PROCEEDINGS OF SCIENCE

Search for leptoquarks and contact interactions at HERA

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A search for physics beyond the Standard Model is performed using high-Q^2 deep inelastic $e^{\pm}p$ scattering data, corresponding to a total integrated luminosity of about 0.5 fb^{-1} per experiment, collected with the H1 and ZEUS detectors at HERA. ZEUS derives limits on the effective mass scale in *eeqq* contact interactions, on the ratio of the mass to the Yukawa coupling for heavy-leptoquark models, on the effective Planck-mass scale in models with large extra dimensions and on the quark charge radius. H1 searches for scalar and vector leptoquarks coupling to first and second generation fermions, and sets constraints on leptoquark models.

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1. Introduction

The HERA $e^{\pm}p$ collider (located at DESY, Hamburg) completed its operation in the year 2007, after 15 years of successful running. Protons, with an energy up to 920 GeV, were collided with electron/positrons of energy 27.5 GeV, providing collisions at a centre-of-mass energy $\sqrt{s}$ of up to 319 GeV. The H1 and ZEUS experiments have collected a data sample of a total integrated luminosity of about 0.5 fb^{-1}, the majority of which was taken with longitudinally polarised lepton beams ($P_e \simeq 0.3-0.4$). The neutral current (NC), $e^{\pm}p \rightarrow e^{\pm}X$, and charged current (CC), $e^{\pm}p \rightarrow \nu X$, deep inelastic scattering (DIS) interactions at high virtuality of exchanged bosons, Q^2, at HERA are an ideal environment to study Standard Model (SM) processes as well as search for new phenomena and physics beyond the SM (BSM). This paper reviews the recent results on searches for *eeqq* contact interactions and leptoquarks performed using the full data samples collected by the ZEUS and H1 experiments.

2. Contact interactions

A new current at a TeV scale or a heavy-boson exchange is expected to alter the NC DIS cross sections at high Q^2 through its interference with the γ or Z^0 fields (Fig. 1, left). For particle masses above the available $\sqrt{s}$, new processes may be described in terms of four-fermion *eeqq* contact interactions[1] (Fig. 1, right). Vector *eeqq* contact interactions considered at HERA introduce an additional term in the SM Lagrangian: $\mathscr{L}_{CI} = \sum_{i,j=L,R} \eta_{ij}^{eq} (\bar{e}_i \gamma^{\mu} e_i)(\bar{q}_j \gamma_{\mu} q_j)$, where the sum runs over electron and quark helicities, and the couplings η_{ij} describe the helicity structure of the contact interactions. ZEUS performed a search for *eeqq* contact interactions using NC processes at high Q^2 and the full luminosity of 0.44 fb^{-1}[1]. No deviations from the SM were found (Fig. 2, left) and limits were set assuming different physics scenarios and chiral structure of the contact interactions.

For general models (compositeness models), limits on an effective mass scale of new interactions, Λ (compositeness scale), were extracted assuming the relation $\eta = \pm 4\pi/\Lambda^2$. Fig. 2 (right) shows the results obtained by ZEUS for 19 different compositeness models. The values of Λ below 3.8-8.9 TeV were excluded at 95 % CL, depending on the model. Limits were also set on the effective Planck mass scale, M_S, in a model with large extra dimensions[2], assuming $\eta \propto \pm 1/M_s^4$. Scales below 0.94 TeV were excluded at 95% CL, for positive and negative couplings. Contact interactions can also be used to describe the effects of leptoquark production or exchange at HERA (see section 3), in the limit of high leptoquark mass $M_{LQ} \gg \sqrt{s}$. Assuming $\eta \propto \lambda^2/M_{LQ}^2$, where λ is

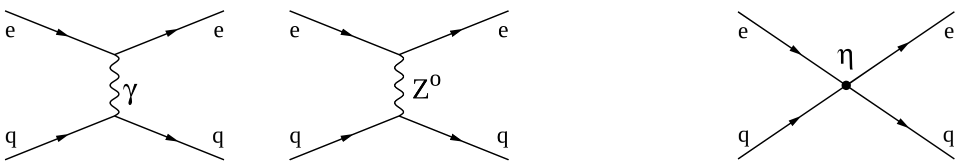

Figure 1: The schematic diagrams of the γ and Z^0 mediated NC DIS processes at HERA (left) and four-fermion *eeqq* contact interactions with the coupling strength η (right).

[1]In analogy to weak interactions which, before $W^{\pm}$ and Z^0 bosons were discovered, were described as four-fermion contact interactions with a Fermi coupling constant $G_F \propto g^2/M_W^2$.

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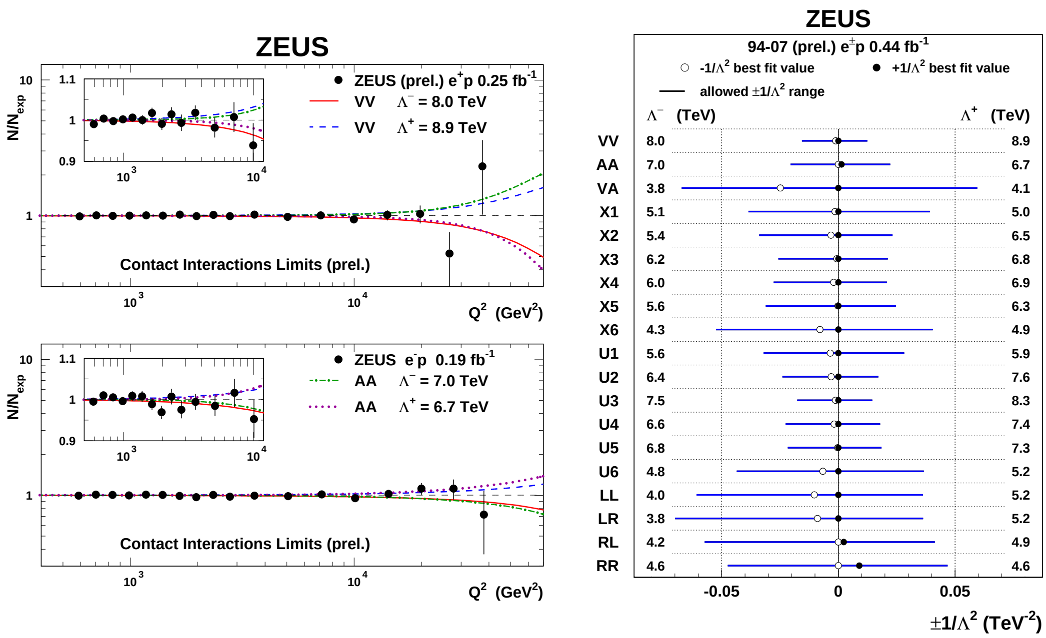

Figure 2: The ZEUS results for general contact interaction models. Left: the NC e^+p and e^-p DIS cross sections as a function of Q^2, compared to SM predictions. Right: Limits for 19 compositeness models: VV, AA, ..., RR. Horizontal bars indicate the 95 % CL limits on $1/\Lambda^2$, values outside the region are excluded.

a Yukawa leptoquark-e-q coupling, 95 % CL limits were set on the ratio $M_{LQ}/\lambda > 0.41$ - 1.88 TeV, depending on the heavy leptoquark type. Also, searches for possible quark substructure were made by measuring a spatial distribution of a quark charge. From a form-factor approximation (assuming the electron is point-like) 95 % CL limits on the mean-square radius of the electroweak charge of the quark were set, excluding quark radii larger than 0.63×10^{-3} fm. Similar limit, 0.74×10^{-3} fm, has been obtained by the H1 collaboration using the full NC data sample[3].

3. Leptoquarks

The H1 collaboration performed a search for leptoquarks (LQs) using NC and CC processes at high Q^2 and the full luminosity of 0.45 fb^{-1}[4]. LQs are hypothetical scalar and vector bosons which connect the lepton and quark sectors of the SM[5]. They are classified in terms of fermion number $F = |3B + L|$, where B and L are the baryon and lepton numbers, respectively. At HERA, LQs may be resonantly produced in the s-channel (for $M_{LQ} < \sqrt{s}$) or exchanged in the u-channel, as shown in Fig. 3. In the search for first generation LQs, the processes $ep \to LQ \to eq$ and $ep \to LQ \to \nu q$ were considered, with final states similar to those of NC and CC DIS interactions. No deviations from the SM expectations in the LQ mass spectra were

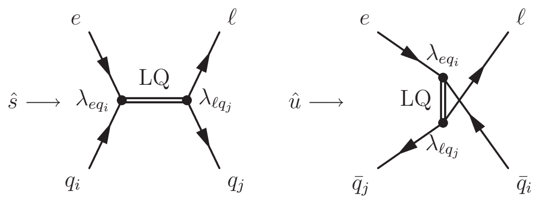

Figure 3: The schematic diagram of LQ production at HERA: s-channel resonant production (left) and u-channel exchange (right), the parameter λ represents a Yukawa LQ-electron-quark coupling.

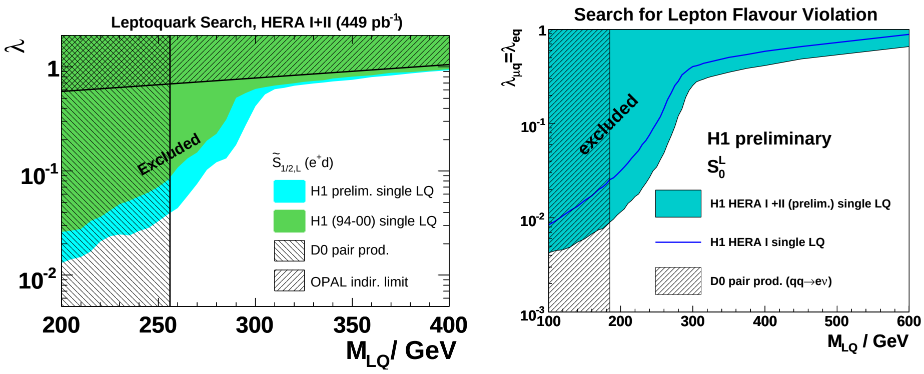

Figure 4: The 95 % CL exclusion limits on the Yukawa coupling λ as a function of the LQ mass for the first generation $\tilde{S}_{1/2,L}$ (left) and the second generation S_0^L (right) leptoquarks. Limits from LEP[7] and Tevatron[8] are also shown for comparison. Recent DØ results[9] are not included in the left plot.

observed and limits were set on the LQ production for all 14 LQ types. Exclusion limits for the $\tilde{S}_{1/2,L}$ LQ are shown in Fig 4 (left) as an example. For a Yukawa coupling with the electromagnetic strength ($\lambda = \sqrt{4\pi\alpha_{em}} = 0.3$), LQ masses below 291-330 GeV were excluded at 95 % CL.

A search for lepton flavor violating (LFV) processes in ep collisions mediated by second generation F = 2 LQs was performed by H1 using the complete set of $e^- p$ data with an integrated luminosity of 158 pb^{-1}[6]. At HERA, the LFV process $eq \to LQ \to \mu q$ may lead to final states with a muon and a hadronic jet. Two such events were observed, in agreement with the SM expectations, and limits were derived for the 7 F=2 LQ types as a function of M_{LQ}. Exclusion limits for the S_0^L LQ are shown in Fig 4 (right) as an example. For a Yukawa coupling with the electromagnetic strength, LFV LQs couplings to a muon-quark pair were excluded for LQ masses below 433 GeV.

4. Summary

Searches for *eeqq* contact interactions and leptoquarks at HERA were performed by the ZEUS and H1 experiment, respectively, using full data samples of about 0.5 fb^{-1}. No evidence for new interactions was found and limits were set in various BSM physics scenarios.

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