SEARCH FOR LEPTOQUARKS AND CONTACT INTERACTIONS WITH ZEUS

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Signals of new physical phenomena have been searched for with the ZEUS detector at HERA using the whole luminosity of 130 pb $^{-1}$ collected in the HERA phase I. No evidence has been found and limits have been set on Leptoquark production, Lepton Flavour Violation processes and Contact Interactions.

Introduction

During the first phase of data taking (HERA I) the HERA accelerator collided 27.5 GeV e^- or e^+ with 820 (920 after 1998) GeV p at a center of mass energy $\sqrt{s}$ of 300 (318 after 1998) GeV and ZEUS collected about 130 pb $^{-1}$ with $e^{\pm}$. Experiments at HERA have studied various processes predicted by the Standard Model (SM). HERA also offers a unique environment to look for the new physics, both for the resonant productions of new particles and for deviations coming from virtual effects.

Leptoquarks

Many extensions of the Standard Model (SM) predict Bosons with both Lepton (L) and Baryon (B) numbers (Leptoquarks, LQs). A widely used model is the phenomenological model of Buchmüller-Rückl-Wyler (BRW) [1]. It assumes invariance under $SU(3)_C \times SU(2)_L \times U(1)_Y$ and conservation of L and B. It contains 14 LQ species (7 scalar and 7 vector); 4 of them ($S_0^L, V_0^L, S_1^L, V_1^L$) decay into both eq and νq. LQs can be classified according to the fermion number F, defined as $F = 3B + L$, which can be either 0 or 2. The model is family diagonal. LQs couple to either left handed or right handed leptons, but not to both, and have fixed branching ratio into $e\nu$ (1, 1/2), νq (0, 1/2). When LQs have masses $M_{LQ} << \sqrt{s}$ resonant production is possible, and it is dominated by s-channel. Such production could occur at HERA from the initial state e and the quark from the proton. $F = 0$ ($F = 2$) LQs are best sought in e^+p (e^-p) collisions, since the production process involves a valence quark in the proton. The resonance shows up as a peak in the x distribution at the value $x_0 = \frac{M^2_{LQ}}{s}$. Let θ^* be the e scattering angle in eq (νq) rest frame; then $y = \frac{1}{2}(1 - cos\theta^*)$. A cut on $cos\theta^*$) allows to enhance the sensitivity to LQ production, as regular Neutral Current (NC) Deep Inelastic Scattering (DIS) has an angular distribution $\frac{d\sigma}{dy} \propto \frac{1}{y^2}$, while for scalar LQs $\frac{d\sigma}{dy}$ is flat in y and for vector LQs $\frac{d\sigma}{dy} \propto (1 - y)^2$. When $M_{LQ} >> \sqrt{s}$, both s- and u-channel contribute, and the process can be represented in terms of contact interactions. ZEUS has looked for resonances decaying into $e - jet$ and into $\nu - jet$ using the

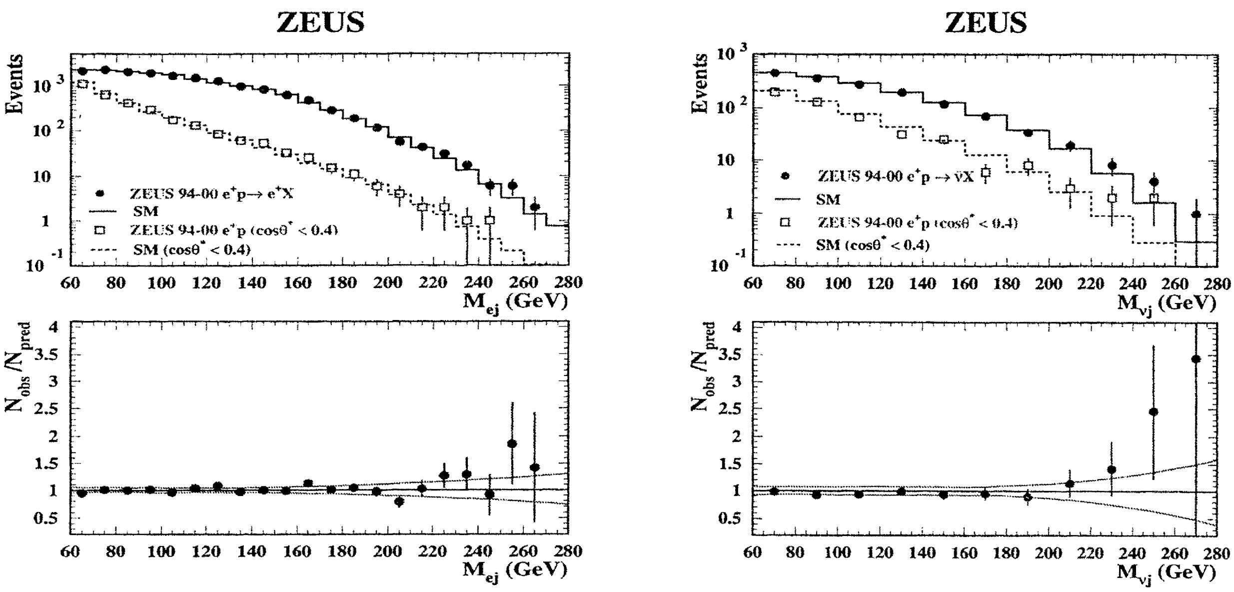

Figure 1: Upper plots: Spectrum of invariant mass (dots) M_{e-jet} (left) and $M_{\nu-jet}$ (right) in e^+p events versus SM expectations before (solid line) and after (dashed) $cos\theta^*$ cut. Lower plots: Ratio of data and SM expectations before the $cos\theta^*$ cut. The shaded area comes from uncertainties on SM expectations

whole integrated luminosity collected at HERA I with $e^{\pm}p$ [2]. No evidence has been found (Fig. 1) and limits have been set on resonantly produced LQs (Fig. 2, where limits from LEP and Fermilab are also shown). ZEUS limits on the Yukawa coupling λ from direct searches improve considerably the LEP limits on the coupling λ for 200 GeV $< M_{LQ} <$ 300 GeV. The right part of Fig. 2 shows the λ limits as function of the branching ratios β_{eq} and $\beta_{\nu q}$, and versus the resonance mass. ZEUS results improve significantly over the D0 limits and have weak β dependence.

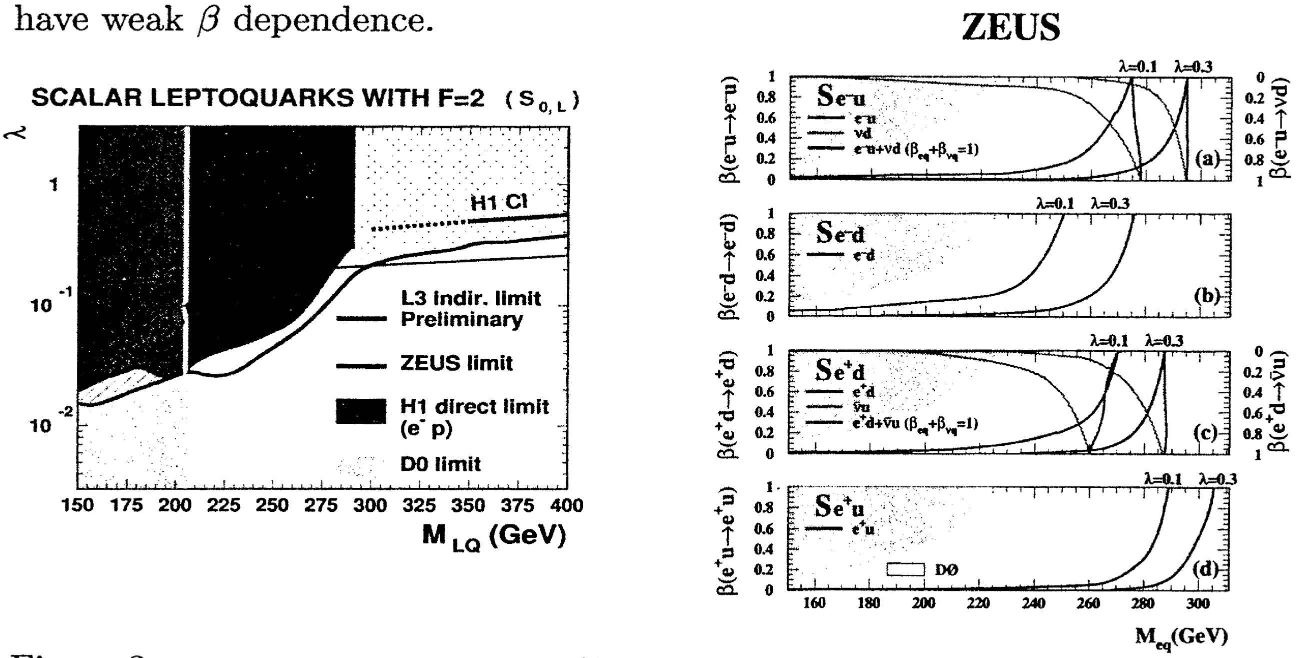

Figure 2: Left : Exclusion limits at 95 % C.L. for the Yukawa coupling λ versus the mass of the scalar LQ S_0^L with $F = 2$. The region above the curve is excluded. Limits from L3 and D0 are also shown. Right: Limits of constant $\lambda = 0.1, 0.3$ for scalar LQs on the branching ratio β versus the LQ mass M_{LQ}. The dotted line comes from Charged Currents only, the dashed line from NC only and the solid line from the combination of both. The shaded area is excluded by D0.

Lepton Flavour Violation

In Lepton Flavour Violation interactions (LFV) the scattered $e^{\pm}$ is replaced by a μ or τ in the final state. Such processes can be mediated by LQs (in family non-diagonal models). The signature for such events is high missing p_t accompanied by an aligned μ or τ. This striking signal has only small background from the SM. ZEUS has analysed the whole HERA I data looking for the LFV μ channel and found no evidence for LFV $ep \to \mu X$ [3]. Limits have been set on the coupling times the square root of the branching ratio $\lambda_{eq_1}\sqrt{\beta_{\mu q}}$ versus the mass M_{LQ} for resonantly produced LQs (Fig 3). Limits have been also set on the four-fermion contact-interaction term $\frac{\lambda_{eq_i}\lambda_{\mu q_j}}{M_{LQ}^2}$ for high mass LQs coupling to different quark generations. For the LFV τ channel the analysis has been performed only on the e^+p data [4]

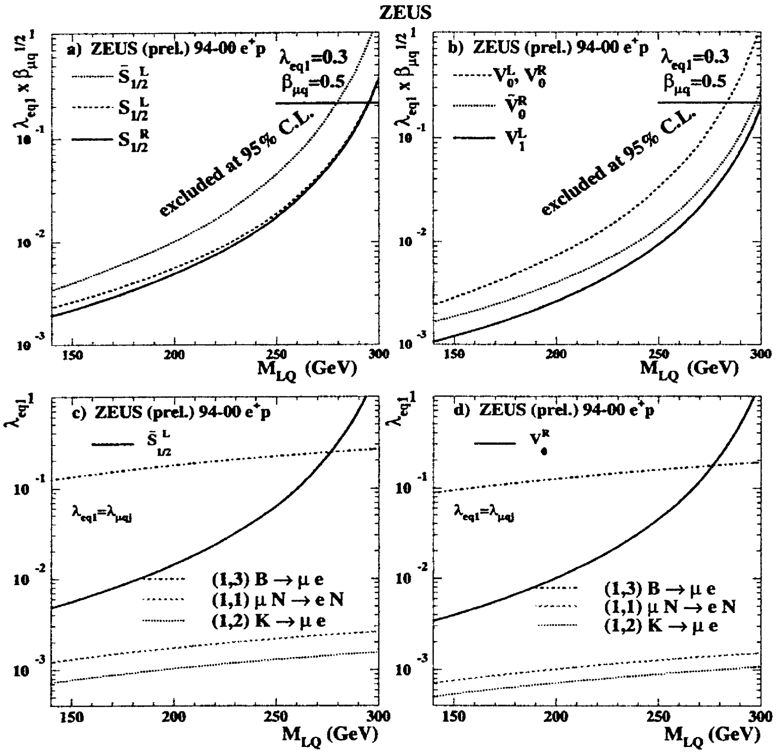

Figure 3: Limits on low mass LQs mediating LFV $ep \to \mu X$. Upper plots: Limits on $\lambda_{eq_1}\sqrt{\beta_{\mu q}}$ for scalar and vector LQs with $F = 0$. Lower plots: Limits on λ for one scalar ($S^{\tilde{L}}_{1/2}$) and one vector (V_0^R) LQ, assuming the same branching ratio to e and μ (solid lines) compared with limits from low energy experiments and and rare decays (other lines).

Contact Interactions

Four-fermion contact interactions (CI) describe effects from processes at much higher scale (exchange of extra gauge bosons or LQs, production of LQs or s-quarks, compositeness, gravitational effects or a finite quark radius). Such effects could alter (enhance) the distributions predicted by the SM at high Q^2 and interfere with the predictions at intermediate Q^2. As scalar and tensor terms are somehow already costrained, we restrict to vector terms and a Lagrangian of the type:

$$L_{CI} = \sum_{\alpha,\beta=L,R}^{q=u,d} \eta^q_{\alpha\beta}(\bar{e}_\alpha\gamma^\mu e_\alpha)(\bar{q}_\beta\gamma_\mu q_\beta),$$

where α and β are helicities (L,R), and q is the quark index. $\eta_{\alpha\beta} = \epsilon\frac{g^2_{CI}}{\Lambda^2}$ define the chiral structure of the model. $g_{CI} = \sqrt{4\pi}$ and $\epsilon = \pm 1$ Comparing NC DIS distributions with the SM expectations ZEUS has set limits on the CI scales for different models [5] (Fig. 4).

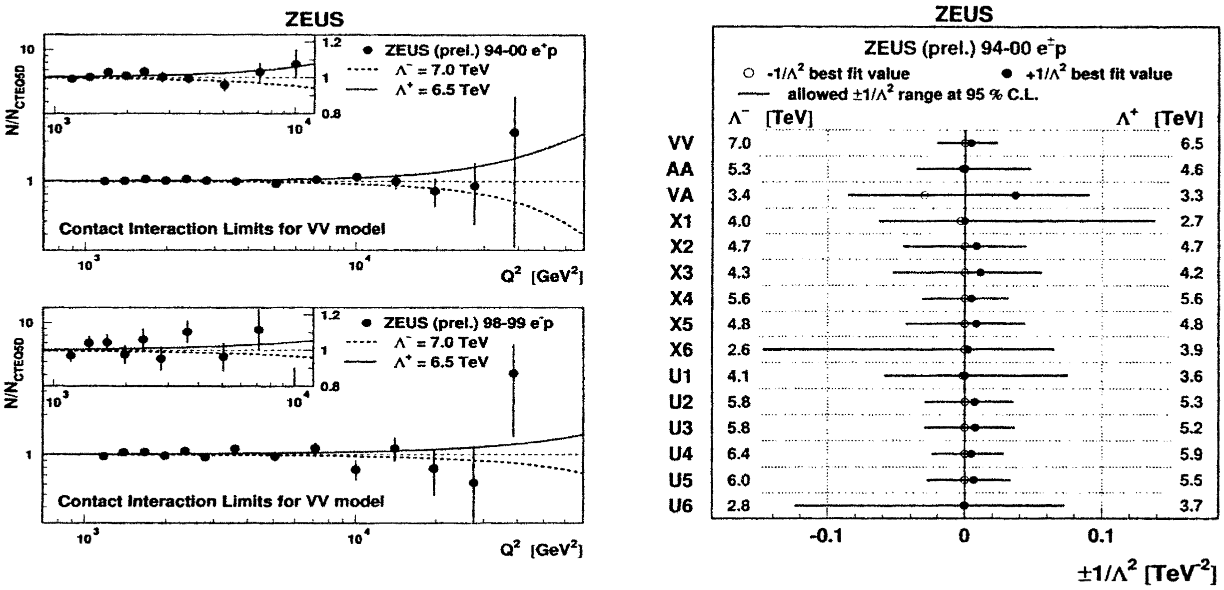

Figure 4: Left: ZEUS NC distributions (normalized to SM predictions using the CTEQ5D set of PDF) (dots) compared to 95 % limit curves for the effective mass scales of the VV (Vector-Vector) CI model for positive (Λ^+) and negative (Λ^-) coupling. Right: ZEUS limits on the compositeness scale Λ from e^-p and e^+p data. Values outside the bars are exluded at 95 % C.L.

Theories that allow for compactified extra-dimensions [6] predict sizeable gravitational effects, via contact interactions terms, if the extra dimensions are large enough. Present constraints from experimental checks on gravity still allow for an extra dimension of size $R \simeq 1$ mm. The order of the effective Planck scale M_S can then be similar to the electroweak scales. The graviton can propagate into the extra dimension, visible in the ordinary 4 dimensions as a Kaluza-Klein tower of excited states with spacing $\Delta m = \frac{1}{R}$. Summing these states up to M_S gives sizeable effects, equivalent to a contact interaction term with $\eta^G = \frac{\lambda}{M_S^4}$ where $\lambda \simeq 1$ [7].
Limits on the scale M_S have been set by ZEUS to $\simeq 0.8$ TeV at 95 % C.L. [5], to be compared with limits of $\simeq 1$ TeV set by LEP and Tevatron. ZEUS has set limits also on another possible source of contact interactions, namely the finite quark radius: $R_q < 0.73 \cdot 10^{-16}$ cm [5] at 95 % C.L.

Conclusions

A search for new physics has been made by ZEUS using the integrated luminosity collected at HERA I and no evidence has been found so far. Limits have been set on Leptoquarks, Lepton Flavour Violation, Contact Interactions (including Large Extra Dimensions and the quark radius). These limits are competitive with or complementary to the ones from LEP and Tevatron. Increased sensitivity for similar searches is expected from the new phase HERA II, taking advantage of the increased luminosity, the upgrade of the detector and of the possibility of having polarized $e^{\pm}$ beams.

References

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