

HIGH Q^2 CROSS SECTIONS, ELECTROWEAK MEASUREMENTS AND PHYSICS BEYOND STANDARD MODEL AT HERA

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HERA, the only $e^\pm p$ collider, operated in the years 1992-2007 at centre-of-mass energies of 300-320 GeV in Hamburg, Germany. Deep inelastic neutral ($ep \rightarrow eX$) and charged ($ep \rightarrow \nu X$) current scattering at HERA provides the possibility to study the structure of the proton, the dynamics of strong interactions and test quantum chromodynamics (QCD) over a huge kinematic range. Both, neutral and charged current interactions provide complementary information on the QCD and electroweak (EW) parts of the Standard Model (SM). In addition, HERA data allow for indirect searches for new phenomena originating at large scales, however, no evidence for the new physics has been found. The full statistics of data collected at HERA have been used for most of the measurements performed by H1 and ZEUS which are presented in this document.

1 Introduction

After the upgrade of HERA in the year 2000, the specific luminosity has been increased by a factor of about four and longitudinally polarised lepton beams have been provided to the collider experiments ("HERA II" period). The average polarisation of the lepton (electron or positron) beam P_e ^a achieved at HERA typically varied between 35% to 40%. Measurements of deep inelastic scattering (DIS) with polarised leptons on protons allow the parton distribution functions (PDFs) of the proton to be further constrained through polarisation asymmetries and specific tests of the electroweak parts of the Standard Model to be performed¹. For example, a test of the $V - A$ structure of charged current interactions can be performed by measuring the polarisation dependence of the charged current cross section. This tests the origin of absence of the right-handed weak currents.

The collected luminosity at HERA of high energy ep interactions (about 1 fb^{-1} by H1 and ZEUS experiments together) gives access to rare processes with cross sections of the order of 0.1 pb, providing a testing ground for the Standard Model complementary to e^+e^- and $p\bar{p}$ scattering. New phenomena at large scales (beyond the maximal available center of mass energy) may be detected indirectly as deviations from the SM predictions. For example the model independent general signature based analysis is based on a search differences between data and SM expectations in various event topologies.

Most of results obtained by H1 and ZEUS collaborations at the high negative four-momentum transfer squared Q^2 as well as of searches for new physics have been combined in order to improve precision and sensitivity. A part of these results are presented in this document.

^aThe polarisation of the lepton beam P_e is defined as $P_e = (N_R - N_L) / (N_R + N_L)$ where N_R (N_L) is the number of right (left) handed leptons in the beam.

2 High Q^2 Cross Sections and Electroweak Physics

The deep inelastic neutral current (NC) scattering cross section is defined as:

$$\frac{d^2\sigma_{NC}^{e^\pm p}}{dx dQ^2} = \frac{2\pi\alpha^2}{xQ^4} \left[Y_+ \tilde{F}_2^\pm \mp Y_- x \tilde{F}_3^\pm - y^2 \tilde{F}_L^\pm \right]. \quad (1)$$

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

$$\begin{aligned} \tilde{F}_2^\pm &= F_2 + k(-v_e \mp P_e a_e) F_2^{\gamma Z} + k^2(v_e^2 + a_e^2 \pm 2P_e v_e a_e) F_2^Z \\ x \tilde{F}_3^\pm &= F_2 + k(-a_e \mp P_e v_e) x F_3^{\gamma Z} + k^2(2v_e a_e \pm P_e(v_e^2 + a_e^2)) x F_3^Z. \end{aligned} \quad (2)$$

Pure photon exchange is described by F_2 , pure Z exchange by F_2^Z and $x F_3^Z$, and γZ interference by $F_2^{\gamma Z}$ and $x F_3^{\gamma Z}$. v_e is the weak vector coupling and a_e the weak axial-vector coupling of the electron to the Z . The quantity k is defined via the Weinberg angle θ_w , the four-momentum transfer squared Q^2 and mass of the Z boson M_Z : $k = \frac{1}{4 \sin^2 \theta_w \cos^2 \theta_w} \frac{Q^2}{Q^2 + M_Z^2}$. As can be seen from Eq. 1, the polarised lepton beams modify the neutral current cross sections mostly via the γZ interference and Z terms.

The charged current (CC) cross section is defined as:

$$\frac{d^2\sigma_{CC}^{e^\pm p}}{dx dQ^2} = (1 \pm P_e) \frac{G_F^2}{2\pi x} \left(\frac{M_W^2}{Q^2 + M_W^2} \right)^2 \tilde{\sigma}_{CC}^{e^\pm p}, \quad (3)$$

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

$$\begin{aligned} e^+ : \quad \tilde{\sigma}_{CC}^{e^+ p} &= x[\bar{u} + \bar{c}] + (1-y)^2 x[d + s] \\ e^- : \quad \tilde{\sigma}_{CC}^{e^- p} &= x[u + c] + (1-y)^2 x[\bar{d} + \bar{s}]. \end{aligned} \quad (4)$$

From Eq. 3 can be seen that in the Standard Model the charged current cross section has a linear dependence on P_e . Therefore the charged current cross section is zero for fully right (left) handed electron (positron) beam providing a consistency test of the electroweak sector of the Standard Model.

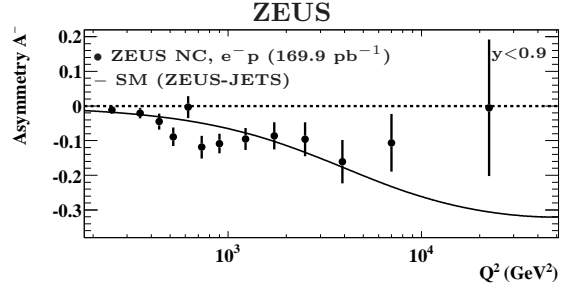
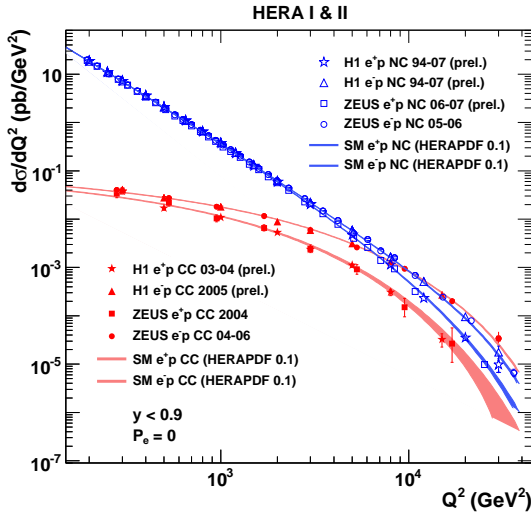


Figure 1: The Q^2 dependences of the neutral and charged current cross sections $d\sigma/dQ^2$ compared to SM predictions determined from the HERAPDF 0.1 fit (left). The polarisation asymmetry A^- as a function of Q^2 (measured by ZEUS) compared to SM predictions evaluated using ZEUS-JETS PDFs (right).

Unpolarised neutral and charged current cross sections measured with the H1 and ZEUS detectors at HERA as function of Q^2 are shown in Figure 1 (left). NC and CC cross sections become about equal in magnitude at $Q^2 \gtrsim 10^4 \text{ GeV}^2$. This follows from the propagator term Q^2 dependence which is different for NC and CC up to $Q^2 \lesssim M_{Z(W)}^2$ (see Eq. 1 and Eq. 3). An access to electroweak effects is also enabled by measuring the charge dependent polarisation asymmetry in neutral currents. The polarisation asymmetry measures a product of vector and axial-vector couplings and thus is a direct measure of parity violation. Neglecting the Z term in Eq. 2 and taking into account that at leading order $F_2^{\gamma Z} = x \sum 2e_q v_q (q + \bar{q})$, then to a good approximation the polarisation asymmetry A^\pm measures the structure function ratio:

$$A^\pm = \frac{2}{P_R - P_L} \frac{\sigma^\pm(P_R) - \sigma^\pm(P_L)}{\sigma^\pm(P_R) + \sigma^\pm(P_L)} \simeq \mp k a_e \frac{F_2^{\gamma Z}}{F_2},$$

which is proportional to $a_e v_q$ combinations and thus directly measures the parity violation. In Figure 1 (right) A^+ measured by the ZEUS collaboration is presented.

The polarisation dependence of the charged current cross sections measured by the H1 and ZEUS collaborations is presented in Figure 2. This found to be consistent with the absence of right handed charged currents as predicted by the SM. Using the NC and CC cross sections a combined electroweak and QCD analysis was performed by the H1 and ZEUS collaborations in order to determine electroweak parameters². In this fit a similar or even better precision was achieved compared to fit performed by Tevatron and LEP experiments.

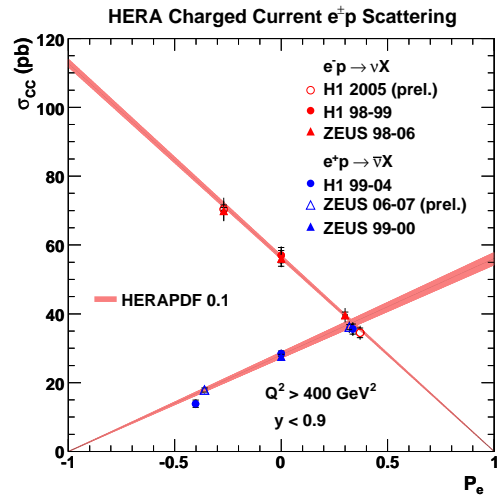


Figure 2: The dependence of the charged current cross section on the lepton beam polarisation P_e at HERA. The data are compared to SM predictions based on HERAPDF 0.1 parametrisation.

3 Physics Beyond Standard Model

A search for excited states of leptons and quarks which are predicted by models assuming composite quarks and leptons has been performed at HERA^{3,4,5}. Generally interactions between excited and ordinary fermions may be mediated by gauge bosons and described by an effective Lagrangian:

$$\mathcal{L}_{GM} = \frac{1}{2\Lambda} \bar{F}_R^* \sigma^{\mu\nu} \left[g f \frac{\tau^a}{2} W_{\mu\nu}^a + g' f' \frac{Y}{2} B_{\mu\nu} + g_s f_s \frac{\lambda^a}{2} G_{\mu\nu}^a \right] F_L + h.c., \quad (5)$$

where, $\sigma^{\mu\nu}$ is the covariant bilinear tensor, $W_{\mu\nu}^a, B_{\mu\nu}$ and $G_{\mu\nu}^a$ are the field-strength tensors of the $SU(2), U(1)$ and $SU(3)_C$ gauge fields, τ^a, Y and λ^a are the Pauli matrices, the weak hypercharge operator and the Gell-Mann matrices, respectively. The standard electroweak and strong gauge couplings are denoted as g, g' and g_s . The compositeness scale Λ reflects the range of the new confinement force, coupling parameters f, f' and f_s associate the three gauge groups. In the recent analysis performed in the H1 collaboration using full HERA statistics the excited lepton and quark decay channels (e.g. $q^* \rightarrow q\gamma, q^* \rightarrow qZ, q^* \rightarrow qW$ for quark) with subsequent hadronic and leptonic decays of Z/W bosons were considered. No indication of a signal was found. An upper limit on the coupling f/Λ as a function of the excited fermion mass was

established and is presented in Figure 3 (the specific relations between couplings are noted in corresponding figures). The results of searches for excited fermions at HERA are complementary or have better sensitivity compare to similar measurements performed at LEP and Tevatron.

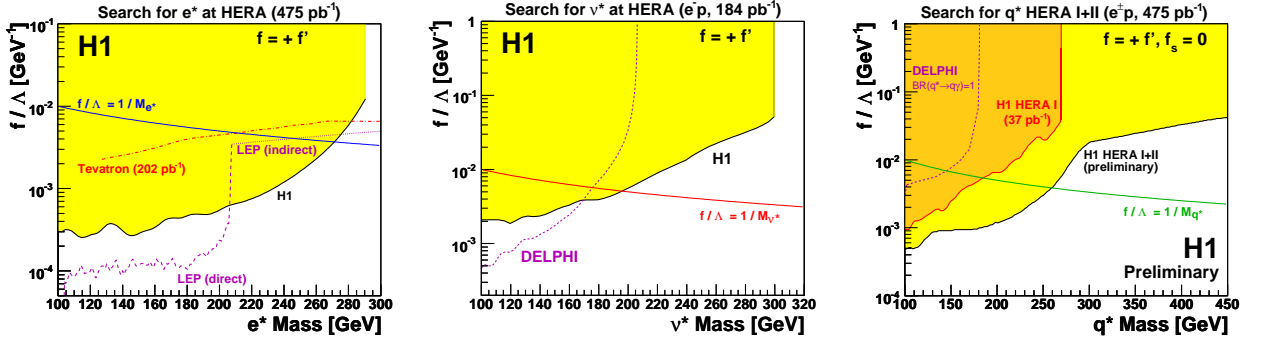


Figure 3: Exclusion limits at 95% CL on the coupling f/Λ as a function of the mass of the excited fermion for $f = +f'$ (e^* and ν^*) and $f = +f', f_s = 0$ (q^*) (for symbol explanation see text). The exclusion domain represented by the shaded area is compared to the corresponding exclusion limits obtained at LEP and Tevatron.

A generic analysis searching for deviations between DIS data and SM expectation in all high transverse momenta P_T event topologies has been recently published by H1 collaboration⁶. An advantage of such a generic analysis is that it does not rely on any a priori definition of expected signature of a specific model, i.e. is model independent. The search has been performed for all event topologies involving isolated electrons, photons, muons, neutrinos and jets with transverse momenta above 20 GeV. In each case deviations from the SM were searched for in the invariant mass and sum of transverse momenta distributions using a dedicated algorithm. A good agreement with the SM expectation was observed in the analysis which demonstrates the very good understanding of high P_T phenomena achieved at HERA. The event yields for analysed event classes comparing data and SM expectations are presented in Figure 4 separately for e^+p and e^-p collisions. Other HERA results like e.g. multi-lepton analysis can be found in the physics result web-sites of H1 and ZEUS collaborations.

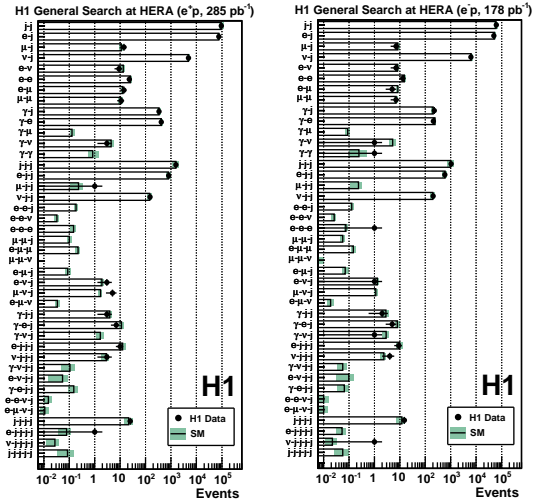


Figure 4: The event yields for data and SM expectations of 27 event classes analysed in the generic search for new phenomena at HERA for e^+p (left) and e^-p (right) collisions.

References

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