Search for contact interactions at HERA

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The H1 and ZEUS collaborations at HERA have searched for signatures of physics beyond the Standard Model using high Q^2 neutral current deep inelastic electron-proton and positron-proton scattering events. No significant deviations from Standard Model predictions were observed. Various *eeqq* contact interaction models have been considered. Limits on the compositeness scale in general *eeqq* contact interaction models, mass to the Yukawa coupling ratio for heavy leptoquarks, the effective Planck mass scale in models with large extra dimensions and the effective quark charge radius are presented.

1. INTRODUCTION

The H1 and ZEUS experiments at HERA (DESY, Hamburg) have facilitated the study of electron-proton and positron-proton collisions at center of mass energies of up to 920 GeV. During the HERA I (1994-2000) running phase, about 100 pb^{-1} of data were collected per experiment, most of it coming from e^+p collisions. The collider was upgraded in 2000-2001, allowing for a significant increase of luminosity. During the second phase of running (2002-2007, HERA II), about 400 pb^{-1} of data per experiment were collected. Additionally, spin rotators installed at the H1 and ZEUS interaction regions provided longitudinal electron and positron polarization. With an average lepton beam polarization of about 30-40% and a significant increase of integrated luminosity, particularly for the e^-p sample, HERA II has significantly increased the sensitivity of the experiments to physics beyond the SM.

2. CONTACT INTERACTIONS

New interactions between electrons and quarks involving mass scales above the center-of-mass energy can modify the deep inelastic $e^{\pm}p$ scattering cross sections at high Q^2 via virtual effects, resulting in observable deviations from Standard Model (SM) predictions. Four-fermion contact interactions form an effective theory, one which allows us to describe such effects in the most general way. Vector *eeqq* contact interactions considered at HERA can be represented as an additional term in the SM Lagrangian:

$$L_{CI} = \sum_{i,j=L,R} \eta_{ij}^{eq} (\bar{e}_i \gamma^\mu e_i)(\bar{q}_j \gamma_\mu q_j),$$

where the sum runs over electron and quark helicities, and a set of couplings η_{ij}^{eq} describe the helicity and flavor structure of the contact interactions. Hence various scenarios, with different chiral structures are possible. Another model which may introduce a new interaction between electrons and quarks is one with large extra dimensions [1]. Lastly, an approach to probe quark substructure is by considering quark form-factors which depend on the effective quark radius. The common feature of all these models is that they alter the cross-sections observed in neutral current deep-inelastic scattering (NC DIS) from that expected within the SM. Tests for such deviations have been performed and limits on the model parameters have been derived by H1 and ZEUS [2, 3, 4].

3. RESULTS

For compositeness models, limits on the effective "new physics" mass (or compositeness) scale, Λ, are extracted assuming the relation $\eta = \pm 4\pi/\Lambda^2$. Figure 1 shows the results obtained by the ZEUS experiment for different compositeness models, based on the analysis of 1994-2006 data. Limits on the effective mass scale Λ range from 2.0

up to 8.0 TeV. Corresponding limits obtained by the H1 collaboration, based on the HERA I data only, range from 1.6 to 5.5 TeV [2].

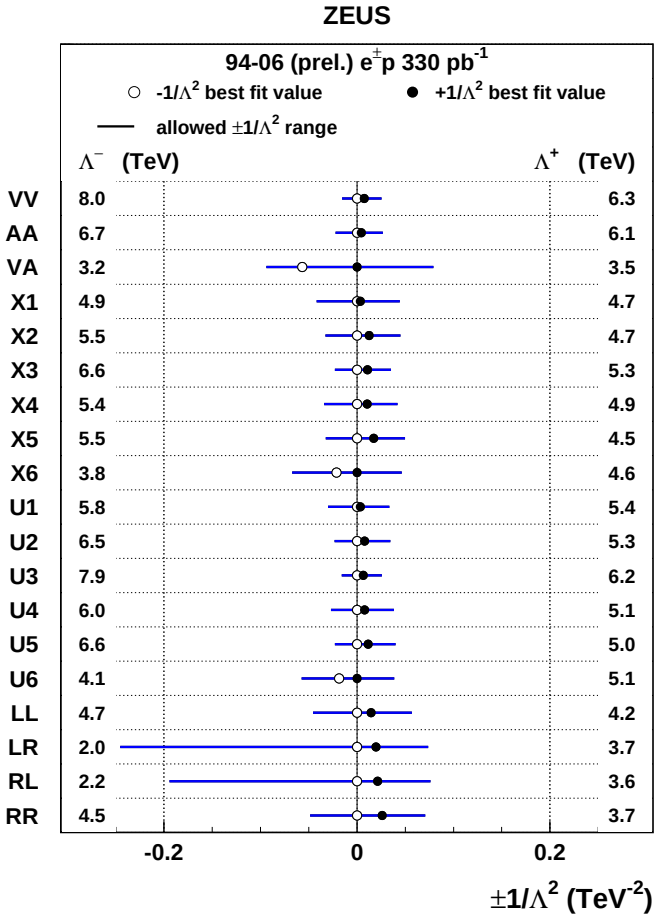

Figure 1: Results for general contact interaction models (compositeness models) obtained using the combined e^+p and e^-p data from ZEUS (1994-2006). Horizontal bars indicate the 95% CL limits on $\eta/4\pi = \varepsilon/\Lambda^2$; values outside these regions are excluded. $\Lambda^{\pm}$ are the 95% CL limits on the compositeness scale for $\varepsilon = \pm 1$.

For the model with large extra dimensions [1], both collaborations have set limits on the effective Planck mass scale M_S. For negative couplings, scales below 0.90 TeV (ZEUS 1994-2006 [4]) and 0.78 TeV (H1 1994-2000 [2]) are excluded at 95% CL. For positive couplings, the limits are 0.88 TeV and 0.82 TeV, respectively. Possible effects of graviton exchange on the Q^2 distribution of NC DIS events, as measured by ZEUS, are shown in Figure 2.

Possible quark substructure can be searched for by measuring the spatial distribution of the quark charge. Using the "classical" form factor approximation and assuming that both the electron and exchanged bosons are point-like, limits on the mean-square radius of the electroweak charge of the quark can be set. From the analysis of the combined HERA I and HERA II datasets, quark radii larger than $0.74 \cdot 10^{-16}$ cm (H1) and $0.62 \cdot 10^{-16}$ cm (ZEUS) have been excluded at 95% CL. Figure 3 shows the H1 data with 95% CL exclusion limits for the effective radius of the quark [5].

In the limit of a large leptoquark mass, $M_{LQ} \gg \sqrt{s}$, contact interactions can also be used to describe the effects of virtual leptoquark production or exchange at HERA. Utilizing the data taken between 1994 and 2006, the ZEUS collaboration has constrained the leptoquark Yukawa coupling for different leptoquark types and masses. Limits on the ratio of the leptoquark mass to Yukawa coupling range from 0.29 to 2.08 TeV. Figure 4 compares the ZEUS indirect limits to H1 exclusion limits (at 95% CL) on the Yukawa coupling of $S_{0,L}$ and $\tilde{S}_{1/2,L}$ leptoquarks as functions of their masses. Also shown are the limits from LEP and the Tevatron.

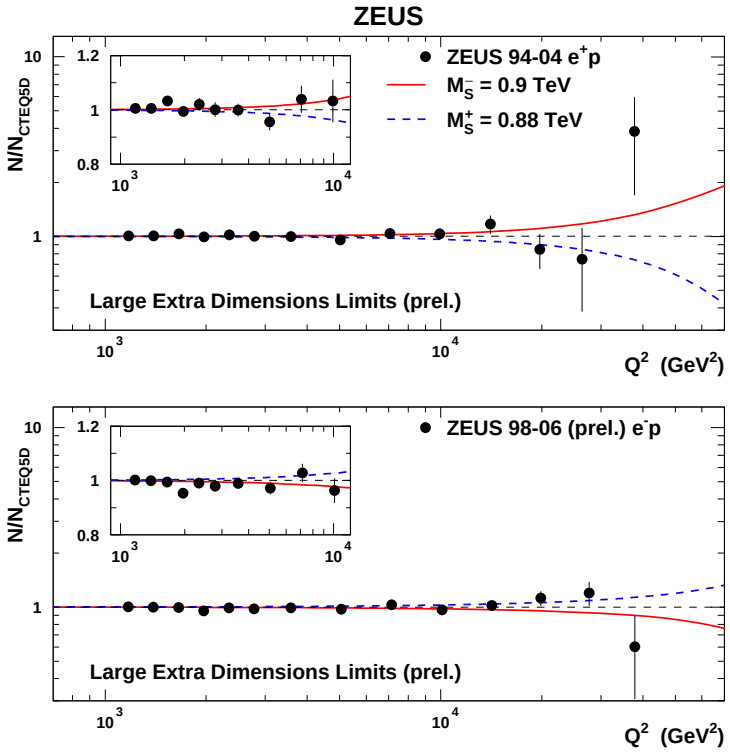

Figure 2: ZEUS data compared with 95% CL exclusion limits for the effective Planck mass scale in models with large extra dimensions for positive (M_S^+) and negative (M_S^-) couplings. Results are normalized to the SM expectations using CTEQ5D parton distributions.

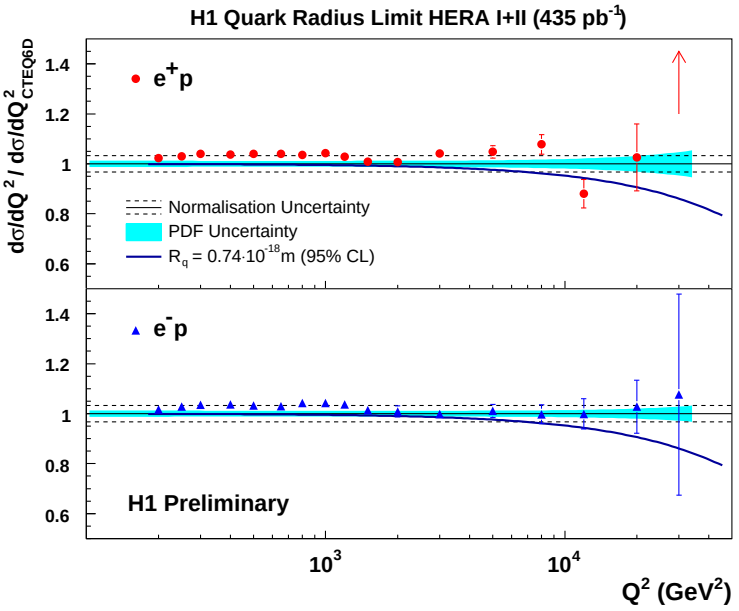

Figure 3: H1 data compared with 95% CL exclusion limits for the effective radius of the quark. Results are normalized to the SM expectations using CTEQ6D parton distributions.

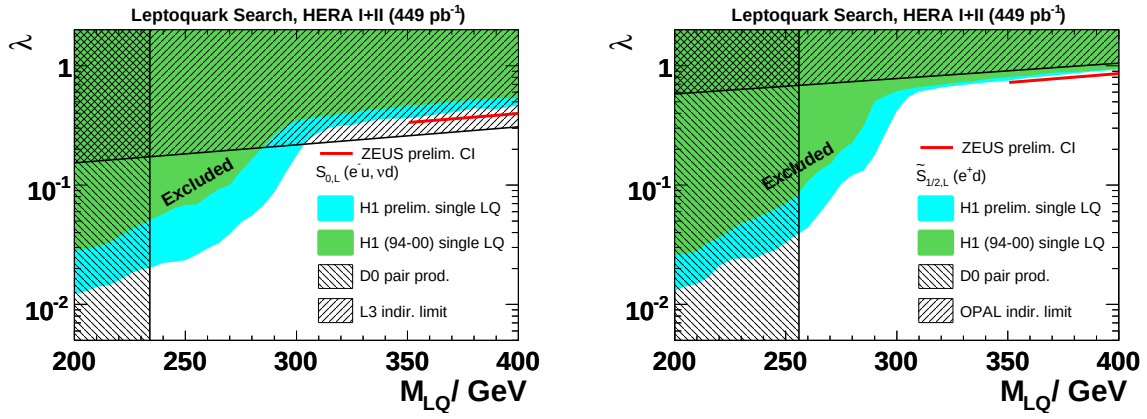

Figure 4: H1 exclusion limits at 95% CL on the coupling as a function of the leptoquark mass for $S_{0,L}$ and $\tilde{S}_{1/2,L}$ leptoquarks [6]. The indirect limits from ZEUS and L3 and the direct D0 limits are shown for comparison.

4. CONCLUSIONS

The high luminosity delivered at HERA in conjunction with lepton beam polarization have opened up a new window for precise EW studies and searches for physics beyond the Standard Model. Measured NC DIS cross sections at high Q^2 are in very good agreement with the SM, hence limits on deviations from the SM could be set within several different models. HERA running has finished, however analyses of large samples of data continue. Updated results can therefore be expected in the near future.

References

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