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LEPTON FLAVOUR VIOLATION AT HERA*

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Results obtained by the H1 and ZEUS collaborations on searches for Lepton Flavour Violation (LFV) are reported. No evidence was found for lepton–flavour violations and constraints were derived on the production of leptoquarks which could mediate such interactions. New limits in the muon channel obtained by ZEUS using 1999 and 2000 data, corresponding to an integrated luminosity of 66 pb^{-1}, have been combined with previous ZEUS results, thus using the whole 1994–2000 statistics (130 pb^{-1}). All limits have been then compared to those obtained by low energy experiments.

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1. Introduction

In the Standard Model (SM) lepton flavour is conserved. While the reported observation of neutrino oscillations [1, 2] implies that lepton–flavour violation does occur, minimal extensions of the SM [3] that allow for finite neutrino masses and thereby account for neutrino oscillations do not predict detectable rates of LFV at current collider experiments. However, many extensions of the SM, such as grand unified theories [4], models based on supersymmetry [5], compositeness [6] or technicolor [7], involve LFV interactions at fundamental level. At HERA, H1 and ZEUS searched for the process:

$$ep \to \ell X\,, \tag{1}$$

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where ℓ is either a μ or a τ and X is the hadronic final state. Such processes can be mediated by leptoquarks (LQ), bosons carrying both lepton (L) and baryon (B) number, coupling with different lepton and quark generations. On LFV interactions there are already strong constraints from low energy experiments [8].

2. Leptoquark model

In this paper the Buchmüller–Rückl–Wyler (BRW) model [9] has been adopted to give a quantitative description of LFV. This model requires $\mathrm{SU}(3)_c \otimes \mathrm{SU}(2)_\mathrm{L} \otimes \mathrm{U}(1)_Y$ invariant leptoquark couplings. In addition it assumes that members of the same isospin multiplet $SU(2)_\mathrm{L}$ are degenerate in mass and that leptoquarks can have left-handed or right handed couplings, but not both. With these assumptions fourteen leptoquark types are allowed, 7 scalars and 7 vectors, with fermion number $F = L + 3B = 0, 2$. According to the Aachen notation [10], scalar (vector) leptoquarks are named $S_T^\chi (V_T^\chi)$ where $\chi =$ L, R is the chirality of the lepton and $T = 0, 1/2, 1$ is the weak isospin. If the leptoquark has a mass below the center mass energy of HERA (300 GeV for 1994–97 data and 318 GeV for 1998–2000 data), it can be produced as a narrow resonance, with the s channel (Fig. 1(left)) giving the dominant contribution. Leptoquarks coupling with a valence quark have a much higher cross section than those coupling with sea quarks, therefore, for a positron beam, only limits for $F = 0$ leptoquarks are considered (the opposite holds for an electron beam). If the leptoquark mass is much greater than the center mass energy of HERA both the s and u channel give a contribution (Fig. 1); the cross section can be approximated with a contact-like interaction formula and it is proportional to the factor $(\lambda_{eq_i}\lambda_{\ell q_j}/M_{LQ}^2)^2$.

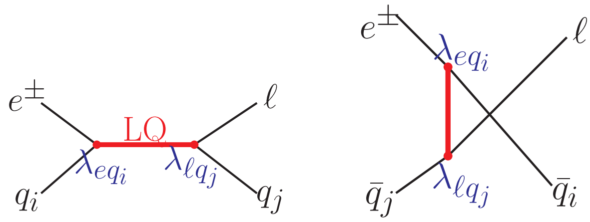

Fig. 1. LFV processes mediated by leptoquarks: s-channel (left) and u-channel (right).

3. Experimental signature

At HERA the experimental signature of a LFV process is a high transverse momentum lepton (μ or τ) and a jet, coming from the struck quark, with an opposite azimuthal angle respect to the lepton. In the τ channel only the τ decay products can be detected. The signature is hence a high transverse momentum $p_{\rm t}$ lepton or a narrow jet with a low track multiplicity coming from the hadronic τ decay. In all decay channels the presence of the μ and/or the neutrinos leads to a missing transverse momentum in the lepton direction. Such processes have a low standard model background and they can be detected with a very high efficiency (up to 40%–60% for the μ channel, 25%–30% for the τ channel). No candidate was observed by the two experiments H1 and ZEUS, in the HERA I data analysed up to now. Therefore, limits were set on the production of leptoquarks that mediate LFV interactions.

4. Results

4.1. Low mass leptoquarks limits

Fig. 2 (left) shows H1 95% CL limits in the τ channel on the coupling constant *versus* the leptoquark mass for $S^{\rm L}_{1/2}$ for different branching ra-

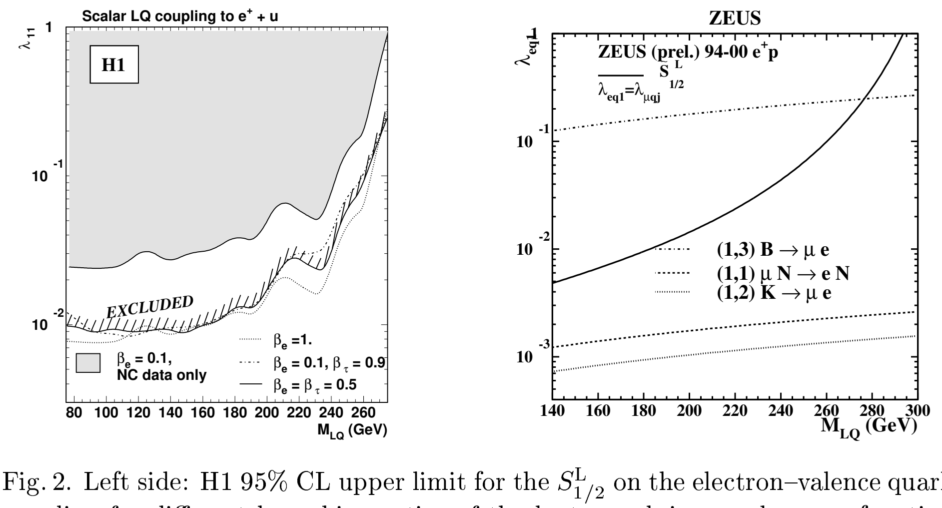

Fig. 2. Left side: H1 95% CL upper limit for the $S^{\rm L}_{1/2}$ on the electron–valence quark coupling for different branching ratios of the leptoquark in e and τ as a function of the leptoquark mass. Right side: ZEUS 95% CL limits (solid line) for $\widetilde{S}^{\rm L}_{1/2}$ leptoquark decaying into μq_i (the subscript i denotes any generation of quarks), compared to the low energy experiments limits (dotted lines).

tios β_ℓ ($\ell = e, \tau$) of the leptoquark in e and τ. These results [11] are obtained analysing 1994–1997 data corresponding to an integrated luminosity of 37 pb^{-1}. Assuming an electromagnetic like coupling constant and $\beta_e = 0.1$, $\beta_\tau = 0.9$, a limit of 250 GeV on the leptoquark mass has been set. Similar results in the τ channel have been obtained by ZEUS [12], with a luminosity of 47.7 pb^{-1}. Fig. 2 (right) shows the ZEUS 95% CL upper limit *versus* the leptoquark mass for $\widetilde{S}^{\mathrm{L}}_{1/2}$ on the coupling constant (μ channel), obtained combining all e^+p statistics (113 pb^{-1}). The results (solid line) are compared to those from low energy experiments (dotted lines). When heavy quarks are involved HERA limits are competitive with those from mesons rare decays. If we assume $\lambda_{eq_1} = 0.3 \sim \sqrt{4\pi\alpha}$ and $\beta_\mu = 0.5$ (or $\beta_\mu = 0.25$ if ν decays are allowed), leptoquarks with masses up to 301 GeV (very close to the HERA kinematic limit) can be excluded at 95% CL.

4.2. High mass leptoquarks limits

ZEUS 95% CL limits on the factor $\lambda_{eq_i}\lambda_{\mu q_j}/M^2_{LQ}$ for the μ channel, obtained combining the whole 1994–2000 statistics (130 pb^{-1}) are reported in Table I. When second generation of quarks are involved ZEUS limits supersede limits from D mesons rare decays.

5. Conclusions

A review on LFV searches at HERA has been presented. The 1994–1997 data have been already analysed by H1 and ZEUS both in the μ and in the τ channel. New ZEUS preliminary results for the whole HERA I statistics in the μ channel have been reported in this paper. No evidence of lepton flavour violating interaction has been found up to now, thus limits on the leptoquarks Yukawa couplings have been set. The presented results are competitive with bounds from low energy experiments, especially when the second or the third generation of quarks are involved.

TABLE I

95% CL upper limits on $(\lambda_{eq_i}\lambda_{\mu q_j})/M^2_{LQ}$ for $F=0$ leptoquarks (in units of TeV^{-2}). The first column indicates the quark generations q_i and q_j coupling to LQ–e and LQ–μ, respectively. The second row indicates the $F=0$ leptoquarks and their couplings. The ZEUS results are shown in the third row of each cell, while in the first and in the second row are reported respectively the low energy process providing the most stringent limit and its value. ZEUS limits which are better than the low energy constraints are enclosed in a box. The * indicates the cases where a top quark would have to be involved.

$F=0$	Zeus preliminary (94–00 combined limits)					$(\lambda_{eq_i}\lambda_{\mu q_j})/M^2_{LQ}$ (TeV^{-2})	
q_iq_j	$S^{\mathrm{L}}_{1/2}$ $e^-\bar{u}$ e^+u	$S^{\mathrm{R}}_{1/2}$ $e^-(\bar{u}+\bar{d})$ $e^+(u+d)$	$\tilde{S}^{\mathrm{L}}_{1/2}$ $e^-\bar{d}$ e^+d	V^{L}_0 $e^-\bar{d}$ e^+d	V^{R}_0 $e^-\bar{d}$ e^+d	$\tilde{V}^{\mathrm{R}}_0$ $e^-\bar{u}$ e^+u	V^{L}_1 $e^-(\sqrt{2}\bar{u}+\bar{d})$ $e^+(\sqrt{2}u+d)$
1 1	$\mu N\to eN$ 7.6×10^{-5} **1.1**	$\mu N\to eN$ 2.6×10^{-5} **0.9**	$\mu N\to eN$ 7.6×10^{-5} **1.6**	$\mu N\to eN$ 2.6×10^{-5} **1.0**	$\mu N\to eN$ 2.6×10^{-5} **1.0**	$\mu N\to eN$ 2.6×10^{-5} **0.8**	$\mu N\to eN$ 1.1×10^{-5} **0.4**
1 2	$D\to\mu\bar{e}$ 4 $\boxed{\mathbf{1.2}}$	$K\to\mu\bar{e}$ 2.7×10^{-5} **1.0**	$K\to\mu\bar{e}$ 2.7×10^{-5} **1.7**	$K\to\mu\bar{e}$ 1.3×10^{-5} **1.2**	$K\to\mu\bar{e}$ $.3\times10^{-5}$ **1.2**	$D\to\mu\bar{e}$ 2 $\boxed{\mathbf{1.0}}$	$K\to\mu\bar{e}$ 1.3×10^{-5} **0.5**
1 3	*	$B\to\mu\bar{e}$ 0.8 **1.8**	$B\to\mu\bar{e}$ 0.8 **1.8**	V_{ub} 0.2 **1.5**	$B\to\mu\bar{e}$ 0.4 **1.5**	*	V_{ub} 0.2 **1.5**
2 1	$D\to\mu\bar{e}$ 4 $\boxed{\mathbf{3.6}}$	$K\to\mu\bar{e}$ 2.7×10^{-5} **2.4**	$K\to\mu\bar{e}$ 2.7×10^{-5} **3.2**	$K\to\mu\bar{e}$ 1.3×10^{-5} **1.3**	$K\to\mu\bar{e}$ 1.3×10^{-5} **1.3**	$D\to\mu\bar{e}$ 2 $\boxed{\mathbf{1.3}}$	$K\to\mu\bar{e}$ 1.3×10^{-5} **0.6**
2 2	$\mu\to3e$ 5×10^{-3} **5.8**	$\mu\to3e$ 7.3×10^{-3} **3.1**	$\mu\to3e$ 1.6×10^{-2} **3.8**	$\mu\to3e$ 8×10^{-3} **1.9**	$\mu\to3e$ 8×10^{-3} **1.9**	$\mu\to3e$ 2.5×10^{-3} **2.9**	$\mu\to3e$ 1.5×10^{-3} **1.2**
2 3	*	$B\to\bar{\mu}eK$ 0.6 **4.4**	$B\to\bar{\mu}eK$ 0.6 **4.4**	$B\to\bar{\mu}eK$ 0.3 **2.9**	$B\to\bar{\mu}eK$ 0.3 **2.9**	*	$B\to\bar{\mu}eK$ 0.3 **2.9**
3 1	*	$B\to\mu\bar{e}$ 0.8 **4.3**	$B\to\mu\bar{e}$ 0.8 **4.3**	V_{ub} 0.2 **1.4**	$B\to\mu\bar{e}$ 0.4 **1.4**	*	V_{ub} 0.2 **1.4**
3 2	*	$B\to\bar{\mu}eK$ 0.6 **5.8**	$B\to\bar{\mu}eK$ 0.6 **5.8**	$B\to\bar{\mu}eK$ 0.3 **2.2**	$B\to\bar{\mu}eK$ 0.3 **2.2**	*	$B\to\bar{\mu}eK$ 0.3 **2.2**
3 3	*	$\mu\to3e$ 7.3×10^{-3} **7.7**	$\mu\to3e$ 1.6×10^{-2} **7.7**	$\mu\to3e$ 8×10^{-3} **3.9**	$\mu\to3e$ 8×10^{-3} **3.9**	*	$\mu\to3e$ 1.5×10^{-3} **3.9**

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