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Search for Leptoquark Bosons in ep Collisions at HERA

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Abstract

A search for scalar and vector leptoquarks coupling to first generation fermions is performed using the the full e^+p and e^-p scattering data collected by the H1 experiment between 1994 and 2007. The data correspond to a total integrated luminosity of $449\,\mathrm{pb}^{-1}$. No evidence for direct or indirect production of such particles is found in data samples with a large transverse momentum final state electron or with large missing transverse momentum. For each of the leptoquark species defined in the Buchmüller, Rückl and Wyler model, the present analysis excludes a previosly unexplored domain in the plane spanned by the mass of the leptoquark and its coupling to fermions.

Introduction

The ep collider HERA offers the unique possibility to search for the resonant production of new particles coupling directly to a lepton and a parton. Leptoquarks (LQs), colour triplet bosons, which appear naturally in various unifying theories beyond the Standard Model (SM) are such an example. At HERA, leptoquarks could be singly produced by the fusion of the initial state lepton of energy 27.6 GeV with a quark from the incoming proton of energy up to 920 GeV.

The phenomenology of LQs at HERA is discussed in detail in [1]. The effective Lagrangian considered therein conserves lepton and baryon number, obeys the symmetries of the SM gauge groups $U(1)_Y$, $SU(2)_L$ and $SU(3)_C$ and includes both scalar and vector LQs. A dimensionless coupling λ defines the coupling at the e-q-LQ vertex. At HERA, LQs can be resonantly produced in the s-channel or exchanged in the u-channel between the incoming lepton and a quark coming from the proton. In the s-channel, a LQ is produced at a mass $M = \sqrt{s_{ep}x}$ where x is the momentum fraction of the proton carried by the interacting quark.

Period	Collisions	$\sqrt{s}$	E-beam polarisation	Luminosity
HERA I	e^+p	301 GeV	0	37 pb^{-1}
	e^-p	319 GeV	0	14 pb^{-1}
	e^+p	319 GeV	0	64 pb^{-1}
HERA II	e^+p	319 GeV	+0.31	99 pb^{-1}
	e^+p	319 GeV	-0.36	78 pb^{-1}
	e^-p	319 GeV	-0.26	104 pb^{-1}
	e^-p (NC)	319 GeV	+0.32	51 pb^{-1}
	e^-p (CC)	319 GeV	+0.37	30 pb^{-1}

Table 1: The data sets used in the present search for leptoquarks. The present paper presents the analysis of the full HERA II data sets. The HERA I data samples are used as analysed in [1].

Due to the more favourable quark-densities of quarks with respect to anti-quarks at high x, the e^-p data sets are mostly sensitive to LQs with fermion number[1] $F = 2$, whereas e^+p collisions are more favourable for the production of $F = 2$ LQs. The search reported here considers the decays LQ $\rightarrow eq$ and LQ $\rightarrow \nu q$ where q represents both quarks and anti-quarks. Such LQ decays lead to final states similar to those of deep-inelastic scattering (DIS) neutral current (NC) and charged current (CC) interactions at very high Q^2, the negative four-momentum transfer squared. If the final state is of type eq, the LQ mass is reconstructed from the measured kinematics of the scattered electron. If the final state is of type νq, the LQ mass is reconstructed from the hadronic final state [1].

This note presents a search for LQs coupling to first generation fermions with fermion number $F = 0$ and $F = 2$ in scattering of longitudinally polarised electrons or positron on protons at a centre-of-mass energy of $\sqrt{s_{ep}}$ of up to ≈ 320 GeV. The new HERA II data sets are analysed in the present preliminary analysis. The results of these searches are combined with the

[1]The fermion number F is given by $F = |3B + L|$ with B and L being the baryon and lepton number respectively.

published results of LQ searches using HERA I data. The data samples[2] are summarised in table 1.

Neutral and Charged Current Event Selection

The H1 detector components most relevant to this analysis are the liquid argon calorimeter, which measures the positions and energies of charged and neutral particles over the range $4^\circ < \theta < 154^\circ$ of polar angle[3], and the inner tracking detectors which measure the angles and momenta of charged particles over the range $7^\circ < \theta < 165^\circ$. A full description of the detector can be found in [2].

This search is based on inclusive NC and CC DIS event samples and follows closely the selection and kinematics reconstruction presented in [1].

The selection of NC DIS events requires an identified electron with an energy above 11 GeV. The photon virtuality Q^2 and the event inelasticity y are restricted to the ranges $Q^2 > 500\,\mathrm{GeV}^2$ and $0.1 < y < 0.9$, respectively. Furthermore, a limited reconstructed momentum loss in direction of the incident electron is expected for the signal events, such that 40 GeV $< E - P_z <$ 70 GeV is demanded.

The selection of CC DIS events requires a significant missing transverse momentum $P_T^{miss} >$ 12 GeV. In addition, a cut is applied on the ratio $V_{ap}/V_p < 0.35$. The quantities V_p and V_{ap} are respectively the transverse energy flow parallel and anti-parallel to the transverse momentum of the hadronic final state $\vec{P}_{T,h}$. The condition is tightened $V_{ap}/V_p < 0.15$ for events with $P_T^{miss} < 25$ GeV in order to reduce the photoproduction background. The photon virtuality Q_h^2 and the event inelasticity y_h, reconstructed from the hadronic final state, are restricted to the ranges $Q_h^2 > 1000\,\mathrm{GeV}^2$ and $0.1 < y_h < 0.9$, respectively. To exploit the expected energy loss due to the undetected neutrino, a longitudinal energy imbalance is required $E - P_z < 50$ GeV.

The mass spectra measured for NC-like and CC-like events in the left- and righthanded data sets are shown in figure 1 for e^-p collisions and in figure 2 for e^+p collisions. Combined spectra for the e^+p and e^-p event samples including HERA I and HERA II data are shown in figure 3. The spectra obtained by combining all data sets presented in table 1 are shown in figure 4.

The data are found to be in good agreement with the SM predictions, obtained using a Monte-Carlo simulation based on the DJANGO generator [3] and CTEQ5D parametrisation [4] of the proton parton densities.

No evidence for LQ production is observed in either the NC or CC data samples. The mass spectra are therefore used to set constraints on LQs coupling to first generation fermions. Further sensitivity to the LQ production is obtained using the inelasticity variable y, related to the polar angle θ^* of the decay lepton in the centre-of-mass frame of the hard subprocess $(eq \to lq)$ by $y = \frac{1}{2}(1 + \cos\theta^*)$. To make use of the different decay angle distributions for DIS and leptoquarks, all selected events are analysed in bins of varying size adapted to the experimental resolution in the $M - y$ plane, with a procedure designed to fully exploit the sensitivity to the signal. The statistical method is described in detail in [1].

[2] A small subsample of data corresponding to a part of the right-handed e^-p run at HERA II is not used in the present preliminary CC analysis.

[3] The polar angle θ is defined with respect to the incident proton momentum vector (the positive z axis).

Limit Results

In the following limits are derived within the phenomenological model proposed by Buchmüller, Rückl and Wyler (BRW) [5].

Table 2 lists the 14 LQ types with fermion number $F = 0$ and $F = 2$ and their respective decays as described by the BRW model. We use here the nomenclature of [6] to label the various scalar $S_{I,L}$ ($\overset{(\sim)}{S}_{I,R}$) or vector $\overset{(\sim)}{V}_{I,L}$ ($V_{I,R}$) LQ types of weak isospin I, which couple to a left-handed (right-handed) electron. The tilde is used to distinguish LQs which differ only by their hypercharge. In the BRW model the branching ratios of the LQ types into electron–quark (β_e) and neutrino–quark (β_ν) are fixed and equal to 1 or 0.5 (β_e) and 0 or 0.5 (β_ν) depending on the LQ quantum numbers.

$F = 2$	Prod./Decay	β_e	$F = 0$	Prod./Decay	β_e
Scalar Leptoquarks					
$S_{0,L}$	$e^-_L u_L \to e^- u$	$1/2$	$S_{1/2,L}$	$e^+_R u_R \to e^+ u$	1
	$\to \nu d$	$1/2$			
$S_{0,R}$	$e^-_R u_R \to e^- u$	1	$S_{1/2,R}$	$e^+_L u_L \to e^+ u$	1
$\tilde{S}_{0,R}$	$e^-_R d_R \to e^- d$	1		$e^+_L d_L \to e^+ d$	1
$S_{1,L}$	$e^-_L d_L \to e^- d$	1	$\tilde{S}_{1/2,L}$	$e^+_R d_R \to e^+ d$	1
	$e^-_L u_L \to e^- u$	$1/2$			
	$\to \nu d$	$1/2$			
Vector Leptoquarks					
$V_{1/2,R}$	$e^-_R d_L \to e^- d$	1	$V_{0,R}$	$e^+_L d_R \to e^+ d$	1
	$e^-_R u_L \to e^- u$	1	$V_{0,L}$	$e^+_R d_L \to e^+ d$	$1/2$
				$\to \overline{\nu} u$	$1/2$
$V_{1/2,L}$	$e^-_L d_R \to e^- d$	1	$\tilde{V}_{0,R}$	$e^+_L u_R \to e^+ u$	1
$\tilde{V}_{1/2,L}$	$e^-_L u_R \to e^- u$	1	$V_{1,L}$	$e^+_R u_L \to e^+ u$	1
				$e^+_R d_L \to e^+ d$	$1/2$
				$\to \overline{\nu} u$	$1/2$

Table 2: Leptoquark isospin families in the Buchmüller-Rückl-Wyler model. For each leptoquark, the subscript denotes its weak isospin and the chirality of the incoming *electron* which could mediate their production in $e^- p$ collisions. Charge conjugate processes are not shown.

The resulting constraints are shown in fig. 5 for all 14 LQ types. The strongest constraints on the coupling λ can be set for LQ masses below the kinematic limit of the s-channel. At higher masses, beyond HERA centre-of-mass energy, the LQ production is not resonant but proceeds via contact interactions. In this region the LQ production cross section scales approximately with $(\lambda/M_{LQ})^4$.

The constraints obtained in the present analysis on the $\tilde{S}_{1/2,L}$ and $S_{0,L}$ LQs are compared in figure 6 to the results obtained at LEP [7, 8] and Tevatron [9]. Indirect constraints were obtained at LEP from $e^+e^- \rightarrow q\overline{q}$ process measurements. The limits from the Tevatron are independent of the coupling λ as they were derived from the dominant pair production processes. The published H1 results [1] from the HERA I phase are also shown for comparison. An unique domain is probed at HERA for LQ masses above Tevatron sensitivity and small coupling constants. The limits on LQs also apply to squarks production is SUSY models with R-parity violation. For instance, the $S_{0,L}$-like LQ also applies to squark $\tilde{d}_{k,R}$ with R-parity violating couplings λ'_{11k} to eu and subsequent decays $\tilde{d}_{k,R} \rightarrow e^-u$ and $\tilde{d}_{k,R} \rightarrow \nu d$ (the subscript k is a generation index here).

To summarise, a search for leptoquarks production is performed using the polarised e^-p and e^+p data recorded by H1 at HERA II in the period 2003-2007. No signal is observed, in agreement with previous investigations at HERA I. The two analysis are combined and constraints on leptoquarks are set, which extend beyond the domains previously excluded.

Acknowledgements

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References

[1] A. Aktas *et al.* [H1 Collaboration], Phys. Lett. B **629** (2005) 9 [hep-ex/0506044].

[2] I. Abt *et al.* [H1 Collaboration], Nucl. Instrum. Meth. A **386** (1997) 310 and 348;
R. D. Appuhn *et al.* [H1 SPACAL Group], Nucl. Instrum. Meth. A **386** (1997) 397.

[3] DJANGO 6.2; G.A. Schuler and H. Spiesberger, Proc. of the Workshop Physics at HERA, W. Buchmüller and G. Ingelman (Editors), (October 1991, DESY-Hamburg) Vol. 3 p. 1419.

[4] H. L. Lai *et al.* [CTEQ Collaboration], Eur. Phys. J. C **12** (2000) 375 [hep-ph/9903282].

[5] W. Buchmüller, R. Rückl and D. Wyler, Phys. Lett. B **191** (1987) 442 [Erratum-ibid. B **448** (1999) 320].

[6] A. Djouadi, T. Köhler, M. Spira and J. Tutas, Z. Phys. C **46** (1990) 679.

[7] G. Abbiendi *et al.* [OPAL Collaboration], Eur. Phys. J. C **6** (1999) 1 [hep-ex/9808023].

[8] M. Acciarri *et al.* [L3 Collaboration], Phys. Lett. B **486** (2000) 81 [hep-ex/0005028].

[9] V. M. Abazov [D0 Collaboration], Phys. Rev. D **71** (2005) 071104 [hep-ex/0412029].

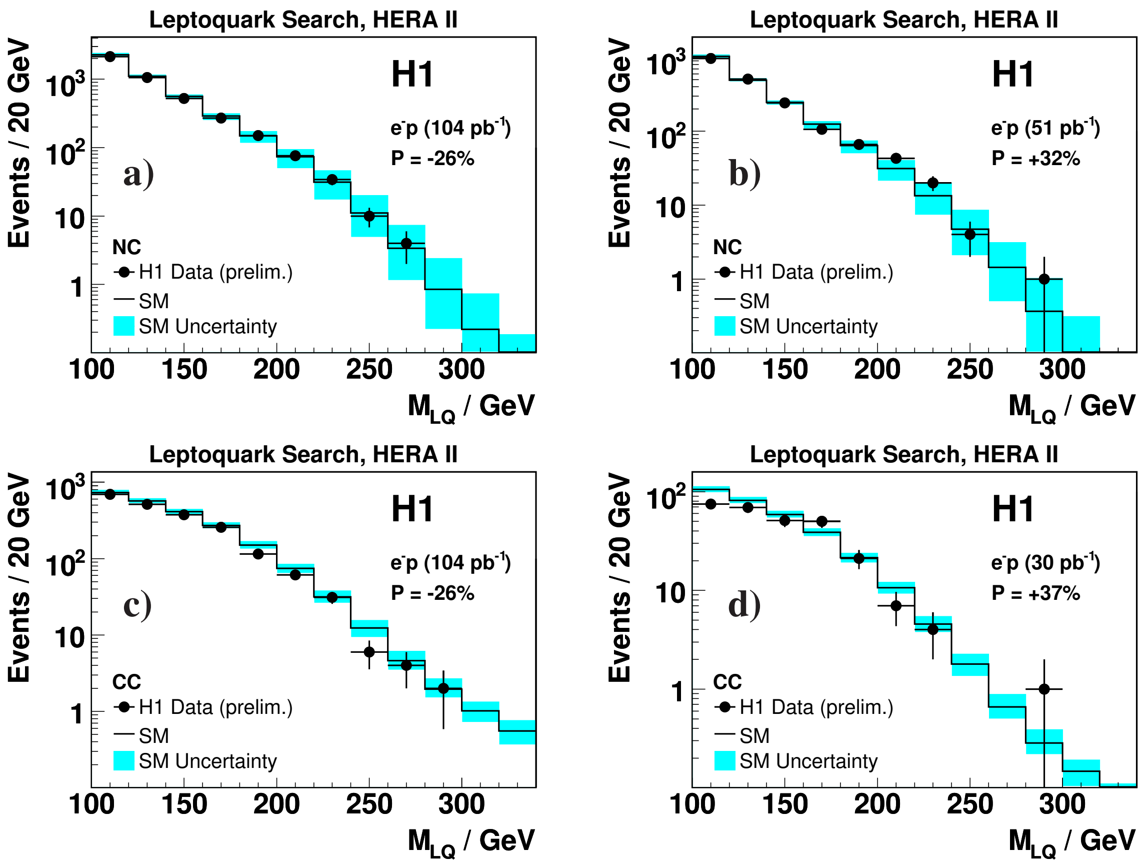

Figure 1: Reconstructed LQ mass spectra of the HERA II e^-p data for Neutral Current (a: left- and b: righthanded data) and Charged Current (c: left- and d: righthanded data) events. The points represent the data and are compared to the SM expectation (histogram). The shaded band indicates the uncertainty on the SM expectation. The average polarisation of each data set is also indicated.

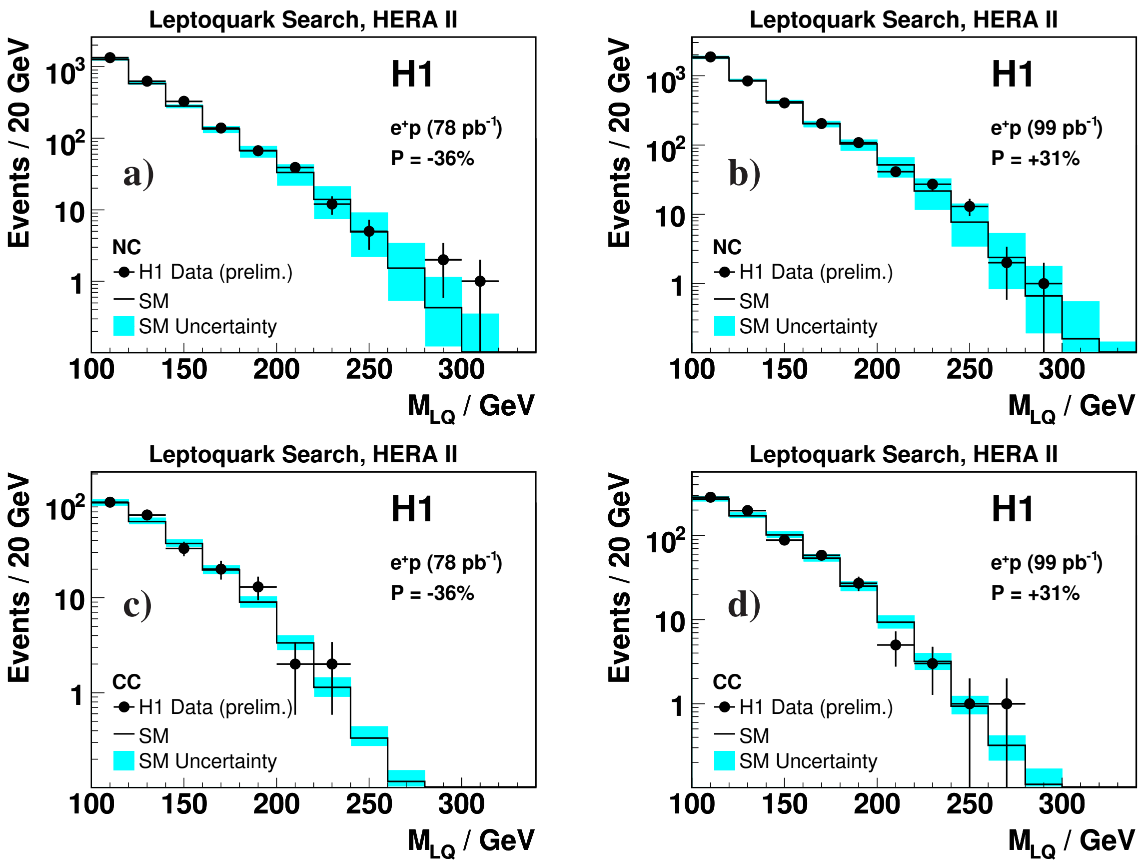

Figure 2: Reconstructed LQ mass spectra of the HERA II e^+p data for Neutral Current (a: left- and b: righthanded data) and Charged Current (c: left- and d: righthanded data) events. The points represent the data and are compared to the SM expectation (histogram). The shaded band indicates the uncertainty on the SM expectation. The average polarisation of each data set is also indicated.

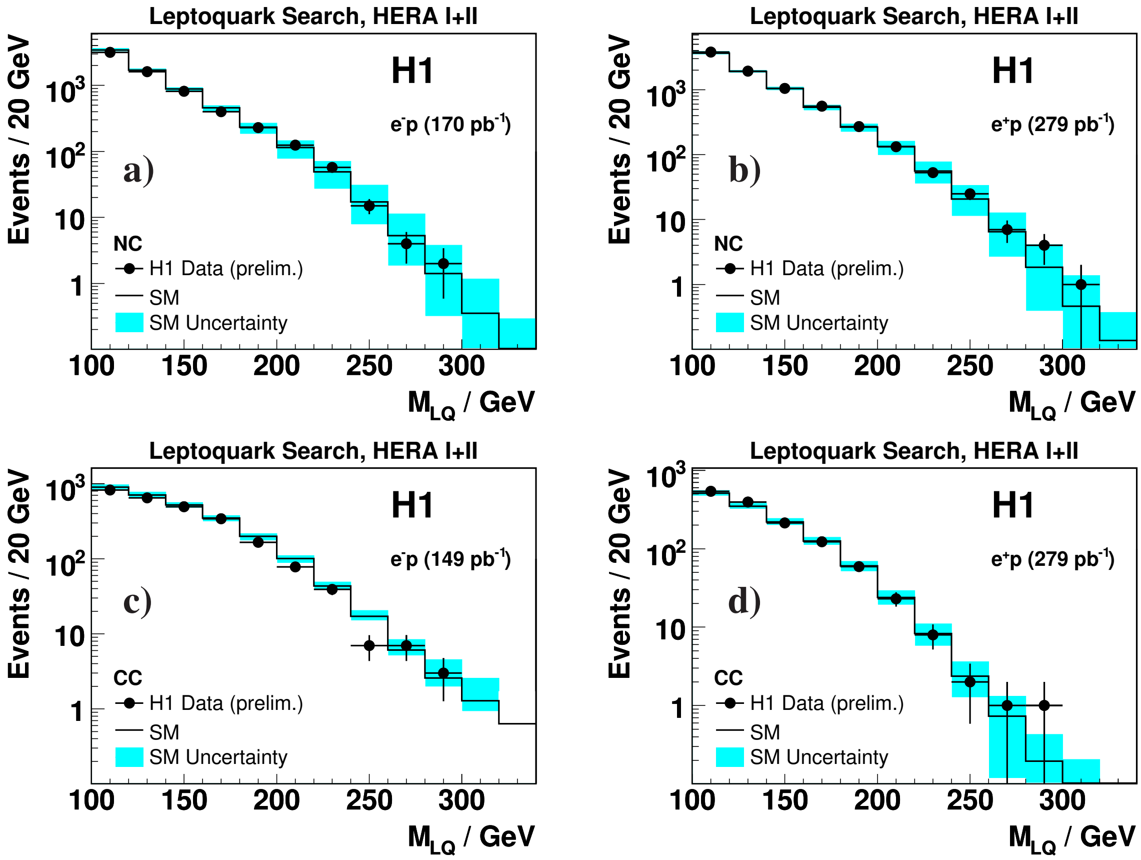

Figure 3: Mass spectra of the complete HERA I+II data for Neutral Current (a: e^-p data and b: e^+p data) and Charged Current (c: e^-p data and d: e^+p data) events in the H1 leptoquark analysis. The points are the data, which are compared to the SM expectation (histogram). The shaded band indicates the uncertainty on the SM expectation.

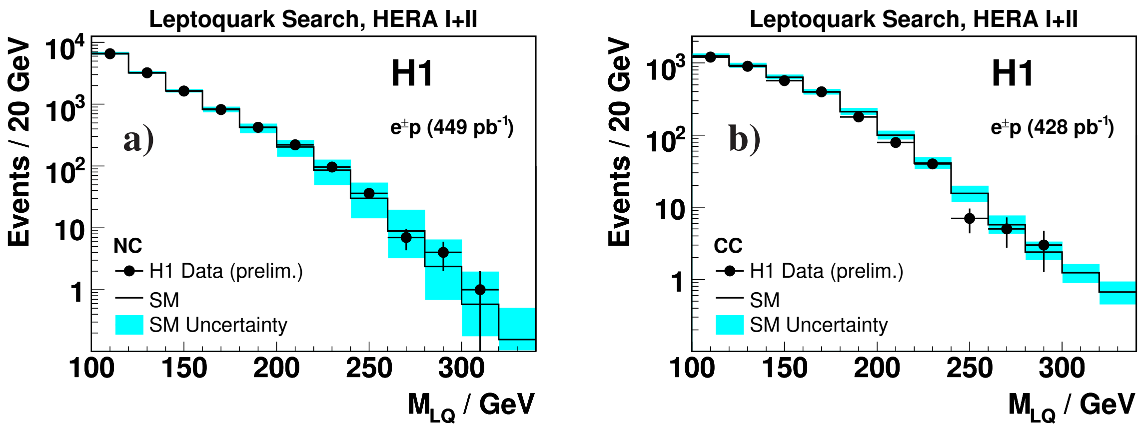

Figure 4: Mass spectra of the complete HERA I+II $e^{\pm}p$ data for Neutral Current (a) and Charged Current (b) events in the H1 leptoquark analysis. The points are the data, which are compared to the SM expectation (histogram). The shaded band indicates the uncertainty on the SM expectation.

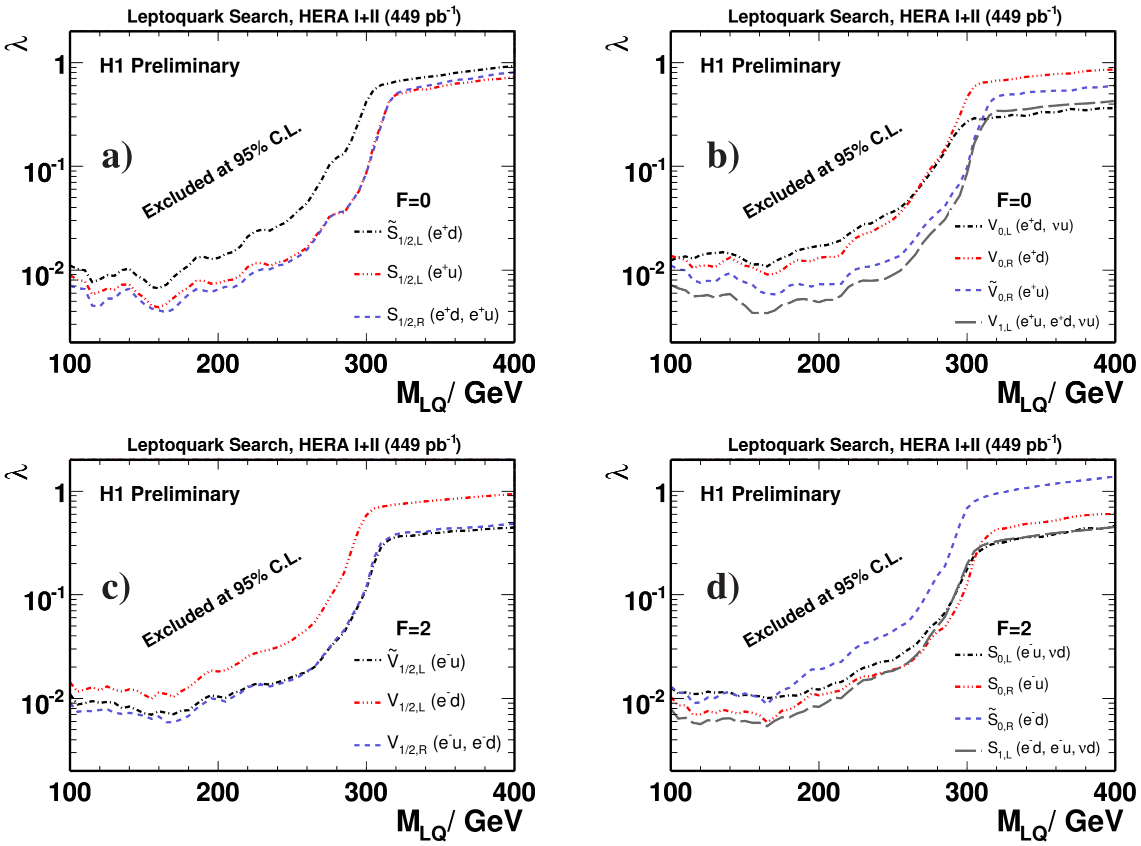

Figure 5: Exclusion limits for the 14 leptoquarks (LQs) with F=2 and F=0 described by the Buchmüller, Rückl and Wyler (BRW) model. The limits are expressed on the coupling λ as a function of the leptoquark mass for the (a) scalar LQs with $F = 0$, (b) vector LQs with $F = 0$ (c) vector LQs with $F = 2$ and (d) scalar LQs with $F = 2$. Domains above the curves are excluded at 95% CL. For each LQ type the pairs of Standard Model fermions coupling to it are indicated in brackets.

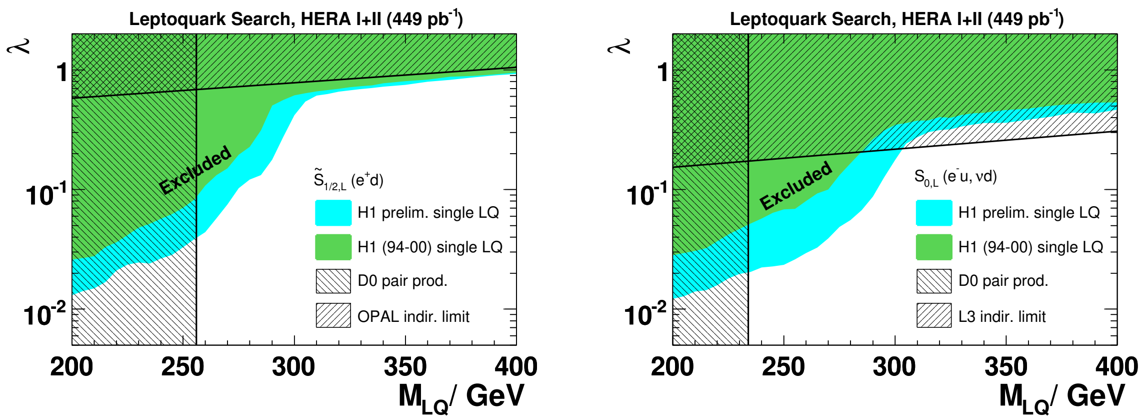

Figure 6: Exclusion limits at 95% CL on the coupling λ as a function of the leptoquark mass for $\tilde{S}_{0,L}$ (left) and $S_{0,L}$ (right) in the framework of the BRW model. The indirect limit from LEP (OPAL and L3) and the direct limits from Tevatron (D0) are shown for comparision. The published H1 limit from HERA I data is also shown.