H1-10/96-500

Searches for Leptoquarks at HERA

Peter Schleper

CERN, Geneva, and Physikalisches Institut, Heidelberg
e-mail: Peter.Schleper@cern.ch

On behalf of the H1 and ZEUS collaboration

Searches for leptoquarks are reported which have been performed by the two HERA experiments H1 and ZEUS. No signal was found and constraints on leptoquark masses up to 275 GeV and leptoquark couplings as small as $0.001 \times \alpha_{elm}$ are derived. The results are compared to those obtained in direct and indirect searches at other colliders and at low energy experiments.

To be published in the Proceedings of ICHEP'96, Warsaw

Searches for Leptoquarks at HERA

Peter Schleper

CERN, Geneva, and Physikalisches Institut, Heidelberg
e-mail: Peter.Schleper@cern.ch
On behalf of the H1 and ZEUS collaboration

Searches for leptoquarks are reported which have been performed by the two HERA experiments H1 and ZEUS. No signal was found and constraints on leptoquark masses up to 275 GeV and leptoquark couplings as small as $0.001 \times \alpha_{elm}$ are derived. The results are compared to those obtained in direct and indirect searches at other colliders and at low energy experiments.

1 Introduction

One of the most intriguing properties of the Standard Model is the symmetry between leptons and quarks, which is apparent in their assignments to doublets and singlets of the weak interaction. Also the quantisation of electric charge in terms of 1/3 of the electron charge points to an internal connection between leptons and quarks, which is not motivated within the Standard Model, but nevertheless needed in order to avoid anomalies. Many of the discussed extensions of the Standard Model address this question and predict a new property of fermions, namely an interaction between leptons, quarks and new particles called leptoquarks (LQ). Examples for such models have been discussed in the context of Grand Unification and Superstring inspired E(6) models, Technicolour and Compositeness [1]. Searches for leptoquarks therefore directly probe a fundamental property of the Standard Model fermions within a wide class of new models.

2 Experimental Search

The dominant production mechanism for leptoquarks at HERA is shown in Fig. 1. A single LQ is

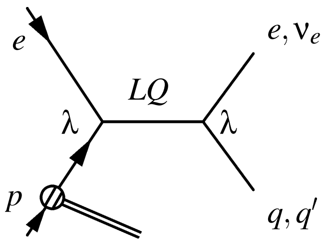

Figure 1: Lowest order Feynman diagram for s-channel leptoquark production in ep collisions.

made as an s-channel resonance between the beam electron and a quark of the proton, and therefore can be produced with masses up to the centre of mass energy of $\sqrt{s}$ =300 GeV. The cross section, as well as the LQ decay width, depends on the Yukawa coupling λ, which is a priori unknown.

The signature for leptoquarks are high momentum quarks and electrons [a] or neutrinos, depending on the LQ quantum numbers. The background consists mainly of deep inelastic scattering events (DIS). Both processes have identical final states and interfere, and the detection of leptoquarks depends critically on a good mass resolution.

A direct mass reconstruction for leptoquarks suffers from the problem of separating the quark jet from the proton remnant. It is more favourable to apply methods developed for the reconstruction of DIS kinematics. The equation

$$M_{LQ}^2 = (e + x_p p)^2 = x_p s$$

relates the LQ mass M_{LQ} to the beam 4-momenta, e, p, and to the momentum fraction of the quark in the proton, x_p. For massless quarks in the initial and final states, and assuming that the initial quark carries no transverse momentum, x_p is equivalent to the Bjorken scaling variable x_{BJ}. For LQ decays into electron and quark, x_{BJ} can be determined at HERA from either the electron alone (H1 [2]), or by using the polar angles of the electron and of the hadronic final state (ZEUS [3]). Both methods differ in their systematic errors, but lead to very similar results. For LQ decays into neutrino and quark, the overall energy flow is used to reconstruct the LQ mass.

The measured leptoquark width depends on:

- the natural LQ width (< 1 GeV),
- the contribution from u-channel LQ exchange,
- the interference with the Standard Model amplitude for DIS,
- the steep decrease at high x of the quark momentum distribution in the proton, which enhances the low mass tail of the Breit–Wigner resonance curve,

[a] Final states with μ or τ are discussed elsewhere in these proceedings.

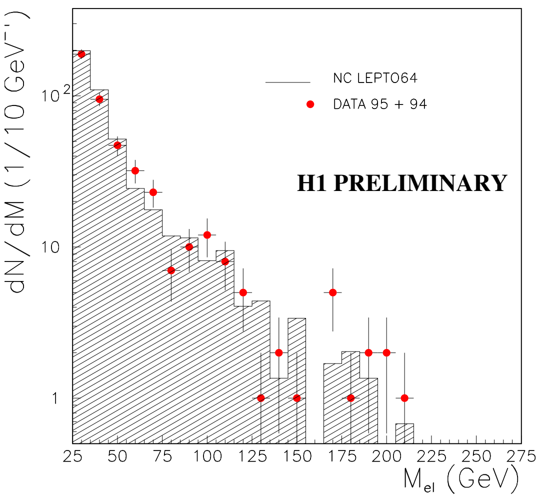

Figure 2: Mass distribution for leptoquark candidates (points) measured using only the electron from H1 in comparison to the background expectation[4] (hatched). A mass dependent cut on y is applied. (preliminary)

- the hadronisation of leptoquarks into colour singlets before the decay,
- and, most important, the fact that the quark from the LQ decay can be highly off–shell, so that $x_{\mathbf{BJ}}$ is not longer a good measure of x_p and M_{LQ}.

These effects dominate the mass resolution, also in comparison to the measurement error in the detector. The measured width is $\approx$ 10 GeV for leptoquark masses below 250 GeV, and becomes considerably worse at larger masses and large couplings due to the distortion of the Breit–Wigner distribution.

For final states with an electron, a further cut on the polar angle θ_e^* of the electron in the electron–quark centre of mass system is useful, because in DIS events the electron is on average much less deflected than in leptoquark decays. The optimum value for this cut depends on the LQ mass, a typical value being $y \equiv (1 + \cos\theta_e^*)/2 \gtrsim 0.1$ for a leptoquark of 200 GeV.

The reconstructed mass distributions for final states with an electron from H1 and ZEUS are shown in Fig. 2 and Fig. 3. They correspond to integrated luminosities of 6.3 pb^{-1} and 9 pb^{-1} of e^+p scattering, respectively. In general the data is well explained by the Standard Model prediction for DIS processes [b]. This background is large at small masses (small x), and becomes vanishingly small for masses above 200 GeV.

[b]Similar agreement with background expectations have been observed in final states with neutrinos and, with $\approx$ 10 times less integrated luminosity, in e^-p scattering.

A small excess is seen at a mass of $\approx$ 170 GeV in both the H1 data and the ZEUS data ($x = 0.32$), which however is not statistically significant.

3 Results

Since no signal was observed only bounds on leptoquark masses and couplings can be derived.

The efficiencies of the above selections range from approx. 50% to 80% for $M_{LQ} > 100$ GeV. The cross section depends quadratically on the unknown Yukawa coupling λ, and on the momentum distributions of the different quark flavours in the proton. The uncertainty in the latter leads to the main systematic error on the predicted cross section of 10 to 30%, which is taken into account in the limit derivation.

In order to be as model independent as possible, an effective low energy Lagrangian [5] is used, which includes all possible gauge invariant leptoquark-lepton-quark Yukawa couplings with Baryon and Lepton number conservation. The leptoquarks carry either spin 0 (scalars S) or spin 1 (vectors V), and have different $SU(2) \times U(1)$ quantum numbers. All together there are 14 different couplings to either left handed (L) or right handed (R) leptons. Leptoquarks of any specific model, which respects the Standard Model symmetries, can be identified with one of these 14 assignments.

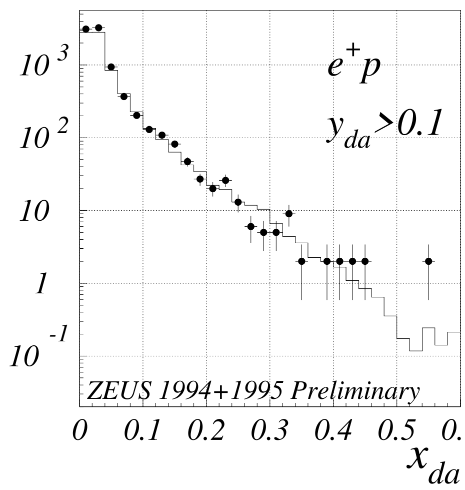

Figure 3: Distribution of x obtained via the double angle method in e^+p scattering by ZEUS (points). Also shown (histogram) is the Standard Model prediction for deep inelastic scattering. A cut of $y > 0.1$ is applied . (preliminary)

Fig. 4 shows, for all of these LQ species, the 95% exclusion limits in the mass–coupling plane as obtained by H1 from e^+p (2.7 pb^{-1}) and e^-p (0.6 pb^{-1}) data [2]. Couplings larger than the bounds shown are excluded. Very small couplings

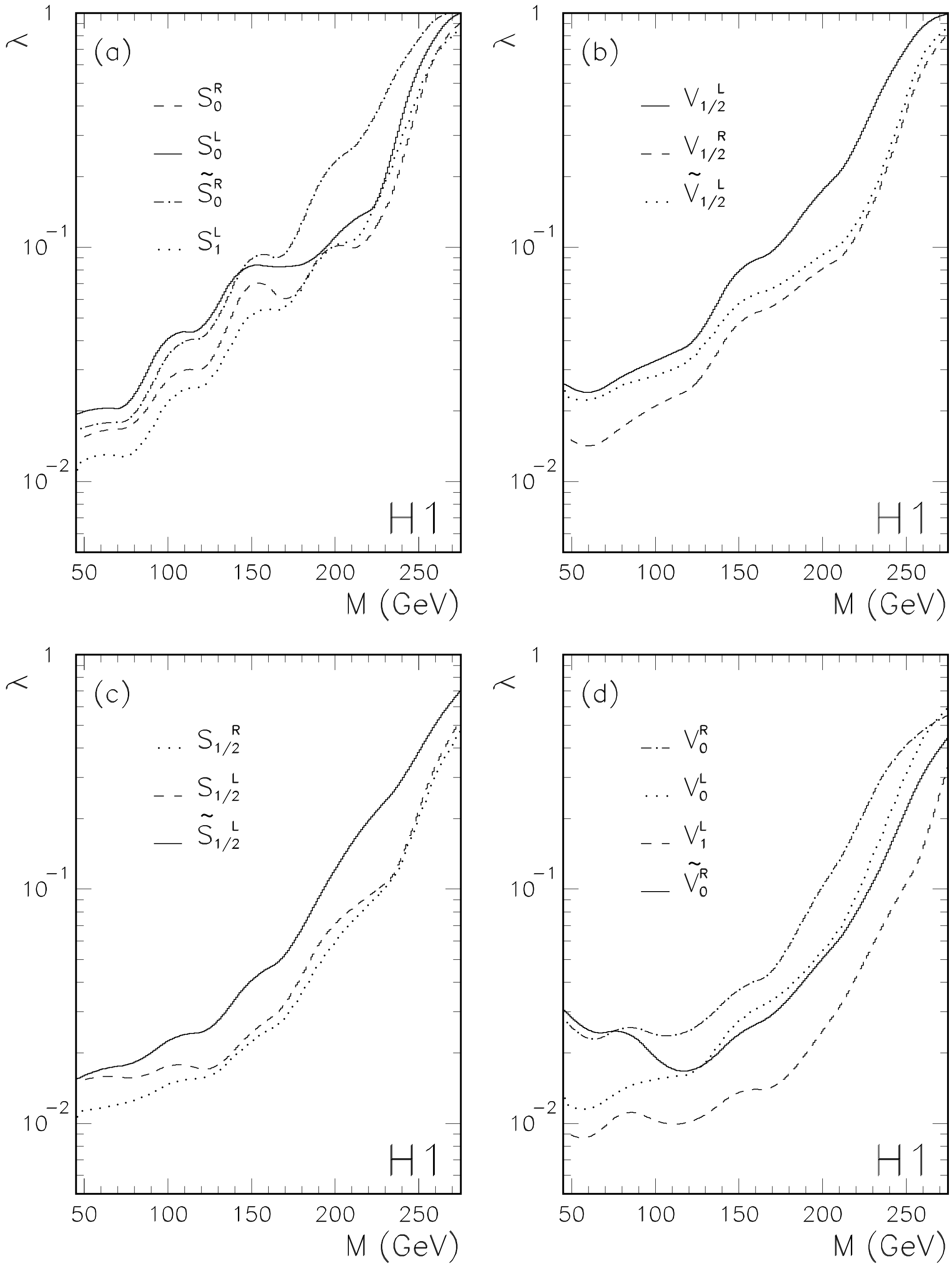

Figure 4: Exclusion limits from H1[2] at 95%CL for leptoquarks in dependence of mass and Yukawa couplings λ to electrons and quarks of the first generation. The nomenclature is such that, for example, $S_{1/2}^R$ is a scalar with weak isospin 1/2 and couplings to righthanded leptons.

can be excluded for low mass leptoquarks because of the large quark flux at low x. Differences between the various LQ species are due to their branching ratio into electron and neutrino, their coupling to different quark flavours and their angular decay distributions. To illustrate the significance of these bounds, the coupling $\alpha_\lambda = \lambda^2/4\pi$ may be compared to α_{elm}, for example. If α_λ is 10 times smaller than α_{elm}, then leptoquarks must be heavier than 170 to 250 GeV.

4 Comparison with other Experiments

For one of the leptoquarks ($S^R_{1/2}$), the result of H1 is compared to the best limits of other experiments (Fig. 5). The most stringent direct bounds

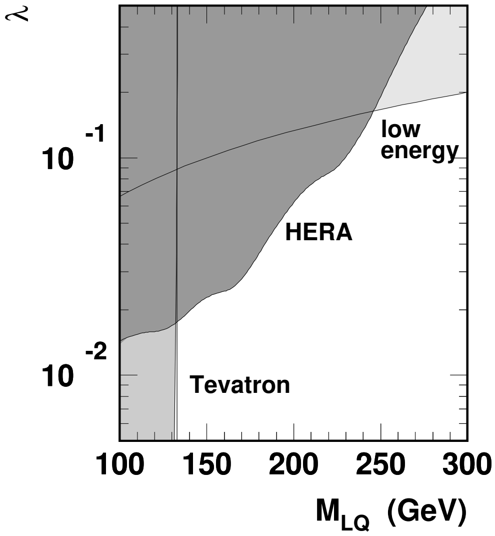

Figure 5: Comparison of excluded regions in the mass– coupling plane for the $S^R_{1/2}$ leptoquark from H1 [2], Tevatron [6] and from indirect searches in low energy experiments [7].

come from $p\bar{p}$ collisions at the Tevatron [6], where leptoquarks could be produced in pairs. Here the Yukawa coupling to lepton–quark pairs is not tested directly, but instead the cross section depends on the gauge coupling to gluons. For scalar leptoquarks masses below 130 GeV are excluded. Note that this bound was derived assuming that leptoquarks are $SU(2)$ singlets, whereas the $S^R_{1/2}$ is a doublet. This should yield a cross section twice as large as assumed and an increase of the Tevatron mass bound by 10 to 20 GeV.

Indirect limits on leptoquarks [7] have been obtained by low energy experiments on parity violation in atoms, on the decay $\pi \to e\nu$, on flavour changing neutral currents and others. These bounds constrain typically the ratio M_{LQ}/λ or M_{LQ}/λ^2. The best indirect limit for the $S^R_{1/2}$ leptoquark is also shown in Fig. 5. It extends, for large couplings, the region covered by the direct searches.

Indirect limits beyond the HERA centre of mass energy have also been obtained by H1 via a search for contact interactions [8]. The bounds on M_{LQ}/λ are of $\mathcal{O}(1000)$ GeV, and up to now slightly less restrictive than the indirect limits from low energy experiments.

5 Conclusion

Leptoquarks have not yet been observed at HERA. Therefore, they have to be heavier than ≈ 200 GeV for couplings 10 times smaller than the electromagnetic coupling. The Tevatron bounds exclude in addition the region of very small couplings but are limited to lower masses. Indirect searches are sensitive to very large masses, but only for large couplings. In the future, direct as well as indirect searches at HERA will considerably improve the present results.

Acknowledgements: It is a pleasure to thank my colleagues of the working groups for particle searches in H1 and ZEUS, i.e. U. Katz, E. Perez, Y. Sirois and B. Straub.

References

1. B. Schrempp, Proceedings of the workshop Physics at HERA, Ed. W. Buchmüller and G. Ingelmann, Hamburg 1991, vol.2, p.1034, and references therein.
2. H1 Collaboration, S. Aid et al., Phys. Lett. B369 (1996) 173.
3. ZEUS Collaboration, M.Derrick et al., Phys. Lett. B306 (1993) 173.
4. G. Ingelman, Proceedings of the workshop Physics at HERA, Ed. W. Buchmüller and G. Ingelmann, Hamburg 1991, Vol.3 p.1366.
5. W. Buchmüller, R. Rückl, D. Wyler, Phys. Lett. B191 (1987) 442.
6. T. Kamon, Contribution to the 31st Rencontres de Moriond, 1996; S. Hagopian, D0 Collaboration, Proceedings to ICHEP'94, Glasgow, 1994; CDF Collaboration, F. Abe et al., Phys. Rev. D48 (1993) 3939; D0 Collaboration, S. Abachi et al., Phys. Rev. Lett. 72 (1994) 965.
7. M. Leurer, Phys. Rev. D49 (1994) 333.; ibid Phys. Rev. D50 (1994) 536.; ibid Phys. Rev. Lett. 71 (1993) 1324; S. Davidson, et al., Z. Phys. C61 (1994) 613.
8. H1 Collaboration, T. Ahmed et al., Phys. Lett. B353 (1995) 578.