

A determination of electroweak parameters at HERA

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Using the deep inelastic $e^\pm p$ charged and neutral current scattering cross sections previously published, a combined electroweak and QCD analysis is performed to determine electroweak parameters accounting for their correlation with parton distributions. The data used have been collected by the H1 experiment in 1994-2000 and correspond to an integrated luminosity of 117.2 pb^{-1} . A first measurement at HERA is made of the light quark weak couplings to the Z^0 boson. An improved measurement is obtained of the W propagator mass in charged current ep scattering. The weak mixing angle $\sin^2\theta_W$ is determined in the on-mass-shell renormalization scheme.

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1. The experimental facts and analysis strategies

In the first phase of HERA operation (HERA-I) with the unpolarized e^\pm beam colliding with the proton beam, the H1 experiment has collected three major data samples of e^+p in years from 1994 to 1997 at a center-of-mass energy of 301 GeV, e^-p in 1998-1999 and e^+p in 1999-2000 at 319 GeV. The corresponding integrated luminosities are 35.6 pb^{-1} , 16.4 pb^{-1} and 65.2 pb^{-1} , respectively. These data have been used to measure neutral current (NC) and charged current (CC) cross sections covering more than 4 orders of magnitude in both Q^2 , the negative four-momentum transfer squared, and Bjorken x . The large kinematic coverage and the different flavor sensitivity of the $e^\pm p$ NC and CC cross section data have enabled 5 sets of parton distribution functions (PDF) to be determined simultaneously in a previous QCD analysis [1]. These five PDF sets are the gluon, up-type and down-type quarks and their anti-quarks distributions.

The inclusive NC and CC cross sections are not only sensitive to PDFs but also to electroweak (EW) parameters. Indeed, the NC cross sections at high Q^2 depend on up- and down-type quark couplings to the Z^0 boson, a_q and v_q ($q=u, d$), via structure functions, whereas the shape of the CC cross sections as a function of Q^2 is controlled by the propagator mass (M_{prop}) of the W boson. It is thus natural to extend the QCD analysis of [1] into a combined EW-PDF analysis so that EW parameters can be determined together with the PDFs taking properly into account the small but non-negligible correlation between them.

This is precisely the strategy chosen in [2,3], namely using the same parameterization forms for the five PDF sets for the QCD part. The QCD analysis is performed using the DGLAP evolution equations [4] at next-to-leading order in the modified minimal subtraction renormalization scheme. All quarks are taken as massless. Several combined EW-PDF fits are performed either in a model independent way (fits $a_u-v_u-a_d-v_d$ -PDF and $G-M_{prop}$ -PDF) or within the Standard Model (SM, fits M_W -PDF and m_t -PDF).

2. First results on light quark couplings to the Z^0 boson at HERA

The sensitivity on the quark couplings at HERA stems from the γZ interference and Z^0 exchange contributions in NC interactions at high Q^2 . The results of the combined $a_u-v_u-a_d-v_d$ -PDF fit are shown in Fig.1 and compared with similar results obtained recently by the CDF experiment [5] and combined LEP experiments [6]. The HERA determination has comparable precision to that from the Tevatron. These determinations are sensitive to u and d quarks separately, contrary to other measurements of the light quark- Z^0 couplings in νN scattering [7] and atomic parity violation [8] on heavy nuclei. They also resolve any sign ambiguity and the ambiguities between v_q and a_q ($q=u,d$) of the determinations based on observables measured at the Z^0 resonance [6].

The HERA precision is expected to improve significantly with the data from HERA-II taken at higher luminosity. The longitudinally polarized e^\pm beams at HERA-II will also provide additional sensitivity in constraining the vector couplings v_q .

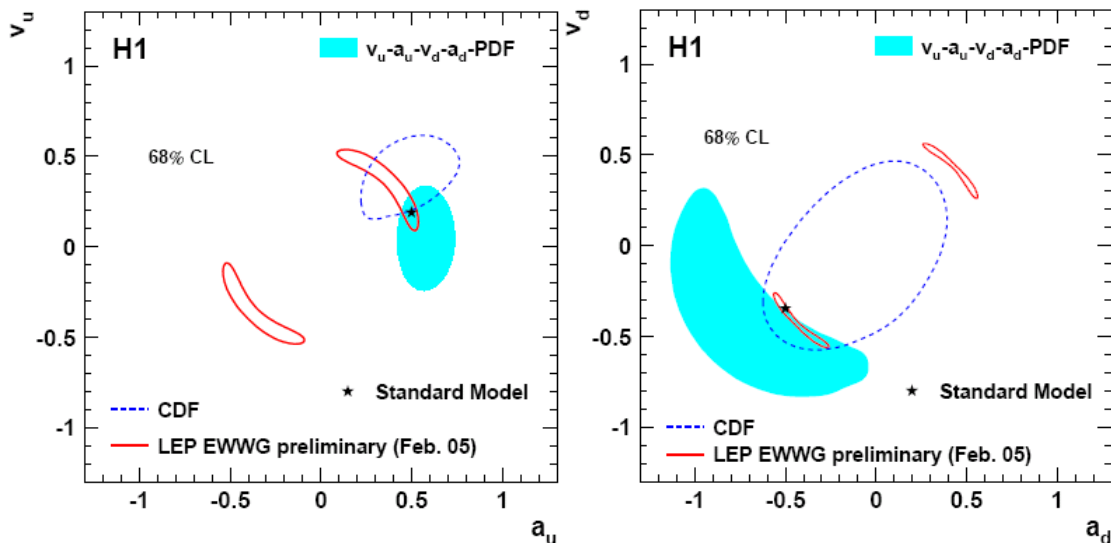


FIGURE 1. H1 results (shaded area) at 68% confidence level (CL) on the couplings of u quark (left) and d quark (right) to Z^0 in comparison with similar results from CDF (dashed curves) and LEP (full curves).

3. Improved W propagator mass measurement at HERA

The cross section data allow a simultaneous determination of the Fermi coupling constant G_F and the W boson mass, and of the PDFs (G - M_{prop} -PDF fit). When treating G and M_{prop} as independent parameters, the sensitivity on G and M_{prop} originates respectively from the normalization and Q^2 dependence of the CC cross sections. The result of the fit is shown in Fig.2 as the shaded area.

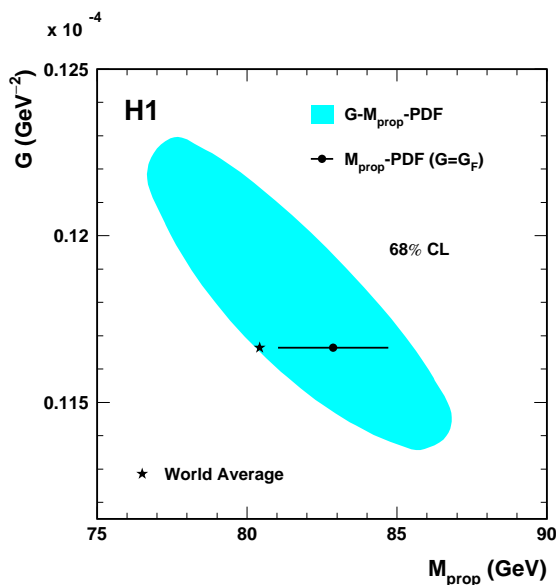


FIGURE 2. The result of the fit to G and M_{prop} at 68% confidence level (CL) shown as the shaded area. The world average values are indicated with the star symbol. Fixing G to G_F , the fit results in a measurement of the propagator mass M_{prop} shown as the circle with the horizontal error bar.

Fixing G to the measured G_F value [9], one gets a determination of M_{prop} , also shown in Fig.1, $M_{\text{prop}} = 82.87 \pm 1.82_{\text{exp}-0.16}^{+0.30} |_{\text{model}}$ GeV where the first error is experimental and the second corresponds to uncertainties due to input parameters and model assumptions as introduced in Table 5 in [1] (e.g., the variation of $\alpha_s=0.1185\pm 0.0020$). This determination differs from all previous ones in the treatment of the correlation between M_{prop} and PDFs and represents the most accurate measurement so far of the CC propagator mass at HERA.

Within the SM, the Fermi coupling constant G_F is connected with the W boson mass M_W through a relation which contains EW radiative corrections including quadratic (logarithmic) dependence on the top quark mass m_t (the Higgs mass M_H). A combined EW-PDF fit in the SM gives

$$M_W = 80.786 \pm 0.205_{\text{exp}-0.029}^{+0.048} |_{\text{model}} \pm 0.025_{\delta m_t} - 0.084_{\delta M_H} \pm 0.033_{\delta(\Delta r)} \text{ GeV} \quad (1)$$

where the measured central value corresponds to using the world averaged values of $M_Z = 91.1876 \pm 0.0021$ GeV, $m_t = 178 \pm 4.3$ GeV and a Higgs mass of 120 GeV. The uncertainty on M_Z has a negligible error on M_W whereas the uncertainty on m_t gives rise to the third quoted error on M_W . Varying M_H from 120 GeV to 300 GeV results in the fourth error. The last error is due to higher order radiative correction uncertainties.

Together with the world average value of M_Z given above, the result obtained on M_W from Eqn.(1) represents an indirect determination of $\sin^2 \theta_W$ in the on-mass shell scheme: $\sin^2 \theta_W = 0.2151 \pm 0.0040_{-0.0011}^{+0.0019}$ where the first error is experimental and the second is theoretical covering all remaining uncertainties in Eqn.(1). The uncertainty due to δM_Z is negligible.

Fixing M_W to the world average value and assuming $M_H=120$ GeV, the fit m_t -PDF gives $m_t=108 \pm 44$ GeV where the uncertainty is experimental. The result represents the first determination of the top quark mass through loop effects in the ep data at HERA.

Again the precision of these determinations will be improved by a large amount as the best sensitivity comes from the CC e^-p cross section which was measured from a very limited data sample at HERA-I. Polarized e^-p data corresponding to an increase of one order magnitude in the integrated luminosity from HERA-II are being taken.

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