Vol. 33 (2002) *ACTA PHYSICA POLONICA B* No 11

SEARCHES FOR CONTACT INTERACTIONS AT HERA*

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(Received June 27, 2002)

During the years 1994–2000 the HERA ep collider has been running with electrons and positrons at center-of-mass energies $\sqrt{s} = 300$–320 GeV. The reaction $ep \to eX$ is sensitive to new physics at mass scales in the TeV range. Contact interaction analyses of the data at high momentum transfer $Q^2 = 200$–$50000\,\mathrm{GeV}^2$ performed by the H1 and ZEUS collaborations are presented here, investigating compositeness models, leptoquarks, quarks of finite size and large extra dimensions.

PACS numbers: 13.60.Hb, 13.90.+i

1. Introduction

At very high momentum transfer Q^2 the process of deep inelastic scattering $ep \to eX$ is probing electron-quark reactions at very short distances. This has been utilised to look for sub-structures of these particles and other effects from physics beyond the standard model with the ZEUS and H1 experiments at the HERA collider [1, 2]. Here updates of these analyses will be presented, making use of all data available at present.

The HERA ep storage ring has been running at two different centre-of-mass energies and with different polarities of the lepton beam. The two collider experiments H1 and ZEUS have both collected about $100\,\mathrm{pb}^{-1}$ in e^+p collisions and $16\,\mathrm{pb}^{-1}$ in e^-p collisions. The e^+p data was recorded at two different centre-of-mass energies, 300 and 320 GeV, where the major part of the data was collected at the higher energy. The centre-of-mass energy of the e^-p data is 320 GeV.

To study contact interaction type models the process $e^{\pm}p \to e^{\pm}X$ is investigated at high momentum transfer Q^2. Both ZEUS and H1 compare single differential cross-section measurements $\frac{d\sigma}{dQ^2}$ to the standard model

* Presented at the X International Workshop on Deep Inelastic Scattering (DIS2002) Cracow, Poland, 30 April–4 May, 2002.

prediction. No significant deviation from the standard model is found and the data are further compared to contact interaction scenarios. Limits on the relevant parameters of these models are derived on 95% confidence level.

2. Contact interactions

Contact interactions between electrons and quarks can be introduced by adding four-fermion interactions to the Standard Model Lagrangian $\mathcal{L}_{\rm SM}$

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \mathcal{L}_{\rm CI}, \quad \mathcal{L}_{\rm CI} = \sum_q \sum_{a,b={\rm L,R}} \eta^q_{ab} (\bar{e}_a \gamma_\mu e_a)(\bar{q}_b \gamma^\mu q_b)$$

with model-dependent coupling constants η^q_{ab} [3].

2.1. Compositeness scale

To investigate general models with fermion substructure it is convenient to introduce a dimensionless coupling $g^2 = 4\pi$ and a universal compositeness scale Λ. The contact interaction couplings then take the form $\eta^q_{ab} = \varepsilon^q_{ab} \frac{4\pi}{\pm \Lambda^2}$, with $\varepsilon^q_{ab} = \pm 1, 0$ fixing the chiral structure of the new interaction. Several models have been considered by H1 and ZEUS. Limits Λ^+ and Λ^- are derived for each model, reflecting the two choices $\pm\Lambda^2$ (positive or negative interference with the Standard Model). Fig. 1 shows the H1 data normalised to the Standard Model expectation and the curves excluded at 95% confidence level for the VV model (all coefficients $\varepsilon^q_{ab} = +1$). The data is shown separately for e^-p and e^+p scattering. The limits on Λ^+ and Λ^- obtained by the H1 and ZEUS collaborations for various models are depicted in Fig. 2.

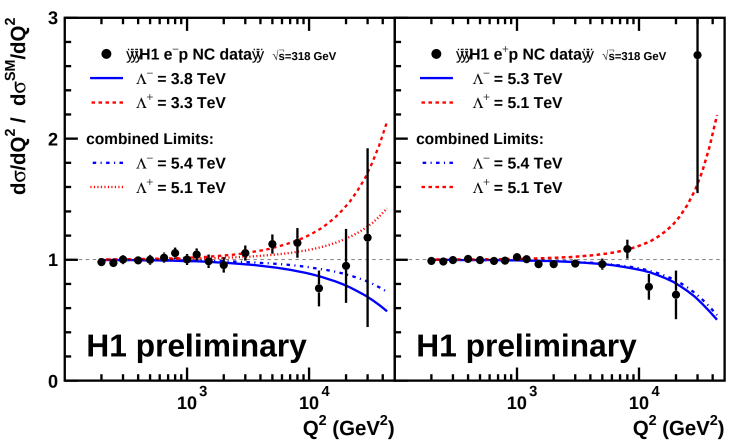

Fig. 1. H1 data points and excluded curves for a VV type contact interaction.

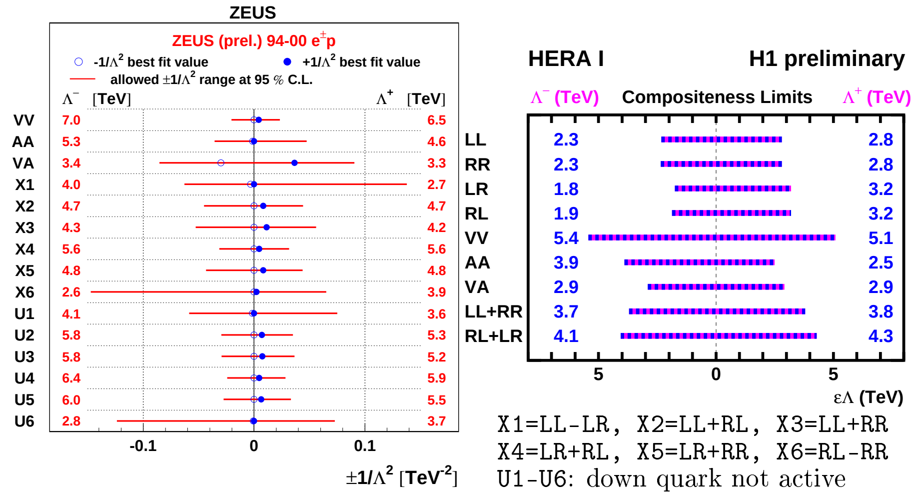

Fig. 2. Limits on the compositeness scale Λ obtained by ZEUS and H1

2.2. Leptoquarks

Leptoquarks appear in some extensions of the Standard Model. They couple to lepton-quark pairs. For high leptoquark masses M_{LQ} they show up as a contact interaction with coupling coefficients $\eta^q_{ab} = \varepsilon^q_{ab}(\lambda^2/M^2_{\mathrm{LQ}})$. Within the generic model described in [4] there exist 14 different types of leptoquarks, with fixed relations ε^q_{ab} [5] and a coupling constant λ. Each leptoquark is either a scalar or a vector particle and has a well-defined fermion number $F = 3B + L$, where B and L are the usual baryon and lepton number. The 95% confidence level limits found for the quantity M_{LQ}/λ are summarised in Table I for the 14 possible leptoquark types, valid for masses $M_{\mathrm{LQ}} \gg 300\,\mathrm{GeV}$.

TABLE I

Limits on M_{LQ}/λ for contact interactions mediated by leptoquarks.

Prel. limits on $\frac{M}{\lambda}$ [GeV]				Prel. limits on $\frac{M}{\lambda}$ [GeV]			
Leptoquark type	F	ZEUS	H1	Leptoquark type	F	ZEUS	H1
S_0^{L}	2	750	720	V_0^{L}	0	690	770
S_0^{R}	2	690	670	V_0^{R}	0	580	640
$\tilde{S}_0^{\mathrm{R}}$	2	310	330	$\tilde{V}_0^{\mathrm{R}}$	0	1030	1000
S_1^{L}	2	550	480	V_1^{L}	0	1420	1380
$S_{1/2}^{\mathrm{L}}$	0	910	870	$V_{1/2}^{\mathrm{L}}$	2	490	420
$S_{1/2}^{\mathrm{R}}$	0	690	370	$V_{1/2}^{\mathrm{R}}$	2	1150	940
$\tilde{S}_{1/2}^{\mathrm{L}}$	0	500	430	$\tilde{V}_{1/2}^{\mathrm{L}}$	2	1260	1020

2.3. Squarks in R_p violating supersymmetry

In R_p violating supersymmetric models squarks can couple to a lepton-quark pair. There are two possible types of couplings, $ed \to \tilde{u}$ with coupling λ'_{1j1} and $eu \to \tilde{d}$ with coupling λ'_{11k}. Here $\tilde{u}$ stands for an up-type squark of generation j and $\tilde{d}$ for a down-type squark of generation k. The squark couplings are identical to those obtained for the leptoquark types $\tilde{S}^{\mathrm{L}}_{1/2}$ and S^{L}_0, respectively. If the flavour-diagonal R-parity violating decay dominates over other decay channels, the corresponding limits on mass over coupling for squark mediated contact interactions can thus be inferred from Table I.

2.4. Quark radius

Substructure of quarks or electrons may be introduced by assigning a finite size to the electroweak charge distributions. The differential cross-section is modified by introducing electron and quark form factors [6]

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{\mathrm{SM}}}{dQ^2} f_e^2(Q^2) f_q^2(Q^2), \quad f(Q^2) = 1 - \frac{\langle r^2 \rangle}{6} Q^2 .$$

Two types of models are often considered: point-like electrons ($f_e \equiv 1$) or common form factors of quarks and electrons $f_e \equiv f_q$. Results are expressed in terms of a particle size $R = \sqrt{\langle r^2 \rangle}$. Figure 3 shows the ZEUS data normalised to the Standard model prediction and the curve expected for a model with $R_q = 0.73 \times 10^{-3}$ fm. The limits obtained by the H1 and ZEUS collaborations are summarised in Table II.

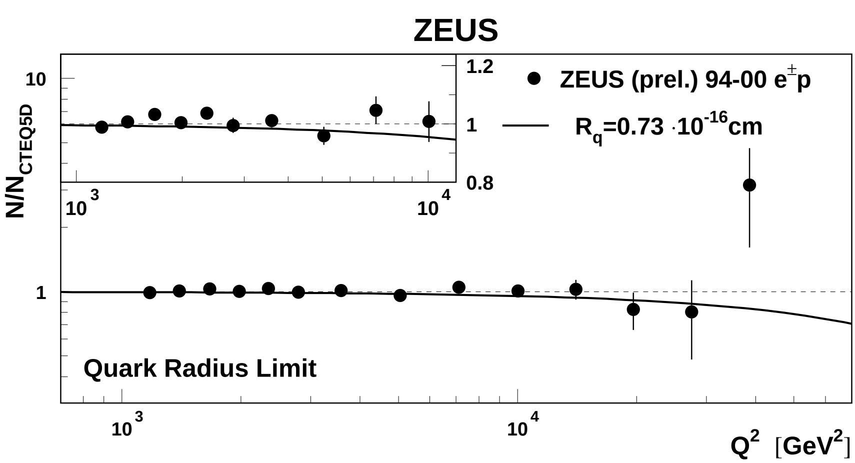

Fig. 3. ZEUS data and excluded curves for quarks with finite size.

TABLE II

Limits on the fermion radius R.

ZEUS prel. ($f_e \equiv 1$)	H1 prel. ($f_e \equiv 1$)	H1 prel. ($f_e \equiv f_q$)
$R_q < 0.73 \times 10^{-3}$ fm	$R_q < 0.82 \times 10^{-3}$ fm	$R_{e,q} < 0.57 \times 10^{-3}$ fm

3. Large extra dimensions

In $4+n$ dimensional string theories the gravitational scale M_{S} can be of order TeV. M_{S} is related to the size R of the compactified extra dimensions and the Planck scale M_{P}, $M_{\mathrm{P}}^2 = R^n M_{\mathrm{S}}^{2+n}$. For some models the spin 2 graviton can propagate into the extra dimensions, visible in the 4-dimensional world as a tower of massive Kaluza–Klein states with level-spacing $\Delta m = 1/R$. These can cause sizeable contact-type interactions with a coupling $\eta_G = \lambda/M_{\mathrm{S}}^4$ [7], where λ is a constant of order unity. For the ZEUS and H1 analyses the two cases $\lambda = \pm 1$ are investigated. The 95% confidence limits on M_{S} set by H1 and ZEUS are shown in Table III.

TABLE III

Limits on the gravitational scale M_{S}.

	ZEUS prel.	H1 prel.
$\lambda = +1$	$M_{\mathrm{S}} > 0.81$ TeV	$M_{\mathrm{S}} > 0.83$ TeV
$\lambda = -1$	$M_{\mathrm{S}} > 0.82$ TeV	$M_{\mathrm{S}} > 0.79$ TeV

4. Summary and conclusions

The HERA data collected from 1994 to 2000 has been searched for evidence of contact interactions, showing up in the single-differential cross-section $\frac{d\sigma}{dQ^2}$. No sign of new physics has been found and limits are derived on the compositeness scale Λ (up to 7 TeV) and on leptoquark masses (for coupling $\lambda = 1$ up to 1.4 TeV). For squarks in some R-parity violating SUSY models with coupling $\lambda' = 1$ masses up to 0.75 TeV are excluded. The quark radius is probed down to distances of 0.7×10^{-3} fm and large extra dimensions are excluded up to gravitational scales $M_{\mathrm{S}} < 0.8$ TeV.

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