High Q^2 Measurements from HERA

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Abstract. New measurements of neutral and charged current cross sections at large negative four–momentum transfer squared Q^2 have been performed by H1 and ZEUS, using up to the complete HERA II $e^{\pm}p$ data, which was taken with polarised electron and positron beams. The data are compared to predictions of the Standard Model, based on various parton distribution function parameterisations. The polarisation asymmetry of the neutral current interaction is measured as a function of Q^2, as well as the polarisation dependence of the charged current cross section and both are found to be in agreement with the Standard Model expectation. The HERA II cross sections are also combined with previously published HERA I data to obtain the most precise unpolarised measurements.

1. Introduction

HERA measurements of proton structure in neutral current (NC) and charged current (CC) deep inelastic scattering (DIS) with polarised lepton beams are crucial to the understanding of the detailed dynamics of QCD as well as allowing the chiral structure of electroweak interactions to be simultaneously probed at the highest energies. The NC interaction $ep \rightarrow ep$ proceeds via γ or Z^0 exchange, whereas the CC interaction $ep \rightarrow e\nu$ involves the exchange of a $W^{\pm}$ boson. The cross sections of such processes are described in terms of the negative four–momentum transfer squared, Q^2, the fraction of proton momentum carried by the struck quark, Bjorken x, and the inelasticity of the interaction, y, which are related according to the expression $Q^2 = sxy$. The first measurements of such processes to include the full HERA II (2003–2007) data are now available, and a selection of results from the H1 [1, 2] and ZEUS [4, 3, 5, 6] Collaborations is presented here.

The HERA II data were taken with a polarised incident electron or positron beam of energy 27.6 GeV in collision with an unpolarised proton beam of energy 920 GeV, yielding a centre-of-mass energy of $\sqrt{s} = 319$ GeV. The e^+p and e^-p data sets are further subdivided into periods of positive and negative longitudinal polarisation, $P_e = (N_R - N_L)/(N_R + N_L)$, where N_R (N_L) is the number of right (left) handed leptons in the beam. The typical lepton beam polarisation of the data is around 30–40%. Unpolarised measurements are performed by correcting for the residual beam polarisation according to the SM prediction, where H1 measurements [1, 2] are also combined with the HERA I (1994–2000) data.

2. Unpolarised measurements

The Q^2 dependence of the unpolarised NC and CC cross sections at HERA is shown in figure 1. The H1 and ZEUS $e^{\pm}p$ data are well described by the SM prediction, which is based on the HERAPDF 1.0 parameterisation of the parton densities in the proton [7]. It can be seen that at low Q^2 the cross sections differ significantly, due to the difference in the propagator terms in the cross section: for NC the photon exchange goes as $\sim 1/Q^4$, whereas the CC process includes the mass of the W boson and is proportional to $[M_W^2/(M_W^2 + Q^2)]^2$. The NC and CC cross sections are of comparable size for $Q^2 \approx M_W^2$ and higher, illustrating the unification of the electromagnetic and the weak interactions.

The difference between the e^+p and e^-p CC cross sections arises from the less favourable helicity factor of $(1 - y)^2$ in the case of e^+p collisions and the difference between the up and down quark distributions in the proton. For the NC process, the e^-p cross section is larger than in e^+p collisions for values of $Q^2 \approx M_{Z^0}^2$ and higher, due to the interference between the pure γ and Z^0 exchange, which is positive in the case of e^-p scattering. This can be seen in more detail in the reduced unpolarised double differential NC cross section $\tilde{\sigma}(x, Q^2)$, as shown measured by ZEUS in figure 2, where the separation of the e^+p and e^-p measurements at low x and high Q^2 is clearly visible, in agreement with the SM prediction from the ZEUS–JETS PDF.

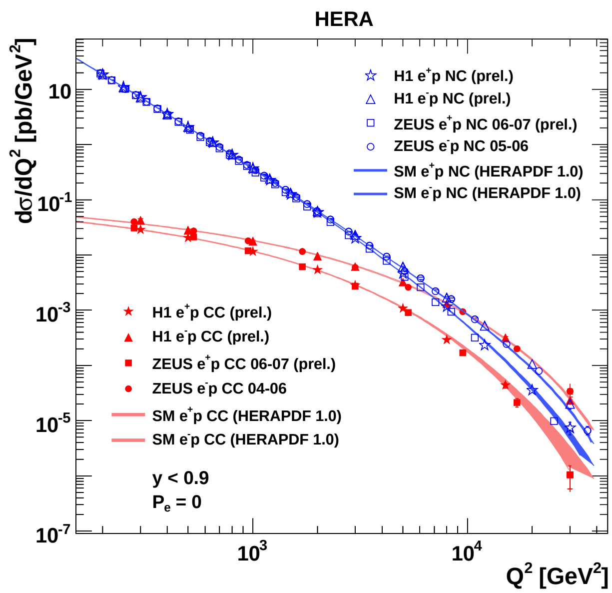

Figure 1. The inclusive unpolarised NC (open symbols) and CC (solid symbols) DIS cross sections measured by H1 and ZEUS as a function of Q^2 using the e^+p (stars, squares) and e^-p (triangles, circles) HERA data. The inner and outer error bars represent respectively the statistical and total errors. The data are compared to the SM prediction based on the HERAPDF 1.0 parameterisation (shaded band).

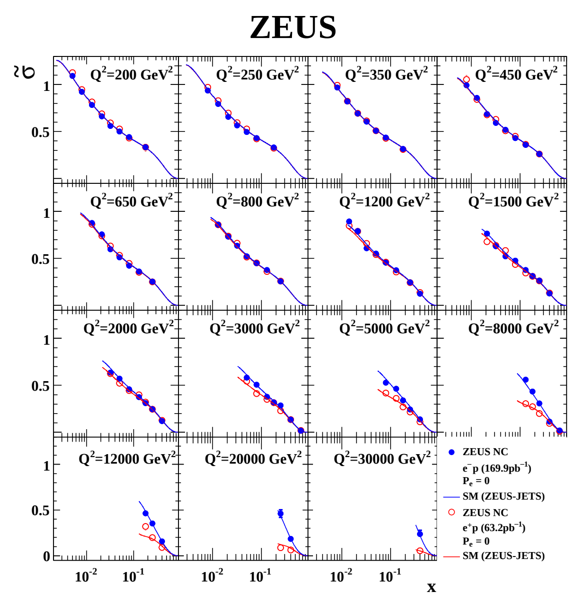

Figure 2. The reduced NC cross section $\tilde{\sigma}(x, Q^2)$ measured by ZEUS as a function of x in different bins of Q^2 for unpolarised e^+p (open points) and e^-p (solid points) data. The inner and outer error bars represent respectively the statistical and total errors. The data are compared to the SM prediction based on the ZEUS–JETS PDF parameterisation (lines).

3. Measurements using polarised data

The Standard Model predicts a difference in the NC cross section for leptons with different helicity states arising from the chiral structure of the neutral electroweak exchange. With longitudinally polarised lepton beams in HERA II such polarisation effects can be tested, providing a direct measure of the electroweak effects in the neutral current cross sections. In effect, there are then four HERA II data sets to consider: electron and positron collisions, with left– or right–handed polarised leptons. The polarisation asymmetry is calculated as: $A^{\pm} = 2/(P_{e,+} - P_{e,-}) \cdot [\sigma^{\pm}(P_{e,+}) - \sigma^{\pm}(P_{e,-})]/[\sigma^{\pm}(P_{e,+}) + \sigma^{\pm}(P_{e,-})]$, where, for example $\sigma^{+}(P_{e,+})$ is the measured cross section for the positively polarised e^+p data set. In positron scattering A is expected to be positive and about equal to $-A$ in electron scattering. The asymmetry measurement performed by H1 as a function of Q^2 is shown in figure 3, compared to the SM expectation based on the H1PDF 2009 parameterisation. The magnitude of the asymmetry is observed to increase with increasing Q^2 and is negative in e^-p and positive in e^+p scattering, in agreement with the SM prediction and confirming parity violation in neutral current interactions.

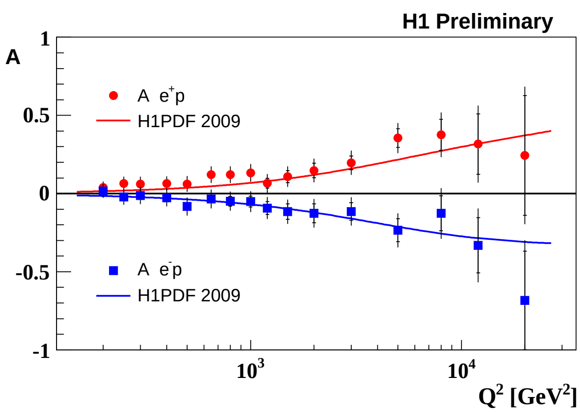

Figure 3. The Q^2 dependence of the polarisation asymmetry, A, measured by H1 using the e^+p (circles) and e^-p (squares) NC DIS data. The inner and outer error bars represent respectively the statistical and total errors. The data are compared to the SM prediction based on the H1PDF 2009 parameterisation (lines).

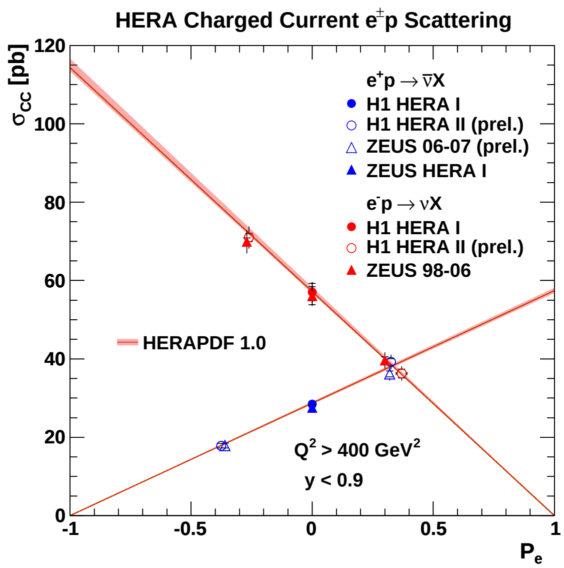

Figure 4. The dependence of the integrated $e^{\pm}p$ CC DIS cross section $\sigma_{\rm CC}$ on the lepton beam polarisation P_e measured by H1 and ZEUS. The inner and outer error bars represent respectively the statistical and total errors. The data are compared to the SM prediction based on the HERAPDF 1.0 parameterisation (shaded bands).

The SM predicts the absence of right handed charged currents and a linear dependence of the CC cross section on the lepton beam polarisation, which is given by the relationship: $\sigma^{\pm}_{CC}(P_e) = (1 \pm P_e) \cdot \sigma^{\pm}_{CC}(P_e = 0)$. In other words, for a fully right–handed electron beam ($P_e = 1$) or a fully left–handed positron beam ($P_e = -1$) the SM cross section is identically zero and any deviation from this linear dependence would indicate new physics. The integrated CC cross section measured by H1 and ZEUS in the kinematic region $Q^2 > 400$ GeV^2 and $y < 0.9$ is shown in figure 4. Measurements of the unpolarised total cross section in the same phase space based on HERA I data are also shown. The measurements are compared to the SM expectation based on the HERAPDF 1.0 parameterisation. The data exhibit a clear linear polarisation dependence of the cross section, which is maximal for left–handed e^-p scattering and right–handed e^+p scattering in agreement with the SM prediction and demonstrating the parity violation of purely weak charged current interactions. The polarised reduced double differential CC cross section $\tilde{\sigma}_{CC}(x, Q^2)$ is shown in figure 5 as measured by H1 using the HERA II e^+p (left) and e^-p (right) data. The polarisation asymmetry is again clearly visible where the positively

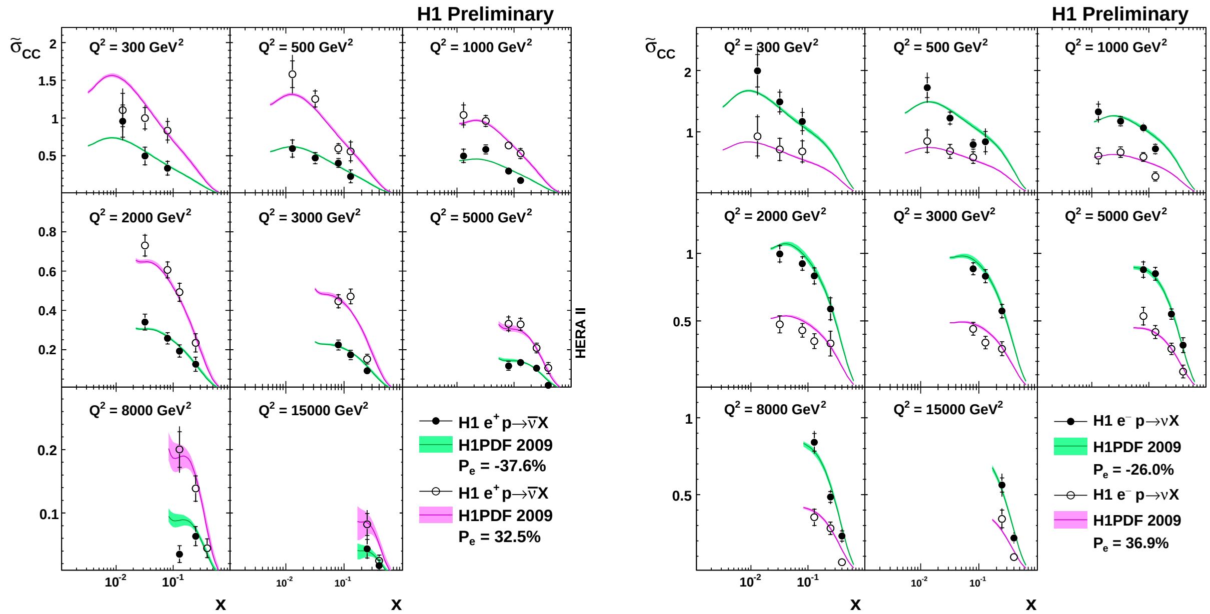

Figure 5. The polarised reduced CC DIS cross section $\tilde{\sigma}_{\mathrm{CC}}(x, Q^2)$ measured by H1 using e^+p (left) and e^-p (right) data as a function of x in different bins of Q^2. The negatively (positively) polarised data are shown by the and solid (open) points. The inner and outer error bars represent respectively the statistical and total errors. The data are compared to the SM prediction based on the H1PDF 2009 parameterisation (shaded bands).

(negatively) polarised CC cross section is higher for e^+p (e^-p), in agreement with the prediction from H1PDF 2009.

4. Conclusions

Measurements by H1 and ZEUS of polarised and unpolarised neutral and charged current cross sections at HERA are presented. The data are found to be consistent with the predicted behaviour of polarised ep scattering in the Standard Model. The high Q^2 data from H1 and ZEUS, separately and ultimately in combination, will provide more constraints on the structure of the proton and input into electroweak fits of the HERA data and QCD fits such as HERAPDF, which are a vital ingredient to the success of proton colliders like the LHC.

References

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