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Abstract:

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Search for Leptoquark Bosons in e^-p Collisions at HERA II

H1 Collaboration

Abstract

A search for scalar and vector leptoquarks coupling to first generation fermions using the e^-p scattering data collected by the H1 experiment in 2005 is presented. The data correspond to a total integrated luminosity of $92\,\mathrm{pb}^{-1}$. Especially the sensitivity to leptoquarks with fermion number F=2 is increased w.r.t. the previous H1 results. No evidence for the 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. The results of the present analysis are used to set new constraints on leptoquark couplings. For leptoquark couplings of electromagnetic strength, F=2 leptoquarks with masses up to $276 - 304\,\mathrm{GeV}$ are ruled out.

Introduction

The ep collider HERA offers the unique possibility to search for the resonant production of new particles which couple 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 there 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.

This note presents a search for LQs coupling to first generation fermions with fermion number $F = 2$ in scattering of longitudinally polarised electrons on protons at a center-of-mass energy of $\sqrt{s_{ep}} \approx 320$ GeV. For the lefthanded running phase with an average polarisation of -27 %, the integrated luminosity amounts to 60 pb^{-1}, whereas for righthanded running phase with an average polarisation of 34 %, 32 pb^{-1} of data are analysed.

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] $F = 2$. The search reported here considers the decays LQ $\rightarrow eq$ and LQ $\rightarrow \nu q$ with q standing for both quarks and anti-quarks. These 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].

Neutral and Charged Current Data

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 $4° < \theta < 154°$ of polar angle[2], and the inner tracking detectors which measure the angles and momenta of charged particles over the range $7° < \theta < 165°$. A full description of the detector can be found in [2].

This search is based on inclusive NC and CC DIS data in the kinematic domain $Q^2 > 500\,\mathrm{GeV}^2$ and $0.1 < y < 0.9$, where the inelasticity variable y is defined as $y = Q^2/M^2$. The

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

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

cuts on y remove regions of poor reconstruction, poor resolution, large QED radiative effects and background from photoproduction processes. The selection of NC-like events requires an identified electron with transverse momentum above 11 GeV. Futhermore, a limited reconstructed momentum loss in direction of the incident electron such that 40 GeV $< E - p_z <$ 70 GeV is demanded. The selection of CC-like events follows closely that presented in [1, 3]. The missing transverse momentum is required to exceed 12 GeV. In addition, a cut is applied on the ratio $V_{ap}/V_p < 0.15$. 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 mass spectra measured for NC-like and CC-like events in the left- and righthanded data sets are compared in Figs. 1a-d with the SM predictions, obtained using a Monte-Carlo calculation [5] and the CTEQ5D parametrisation [6] for the parton densities. In all cases the data are well described by the SM prediction.

Since no evidence for LQ production is observed in either the NC or CC data samples, the data are used to set constraints on LQs which couple to first generation fermions.

The inelasticity variable y is 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, scalar and vector 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 has been described in detail in [4].

Limit Results

In the following we will show limits derived within the phenomenological model proposed by Buchmüller, Rückl and Wyler (BRW) [7].

The BRW model describes 7 LQs with $F = 0$ and 7 LQs with $F = 2$ coupling to eq. We use here the nomenclature of [8] 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. Table 1 lists the 7 LQ types with fermion number $F = 2$ described by the BRW model.

The resulting constraints are shown in fig. 2a for the four scalar and in fig. 2b for the three vector LQs with $F = 2$. The areas above the curves are excluded at 95% confidence level. The strongest constraints on the coupling λ can be set for LQ masses below the kinematic limit of the s-channel. At higher masses the production is not resonant anymore but contact interaction–like and the cross–sections scale approximately with $(\lambda/M_{LQ})^4$. For a coupling of electromagnetic strength α_{em} ($\lambda = \sqrt{4\pi\alpha_{\text{em}}} = 0.3$) this analysis rules out LQ masses below 276 to 304 GeV, depending on the LQ type.

Fig. 3 summarises the constraints on the $S_{0,L}$ obtained by H1, by the L3 experiment at LEP [9], and by the D0 experiment at the Tevatron [10]. The limits shown from LEP are from

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

Table 1: Leptoquark isospin families with F=2 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.

indirect constraints from $e^+e^- \to q\overline{q}$. 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 [4] from the HERA I phase (mainly e^+p running) are shown for comparison. Above the kinematic limit, the improvement w.r.t. to the HERA I results is smaller than at lower masses, because the production is not resonant anymore and thus the sensitivities of the e^+p and the e^-p datasets (which have approximately the same integrated luminosity) to $F=2$ LQs are very similar. The H1 limit on 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 $\tilde{d}_{k,R} \to e^-u$ and $\tilde{d}_{k,R} \to \nu d$ (the subscript k is a generation index here).

To summarise, a search for leptoquarks with fermion number $F=2$ has been performed using the polarised e^-p data recorded by H1 in 2005. No signal has been observed and constraints on leptoquarks have been set, which for $F=2$ leptoquarks extend beyond the domains excluded previously by H1. For a coupling of electromagnetic strength, leptoquark masses below $276-304$ GeV can be ruled out, depending on the leptoquark type.

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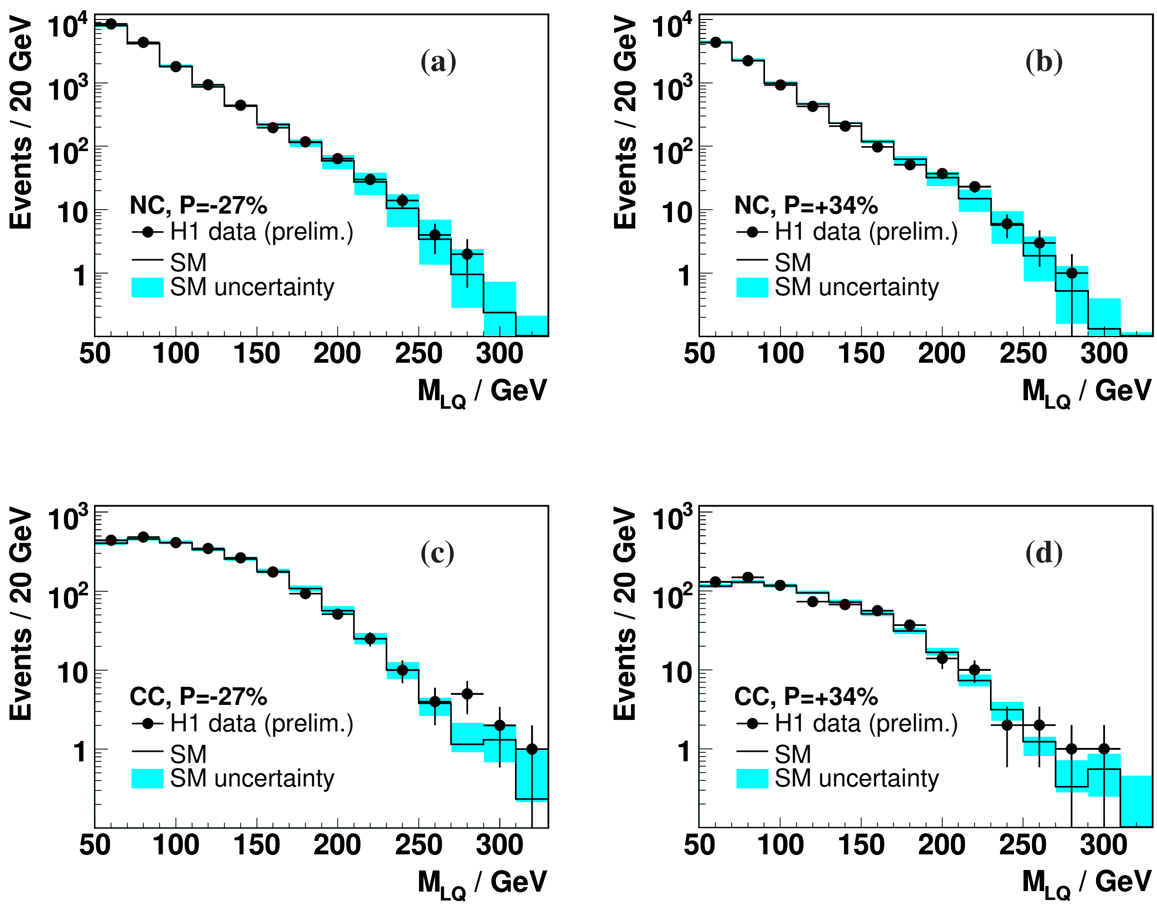

Figure 1: Mass spectra for the neutral current (a: left- and b: righthanded data sample) and the charged current (c: left- and d: righthanded data sample) events (points with error bars), together with the corresponding SM expectations (histogram). The shaded bands indicate the $\pm 1\sigma$ uncertainty on the SM expectations.

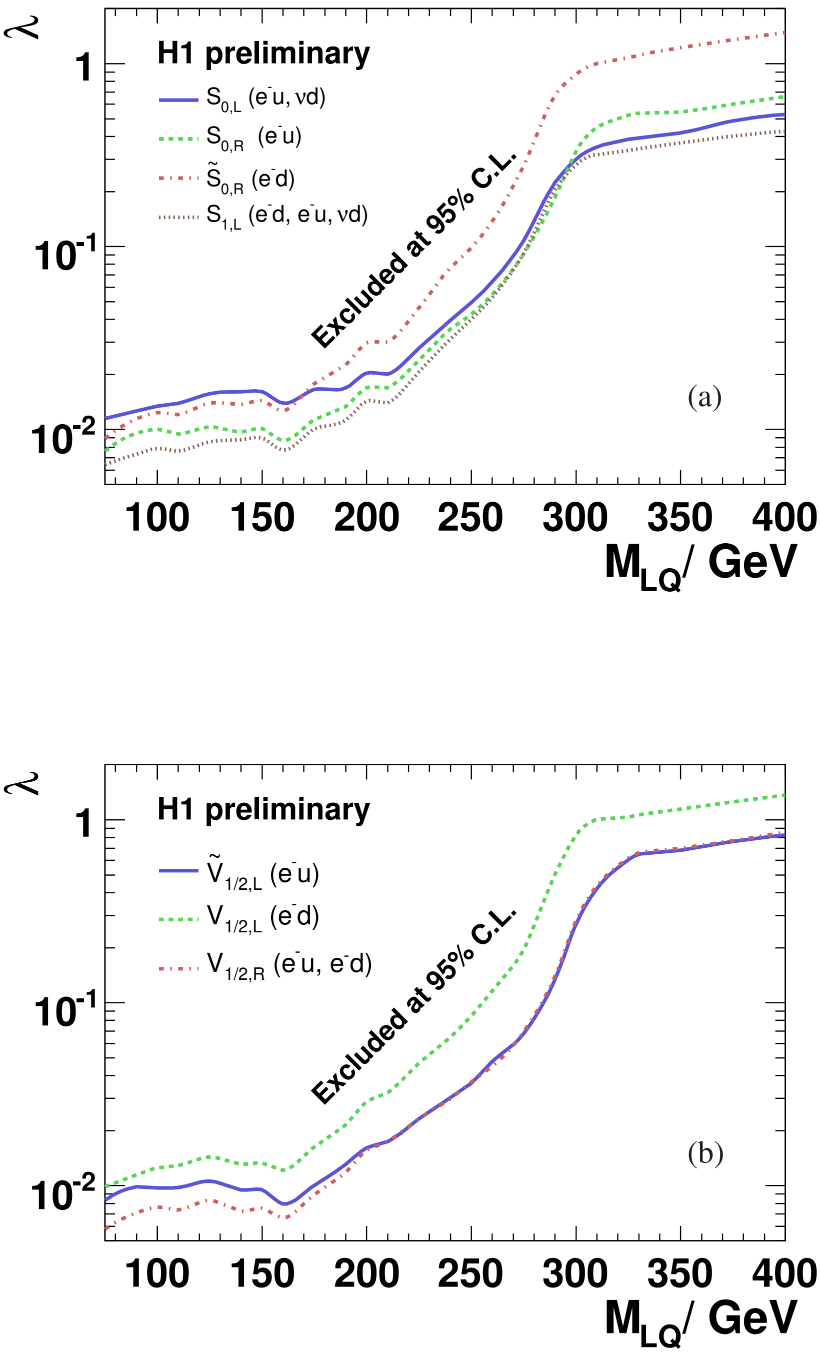

Figure 2: Exclusion limits for the 7 leptoquarks (LQs) with F=2 described by the Buchmüller, Rückl and Wyler (BRW) model. The limits are expressed at 95% CL on the coupling λ as a function of the leptoquark mass for the (a) scalar LQs with $F = 2$, (b) vector LQs with $F = 2$. Domains above the curves are excluded. For each LQ type the pairs of Standard Model fermions coupling to it are indicated in brackets.

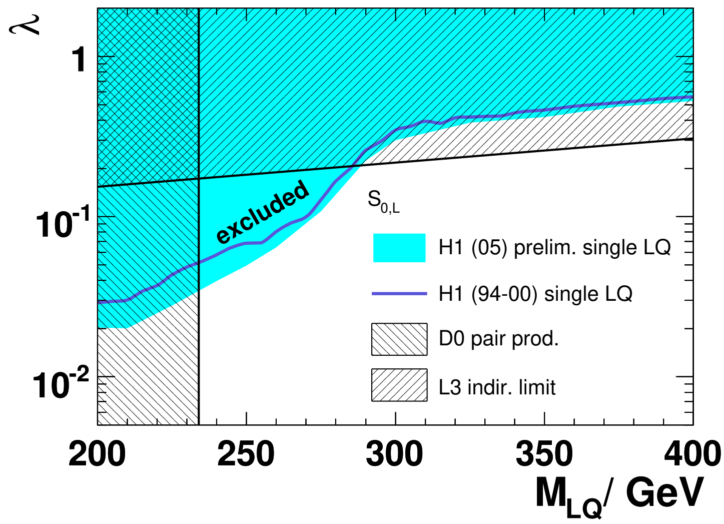

Figure 3: Exclusion limits at 95% CL on the coupling λ as a function of the leptoquark (LQ) mass for $S_{0,L}$ in the framework of the BRW model. The indirect limit from L3 and the direct D0 limits are shown for comparision. For comparison, the published H1 limit on $S_{0,L}$ from HERA I data is shown in addition.