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Searches for New Physics at H1

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Recent results of searches for leptoquarks, lepton flavour violating leptoquarks and excited fermions (electrons, neutrinos and quarks) with the H1 experiment at HERA are presented, which use up to the full $e^{\pm}p$ H1 data set. No evidence for the direct or indirect production of such particles is found. The results are interpreted in terms of limits on the Yukawa coupling of leptoquarks and lepton flavour violating processes and for excited fermions on the ratio of the coupling parameter to the compositeness scale f/Λ, mainly in the framework of gauge mediated interactions. The derived limits extend the excluded regions to higher masses than those reported in previous results.

1. INTRODUCTION

The HERA $e^{\pm}p$ collider, located in Hamburg, Germany, was in operation in the years 1992–2007. Protons with an energy up to 920 GeV were brought into collision with electrons or positrons of energy 27.6 GeV at two experiments, H1 and ZEUS, each of which collected a data sample with a total integrated luminosity of about 0.5 fb^{-1}. The deep inelastic scattering (DIS) interactions produced at HERA, at a centre of mass energy $\sqrt{s}$ of up to 319 GeV, provided an ideal environment to study rare processes, set constraints on the Standard Model (SM) and search for new particles and physics beyond the Standard Model (BSM). Searches performed by the H1 Collaboration for leptoquarks, lepton flavour violating leptoquarks and excited fermions are presented in the following. Analyses of other rare processes at HERA are described elsewhere in these proceedings.

2. SEARCHES FOR LEPTOQUARKS

The HERA data provide the unique possibility to search for the resonant production of new particles that couple directly to a lepton and a parton. Leptoquarks (LQs), which appear naturally in various unifying BSM theories, are such an example. At HERA, LQs may be resonantly produced in the s-channel up to the centre of mass energy or virtually exchanged in the u-channel between the initial state lepton and a quark coming from the proton. Beyond the centre of mass energy the production mechanism proceeds via contact interactions.

A search for LQ production is performed by H1 in the 14 LQ framework of the Buchmüller, Rückl and Wyler (BRW) model [1], using the full H1 HERA data set. LQs are classified in terms of fermion number $F = |3B + L|$, where B and L are the baryon and lepton number respectively. Due to the more favourable density of quarks with respect to anti–quarks at high x, the e^-p data are mostly sensitive to LQs with fermion number $F = 2$, whereas the e^+p data are more sensitive to $F = 0$ LQs. H1 results based on HERA I data are presented in [2].

In the search for first generation LQs, the processes $ep \to LQ \to eq$ and $ep \to LQ \to \nu q$ are considered. These LQ decays lead to final states similar to those of neutral current (NC) and charged current (CC) DIS interactions, which constitute an irreducible SM background. No signal is observed in the DIS mass spectra and constraints on LQ production are set, which extend beyond the previously excluded domains. For a Yukawa coupling λ of electromagnetic strength, LQ masses below 291–330 GeV are ruled out by H1, depending on the LQ type [3]. Figure 1 presents the constraints on λ for the $S_{0,L}$ and $\tilde{S}_{1/2,L}$ LQs obtained by H1 as a function of LQ mass, M_{LQ}. Limits from LEP [4] are also shown, derived from indirect constraints on the process $e^+e^- \to q\overline{q}$, as well as limits from the Tevatron [5], where LQs would be pair–produced via the strong interaction resulting in a production rate that is independent of λ. As mentioned above, contact interactions can also be used to describe the effects of virtual

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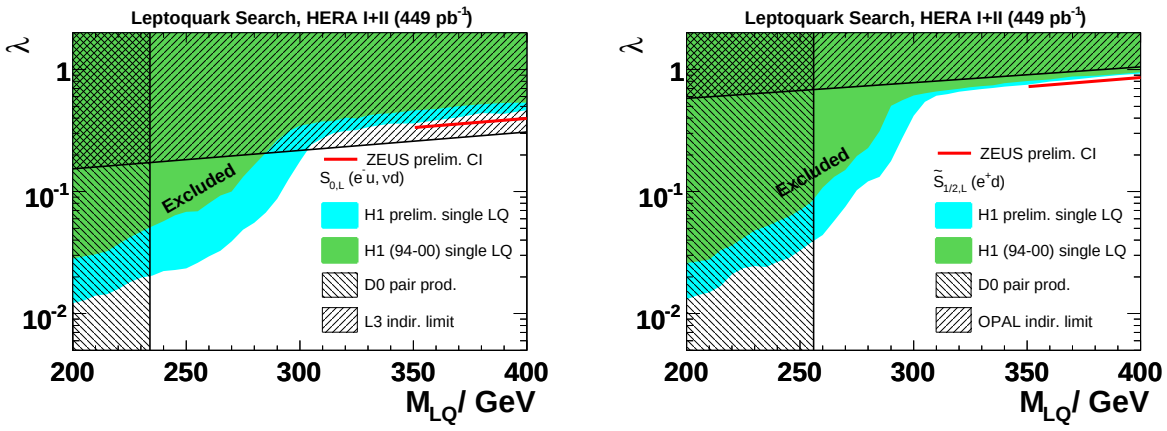

Figure 1: H1 exclusion limits at 95% C.L. on the Yukawa coupling λ as a function of the LQ mass for the $S_{0,L}$ (left) and $\tilde{S}_{1/2,L}$ (right) leptoquark in the BRW model. The improvement with respect to previous HERA I H1 results [2] is also visible.

LQ production or exchange at HERA in the limit of large LQ mass $M_{LQ} \gg \sqrt{s}$ and indirect LQ limits from the ZEUS contact interaction analysis [6] are also illustrated in figure 1.

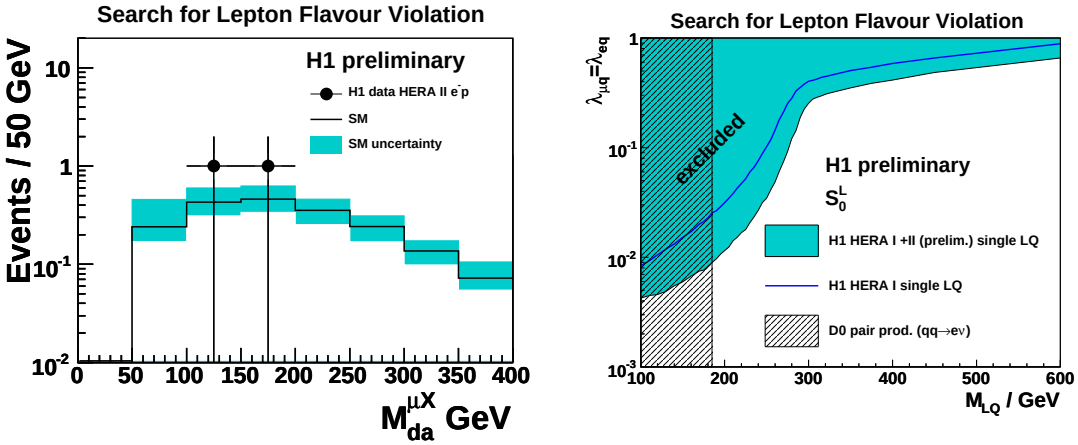

Figure 2: Left: Leptoquark mass spectrum after the final selection. The histogram shows the SM expectation, and the shaded band the SM uncertainty. Right: Exclusion limits at 95% C.L. on the coupling $\lambda_{\mu q} = \lambda_{eq}$ as a function of LQ mass for the $S_{0,L}$ leptoquark in the BRW model. The improvement with respect to previous HERA I H1 results [7] is also visible.

A search for lepton flavour violating (LFV) processes in ep collisions mediated by LQs is also performed by H1. At HERA, the LFV processes $eq \to LQ \to \mu q$ and $eq \to LQ \to \tau q$ may lead to final states with a muon or tau lepton, together with a hadronic jet. H1 results based on HERA I data are presented in [7], where searches for both second and third generation LQs are included. A new search for second generation $F = 2$ LQs using the complete H1 HERA II e^-p data is presented here [8]. Events are selected with a high P_T muon and large missing calorimetric P_T. The resulting LQ mass spectrum is shown in figure 2 (left). Two candidate data events are observed in agreement with the SM prediction, which, in contrast to the first generation, is negligible. In the absence of a LQ signal, limits are derived for the 7 $F = 2$ LQ types as a function of M_{LQ}. For Yukawa couplings of electromagnetic strength, LFV LQs coupling to a muon–quark pair are ruled out for LQ masses up to 433 GeV. Figure 2 (right) presents the constraints for the coupling $\lambda_{\mu q} = \lambda_{eq}$ for the $S_{0,L}$ LQ obtained by H1 as a function of M_{LQ}. A direct limit obtained at the TeVatron from leptoquark pair production is also shown for comparison [9].

3. SEARCHES FOR EXCITED FERMIONS

The existence of excited states of leptons and quarks is a natural consequence of models assuming composite fermions, and their discovery would provide convincing evidence of a new scale of matter. The production and decay of such particles is described in gauge–mediated (GM) and contact–interaction (CI) models.

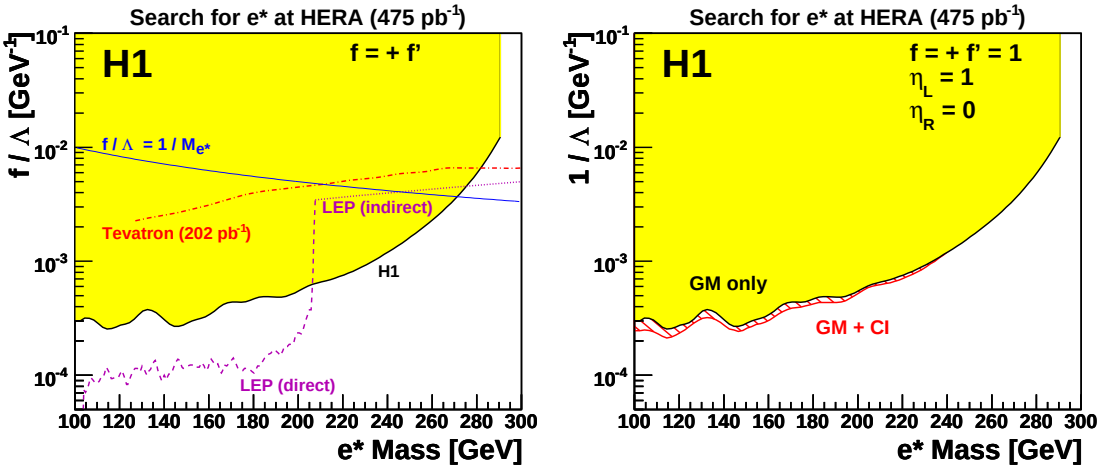

Figure 3: Left: H1 exclusion limits at 95% C.L. on f/Λ as a function of the mass of the excited electron considering GM interactions only, with the assumption $f = +f'$. The excluded domain is represented by the shaded area. Right: H1 exclusion limits at 95% CL on the inverse of the compositeness scale $1/\Lambda$ as a function of the mass of the excited electron. The hatched area corresponds to the additional domain excluded if GM and CI e^* production are considered together.

The excited electron decays $e^* \to e\gamma$, $e^* \to eZ$ and $e^* \to \nu W$ with subsequent hadronic or leptonic decays of the W and Z bosons are examined at HERA in a search for excited electrons by H1 [10]. In this search, which uses the complete H1 $e^{\pm}p$ data sample, each decay channel is investigated and no indication of a signal is observed. New limits on the production cross section of excited electrons are obtained within a GM model [11], where an upper limit on f/Λ as a function of the excited electron mass is established for the specific relation $f = +f'$ between the couplings. Assuming $f = +f'$ and $f/\Lambda = 1/M_{e^*}$ excited electrons with a mass lower than 272 GeV are excluded at 95% C.L, as shown in figure 3 (left). Also shown are direct [12] and indirect [13] exclusion limits obtained at LEP, as well as a result from the Tevatron [14]. For the first time in ep collisions, gauge and four–fermion contact interactions are also considered together for e^* production and decays, assuming $f = +f' = 1$. The CI term improves the limit on $1/\Lambda$ only slightly, demonstrating that the GM mechanism is dominant for excited electron processes at HERA, as illustrated in figure 3 (right).

A search for the production of excited neutrinos is performed by H1, using the full e^-p data sample, integrated luminosity 184 pb^{-1} [15]. Due to the helicity dependence of the weak interaction and given the valence quark composition and density distribution of the proton, the ν^* production cross section is predicted to be much larger for e^-p collisions than for e^+p. The excited neutrino decay channels $\nu^* \to \nu\gamma$, $\nu^* \to \nu Z$ and $\nu^* \to eW$ with subsequent hadronic or leptonic decays of the W and Z bosons are considered and no indication of a ν^* signal is found. Upper limits on the coupling f/Λ as a function of the excited neutrino mass are established within the GM model for specific relations between the couplings. Assuming $f = -f'$ and $f/\Lambda = 1/M_{\nu^*}$, excited neutrinos with a mass lower than 213 GeV are excluded at 95% C.L., as shown in figure 4 (left). The best limit obtained at LEP is also indicated [16]. The excluded region is greatly extended with respect to previous results, based on only 15 pb^{-1} of e^-p data [17], and demonstrates the unique sensitivity of HERA to excited neutrinos with masses beyond the LEP reach.

Finally, a search for excited quarks is performed using the full H1 $e^{\pm}p$ data sample [18]. The electroweak decays of excited quarks $q^* \to q\gamma$, $q^* \to qZ$ and $q^* \to qW$ with subsequent hadronic or leptonic decays of the W and Z bosons are considered. No evidence for excited quark production is found. Mass dependent exclusion limits on the ratio f/λ are derived within the GM model, as illustrated in figure 4 (right). Assuming $f = +f'$, no strong interactions

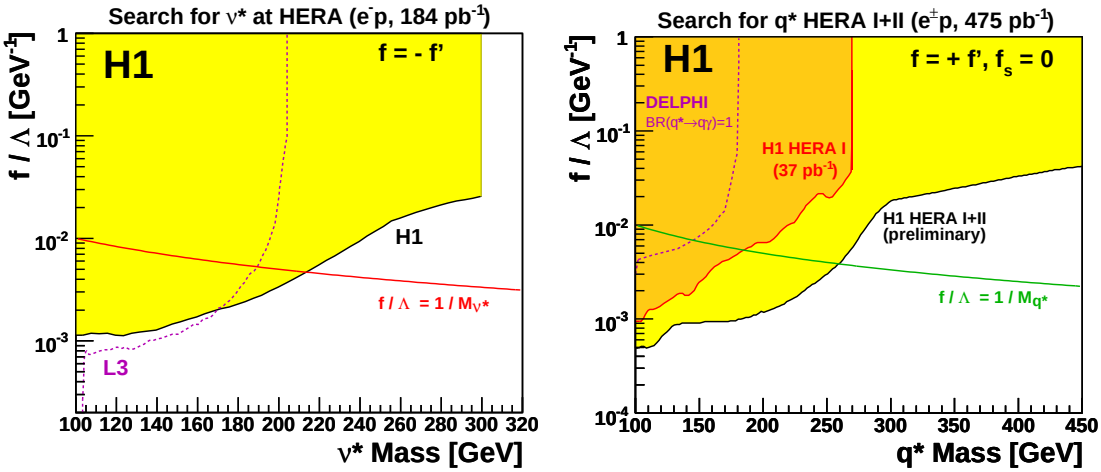

Figure 4: Left: H1 exclusion limits at 95% C.L. on the coupling f/Λ as a function of the mass of the excited neutrino with the assumption $f = -f'$. The excluded domain is represented by the shaded area. Right: H1 exclusion limits at 95% C.L. on the coupling f/Λ as a function of the mass of the excited quark with the assumptions $f = +f'$, $f_s = 0$. The excluded domain is represented by the shaded area. The improvement with respect to previous HERA I H1 results [20] is also visible.

$f_s = 0$ and $f/\Lambda = 1/M_{q^*}$, excited quarks with a mass lower than 259 GeV are excluded at 95% C.L. The best limit obtained at LEP also indicated [19], assuming that the branching ratio $BR(q^* \to q\gamma) = 1$. These limits extend the excluded region compared to previous H1 excited quark searches [20].

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