Contact Interactions: Results from ZEUS and a Global Analysis

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In a search for signatures of physics processes beyond the Standard Model, various *eeqq* vector contact interaction hypotheses have been tested in the ZEUS experiment. No significant evidence of a contact interaction signal has been found. The analysis is based on NC e^+p DIS data corresponding to an integrated luminosity of $47.7\,\mathrm{pb}^{-1}$ and results in 95% CL limits on the effective mass scales Λ ranging from 1.7 to 5 TeV for the different one-parameter contact interaction scenarios considered.

Within the global analysis, including data from other experiments as well, any contact interactions with mass scale below 2.1 TeV are excluded at 95% CL. Combined mass scale limits for specific one-parameter scenarios range from 5.1 to 18 TeV. Upper limits on possible effects to be observed in future HERA, LEP and Tevatron running are estimated. The total hadronic cross-section at LEP and e^-p scattering cross-section at HERA are strongly constrained by existing data, whereas large cross-section deviations are still possible for Drell-Yan lepton pair production at the Tevatron.

1. INTRODUCTION

The HERA *ep* collider has extended the kinematic range available for the study of deep–inelastic scattering (DIS) by two orders of magnitude to values of Q^2 upto about $50000\,\mathrm{GeV}^2$. Measurements in this domain allow new searches for physics processes beyond the Standard Model (SM) at characteristic mass scales in the TeV range. The recent analyses were stimulated in part by an excess of events over the SM expectation for $Q^2 > 20000\,\mathrm{GeV}^2$ reported in 1997 by the ZEUS [1] and H1 [2] collaborations, for which electron-quark contact interactions (CI) have been suggested as possible explanations.

2. CONTACT INTERACTIONS

Four-fermion contact interaction is an effective theory, which allows us to describe, in the most general way, possible low energy effects coming from "new physics" at much higher energy scales. This includes the possible existence of second-generation heavy weak bosons, leptoquarks as well as electron and quark compositeness [3,4]. As strong limits beyond the HERA sensitivity have already been placed on the scalar and tensor terms [4], only the vector *eeqq* contact interactions are considered in this study. They can be represented as additional term in the Standard Model Lagrangian [4]:

$$L_{CI} = \epsilon \frac{g^2}{\Lambda^2} \sum_{i,j=L,R} \eta^{eq}_{ij} (\bar{e}_i \gamma^\mu e_i)(\bar{q}_j \gamma_\mu q_j) \qquad (1)$$

where the sum runs over electron and quark helicities, ϵ is the overall sign of the CI Lagrangian, g is the coupling, and Λ is the effective mass scale. Helicity and flavour structure of contact interactions is described by set of parameters η^{eq}_{ij}. Since g and Λ always enter in the combination g^2/Λ^2, we fix the coupling by adopting the convention $g^2 = 4\pi$. In the ZEUS analysis 30 specific CI scenarios are considered. Assumed relations between different couplings are listed in Table 1. Each line in the table represents two scenarios, one for $\epsilon = +1$ and one for $\epsilon = -1$. For the models VV, AA, VA and X1 to X6 all quark flavours are assumed to have the same contact interaction couplings and each of the η^{eq}_{ij} is either zero or ± 1. For the U1 to U6 models only couplings of up-type quarks (u and c) are considered.

The global analysis combining data from different experiments (see sections 4 and 5) also takes into account three less constrained models, in which different couplings can vary independently. The **General Model** assumes that contact interactions couple only electrons to u and

Table 1
Coupling structure and the 95% CL limits on the effective mass scales for different one-parameter contact interaction models. Results from the ZEUS analysis based on high-Q^2 e^+p NC DIS data are compared to results based on the combined electron/muon NC data (global analysis not assuming SU(2) invariance) and those corresponding to all available data (global analysis with SU(2) universality).

					ZEUS analysis		Global analysis			
Model	Couplings				e^+p NC DIS data		e/μ NC data		All data	
	η^{eq}_{LL}	η^{eq}_{LR}	η^{eq}_{RL}	η^{eq}_{RR}	Λ^-_{min} [TeV]	Λ^+_{min}	Λ^-_{min} [TeV]	Λ^+_{min}	Λ^-_{min} [TeV]	Λ^+_{min}
VV	+	+	+	+	5.0	4.7	9.8	10.7	9.6	11.4
AA	+	−	−	+	2.6	2.5	10.5	10.1	9.9	11.1
VA	+	−	+	−	3.7	2.6	6.6	6.2	6.3	8.0
X1	+	−			2.8	1.8	8.7	8.1	8.1	9.5
X2	+		+		3.1	3.4	8.2	8.4	7.8	9.6
X3	+			+	2.8	2.9	9.9	10.2	9.5	11.1
X4		+	+		4.3	4.0	5.7	5.2	6.0	5.4
X5		+		+	3.3	3.5	5.9	6.4	6.2	6.4
X6			+	−	1.7	2.8	6.2	5.8	6.2	5.8
U1	+	−			2.6	2.0	6.4	7.7	7.9	17.0
U2	+		+		3.9	4.0	6.9	9.1		
U3	+			+	3.5	3.7	8.5	11.7	8.6	18.2
U4		+	+		4.8	4.4	5.1	5.5		
U5		+		+	4.2	4.0	6.4	8.8	7.1	8.8
U6			+	−	1.8	2.4	7.0	5.6		

d quarks (8 independent couplings). All other couplings (for s, c, b, t, μ, τ) are assumed to vanish. The model with **Family Universality** assumes lepton universality ($e{=}\mu$) and quark family universality ($u{=}c$ and $d{=}s{=}b$). There are also 8 independent couplings. In a model assuming $\mathbf{SU(2)_L \times U(1)_Y}$ gauge invariance, the number of free model parameters is reduced from 8 to 7 ($\eta^{eu}_{RL}{=}\eta^{ed}_{RL}$). In this model the $eeqq$ contact interaction couplings can be also related to $\nu\nu qq$ and $e\nu qq'$ couplings [5].

3. ZEUS ANALYSIS

This analysis [6] is based on $47.7\,\mathrm{pb}^{-1}$ of NC e^+p DIS data collected by the ZEUS experiment in 1994-97. Monte Carlo simulation, event selection, kinematic reconstruction, and assessment of systematic effects is that of the NC DIS analysis described in [7]. The event sample used in the CI analysis is limited to $0.04 < x < 0.95$, $0.04 < y < 0.95$ and $Q^2 > 500\,\mathrm{GeV}^2$.

A cross-section increase at highest Q^2, corresponding to the direct "new physics" contribution, is expected for most CI scenarios, as shown in Figure 1. At intermediate Q^2 a moderate increase or decrease due to CI-SM interference terms is possible. As the helicity structure of new interactions can be different from that of the Standard Model, also the differential cross-section $d\sigma/dx$ (for fixed Q^2) is modified. Sensitivity to many CI scenarios is significantly improved by considering the two-dimensional event distribution.

The ZEUS CI analysis compares the distributions of the measured kinematic variables with the corresponding distributions from a MC simulation of $e^+p \rightarrow e^+X$ events reweighted to simulate the CI scenarios. An unbinned log–likelihood technique is used to calculate $L(\epsilon/\Lambda^2)$ from the individual kinematic event coordinates (x_i, y_i):

$$L(\epsilon/\Lambda^2) = -\sum_{i\in\mathrm{data}} \log p(x_i, y_i; \epsilon/\Lambda^2)\,, \qquad (2)$$

where the sum runs over all events in the selected data sample and $p(x_i, y_i; \epsilon/\Lambda^2)$ is the probability

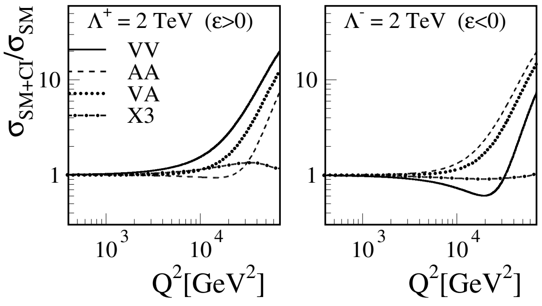

Figure 1. Examples of the relative influence of a CI on the e^+p NC DIS cross-section $d\sigma/dQ^2$.

that an event i observed at (x_i, y_i) results from the model described by coupling ϵ/Λ^2. L tests the shape of the (x,y)–distribution but is independent of its absolute normalisation.

The best estimates, $\Lambda_\circ^\pm$, for the different CI scenarios are given by the positions of the respective minima of $L(\epsilon/\Lambda^2)$ for $\epsilon=\pm1$. All results are consistent with the Standard Model, the probability that the observed values of $\Lambda_\circ^\pm$ result from the Standard Model does not fall below 16%. The 95% C.L. lower limits Λ_{min} on the effective mass scale Λ are defined as the mass scales for which MC experiments have a 95% chance to result in $\Lambda_\circ$ values smaller than that observed in data. The lower limits on Λ ($\Lambda^\pm_{min}$ for $\epsilon=\pm1$) are summarized in Table 1. The Λ limits range from 1.7 to 5 TeV.

4. GLOBAL ANALYSIS

The global analysis [8] of *eeqq* contact interactions combines relevant data from different experiments: ZEUS and H1 high-Q^2 NC DIS results; Tevatron data on high-mass Drell-Yan lepton pair production; LEP2 results on the hadronic cross-section $\sigma(e^+e^- \rightarrow q\bar{q}(\gamma))$, the heavy quark production ratios R_b and R_c, and the forward-backward asymmetries A^b_{FB}, A^c_{FB}, A^{uds}_{FB}; data from low-energy eN and μN scattering and from atomic parity violation (APV) measurements.

For models assuming $SU(2)_L \times U(1)_Y$ universality, additional constraints come from HERA e^+p CC DIS results, data on νN scattering, unitarity of the CKM matrix and electron-muon universality.

The combined data are consistent with the Standard Model predictions. The mass scale limits Λ^-_{min} and Λ^+_{min} obtained from fitting one-parameter models to all available data are summarized in Table 1. For models not assuming $SU(2)_L \times U(1)_Y$ universality (only e/μ NC data used) the mass limits range from 5.1 to 11.7 TeV. With $SU(2)_L \times U(1)_Y$ universality (using also νN and CC data) the limits extend up to about 18 TeV.

Limits for single couplings derived in multi-parameter models (of Section 2) are weaker than in the case of one-parameter models, as no relation between separate couplings is assumed. The mass limits obtained for the general model range from 2.1 to 5.1 TeV. All limits improve significantly and reach 3.5 to 7.8 TeV for the SU(2) model with family universality.

Taking into account possible correlations between couplings, any contact interaction with a mass scale below 2.1 TeV (3.1 TeV when SU(2) universality is assumed) is excluded at 95% CL.

5. PREDICTIONS

Likelihood function for the possible cross-section deviations from the Standard Model predictions is calculated as the weighted average over all contributing CI coupling combinations [8]. The results for HERA, in terms of the 95% C.L. limit bands on the ratio of predicted and the Standard Model cross-sections as a function of Q^2, are shown in Figure 2, for the general model and the SU(2) model with family universality.

The allowed increase in the integrated e^+p NC DIS cross-section for $Q^2 > 15{,}000$ GeV^2 is about 40% for the general model and about 30% for the SU(2) model. In order to reach the level of statistical precision which would allow to confirm a possible discrepancy of this size, the HERA experiments would have to collect e^+p integrated luminosities of the order of 100-200 pb^{-1} (depending on the model). This will be possible after the HERA upgrade planned for year 2000.

Constraints on possible deviations from the Standard Model predictions are much stronger in

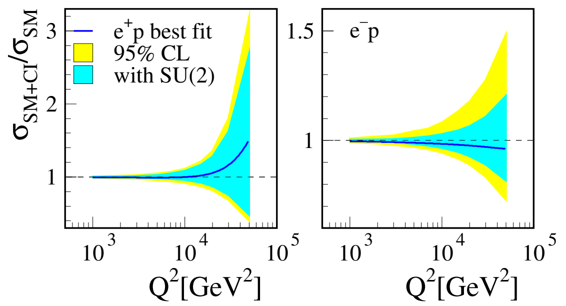

Figure 2. The 95% CL limit band on the ratio of predicted to the Standard Model cross-section for e^+p and e^-p NC DIS scattering at HERA.

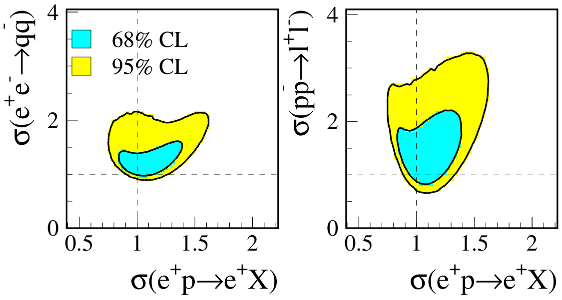

Figure 3. The 68% and 95% CL contours for the possible deviation from the Standard Model predictions, for e^+p NC DIS cross-section at HERA, at Q^2 = 30,000 GeV^2, total $e^+e^- \to q\bar{q}$ cross-section at $\sqrt{s}$ = 400 GeV and Drell-Yan lepton pair production cross-section at the Tevatron, at M_{ll} = 500 GeV, as indicated on the plot. The limits are calculated using the SU(2) contact interaction model with family universality.

the case of e^-p NC DIS. For the general model deviations larger than about 20% are excluded for Q^2 >15,000 GeV^2, whereas for the SU(2) model with family universality the limit goes down to about 7%. In such a case it would be very hard to detect contact interactions in future HERA e^-p running. However, for scattering with 60% longitudinal e^-_R polarisation, the maximum allowed deviations increase to 28% and 19%, respectively, and significant effects could be observed already for integrated luminosities of the order of 120 pb^{-1}.

For the hadronic cross-section at LEP, for $\sqrt{s}\sim 200$ GeV, the possible deviations from the Standard Model are only about 8%. However, significant deviations are still possible for the heavy quark production ratios R_c and R_b, and for the forward-backward asymmetries A^c_{FB} and A^b_{FB}. Significant cross-section deviations will be possible in the Next Linear Collider (NLC), for $\sqrt{s} > 300$ GeV. The largest cross-section deviations from the Standard Model predictions are still allowed at the Tevatron. For Drell-Yan lepton pair production, deviations of the cross-section at M_{ll}=500 GeV up to a factor of 5 are still not excluded.

In Figure 3 relations between possible cross-section deviations at HERA, NLC and the Tevatron are presented. There are no clear correlations between different experiments. All experiments should continue to analyse their data in terms of possible new electron-quark interactions, as constraints resulting from different processes are, to large extent, complementary.

REFERENCES

1. The ZEUS Collaboration, J.Breitweg et al., Z. Phys. **C74** (1997) 207.
2. The H1 Collaboration, C.Adloff et al., Z. Phys. **C74** (1997) 191.
3. R.Rückl, Phys. Lett. **B129** (1983) 363. E.Eichten, K.Lane, M.Peskin, Phys. Rev. Lett. **50** (1983) 811.
4. P.Haberl, F.Schrempp, H.U.Martyn, in *Proc. Workshop Physics at HERA*, ed. W. Buchmüller and G.Ingelman, Hamburg 1991, Vol. 2, pg. 1133.
5. V. Barger, K. Cheung, K. Hagiwara, D. Zeppenfeld Phys. Rev. **D57** (1998) 391.
6. The ZEUS Collaboration, J.Breitweg et al., DESY 99-058, submitted to Euro.Phys.J. **C**.
7. The ZEUS Collaboration, J.Breitweg et al., DESY 99-056, submitted to Euro.Phys.J. **C**. R.Pawlak, *ZEUS High Q^2 e^+p and e^-p Cross Sections,* these proceedings.
8. A.F.Żarnecki, IFD-02/99, hep-ph/9904334, submitted to Euro.Phys.J. **C**.