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Combined Electroweak and QCD Fit of Inclusive Neutral and Charged Current Data with Polarised Lepton Beams at HERA

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Abstract

Using the final deep inelastic e^+p and e^-p neutral and charged current scattering cross sections from the H1 experiment, including data with polarised electron beams, a combined electroweak and QCD analysis is performed to determine vector and axial-vector couplings v_q and a_q of light quarks (u- and d-type) to the Z^0 boson accounting for their correlation with parton distributions. The precision has been improved in particular for vector couplings with respect to the published results based on the unpolarised HERA-I data only. The determinations from HERA are compared with those from LEP and Tevatron. Furthermore, the Standard Model of particle physics is probed by determining simultaneously the mass values of the $W^\pm$ and Z^0-bosons. Similarly, a simultaneous determination of the Fermi Coupling Constant G_F or the weak mixing angle $\sin^2\Theta_W$ together with the $W^\pm$-boson mass in the on-shell scheme is performed. By using the mass of the Z^0-boson as external input to the fits, the value of the mass of the $W^\pm$-boson is determined to $m_W = 80.407 \pm 0.118(\mathrm{exp,pdf}) \pm 0.005(\mathrm{m_Z, m_t, m_H})\,\mathrm{GeV}$. Values of the weak mixing angle in the on-shell scheme are determined at various energy scales, exploiting the large kinematic range of the data.

1 Summary

Double-differential inclusive neutral-current and charged current cross sections from the H1 experiment are used in a combined QCD and electroweak fit to determine the light-quark couplings to the Z^0-boson and perform consistency checks of the Standard Model. The determination benefits from the longitudinal polarised lepton beam in HERA-II. A summary of the used dataset is given in table 1.

Dataset	Q^2_{min} [GeV^2]	Q^2_{max} [GeV^2]	No. of points	Polarisation [%]	Reference
e+ Combined low-Q^2	12 [0.5]	150	81 [262]		ref. [1]
e+ Combined low-Q^2	12 [1.5]	90	118 [136]		ref. [1]
e+ NC 94-97	150	30000	130		ref. [2]
e+ CC 94-97	300	15000	25		ref. [2]
e- NC 98-99	150	30000	126		ref. [3]
e- CC 98-99	300	15000	25		ref. [3]
e- NC 98-99 high-y	100	800	13		ref. [4]
e- CC 99-00	150	30000	147		ref. [4]
e+ NC 99-00	300	15000	28		ref. [4]
e+ NC high-y	60	800	11		ref. [5]
e- NC high-y	60	800	11		ref. [5]
e+ NC L	120	30000	137	-37.0 ± 1.0	ref. [5]
e+ CC L	300	15000	28	-37.0 ± 1.0	ref. [5]
e+ NC R	120	30000	137	$+32.5 \pm 0.7$	ref. [5]
e+ CC R	300	15000	28	$+32.5 \pm 0.7$	ref. [5]
e- NC L	120	50000	138	-25.8 ± 0.7	ref. [5]
e- CC L	300	30000	29	-25.8 ± 0.7	ref. [5]
e- NC R	120	30000	139	$+36.0 \pm 0.7$	ref. [5]
e- CC R	300	15000	28	$+36.0 \pm 0.7$	ref. [5]

Table 1: Datasets used in the combined QCD and electroweak fit. The low and medium-Q^2 datasets for $\sqrt{s}$ = 319, 301, 252 and 225 GeV, are combined into two common datasets as described in reference [1]. The respective high-Q^2 datasets are included separately in the fit. The datasets include electron and positron beams as well as neutral-current (NC) and charged-current (CC) cross sections.

The fit-methology of the QCD-fit follows closely the approach of the HERAPDF2.0 PDF [6], where identical parameterisations of the PDFs at the starting scale $Q_0^2 = 1.9\text{GeV}^2$ are used. The QCD fit is performed in NNLO in pQCD using the ZM-VFNS as implemented in QCDNUM and 13 PDF parameters are fitted. The correlation of systematic uncertainties between the different datapoints is described in ref. [5]. Higher-order electroweak corrections [7] are only considered as corrections Δr to the muon decay constant G_F and are not considered otherwise. The data is corrected for QCD radiative and 1-loop effects as described in [2]. The definition of the χ^2-function is similar to ref. [8], where in addition the polarisation measurements are considered as independent datasets with normal-distributed uncertainties. The fits were performed using the Alpos fitting framework [9]. The fit yields a fit quality of $\chi^2/n_{\mathrm{dof}} = 1370.5/(1388-21)$, where the degrees of freedom is calculated from 1384 cross section data points, 4 measurements of the polarisation, 13 free PDF parameters, 4 free couplings and 4 free polarisation values. The results are similar to results obtained with a different χ^2-definition as used in ref. [6]. The results are found to be compatible with fits, where external PDFs such as CT10, MSTW or NNPDF3.0 were used. Also variations of the QCD fit methology, such as the perturbative order, the number of free PDF parameters or variations of the strange fraction f_s, are found to be small compared to the experimental uncertainties.

By using the mass of the Z^0-boson as external input to the fits, the value of the mass of the $W^{\pm}$-boson is determined to $m_W = 80.407 \pm 0.118(\mathrm{exp,pdf}) \pm 0.005(\mathrm{m_Z, m_t, m_H})\,\mathrm{GeV}$. Uncertainties from the values of the Z^0 mass, the top-mass and the Higgs mass are found to be small. Further theoretical uncertainties, such as higher order corrections to Δr are not considered, but are expected to be small ($\mathcal{O}(30\,\mathrm{MeV})$) [10].

2 Results

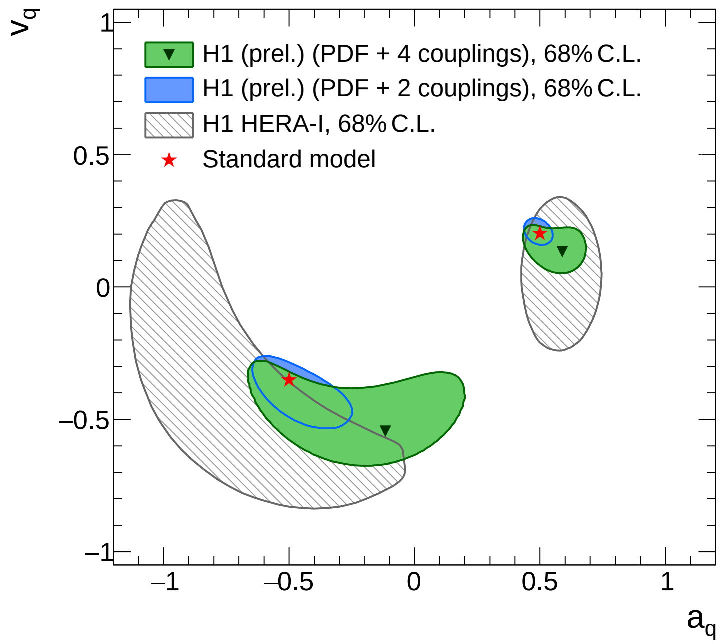

Figure 1: Results at 68 % confidence level (C.L.) on the weak neutral current couplings of u and d-type quarks to the Z^0-boson. The results are compared to previous results from H1 based on HERA-I data [10]. The displayed 68 % C.L. contours correspond to $\Delta\chi^2 = 2.3$, where all other fit parameters are minimised.

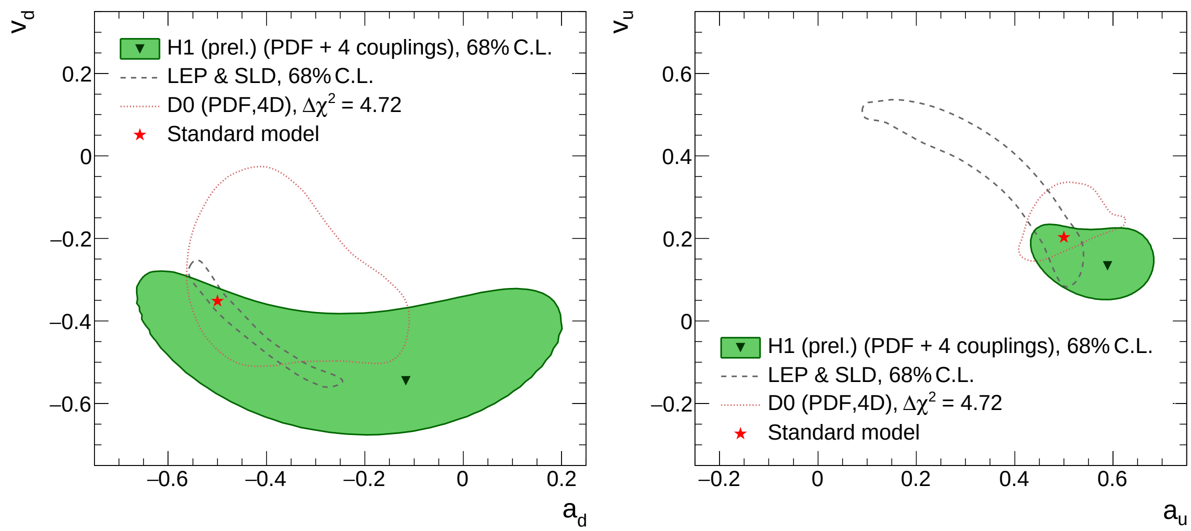

Figure 2: Same as in Fig. 1, the new results are compared with the results from the LEP experiments and SLD [11], and D0 [12]. The mirror solutions of LEP are not shown.

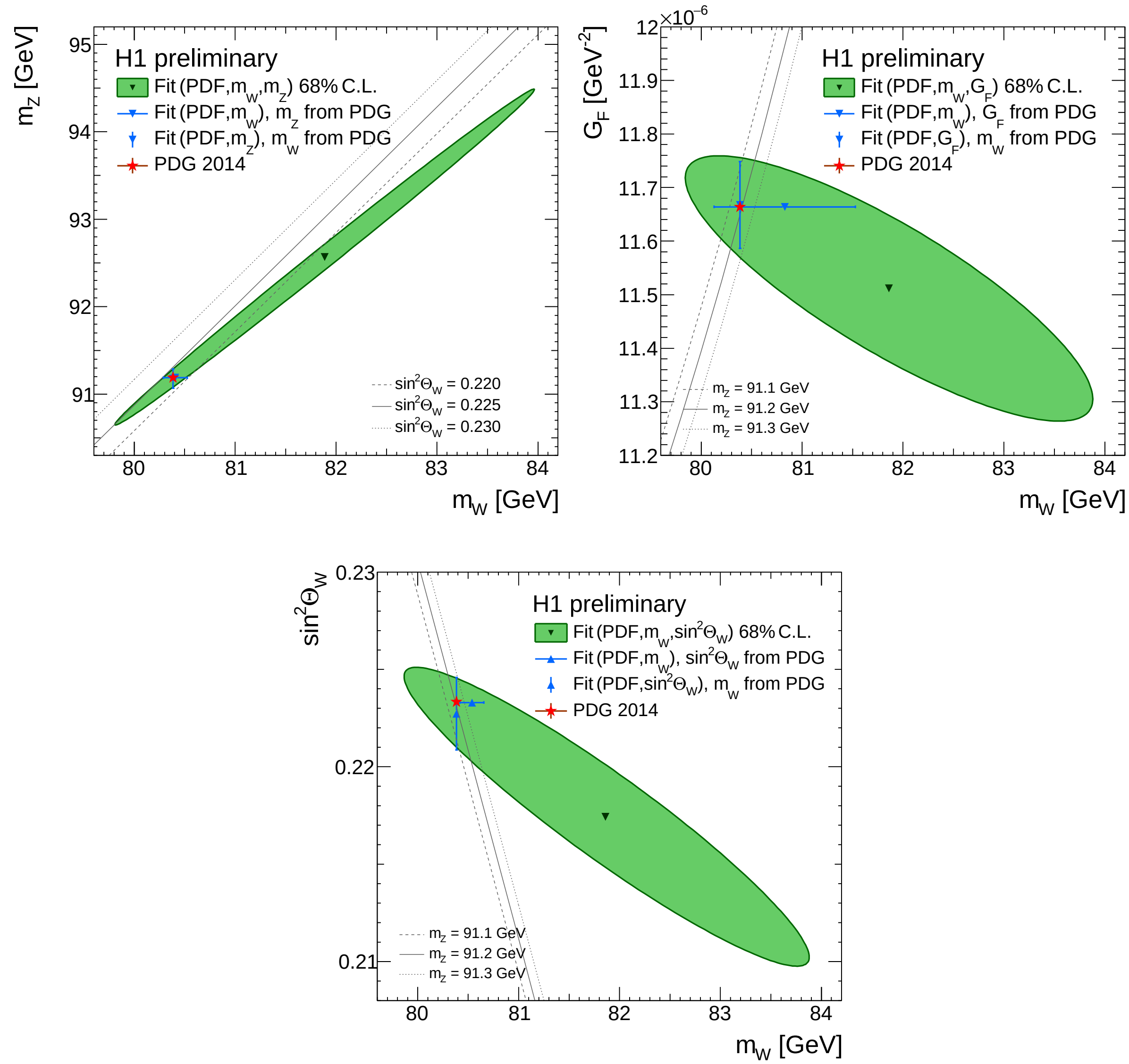

Figure 3: Fits of the PDF parameters and the $W^{\pm}$-boson mass, together with the Z^0-boson mass, the Fermi Coupling Constant G_F or the Weinberg angle $\sin^2\Theta_W$. The respective calculations are all performed in the on-shell scheme, where α, m_Z and m_W are the only electroweak parameters on Born-level. In case of the latter two fits, the value of m_Z is calculated from the fit parameter and α, m_W and $\Delta r = \Delta r(\alpha, m_W, m_Z, m_t, m_H, ...)$.

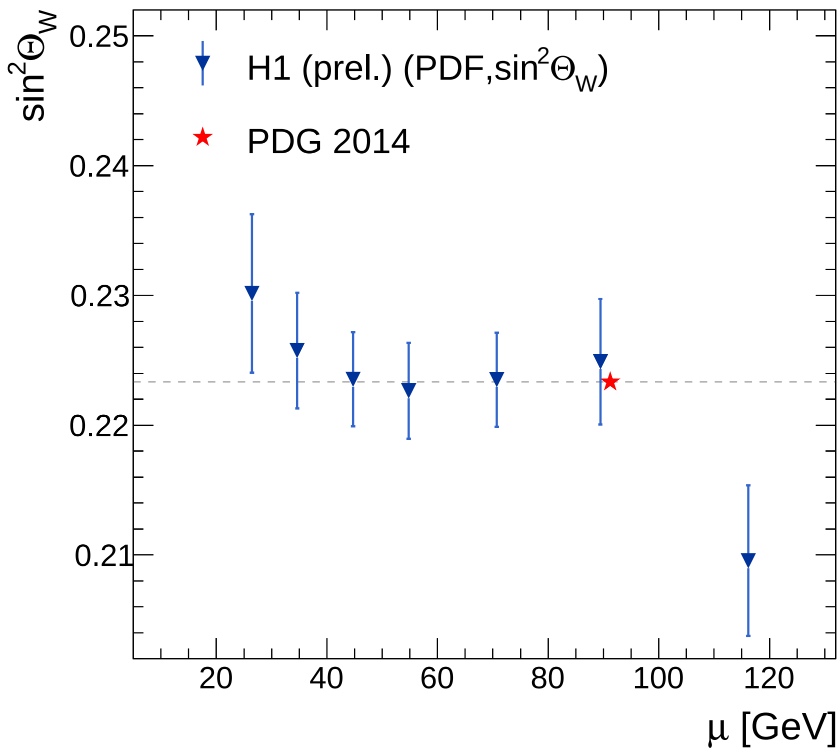

Figure 4: Fits of the Weinberg angle $\sin^2\Theta_W$ in the on-shell scheme definition. A single fit of all data points together with the PDF is performed, where data points at different values of Q^2 are grouped together for $Q^2 \leq 1200\,\mathrm{GeV}^2$ and $Q^2 \geq 12000\,\mathrm{GeV}^2$, but kept separately for data points between 2000 and 8000 GeV^2. The results are compared to the well-known value which is derived from measurements at the Z^0-pole. All point-to-point correlations are below $\rho_{ij} < 0.3$ for the four data points at $\mu \geq \sqrt{3000\,\mathrm{GeV}^2} \approx 55\,\mathrm{GeV}$ and of the order of $0.2 < \rho_{ij} < 0.5$ for the first three data points among themselves, because of the simultaneous determination of the PDF parameters.

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