Charged Current Interactions and Search for Contact Term Effects at HERA

Friedrich Niebergall
II. Institut für Experimentalphysik
Luruper Chaussee 149
D-22761 Hamburg, Germany

Representing the H1 and ZEUS Collaborations

Abstract

We present preliminary results from H1 and ZEUS on the measurement of charged current interactions. Cross sections are derived by H1 for the reactions $e^- p \rightarrow \nu_e + hadrons$ and $e^+ p \rightarrow \overline{\nu}_e + hadrons$ for transverse momenta above $25\,GeV$. ZEUS compares differential cross section ratios for e^+ and e^- proton scattering. H1 has also searched for effects of contact term interactions in the sample of neutral current deep inelastic scattering events.

1 Introduction

At HERA electrons, (or positrons), of $27.5\,GeV$ collide with protons of $820\,GeV$ to yield a center of mass energy of $\sqrt{s} = 296\,GeV$. Experiments are possible at very high Q^2 values, where electroweak interactions, which manifest themselves by the presence of charged current events, are comparable in strength to ordinary QED effects. High Q^2 is also the domain for the search of new phenomena arising from the exchange of heavy unknown objects. With an integrated luminosity of the order of $3pb^{-1}$ in 1994 a Q^2 range of up to $20000\,GeV^2$ was accessible to these investigations.

2 Charged Current Interactions

The existence of electroweak effects in ep collision was already demonstrated with data taken in 1993[1−4)]. In 1994 HERA was operated (mainly) with positrons which, due to the difference in electroweak coupling, yields event rates for charged current (CC) interactions which are about a factor of 2.5 lower than for electrons and have a correspondingly deteriorated signal to background ratio. (This factor includes acceptance effects). The advantage however is that the two lepton charges allow two independent measurements of the electroweak cross section and provide an increased sensitivity to the quark structure of the nucleon.

Experimentally CC events of the reaction $e + p \to \nu_e +$ *hadrons* have the clear signature of missing transverse momentum $\vec{p}_\perp$ due to the invisibility of the final state neutrino. The cross section is small, of order $50pb$ compared to about $150\mu b$ for the total γp cross section, but it becomes comparable or even bigger than ordinary QED at high values of Q^2 as was nicely demonstrated by the ZEUS result shown last year[2)]. The second experimental tool in addition to searching for events with missing $\vec{p}_\perp$ is therefore the restriction of the search to high values of Q^2, (or $\vec{p}_\perp$ respectively).

For selecting candidate events both experiments, H1 and ZEUS, use missing energy and timing information from calorimeter and track detectors already at the trigger level. The H1 collaboration performs then a two dimensional analysis in comparing the scalar sum of the transverse momentum, $S \equiv \sum_i |\vec{p}_{\perp i}|$ to the vector sum $V \equiv |\sum_i \vec{p}_{\perp i}|$. Here $\vec{p}_{\perp i}$ is determined from the position of the energy clusters in the calorimeter and the interaction point. For momentum balanced events $V \approx 0$ whereas $V \approx S$ for CC events.

H1 requires $V \geq 25\,GeV/c$ and ZEUS $Q^2 \geq 400\,GeV^2$ to retain CC event candidates. Topological criteria are used to reject background from cosmic rays, beam-gas interactions and beam-halo particles and a visual scan is applied to eliminate remaining background. Efficiency corrections are performed by H1 mainly by using events from neutral current deep inelastic scattering, NC, "removing" the electron from the data and applying a weighting function to compensate for differences in the differential distributions for NC and CC events.This procedure is supplemented by Monte Carlo calculations.

The observed event numbers of 41 for e^+ and 12 for e^- running for integrated luminosities of $\mathcal{L} = 2.70 \pm 0.05pb^{-1}$ and $\mathcal{L} = 0.36 \pm 0.01pb^{-1}$ respectively give cross sections of

$$\sigma(e^-p|p_\perp > 25\,GeV) = 46.6 \pm 13.5 \pm 3.5\,pb \quad \sigma(e^+p|p_\perp > 25\,GeV) = 21.9 \pm\ 3.4 \pm 2.0\,pb$$

Combined with 14 events observed in the e^- data of 1993 and taking into account common systematics we obtain $\sigma(e^-p|p_\perp > 25\,GeV) = 50.6 \pm 10.9\,pb$ and for the ratio R_e of the two measured cross sections

$$\frac{\sigma(e^+p|p_\perp > 25\,GeV)}{\sigma(e^-p|p_\perp > 25\,GeV)} = 0.43 \pm 0.11$$

In figure 1 the results are compared to predictions. (See also ref. 5).

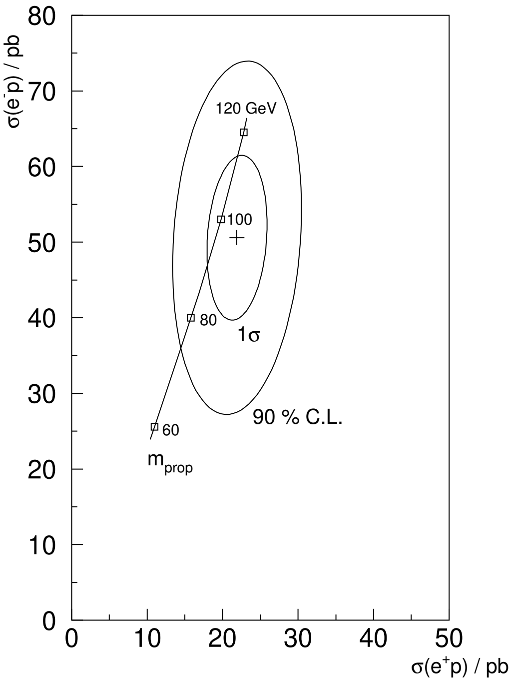

Figure 1: *The measured e^-p and e^+p cross sections compared with the predicted cross section as a function of the W propagator mass (m_{prop}). The two ellipses correspond to the 39.4 % (1-σ) and 90 % CL contours.*

ZEUS uses Monte Carlo methods for data and acceptance corrections and obtains the preliminary result of cross section ratios shown in figure 2, which illustrates also the very different dependence of $d\sigma/dQ^2$ for NC and CC events comparing e^+p and e^-p collisions.

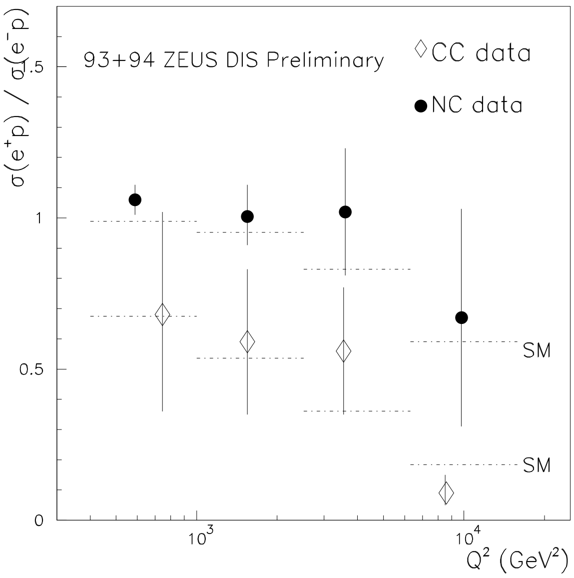

Figure 2: *Ratio of the differential cross sections for e^+ over that for e^- proton collisions for CC and NC interactions compared to the Standard Model predictions (SM)*

3 Contact Interactions

The virtual exchange of a new heavy particle in ep collisions would manifest itself by interference effects with the Standard Model γ, Z fields[6)]. If the mass m_x of the particle is large compared to the energy, ($m_x \geq 350\,GeV$ at HERA), the exchange can be described by adding a point-like four-fermion interaction to the Standard Model Lagrangian. The H1 collaboration tried to find an effect of such a term by measuring the inclusive differential cross section $\frac{d\sigma}{dQ^2}$ for $e^{\pm}p \to e^{\pm}X$ and searching for deviations from the SM cross section at high Q^2.

Events were selected in which the final state electron was detected in the liquid argon calorimeter in the angular range of $10° \leq \Theta_e \leq 150°$ with a transverse energy of more than 8 GeV. Constraints were imposed on longitudinal and transverse momentum balance and the event vertex position and the range in inelasticity was limited to $0.05 < y < 0.80$. (This latter restriction avoids regions of high radiative corrections). Kinematic variables were then calculated from the energy $E_{e'}$ and angle Θ_e of the final state electron as $Q^2 = 4E_eE_e' \cos^2(\Theta_e/2)$ and $y = 1 - (E_e'/E_e)\sin^2(\Theta_e/2)$. Distributions were corrected by a high statistics Monte Carlo calculation which simulated resolution and detector effects on the level of four-vectors.

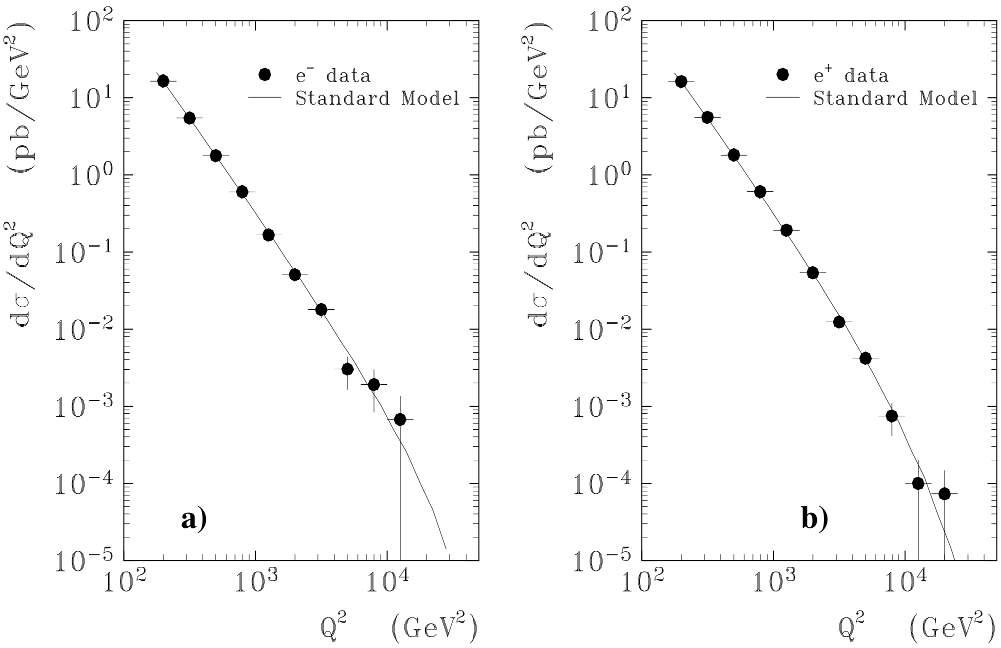

Figure 3: Differential cross sections $d\sigma/dQ^2$ normalized to the Standard Model expectation versus Q^2 for $e^-\,p$ and $e^+\,p$ data (•).

Results are obtained for e^+ and e^- scattering for integrated luminosities of $2.95pb^{-1}$ and $0.92pb^{-1}$ respectively combining data from 1993 and 1994. As shown in figure 3 they are consistent with SM predictions up to Q^2 values of $20000\,GeV^2$. The combined e^+ and e^- data can be used to set lower limits to the mass of leptoquarks as illustrated for a particular example in figure 4. Table 1 shows the results for all leptoquarks for which we obtain significant limits.

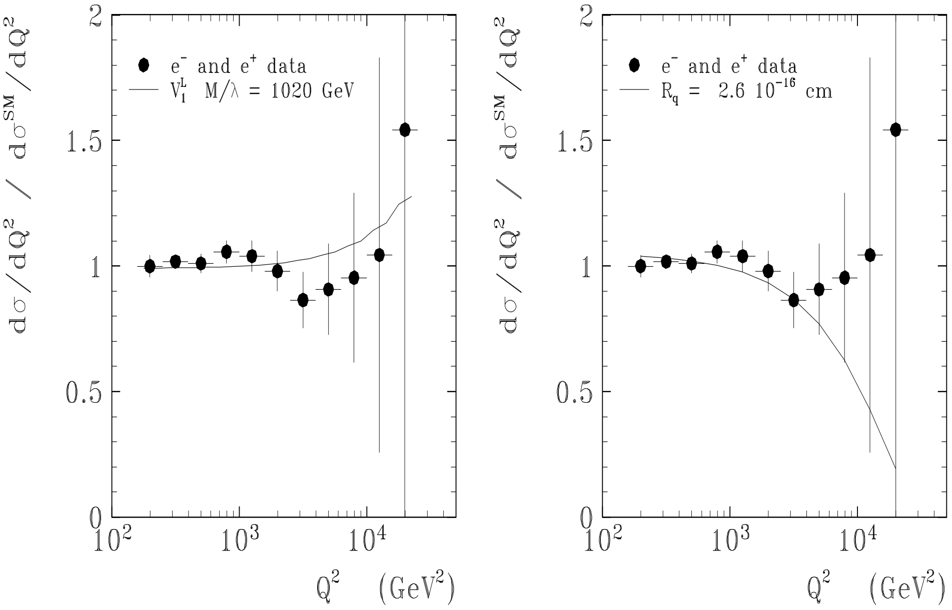

Figure 4: Differential cross sections $d\sigma/dQ^2$ normalized to the Standard Model expectation versus Q^2 for the combined $e^-\,p$ and $e^+\,p$ data (•). The curves show the allowed contribution (95% confidence level) of a vector leptoquark V_1^L with $M_{LQ}/\lambda = 1020\ \ GeV$. [left], and the effect of a form factor with a quark radius $R_q = 2.6 \cdot 10^{-16}\ \ cm$ (95% confidence level)[right].

A possible deviation from the SM cross section may also be caused by the existence of substructure in the particles participating in the reaction. In such a case the additional coupling $\eta_{if} \equiv g^2/\Lambda^2_{if}$, where i, f represent righthanded or lefthanded couplings, can be used as a measure of compositeness. Λ is interpreted as compositeness scale and assuming $g = 1$, (strong coupling), one can set limits on Λ as given in table 2.

An alternative method to study substructure is the interpretation of a possible deviation from the SM cross section by the existence of a form factor $f(q^2) = 1 - 1/6R^2Q^2$. Analyzed in this way the data yield an upper limit at 95% confidence of $R < 2.6 \cdot 10^{-16}\,cm$, which may be interpreted as a limit on the radius of the light quarks since the pointlike nature of the electron is already established to much lower limits. (The results of the contact term analysis can also be found in ref. 7)

4 Conclusion

It was demonstrated that HERA can be used to investigate electroweak physics and the search for phenomena that lead beyond the Standard Model. The results discussed here are still all limited by statistics and will doubtlessly improve by future data taking with the rapidly improving performance of HERA.

leptoquark	coupling to u quark $[GeV^{-2}]$	coupling to d quark $[GeV^{-2}]$	F	M_{LQ}/λ $[GeV]$
S_0^L	$\eta_{LL}^u = -\frac{1}{2}\,(\lambda/M_{LQ})^2$		2	
S_0^R	$\eta_{RR}^u = -\frac{1}{2}\,(\lambda/M_{LQ})^2$		2	
$\tilde{S}_0^R$		$\eta_{RR}^d = -\frac{1}{2}\,(\lambda/M_{LQ})^2$	2	350
$S_{1/2}^L$	$\eta_{LR}^u = -\frac{1}{2}\,(\lambda/M_{LQ})^2$		0	
$S_{1/2}^R$	$\eta_{RL}^u = -\frac{1}{2}\,(\lambda/M_{LQ})^2$	$\eta_{RL}^d = -\frac{1}{2}\,(\lambda/M_{LQ})^2$	0	
$\tilde{S}_{1/2}^L$		$\eta_{LR}^d = -\frac{1}{2}\,(\lambda/M_{LQ})^2$	0	360
S_1^L	$\eta_{LL}^u = -\frac{1}{2}\,(\lambda/M_{LQ})^2$	$\eta_{LL}^d = -1\,(\lambda/M_{LQ})^2$	2	340
V_0^L		$\eta_{LL}^d = +1\,(\lambda/M_{LQ})^2$	0	
V_0^R		$\eta_{RR}^d = +1\,(\lambda/M_{LQ})^2$	0	
$\tilde{V}_0^R$	$\eta_{RR}^u = +1\,(\lambda/M_{LQ})^2$		0	760
$V_{1/2}^L$		$\eta_{LR}^d = +1\,(\lambda/M_{LQ})^2$	2	300
$V_{1/2}^R$	$\eta_{RL}^u = +1\,(\lambda/M_{LQ})^2$	$\eta_{RL}^d = +1\,(\lambda/M_{LQ})^2$	2	710
$\tilde{V}_{1/2}^L$	$\eta_{LR}^u = +1\,(\lambda/M_{LQ})^2$		2	800
V_1^L	$\eta_{LL}^u = +2\,(\lambda/M_{LQ})^2$	$\eta_{LL}^d = +1\,(\lambda/M_{LQ})^2$	0	1020

Table 1: Contact interaction coefficients η_{if}^q, fermion number F and lower limits at 95% confidence level on M_{LQ}/λ for scalar (S) and vector (V) leptoquarks. The leptoquark notation indicates the lepton chirality *L, R* and the weak isospin $I = 0,\ 1/2,\ 1$. The leptoquarks $\tilde{S}$ and $\tilde{V}$ differ by two units of hypercharge from S and V, respectively.

Λ_{LL}^+	Λ_{LL}^-	Λ_{LR}^+	Λ_{LR}^-	Λ_{RL}^+	Λ_{RL}^-	Λ_{RR}^+	Λ_{RR}^-
2.3	1.0	2.5	1.2	2.5	1.2	2.3	1.0

Table 2: Lower limits at 95% confidence level on compositeness scale parameters $\Lambda^\pm$ $[TeV]$ for chiralities *LL, LR, RL* and *RR* with positive and negative interference with the Standard Model currents. The coupling constants are $\pm g^2/\Lambda^{\pm\,2}$ with the convention $g^2/4\,\pi = 1$.

References

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