Electroweak Physics at HERA

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Abstract.
Results on the measurement of electroweak processes in $e^{\pm}p$ collisions at HERA by the H1 and ZEUS experiments are presented. All data collected at HERA corresponding to a total integrated luminosity of about 1 fb^{-1} are used for most of the measurements. Inclusive cross section measurements of deep inelastic neutral current ($ep \to eX$) and charged current ($ep \to \nu X$) scattering are shown. The influence of polarisation and lepton beam charge on the cross sections and sensitivity to electroweak effects is demonstrated. Rare electroweak processes with a small cross section $\mathcal{O}(1\text{ pb})$ are also presented. Measurements of lepton-pair production and single W production are shown.

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DEEP INELASTIC SCATTERING

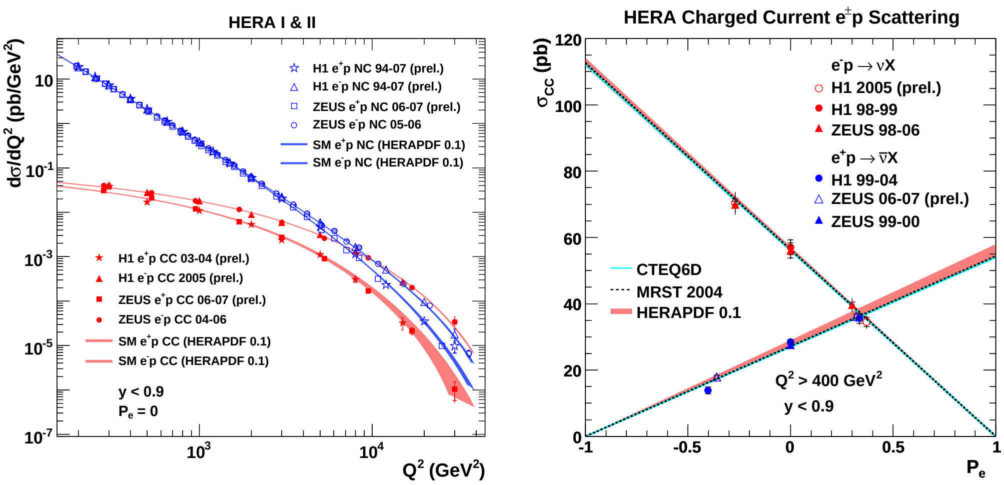

FIGURE 1. Left: The inclusive neutral and charged current cross section measured at HERA. At the scale of $Q^2 \simeq m_W^2$ the electroweak unification is visible. At very high Q^2 the Z exchange and γZ interference lead to differences in the e^+p and e^-p cross sections. Right: The charged current cross section as a function of the lepton beam polarisation P_e at HERA. The data are compared to the SM prediction (HERAPDF 0.1 parametrisation).

HERA, the only $e^{\pm}p$ collider, took data in the years 1994-2007 at centre-of-mass energies of up to 320 GeV in Hamburg, Germany. This talk [1] highlights some results of the electroweak processes measured by the H1 and ZEUS experiments at HERA. Deep inelastic scattering at HERA provides the possibility to study the structure of the proton and test QCD over a huge kinematic range. Inclusive cross section measurements of deep inelastic neutral ($ep \rightarrow eX$) and charged ($ep \rightarrow \nu X$) current scattering are shown in figure 1. The deep inelastic neutral current (NC) scattering cross section can be written at high four-momentum transfer squared Q^2 as

$$\frac{d^2\sigma_{NC}^{e^\pm p}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+\tilde{F}_2^\pm \mp Y_- x\tilde{F}_3^\pm\right],$$

where $Y_\pm = 1 \pm (1-y)^2$ is the helicity factor, $\tilde{F}_2^\pm$, $\tilde{F}_3^\pm$ and $\tilde{F}_L^\pm$ are generalised structure functions

$$\tilde{F}_2^\pm = F_2 + k\big(-v_e \mp P_e a_e\big)F_2^{\gamma Z} + k^2\Big(v_e^2 + a_e^2 \pm 2P_e v_e a_e\Big)F_2^Z \quad \text{and}$$
$$x\tilde{F}_3^\pm = F_2 + k\big(-a_e \mp P_e v_e\big)xF_3^{\gamma Z} + k^2\big(2v_e a_e \pm P_e(v_e^2 + a_e^2)\big)xF_3^Z.$$

Pure photon exchange is described by F_2, pure Z exchange by F_2^Z and xF_3^Z, and γZ interference by $F_2^{\gamma Z}$ and $xF_3^{\gamma Z}$. v_e and a_e are the weak vector and axial-vector couplings of the electron to the Z. The quantity is the ratio of the Z and γ propagators $k = \frac{1}{4\sin^2\theta_w\cos^2\theta_w}\frac{Q^2}{Q^2+m_Z^2}$ with the Weinberg angle θ_w and mass of the Z boson m_Z. The dependence of $\sigma_{NC}^{e^\pm p}$ on the beam lepton charge may be exploited to measure the interference structure function $xF_3^{\gamma Z}$ [2]. Polarised lepton beams modify the neutral current cross sections mostly via the γZ interference and Z terms which leads to polarisation asymmetries $A^\pm$ [3]. The $A^\pm$ are measured and lead to a direct observation of parity violation at scales down to 10^{-18} m.

The charged current (CC) cross section is defined as

$$\frac{d^2\sigma_{CC}^{e^\pm p}}{dxdQ^2} = (1 \pm P_e)\frac{G_F^2}{2\pi x}\left(\frac{M_W^2}{Q^2 + M_W^2}\right)^2 \tilde{\sigma}_{CC}^{e^\pm p},$$

where the reduced charged current cross section $\tilde{\sigma}_{CC}^{e^\pm p}$ is related to the quark densities in $e^\pm p$ scattering via

$$\tilde{\sigma}_{CC}^{e^+ p} = x[\overline{u} + \overline{c}] + (1-y)^2 x[d+s] \ \text{ and}$$
$$\tilde{\sigma}_{CC}^{e^- p} = x[u+c] + (1-y)^2 x[\overline{d} + \overline{s}].$$

The linear dependence on P_e is directly visible in figure 1 (right) which shows measurements of $\sigma_{CC}^{e^\pm p}$ as a function of P_e by the H1 and ZEUS experiments, demonstrating a fundamental characteristic of the SM: Only L(R)-handed (anti)particles interact weakly. It can also be seen that the dependence on the beam lepton charge due to the sensitivity to flavour in the proton results in a higher $\sigma_{CC}^{e^- p} \simeq 2 \cdot \sigma_{CC}^{e^+ p}$.

Using the NC and CC cross sections, a combined electroweak and QCD analysis was performed by the H1 and ZEUS collaborations in order to simultaneously extract electroweak couplings to the Z boson and parton density functions of the proton [3]. In this fit, a similar or even better precision for constraints on the couplings was achieved compared to fits performed by Tevatron and LEP experiments.

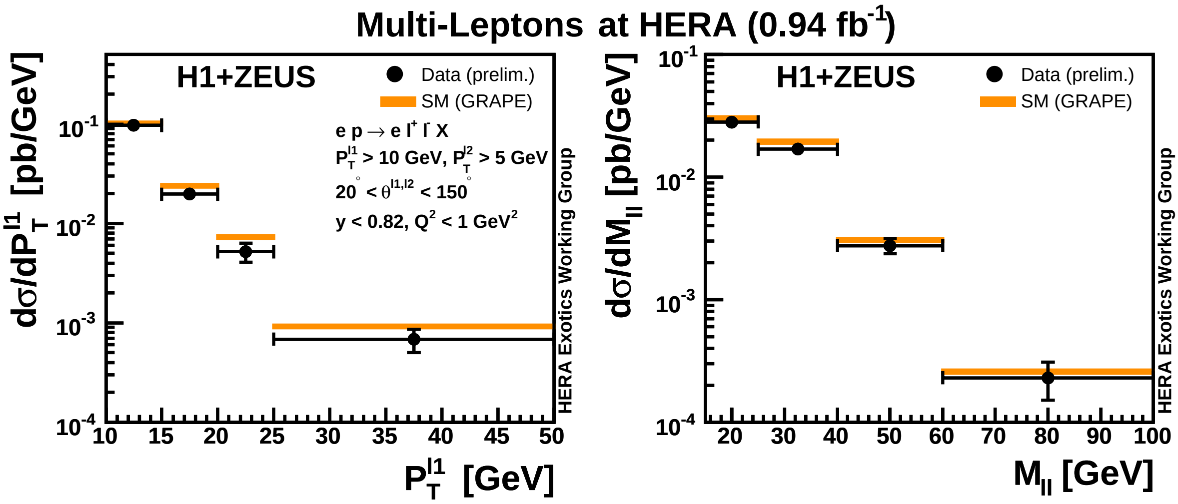

FIGURE 2. The measured cross section of lepton pair production in a phase space dominated by photon-photon processes as a function of the leading lepton transverse momentum $P_T^{\ell 1}$ (left) and the invariant mass of the lepton pair $M_{\ell\ell}$ (right).

RARE ELECTROWEAK PROCESSES

Two electroweak processes measured at HERA and having a small cross section together with clean signature, due to leptons in the final state, that are are lepton pair-production and single W boson production.

Processes leading to a final state with at least two high transverse momentum leptons (electrons or muons) are studied by the H1 and ZEUS experiments, and their data are combined [4, 5, 6]. The combined data sample corresponds to an integrated luminosity of 0.94 fb^{-1}. The observed event yields are compared to the prediction from the Standard Model. In general, a good agreement is found. The analysis is sensitive to new physics beyond the SM at high values of the sum of lepton transverse momenta $\sum P_T$ and invariant masses $M_{\ell\ell}$, where a few interesting events are observed in e^+p collisions only. The photoproduction cross section of electron and muon pair-production is also measured in a restricted phase space dominated by photon-photon collisions. The average differential cross section as a function of $P_T^{\ell 1}$ and $M_{\ell\ell}$ is presented in figure 2.

Events with high energy ($P_T > 10$ GeV) isolated electrons or muons and missing transverse momentum $P_T^{\mathrm{miss}} > 12$ GeV are studied using the full $e^{\pm}p$ data samples collected by the H1 [7] and ZEUS [8] experiments at HERA, corresponding to an integrated luminosity of about 0.5 fb^{-1} per experiment. Within the SM, this topology mainly originates from single W boson production. Figure 3 shows the transverse mass distributions measured by H1 (left, $e+\mu$ channels combined) and ZEUS (right, e channel). A Jacobian peak structure is visible close to $m_W = 80.2$ GeV, and the SM prediction is dominated by single W production. This strong evidence for W production at HERA allows H1 and ZEUS to measure the single W production cross section to be 1.14 ± 0.25 (stat.) ± 0.14 (sys.) pb, and $0.89^{+0.25}_{-0.22}$ (stat.) ± 0.10 (syst.) pb, respectively. The measurements are in agreement with each other and with the SM expectation of

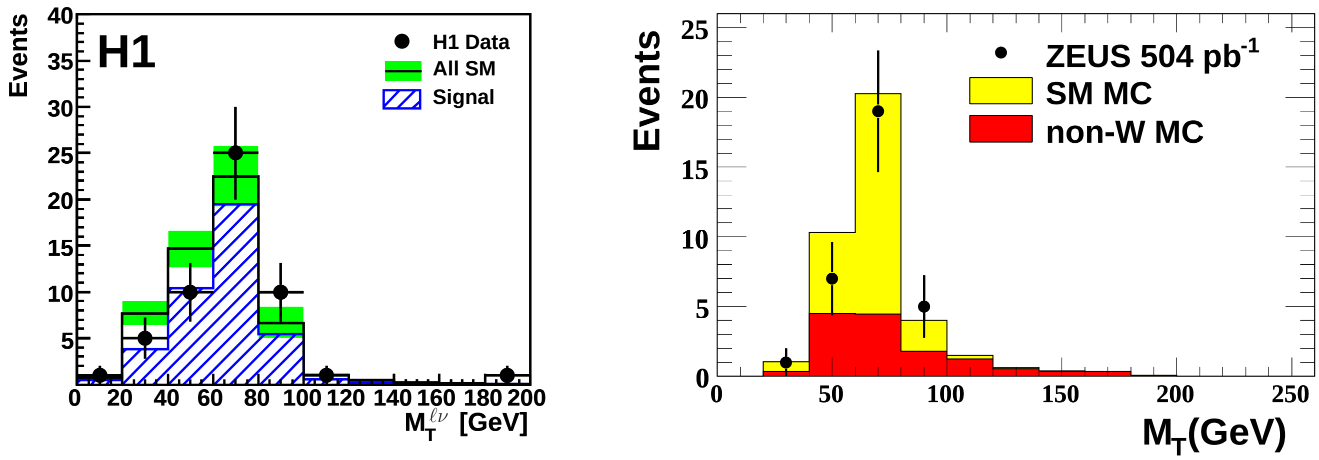

FIGURE 3. The transverse mass distributions of events with isolated leptons and missing transverse momentum measured by H1 (left, $e+\mu$ channels combined) and ZEUS (right, e channel).

1.27 ± 0.19 pb.

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