Tests of the Standard Model in inclusive scattering at large transverse momenta at HERA

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Abstract
The HERA collider experiments H1 and ZEUS present ep- scattering data at very large momentum transfers that enable electroweak tests to be performed. Neutral and charged current processes are analysed in terms of boson-parton couplings. The helicity structure of the electron quark interaction is probed at 10^{-3} fm. The combined result for the W propagator mass is derived showing good consistency with the Standard Model.

1. Introduction

Recently the H1- and ZEUS- collaborations have presented their final results [1, 2, 3] on e^+p-scattering at large momentum transfers Q^2. In the meantime for the 1998-99 running period some 15 pb^{-1} of e^-p scattering data have been analysed by each collaboration and preliminary results have been presented at this conference [4, 5, 6].

The scattering process at high Q^2 and high x is governed by the exchange of a boson (γ, Z or W) between the lepton and a quark in the proton. The cross section is described by a coupling, a propagator and parton momentum probability term ϕ. Due to the combined contribution of γ and Z in the neutral current, ϕ_{NC}, in addition, absorbs terms containing ratios of propagators and electroweak couplings. Simplifying, the cross sections may thus be written as

$$\frac{\mathrm{d}^2\sigma^{NC}}{\mathrm{d}x\mathrm{d}Q^2} = \frac{2\pi\alpha^2}{x}\frac{1}{Q^4}\phi_{NC} \tag{1}$$

$$\frac{\mathrm{d}^2\sigma^{CC}}{\mathrm{d}x\mathrm{d}Q^2} = \frac{G_F^2}{2\pi x}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2\phi_{CC} \tag{2}$$

where ϕ_{NC} and ϕ_{CC} are functions of x and Q^2.

2. γZ-interference

In more general terms the quark density function for the neutral current comprises the structure functions $\tilde{F}_2(x, Q^2)$ and $x\tilde{F}_3(x, Q^2)$

$$\begin{aligned}\phi_{NC}^{\pm} &= \left(1+(1-y)^2\right)\tilde{F}_2(x,Q^2)\\ &\mp \left(1-(1-y)^2\right)x\tilde{F}_3(x,Q^2)\end{aligned}$$

which demonstrates explicitly the dependence on the incident lepton charge $e^{\pm}$ at high $y = Q^2/sx$ (cf. fig. 1).

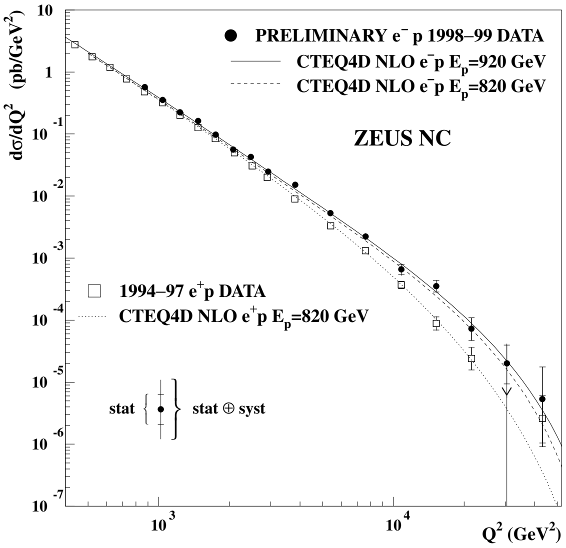

Figure 1. The Q^2 dependence of the neutral current for e^+- (e^--) beams seen by the ZEUS experiment. The destructive (constructive) γZ-interference is visible at high Q^2.

A more detailed analysis is given in fig. 2, which depicts the x-dependence of the cross section. The effect of γZ-interference is clearly tracked in the data with the exception of the bin at $x = 0.40$, where the H1 e^+p data demonstrate the excess of events over the Standard Model expectation discussed in ref. [1, 7, 8, 9].

3. Electroweak Unification

The e^-p charged current measurement of ZEUS is shown in fig. 3 together with the neutral current data.

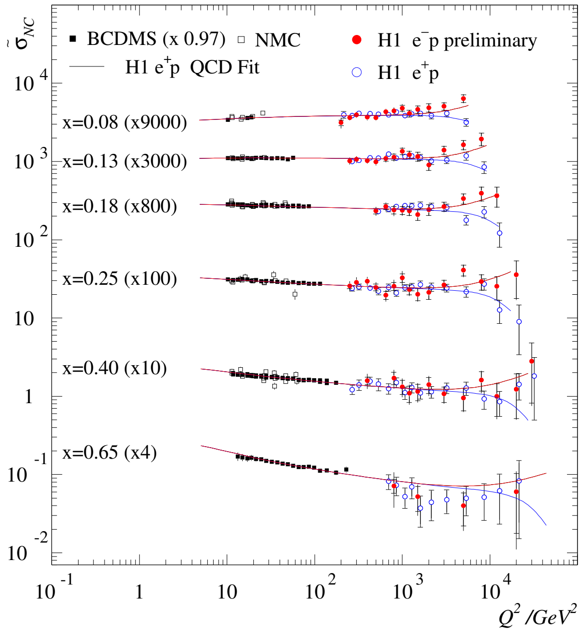

Figure 2. $\tilde{\sigma}_{NC} = (xQ^4)/(2\pi\alpha^2)d^2\sigma^{NC}/dxdQ^2$ for various values of x at high Q^2. The effect of γZ-interference is seen in the different behaviour of the cross sections at large Q^2.

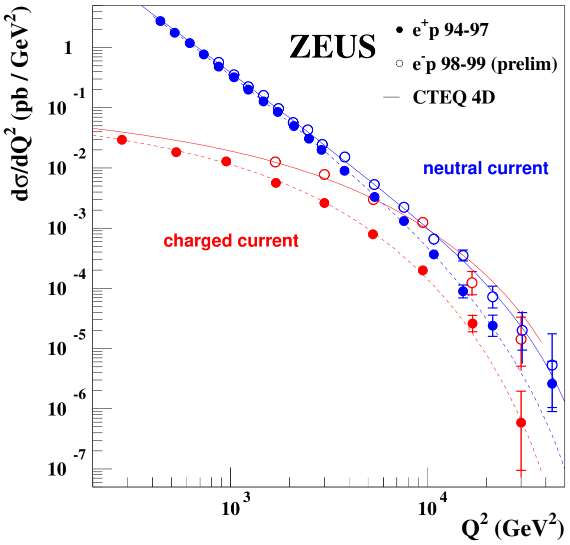

Figure 3. Comparison of the neutral and charged current cross sections for e^-p- and e^+p-scattering as measured in the ZEUS data.

At large Q^2, where the dominance of the photon propagator is diminished, both currents assume roughly equal strength, thus indicating *electroweak unification* at large Q^2. e^-p scattering data are well suited for this comparison, because both currents couple predominantly to the elusive u valence quark in the proton.

4. Helicity Structure of eq-scattering

The weak-isospin dependence of the couplings has been demonstrated in the data of the H1 collaboration at very large Q^2. Written in terms of couplings to individual partons the functions ϕ_{NC} and ϕ_{CC} show a behaviour

$$\phi_{NC} \propto (1+(1-y)^2)\,(4/9u+1/9d) \qquad (3)$$

$$\phi_{CC} \propto 1\times\bar{u}+(1-y)^2\times d \quad \text{for } e^+p \qquad (4)$$

$$\phi_{CC} \propto 1\times u+(1-y)^2\times\bar{d} \quad \text{for } e^-p \qquad (5)$$

where the u and d symbols distinguish *up*- and *down*-type quarks. Fig. 4 shows a marked dependence on the variable $(1-y)^2$, which is related to the scattering angle θ^* in the eq system: in the kinematic region of approximate scaling ($x = 0.13$, c.f. fig. 2) ϕ_{cc} increases almost linearly with $(1-y^2)$ for e^+p while in e^-p scattering the ϕ_{CC} data are well compatible with a large isotropic contribution. The e^+p charged current data exhibit the expected suppression of backward scattering and leave a small "pedestal" of sea quark coupling. The neutral current gives evidence of the more democratic coupling to all spin states.

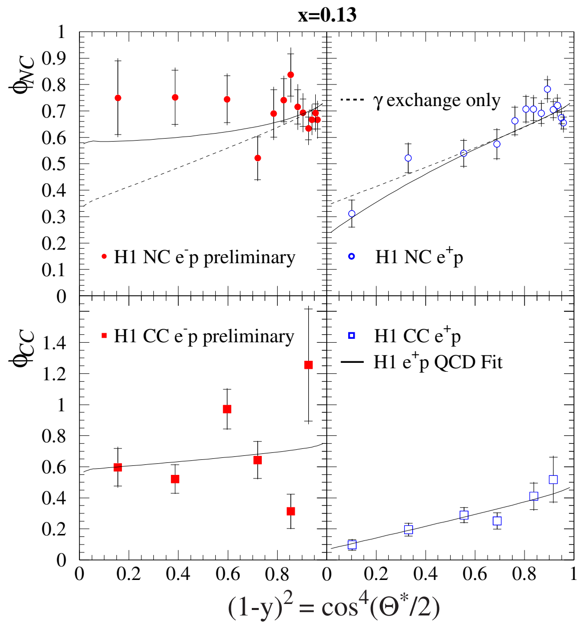

Figure 4. The helicity dependence of the quark density terms ϕ for e^-- and $e^+ - p$ neutral and charged current in the region of approximate scaling ($x = 0.13$).

5. Propagator Mass

The charged current cross section can be analysed in terms of an overall normalisation and a Q^2-dependence. Using the expression of eq. 2 the normalisation G^2_{CC} and the propagator mass can be extracted from a fit of the generalised cross section

$$\frac{\mathrm{d}^2\sigma^{CC}}{\mathrm{d}x\mathrm{d}Q^2} = \frac{G^2_{CC}}{2\pi x}\left(\frac{M^2_{\mathrm{prop}}}{M^2_{\mathrm{prop}} + Q^2}\right)^2 \phi_{CC} \qquad (6)$$

to the measured data. The result is shown in fig. 5.

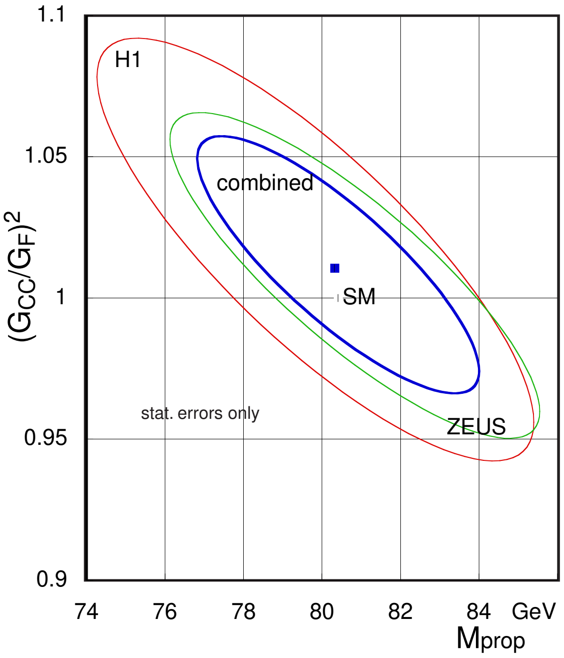

Figure 5. Experimental correlation between normalisation and propagator mass as determined from the HERA data according to eq. 6. The error ellipses include statistical errors only and correspond to $\chi^2 + 1$-contours.

Both experiments find consistent results, which therefore have been averaged. The measurement tests the consistency with the Standard Model (SM) at unprecedentedly small distances of 10^{-3} fm in deep-inelastic scattering. (For the sake of definiteness the uncertainties in the parton distributions of the SM have been ignored). As a figure of merit both experiments have determined the systematic contributions to the measurement for fixed $(G_{CC}/G_F)^2 = 1$ and find for the value of the propagator mass M_{prop}

$$80.9 \pm 3.3(\mathrm{stat.}) \pm 1.7(\mathrm{syst.}) \pm 3.7(\mathrm{pdf}) \qquad \mathrm{H1}$$

$$81.4^{+2.7}_{-2.6}(\mathrm{stat.}) \pm 2.0(\mathrm{syst.})^{+3.3}_{-3.0}(\mathrm{pdf}) \qquad \mathrm{ZEUS}$$

leaving little room for other contributions in the charged current beyond that of the W. Note that together with LEP results reported at this conference [10] the Standard Model has now been tested at very large momentum transfers in the time- and in the space-like region, supporting nicely the well established results of $Q^2 \approx 0$ and leading to a consistent picture of the SM down to a distance of 10^{-3} fm.

6. Acknowledgment

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