Searches for Exotics at HERA

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Abstract
Searches for contact interactions, leptoquark bosons and excited fermions carried out at the HERA ep collider are presented here. The searches are based on $\sim 40\text{pb}^{-1}$ of e^+p data per experiment collected at a centre of mass energy ~ 300 GeV. First results on e^-p data collected in 1998-1999 are also presented.

1. Contact Interactions

Contact Interactions (CI) can be used to parameterize any new physics process appearing at an energy scale Λ above the centre of mass energy $\sqrt{s}$. At HERA, $eeqq$ four-fermions terms would interfere (constructively or destructively) with the Standard Model (SM) Neutral Current (NC) Deep Inelastic Scattering (DIS), where the incoming lepton interacts with a quark coming from the proton, via the t-channel exchange of a virtual gauge boson, such that the distributions of the Lorentz invariant variables Q^2, x and y (related via $Q^2 = xys$) would be affected.

The H1 [1] and ZEUS [2] Collaborations searched for such distorsions in the full e^+p data collected between 1994 and 1997, using respectively a χ^2 fit of the single differential cross-section $d\sigma/dQ^2$, and a 2-dimensional likelihood analysis in (x, y). Various models (characterizing the structure of the CI) have been constrained and the resulting lower bounds on the scale Λ range for the ZEUS analysis [2] between 1.7 and 5 TeV. In contrast to the more stringent limits obtained by LEP experiments, these bounds do not rely on the flavor symmetry hypothesis. Moreover some models have been considered by ZEUS only.

The CI analysis has been interpreted by the H1 Collaboration in terms of quark radius, applying a multiplicative form factor to the SM $d\sigma/dQ^2$. This leads to an upper limit on the quark radius of 1.9×10^{-16} cm [1].

2. Leptoquarks

Leptoquarks (LQs) are scalar or vector color-triplet bosons, carrying both lepton (L) and baryon (B) numbers, which appear in many extensions of the SM. At HERA, LQs with fermion number $F = 3B + L = 0$ ($F = -2$) could be resonantly produced via a fusion between the incoming positron and a quark (antiquark) coming from the proton.

Assuming in particular that a given LQ couples only to known SM fermions of a given generation, Buchmüller, Rückl and Wyler (BRW) [3] proposed a model in which the LQs decay exclusively into $e+q$ or $\nu + q$, with a branching $\beta_e = \beta(LQ \to eq) = 1$ or 0.5. Relaxing the hypothesis mentioned above, other models can be built, where this branching β_e is a free parameter.

We will first consider LQs coupling to first generation fermions only, henceforth called first generation LQs. The case of Lepton Flavor Violating (LFV) LQs, possessing couplings both to eq and μq or τq pairs, will be addressed in the following paragraph.

2.1. First Generation Leptoquarks

A first generation LQ signal would manifest itself as an excess of NC DIS-like high y events. A search for such LQs has been perfomed by H1 [4] and ZEUS [5] in the framework of the BRW model, using the full e^+ dataset. No significant deviation from the SM has been observed, apart from a slight excess in H1 data for invariant masses around 200 GeV, mainly due to events previously reported in the 94-96 data. The resulting mass-dependent limits on the Yukawa coupling λ of the LQ to the $e - q$ pair are shown in Fig. 1a, for the scalar $F = 0$ LQs of the BRW model. For LQ masses close to or above the kinematic limit, the sensitivity on the signal is provided by the interference of the LQ processes with NC DIS and by the effects of finite LQ width. For a coupling of the electromagnetic strength (i.e. $\lambda = 0.3$), masses below 275 GeV are ruled out at 95% confidence level (CL).

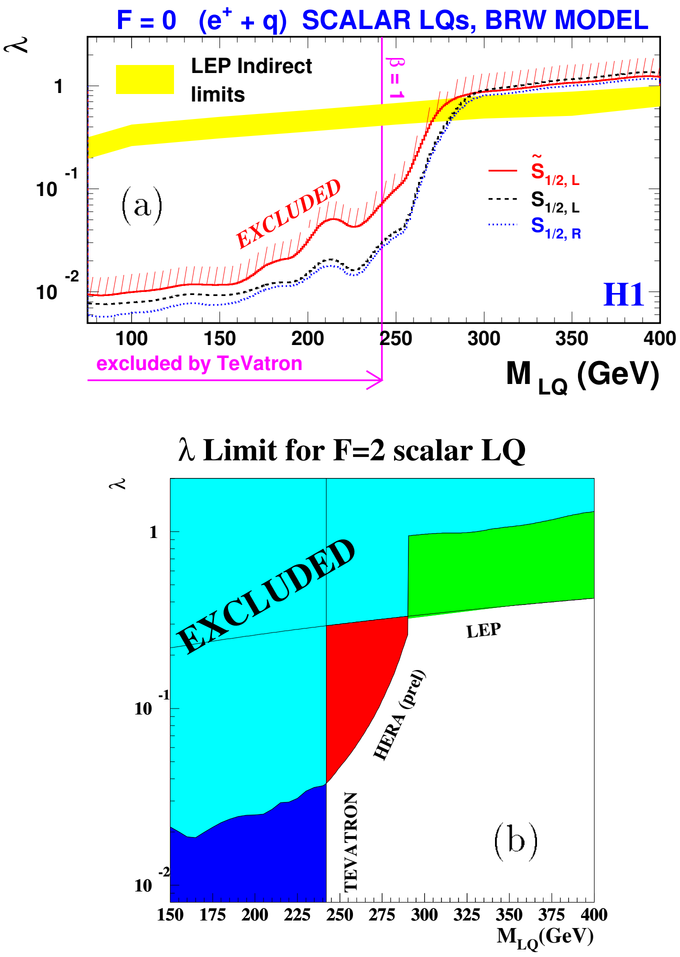

Figure 1. Exlusion limits at 95% CL on the Yukawa coupling λ as a function of the LQ mass, for scalar LQs with fermion number (a) $F = 0$ and (b) $\mid F \mid = 2$. In (b) a typical LQ example ($S_{1,L}$) is shown.

The ZEUS Collaboration [6] also analysed the recent e^- data accumulated between 1998 and 1999 at $\sqrt{s} \sim 320$ GeV, corresponding to an integrated luminosity of $\sim 16\text{pb}^{-1}$. No deviation from the SM has been observed and constraints on $\mid F \mid = 2$ LQs have been set. The sensitivity achieved is better than the one provided by the higher statistics e^+ data sample, since with e^- in the initial state the production of such LQs occurs via a fusion with a quark (instead of a $\bar{q}$). Typical results obtained by ZEUS are shown in Fig. 1b. Scalar $\mid F \mid = 2$ LQs can be excluded up to 290 GeV for $\lambda = 0.3$.

The case of LQs decaying to eq as well as to νq has also been addressed by both Collaborations [4, 7]. No signal has been observed in the Charged Current (CC) DIS sample, and the CC channel has been used to better constrain such LQs [4].

Moving away from the BRW model, mass-dependent limits on the branching β_e have been derived by the H1 Collaboration [4], for fixed values of the coupling λ. These are shown in Fig. 2 for the case of a generic scalar LQ coupling to $e^+ + u$, for $\lambda = 0.1$ and $\lambda = 0.05$. The domain covered by H1 extends significantly beyond the region exluded by the $D\emptyset$ experiment, especially for low values of β_e.

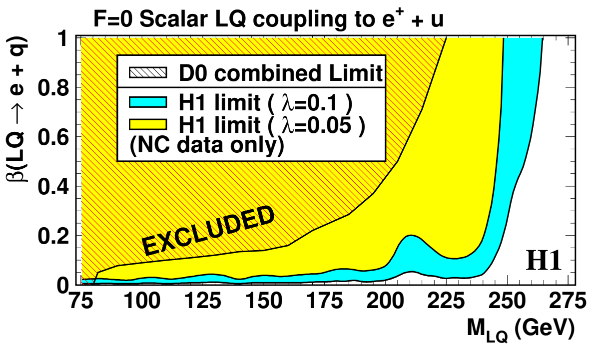

Figure 2. Mass-dependent exclusion limits on the branching $\beta(LQ \to eq)$ for a scalar LQ produced by an $e^+ + u$ fusion. Two exclusion domains corresponding to $\lambda = 0.1$ and $\lambda = 0.05$ are represented as shaded areas. The $D\emptyset$ limit is also shown as the hatched region.

2.2. Lepton Flavor Violating Leptoquarks

LQs coupling to eq and μq pairs have been considered by H1 [4] and ZEUS [8]. No $e^+ + p \to \mu + jet$ event compatible with LQ kinematics has been found in the e^+p dataset. In particular, the $e^+ + p \to \mu + X$ events reported by H1 in [9] fail significantly the kinematic constraints for LQ-induced $eq \to \mu q'$ processes.

Upper bounds on the product $\lambda \times \sqrt{\beta_\mu}$, where β_μ denotes the branching $\beta(LQ \to \mu + q)$, have been obtained by ZEUS as a function of the LQ mass. Scalar (vector) LQs decaying only into eq and μq are excluded up to 278 (285) GeV when the couplings at the vertices $LQ - e - q$ and $LQ - \mu - q$ are both of the electromagnetic strength.

The H1 Collaboration [4] also performed a search for $\tau + jet$ events, followed by a hadronic decay of the τ. No event compatible with LQ kinematics has been observed and constraints on LQs coupling to eq and τq have been derived, showing the important discovery potential provided by HERA for LQs decaying with a small branching into eq and a high branching into τq.

The case of very high mass ($M_{LQ} \gg \sqrt{s}$) LFV LQs was also addressed by H1 in [4]. For both

$e \leftrightarrow \mu$ and $e \leftrightarrow \tau$ transitions, direct constraints on such LQs obtained by H1 were compared to the most stringent indirect bounds. For some LQ types and some $eq_i \leftrightarrow l_j q_k$ reactions H1 limits extend significantly beyond the reach of other experiments [4].

3. Excited Fermions

Excited fermions (f^*) would be a clear evidence for fermion substructure. Singly produced f^* (via the t-channel exchange of a gauge boson) have been searched for at HERA, and results have been interpreted in the framework of the phenomenological model proposed in [10].

e^* have been searched for by ZEUS [11] and H1 [12] through $e^* \to f + V$ with $V = \gamma, Z, W$, the electroweak bosons decaying hadronically or via $W \to e\nu$, $Z \to e^+e^-$, $Z \to \nu\bar{\nu}$. The e^+p data showed no deviation from the SM in all analysed channels. Assuming an equal coupling f of the e^*-e pair to $U(1)$ and $SU(2)$ bosons, upper bounds on f/Λ where Λ denotes the compositeness scale have been obtained as a function of the e^* mass. ZEUS limits shown in Fig. 3a exclude e^* masses below 229 GeV at 95% CL for $f/\Lambda = 1/M(e^*)$, and these bounds extend beyond the domain covered by single e^* production at LEP.

ZEUS [11] also searched for $\nu^* \to \nu\gamma$ using e^-p data, which provide a higher sensitivity than the e^+p dataset due to a higher ν^* production cross-section. ν^* lighter than 161 GeV are excluded for $f/\Lambda = 1/M(\nu^*)$, as can be seen in Fig. 3b.

Searches for q^* were reported in [12] and q^* constraints have been set for a vanishing coupling f_s of the q^* to the gluon, complementary to the stringent bounds obtained at the TeVatron where q^* production requires $f_s \neq 0$.

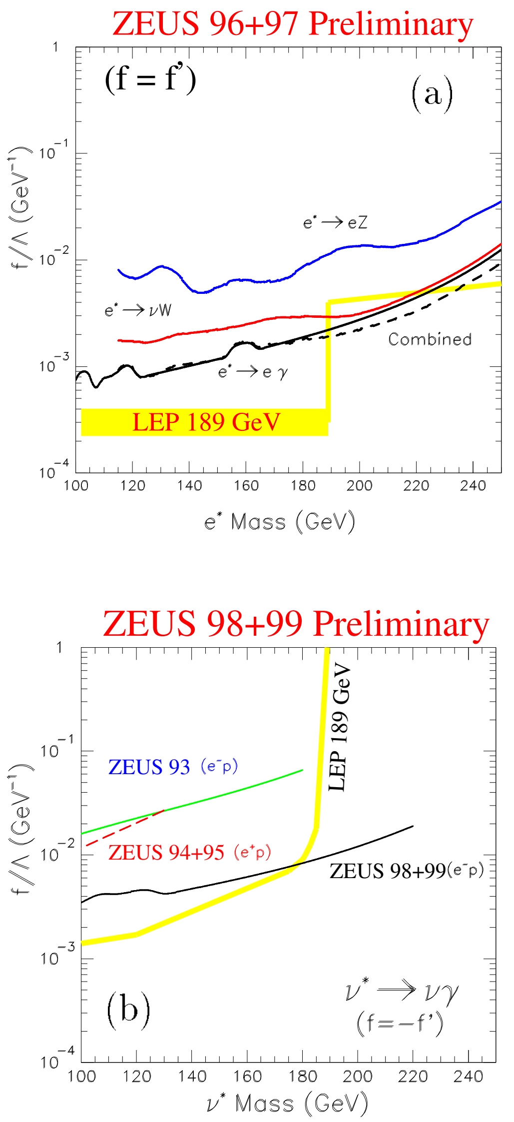

Figure 3. Upper limit at 95% CL on f/Λ as a function of (a) the e^* and (b) the ν^* mass. The dashed curve in (a) represents the limit obtained combining $e^* \to e\gamma$, $e^* \to eZ$ and $e^* \to \nu W$.

4. Conclusions and Outlook

HERA's discovery potential for new physics has been pointed out. Although the available data show a general good agreement with the Standard Model, some observations require clarification. The five-fold increase of the luminosity as well as the e-beam polarization expected from year 2001 will thus allow exciting searches to be carried out.

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