

# Recent HERA Results on Leptoquarks and other SUSY-related Signatures

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**Abstract.** The HERA  $ep$  collider and the experiments H1 and ZEUS operated from 1994-2007. A total integrated luminosity of almost  $1 \text{ fb}^{-1}$  was collected at centre-of-mass energies up to 320 GeV. Results from searches for leptoquarks and squarks, final states with an isolated lepton and missing transverse momentum and final states with multi-leptons are presented. The leptoquark limits are interpreted in terms of limits on squark production in SUSY models with  $R$ -parity violating couplings.

**Keywords:** heras, zeus, h1, deep inelastic, dis, electroweak, susy, lepton flavour violation, r-parity violation, anomalous coupling, leptoquark, squark, isolated lepton, w production, limit, search, new physics, beyond the standard model

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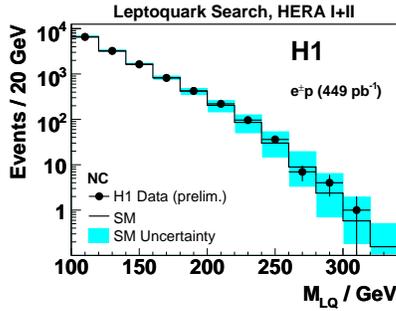


FIGURE 1. H1 reconstructed mass spectra for  $LQ \rightarrow eq$ .

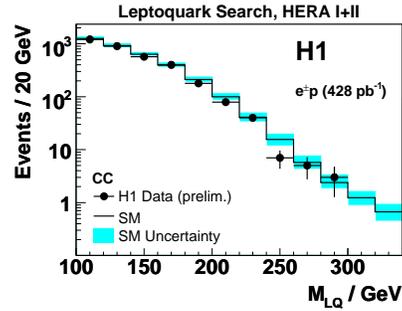


FIGURE 2. H1 reconstructed mass spectra for  $LQ \rightarrow \nu q$ .

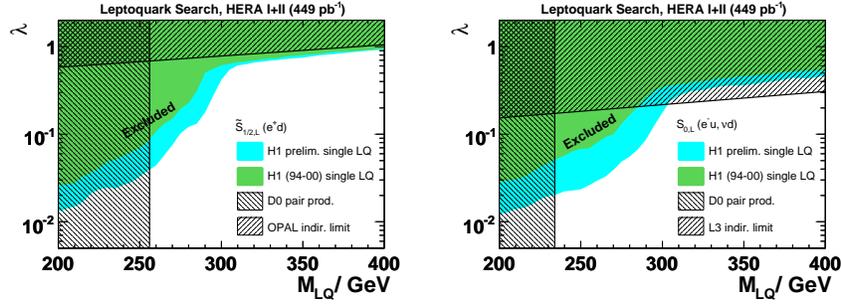
## SEARCHES FOR LEPTOQUARKS AT HERA

At HERA, leptoquarks (LQs) may be resonantly produced by the fusion of the incoming lepton and a quark originating from the proton. Depending on their quantum numbers and couplings, these objects may decay into a charged or neutral lepton and a quark. However, for both reactions  $ep \rightarrow eX$  and  $ep \rightarrow \nu X$  there is irreducible background from deep-inelastic scattering. For LQ masses below the kinematic limit of HERA (320 GeV) one may be able to see LQs as a resonant structure in the reconstructed mass  $M_{LQ}$ . If the LQ mass is higher, LQs may show up as contact interactions.

Dedicated searches for LQs and contact interactions mediated by LQs have been reported earlier [1, 2, 3, 4] for a subset of the HERA data, collected from 1994-2000. Here updated results, comprising the full HERA datasets are presented [5]. Figure 1 and 2 show the reconstructed LQ mass spectra seen by the H1 collaboration. No evidence for LQ production is seen, and limits are set on the LQ coupling  $\lambda$  as a function of the LQ mass.

A total of 14 LQ models are investigated [6]. Two LQs, namely the  $\tilde{S}_{1/2,L}$  and the  $S_{0,L}$  are of special interest, because these can be interpreted as a squark produced via  $R$ -parity ( $R_P$ ) violating coupling  $\lambda'_{ij}$  [7]. The correspondence of LQ type and SUSY particle is indicated in Table 1. Limits on LQ production at 95% confidence level, determined from the complete H1 data are shown in Figure 3. They may be interpreted as squark limits for SUSY models where the direct  $R_P$  violating decay dominates or for models with squark masses larger than the HERA centre-of-mass energy. For couplings of electromagnetic strength,  $\lambda = 0.3$ , the production of  $\tilde{S}_{1/2L}$  and  $S_{0L}$  LQs are excluded for masses up to 295 GeV and 310 GeV, respectively.

The single-differential cross-sections  $d\sigma/dQ^2$  in neutral-current deep-inelastic scattering are sensitive to LQ production, mediated by contact interactions. Again,  $\tilde{S}_{1/2L}$  and  $S_{0L}$  LQs may be interpreted as squarks in  $R_P$  violating SUSY models. The ZEUS collaboration reports preliminary limits on the ratio of LQ mass to coupling  $M/\lambda$ , using  $274 \text{ pb}^{-1}$  of data [8]. The 95% confidence limits on are summarised in Table 1.



**FIGURE 3.** H1 preliminary 95% confidence limits on the production of  $\tilde{S}_{1/2L}$  and  $S_{0L}$  leptoquarks, corresponding to  $\tilde{u}_i$  and  $\tilde{d}_j$  squarks in  $R_P$  violating models, respectively. Limits on the coupling  $\lambda$  are shown as a function of the leptoquark mass.

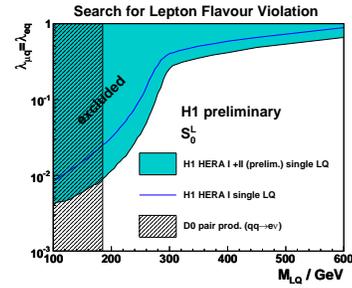
**TABLE 1.** ZEUS exclusion limits on  $M/\lambda$  in contact interactions mediated by leptoquarks.

ZEUS 1994-2005 (prel.) $e^\pm p$				
Scalar leptoquarks		Vector leptoquarks		
LQ	$\tilde{q}$	95% C.L. [TeV]	LQ	95% C.L. [TeV]
$S_0^L$	$\tilde{d}_j$	0.96	$V_0^L$	0.80
$S_0^R$		0.82	$V_0^R$	0.62
$\tilde{S}_0^R$		0.32	$\tilde{V}_0^R$	1.33
$S_{1/2}^L$	$\tilde{u}_i$	0.88	$V_{1/2}^L$	0.46
$S_{1/2}^R$		0.46	$V_{1/2}^R$	1.00
$\tilde{S}_{1/2}^L$		0.44	$\tilde{V}_{1/2}^L$	1.10
$S_1^L$		0.74	$V_1^L$	1.91

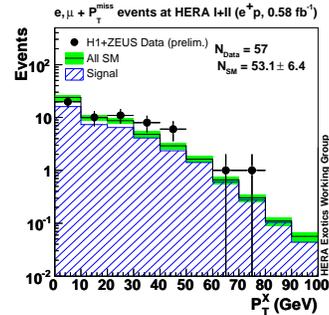
Another model for LQ production at HERA includes flavour-violating decays. The LQ may have a couplings  $\lambda_{\mu q'}$  or  $\lambda_{\tau q'}$  in addition to the coupling  $\lambda_{eq}$ , which has been discussed above. At HERA such models are probed in the reactions  $ep \rightarrow \mu X$  or  $ep \rightarrow \tau X$  [9, 10]. It is worth noting that the limits on the search for  $\tilde{S}_{1/2,L}$  and  $S_{0,L}$  LQs may be interpreted as a search for squarks with off-diagonal  $R_P$  violating couplings  $\lambda'_{ijk}$ . Results from a search for LQs decaying to  $\mu^- + \text{jet}$  using the full H1  $e^-p$  data [11] are shown in Figure 4. For couplings of electromagnetic strength  $\lambda_{\mu q'} = \lambda_{eq} = 0.3$ , assuming  $\lambda_{\tau q'} = 0$ , the production of a  $S_{0L}$  is excluded for masses up to 305 GeV.

## SIGNATURES WITH ISOLATED LEPTON AND MISSING TRANSVERSE MOMENTUM

The HERA data are searched for events with an isolated lepton ( $\ell = e, \mu$ ) with high transverse momentum  $P_T^\ell > 10 \text{ GeV}$  and high missing transverse momentum  $P_T^{\text{miss}} > 12 \text{ GeV}$ . The  $P_T^{\text{miss}}$  is attributed to a neutrino

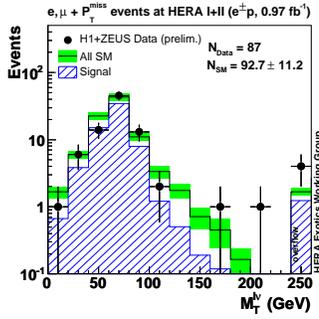


**FIGURE 4.** H1 preliminary 95% confidence limits on the production of a  $S_{0L}$  leptoquark with flavour-violating couplings  $\lambda_{\mu q'} = \lambda_{eq}$  ( $\lambda_{\tau q'} = 0$ ).



**FIGURE 5.** H1 and ZEUS combined data on isolated leptons ( $\ell = e, \mu$ ) with missing transverse momentum. The  $e^+p$  data are shown as a function of the transverse momentum of the hadronic system  $P_T^X$ .

which escaped detection. The main signal process is SM real  $W$  production. Heavy resonances would be expected to produce an excess over the SM predictions at large values of total hadronic transverse momentum,  $P_T^X$ . The data from both experiments, ZEUS and H1, are combined in a common phase-space [12]. Figure 5 shows the distribution of  $P_T^X$  for the  $e^+p$  data. At high  $P_T^X$ , where the SM prediction is small, there is an excess of events, with 23



**FIGURE 6.** H1 and ZEUS combined data on isolated leptons ( $\ell = e, \mu$ ) with missing transverse momentum. The data are shown as a function of the transverse mass.

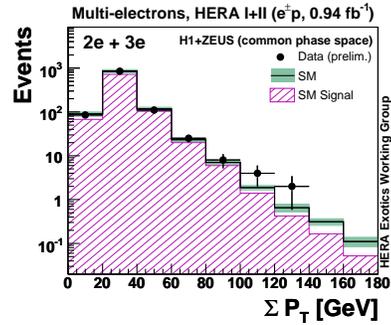
observed over  $14.6 \pm 1.9$  expected from Standard Model (SM) processes. No such excess is present in the  $e^-p$  data. The transverse mass of the lepton and the neutrino is investigated in Figure 6. There is clear evidence that the events are dominated by SM single  $W$  production. An excess of such events in  $e^+p$  data may originate in SUSY models from bosonic stop decays, as studied in detail with HERA I data [13]. Alternatively, an enhanced production of real  $W$  bosons at HERA may originate from the decay of anomalously produced top quarks, as previously investigated with HERA I data [14, 15]. The H1 collaboration reports a preliminary 95% confidence limit on the anomalous coupling  $|\kappa_{tuy}| < 0.14$ , using their complete dataset [16].

## MULTI-LEPTON SIGNATURES

H1 and ZEUS have searched their complete data for signatures with two or three leptons ( $\ell = e, \mu$ ) [17, 18]. Such events are predicted in several exotic models, for example from the decay of doubly charged Higgs bosons [19]. The combined H1 and ZEUS data from a search for three electron final states [20] are shown in Figure 7. At high transverse momenta  $\sum P_T > 100 \text{ GeV}$  there is an upward fluctuation of 6 data events compared to  $3 \pm 0.34$  expected. Because the HERA collider has ceased operation, it is not possible to investigate further the nature of this fluctuation.

## SUMMARY

New results from searches for Leptoquarks, isolated leptons with missing transverse momentum and multi-lepton signatures at HERA have been reported. No clear evidence of new physics has been found. Compared to older results, improved limits on Leptoquark production and anomalous top couplings are derived.



**FIGURE 7.** H1 and ZEUS combined data on multi-electrons. The data are shown as a function of the scalar sum of the transverse momenta.

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