the HERA high Q^2 cross-section data can be used to determine the valence distributions. This has the advantage that it eliminates the need for heavy target corrections, which must be applied to the ν-Fe and μD fixed target data. Furthermore there is no need to assume isospin symmetry, i.e. that d in the proton is the same as u in the neutron, since the d distribution can be obtained directly from CC e^+p data.

The ZEUS-JETS PDF fit [4] was an NLO QCD fit in the DGLAP formalism to ZEUS inclusive cross-section data and jet production data from HERA-I. The PDFs were parametrized at $Q_0^2 = 7\text{GeV}^2$ by the form $xf(x) = p_1 x^{p_2}(1-x)^{p_3}(1+p_4 x)$, using 11 free parameters. Predictions for the cross-sections were made by evolving the PDFs to the Q^2 values of the measurements and convoluting them with coefficient functions, calculated in the general mass variable flavour-number scheme of Thorne and Roberts [7], to produce structure function predictions. Predictions for jet cross-sections were made using NLO programmes [5,6]. In evaluating the uncertainty on the PDF parameters and the cross-section predictions which derive from them full acount is taken of correlated experimental uncertainties using the OFFset method. However the determinations of the valence PDFs from HERA-I data are not as accurate as those from global fits because of poor statistics at high-x. The addition of data from HERA-II has changed this situation. This paper describes the improvement to the ZEUS-JETS PDFs from adding ZEUS e^-p NC data from the 2004-6 running period.

The polarization of the HERA-II data has also been exploited to measure electroweak couplings. The CC cross-sections give information on the propagator mass and the weak coupling. The NC cross-sections give information on the quark couplings to Z_0. This paper describes model independent extractions of these parameters. Since DIS is a space-like process this gives complementary information to that extracted from e^+e^- and $p\bar{p}$ analyses.

2 Results

Fig 1 shows ZEUS data on NC e^-p double differential cross-sections from the 2004-2006 running period. There are $105pb^{-1}$ of negatively polarised, $P_e = -0.27$, data and $71.8pb^{-1}$ of positively polarised, $P_e = +0.30$, data. Fig 2 shows ZEUS data on CC e^-p double differential cross-sections from the 2004-2005 running period. There are $78.8pb^{-1}$ of negatively polarised, $P_e = -0.27$, data and $42.7pb^{-1}$ of positively polarised, $P_e = +0.33$, data. These data have been input to the ZEUS-JETS fit analysis framework and this new fit is called the ZEUS-pol fit. The results of this ZEUS-pol fit are superimposed on the data in Fig 1 and Fig 2. The PDFs extracted from the ZEUS-pol fit are compared to those of the ZEUS-JETS fit in Fig 3. The central values of the fit are very compatible with the ZEUS-JETS fit, but the u-valence quark uncertainty is reduced significantly at large x, as can be seen from comparison of the fractional uncertainties of the PDFs shown on the right-hand-side of the figure. The improvement is mostly in the u-valence quark at present because the e^-p data are u quark dominated at large x. There will be further improvements in the d-valence distribution when the final e^+p CC HERA-II data become available.

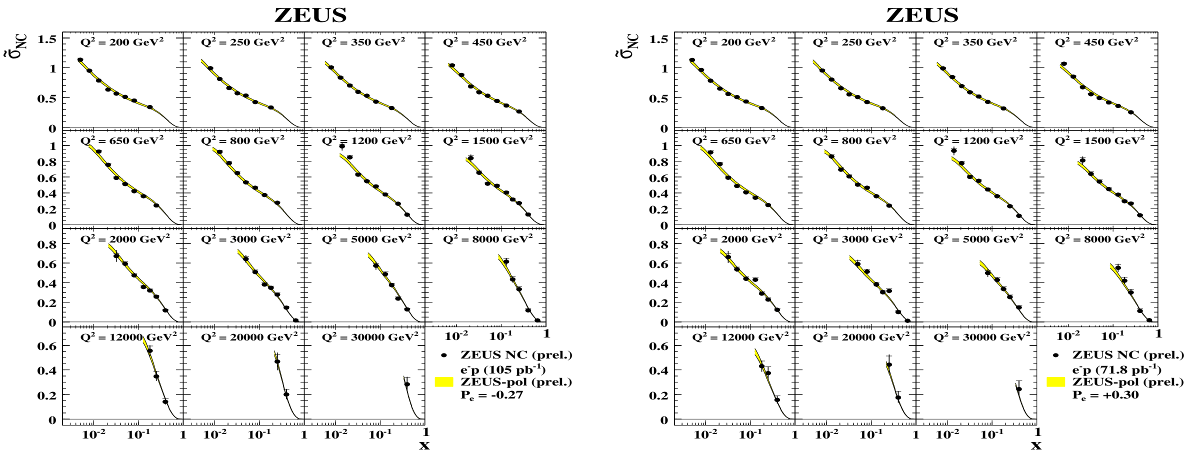

Fig. 1: ZEUS NC e^-p data from HERA-II running with polarised beams. The predictions of the ZEUS-pol fit are superimposed

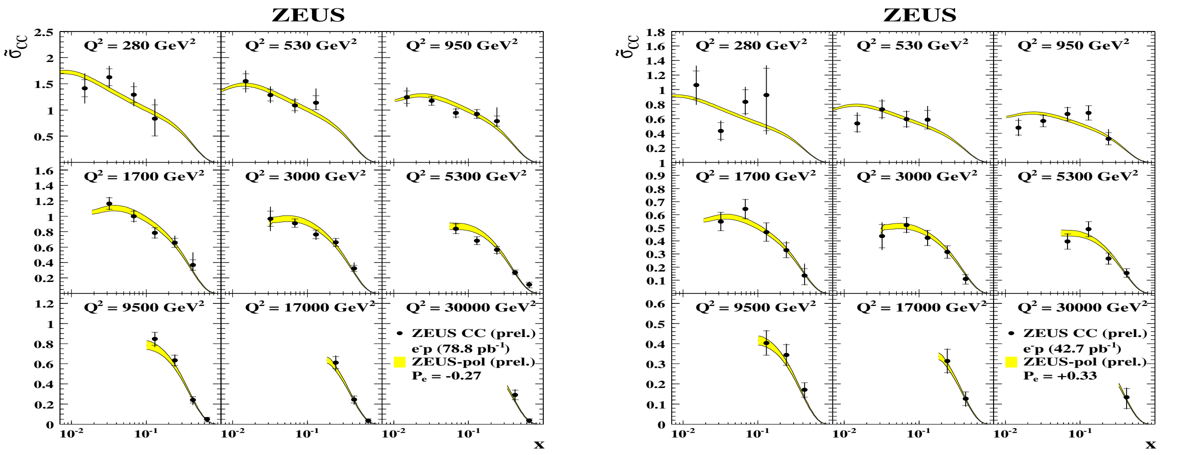

Fig. 2: ZEUS CC e^-p data from HERA-II running with polarised beams. The predictions of the ZEUS-pol fit are superimposed

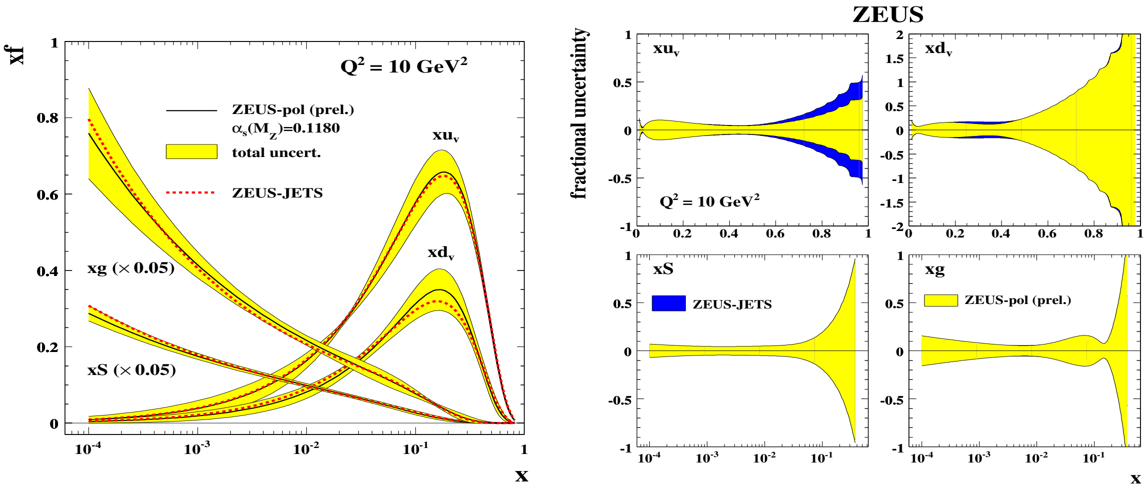

Fig. 3: Left hand side: The PDFs extracted from the ZEUS-pol fit and their uncertainties, compared to the ZEUS-JETS fit at $Q^2 = 10\mathrm{GeV}^2$. Right hand side: The fractioanl uncertainties of the ZEUS-pol PDFs compared to those of the ZEUS-JETS PDFs

	a_u	a_d	v_u	v_d
SM value	0.5	-0.5	0.196	-0.346
Fitted value	$0.51 \pm 0.10 \pm 0.17$	$-0.54 \pm 0.32 \pm 0.18$	$0.05 \pm 0.09 \pm 0.05$	$-0.64 \pm 0.20 \pm 0.14$

Table 1: Axial and vector quark couplings to the Z_0 as determined by a fit to the ZEUS e^-p data with polarised beams.

The polarization of the data has been exploited to measure the electroweak (EW) parameters. The stability of the extraction of the PDFs allows the determination of PDF and EW parameters simultaneously. The advantage of such a combined analysis is that correlations between the EW and the PDF parameters are automatically taken into account in the fit.

The CC cross-sections give information on the propagator mass. A fit in which M_W, the general coupling, $g = (G_F M_W^2$ in SM), and the PDF parameters are free gives [1]

$$M_W = 82.8 \pm 1.5 \pm 1.3\text{GeV}, g = 7.72 \pm 0.21 \pm 0.19 \times 10^{-2}.$$

Assuming the universality of the weak interaction G_F can be fixed to the world average value and M_W can be fitted together with the PDF parameters. Such a fit gives $M_W = 79.1 \pm 0.77 \pm 0.99$GeV. This can be compared with 78.9 $\pm$ 2.1 $\pm$ 1.8 $\pm$ 2.0(PDF) from a previous ZEUS analysis [11] in which the uncertainty coming from PDFs was not evaluated simultaneously. Freeing the EW parameters in the fit does not change the PDF parameters significantly.

The NC cross-sections give information on the quark couplings to Z_0, which appear in the coefficients $A_i^{0,P}$ and $B_i^{0,P}$. From equations 3,4,5,6 one can see that, since $v_e(\approx 0.04)$ is very small and $P_Z \gg P_Z^2$ for the HERA kinematic regime, the axial (a_q) and vector (b_q) couplings are dominant in unpolarized xF_3^0 and polarized F_2^P respectively. These EW parameters can be fitted simultaneously with the PDF parameters to perform a model independent extraction. Table 1 gives the extracted values of the four parameters a_u, a_d, v_u, v_d, compared with the SM values of $a_u = \frac{1}{2}$, $v_u = \frac{1}{2} - \frac{4}{3}sin^2\theta_W$, $a_d = -\frac{1}{2}$, $v_d = -\frac{1}{2} + \frac{2}{3}sin^2\theta_W$. The PDF parameters are not significantly altered from those of the ZEUS-pol fit.

Fig. 4 shows The 68% CL contour plots from the determination of a_q and v_q for u and d-type quarks. Fig. 5 shows the same contours together with results from other experiments [8–10]. The HERA extractions are dominated by the light-quark couplings and are thus compared with the corresponding light-quark extractions from LEP. The present analysis gives the best determinations using light quarks.

In the LEP and CDF measurements the quark couplings enter into the cross-sections such that a_q and v_q are strongly correlated for each flavour. However in the DIS process the quark couplings a_u and a_d are strongly correlated, as they both enter into xF_3^0, and the quark couplings v_u and v_d are strongly correlated, as they both enter into F_2^P. Thus it is interesting to look at the correlation plots for these quantities as shown in Fig. 6. Clearly the couplings to the u quark are much better detrmined than those of the d-quark, partly beacuse the d-quark PDF itself is not so well determined. This situation will improve as e^+p HERA data are input to the fit.

3 Summary

A NLO QCD analysis on ZEUS jet-production data and inclusive cross-section data, including data with polarised lepton beams, results in an improved determination of the u-valence quark PDF. The analysis is extended to fit electroweak parameters, resulting in the best determination of the light-quark vector and axial vector couplings to the Z_0.

[1]The first and second uncertainties given derive from experimental statistical and uncorrelated systematic sources, and from correlated systematic sources, respectively

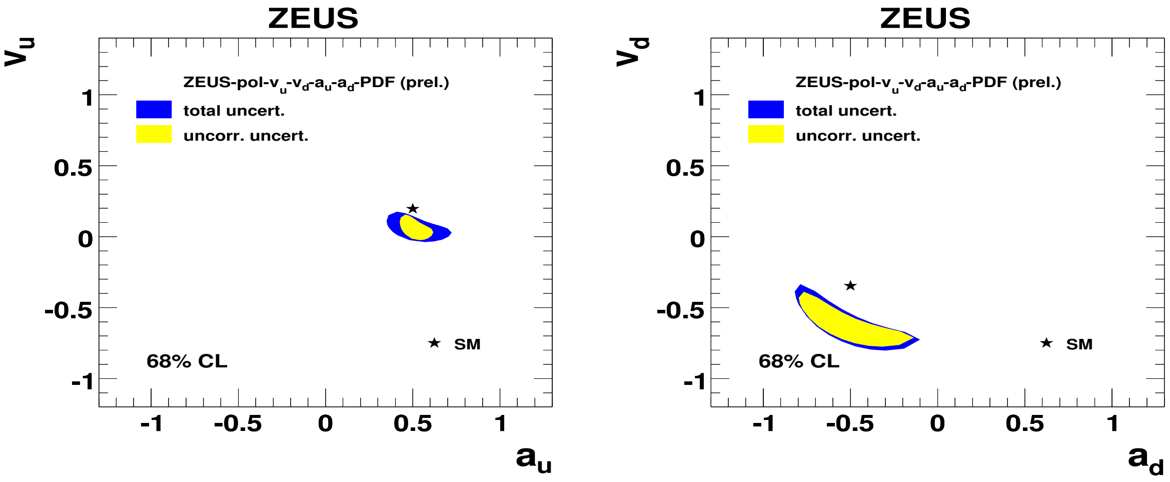

Fig. 4: Contour plots of the 68% CL limits on the electroweak couplings of the quarks to the Z_0. Left hand side: a_u vs v_u. Right hand side: a_d vs v_d. The yellow area represents experimental uncertainties from statistical and uncorrelated systematic sources and the blue area represents additional experimental uncertainties from correlated systematic sources

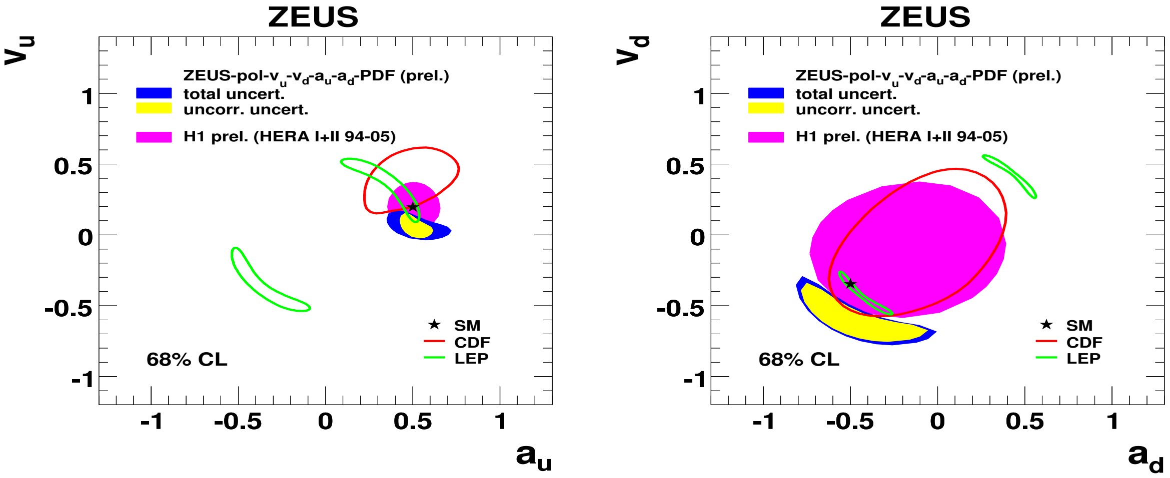

Fig. 5: Contour plots of the 68% CL limits on the electroweak couplings of the quarks to the Z_0 compared to those from H1 [8], CDF [9] and LEP-II [10]. Left hand side: a_u vs v_u. Right hand side: a_d vs v_d.

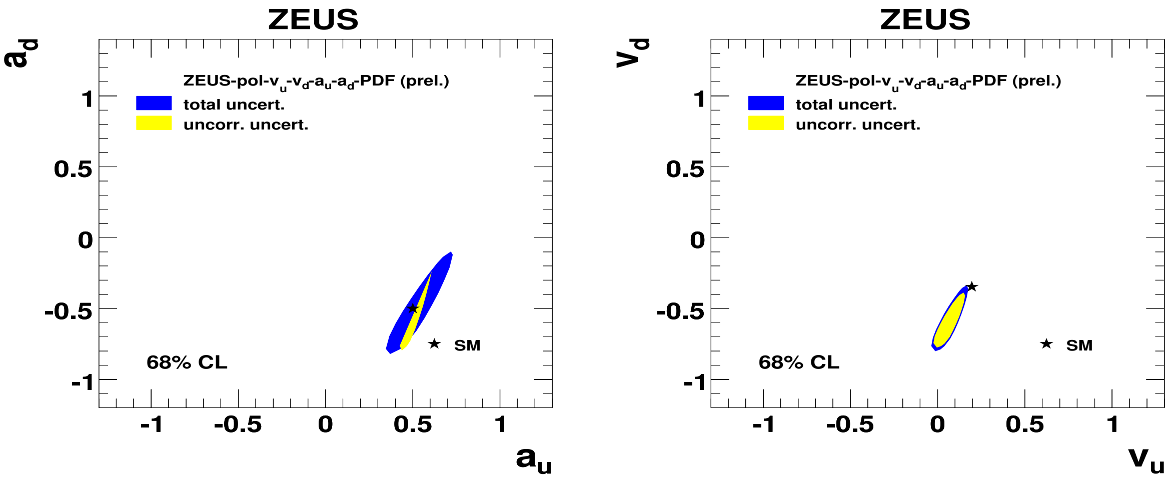

Fig. 6: Contour plots of the 68% CL limits on the electroweak couplings of the quarks to the Z_0. Left hand side: a_u vs a_d. Right hand side: v_u vs v_d. The yellow area represents experimental uncertainties from statistical and uncorrelated systematic sources and the blue area represents additional experimental uncertainties from correlated systematic sources

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