Leptoquarks and Contact Interactions at HERA

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Abstract. Leptoquark and Contact Interaction searches have been performed in $e^{\pm}p$ collisions at HERA at a centre-of-mass energy of 300-320 GeV. The deep inelastic scattering data collected in the years 1994-2005 have been used for searches thus exploiting nearly whole available HERA statistics. No evidence for the leptoquarks was found. The limits from searches of leptoquarks coupling to first generation fermions (lepton flavour conserved) and searches of lepton flavour violation in ep collisions have been derived.
The deep inelastic neutral current scattering at high negative four momentum transfer squared Q^2 have been used to search for eq contact interactions associated to scales beyond HERA centre-of-mass energy. The neutral current cross section measurements are well described by the Standard Model and are used to set constraints on new phenomena.

1. Introduction

According to the general classification proposed by Buchmüler, Rückl and Wyler [1], there are 14 possible leptoquark (scalar and vector) states which obey the symmetries of the Standard Model (SM) gauge groups $\mathrm{U}(1)_Y$, $\mathrm{SU}(2)_L$, $\mathrm{SU}(3)_C$ and conserve lepton and baryon quantum numbers. At HERA, LQs can be resonantly produced in the s-channel or exchanged in the u-channel between the incoming lepton and a quark from the proton. The s-channel is dominant for leptoquark masses below the centre-of-mass energy of HERA, whereas for leptoquark masses above this threshold both u- and s-channels become equally important. In general, leptoquarks can couple and decay to the first generation leptons where the lepton flavour is conserved as well as to the higher generation leptons where lepton flavour is violated. The production of first generation leptoquarks may interfere with SM deep inelastic scattering (DIS), which is the main background process, thus modifying the cross section.
Similarly to the above, the new eq interactions involving mass scales above the centre-of-mass energy may constructively or destructively interfere with the DIS cross section at high Q^2 via virtual effects. A convenient way to study such new Beyond the Standard Model (BSM) phenomena is to search for four-fermion contact interactions (CI) at the very high Q^2 in neutral current (NC) DIS events.

2. Searches for leptoquarks coupling to the first generation fermions

Searches for leptoquarks coupling to e and ν have been performed by the H1 and ZEUS experiments using data taken in the years 1994-2000. In addition, data collected in 2005 with a polarised electron beam, corresponding to an integrated luminosity of 92 pb^{-1}, have been analysed by the H1 collaboration. Due to the more favorable quark-densities of quarks with respect to anti-quarks at high x, the 2005 electron data are mostly sensitive to leptoquarks with

fermion number F=2.
All searches consider LQ decays into eq and νq leading to final states similar to those of deep inelastic scattering neutral and charged current (CC) interactions at very high four momentum transverse Q^2. The leptoquarks would appear as a deviation in reconstructed invariant mass from the irreducible deep inelastic scattering background. No such deviations have been found and constraints on the leptoquarks in terms of mass and coupling strength λ [1] have been set.
In Figure 1 the leptoquark mass spectra and limits obtained for 2005 data are shown. For a coupling of electromagnetic strength, leptoquark masses below 276-304 GeV were ruled out, depending on the leptoquark type. A full description of first generation leptoquarks can be found in [2, 3, 4].

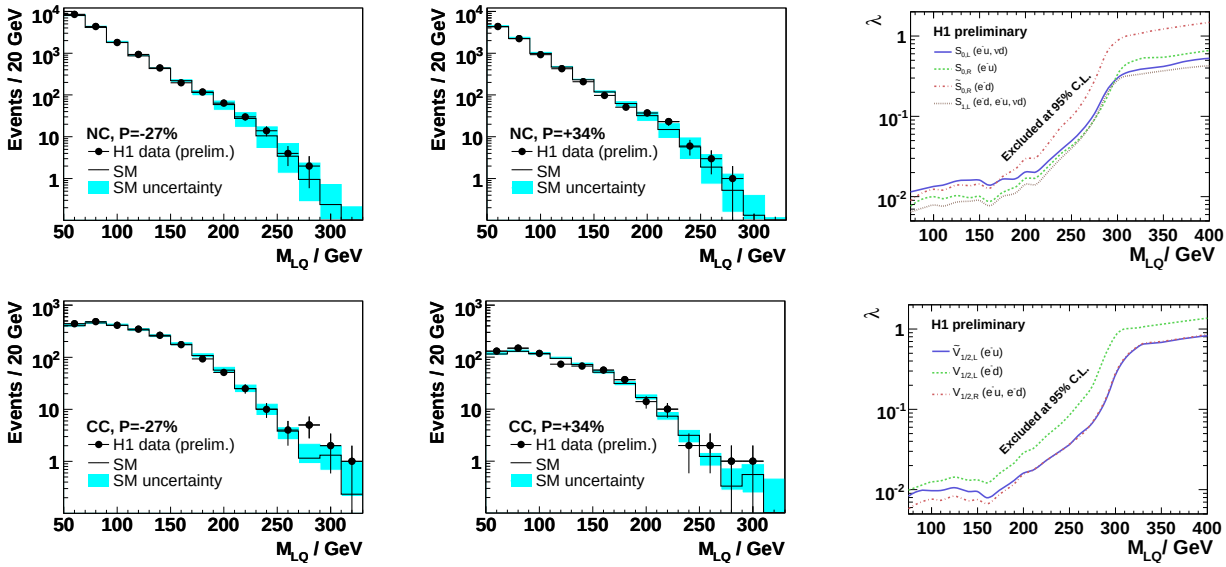

Figure 1. *Mass spectra for the neutral and charged current events in the 2005 H1 e^-p data of the negative and positive electron polarisation samples (left and middle), together with the SM expectation. On the right side the exclusion limits obtained for the 7 LQs with F=2 are shown.*

3. Searches for lepton flavour violating leptoquarks

Similarly to leptoquarks coupling to first generation fermions, leptoquarks coupling to μ and τ have been searched for in the years 1994-2000 by H1 and ZEUS experiments. The final states with a muon (tau) and a hadronic jet are searched for in the lepton flavour violating process $ep \to \mu X (ep \to \tau X)$. No evidence for lepton flavour violation is found and limits are derived on the mass and leptoquark couplings. Moreover, since the LQ production at HERA involves both lepton flavour conserved as well as lepton flavour violated decays, the combination of both processes have been analysed by the H1 collaboration [5]. Depending on the mass and type of leptoquark, the combination may bring a factor of 2 to 4 more stringent limits than without combination. Allowing for an arbitrary decay rate between both decay channels (β_{LFV}), the excluded regions for two leptoquark types and four masses are shown in Figure 2. For $\beta_{LFV} >> 0.5$, limits on the coupling strength λ_{eq} are significantly extended to lower values. Assuming a coupling of electromagnetic strength, leptoquark mediating lepton flavour violating processes are ruled out up to 459 GeV ($eq \to \tau X$) and 379 GeV ($eq \to \tau X$).

[1] A dimensionless parameter λ defines the coupling at the lepton-quark LQ vertex.

A detailed description of searches for the lepton flavour violation at HERA may be found in [5, 6].

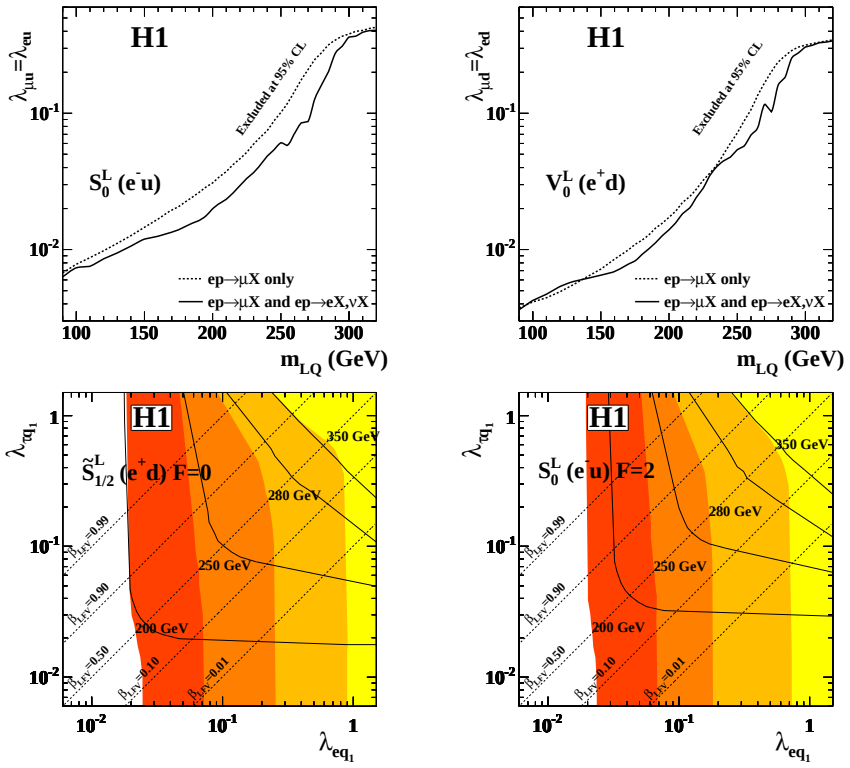

Figure 2. *Limits ruled out at 95% CL on the coupling strength λ under assumption $\lambda_{\mu q} = \lambda_{eq}$ as a function of leptoquark mass m_{LQ} for scalar S_0^L (top left) and vector V_0^L (top right) leptoquarks. Solid lines are limits after combination of lepton flavour conserving with violating channels. The lower plots show excluded regions at 95% CL on $\lambda_{\tau q1}$ as a function of λ_{eq1} for four different LQ masses where branching ratio between two channels is not fixed.*

4. Searches for eeqq contact interactions

New physics processes with characteristic mass scales in the TeV range may be present in deep inelastic $e^{\pm}p$ NC scattering at very high Q^2. The four fermion contact interaction concept may be exploited as a method to investigate the interference between any new particle field with the SM boson field. Several contact interaction models such as general models of compositeness, graviton exchange in models with large extra dimensions, heavy leptoquarks and quark form factor have been considered by H1 and ZEUS experiments. No significant deviations from Standard Model are found. Limits were derived on the effective mass scale in *eeqq* contact interactions, on the ratio of mass to the Yukawa coupling for heavy leptoquark models, mass scale parameter in models with large extra dimensions and limits on the quark charge radius in the classical form factor approximation. For example, under the assumption that the electron is point like, the 95% CL upper limit on the effective quark-charge radius is derived to be $R_q < 0.67 \times 10^{-18}$m by the ZEUS collaboration [7] (see Figure 3). More details of contact interaction searches at HERA can be found in [7, 8, 9].

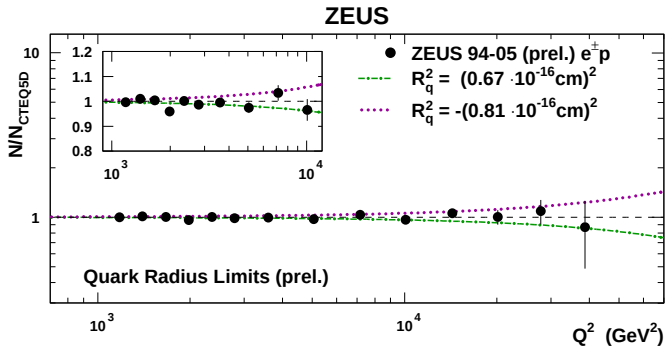

Figure 3. 1994-2005 ZEUS data compared with 95% CL exclusion limits for the effective mean square radius of the electroweak charge of the quark. Results are normalised to the SM expectations.

5. Conclusions

The $e^{\pm}p$ data collected in the years 2003-2005 at HERA have been combined with the HERA I data sets (1994-2000) and analysed by the H1 and ZEUS collaborations. In particular, the large statistics of electron data have increased the sensitivity for leptoquark and physics beyond the SM searches. No signal or large deviations from the SM predictions have been found and corresponding limits on a variety of models have been derived.

References

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