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MEASUREMENTS OF THE CHARGED CURRENT CROSS SECTIONS WITH THE ZEUS DETECTOR*

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A new measurement of the charged current cross section in e^-p scattering is presented in the range of $Q^2 > 200\,\mathrm{GeV}^2$, using the 1998 and 1999 data with an integrated luminosity of $16.4\,\mathrm{pb}^{-1}$. This cross section is compared to the preliminary charged current cross section in e^+p scattering using the 1999 and 2000 data with an integrated luminosity of $61.0\,\mathrm{pb}^{-1}$, and to predictions of the Standard Model using PDFs extracted from fits to NC data. Finally, the mass of the W boson determined from a fit to $d\sigma/dQ^2$ of the e^-p scattering data is presented.

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1. Introduction

Deep Inelastic Scattering (DIS) of leptons on nucleons has been vital in the development of our understanding of the structure of the nucleon. In the Standard Model (SM), Charged Current (CC) DIS is mediated by the exchange of the W boson. In contrast to Neutral Current (NC), where all quarks and antiquarks flavors contribute, only up(down)-type quarks and down(up)-type antiquarks participate at leading order in $e^-(e^+)$ CC DIS interactions.

The Born level differential cross sections for the CC DIS processes $e^-p \to \nu_e X$ and $e^+p \to \bar{\nu}_e X$ with longitudinal unpolarized lepton beams are given by:

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$$\frac{d^2\sigma^{\rm CC}(e^-p)}{dxdQ^2} = \frac{G_{\rm F}^2}{2\pi x}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2\left[x(u+c)+(1-y)^2x(\bar{d}+\bar{s})\right], \quad (1)$$

$$\frac{d^2\sigma^{\rm CC}(e^+p)}{dxdQ^2} = \frac{G_{\rm F}^2}{2\pi x}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2\left[x(\bar{u}+\bar{c})+(1-y)^2x(d+s)\right], \quad (2)$$

where $G_{\rm F}$ is the Fermi constant, M_W the mass of the W boson, x the Bjorken scaling variable, $y = Q^2/xs$ the inelasticity with $\sqrt{s} = 2\sqrt{E_eE_p}$ the center-of-mass energy, with E_e and E_p the electron and proton beam energies, respectively, and d, u, s and c ($\bar{d}, \bar{u}, \bar{s}$ and $\bar{c}$) the quark (antiquark) momentum distributions. The contribution from the third generation quarks in CC DIS at HERA can be neglected.

Due to the vector axial-vector (V–A) structure of the weak interaction, particles (anti-particles) are in the case of the exchange of the W boson for the e^+p (e^-p) interaction suppressed by the factor $(1–y)^2$ where $y=1/2(1–\cos\theta^*)$ with θ^* the angle of the scattered neutrino.

2. Charged current cross section measurement

2.1. Data sets

In 1998 and part of 1999 HERA collided 27.5 GeV electrons on 920 GeV protons, providing ZEUS with an integrated luminosity of 16.7 pb^{-1} at a centre-of-mass energy of $\sqrt{s} \approx 318$ GeV. In 1999 HERA changed the electron beam to a positron beam, maintaining the same beam energies, and providing ZEUS with an integrated luminosity of 66.3 pb^{-1}. After applying data quality criteria an integrated luminosity of 16.4 pb^{-1} (61.0 pb^{-1}) of e^-p (e^+p) data is used in the analyses presented here.

2.2. Event selection

The signature of CC DIS at HERA is the presence of a large missing transverse momentum, $P_{\rm Tmiss}$, that arises from the energetic final-state (anti-)neutrino that escapes detection. The quantity $P_{\rm Tmiss}$ was calculated from

$$P_{\rm Tmiss}^2 = P_x^2 + P_y^2 = \left(\sum E_i \sin\theta_i \cos\phi_i\right)^2 + \left(\sum E_i \sin\theta_i \sin\phi_i\right)^2,$$

where the sums run over all ZEUS calorimeter [1] energy deposits, and θ_i and ϕ_i are the polar and azimuthal angles of the energy deposits as viewed from the interaction vertex.

Charged current DIS candidates are selected by requiring a large P_{Tmiss} and a reconstructed event vertex consistent with an ep interaction. The events were classified according to γ_0, the value of γ_h measured with respect to the nominal interaction point, where γ_h, the polar angle of the hadronic system, is defined by $\cos\gamma_h = (P^2_{\mathrm{Tmiss}} - \delta^2)/(P^2_{\mathrm{Tmiss}} + \delta^2)$, and $\delta = \sum(E_i - E_i \cos\theta_i) = \sum(E - P_z)_i$.

For events with $\gamma_0 > 0.4$ rad the current jet lies in the central region of the detector, and tracks in the Central Tracking Detector (CTD) [2] can be used to reconstruct an event vertex. The CC candidates are selected by requiring $P_{\mathrm{Tmiss}} > 12\,\mathrm{GeV}$. For events with $\gamma_0 < 0.4$ rad the charged particles from the hadronic final state are often outside the acceptance of the CTD, and the calorimeter timing is used to reconstruct an event vertex. The CC candidates in the e^-p (e^+p) data are selected by requiring $P_{\mathrm{Tmiss}} > 25(14)\,\mathrm{GeV}$.

The main sources of background come from NC scattering and high-E_{T} photoproduction, where E_{T}, the total transverse energy, is given by $E_{\mathrm{T}} = \sum E_i \sin\theta_i$. Events other than ep collisions, such as beam-gas interactions, beam-halo muons or cosmic rays can also cause substantial apparent imbalance in the transverse momentum and so constitute other sources of background. The selection criteria used in these analyses were imposed to separate CC events from all backgrounds, and are detailed in [4] and [5] for the e^-p and e^+p data, respectively.

2.3. Results

The single differential cross sections $d\sigma/dQ^2$, $d\sigma/dx$ and $d\sigma/dy$ for e^-p for $Q^2 > 200\,\mathrm{GeV}^2$, extrapolated to the full y range, are shown in Fig. 1. Also the ZEUS NLO QCD fit [6], CTEQ5D [7] and MRST(99) [8] parameterisations for the PDFs are shown.

The single differential cross sections $d\sigma/dQ^2$ for e^-p and e^+p are shown as function of Q^2 in Fig. 2. The e^-p CC cross section is higher than the e^+p cross section starting with about a factor of two at $Q^2 = 200\,\mathrm{GeV}^2$ and going up to about an order of magnitude at $Q^2 > 10000\,\mathrm{GeV}^2$. This difference is mainly due to the higher u quark content of the proton w.r.t. the d quark content and to the additional suppression, with $(1-y)^2$ of the d quark distribution in the case of e^+p.

The reduced double differential cross section, $\tilde{\sigma} = [(G_{\mathrm{F}}^2/2\pi x)(M_W^4/(M_W^2 + Q^2)^2)]^{-1} d^2\sigma/dxdQ^2$ is shown in Fig. 3 for e^-p and e^+p as function of x, for various values of Q^2. It is clear that the e^-p cross section is completely dominated by the u quark distribution at higher x and Q^2, whereas the e^+p cross section is sensitive for the d quark distribution in the proton at higher x.

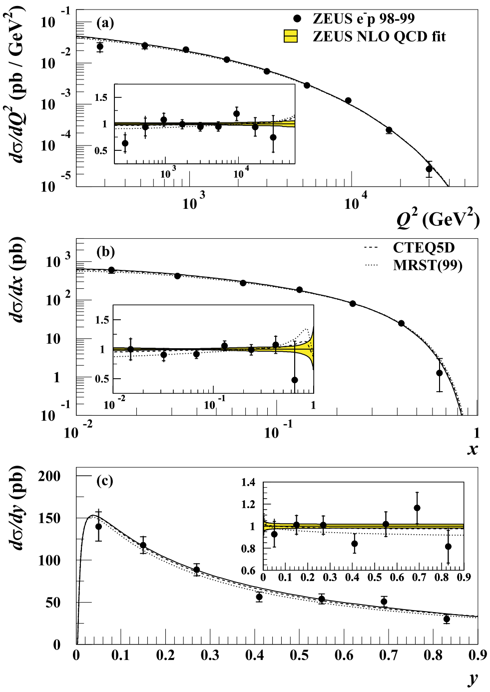

Fig. 1. The e^-p CC DIS cross sections (a) $d\sigma/dQ^2$, (b) $d\sigma/dx$ and (c) $d\sigma/dy$ for data (solid points) and the SM expectation evaluated using the ZEUS NLO QCD fit and CTEQ5D and MRST(99) PDFs. The insets show the ratios of the measured cross sections to the SM expectation evaluated using the ZEUS NLO QCD fit.

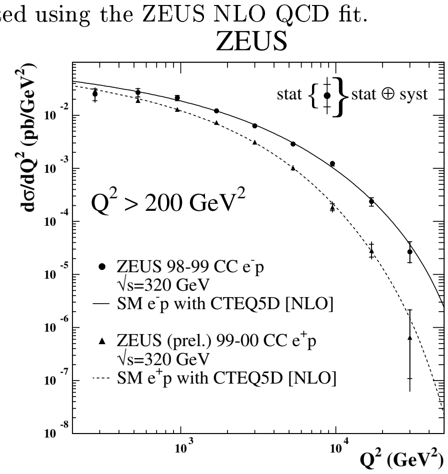

Fig. 2. The single-differential cross section $d\sigma/dQ^2$ for the e^-p data (solid points) with the SM expectation evaluated using the CTEQ5D PDFs (solid line) and for the e^+p data (solid triangles) with the CTEQ5D PDFs (dashed line).

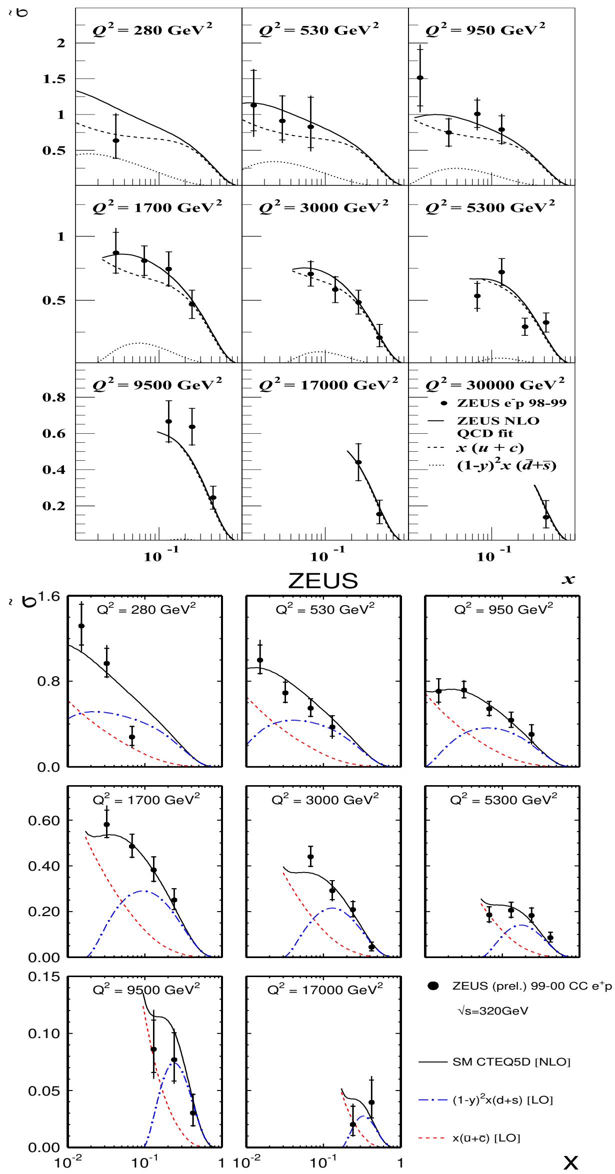

Fig. 3. The reduced cross section, $\tilde{\sigma}$, as function of x, for different values of Q^2. (Top): e^-p data, the points represent the data and the solid line the ZEUS NLO QCD fit. The separate contributions of the PDF combinations $x(u+c)$ and $(1-y)^2x(\bar{d}+\bar{s})$ are shown by the dashed and dotted lines, respectively. (Bottom): e^+p data, the points represent the data and the solid line the NLO CTEQ5D fit. The separate contributions of the PDF combinations $(1-y)^2x(d+s)$ and $x(\bar{u}+\bar{c})$ are shown by the dashed/dotted and dashed lines, respectively.

3. Electroweak analysis

Eq. 1 shows that the magnitude of the CC DIS cross section is determined by $G_{\rm F}$ and the PDFs. The fall in the cross section with increasing Q^2 is dominated by the propagator term $M_W^4/(Q^2+M_W^2)^2$. An electroweak analysis performed by fitting $d\sigma/dQ^2$ with $G_{\rm F}$ fixed at the PDG value of $1.16639\times10^{-5}\,{\rm GeV}^{-1}$ and M_W as free parameter gives $M_W = 80.3 \pm 2.1({\rm stat.}) \pm 1.2({\rm syst.}) \pm 1.0({\rm PDF})\,{\rm GeV}$. This measurement, in the space-like region, is in good agreement with the more precise measurements of W-boson production in the time-like region, and with the previous ZEUS measurement of M_W for e^+p CC DIS at $\sqrt{s} = 300\,{\rm GeV}$ [3]

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