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# Search for Contact Interactions at HERA

H1 Collaboration

**Abstract**

The measured differential cross section $\mathrm{d}\sigma/\mathrm{d}Q^2$ of the neutral current reaction $e^+p \to e^+$ hadrons is compared to the Standard Model expectation and analyzed to search for $(\bar{e}\,e)(\bar{q}\,q)$ contact interactions. No significant deviation is observed and limits on lepton–quark compositeness scales, virtual leptoquark exchange and form factors are presented.

**Abstract: 157 f**
**Parallel session: 7**
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# 1 Introduction

In deep inelastic scattering $e^+p \to e^+$ hadrons any new currents or heavy bosons may produce indirect effects through the interference of a *virtual* particle exchange with the $\gamma$ and $Z$ fields of the Standard Model. For particle masses well above the available production energy, such indirect signatures may be investigated by searching for a 4–fermion pointlike $(\bar{e}\, e)(\bar{q}\, q)$ contact interaction. The Contact Interaction Lagrangian [1] including only vector-vector terms contains 8 coupling coefficients $\eta^q_{if}$ where the indices $i, f = \{L, R\}$ denote the left–handed and right–handed fermion helicities and $q = \{u, d\}$. The general ansatz [1] can be applied to any new phenomena, e. g. $(e\, q)$ compositeness, leptoquarks or new gauge bosons, by an appropriate choice of the coupling coefficients. Possible deviations of the measured cross section from the Standard Model are analyzed in terms of contact interactions. Figure 1 shows the measured differential cross section $\mathrm{d}\sigma/\mathrm{d}Q^2$ [2], which is well described over six orders of magnitude by the Standard Model expectation. Choosing different parton distributions CTEQ4D, MRST and GRV 94 [3] for the cross section calculation, does not change the shape of the $Q^2$ spectrum significantly, but rather the normalisation by up to 1.2%.

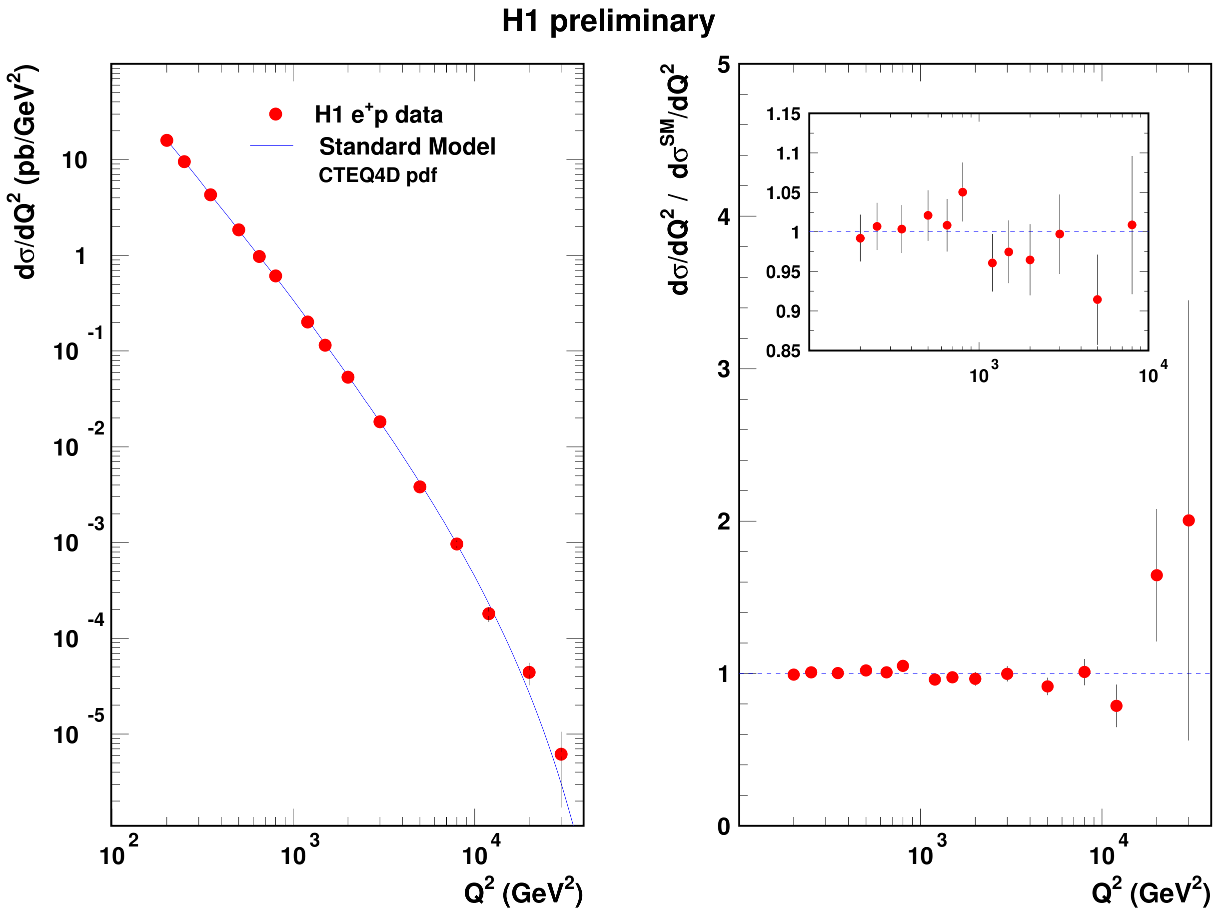


Figure 1: Differential NC cross section $\mathrm{d}\sigma(e^+p \to e^+X)/\mathrm{d}Q^2$. Preliminary H1 data (•) are compared with the Standard Model expectation (—) using the CTEQ4D parton distributions. The errors represent statistics and uncorrelated experimental systematics. The overall normalisation uncertainty of 1.8% is not included.

## 2 Compositeness Scales

A possible fermion compositeness or substructure can be expressed by the coupling coefficients $\eta_{if} \equiv \pm g^2/{\Lambda^{\pm}_{if}}^2$, where the signs indicate positive and negative interference with the Standard Model currents. The coupling strength is conventionally chosen as $g^2 = 4\pi$ and $\Lambda$ denotes the compositeness scale. Both $u$ and $d$ quarks are assumed to contribute with the same scale.

The results of the $\chi^2$ fits for different chiral structures are compiled in table 1. The dominant correlated systematic errors, i. e. the experimental uncertainty of the lepton energy scale, the scattering angle and the theoretical uncertainty due to the uncertainty of $\alpha_s$, are taken into account in the fit procedure. The pure chiral couplings prefer negative interference respectively negative values of $\eta$ as a consequence of the trend of the data being slightly low compared to the Standard Model prediction around $Q^2 \simeq 5,000\ \mathrm{GeV}^2$ followed by an upward fluctuation at higher $Q^2$. The $LR$ model, shown in figure 2, gives the best description of the data. However, the couplings $\eta/4\pi$ for all investigated chiral structures are compatible with the Standard Model within two standard deviations.

**H1 Preliminary**

| coupling | $\Lambda^+$ [TeV] | $\Lambda^-$ $[TeV]$ |
|---|---|---|
| LL | 2.3 | 1.2 |
| LR | 3.0 | 1.5 |
| RL | 3.0 | 1.5 |
| RR | 2.3 | 1.2 |
| VV | 5.0 | 1.9 |
| AA | 2.0 | 3.4 |
| VA | 2.6 | 2.6 |
| LL+RR | 3.1 | 1.3 |
| LR+RL | 4.1 | 1.8 |

Table 1: Lower limits at 95% confidence level on compositeness scale parameters $\Lambda^{\pm}$ for various chiral models

Limits on the compositeness scale parameters are derived by fitting $\Lambda^+$ and $\Lambda^-$ with the appropriate interference signs and taking the corresponding changes in $\chi^2$ with respect to the fit to the Standard Model. The most conservative values obtained from a variation of the parton distributions are quoted.

The limits on compositeness scale parameters $\Lambda$ vary between 1.2 TeV and 5.0 TeV depending on the chiral structure of the model. The data are more sensitive to the $VV$, $AA$ and $VA$ models, where all chiral couplings contribute with different relative signs. In general the limits of $\Lambda^+$ are more restrictive compared to $\Lambda^-$ due to the preference of negative interference.

## 3 Leptoquarks

Leptoquarks are colour triplet bosons of spin 0 or 1, carrying lepton ($L$) and baryon ($B$) number and fractional electric charge. The leptoquark mass $M_{LQ}$ and its coupling $\lambda$ is related to the con-

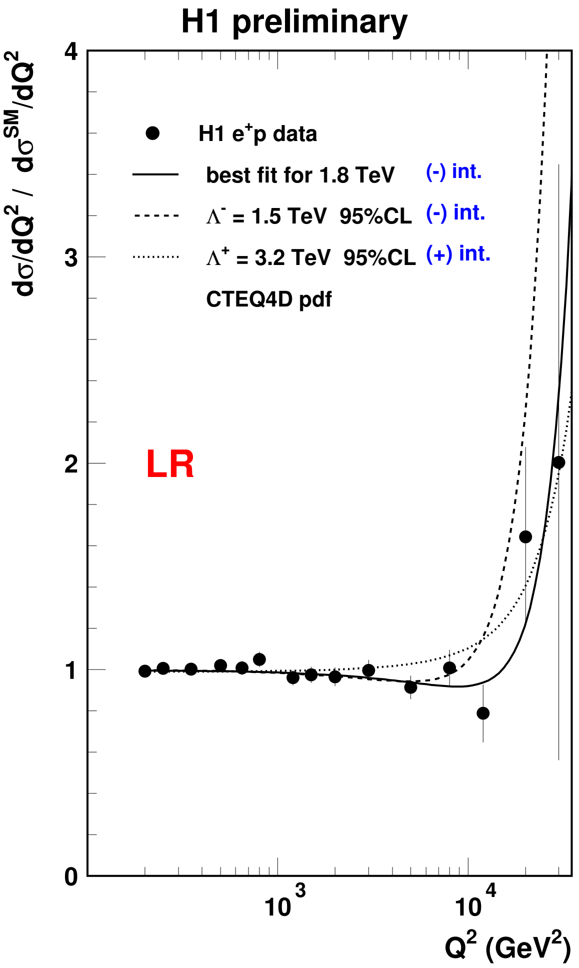


Figure 2: NC cross section $\mathrm{d}\sigma/\mathrm{d}Q^2$ normalised to the Standard Model expectation using CTEQ4D parton distributions. Preliminary H1 data (•) compared to the best fit (—) and contributions from limits $\Lambda^+$ and $\Lambda^-$ of the LR model. The errors represent statistics and uncorrelated experimental systematics without the overall normalisation uncertainty of $1.8\%$.

tact interaction coefficients $\eta^q_{if} = c^q_{if}(\lambda/M_{LQ})^2$. The notation [1] and the coupling coefficients $\eta_{if}$ for leptoquarks are given in table 2.

The differential cross section analysis shows no evidence for a virtual leptoquark exchange. The resulting lower limits on $M_{LQ}/\lambda$, which is the only unknown parameter, is summarized in table 2. They include all experimental systematics and represent the most conservative values obtained from a variation of different parton densities. In general vector leptoquarks which couple to $u$ quarks with positive interference provide the most restrictive limits of $M_{LQ}/\lambda \sim \mathcal{O}(1.0\ \mathrm{TeV})$. It should be emphasized that upper bounds on the coupling strength $\lambda$ can only be set for leptoquark masses exceeding the accessible center of mass energy of HERA. Masses around 300 GeV are excluded for almost all types of leptoquarks with a coupling of $\lambda \gtrsim 1$. Complementary limits from direct leptoquark searches at HERA can be found elsewhere [5].

# 4 Form Factors

An alternative method to study possible fermion substructures is to assign a finite size of radius $R$ to the leptons and/or quarks [6]. A convenient parametrization is to introduce in a 'classical'

| H1 Preliminary | | | | |
|---|---|---|---|---|
| leptoquark | coupling to $u$ quark $[\mathrm{GeV}^{-2}]$ | coupling to $d$ quark $[\mathrm{GeV}^{-2}]$ | $F$ $3B+L$ | $M_{LQ}/\lambda$ [GeV] |
| $S_0^L$ | $\eta_{LL}^u = +\frac{1}{2}\,(\lambda/M_{LQ})^2$ | | 2 | 598 |
| $S_0^R$ | $\eta_{RR}^u = +\frac{1}{2}\,(\lambda/M_{LQ})^2$ | | 2 | 554 |
| $\tilde{S}_0^R$ | | $\eta_{RR}^d = +\frac{1}{2}\,(\lambda/M_{LQ})^2$ | 2 | 202 |
| $S_{1/2}^L$ | $\eta_{LR}^u = -\frac{1}{2}\,(\lambda/M_{LQ})^2$ | | 0 | 294 |
| $S_{1/2}^R$ | $\eta_{RL}^u = -\frac{1}{2}\,(\lambda/M_{LQ})^2$ | $\eta_{RL}^d = -\frac{1}{2}\,(\lambda/M_{LQ})^2$ | 0 | 308 |
| $\tilde{S}_{1/2}^L$ | | $\eta_{LR}^d = -\frac{1}{2}\,(\lambda/M_{LQ})^2$ | 0 | 416 |
| $S_1^L$ | $\eta_{LL}^u = +\frac{1}{2}\,(\lambda/M_{LQ})^2$ | $\eta_{LL}^d = +1\,(\lambda/M_{LQ})^2$ | 2 | 385 |
| $V_0^L$ | | $\eta_{LL}^d = -1\,(\lambda/M_{LQ})^2$ | 0 | 655 |
| $V_0^R$ | | $\eta_{RR}^d = -1\,(\lambda/M_{LQ})^2$ | 0 | 547 |
| $\tilde{V}_0^R$ | $\eta_{RR}^u = -1\,(\lambda/M_{LQ})^2$ | | 0 | 299 |
| $V_{1/2}^L$ | | $\eta_{LR}^d = +1\,(\lambda/M_{LQ})^2$ | 2 | 345 |
| $V_{1/2}^R$ | $\eta_{RL}^u = +1\,(\lambda/M_{LQ})^2$ | $\eta_{RL}^d = +1\,(\lambda/M_{LQ})^2$ | 2 | 859 |
| $\tilde{V}_{1/2}^L$ | $\eta_{LR}^u = +1\,(\lambda/M_{LQ})^2$ | | 2 | 952 |
| $V_1^L$ | $\eta_{LL}^u = -2\,(\lambda/M_{LQ})^2$ | $\eta_{LL}^d = -1\,(\lambda/M_{LQ})^2$ | 0 | 400 |

Table 2: Coupling coefficients $\eta_{if}^q$, fermion number $F$ and 95% cl lower limits on $M_{LQ}/\lambda$ for scalar (S) and vector (V) leptoquarks. The notation indicates the lepton chirality *L, R* and weak isospin $I = 0,\ 1/2,\ 1$. $\tilde{S}$ and $\tilde{V}$ differ by two units of hypercharge from $S$ and $V$. (Sign errors of the coupling coefficients for the $F = 2$ scalar leptoquarks and the $F = 0$ vector leptoquarks in ref [1] are corrected [4].)

way form factors $f(Q^2)$ at the gauge boson–fermion vertices, which depend on the squared momentum transfer $Q^2$

$$f(Q^2) \;=\; 1 - \frac{1}{6}\,R^2\,Q^2\ .$$

A finite extension of a lepton or quark is expected to diminish the Standard Model cross section at high $Q^2$ according to

$$\frac{d\sigma}{dQ^2} \;=\; \frac{d\sigma^{SM}}{dQ^2}\,f_e^2(Q^2)\,f_q^2(Q^2)\ .$$

The data are analyzed in terms of a single form factor, yielding as an upper limit at 95% confidence level a radius of

$$R \;<\; 1.9\cdot 10^{-16}\ \mathrm{cm}\ .$$

This result may be interpreted as a limit on the light quark sizes, since the pointlike nature of the electron is already established down to much lower distances in $e^+\,e^-$ and $(g-2)_e$ experiments [7]. Figure 3 shows the effect of a form factor with a quark radius $R_q$ given by the experimental limit; again the sensitivity rises with $Q^2$.

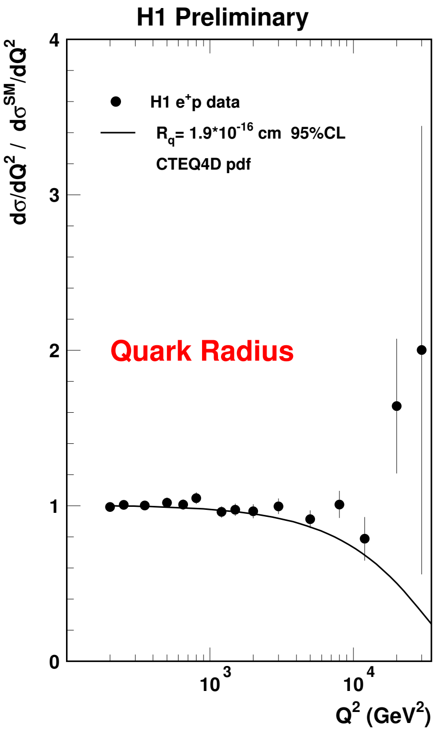


Figure 3: NC cross section $\mathrm{d}\sigma/\mathrm{d}Q^2$ normalised to the Standard Model expectation using CTEQ4D parton distributions. Preliminary H1 data (•) are compared to the effect of a form factor with a quark radius $R_q = 1.9 \cdot 10^{-16}$ cm (—). The errors represent statistics and uncorrelated experimental systematics without the overall normalisation uncertainty of $1.8\%$.

# References


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[2] H1 Collaboration, *'Measurement of Inclusive Cross Sections for Neutral and Charged Current Interactions at High $Q^2$'*, paper # 533 submitted to ICHEP 98, Vancouver.

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[7] see e.g. reviews by T. Kinoshita and D.R. Yennie, H.-U. Martyn, and R.S. van Dyck Jr. in *'Quantum Electrodynamics'*, ed. T. Kinoshita, World Scientific (1990).