Searches for SUSY Particles at HERA

Y. Sirois

0LPNHE, Ecole Polytechnique, IN2P3-CNRS, 91128 Palaiseau, France

Searches at the ep collider HERA for supersymmetric partners of the Standard Model fermions are presented. Assuming R-parity conservation, selectrons and squarks of the Minimal Supersymmetric Standard Model are excluded for masses up to 65 GeV in a new region of the standard parameter space. Admitting in addition a R-parity violating Yukawa coupling \( \lambda' \), squarks are sought through direct e-q fusion in a yet unexplored mass-coupling domain, taking into account all possible squark decays. Squark masses up to 240 GeV are excluded for \( \lambda' \gtrsim \sqrt{4\alpha_{em}} \), depending only weakly on the free model parameters.

1. INTRODUCTION

Supersymmetry (SUSY) is a likely ingredient of a true fundamental theory beyond the Standard Model (SM). Until the SM gets falsified by experimental data, the Minimal Supersymmetric extension of the Standard Model (MSSM) offers a natural framework to guide the search for new scalar superpartners of SM fermions.

The analyses described in this paper assume the minimal field representation of the MSSM. This contains in particular selectrons \( \tilde{e}_L \) and \( \tilde{e}_R \), and squarks \( \tilde{q}_L \) and \( \tilde{q}_R \), as partners of left- and right-handed electrons and quarks. The masses of such bosonic sparticles are treated here as free parameters. Gauginos and higgsinos, respectively partners of the \( Z^0, \gamma, W^\pm \) gauge bosons and of the two required Higgs doublets, mix in the neutral and charged sectors to form four neutral \( \chi_1^0, \chi_2^0, \chi_3^0, \chi_4^0 \) (neutralinos) and two charged \( \chi_1^\pm, \chi_2^\pm \) (charginos) mass eigenstates. The mass mixing matrices for the \( \chi_m^0 \) and \( \chi_m^\pm \) depend on the soft supersymmetry breaking parameters \( M_1 \) and \( M_2 \) associated to \( SU_2 \) and \( U_1 \) gauginos, on the ratio \( \tan\beta \equiv v_2/v_1 \) of the two Higgs field vacuum expectation values, and finally on the mixing parameter \( \mu \) associated to Higgs superfields.

In the strict MSSM context, a discrete symmetry ensures the multiplicative conservation of the \( R \)-parity quantum number defined as \( R_p = (-1)^{3B+L+2S} \), where \( B \) denotes the baryon number, \( L \) the lepton number and \( S \) the spin such that \( R_p = 1 \) for the SM particles and \( -1 \) for their superpartners. As a consequence, sparticles must be produced by pairs and the lightest SUSY particle (LSP) is stable. Throughout this paper, it is assumed that the LSP is the lightest neutralino \( \chi_1^0 \). The number of free MSSM parameters is further reduced by assuming that \( M_1 \) and \( M_2 \) are related via the weak mixing angle \( \theta_W \) as suggested by Grand Unified Theories (GUT’s), \( M_1 = 5/3M_2 \tan^2 \theta_W \). No other GUT relations are used. In particular, the mass of the gluinos \( \tilde{g} \), partners of SM gluons, is left here as a free parameter. We assume that \( M_{\tilde{g}} > M_\tilde{q} \) such that \( \tilde{q} \rightarrow q\tilde{g} \) decays are kinematically forbidden.

The general SUSY superpotential allows, beyond the MSSM, for gauge invariant terms with \( R_p \) violating (\( R_p \)) Yukawa couplings between the quarks and leptons and their squark (\( \tilde{q} \)) or slepton (\( \tilde{l} \)) partners. Of particular interest for HERA are the terms \( \lambda'_{ijk} L_i Q_j D_k \) which allow for lepton number violating processes. Provided that baryon number is effectively conserved at low energy, sizeable \( \lambda' \) couplings are consistent with GUT’s, Supergravity and Superstring theories. They moreover do not unavoidably suffer from cosmological constraints and are even required for baryon asymmetry genesis in some cosmological models with first order electroweak phase transition. By convention the \( ijk \) indices correspond to the generations of the superfields.
$L_i$, $Q_j$ and $D_k$ containing respectively the left-handed lepton doublet, quark doublet and the right-handed quark singlet. Expanded in terms of matter fields, the corresponding interaction Lagrangian is:

$$\mathcal{L}_{L_i Q_j D_k} = \begin{bmatrix} \bar{\nu}_L \bar{d}_R \\
\bar{e}_L \bar{u}_R \\
\bar{\nu}_L \bar{u}_R \\
\bar{e}_L \bar{d}_R \end{bmatrix} \lambda^i_{j,k} \begin{bmatrix} 0 \nu^c_L \bar{d}_R \\
0 \bar{u}_R \\
\nu^c_L \bar{u}_R \\
0 \bar{d}_R \end{bmatrix} + \text{h.c.}$$

where the superscripts $^c$ denote the charge conjugate spinors and the $^*$ the complex conjugate of scalar fields. Hence the couplings $\lambda^i_{j,k}$ allow for resonant production of squarks through $e$-$q$ fusion.

Slepton-squark searches at HERA in the MSSM framework are described in section 3. Conclusions are presented in section 4.

2. SEARCH FOR SLEPTON-SQUARK PRODUCTION IN THE MSSM

The dominant MSSM process at HERA is the pair production $e p \rightarrow \tilde{e} \tilde{q} X$ via $t$-channel $\chi^0$ exchange as shown in Fig. 1. The production cross section depends on first approximation only on the $\chi^0$ mass and couplings, and on the hard process energy threshold ($M_\tilde{e} + M_\tilde{q}$). The sfermion decays involve mainly the $\chi^0_L$ which lead to striking event signatures looking like Deep Inelastic Scattering Neutral Current (DIS NC) except for large associated missing energy and momentum.

The H1 analysis based on an integrated luminosity of $L = 6.1 \text{ pb}^{-1}$, requires an isolated $e$ within $10^\circ < \theta^e < 135^\circ$ possessing an energy $E^e \geq 10 \text{ GeV}$ and a transverse momentum $P^e_T \geq 8 \text{ GeV}$. Furthermore, it is asked that the quantity $\sum E - P_e$ which peaks at twice the incident electron energy (i.e. 55 GeV) for DIS NC events be found below 40 GeV. Finally, the absolute value of both the parallel and perpendicular (relative to the measured electron) component of the total transverse "momentum" $\vec{P}_T$ should be large ($\geq 3 \rightarrow 7 \text{ GeV}$).

No event candidate remains in the data while $0.6\pm 0.2$ radiative charge current (CC) events that

![Figure 1](image1.png)

Figure 1. Lowest order Feynman diagram for $\tilde{e} + \tilde{q}$ production in $e p$ collisions with typical subsequent sfermion decays involving the LSP.

![Figure 2](image2.png)

Figure 2. Excluded mass domains at 95% CL in the (top) $M_{\chi^0}$ versus $(M_\tilde{e} + M_\tilde{q})/2$ plane and (bottom) in the $M_\tilde{q}$ versus $\mu$ plane for tan $\beta = 1.41$. 
mimic the desired event topology are expected. This background dominates over expectations from DIS NC and $\gamma g$ fusion (photoproduction) processes. The signal detection efficiency $\epsilon(P)$ with $P^2 = (M_Z^2 - M_{\chi_1^0}^2)(M_{\bar{q}}^2 - M_{\chi_1^0}^2)/4M_Z M_{\bar{q}}$ is estimated to reach 56% for $P > 25$ GeV and drops to $\lesssim 20\%$ for $P \lesssim 10$ GeV.

Exclusion limits are derived at 95% Confidence Level (CL) and presented in Fig. 2. The excluded mass range (Fig. 2 top) extends to $(M_{\bar{q}} + M_{\chi_1^0})/2 = 65$ GeV and to $M_{\chi_1^0} = 40$ GeV. The search is sensitive to mass differences of $M_{\chi_i^0} - M_{\chi_j^0} \sim 10$ GeV. In the MSSM parameter space, the excluded domain (Fig. 2 bottom) covers an area at $\mu \ll 0$ where the $\chi_1^0$ is dominated by its $\gamma$ component such that the couplings of the $\bar{\psi}$ and $\bar{\bar{q}}$ are of electromagnetic strength and the cross section is maximal. The domain excluded by H1 results extends to larger values of $M_2$ than recent MSSM searches at LEP results [7] and might still be uncovered by searches at the TEVATRON for $M_{\bar{q}} \gg M_{\bar{q}}$ and $M_{\chi_i^0} \sim M_{\bar{q}}$ [8].

3. SEARCH FOR $R_p$-SUSY SQUARKS

Squarks can be directly produced in the $s$-channel at HERA through $e-\bar{q}$ fusion as shown in Fig. 3. By gauge symmetry, only partners of left-handed $u$-like quarks (i.e. $\tilde{u}_L$, $\tilde{c}_L$ or $\tilde{\bar{q}}_L$) or right-handed $d$-like quarks (i.e. $\tilde{d}_R$, $\tilde{\bar{s}}_R$ or $\tilde{\bar{b}}_R$) can be resonantly produced through nine possible $\lambda'_{ijk}$ couplings. The production cross-section scales with $\lambda^2$ and with the probability $P(x)$ to find in the proton the relevant quark with momentum fraction $x \sim M_{\tilde{q}}^2/s_{ep}$ for $ep$ collisions at $\sqrt{s_{ep}} \sim 300$ GeV. The couplings $\lambda'_{ijk}$ are best probed with an $e^-$ beam via processes involving the $u$ valence quark (e.g. $e^- u \to \bar{\bar{q}}_R$) while $\lambda'_{ij1}$ ($j \neq 1$) are best probed with an $e^+$ beam via processes involving the $d$ valence quark (e.g. $e^+ d \to \bar{\bar{q}}_L$). The other $\lambda'_{ijk}$ couplings ($j, k \neq 1$) involve heavier quark flavours that have to be extracted from the sea.

The dominant squark decays result from a competition between the $R_p$ Yukawa couplings and the MSSM gauge couplings. “Right”- and “left”-handed squarks have different allowed or dominant decay modes. In $R_p$-decay modes, the $\tilde{u}_L$-like squarks decay only via $\tilde{u}_L \to \tilde{\nu} + e^+ d$ while the $\tilde{d}_R$-like squarks have an additional decay with missing transverse momentum due to an escaping neutrino $\tilde{d}_R \to \tilde{\nu} + e^+ u \bar{d}$. The partial decay widths for these $R_p$-decay modes scale with $\lambda^2 \bar{M}_{\tilde{q}}$. In “gauge decay” modes, the $\tilde{u}_L$-like squarks decay only via the $\lambda'_{1jk}$ partners of the $\chi_1^0$ or the $\chi_1^+$, $\tilde{u}_L \to u\chi_1^0$ or $d\chi_1^+$. In contrast the gauge symmetry forbids an electroweak coupling of the $\tilde{d}_R$-like squarks to the $\chi_1^+$. Hence the $\tilde{q}_R \to q' \chi_1^+$ is strongly suppressed for first and second generation squarks as it can only proceed through the $H^+$ component of the $\chi_1^+$ with a coupling proportional for the $q'$ mass. The partial decay widths for the gauge decays scale with $M_{\tilde{q}} \times (1 - M_{\chi_1^+}^2/M_{\tilde{q}}^2)^2$ and, in detail, depend on MSSM parameters via the mass-mixing in the gaugino-higgsino sector [9].

The gauge decay modes are expected to dominate through most of the parameter space for the $\lambda' - M_{\tilde{q}}$ domain accessible at HERA. The $R_{\mu}$-decay modes will only dominate near the kinematical limit (e.g. at $M_{\tilde{q}} \gtrsim 250$ GeV) where a large $\lambda'$ is required at production.

The $\tilde{u}_L$ gauge decays dominantly involve a $\chi_1^+$ as soon as kinematically allowed, i.e. everywhere except in a domain at large $M_2$ and $\mu \ll 0$ where the $\chi_1^0$ is heavy and has a large $\gamma$ component. This can be seen in Fig. 4. The lightest state $\chi_1^+$ is found to be concerned in a vast portion of the parameter space. The $\tilde{d}_R$ gauge decay involves dominantly the $\chi_1^+$ (> 90% of gauge decays) when this LSP is dominantly $\tilde{\nu}$-like, i.e. at $\mu/M_2 \lesssim -5/9$. Else the LSP participates in 20 to 80% of the gauge decays in the region where its $Z$ component dominates. Its contribution is negligible only in the $\mu \lesssim 0$ region when dominated by its $H$ component.

The $\chi_1^+$ couple to fermion-boson pairs. The $\chi_1^+$ can decay into a $\chi_1^0$ and two matter fermions (quark or lepton pairs) via the exchange of a real or virtual $W^+$ boson, e.g. $\chi_1^+ \to \chi_1^0 W^+; W^+ \to q\bar{q}'$ or $l^+\nu$. It can also decay into three matter fermions (a lepton and two quarks) when involving the $R_p$ couplings $\lambda'_{ijk}$ through the exchange of a virtual sfermion, e.g. $\chi_1^+ \to \bar{u}_L \chi_1^0 \to \bar{e}^+ d$ or $\chi_1^+ \to \bar{u}_L \chi_1^0 \to \bar{d}^+ L$ or $d_L \to \nu d$. The $R_p$ decays $\chi_1^+ \to \bar{\nu} + e^+ d$.
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\[\begin{array}{c}
\text{Figure 3.} \quad \text{Lowest order } s\text{-channel diagrams for } \tilde{u}_L \text{ squark production at HERA followed by (top) a } R_p \text{ decay or (bottom) a gauge decay involving a gaugino-higgsino } \chi. \text{ Typical decays of the emerging } \chi^0_1 \text{ or } \chi^+_1 \text{ are shown in the dotted boxes.}
\end{array}\]

\[\begin{array}{c}
\text{Figure 4.} \quad \text{(top) } \chi^0_m \text{ or } \chi^{\pm}_n \text{ eigenstates involved in the dominant decay modes of the } \tilde{u}_L \text{ in regions of the } (M_2, \mu) \text{ plane for } \tan \beta = 1; \text{(bottom) physical masses of the } \chi^0_m \text{ or } \chi^{\pm}_n \text{ versus } \mu \text{ for } M_2 = 60 \text{ GeV.}
\end{array}\]

e^+ \bar{d}_j d_k \text{ or } \nu_e u_j \bar{d}_k \text{ dominate for } \lambda^2_{1jk} \text{ couplings values of } \mathcal{O}(\sqrt{\Delta m^2} \alpha_\beta^2). \text{ The } \chi^0_1 \text{ is generally unstable and will also decay via the } R_p \text{ coupling } \lambda^2_{1jk} \text{ through virtual sfermion exchange, } \chi^0_1 \to \nu d_j d_k, \text{ or } e^+ \bar{u}_j d_k \text{ or } e^- u_j d_k. \text{ The } \chi^+_1 \text{ being a Majorana particle, there is an equal probability for decays into the like (with respect to the incident } e \text{ beam) and unlike sign leptons. Thus, this leads to striking and background free lepton number violating signals. The } \chi^0_1 \to e^+ q \bar{q} \text{ decays dominate (63% to 88% of the } \chi^0_1 \text{ branching ratio) where the } \chi^0_1 \text{ is } \tilde{\gamma}\text{-like. The } \chi^0_1 \to \nu q \bar{q} \text{ decays generally dominate where the } \chi^0_1 \text{ is } \tilde{Z}\text{-like. A } H\text{-like } \chi^+_1 \text{ will most probably be long-lived and escape detection.}
\end{array}\]

In summary, the event topologies can be broadly classified in three families. (A) squark } R_p \text{ two-body decays (e.g. } q' \to \nu q' \text{ or } q' \to eq); \text{(B) squark gauge decays into three charged fermions final states (e.g. } q' \to q' \chi^+_1; \chi^+_1 \to e^+ q q' \text{ or for } \tilde{u}_L\text{-like squarks, (e.g. } q' \to q \chi^+_1; \chi^+_1 \to e^+ q q) \text{ (C) squark gauge decays with escaping } \nu' \text{'s (missing transverse momentum } P_{T}\text{), jet(s) and/or charged lepton(s). These were studied in a recent H1 analysis \cite{10} based on } L = 2.8 \text{ pb}^{-1}. \text{ The event topologies of type (A) are indistinguishable on event-by-event from the DIS NC or CC backgrounds. These are statistically suppressed by requiring either an isolated } e \text{ with } P_{T}^e > 7 \text{ GeV in the angular range } 10^\circ < \theta^e < 145^\circ (e+q+X \text{ final}}
states) or overall $P_\perp > 25$ GeV ($\nu + q + X$ final states). In the former case, the background is further suppressed by requiring that the $e$ be found at high $y_e$ where $y_e = 1/2(1 + \cos \theta_e^*)$ and $\theta_e^*$ is the electron angle in the $e$-$q$ CM frame. The uniform decay of the scalar particle in the CM frame leads to a flat $y_e$ spectrum which is in contrast to the $1/y_e^2$ spectrum expected for the DIS NC background at fixed quark momentum fraction $x$.

The DIS NC background for event topologies of type (B) with a “right” sign $e$ is suppressed by exploiting both the angular distribution of the $e$ and that of the highest $P_\perp$ jet found in the azimuthal hemisphere opposite to the electron [11]. Event topologies of type (B) with a “wrong” sign $e$ are essentially background free. The misidentified DIS CC or photoproduction background in event topologies of type (C) are suppressed by a combination of loose lepton ($e$ or $\mu$'s) identification and/or stringent $P_\perp$ requirements ($P_\perp > 15$ or 25 GeV). A good signal detection efficiency is obtained in each possible channel, e.g. ranging from 25% to 80% at $M_\tilde{q} = 150$ GeV depending on the event topologies and model parameters.

Except for a slight ($\sim 2.4\sigma$) excess around $M_\tilde{q} = 70$ GeV for “right” sign events in (B), an excellent agreement is found between observations and background expectations in all channels and exclusion limits at 95% CL are derived. The results for $\lambda'_{i\tilde{j}k}$ combining all contributing channels are shown in Fig. 5 (top) for $M_{\tilde{q}} = 150$ GeV. The existence of squarks with $R_p$ Yukawa couplings $\lambda'_{i\tilde{j}1}$ is excluded for masses up to $\sim 220$ GeV (240 GeV for $M_{\tilde{q}} \simeq 160$ GeV) for coupling values $\lambda'_{i\tilde{j}1} \gtrsim \sqrt{4\pi\alpha_{em}}$. The Fig. 5 (bottom) shows the excluded domains in the $M_2$ versus $\mu$ plane for a $\lambda'$ close to the upper limits at $M_\tilde{q} = 150$ GeV.

### Table 1

Exclusion upper limits at 95% CL on $\lambda'_{i\tilde{j}k}$ for $M_\tilde{q} = 150$ GeV and $M_{\chi_0^1} = 40$ GeV for $\tilde{\gamma}$-like and $\tilde{Z}$-like $\chi_0^1$. Indirect limits have been scaled to $M_{\tilde{q}} = 150$ GeV and are quoted at 95% CL.

| $\lambda'_{i\tilde{j}1}$ | $\tilde{\gamma}$-like | $\tilde{Z}$-like | Value | Process | [Ref.] |
|-------------------------|----------------------|-----------------|-------|---------|--------|
| $\lambda'_{111}$        | 0.056                | 0.048           | 0.006 | $\existence$ of $\beta\beta$ decay | [14]   |
| $\lambda'_{112}$        | 0.14                 | 0.12            | 0.05  | CC-univ. | [15]   |
| $\lambda'_{113}$        | 0.18                 | 0.15            | 0.05  | CC-univ. | [15]   |
| $\lambda'_{121}$        | 0.058                | 0.048           | 0.6   | $D^+$ decays | [16]   |
| $\lambda'_{122}$        | 0.19                 | 0.16            | 0.04  | $\nu_e$-mass | [17]   |
| $\lambda'_{123}$        | 0.30                 | 0.26            | 0.6   | $D^+$ decays | [16]   |
| $\lambda'_{131}$        | 0.06                 | 0.05            | 0.7   | $\Gamma_h/\Gamma_e$ | [18]   |
| $\lambda'_{132}$        | 0.22                 | 0.19            | 0.7   | $\Gamma_h/\Gamma_e$ | [18]   |
| $\lambda'_{133}$        | 0.55                 | 0.48            | 0.002 | $\nu_e$-mass | [17]   |

Figure 5. (top) Exclusion upper limits at 95% CL on $\lambda'_{i\tilde{j}1}$ for $M_{\tilde{q}} = 40$ GeV. The existence of squarks with $R_p$ Yukawa couplings $\lambda'_{i\tilde{j}1}$ is excluded for masses up to $\sim 220$ GeV (240 GeV for $M_{\tilde{q}} \simeq 160$ GeV) for coupling values $\lambda'_{i\tilde{j}1} \gtrsim \sqrt{4\pi\alpha_{em}}$. The Fig. 5 (bottom) shows the excluded domains in the $M_2$ versus $\mu$ plane for a $\lambda'$ close to the upper limits at $M_\tilde{q} = 150$ GeV.

To our knowledge, no direct searches in the
$R_p$-SUSY framework with $\lambda' \neq 0$ have been performed yet by $e^+e^-$ and $p\bar{p}$ experiments. It is likely that in $e^+e^-$ collisions at LEP 200 where squarks are dominantly pair produced through gauge couplings, squarks masses up to near the kinematical limit of $\sqrt{s_{e^+e^-}}/2 \approx 90$ GeV can be reached within few years. In $p\bar{p}$ collisions at the TEVATRON, squarks can be produced in pairs or in association with gluinos. Given the current mass reach for scalar leptoquark and MSSM searches in D0 and CDF experiments\cite{12}, it is likely that $M_{\tilde{q}} \gtrsim 200$ GeV can be probed through most of the MSSM parameter space even for $M_{\bar{q}} > M_{\bar{\tilde{q}}}$. Such a mass reach might be provided already by di-lepton data alone as was inferred in ref.\cite{13}.

From the analysis of the $\lambda'_{ijk}$ case involving the $\tilde{d}_R$ and $\tilde{u}_L$ squarks, limits can be deduced on the $\lambda'_{ijk}$ by folding in the proper parton densities. Such limits are given in Table 1 at $M_{\tilde{q}} = 150$ GeV. Also quoted in this table are the most severe indirect limits existing. The most stringent concerns $\lambda'_{ijk}$ with $j = k$ and come either from the non-observation of neutrinoless double-beta decay ($j = k = 1$) or from constraints on the $\nu_e$ mass ($j = k = 2, 3$). The limit from $\beta\beta 0\nu$ decay depends on the gluongino mass \cite{14} and is given here for $M_{\bar{q}} = 1$ TeV. The limits on $\lambda'_{1jk}$ from CC universality \cite{15} affect only the $\tilde{d}_R$. The limits inferred\cite{17} from $M_{\nu_e}$ constraints assume slepton and squark mass degeneracy and are valid only \cite{16} for $\lambda'_{ijk}$ with $j = k$.

In the presence of two simultaneously non-vanishing Yukawa couplings (e.g. $\lambda'_{ijk}$ and $\lambda'_{ij'}$ with $i \neq 1$), resonant $\tilde{q}$ production at HERA can be directly followed by a lepton flavor violation (LFV) decay leading to $\mu +$ jet or $\tau +$ jet signatures. Relevant analyses for these quasi-background free channels have been performed by the H1\cite{19} and ZEUS\cite{20} collaborations. Exclusion limits in the context of $R_p$-SUSY have been derived by ZEUS\cite{20} based on $L = 3.8$ pb$^{-1}$ of data and taking into account the branching ratio for gauge decays involving a pure $\tilde{\gamma}$ LSP (more unfavorable cases of mixed gaugino-higgsino mass eigenstates have not been considered) and assuming that only one type of squark is produced. The results are shown in Fig. 3. A sensitivity comparable or better than existing indirect LFV limits\cite{21} is obtained at $M_{\tilde{q}} \approx 150$ GeV for some coupling combinations. Squarks masses up to $\sim 210$ GeV (depending on the LFV couplings) are excluded for $\lambda' \gtrsim \sqrt{4\pi\alpha_{em}}$.

**4. CONCLUSION**

Selectrons and squarks of the Minimal Supersymmetric Standard Model were searched through pair production at HERA and masses up to 65 GeV were excluded in a new region at large $M_2$ and $\mu \ll 0$.

Squarks of $R$-parity violating supersymmetry were searched through direct resonant production via Yukawa couplings $\lambda_{ijk}$ by the H1 and ZEUS.
experiments at HERA. Assuming that one of the $\lambda'_{jk}$ dominates, three families of event topologies were identified for $R$-parity violating and gauge decays of squarks. It was found that squark decays via a $\lambda'$ coupling into $l + q$ final states dominate only at largest accessible masses, while elsewhere squarks undergo mainly gauge decays into a quark and a (generally) unstable gaugino-higgsino. No significant evidence for the production of squarks was found in any of the channels and mass dependent limits were derived. The existence of first generation squarks with masses up to $220 \rightarrow 240$ GeV (depending on the MSSM parameter values) are excluded by H1 at 95% confidence level for $\lambda'_{j1} \gtrsim \sqrt{4\alpha_{em}}$. These limits extend beyond the current reach at other existing colliders. At $M_{\tilde{q}} = 150$ GeV, the upper limits obtained for the four couplings $\lambda'_{ijk}$ with $j \neq 1$ and $j \neq k$ are comparable or better than the most stringent indirect limits existing.

Considering a combination $\lambda'_{ijk} \times \lambda'_{ijk} \neq 0$ with $i \neq 1$, squarks can undergo direct lepton flavor violation decays leading to $\mu + jet + X$ or $\tau + jet + X$ signatures. For some coupling products, a sensitivity comparable or better than the most stringent indirect limit existing was obtained by ZEUS in the case of a “pure” $\tilde{\gamma}$ LSP.

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