Theoretical Uncertainties in Precision Electroweak Physics at HERA

Bernd A. Kniehl[ab]

[a] Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), Föhringer Ring 6, 80805 Munich, Germany

[b] Institut für Theoretische Physik, Ludwig-Maximilians-Universität, Theresienstraße 37, 80333 Munich, Germany

Abstract: We assess the influence of those radiative corrections which are not presently included in the theoretical calculations underlying this study group report, and estimate the theoretical uncertainties from unknown higher orders.

The discussion of Ref. [1] focuses attention on the experimental uncertainties in the values of m_W and other electroweak observables extracted from the measurements of the cross sections of charged-current (CC) and neutral-current (NC) deep inelastic scattering (DIS) at HERA through the comparison with theoretical predictions. For the sake of estimating experimental sensitivities, it should be sufficient to compute the theoretical predictions with electroweak one-loop precision and to disregard the available QCD and higher-order electroweak corrections (see Section 2.2 of Ref. [1]). However, since, under favourable conditions, future measurements at HERA are aiming at experimental errors on m_W of order $\delta m_W = \pm 60$ MeV [1], which is considerably smaller than the shift due to the inclusion of the electroweak one-loop corrections, it is important to study by how much the extracted value of m_W is affected by the known QCD and higher-order electroweak corrections, and to estimate the residual uncertainty from theoretical sources.

In the case of the electroweak corrections, we may simplify this problem by studying the value of m_W predicted from the measured muon lifetime via Δr [2], i.e. the so-called G_μ constraint, since the dominant higher-order corrections coincide with those to the CC DIS cross section (see Fig. 9 of Ref. [1]), which is most important for the m_W determination at HERA (see Figs. 4 and 5 of Ref. [1]). The values of m_W derived through Δr to $\mathcal{O}(\alpha)$ in the electroweak on-shell scheme and the shifts due to the $\mathcal{O}(\alpha\alpha_s)$ [3], $\mathcal{O}(\alpha\alpha_s^2)$ [4], $\mathcal{O}(G_F^2 m_t^4)$ [5] and $\mathcal{O}(G_F^2 m_W^2 m_t^2)$ [6] corrections are listed in Table 1 for $m_t = (175 \pm 9)$ GeV and selected values of m_H [7]. We see that all higher-order corrections act in the same direction and typically reduce m_W by 100 MeV, to be contrasted with the envisaged experimental error $\delta m_W = \pm 60$ MeV [1]. It will therefore be crucial to implement these corrections in the theoretical predictions of Ref. [1] before one attempts to confront the latter with precision data on DIS to be collected with HERA or possible upgrades. In general, these corrections will shift, tilt and distort the ellipses shown in Figs. 1, 2 and 9 of Ref. [1].

The residual theoretical uncertainty in m_W is either due to experimental errors in the input parameters or to the corrections beyond present knowledge. From Table 1, we read off the errors

Table 1: m_W predicted for various values of m_t and m_H via Δr to one loop and shifts due to higher-order corrections. All masses are given in GeV.

m_t	m_H	m_W	δm_W			
		$\mathcal{O}(\alpha)$	$\mathcal{O}(\alpha\alpha_s)$	$\mathcal{O}(\alpha\alpha_s^2)$	$\mathcal{O}(G_F^2 m_t^4)$	$\mathcal{O}(G_F^2 m_W^2 m_t^2)$
166	100	80.420	−0.058	−0.011	−0.009	−0.011
	300	80.349	−0.058	−0.011	−0.015	−0.009
	800	80.273	−0.058	−0.011	−0.017	−0.006
175	100	80.485	−0.063	−0.012	−0.011	−0.013
	300	80.414	−0.063	−0.012	−0.017	−0.011
	800	80.338	−0.063	−0.012	−0.021	−0.007
184	100	80.553	−0.068	−0.013	−0.012	−0.015
	300	80.482	−0.068	−0.013	−0.021	−0.013
	800	80.406	−0.068	−0.013	−0.026	−0.008

$\delta m_W = {}^{+57}_{-54}$ MeV and ± 76 MeV due to the variations $\delta m_t = \pm 9$GeV and $\delta m_H = {}^{+500}_{-200}$ GeV around the central values $m_t = 175$ GeV and $m_H = 300$ GeV, respectively. Furthermore, the errors in $\alpha_s(M_Z) = 0.117 \pm 0.006$ and the hadronic contribution $\Delta\alpha_{had} = 0.0280 \pm 0.007$ [8] to the running fine-structure constant lead to $\delta m_W = \pm 4$ MeV and ± 13 MeV, respectively. The higher-order uncertainty may be estimated to be less than $\delta m_W = \pm 10$ MeV by considering the renormalization scheme and scale dependences of the presently known corrections [7, 9].

The next-to-leading order QCD corrections to NC and CC DIS are well under control [10], and in the case of the photon-exchange contribution to NC DIS even the next-to-next-to-leading-order QCD corrections are available [11]. As may be gleaned from Ref. [11], in the kinematic regime of interest here, the residual QCD uncertainty is likely to be smaller than the one from the parton distribution functions.

In conclusion, the extraction of electroweak parameters from future precision measurements of DIS at HERA will essentially be meaningless unless the presently known QCD and higher-order electroweak corrections will be included in the theoretical calculations. On the other hand, the residual uncertainty due to unknown higher-order corrections is estimated to be small against the envisaged [1] experimental accuracy.

References

[1] R. Beyer et al., in this working group report.

[2] A. Sirlin, Phys. Rev. D22 (1980) 971.

[3] A. Djouadi and C. Verzegnassi, Phys. Lett. B195 (1987) 265; B.A. Kniehl, Nucl. Phys. B347 (1990) 86.

[4] L. Avdeev, J. Fleischer, S. Mikhailov and O. Tarasov, Phys. Lett. B336 (1994) 560; (E) B349 (1995) 597; K.G. Chetyrkin, J.H. Kühn and M. Steinhauser, Phys. Lett. B351 (1995) 331.

[5] R. Barbieri, M. Beccaria, P. Ciafaloni, G. Curci and A. Viceré, Phys. Lett. B288 (1992) 95; (E) B313 (1993) 511; Nucl. Phys. B409 (1993) 105; J. Fleischer, O.V. Tarasov and F. Jegerlehner, Phys. Lett. B319 (1993) 249; Phys. Rev. D51 (1995) 3820.

[6] G. Degrassi, S. Fanchiotti and P. Gambino, Int. J. Mod. Phys. A10 (1995) 1337; G. Degrassi, S. Fanchiotti, F. Feruglio, P. Gambino and A. Vicini, Phys. Lett. B350 (1995) 75; G. Degrassi, P. Gambino and A. Vicini, Phys. Lett. B383 (1996) 219.

[7] B.A. Kniehl, Preprint FERMILAB–PUB–95/247–T, MPI/PhT/95–74 and hep–ph/9403386 (July 1995), to appear in Z. Phys. C.

[8] S. Eidelman and F. Jegerlehner, Z. Phys. C67 (1995) 585; H. Burkhardt and B. Pietrzyk, Phys. Lett. B356 (1995) 398.

[9] B.A. Kniehl and A. Sirlin, Nucl. Phys. B458 (1996) 35.

[10] J.G. Körner, E. Mirkes and G.A. Schuler, Int. J. Mod. Phys. A4 (1989) 1781.

[11] E.B. Zijlstra and W.L. van Neerven, Nucl. Phys. B383 (1992) 525.