PROCEEDINGS OF SCIENCE

Search for first-generation leptoquarks at HERA

Katarzyna WICHMANN* **on behalf of the ZEUS Collaboration**
DESY
E-mail: kklimek@mail.desy.de

A search for first-generation leptoquarks was performed in *ep* collisions at HERA using the ZEUS detector, using an integrated luminosity of 366 pb^{-1}. Final states with an electron and jets or with missing transverse momentum and jets were analysed, searching for resonances or other deviations from the Standard Model predictions. No evidence for any leptoquark signal was found. The data were combined with data previously taken at HERA, resulting in a total integrated luminosity of 498 pb^{-1}. Limits on the Yukawa coupling, λ, of leptoquarks were set as a function of the leptoquark mass for different leptoquark types within the Buchmüller-Rückl-Wyler model. Leptoquarks with a coupling $\lambda = 0.3$ are excluded for masses up to 699 GeV.

36th International Conference on High Energy Physics,
July 4-11, 2012
Melbourne, Australia

*Speaker.

PoS(ICHEP2012)145

1. Introduction

Many extensions of the Standard Model (SM) predict the existence of particles carrying both baryon and lepton number, such as leptoquarks (LQs) [1]. In ep collisions at HERA, such states could have been produced directly through electron[1]-quark fusion if their masses, M_{LQ}, were lower than the HERA centre-of-mass energy, $\sqrt{s}$. The leptoquarks would have decayed into an electron and quark or an electron neutrino and quark, yielding peaks in the spectra of the final-state lepton-jets[2] invariant mass, M_{ljs}. Leptoquarks with $M_{\mathrm{LQ}} > \sqrt{s}$ could not have been produced as resonances, but they would still have caused deviations from the SM prediction in the observed M_{ljs} spectrum due to virtual LQ exchange. This paper presents an analysis of the M_{ljs} spectrum searching for evidence for leptoquarks.

The prediction for the M_{ljs} spectrum is given by SM neutral current (NC) and charged current (CC) deep inelastic scattering (DIS). Any leptoquark signal would have to be identified as a deviation from this SM prediction.

Leptoquarks have been searched for previously in ep collisions [2, 3, 4, 5] and in e^+e^- [6, 7], $p\bar{p}$ [8, 9] and pp [10, 11, 12] collisions. Using ep collisions, the Yukawa coupling, λ, of possible LQ states to electron and electron neutrino is probed. In $p\bar{p}$ and pp collisions, the LQ production proceeds via the strong interaction and is independent of λ. Thus the experimental approaches are complementary and ep collisions provide a unique testing ground. In the analysis presented here [13], no evidence for any leptoquark signal was found. Therefore limits on λ were derived as a function of M_{LQ} for the different leptoquark states described by the Buchmüller-Rückl-Wyler model) [1].

2. Experimental set-up

HERA was the world's only high-energy ep collider, with an electron beam of 27.6 GeV and a proton beam of 920 GeV (820 GeV until 1997).

The analysis is based on the data collected by the ZEUS experiment in the period 2003–2007, corresponding to an integrated luminosity of 366 pb^{-1}. During this period, HERA was operated with a polarised lepton beam. For the limit setting, $e^{\pm}p$ collision data collected with the ZEUS detector between 1994 and 2007, amounting to 498 pb^{-1} of integrated luminosity, have been used.

The ZEUS detector is a standard multi-purpose high-energy physics detector. A detailed description of the ZEUS detector can be found elsewhere [14].

3. Monte Carlo simulations

Monte Carlo techniques were used to determine the SM DIS background and the M_{ljs} resolution of a possible signal.

Standard Model NC and CC DIS events were simulated using the HERACLES 4.6.6 [15] program with the DJANGOH 1.6 [16] interfaces to the hadronisation programs and using CTEQ5D [17]

[1]Unless otherwise specified, 'electron' refers to both positron and electron and 'neutrino' refers to both neutrino and antineutrino.

[2]There can be more than one jet in the final state due to QCD initial- or final-state radiation.

PoS(ICHEP2012)145

PDFs. Radiative corrections for initial- and final-state electroweak radiation, vertex and propagator corrections, and two-boson exchange were included. The colour-dipole model of ARIADNE 4.12 [18] was used to simulate $\mathscr{O}(\alpha_S)$ plus leading-logarithmic corrections to the result of the quark-parton model. ARIADNE uses the Lund string model of JETSET 7.4.1 [19] for the hadronisation.

The production and decay of resonances were simulated using PYTHIA 6.1 [20], which takes into account the finite width of the resonant state, but includes only the s-channel diagrams. It also takes into account initial- and final-state QCD radiation from the quark and the effect of LQ hadronisation before decay [21] as well as the initial-state QED radiation from the electron.

The generated MC events were passed through the ZEUS detector and trigger simulation programs based on GEANT 3.13 [22]. They were reconstructed and analysed by the same programs as the data.

The Buchmüller-Rückl-Wyler (BRW) model [1] was used to calculate the cross sections in LO using the CTEQ5D PDFs for 14 LQ states. All limits presented in this paper are for LQ production in this model.

4. Signal search

Events from a hypothetical resonance decaying into eq (νq) have a topology identical to DIS NC (CC) events. Hence the final state from a high-mass resonance is expected to have at least one jet and either an identified final-state electron or large missing transverse momentum.

4.1 Neutral current, $ep \to eX$, topology

The double-angle (DA) method [23] was used to reconstruct the kinematic variables. Events with the topology $ep \to eX$, where X denotes one or more jets, were selected using the standard NC DIS criteria [13]. It included a requirement of well reconstructed electron and at least one hadronic jet with transverse momentum $p_T^j > 15$ GeV and its pseudorapidity $|\eta| < 3$, obtained using the k_T cluster algorithm [24] in its longitudinally invariant inclusive mode [25].

The measurement was restricted to the region most relevant to the LQ search, cuts $Q^2_{\rm DA} > 2500\,{\rm GeV}^2$ and $x_{\rm DA} > 0.1$ were applied.

After the selection, 9 369 events were found in the data from 2003–2007, compared to 9 465 $\pm$ 494 expected from the NC MC. The measured distributions of the M_{ejs} spectra for $e^{\pm}p$ data with a left-handed and a right-handed lepton beam are in good agreement with the SM NC prediction. Figure 1 shows the e^-p data for the left-handed electron beam together with the predictions for a S_0^L LQ state with a mass of 210 GeV and a coupling λ of 0.3, as well as a mass of 400 GeV and a coupling λ of 1.

4.2 Charged current, $ep \to \nu X$, topology

The kinematic variables in the events with the topology $ep \to \nu X$, where X denotes one or more jets, were reconstructed using the Jacquet-Blondel method [26].

The events were selected using the standard CC criteria [13], which include a missing transverse momentum $p_T > 22$ GeV and at least one hadronic jet with transverse momentum $p_T^j >$

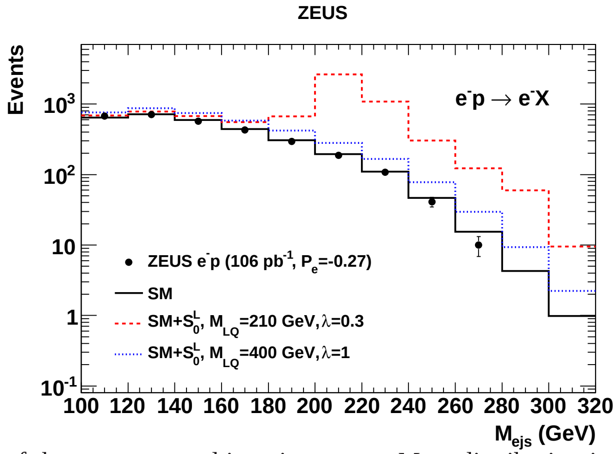

Figure 1: Comparison of the reconstructed invariant mass, M_{ejs}, distribution in the $e^-p \rightarrow e^-X$ topology for the left-handed e^-p sample (dots) to the NC SM expectation (solid histogram) and to the predictions of the model including a S_0^L LQ state with a mass of 210 GeV and a coupling λ of 0.3 (dashed histogram) as well as a mass of 400 GeV and a coupling λ of 1 (dotted histogram).

10 GeV and $|\eta| < 3$, obtained using the k_T cluster algorithm [24] in its longitudinally invariant inclusive mode [25].

After the selection, 8 990 events were found in the data from 2003–2007, compared to 9 068 $\pm$ 501 expected from the CC MC. The measured distributions of the $M_{\nu js}$ spectra for the left-handed and right-handed $e^{\pm}p$ data are in good agreement with the SM CC prediction.

5. Limits on leptoquarks

Since no evidence for the LQs was seen, the limits were calculated including the results of the search presented here and the data recorded with the ZEUS detector in the years 1994–2000 [4]. They were set using a binned likelihood technique in the (M_{ljs}, $\cos\theta^*$) plane, where θ^* is the lepton scattering angle in the lepton-jets centre-of-mass frame. The region $150 < M_{ljs} < 320$ GeV was used. The fitting procedure took into account different beam charges and polarisation. The upper limit on the coupling strength, $\lambda_{\rm limit}$, as a function of $M_{\rm LQ}$, was obtained. The coupling limits for the 14 BRW LQs were calculated for masses up to 1 TeV.

Figure 2 shows an example of the coupling limits on the scalar LQs with $F = 0$, where $F = 3B + L$ is the fermion number of the LQ and B and L are the baryon and lepton numbers, respectively. The limits were also calculated for the vector LQs with $F = 2$. The limits range from 0.004–0.017 for $M_{\rm LQ} = 150$ GeV, and from 0.43–3.24 for $M_{\rm LQ} = 1$ TeV. The lowest masses for which LQs with $\lambda = 0.1$ and with $\lambda = 0.3$ are not excluded range from 274 to 300 GeV for $\lambda = 0.1$ and from 290 to 699 GeV for $\lambda = 0.3$.

Figure 3 shows the limits on the $S^L_{1/2}$ LQ compared to the limits from ATLAS [10], H1 [5] L3 [6] and OPAL [7]. In general, the limits from this analysis are significantly better than the LEP limits for $M_{\rm LQ} < \sqrt{s}$, and comparable for $M_{\rm LQ} > \sqrt{s}$. The limits obtained by ZEUS are similar to those obtained by H1.

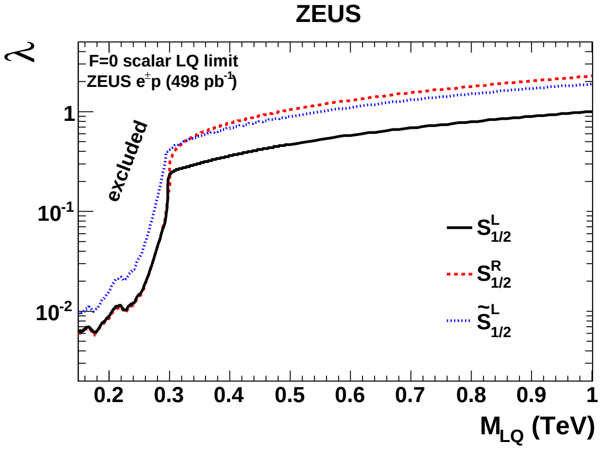

Figure 2: Coupling limits, $\lambda_{\rm limit}$, as a function of LQ mass for scalar F=0 BRW LQs.

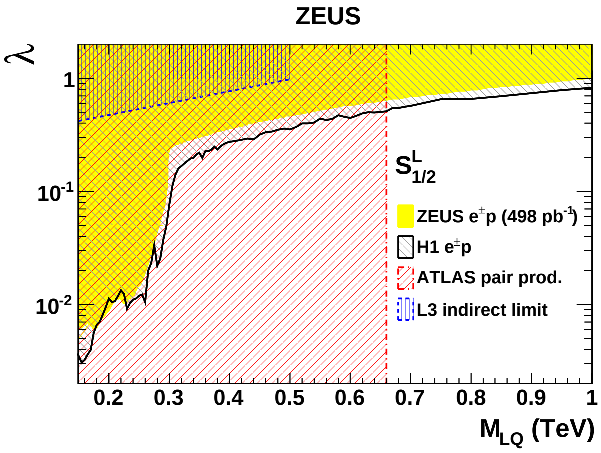

Figure 3: Coupling limits as a function of LQ mass for the $S^L_{1/2}$ LQ from ATLAS, L3, H1 and ZEUS.

6. Conclusions

Data recorded by the ZEUS experiment at HERA were used to search for the presence of first-generation scalar and vector leptoquarks. The data samples include 185 pb^{-1} of e^-p and 181 pb^{-1} of e^+p collisions with polarised electrons and positrons. No resonances or other deviations from the Standard Model were found. The inclusion of data with unpolarised beams yields a total set of data corresponding to 498 pb^{-1}, which was used to set upper limits on the Yukawa coupling λ for the 14 Buchmüller-Rückl-Wyler leptoquark states as a function of the leptoquark mass. Assuming $\lambda = 0.3$, the mass limits range from 290 to 699 GeV.

References

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

[2] ZEUS Coll., J. Breitweg et al., Eur. Phys. J. **C 16**, 253 (2000).

[3] ZEUS Coll., J. Breitweg et al., Phys. Rev. **D 63**, 052002 (2001).

[4] ZEUS Coll., S. Chekanov et al., Phys. Rev. **D 68**, 052004 (2003).

[5] H1 Coll., F.D. Aaron et al., Phys. Lett. **B 704**, 388 (2011).

[6] L3 Coll., M. Acciarri et al., Phys. Lett. **B 489**, 81 (2000).

[7] OPAL Coll., G. Abbiendi et al., Eur. Phys. J. **C 6**, 1 (1999).

[8] D0 Coll., V.M. Abazov et al., Phys. Lett. **B 681**, 224 (2009).

[9] CDF Coll., D. Acosta et al., Phys. Rev. **D 72**, 051107 (2005).

[10] ATLAS Coll., G. Aad et al., Phys. Lett. **B 709**, 158 (2012).

[11] CMS Coll., V. Khachatryan et al., Phys. Rev. Lett. **106**, 201802 (2011).

[12] CMS Coll., S. Chatrchyan et al., Phys. Lett. **B 703**, 246 (2011).

[13] ZEUS Collaboration, H. Abramowicz et al., DESY-12-077, accepted by Phys. Rev. D.

[14] ZEUS Coll., U. Holm (ed.), *The ZEUS Detector.* Status Report (unpublished), DESY (1993), available on http://www-zeus.desy.de/bluebook/bluebook.html.

[15] A. Kwiatkowski, H. Spiesberger and H.-J. Möhring, Comp. Phys. Comm. **69**, 155 (1992). Also in Proc. Workshop Physics at HERA, eds. W. Buchmüller and G.Ingelman, (DESY, Hamburg, 1991); H. Spiesberger, An Event Generator for ep Interactions at HERA Including Radiative Processes (Version 4.6), 1996, available on http://www.desy.de/ hspiesb/heracles.html.

[16] H. Spiesberger, HERACLES and DJANGOH: Event Generation for ep Interactions at HERA Including Radiative Processes, 1998, available on http://www.desy.de/ hspiesb/djangoh.html.

[17] CTEQ Coll., H.L. Lai et al., Eur. Phys. J. **C 12**, 375 (2000).

[18] L. Lönnblad, Comp. Phys. Comm. **71**, 15 (1992).

[19] T. Sjoštrand, Comp. Phys. Comm. **39**, 347 (1986); T. Sjoštrand and M. Bengtsson, Comp. Phys. Comm. **43**, 367 (1987); T. Sjoštrand, Comp. Phys. Comm. **82**, 74 (1994).

[20] T. Sjoštrand et al., Comp. Phys. Comm. **135**, 238 (2001).

[21] C. Friberg, E. Norrbin and T. Sjoštrand, Phys. Lett. **B 403**, 329 (1997).

[22] R. Brun et al., GEANT3, Technical Report CERN-DD/EE/84-1, CERN, 1987.

[23] S. Bentvelsen, J. Engelen and P. Kooijman, Proc. Workshop on Physics at HERA, W. Buchmüller and G. Ingelman (eds.), Vol. 1, p. 23. Hamburg, Germany, DESY(1992); K.C. Höger, Proc. Workshop on Physics at HERA, W. Buchmüller and G. Ingelman (eds.), Vol. 1, p. 43. Hamburg, Germany, DESY (1992).

[24] S. Catani et al., Nucl. Phys. **B 406**, 187 (1993).

[25] S.D. Ellis and D.E. Soper, Phys. Rev. **D 48**, 3160 (1993).

[26] F. Jacquet and A. Blondel, Proceedings of the Study for an ep Facility for Europe, U. Amaldi (ed.), p. 391. Hamburg, Germany (1979). Also in preprint DESY 79/48.