

# Recent HERA Results Sensitive to SUSY

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Recent results of searches for new physics at HERA using the complete data sample corresponding to about  $0.5 \text{ fb}^{-1}$  per experiment are reviewed. Searches for leptoquarks, isolated leptons (electrons, muons and taus) and a generic search for new physics in many topologies are reported. No evidence for new physics is found. The  $ep$  collisions at HERA are ideally suited to search for resonantly produced squarks in SUSY with  $R$ -parity violation. It is highlighted how the present results can be interpreted in this way.

## 1. LEPTOQUARKS

The  $ep$  collider HERA located at DESY, Hamburg, was ideally suited to search for new particles coupling to electron- or positron-quark pairs during its operation time from 1992 to 2007. Such leptoquark (LQ) particles could be resonantly produced up to a centre-of-mass energy of  $\sqrt{s} = 320 \text{ GeV}$ . Via contact-interaction-like exchange of particles the sensitivity of HERA extends to even higher energies. In the general Buchmüller-Rückl-Wyler (BRW) framework a total of 14 LQs are investigated [1]. In SUSY with  $R$ -parity violation, squarks are produced in the same way via Yukawa couplings  $\lambda'_{ijk}$ , where the indices denote families [2, 3, 4]. Two of the LQs, namely the  $\tilde{S}_{1/2}^L$  and the  $S_0^L$  in the BRW notation can be interpreted as  $\tilde{u}_j$  or  $\tilde{d}_k$  squarks produced via  $R$ -parity violating couplings  $\lambda'_{1j1}$  or  $\lambda'_{11k}$ , respectively.

These objects may appear in the reactions  $ep \rightarrow eX$  and  $ep \rightarrow \nu X$ , where the  $X$  denotes the hadronic final state. For these reactions there is an irreducible background from deep-inelastic neutral and charged current scattering. For LQ masses below the kinematic limit of HERA (320 GeV) one may see LQs as a resonant structure in the reconstructed mass  $M_{LQ}$ . Figure 1 shows the LQ mass spectra seen by the H1 collaboration using the full HERA dataset [5]. No evidence for LQ production is seen, and limits are set on the LQ coupling  $\lambda_{eq}$  as a function of the LQ mass. Limits on LQ production at 95% confidence level are shown in Figure 2. They may also be interpreted as squark limits for SUSY models where the direct  $R$ -parity 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  $\tilde{S}_{1/2}^L$  and  $S_0^L$  LQs are excluded for masses up to 295 GeV and 310 GeV, respectively.

If the LQ mass is higher than the kinematic limit, LQs may show up as contact interactions. For this region, the ZEUS collaboration reports preliminary limits on the ratio of LQ mass to coupling  $M/\lambda$ , using  $274 \text{ pb}^{-1}$  of data [6]. For example, the production of  $\tilde{S}_{1/2}^L$  LQs is excluded for  $M/\lambda < 0.96 \text{ TeV}$ .

Another model for LQ production at HERA includes flavour-violating decays. Here the LQ may also have couplings  $\lambda_{\mu q'}$  or  $\lambda_{\tau q'}$ . At HERA such models are probed in the reactions  $ep \rightarrow \mu X$  or  $ep \rightarrow \tau X$  [7, 8]. Again 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  $R$ -parity violating couplings  $\lambda'_{ijk}$ . A preliminary search for LQs decaying to  $\mu^- + \text{jet}$  has been updated using the full H1  $e^-p$  data [9]. For couplings of electromagnetic strength  $\lambda_{\mu q'} = \lambda_{e q} = 0.3$ , assuming  $\lambda_{\tau q'} = 0$ , the production of a  $S_{0L}$  is excluded for masses up to 305 GeV.

## 2. ISOLATED LEPTONS

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 which escaped detection. SUSY models predict an enhanced rate of such events with isolated leptons in  $ep$  collisions, for example due to resonant  $\tilde{t}$  production, as has been investigated in HERA-I data [10]. Such heavy resonances would be expected to produce an excess over the SM predictions at large values of total hadronic transverse momentum

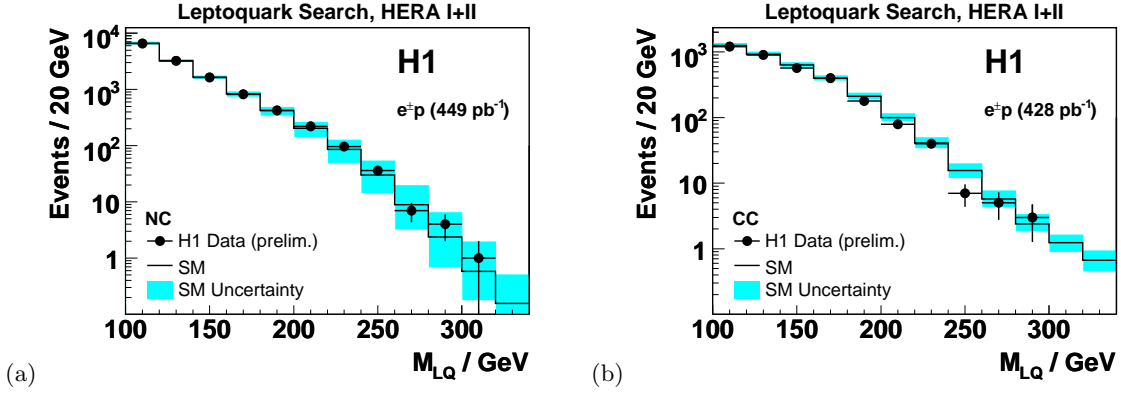


Figure 1: Reconstructed mass spectra for the HERA I+II  $e^\pm p$  data for neutral current (a) and charged current (b) events in the H1 leptoquark analysis.

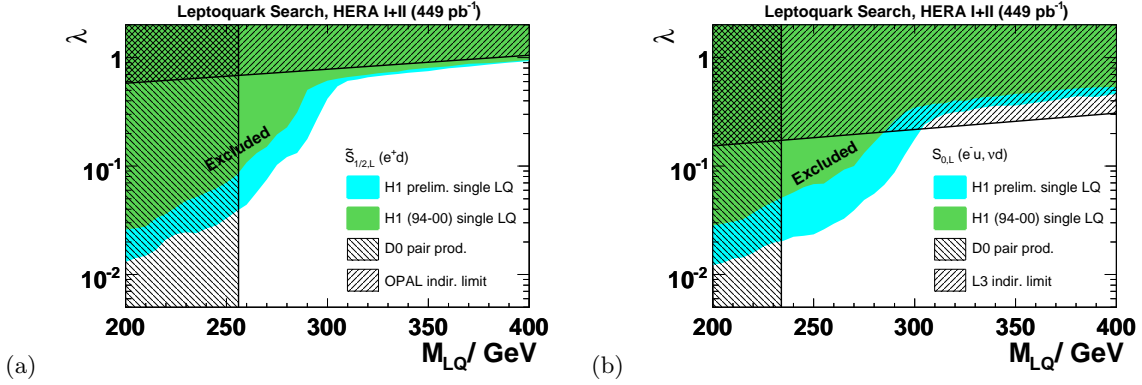


Figure 2: H1 preliminary 95% confidence limits on the production of  $\tilde{S}_{1/2L}$  (a) and  $S_{0L}$  (b) leptoquarks, corresponding to  $\tilde{u}_i$  and  $\tilde{d}_j$  squarks in  $R$ -parity violating models, respectively. Limits on the coupling  $\lambda$  are shown as a function of the leptoquark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

$P_T^X$ . The data from both experiments, ZEUS and H1, are combined in a common phase-space [11]. Figure 3 (a) 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 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 for the complete  $e^\pm p$  data is shown in Figure 3 (b). There is clear evidence that the events are dominated by single  $W$  production.

An enhanced production of real  $W$  bosons with high  $P_T^X$  at HERA may also originate from the decay of top quarks, as previously investigated with HERA I data [12, 13]. While the SM predicts a cross section too small to observe in the available data, many models, including  $R$ -parity violating SUSY [14], predict an observable rate of anomalously produced top quarks. The H1 collaboration reports a preliminary 95% confidence limit on the anomalous coupling  $\kappa_{tW\gamma} < 0.14$ , using their complete dataset [15].

Also interesting in the context of SUSY is the production of tau leptons, which exhibits an enhanced rate over SM expectations in many SUSY scenarios, for example if the LSP is  $\tilde{\tau}_1$  decaying via  $\tilde{\tau}_1 \rightarrow \tau\nu_i$ . H1 has searched for events with isolated tau leptons and missing transverse momentum  $P_T^{\text{miss}} > 12$  GeV, where the tau lepton decays hadronically [16]. The tau is identified by looking for a narrow jet of  $P_T > 7$  GeV with exactly one isolated track (“1-prong” signature). 20 events are observed in the data, which agrees well with the SM expectation of  $19.5 \pm 3.2$ . This expectation is dominated by irreducible CC background.

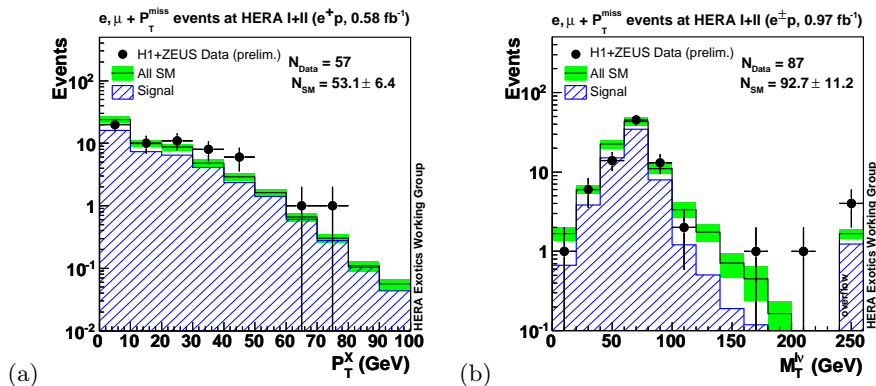


Figure 3: (a) H1 and ZEUS combined data on isolated leptons ( $\ell = e, \mu$ ) with missing transverse momentum. The  $e^+p$  data are shown as a function of the transverse momentum of the hadronic system  $P_T^X$ . (b) H1 and ZEUS combined data on isolated leptons ( $\ell = e, \mu$ ) with missing transverse momentum. The data are shown as a function of the transverse mass.

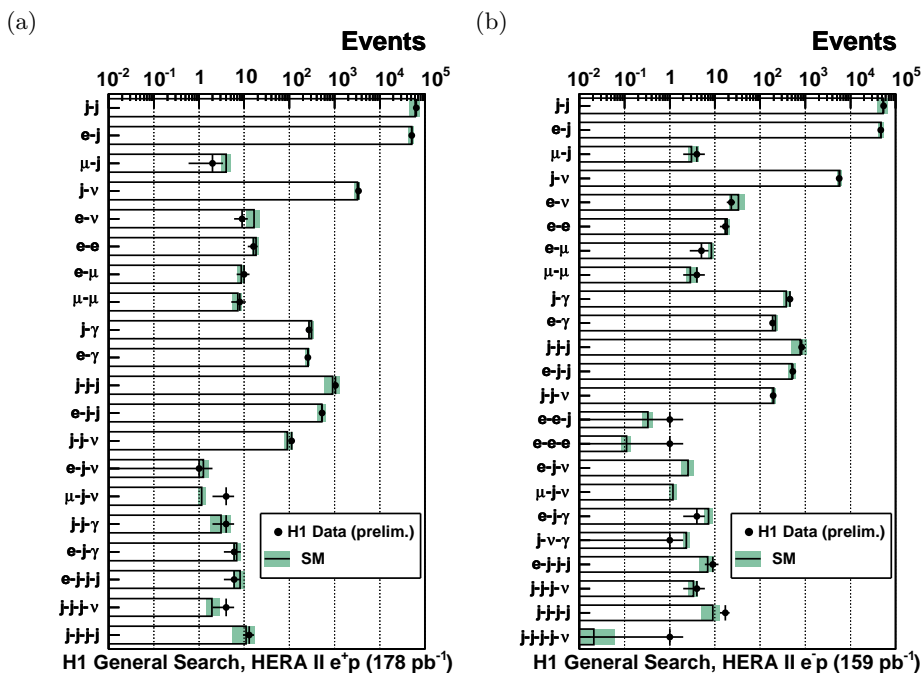


Figure 4: The data and the SM expectation in event classes investigated by the H1 general search. Only channels with observed data events or a SM expectation greater than one event are displayed. The results are presented separately for  $e^+p$  (a) and  $e^-p$  (b) collision modes.

### 3. GENERAL SEARCH

From previous searches for  $R$ -parity violating SUSY at HERA it is known that the inclusion of as many final state topologies as possible is necessary to be sensitive to SUSY fairly independently of the model parameters [4]. In a general search developed by the H1 Collaboration on HERA I data [17] all final states containing at least two objects ( $e, \mu, j, \gamma, \nu$ ) with  $P_T > 20 \text{ GeV}$  in the polar angle range  $10^\circ < \theta < 140^\circ$  are investigated [18]. The observed and predicted event yields in each channel are presented in Figure 4(a) and (b) for  $e^+p$  and  $e^-p$  collisions, respectively. While the interesting events observed in the search for isolated leptons are found again, overall good agreement between data and SM prediction is observed.

## 4. SUMMARY

New results from searches for leptoquarks, isolated leptons with missing transverse momentum and a general search at HERA have been reported. No evidence of new physics has been found, but a good agreement of data and SM expectations is found in all channels. While SUSY in the reach of HERA can be excluded with these results to the extent discussed in these proceedings, a dedicated interpretation of the HERA data in terms of  $R$ -parity violating SUSY by means of an extensive parameter scan of the phase space to exclude SUSY is still possible.

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H1 preliminary documents are available at

[http://www-h1.desy.de/publications/H1preliminary.short\\_list.html](http://www-h1.desy.de/publications/H1preliminary.short_list.html)