Searches for SUSY at HERA

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Abstract

In supersymmetric models with R-parity violation, the $LQ\bar{D}$ coupling term allows for single production of a squark in eq fusion. Searches at HERA are presented for the production of such squarks decaying to a lepton and one or more jets.

1. Introduction

R-parity is a multiplicative quantum number defined as $R_P = (-1)^{3B+L+2S}$, where B, L and S denote the baryon number, lepton number and spin of the particle, respectively. While R_P is assumed to be conserved in the Minimal Supersymmetric Standard Model (MSSM), the general supersymmetric and gauge-invariant superpotential allows for terms which violate R_P through Yukawa couplings λ, λ', λ'':

$$W_{\not R_P} = \frac{1}{2}\lambda_{ijk}L_iL_j\bar{E}_k + \lambda'_{ijk}L_iQ_j\bar{D}_k + \frac{1}{2}\lambda''_{ijk}\bar{U}_i\bar{D}_j\bar{D}_k\,, \tag{1}$$

where L and Q are the left-handed lepton and quark doublet superfields, $\bar{E}$, $\bar{U}$ and $\bar{D}$ are the right-handed singlet superfields for charged leptons, up-type quarks and down-type quarks, respectively, and the indices i, j, k refer to the fermion generation. The consequences of R_P violation ($\not R_P$) are that the superparticles can be produced singly, and that the lightest superparticle (LSP) is not stable and can decay to normal fermions. The term $\lambda'_{ijk}L_iQ_j\bar{D}_k$ with i=1 is most interesting for HERA experiments [1], since a squark can be singly produced in ep collisions. Expanded into four-component Dirac notation, this term becomes:

$$\lambda'_{ijk}\Big[-\tilde{e}^i_L u^j_L \bar{d}^k_R - e^i_L \tilde{u}^j_L \bar{d}^k_R - (\bar{e}^i_L)^c u^j_L (\tilde{d}^k_R)^* + \tilde{\nu}^i_L d^j_L \bar{d}^k_R + \nu^i_L \tilde{d}^j_L \bar{d}^k_R + (\bar{\nu}^i_L)^c d^j_L (\tilde{d}^k_R)^*\Big] + \text{h.c.} \tag{2}$$

In e^+p collisions, the second term with λ'_{1j1} can fuse e^+ with valence d quarks to produce $\tilde{u}^j_L$ squarks, while in e^-p collisions, the third term with λ'_{11k} produces $\tilde{d}^k_R$ squarks in a fusion of e^- with u quarks.

The production cross section, in the approximation of narrow width of the squark resonance, is proportional to $\lambda'^2_{1jk} \times q(x{=}M_q^2/s)$, where $q(x)$ is the quark distribution function evaluated at the resonance, M_q is the squark mass, and s is the square of ep center-of-mass energy, respectively.

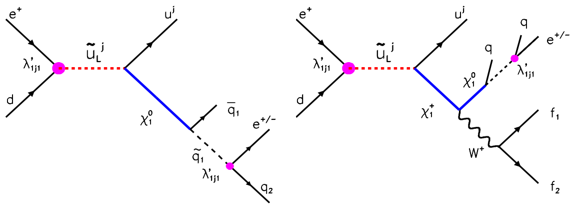

Figure 1. Two examples of $\not R_P$ squark production, followed by a simple gauge decay (left), or a longer cascade involving a chargino (right).

2. Squark signal in R_P-violating MSSM

The squark can decay with the same $\not R_P$ coupling to the eq final state (note that the $\not R_P$ decay to νq is possible only for $\tilde{d}^k_R$ and not for $\tilde{u}^j_L$ as seen in Eq. 2). In addition, it can decay to a quark and a gaugino (neutralino or chargino) with an R_P-conserving MSSM coupling (gauge decays). The gaugino can subsequently decay to a lepton (e or ν) and two quarks via the $\not R_P$ coupling, or, in case of a heavy gaugino, to a lighter gaugino and two fermions (e.g. $q\bar{q}$). These two kinds of gauge decays of a squark are illustrated in Fig. 1.

This offers a variety of final-state topologies, while the branching ratios to each channel depend on $M_{\tilde{q}}$ and λ'_{ijk}, as well as on the masses and mixings of the gaugino sector which are determined by the MSSM parameters μ, $\tan\beta$ and M_2.

The recent searches from H1 and ZEUS experiments make following assumptions:

- at most one λ'_{1jk} is non-zero
- the LSP is the lightest neutralino χ^0_1
- the gluino is heavier than the squark, so $\tilde{q} \to q\tilde{g}$ is forbidden

The experimental search of $\tilde{u}^j$ decay covers the following final-state topologies:

- e^+ + jet
- e^+ + multi-jet
- e^- + multi-jet
- $\nu(\bar{\nu})$ + multi-jet

The first three channels are discussed in Sect. 3 and the last channel is discussed in Sect. 4. Note that the third channel has a lepton with a charge opposite to the beam positron, which produces a striking signature with almost no background.

3. Final states with jet(s) and $e^\pm$

The analysis by the H1 collaboration in these channels from 1994–97 e^+p data has been presented previously [2]. It takes into account the mixing of the gauginos and considers cascade decays involving χ_2^0 and χ_1^+. The search yields no positive evidence, and limits on λ'_{1j1} are set for three different masses of photino-dominated χ_1^0 and one case of zino-dominated χ_1^0.

The ZEUS collaboration has recently presented an analysis in these channels using 46.8 pb^{-1} of e^+p collisions collected during 1994–97 [3]. Two additional simplifying assumptions are made:

- the χ_1^0 is a pure photino
- the dominant gauge decay of the squark is $\tilde{q} \to q\chi_1^0$

Three non-overlapping event samples are selected as desribed below.

For the e^+ + jet sample, the production and decay of the squark is identical to those of a scalar leptoquark (LQ), and the event selection is similar to a LQ search. A positron and a jet are required, both with transverse momentum (p_T) greater than 30 GeV. A mass-dependent cut in the DIS y variable further enhances the signal of a two-body decay of a scalar particle. In the data, 78 events pass this selection, while 88.3 are expected from neutral-current DIS and photoproduction. The distribution of $\log_{10} Q^2$ and mass of the e-jet sample are shown on the left in Fig. 2, showing good agreement between data and the simulated background distributions.

Events with an $e^\pm$ with energy larger than 15 GeV and two jets with p_T greater than 40 GeV and 20 GeV are put into one of the two multi-jet subsamples. If in addition the charge of the electron is negative by more than 3σ, it belongs to the e^- + multi-jet sample, otherwise it is classified as e^+ + multi-jet. No e^- + multi-jet events are observed in the data, while 0.06 are expected from the simulated background. The e^+-multijet sample contains 33 events, while 33.6 are expected. The distributions of $\log_{10} Q^2$ and mass on the right-hand side of Fig. 2 show good agreement between data and the simulated background.

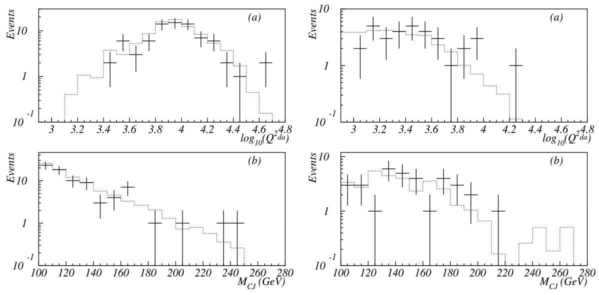

Figure 2. Distributions of (a) $\log(Q^2)$ and (b) reconstructed mass for the final eq sample (left) and the e^+qqq sample (right). The points with error bars are the data, and the histograms show the estimated backgrounds.

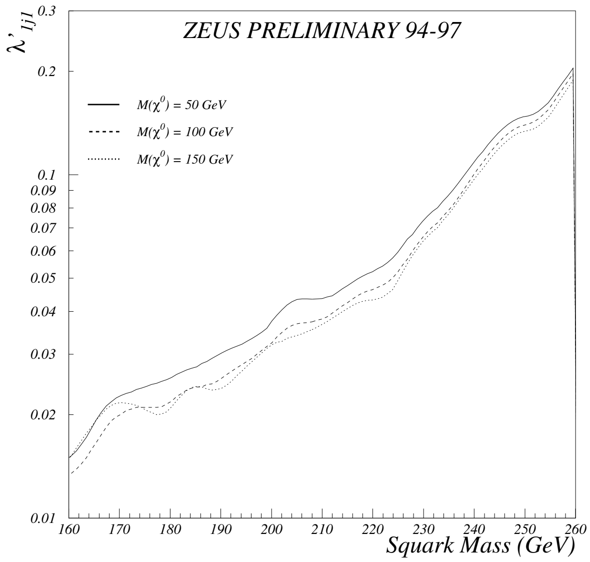

Figure 3. The 95% CL upper limit on λ'_{1j1} vs. the mass of the squark $\tilde{u}^j$ for $M_{\chi_1^0} = 50$ GeV, 100 GeV and 150 GeV.

Since no clear resonance-like excess of events is observed in the distribution of the invariant masses of the three above samples, 95% C.L. upper limits on the cross section of squark production and on the Yukawa couplings λ'_{1j1} are derived. A likelihood method was used that takes into account the efficiencies of the various squark final states to be observed in the three described subsamples. Fig. 3 presents the 95% C.L. limits on λ'_{1j1} vs. the mass of the squark $\tilde{u}^j$, for $M_{\chi_1^0} = 50$ GeV, 100 GeV and 150 GeV.

For the considered cases, squark masses below 260 GeV are excluded for a Yukawa coupling of the electromagnetic strength.

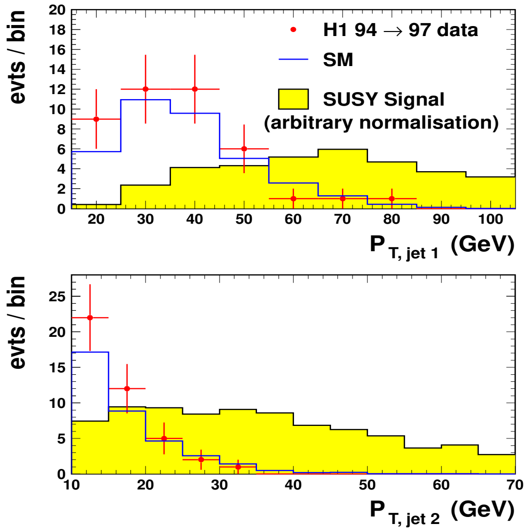

Figure 4. Distribution of H1 data in the jets plus missing-p_T channel, compared with SM and typical SUSY expectations.

4. Final states with jets and missing p_T

The H1 collaboration had a first look in 37 pb^{-1} of e^+p collisions for final states with missing p_T and multiple jets. These arise when $\tilde{u}^j$ decays to $u^j\chi^0$ or $d^j\chi^+$, and the gaugino has a substantial branching ratio to final states with a neutrino. Selecting events with missing $p_T > 25$ GeV and at least two jets with each $p_T > 15$ GeV, the data yield 20 events while 18.5 ± 2.8 are expected from Standard Model processes (mainly charged-current DIS). The result is shown in Fig. 4. No evidence for a SUSY signal is seen in this channel.

5. Events with a high-p_T lepton and missing p_T

The H1 collaboration previously reported the observation of events with a high-p_T muon and missing p_T, in excess of expectations from the Standard Model [4]. Within the context of $\not{R}_P$ SUSY with λ'_{131}, such events could originate from production of a $\tilde{t}_1$, decaying to $\tilde{b}_1 W^+$, assuming that $\tilde{b}_1$ is the LSP and $M_{\tilde{b}_1} < M_{\tilde{t}_1} < M_{\chi_1^+}$ [5]. In this case, the $\tilde{b}_1$ must decay to $\bar{\nu}_e d$ (see Fig. 5).

However, if the H1 high-p_T muon events are to be explained by the final states with $W \to \mu\nu$, an accompanying excess is expected where $W \to q\bar{q}'$. Requiring missing $p_T > 25$ GeV and two or more jets with $p_T > 25$ GeV, three events are observed in H1 data, while 4.7 ± 0.7 are expected from the Standard Model. From this result, for a specific case of $M_{\tilde{t}_1}$ = 200 GeV and $M_{\tilde{b}_1}$ = 100 GeV, it is derived that no more than 0.36 of the high-p_T muon events are expected to be seen from the proposed SUSY channel, which makes the interpretation of the four observed H1 events with this hypothesis difficult.

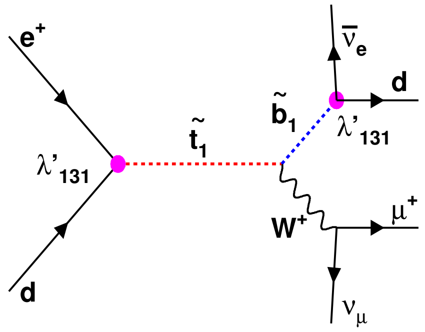

Figure 5. Production of $\tilde{t}$ and decay to $\tilde{b}$, which is the LSP.

6. Other related results

The ZEUS collaboration searched in 16 pb^{-1} of 1998–99 e^-p data for any LQ-like resonance decaying to electron and jet. No excess is observed, and limits on LQ production are presented [6]. The limits for scalar LQ are relevant to $\not{R}_P$ down-type squarks in cases where the $\not{R}_P$ decay to eq dominates.

Both H1 and ZEUS collaborations looked for LQ decaying to νq in e^+p data and found no evidence [6]. These limits are relevant only for down-type squarks as mentioned in Sect. 2, and thus will benefit much more from analyzing the new e^-p data.

7. Summary

First results from the ZEUS collaboration on the searches for $\not{R}_P$ squark production and decay with an $e^\pm$ in the final state have been presented using 1994–97 e^+p data. No signal was observed, and limits on Yukawa couplings λ'_{1j1} were derived as a function of the squark and neutralino masses.

The H1 collaboration has extended the search to decays with several jets and a neutrino in the final state. No excess of events was observed.

References

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