ELECTROWEAK MEASUREMENTS FROM HERA

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New preliminary electroweak results from the HERA lepton-proton collider experiments H1 and ZEUS are presented. These include new high Q^2 neutral current cross section measurements, limits on a possible quark radius in the search for contact interactions as well as on quark-Z coupling parameters, extracted in combined electroweak and QCD fits. Furthermore, new charged current cross section measurements as a function of the lepton-beam polarisation are presented, as well as charged current measurement results, using the combined HERA I data from H1 and ZEUS. Finally, measurements of the single W boson production cross section and the W boson polarisation fractions are presented.

1 Introduction

The lepton-proton collider HERA [1] has facilitated measurements of electroweak (EW) interactions between quarks and leptons in deep inelastic scattering (DIS) at a centre of mass energie up to 320 GeV and four momentum of the exchanged boson squared (Q^2) up to 40000 GeV^2. The data taking took place in the years 1994-2000 (HERA I) and 2003-2007 (HERA II). Two collider-mode detectors, H1 [2] and ZEUS [3], have each collected approximately 0.5 fb^{-1} of data, divided in electron-proton (e^-p) and positron-proton (e^+p) data. Previously obtained HERA results have led to a significantly improved understanding of the proton substructure [4,5] allowing for measurements of important EW parameters [6,7,8,9] as well as searches [10,11] for contact interactions. In these proceedings, updates are presented to these analyses along with new results from H1 regarding the single production of W bosons at HERA.

2 Neutral Current Cross Section Measurement

New H1 Neutral Current (NC) single differential cross section measurements [12] as a function of Q^2, are presented in Figure 1. The analysis includes previously published [7,13,14] HERA I and preliminary [15] HERA II data, corresponding to an integrated luminosity of 270 pb^{-1} of e^+p data and 165 pb^{-1} of e^-p data. The measurement precision is better than 10% for Q^2 up to 20000 GeV^2. The data agree well with SM QCD expectations, which are based on parton distribution functions obtained using high energy HERA I data. [4]

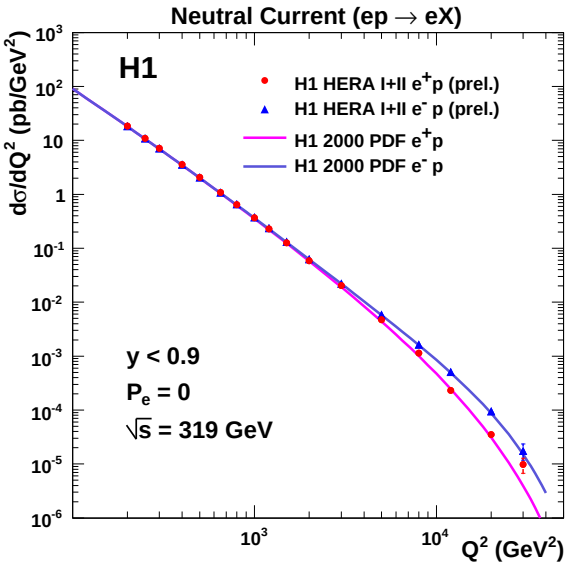

Figure 1: NC single differential cross sections as a function of Q^2, measured by H1 using e^+p (points) and e^-p (triangles) DIS data from the full HERA I+II data set, compared to the SM QCD expectations (solid lines). The interference between the photon and Z boson, which is different in e^+p and e^-p collisions, becomes visible at Q^2 of the order 10^4 GeV^2.

3 Derivation of Limits on the Quark Radius in Contact Interactions

In the search for contact interactions, both H1 and ZEUS derive limits on a possible quark radius using high Q^2 NC events. [12,16] A form factor f_q, as a function of Q^2 and a hypothetical quark radius R_q, is defined as $f_q\left(Q^2, R_q\right) \equiv 1 - \frac{1}{6}\left\langle R_q^2 \right\rangle Q^2$. This leads to an altered single differential cross section $\mathrm{d}\sigma/\mathrm{d}Q^2 = f_q\left(Q^2, R_q\right)\mathrm{d}\sigma_{SM}/\mathrm{d}Q^2$ for contact interactions, which can be fit to the data, as is shown in Figure 2. The 95% Confidence Level (CL) limits on the quark radius are determined from the fit to be $0.74 \cdot 10^{-18}$ m and $0.62 \cdot 10^{-18}$ m, by H1 and ZEUS, respectively. These limits confine a hypothetical quark radius to be less than or equal to the resolution power of HERA.

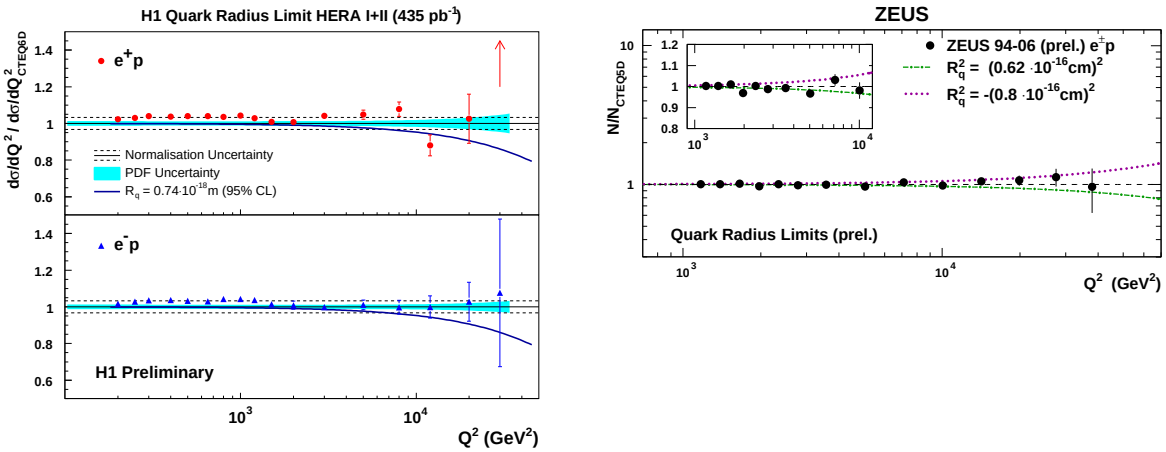

Figure 2: NC single differential cross sections as a function of Q^2 normalised to the SM expectation $\mathrm{d}\sigma_{SM}/\mathrm{d}Q^2$. The lines represent corrections due to the hypothetical quark radius R_q at its 95% CL limit for H1 e^+p data (top left), H1 e^-p data (bottom left), and for ZEUS $e^\pm p$ (right).

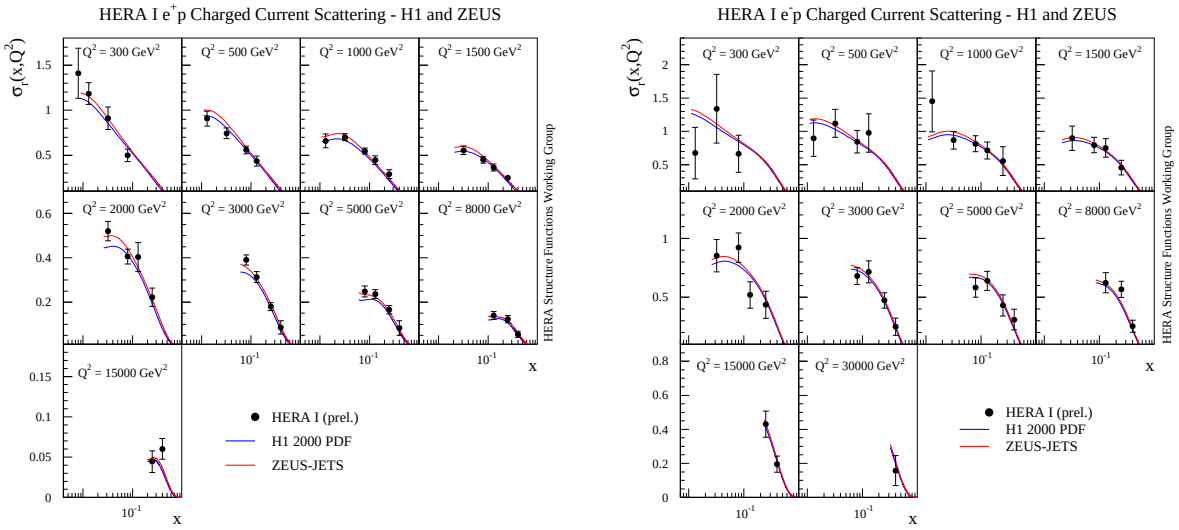

Figure 3: Reduced CC cross sections (points), using the combined HERA I data of H1 and ZEUS, in bins of Q^2 for e^-p (left) and e^+p (right) data. The curves are NLO QCD fits, performed by H1 and ZEUS to their own data.

4 Combination of H1 and ZEUS Charged Current HERA I Data

The H1 and ZEUS collaborations are combining their data to improve the precision of DIS measurements. [17] New preliminary results, using combined HERA I data of H1 and ZEUS, are shown in Figure 3, depicting CC reduced cross sections in bins of Q^2. A good agreement is observed between the combined data [18] and the QCD fits of each experiment [4,19] to their own data. The e^+p data correspond to a total integrated luminosity of approximately $200\,\mathrm{pb}^{-1}$ and have a typical precision of 8%. The statistical gain in precision is most significant in the statistically limited e^-p data set, where the combined data ($30\,\mathrm{pb}^{-1}$) leads to an increase of the precision to about 20%. The precision is expected to increase further with the future inclusion of the HERA II data.

5 Charged Current Cross Section Measurement using Polarised Lepton-Beams

During the HERA II running period, longitudinally polarised lepton-beams were used. The polarisation is defined as $P_e \equiv (N_R - N_L)\,/\,(N_R + N_L)$, with $N_R\,(N_L)$ the number of right (left) handed leptons in the beam. The SM predicts a linear scaling of the CC cross section with the beam polarisation, due to the absence of a right handed neutrino. New ZEUS results, [20] using data from the years 2006-2007, are shown in Figure 4, together with previously obtained HERA measurements. [21,9] A good agreement between the measurements in the different data sets and the SM expectations is observed.

6 Measurement of the quark-Z coupling

The cross section of NC DIS events composes of photon (γ) and Z exchange diagrams. Due to the heavy Z boson propagator, the contribution from pure Z exchange is suppressed. The contribution from γZ interference, however, is still sensitive to the vector and axial-vector couplings of the Z boson to the quark. Limits at 68% CL on these couplings are extracted, using combined EW and QCD fits where the coupling parameters pertaining to both the up and down quark are left free in the fit. [22,23] In particular, the limits concerning the couplings to the up quark (v_u and a_u) profit from including the polarised HERA II data. The results are shown in

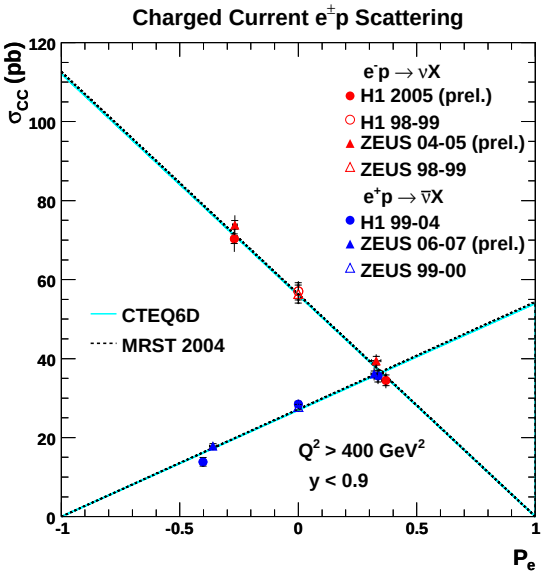

Figure 4: The polarisation dependence of the charged current cross section on the lepton-beam polarisation P_e. The curves are the SM QCD predictions using two different PDF fits.

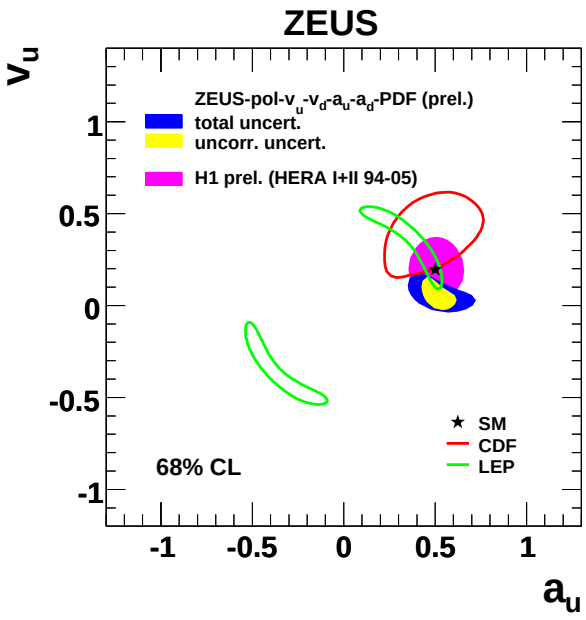

Figure 5: Limits at 68% CL on the vector and axial-vector couplings of the Z boson to the up quark, a_u and v_u respectively, shown for H1 and ZEUS in comparision with other experiments and the SM prediction.

Figure 5, in comparison with results obtained by CDF and LEP.[24,25] The HERA experiments provide a better measurement than the Tevatron and resolve the ambiguity in the LEP results.

7 Measurement of Single W Boson Production

Single W boson production in the SM is a rare process at HERA with a cross section of order 1 pb.[26] In the case of leptonic W boson decay, for which the branching ratio is about 30%, the event gives rise to a characteristic '$\ell + \not{P}_T$' detector signature, consisting of an energetic isolated electron or muon (ℓ) and large missing transverse momentum ($\not{P}_T$). The full HERA I+II high energy data sample, collected with the H1 detector in the years 1994-2007 and corresponding to an integrated luminosity of 478 pb^{-1}, is analysed and 59 $\ell + \not{P}_T$ events are selected[27] compared to a SM expectation of 58.9 ± 8.2. This yield is presented in Figure 6 (left) as a function of the tranverse momentum of the hadronic system (P_T^X). Notwithstanding an excess of the data over the MC prediction in the small region of phase space where $P_T^X > 25$ GeV, a good over-all agreement with the SM is observed. The single W boson production cross section is determined[28] to be $\sigma_W = 1.2 \pm 0.3$ (stat) ± 0.2 (sys) pb, which is in good agreement with the (NLO) SM expectation of 1.3 ± 0.2 pb. The quoted errors on the measured cross section include theoretical and experimental uncertainties.

8 Measurement of the W Boson Polarisation Fractions

The measurement of the W boson polarisation fractions is based on the $\ell + \not{P}_T$ data sample discussed in Section 7 and makes use of the $\cos\theta^*$ distributions in the decay $W \to e/\mu + \nu$. θ^* is defined as the angle between the W boson momentum in the lab frame and that of the charged decay lepton in the W boson rest frame. For the left handed polarisation fraction F_-, the longitudinal fraction F_0 and the right handed fraction $F_+ \equiv 1 - F_- - F_0$, the $\cos\theta^*$

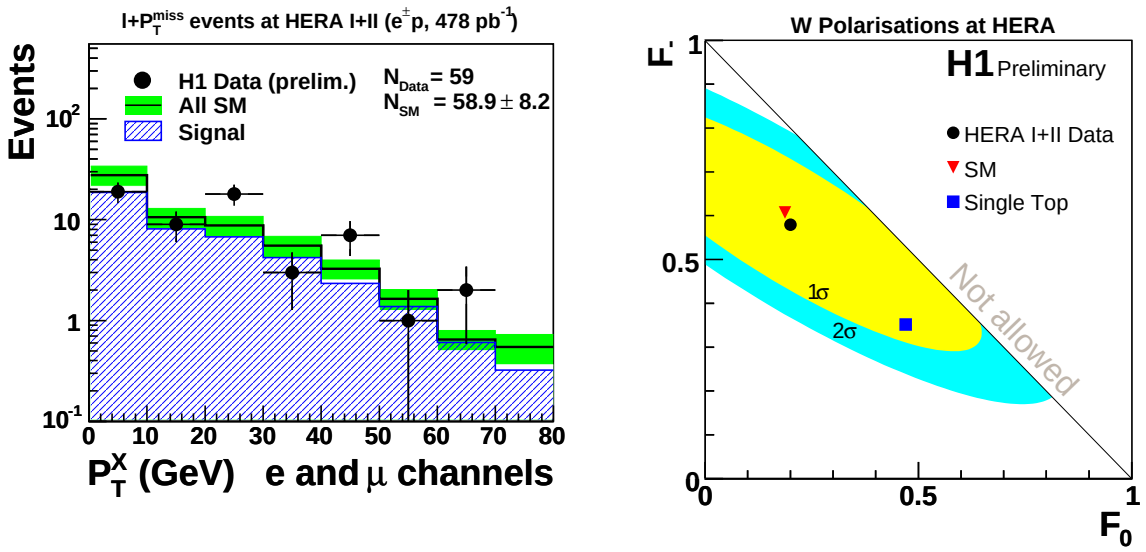

Figure 6: Left: The hadronic transverse momentum (P_T^X) distribution in the electron and muon channels combined. The data (points) are compared to the SM expectation (open histogram). The main contribution from single W production is also shown (hatched histogram). Right: Measured values for the polarisation fractions F_- and F_0 with the 1 and 2σ CL contours.

distributions for W^+ bosons are given [29] by

$$\frac{d\sigma_W}{d\cos\theta^*} \propto (1 - F_- - F_0) \cdot \frac{3}{8}(1+\cos\theta^*)^2 + F_0 \cdot \frac{3}{4}\left(1-\cos^2\theta^*\right) + F_- \cdot \frac{3}{8}(1-\cos\theta^*)^2 . \quad (1)$$

For W^- bosons, the $\cos\theta^*$ distributions have opposite values. To allow the combination of both channels, $\cos\theta^*$ is multiplied with the sign of the lepton charge $q_\ell = \pm 1$. Therefore, from the $\ell + \not{P}_T$ data sample, only events for which a reliable measurement of the charge of the isolated lepton exists are used. The reconstruction of the W boson rest frame is performed and the W boson differential cross section as a function of the decay angle θ^* is derived and fit to the model defined in Equation 1. In the fit, the optimal values for F_- and F_0 are simultaneously extracted using a χ^2 minimisation method. The result is shown in Figure 6 (right) and found to be in good agreement with the SM. F_- and F_0 are also extracted in fits where one parameter is fixed to its SM value. No deviations from the SM are observed and the values are determined to be:

$$\begin{aligned} F_- &= 0.58 \pm 0.15\,(\text{stat}) \pm 0.12\,(\text{sys}) \quad \text{SM:} \quad 0.61 \pm 0.01\,(\text{stat}), \\ F_0 &= 0.15 \pm 0.21\,(\text{stat}) \pm 0.09\,(\text{sys}) \quad \text{SM:} \quad 0.19 \pm 0.01\,(\text{stat}). \end{aligned}$$

9 Summary

Preliminary H1 results of NC cross section measurements at high Q^2 have been presented, using the complete HERA I+II high energy data set. A good agreement with the QCD SM expectations is observed. In the search for contact interactions, H1 and ZEUS derive strong upper limits on a possible quark radius of respectively $0.74 \cdot 10^{-18}$ m and $0.62 \cdot 10^{-18}$ m at 95% CL. In addition, two dimensional limits at 68% CL on the vector and axial vector couplings of the Z boson to the up quark were shown, using combined EW and QCD fits. New measurements of the charged current cross section as a function of the lepton-beam polarisation, using data taken in the years 2006-2007, have been presented. A good agreement is observed with previous measurements and with the SM, which forbids right handed charged currents. Recently derived CC cross section measurements are presented, using the combined HERA I data of both experiments. The combination of the data has led to significant improvements in the statistical

precision. The cross section measurements using the combined data are in good agreement with the previously established QCD fits of H1 and ZEUS to their own data. A single W boson production cross section measurement is performed by H1 using the full HERA I+II data and found to be $\sigma_W = 1.2 \pm 0.3$ (stat) ± 0.2 (sys) pb, which is in good agreement with the (NLO) SM expectation of 1.3 ± 0.2 pb. Finally, the W boson polarisation fractions are measured and found to be in good agreement with the SM.

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