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.

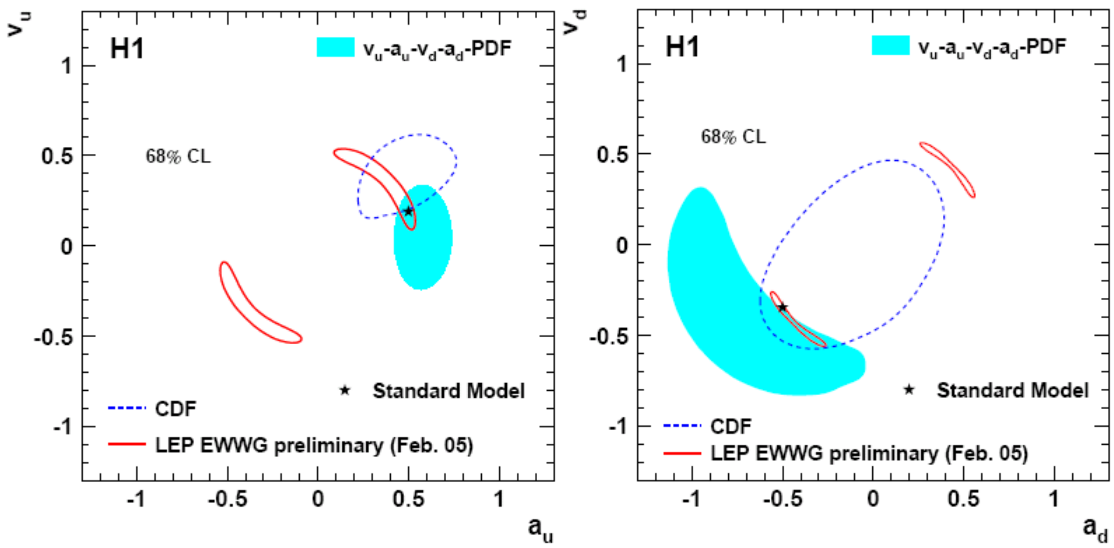

FIGURE 1. H1 results (shaded area) at 68% confidence level (CL) on the couplings of *u* quark (left) and *d* quark (right) to Z^0 in comparison with similar results from CDF (dashed curves) and LEP (full curves).

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.

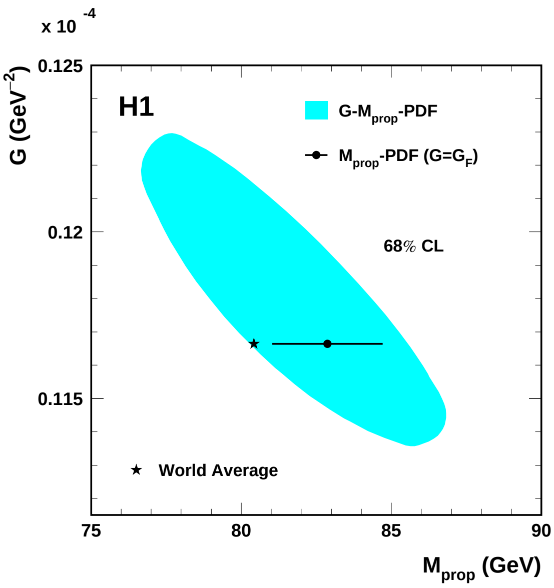

FIGURE 2. The result of the fit to G and M_{prop} at 68% confidence level (CL) shown as the shaded area. The world average values are indicated with the star symbol. Fixing G to G_F, the fit results in a measurement of the propagator mass M_{prop} shown as the circle with the horizontal error bar.

Fixing G to the measured G_F value [9], one gets a determination of M_{prop}, also shown in Fig.1, $M_{prop} = 82.87 \pm 1.82_{exp}{}^{+0.30}_{-0.16}|_{model}$ 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 α_s=0.1185±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

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

where the measured central value corresponds to using the world averaged values of M_Z = 91.1876±0.0021GeV, m_t=178±4.3GeV and a Higgs mass of 120GeV. 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 120GeV to 300GeV 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: $\sin^2\theta_W = 0.2151 \pm 0.0040^{+0.0019}_{-0.0011}$ 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=120GeV, the fit m_t-PDF gives m_t=108±44GeV 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 HEAR-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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