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Measurements at high Q^2 and searches at the ep energy frontier

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Abstract

A brief overview is given on most recent, preliminary results obtained by the HERA experiments H1 and ZEUS on the measurements of the neutral current ($ep \to eX$) and charged current ($ep \to \nu X$) deep inelastic scattering (DIS) cross sections at high values of negative four-momentum transfer squared, Q^2. Such processes provide the possibility to study the structure of the proton, the dynamics of strong interactions, to test quantum chromodynamics (QCD) and also provide complementary information on the QCD and electroweak parts of the Standard Model (SM). In addition, a short report is given on indirect searches for new phenomena in which no evidence for the new physics has been found. The results presented in this paper are based on the full statistics of data collected at HERA, the only $e^{\pm}p$ collider, operated in the years 1992-2007 at centre-of-mass energies 300-320 GeV.

Keywords: deep inelastic scattering, neutral current, charged current, polarisation, multileptons, isolated leptons

1. Introduction

At HERA about 100 (20) pb^{-1} of e^+p (e^-p) data were collected until the year 2000 (HERA-I). Afterwords, HERA underwent a major upgrade (HERA-II) aiming for higher luminosity, and until March 2007, HERA provided in total about 500 pb^{-1} of $e^{\pm}p$ collisions per experiment to H1 and ZEUS. After the upgrade, longitudinally polarised lepton beams have been provided to the H1 and ZEUS experiments with an average polarisation, P_e, from 35 to 40%. DIS measurements 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 part of the SM to be performed. In particular, by measuring the polarisation dependence of the charged current cross section, the V-A structure of charged current interactions can be tested.

The total luminosity collected at HERA of about 1 fb^{-1} provides access to rare processes with cross sections of the order of 0.1 pb, giving a solid ground for testing of the SM which is complementary to the tests performed in e^+e^- and $p\overline{p}$ scattering. Searches for new physics often compare the data to the predictions of specific models. Recent H1 and ZEUS analysis searched for single top production, excited quarks, supersymmetric particles or lepton flavor violation [1–5]. A complementary approach is followed in signature based searches by looking for differences between data and SM expectation in various event topologies. Therefore, such model independent analysis do not rely on any a priori definition of expected signatures for new phenomena. Combinations of the H1 and ZEUS results based on model-independent searches which exploit the complete $e^{\pm}p$ data samples of both experiments have been published [6, 7] and will be discussed in this paper.

The kinematics of inclusive deep inelastic electron[1]-proton scattering is described in terms of the variables Q^2, the four-momentum transfer squared of the exchanged vector boson, Bjorken x, the fraction of the momentum of the incoming nucleon carried by the struck quark, and inelasticity $y = Q^2/sx$, which is a measure of the energy transfered between the electron and the proton. The centre of mass energy squared, s, is given by the electron and the proton beam energies, $s = 4E_eE_p$.

The neutral current (NC) cross section can be expressed by three generalised proton structure functions,

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[1]The term electron is used to denote both electrons and positrons.

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$\tilde{F}_2$, $\tilde{F}_L$ and $x\tilde{F}_3$ as

$$\frac{d^2\sigma(e^\pm p \to e^\pm X)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4} Y_+ (\tilde{F}_2^\pm \mp \frac{Y_-}{Y_+} x\tilde{F}_3^\pm - \frac{y^2}{Y_+}\tilde{F}_L^\pm),$$

with $Y_\pm = 1 \pm (1 - y^2)$ and

$$\tilde{F}_2^\pm = F_2 + k_z(-v_e \mp P_e a_e)F_2^{\gamma Z} + k_z^2(v_e^2 + a_e^2 \pm 2P_e v_e a_e)F_2^Z,$$
$$x\tilde{F}_3^\pm = k_z(-a_e \mp P_e v_e)xF_3^{\gamma Z} + k_z^2(2v_e a_e \pm P_e(v_e^2 + a_e^2))xF_3^Z.$$

F_2 describes pure photon exchange, F_2^Z and xF_3^Z describe pure Z exchange and $F_2^{\gamma Z}$ and $xF_3^{\gamma Z}$ γZ interference. v_e is the weak vector coupling and a_e the weak axial-vector coupling of the electron to the Z. The quantity k_z is defined via Weinberg angle θ_w, the four-momentum transfer squared Q^2 and mass of the Z boson, $k_z = \frac{Q^2}{Q^2+M_Z^2}\frac{1}{4cos^2\theta_W sin^2\theta_W}$. The longitudinal structure function $\tilde{F}_L$ gives sizable contribution only at high y. The terms from the generalised structure functions are given by the following expressions,

$$[F_2, F_2^{\gamma Z}, F_2^Z] = x\sum_q [e_q^2, 2e_q v_q, v_q^2 + a_q^2](q + \overline{q}),$$
$$[xF_3^{\gamma Z}, xF_3^Z] = 2x\sum_q [e_q a_q, v_q a_q](q - \overline{q}).$$

v_q and a_q are the vector and axial-vector coupling constants of the quarks to the Z^0 respectively. xq and $x\overline{q}$ are quark and antiquark PDFs. e_q is quark charge.

In the SM the cross sections of the charged current (CC) DIS interaction has a linear dependence on polarisation, P_e, and can be written as,

$$\frac{d^2\sigma_{CC}^{e^\pm p}}{dxdQ^2} = (1 \pm P_e)\frac{{G_F}^2}{2\pi x}\frac{{M_W}^4}{(Q^2 + {M_W}^2)^2}\overline{\sigma}_{CC}^{e^\pm p},$$

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

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

thus bringing flavor sensitivity of the valence quark PDFs at large x.

2. High Q^2 measurements and electroweak physics

Unpolarised neutral and charged current cross sections measured at HERA as function of Q^2 are shown in Fig. 1. NC and CC cross sections become about equal in magnitude for $Q^2 \geq M_{Z,(W)}^2$. In this region also the influence of $x\tilde{F}_3$ in the e^+p and e^-p NC cross sections is visible. At low Q^2 the NC cross section, driven by the electromagnetic interaction, is two orders of magnitude

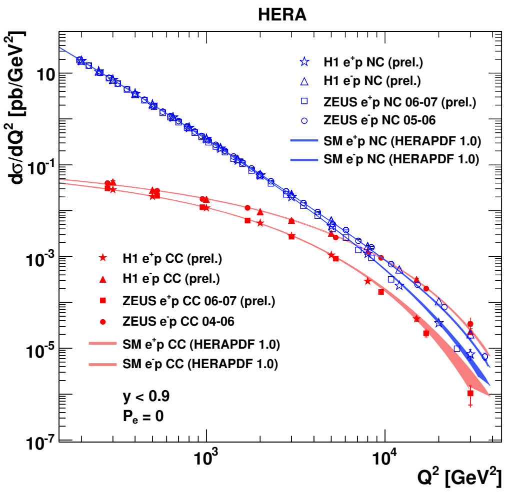

Figure 1: The Q^2 dependence of the unpolarised NC and CC cross sections shown for e^+p (open points) and e^-p (solid points) scattering data from the H1 and ZEUS collaborations. The inner and outer error bars represent respectively the statistical and total errors. The results are compared with the corresponding SM expectations determined from the HERAPDF 1.0 fit.

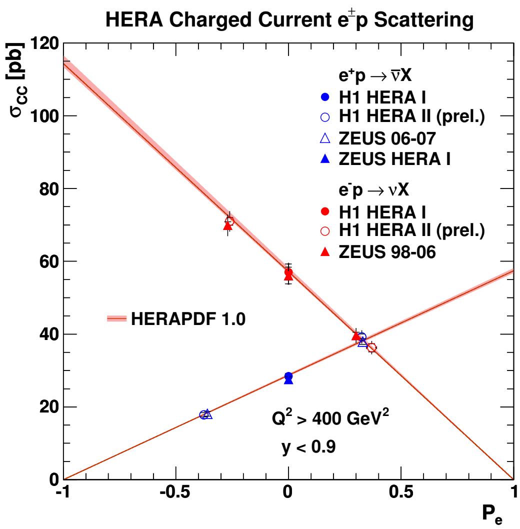

Figure 2: The dependence of the $e^\pm p$ CC cross section on the lepton beam polarisation P_e. The inner and outer error bars represent respectively the statistical and total errors. The data are compared to the SM prediction based on the HERAPDF 1.0 parametrisation.