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Fit of electroweak parameters in polarised deep-inelastic scattering using data from the H1 experiment

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Using inclusive deep-inelastic scattering cross sections from the H1 experiment at HERA, electroweak parameters of the Standard Model are determined accounting for their correlation with parton distribution functions. The cross sections were measured using longitudinally polarised lepton beams, which enhance the sensitivity to the vector couplings of the light quarks. The quark couplings and the electroweak mixing angle are probed through the γ/Z interference. This gives access to electroweak parameters in t-channel exchange at virtuality up to scales exceeding 10 000 GeV^2.

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The deep inelastic scattering (DIS) of lepton off nucleons has played an important role in revealing the structure of matter, in the discovery of weak neutral current interactions and in the foundation of the Standard Model (SM) as the theory of strong and electroweak (EW) interactions. At HERA, electrons (or positrons) of 27.6 GeV were colliding with protons of up to 920 GeV in the years of 1993 to 2007. In the first data taking period, HERA-I from 1993 to 2000, the lepton beam were unpolarised, while in the second period, HERA-II from 2003 to 2007, the lepton beams were longitudinally polarised to a level between 25% and 37%. In addition, the integrated luminosity value of the e^+p and e^-p collisions at HERA-II has increased by a factor of 1.5 and 15 over that at HERA-I, respectively. Both neutral current (NC) and charged current (CC) interactions occur in ep collisions and a large set of precise NC and CC cross sections was measured by the H1 experiment as well as the ZEUS experiment. In terms of Q^2, the negative four-momentum transfer squared, the kinematic coverage includes the region where the weak and electromagnetic interactions become of comparable strength.

A first determination of EW parameters including the vector, v_q, and axial-vector, a_q, weak neutral couplings of the light quarks, $q = u,d$, to the Z-boson was performed using HERA-I H1 data [1]. In this proceedings, we present new preliminary results from H1 by including NC and CC cross section data from HERA-II [2].

NC interactions in the process $e^{\pm}p \to e^{\pm}X$, with X standing for any hadronic final state, are mediated by a virtual photon, γ, or Z boson in the t-channel and the prediction for the cross section can be expressed in terms of generalised structure functions $\tilde{F}_2^{\pm}$, $\tilde{F}_3^{\pm}$ and $\tilde{F}_L^{\pm}$ as

$$\frac{\mathrm{d}^2\sigma^{\mathrm{NC}}(e^{\pm}p)}{\mathrm{d}x\mathrm{d}Q^2} = \frac{2\pi\alpha^2}{xQ^2}\left[Y_+\tilde{F}_2^{\pm}(x,Q^2) \mp Y_- x\tilde{F}_3^{\pm}(x,Q^2) - y^2\tilde{F}_L^{\pm}(x,Q^2)\right], \tag{1}$$

where x is the Bjorken x and α the fine structure constant. The helicity dependence of the interactions are contained in the terms $Y_{\pm} = 1 \pm (1-y)^2$ with y being the inelasticity of the process. The generalised structure functions are further decomposed into pure γ, Z-exchange structure function terms and the interference term of the two as:

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

$$x\tilde{F}_3^{\pm} = -(a_e \pm P_e v_e)\kappa_Z xF_3^{\gamma Z} + \left[2v_e a_e \pm P_e(v_e^2 + a_e^2)\right]\kappa_Z^2 xF_3^Z, \tag{3}$$

and similarly for $\tilde{F}_L^{\pm}$, which is only significant at very low Q^2 and irrelevant for this analysis. The quantities v_e and a_e are vector and axial-vector weak couplings of the electron to the Z boson, P_e is the degree of the longitudinal polarisation of the electron beam, and κ_Z is scheme dependent and takes the form

$$\kappa_Z(Q^2) = \frac{Q^2}{Q^2 + m_Z^2}\frac{m_Z^2}{4m_W^2}\left(1 - \frac{m_W^2}{m_Z^2}\right)^{-1}(1 + \Delta r), \tag{4}$$

in the on-mass shell scheme with m_Z and m_W being the Z and W boson mass, respectively. The term $\Delta r = \Delta r(\alpha, m_Z, m_W, m_t, m_H, \cdots)$ contains corrections to the muon decay, where m_t and m_H being the top-quark and Higgs boson mass, respectively. The structure functions are related to linear combinations of the quark and anti-quark momentum distributions, xq and $x\bar{q}$, in the quark-parton model as:

$$\left[F_2, F_2^{\gamma Z}, F_2^Z\right] = x\sum_q \left[e_q^2, 2e_q v_q, v_q^2 + a_q^2\right]\{q + \bar{q}\}, \tag{5}$$

$$\left[F_3^{\gamma Z}, F_3^Z\right] = x\sum_q [2e_q a_q, 2v_q a_q]\{q-\bar{q}\}. \tag{6}$$

The quark couplings are predicted in the SM to be $a_q = I_{q,L}^{(3)}$ and $v_q = I_{q,L}^{(3)} - 2e_q \sin^2\theta_W$, with $I_{q,L}^{(3)}$ and e_q being the third component of the left-handed isospin and the electric charge of the quark, respectively. The coupling a_q at HERA-I is mainly constrained by $xF_3^{\gamma Z}$ whereas at HERA-II additional sensitivity on v_q is obtained via $F_2^{\gamma Z}$ due to the non-zero P_e. The cross sections of CC interaction, mediated by a W boson exchange, are of importance for distinguishing different quark flavours and for the determination of the W boson mass, and can be expressed in similar formulae.

The analysis is performed at next-to-next-to-leading order (NNLO) in QCD. The DGLAP formalism [3] is used to describe the evolution of the PDFs with Q^2. The PDFs are parameterised with 13 parameters at a starting scale of 1.9 GeV^2 following Ref. [2]. The EW parameters are determined together with PDF parameters in combined EW and QCD fits to all NC and CC cross section data from HERA-I and HERA-II measured by H1 by minimising

$$\chi^2 = \sum_{ij} \log\left(\frac{d_i}{\tilde{\sigma}_i}\right) V_{ij}^{-1} \log\left(\frac{d_j}{\tilde{\sigma}_j}\right), \tag{7}$$

where d_i are the cross section data points, $\tilde{\sigma}_j$ the corresponding predictions, and V_{ij} the covariance matrix constructed from all relative uncertainties taking into account correlations between the data sets as described in Ref. [2].

For the quark coupling determination, the couplings are treated as free parameters together with the PDF parameters. The χ^2 value of the fit is 1370.5 for 1367 degrees of freedom. The results are shown in Figure 1. The precision of the vector couplings is significantly improved as compared to that of HERA-I [1], mainly due to the polarised lepton beams at HERA-II. When fitting only the couplings of one quark type and fixing those of the other type to their SM values, the precision also improves due to the reduced correlation. The precision is also comparable to that obtained from a similar fit performed by ZEUS [4], where they used not only their own data but also those from H1 treating the H1 HERA-II data as unpolarised. The H1 results are also compared to those from LEP+SLC [5] and D0 [6] at Tevatron. The different contour shapes, particularly for the u-type quarks, show the potential to achieve an ultimate precision if they would be combined.

In another fit, the W boson mass, m_W, is treated as a free parameter, it is determined together with the PDF parameters with the result

$$m_W = 80.407 \pm 0.118(\text{exp, PDF-fit}) \pm 0.005(m_Z, m_t, m_h)\,\text{GeV}. \tag{8}$$

The corresponding χ^2 value is 1372.3 for 1370 degrees of freedom. In comparison with the previous result from HERA-I [1], $m_W = 80.786 \pm 0.205(\text{exp})^{+0.063}_{-0.098}(\text{th})\,\text{GeV}$, the experimental precision is improved by a factor of about two. Together with the world average value of m_Z, the result obtained on m_W from Eq.(8) represents an indirect determination of $\sin^2\theta_W$ in the on-shell mass scheme. Given the large coverage in Q^2 of the NC and CC cross section data, it is possible to simultaneously fit several m_W or $\sin^2\theta_W$ at different energy scale together with one common set of PDF parameters. The results of such a fit is shown in Figure 2 and are found in good agreement with the corresponding measured value from the Z-pole [7]. Part of the uncertainties at the different

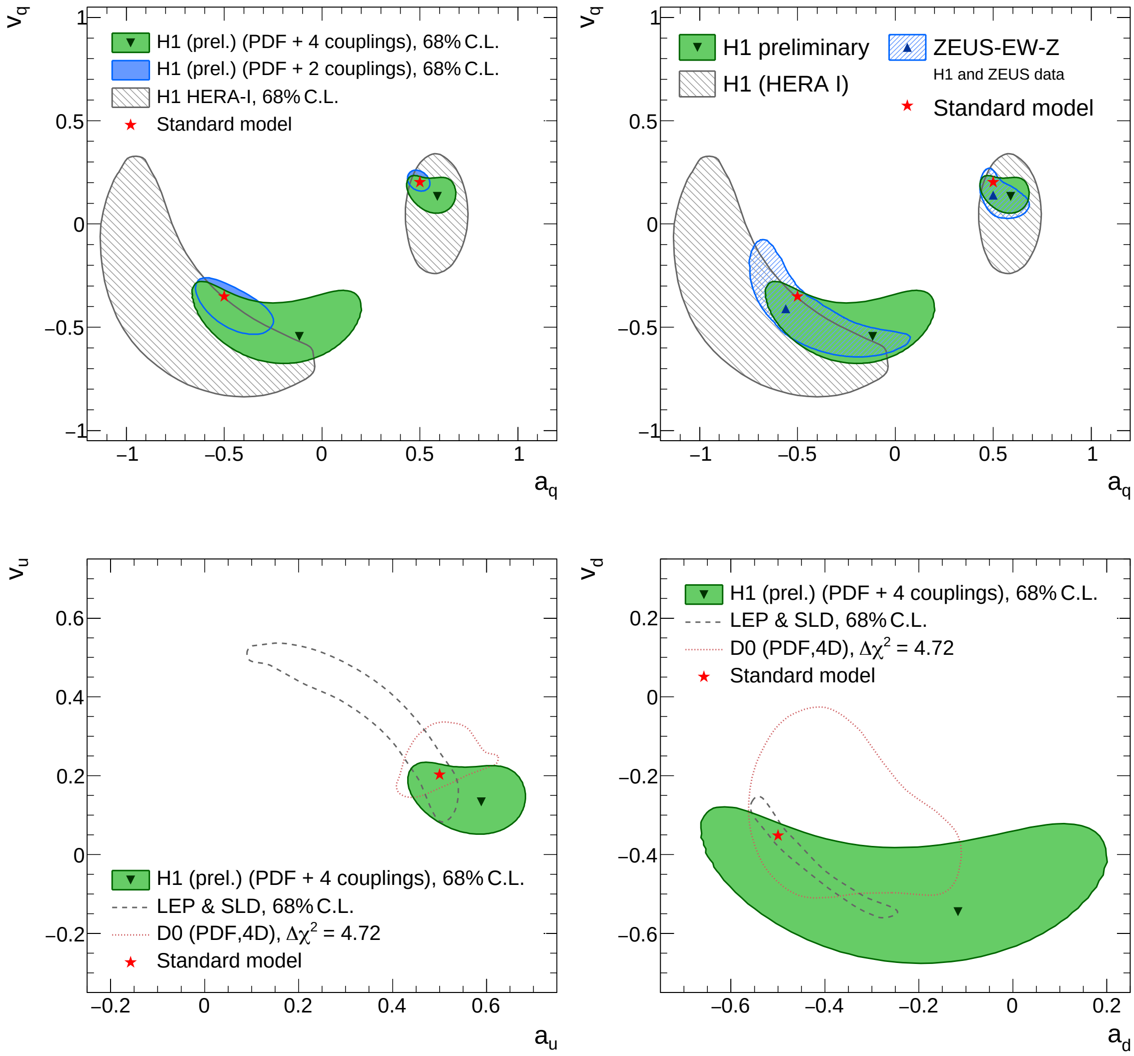

Figure 1: Results for the weak neutral couplings of the u and d quarks to the Z boson at 68% confidence level (C.L.). The default results of the four parameters fit are compared with those of the two parameters fit and the corresponding results from HERA-I (upper-left), with the results from a similar fit from ZEUS (upper-right), with the results from LEP and D0 separately for u quark (bottom left) and d quark (bottom right), respectively.

scale are correlated. By definition, $\sin^2\theta_W$ in the on-shell mass scheme has no scale dependence. To check the scale dependence of $\sin^2\theta_W$, a different scheme definition is needed.

To conclude, the inclusive deep-inelastic scattering cross section data measured by H1 at HERA-II with the longitudinally polarised lepton beams and higher integrated luminosity have provided additional sensitivity for improving the precision of the electroweak parameters.

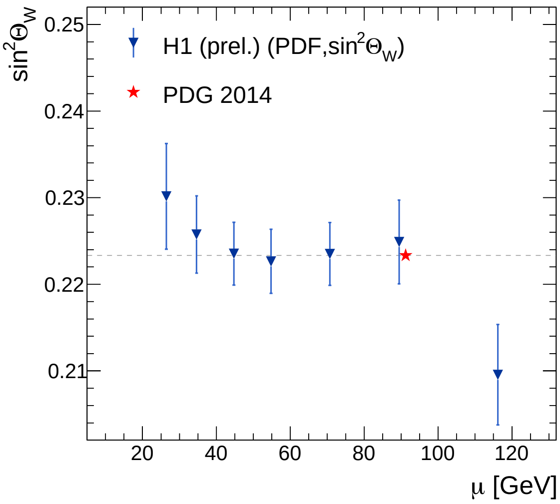

Figure 2: The weak-missing angle $\sin^2\theta_W$ in the on-shell mass scheme at different scale in comparison with the value from measurements at the Z-pole.

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