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PROCEEDINGS OF SCIENCE

Combined electroweak and QCD fits including NC and CC data with polarised electron beam at HERA-2

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A combined electroweak and QCD analysis is performed to determine electroweak parameters accounting for their correlation with parton distributions. The analysis is based on the deep inelastic e^+p and e^-p charged and neutral current scattering cross sections measured by the H1 experiment, including data with polarised lepton beams. The precision has been improved in particular for u quark coupling to the Z^0 boson with respect to the published results based on the unpolarised HERA data only. The determinations from HERA are compared with those from LEP and Tevatron.

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1. Introduction

HERA was a unique machine in which electrons (or positrons) of 27.6 GeV were collided on protons of up to 920 GeV. It has pushed the study of deep inelastic scattering into the highest energy frontier.

One of the studies made is the measurement of inclusive neutral current (NC) and charged current (CC) cross sections covering a large kinematic region. The NC and CC cross sections are primary source of information for probing the inner structure of the proton in terms of the momentum distributions of quarks (PDFs). The inclusive cross sections are also sensitive to electroweak (EW) parameters involved in the interactions. The study of the NC interaction especially enables the determination of the weak neutral couplings a_q and v_q of light quarks ($q = u,d$) to the Z^0 boson.

At HERA, a first determination of these couplings was performed using the published H1 data taken in the first phase of the HERA operation (HERA-1) [1]. This was performed in a combined EW-PDF analysis to take into account the correlation between the couplings and the PDFs. The precision of the H1 determination is comparable with those from the Tevatron [2] and from a combined LEP/SLC analysis [3]. The H1 and Tevatron determinations are sensitive to u and d quarks separately, contrary to other measurements of the light quark-Z^0 couplings in νN scattering and atomic parity violation on heavy nuclei. They also resolve any sign ambiguities between vector and axial-vector couplings in observables measured at the Z^0 resonance.

In a new combined EW-PDF fit presented here, the preliminary results of the NC and CC cross sections obtained recently using the full H1 HERA-2 data are included together with the previously used HERA-1 data and two sets of newly published precision data at low Q^2 also from H1 HERA-1 data [4]. At HERA-2, the electron beam was longitudinally polarised, which brings additional sensitivity to constraining the weak neutral couplings.

This contribution is organised as follows. In Section 2, the NC cross sections and their connection with the PDFs and weak neutral couplings are explicitly shown. The fit procedure is also briefly discussed. The results of the fits are presented in Section 3, followed by the conclusion in Section 4.

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2. NC cross sections and weak neutral couplings

The NC cross sections for interactions $e^\pm p \to e^\pm X$ (with X standing for the hadronic final state), mediated by photon (γ) or Z^0 exchange in the t channel, can be in general expressed in terms of generalised structure functions $\tilde{F}_2^\pm$, $x\tilde{F}_3^\pm$ and $\tilde{F}_L^\pm$ as

$$\frac{d^2\sigma^{\rm NC}(e^\pm p)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^2}\left[Y_+\tilde{F}_2^\pm(x,Q^2) \mp Y_- x\tilde{F}_3^\pm(x,Q^2) - y^2\tilde{F}_L^\pm(x,Q^2)\right], \tag{2.1}$$

where the Bjorken x and the negative four-momentum transfer squared Q^2 are related to the lepton inelasticity y and the centre-of-mass energy squared s by $y = Q^2/(xs)$. The electromagnetic fine structure constant is denoted by α and the factors $Y_\pm$ are defined as $Y_\pm = 1 \pm (1-y)^2$. The first two of the generalised structure functions can be further decomposed as

$$\tilde{F}_2^\pm = F_2 - (v_e \pm P_e a_e)\kappa_Z F_2^{\gamma Z} + \left[(v_e^2 + a_e^2) \pm 2P_e a_e\right]\kappa_Z^2 F_2^Z, \tag{2.2}$$

$$x\tilde{F}_3^\pm = -(a_e \pm P_e v_e)\kappa_Z xF_3^{\gamma Z} + \left[2v_e a_e \pm P_e(v_e^2 + a_e^2)\right]\kappa_Z^2 xF_3^Z. \tag{2.3}$$

Here κ_Z is scheme dependent and takes the form

$$\kappa_Z^{-1} = \frac{2\sqrt{2}\pi\alpha}{G_F M_Z^2}\frac{Q^2+M_Z^2}{Q^2}\,, \tag{2.4}$$

in the modified on-mass-shell scheme [5] with M_Z and G_F being the Z^0 mass and the Fermi coupling constant, respectively. The quantities v_e and a_e are vector and axial-vector weak couplings of the electron to the Z^0. Given the fact that v_e is much smaller than a_e, some of the terms can thus be neglected in Eqs.(2.2) and (2.3), and the non-zero value of the longitudinal polarisation of the electron beam at HERA-2, defined as $P_e = (N_R - N_L)/(N_R + N_L)$ with $N_R(N_L)$ being the number of right (left) handed electrons in the beam, makes also a difference between HERA-1 and HERA-2. In the bulk of the HERA phase space, $\tilde{F}_2$ is dominated by the electromagnetic structure function F_2 originating from photon exchange only. The structure functions F_2^Z and xF_3^Z are the contributions to $\tilde{F}_2$ and $x\tilde{F}_3$ from Z^0 exchange and the functions $F_2^{\gamma Z}$ and $xF_3^{\gamma Z}$ are the contributions from γZ^0 interference. These contributions only become important at large values of Q^2.

In the quark parton model, the longitudinal structure function $\tilde{F}_L$ equals zero and the structure functions F_2, $F_2^{\gamma Z}$ and F_2^Z are related to the sum of the quark and anti-quark momentum distributions, xq and $x\overline{q}$,

$$[F_2, F_2^{\gamma Z}, F_2^Z] = x\sum_q [e_q^2, 2e_q v_q, v_q^2 + a_q^2]\{q + \overline{q}\}\,, \tag{2.5}$$

whereas the structure functions $xF_3^{\gamma Z}$ and xF_3^Z are related to their difference,

$$[xF_3^{\gamma Z}, xF_3^Z] = 2x\sum_q [e_q a_q, v_q a_q]\{q - \overline{q}\}\,. \tag{2.6}$$

From Eqs.(2.2-2.6), one observes that at HERA-1 the coupling a_q is mainly constrained by the $xF_3^{\gamma Z}$ whereas at HERA-2 additional sensitivity on v_q is obtained via the $F_2^{\gamma Z}$ due to non-zero P_e.

To determine the neutral weak couplings, fits are performed both to the measured NC cross sections and to the measured CC cross sections (the latter is used as it allows to distinguish different quark flavours coupled to either W^+ or W^- boson exchanged in the t channel) using the following χ^2 function [6]:

$$\chi^2(\sigma^{\rm data}, \alpha) = \sum_{\rm exp.\ data} \frac{[\sigma^{\rm data}(1 - \sum_l \alpha_l \delta_l) - \sigma^{\rm th}]^2}{\delta^2_{\rm stat} + \delta^2_{\rm uncor}} + \sum_l \alpha_l^2\,, \tag{2.7}$$

where $\delta_l(\alpha_l)$ are different correlated systematic error sources (fitted systematic shifts) of the cross sections $\sigma^{\rm data}$ which are in fact the measured double differential cross sections $d^2\sigma(x,Q^2)/dxdQ^2$ whereas $\sigma^{\rm th}$ are the corresponding theoretical cross sections calculated in terms of the couplings and PDFs. The PDFs are evolved in Q^2 with the DGLAP equations [7] in NLO [8] from a functional form in x defined at an initial scale Q_0^2.

In Ref. [1], Q_0^2 was chosen to be $4\,{\rm GeV}^2$ and five PDF sets xg, xU, xD, $x\overline{U}$ and $x\overline{D}$ were defined, where $xU = x(u+c)$ and $xD = x(d+s)$ below the b quark mass threshold. At high x the light quarks u and d dominate over c and s respectively, this is why the light quark couplings are predominantly probed at HERA.

In this analysis, different Q_0^2 $(= 1.9\,{\rm GeV}^2)$ and PDF sets (xg, xu_v, xd_v, $x\overline{U}$ and $x\overline{D}$) are used, following HERAPDF1.0 [9]. The difference of the two may be considered as a systematic uncertainty due to the PDF parameterisation.

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3. Results

Based on a total number of 1244 data points (of which 590 are from HERA-2) covering a large kinematic domain from 3.5 GeV^2 up to 30 000 GeV^2 in Q^2 and from 0.8×10^{-4} to 0.65 in x, a simultaneous fit of the couplings and PDFs is performed with a χ^2 per degree of freedom of 0.96. The results of the fit are shown in Fig. 1 comparing the new couplings using the full HERA-1+2 data and the previously published one using the HERA-1 data only. The precision is improved in particular for the vector couplings as expected and explained in Section 2. The H1 results are

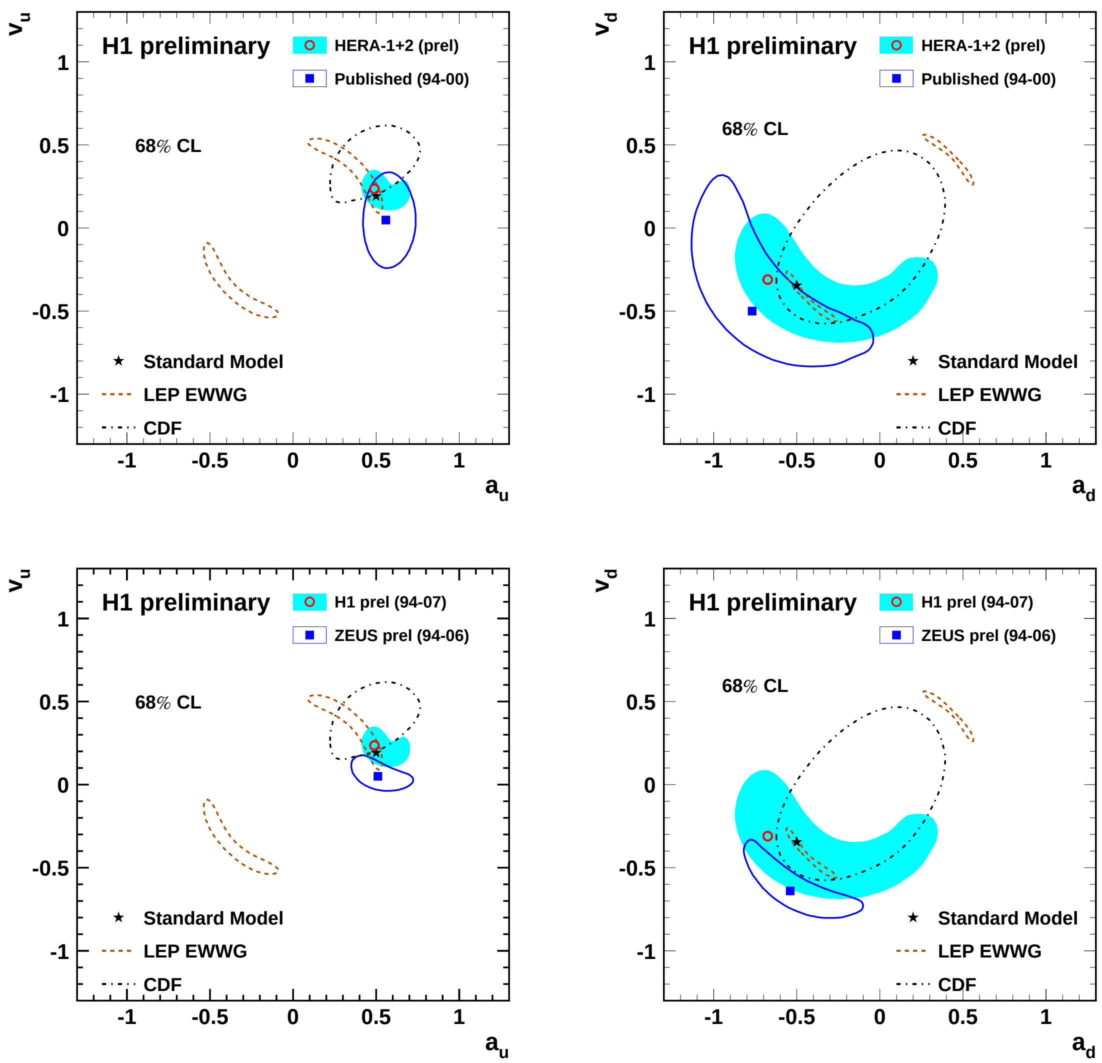

Figure 1: In the upper plots, results at 68% confidence level (CL) on the weak neutral couplings of u (left) and d (right) quarks to the Z^0 boson determined using the full HERA-1+2 H1 data (shaded contours) in comparison with the corresponding results published previously using the HERA-1 data [1]. In the lower plots, the H1 results are compared with those from ZEUS [10]. In all plots, the HERA results are also compared with those determined by the LEP EWWG [3] and the CDF experiment [2].

also compared with those determined by ZEUS [10], by the CDF experiment [2] and the LEP EW

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working group [3].

It is also checked that the results do not depend significantly on the model parameters (the strange quark fraction, the charm and bottom quark masses and the minimum $Q^2_{\rm min}$ value), on the Standard Model parameters (the top quark, W and Z boson masses and the strong coupling constant value). The dominant systematic uncertainty stems from the PDF parameterisation variation and amounts to $0.03(0.06)$ e.g. for $a_u(v_d)$. This is to be compared with the experimental uncertainty of $0.06(0.27)$ for the same couplings.

4. Conclusion

In summary, the inclusion of the new cross section data from HERA-2 with polarised electron and positron beams lead to a substantial improvement of the precision on the weak neutral couplings with respect to the previously published results based on the HERA-1 data only. The results are also complementary and competitive in comparison with those determined from other e^+e^- and $p\overline{p}$ experiments. It is expected that the precision will further improve using combined H1 and ZEUS data when they will be available.

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