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A Search for Squarks of Rp-Violating SUSY in H1 at HERA

H1 Collaboration

Abstract

A search for squarks of R-parity violating supersymmetry was performed in $e^{\pm}p$ collisions at HERA using H1 1994 e^{+} data corresponding to an integrated luminosity of 3.15 pb $^{-1}$. Direct single production of first generation squarks and scalar stop squark by electron-quark fusion as well as pair production of stops in γ-gluon fusion processes were studied. No significant deviation from the Standard Model predictions is found in the various multi-lepton and multi-jet final states studied and exclusion limits are derived. For a strength of $\lambda_{111}^{'2}/4\pi = \alpha_{em}$ of the Rp-violating Yukawa coupling $\lambda_{111}^{'}$, the existence of first generation squarks at masses below 240 GeV is excluded at 95% level. In the case of the stop search in pair production, masses below 27 GeV are excluded at 95% level for non-vanishingly small $\lambda_{13k}^{'}$ ($k = 1, 2, 3$). For single stop production, masses below 140 GeV are excluded for coupling strength of $(\lambda_{131}^{'} \times \cos\theta_t)^2/4\pi \gtrsim 0.1\alpha_{em}$.

1 Introduction

The search for squarks possessing a lepton number violating Yukawa coupling to electron–quark pairs, as present in R-parity ($\not{R}_p$) violating supersymmetric (SUSY) extension of the Standard Model (SM), is especially promising at the ep collider HERA. Such squarks can be singly produced via a Yukawa coupling as s-channel resonances up to the kinematic limit of 300 GeV by the fusion of the 27.6 GeV initial state electron with a quark of the 820 GeV incoming proton. In the low mass range, pair production via γ-gluon fusion provides a complementary search insensitive to the Yukawa coupling (provided it is not vanishingly small).

In this paper, first generation squarks are searched through single production considering both $\not{R}_p$ decays via Yukawa couplings and gauge decays into a quark and the lightest supersymmetric particle (LSP) which is assumed to be a neutralino (χ_1^0). This unstable LSP then decays into leptons and quarks. For the pair production, only the case of a light scalar stop ($\tilde{t}$) is considered. Finally, the stop search is extended by considering single production and decay via a $\not{R}_p$ coupling.

This analysis uses the 1994 e^+p data corresponding to an integrated luminosity of 3.15 pb $^{-1}$ which represents a factor $\sim$ 8 increase compared to the 1993 e^-p data used earlier in H1 squark searches [1].

2 Phenomenology

The general SUSY super-potential allows for gauge invariant terms with Yukawa couplings between the scalar squarks ($\tilde{q}$) and the known SM fermions. Such couplings exist if one assumes the possibility of violating (multiplicatively) the conservation of R-parity which is imposed in the Minimal Supersymmetric Standard Model (MSSM); $R_p = (-1)^{3B+L+2S}$ where S denotes the spin, B the baryon number and L the lepton number of the particles.

At HERA specifically the $\not{R}_p$ couplings λ'_{ijk} (where ijk are generation indices) between a lepton, a quark and a squark are of interest. Given the constraints from low energy experiments [2] these are studied with the additional simplifying assumptions that:

- Only one of the λ'_{ijk} dominates.
- Only couplings to fermions of the first generation are considered.
- Squarks of the first and second generation are degenerate in mass. The case of a light top–squark is considered separately.
- Squarks decay either via their Yukawa couplings into fermions, or via their gauge coupling into a quark and the LSP (here the lightest neutralino χ_1^0). In this extension of the MSSM, the χ_1^0 is unstable and decays into a quark, an antiquark and a lepton [2]. Cascade decays via other gauginos are neglected.

The case λ'_{131} is of special interest[1] since it allows for direct production of the $\tilde{t}$ via

[1]By convention the ijk indices correspond to the generations of the supermultiplets in the superpotential (see [2]). In the $s-$channel at HERA, the coupling λ'_{111} allows for $e^+\bar{u} \rightarrow \bar{\tilde{d}}$ or $e^+d \rightarrow \tilde{u}$. The coupling λ'_{131} allows in the $s-$channel for $e^+\bar{t} \rightarrow \bar{\tilde{d}}$ or $e^+d \rightarrow \tilde{t}$.

$e^+d \to \tilde{t}$. The stop is particular in the sense that a "light" stop mass eigenstate ($\tilde{t}_1$) could exist much lighter (depending upon the mass parameters for the chiral states and on the free parameters of the model) than the top and lighter than other squarks. Such a mass eigenstate is considered in this paper and is moreover assumed to be lighter than the lightest chargino. This is the case only for the stop since the off-diagonal terms which appear in the mass matrix associated to the superpartners of chiral fermions are proportional to the partner fermion mass.

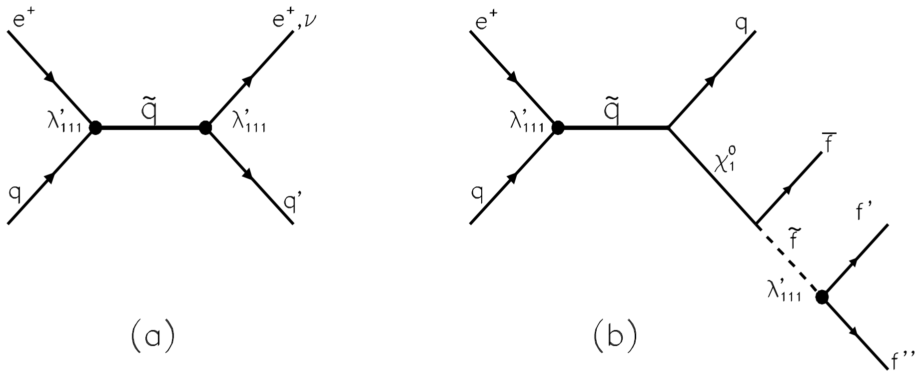

Figure 1: *Lowest order s-channel diagrams for squark production with (a) $\not{R}_p$ decays and (b) gauge decays at HERA. In (b), the $\tilde{f}$ might be a squark or a slepton such that the χ_1^0 decays into a lepton and a $q\bar{q}$ pair.*

In the case of single squark **resonant production**, the Yukawa couplings resemble very much the ones for leptoquarks, and the production cross-section for *up*–type squarks is indeed the same as the one of the $\tilde{S}_{1/2}$ leptoquark. The same resemblance holds for *down*–type squarks and the S_0 leptoquark. Also the partial decay width for the $\not{R}_p$ decay into fermions is the same. In such production mode, the $\tilde{t}$ resembles the $\bar{\tilde{S}}_{1/2}$.

Under the further simplifying assumption that the neutralino is a pure photino $\tilde{\gamma}$, the gauge decay width is given by

$$\Gamma_{\tilde{q}\to\tilde{\gamma}q} = \Gamma_{\tilde{q}\to eq'} \, \frac{2e^2e_q^2}{\lambda'^2} \left(1 - \frac{M_{\tilde{\gamma}}^2}{M_{\tilde{q}}^2}\right)^2$$

and contributes mainly at low $\tilde{\gamma}$ masses and small Yukawa couplings.

When the squark undergoes a $\not{R}_p$ decay (Fig. 1a), the final state signature consists of a lepton and a jet and is practically indistinguishable event-by-event from the SM neutral (NC) and charged current (CC) deep inelastic scattering (DIS). The strategy is then to look for DIS–like events at high mass and high y, and to separate them statistically from the standard DIS background.

In the gauge decay mode (Fig. 1b), the dominant expected signature consists of an electron (or positron), accompanied by hadronic activity more or less resolved into three jets plus the proton fragments. Both the "right" and the "wrong" sign lepton (compared to incident beam) are equally probable leading to a largely background free striking signature for lepton number violation.

In case of **stop pair production** via γ-gluon fusion, the stop decays dominantly in an electron and a quark.

3 Analysis

3.1 Single production of squarks

For squarks which are singly produced as $s-$channel resonances we can make use of the event pre-selection optimized for leptoquarks and presented in detail elsewhere [3]. This pre-selection which looks for NC-like $(e+X)$ or CC-like $(\nu+X)$ signatures essentially relies on the electron finding and global energy conservation cuts. Hence, it is relevant for both the $\not R_p$ decays $\tilde{q} \rightarrow eq'$ (indistinguishable from leptoquarks) as well as for squarks undergoing gauge decays $\tilde{q} \rightarrow e^{+-}q''\bar{q}''q'$.

For $e+X$ **final states**, the main selection criteria (see [3] for complete set of requirements) to reject contaminating physics background are (see [4] for a description of the relevant detector components):

1. An electron with $E_{T,e} = E_e sin\theta_e > 7$ GeV and $10^\circ \leq \theta_e \leq 145^\circ$ (a range covered by the H1 LAr calorimeter). There must be either only one electron candidate or the highest $E_{T,e}$ candidate must be at highest polar angle. Moreover, the electron must be isolated within a pseudorapidity-azimuth cone of opening $\sqrt{(\Delta\eta_e)^2 + (\Delta\phi_e)^2} <$ 0.25

2. A total missing transverse momentum $P_{T,miss} \approx \sqrt{\left(\sum E_x\right)^2 + \left(\sum E_y\right)^2} \leq 15$ GeV summed over all energy depositions in the calorimeters.

3. A minimal longitudinal momentum loss in the direction of the incident electron, i.e. $43 \leq \sum(E - p_z) \leq 63$ GeV .

These cuts provide a powerful rejection of photoproduction contamination and eliminate DIS CC events. Cut (3) also suppresses DIS NC-like events with a very hard γ emitted from the initial state electron.

For these NC-like (i.e. leptoquark like) signatures, 1822 events satisfy pre-selection requirements in the relevant mass and y range at $M_e > 45$ GeV and $0.05 < y_e < 0.95$ where M_e and y_e are reconstructed from the final state electron energy E_e and angle θ_e as

$$M_e = \sqrt{s x_e} = \sqrt{\frac{Q_e^2}{y_e}}, \quad Q_e^2 = \frac{E_{T,e}^2}{1-y_e}, \quad y_e = 1 - \frac{E_e - E_{z,e}}{2E_e^0},$$

where E_e^0 is the incident electron beam energy. This is in good agreement with the mean expected SM background of 1867.5 ± 28.3 events for DIS NC [5, 6].

As was seen in ref. [3], the signal significance over the DIS NC background can be maximized taking profit of the fact that the electrons from squark decays should have a flat spectrum in y. Applying an optimal mass dependent y_e cut, we are left with 94 events while 93.3 ± 6.3 events are expected from SM for $M_e > 45$ GeV .

For $\nu + X$ **final states**, the main selection criteria to reject contaminating physics background are :

1. No electron satisfying the above requirements.
2. $P_{T,miss} > 15$ GeV .
3. The total transverse energy $E_T \approx \sum \mid \vec{P}_T \mid$ should match the total missing transverse momentum $P_{T,miss}$ such that $(E_T - P_{T,miss})/E_T < 0.5$.

These cuts eliminates photoproduction and DIS NC background.

In total, 47 CC-like events satisfy all above requirements in the relevant mass and y range at $M_h > 45$ GeV and $y_h < 0.95$ where M_h and y_h are reconstructed by summing over all visible final state "hadrons":

$$M_h = \sqrt{\frac{Q_h^2}{y_h}}, \quad Q_h^2 = \frac{P_{T,miss}^2}{1 - y_h}, \quad y_h = \frac{\sum (E - p_z)}{2E_e^0}.$$

This is in excellent agreement with the SM expectations [7] of 47.9 ± 1.4 which we estimated in ref. [3].

For **gauge decay of the squarks** leading to a **"right" sign** final state lepton (i.e. $e^+ q \to \tilde{q} \to \chi_1^0 + q' \to e^+ q'' \bar{q}'' q'$), the following additional stringent requirements are imposed :

1. The electron must give $y_e > 0.4$.
2. The fraction (attributed to the χ_1^0) of the total hadronic energy measured in an azimuthal range excluding $\phi \pm \pi/4$ around the orientation of the "current" jet, must be at least 10% of the overall hadronic energy. Here the proton fragment is excluded from the hadronic energy flow sums by a pseudorapidity cut. Only the calorimeter cells at $\eta < \eta_{cut}$ are considered where η_{cut} is the largest value between $\eta_{cut} = \eta_h + 1.5$ and $\eta_{cut} = 2.43$, and η_h is the pseudorapidity of the "current" jet. The "current" jet is taken as the highest P_T jet in the azimuthal hemisphere opposite to the electron.
3. The invariant mass attributed to the χ_1^0 calculated from the electron and the accompanying hadronic energy flow (see cut (1)) must verify $M_{\chi_1^0} \gtrsim 10$ GeV .
4. The invariant mass M_{dec} calculated from all final state particles excluding the proton fragments (see cut (1)) must deviate from M_e by more than 10%.

Cut (1) strongly suppresses DIS NC background. The y_e distribution calculated from the electron in SUSY events appears strongly shifted towards large y_e since the squark decays uniformly in its center-of-mass frame and, further, since the electron takes away only a fraction of the χ_1^0 momentum. Cut (2) exploits the fact that the χ_1^0 of the $\tilde{q} \rightarrow \chi_1^0 + q$ decay contributes in balancing the transverse momenta of the "current" jet in DIS. Cut (2) and (3) by imposing sufficient energy flow activity opposite to the "current" jet, besides the electron, further suppress lowest order DIS NC events. Cut (4) ensures that events accepted as squark gauge decay candidates are not simultaneously accepted as squark $R\!\!\!/_p$ decay candidates.

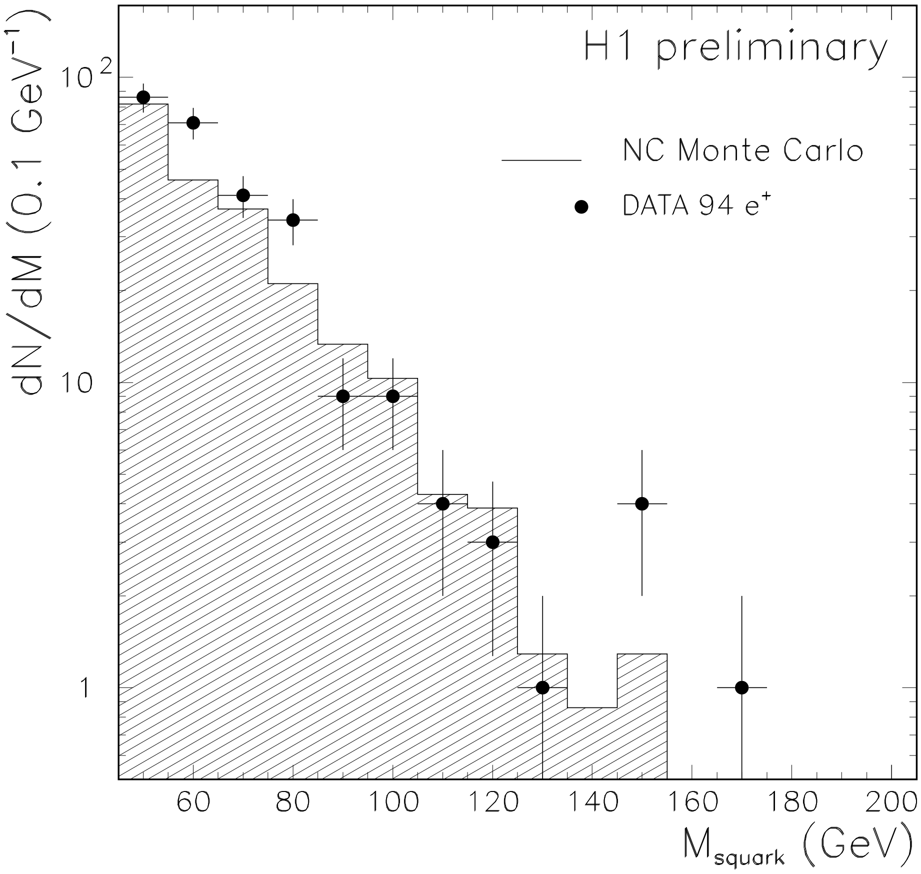

Figure 2: Measured mass spectrum (uncorrected) for the squark candidates in the $e^+q \rightarrow e^+q''\bar{q}'' + q'$ channel for data (dots) and DIS NC Monte Carlo (histogram).

We find 263 candidates satisfying the cuts specific to gauge decays of squarks and with masses $M_{dec} > 45$ GeV , which is to be compared with the mean SM background of 221.9 ± 9.8 events expected from DIS NC [5, 6]. Given the uncertainty on this mean expectation, this represents an excess of 2.5 standard deviations. The measured mass spectra is compared to the remaining contamination expected from DIS NC in Fig. 2

where it is seen that the slight excess of events is mostly concentrated at low masses. The data is better described by the Monte Carlo in the harder collisions towards high masses. An excellent agreement is observed for $M_{dec} > 100$ GeV where we find 18 events while the mean DIS NC expectation is 15.9 ± 2.6 events. For $M_{dec} > 140$ GeV , 5 events are found which agrees well with the expectation of 2.6 ± 1.1 from DIS NC. The deviation which appears towards low masses might originate from higher order QCD sub-processes which are enhanced by the event selection and become softer towards low masses. For $\not{R}_p$ decays of the squarks (NC-like) which are mostly characterized by a single hard jet balancing the final state electron, an excellent description of the hadronic energy flow is obtained.

For **gauge decay of the squarks** leading to a **"wrong" sign** final state lepton (i.e. $e^+q \rightarrow \tilde{q} \rightarrow e^- q'' \bar{q}'' q'$) we perform a charge analysis using the H1 tracking chamber information. We impose in addition to the above criteria :

1. The electron LAr cluster must be linked to a charged track and the energy from the cluster must match the momentum from tracking within $\mid (E-P)/(E+P) \mid < 0.5$.

2. The track must be made of at least 40 hits in the central tracking chamber.

3. The error in the curvature κ must fulfil $1 < \mid \kappa/\delta\kappa \mid < 50$.

4. The distance of closest approach Z_{dca} of the charged track to the main vertex must lie within $\mid Z_{dca} \mid < 0.3$ cm .

These cuts ensure a good quality of the track reconstruction and track-cluster matching at the expense of a reduced efficiency to accept the electron track of about $\sim 60\%$ in the angular range $\theta \geq 35°$ well covered by the central tracking chambers in H1 [4].

We observe no e^- (wrong sign) events among the 263 candidates satisfying the kinematical requirements for squark gauge decays.

3.2 Pair production of stop squarks

For **squarks** which are **pair produced in γ-gluon fusion**, we impose the same vertex and $P_{T,miss}$ cut as for single production. The requirement of a low $P_{T,miss}$ suppresses the contamination of $b\bar{b}$ photoproduction where the heavy b quarks can undergo semi-leptonic decays.

On the other hand, we require :

1. Two electron candidates i satisfying $E^i_{T,e} > 5$ GeV within $10° \leq \theta^i_e \leq 145°$. The electrons must be isolated within pseudorapidity-azimuth cones of opening $\sqrt{(\Delta\eta^i_e)^2 + (\Delta\phi^i_e)^2} < R_i$ where $R_{i=1} = 0.5$ and $R_{i=2} = 0.25$.

The transverse energy requirement in cut (1) is high enough to eliminate contamination from J/ψ photoproduction. Asking for two isolated electrons strongly suppresses the main DIS NC and photoproduction background, leaving only events where either a photon or a hadronic jet is misidentified as an electron. Such a misidentified hadronic jet in DIS NC events is most probably found to be colinear with the true electron in the

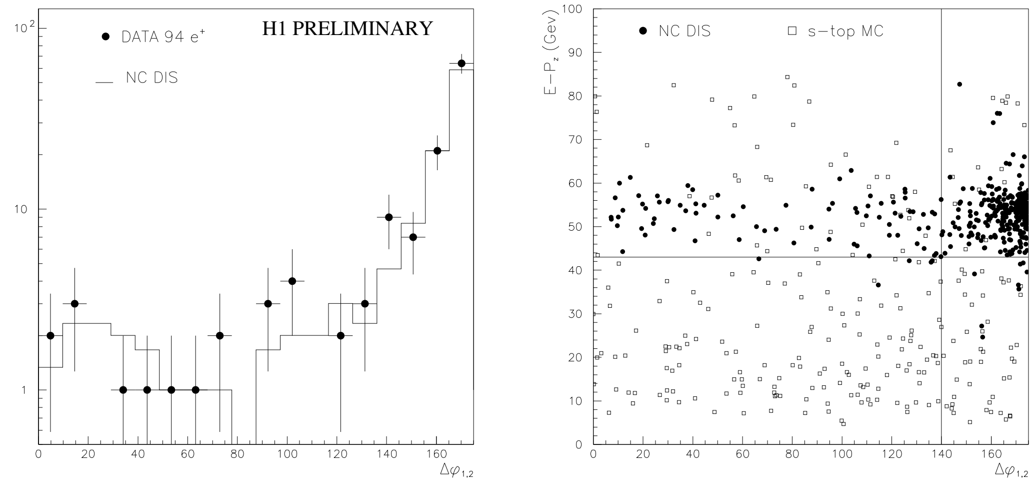

Figure 3: (a) Azimuthal balance $\Delta\phi_{1,2}$ of the two electron candidates for data (closed dots) and DIS Neutral Current Monte Carlo (histogram) when $\sum(E-p_z) > 43$ GeV .
(b) Comparison of Monte Carlo expectations for the missing longitudinal momentum $\sum(E-p_z)$ versus the balance in azimuth of the two "electron" candidates $\Delta\phi_{1,2}$ for DIS Neutral Current (closed dots) and 20 GeV stop pair production in γ-gluon fusion (open squares).

transverse plane. This can be seen in Fig. 3a where the azimuthal balance $\Delta\phi_{1,2}$ between the two electron candidates found in the data is compared with SM Monte Carlo [7] expectations for events where $\Delta\phi_{1,2} < 175°$. Here an additional cut of $\sum(E-p_z) > 43$ GeV is imposed which admits 95% of the remaining DIS NC contamination and suppresses photoproduction background in the data. The observed acolinearity in ϕ between the two electron candidates is seen to be well described by the Monte Carlo.

Irrespective of the $\sum(E-p_z)$ cut, we are left at this point in the range $\Delta\phi_{1,2} < 175°$ with 135 candidates in the data compared to mean contamination of 121.2 ± 6.4 events from DIS NC, estimated from a Monte Carlo simulation based on [7], and 18.8 ± 2 events from photoproduction estimated using [6].

In order to further reduce the DIS NC and photoproduction contamination, we impose finally that :

1. The two electron candidates must be acolinear in the transverse plane, $\Delta\phi_{1,2} < 140°$.
2. There must be missing longitudinal momenta such that $\sum(E-p_z) < 43$ GeV .
3. At least two jets must be found by a JADE algorithm (with the fractional invariant mass parameter $y_{cut} = 0.02$).

Cut (1) eliminates the remaining misidentified photoproduction while cut (2) strongly suppresses DIS NC events. Cut (3) asks for a sufficiently hard sub-process. With these cuts we are finally left with no observed event candidates while 1.0 ± 0.77 event is expected from misidentified DIS NC background.

4 Results

In absence of significant deviation from the SM expectations, we now derive exclusion limits for the Yukawa couplings as a function of mass. For each contributing channel, we use the number of observed events, the signal detection efficiencies and the expected number of background events within a mass bin which slides over the accessible mass range. The statistical procedure which folds in channel per channel the statistical and systematic errors is decribed in detail in [1].

The signal detection efficiencies are typically determined over a coupling-mass grid with steps in mass of 25 GeV and for coupling values corresponding roughly to the expected ultimate sensitivity. Detailed Monte Carlo simulation of about 500 events per point on the grid is performed followed by the application of the full analysis chain.

Single production of squarks:

The simulation of leptoquark-like signatures in the $\not R_p$ decay mode is based on the event generator described in [3]. For squarks undergoing a gauge decay into a quark and a neutralino, the generator [8] based on the cross-sections given in [2] is used. Both generators also simulate initial state bremsstrahlung in the Weizsäcker–Williams approximation, initial and final state parton showers and fragmentation [6] and properly take into account the correction of the kinematics at the decay vertex for effects of the parton shower masses. The parton density used is evaluated at the scale of the new particle mass, and this scale is also chosen for the maximum virtuality of parton showers.

The efficiencies for the detection of $\not R_p$ decays in the $\tilde{q} \rightarrow eq'$ channel are found to be weakly dependent of the squark mass and range from 29% at 45 GeV to 56% at 150 GeV in the middle of the mass range considered here. These numbers include the effect of the mass dependent y_e cut ($y_e > 0.5$ at 45 GeV and $y_e > 0.35$ at 150 GeV) and the finite width of the sliding mass bin which is chosen to contain about 68% of the signal at a given mass. Comparable efficiencies ranging from 34% at 45 GeV to 61% at 150 GeV are obtained in the $\tilde{q} \rightarrow \nu q'$ channel.

Systematics errors come from the uncertainty on the luminosity measurement (2%), the absolute energy calibration (which gives an uncertainty on the background estimation of 10%), the choice of the scale entering the structure function calculation (leads to $\approx 7\%$ uncertainties in the cross-section) and the choice of the parton density parametrization.

For gauge decays with the "right sign" final state lepton (actually $right\ sign + unsigned$) the efficiencies depend mainly on the χ_0^1 mass and range typically from $\sim 24\%$ at $m_{\chi_0^1} =$ 20 GeV to $\sim 43\%$ at $m_{\chi_0^1} = 80$ GeV . For gauge decays with the "wrong sign" final state lepton, the restriction for sign determination to the region $\theta_e > 35°$ implies an efficiency loss which is negligible at 45 GeV but which increases to 10% at 150 GeV and 20% at 150 GeV .

The exclusion limits obtained on the coupling λ'_{111} at 95% confidence level (CL) are shown in fig. 4 as a function of the ($\tilde{d}$ and $\bar{\tilde{u}}$) squark mass. The derivation combines all

$\not{R}_p$ and gauge decay channels with branching ratios determined from the theory [9, 2]. In the case of the gauge decays, the branching of the χ_1^0 into $e^{\pm}q'\bar{q}'$ is taken at the value for a pure photino $\tilde{\gamma}$ and is of about $\approx 88\%$. In our minimal extension above the MSSM (i.e. introducing one Yukawa coupling on top of the MSSM free parameters), this actually is a maximal branching value. Nevertheless, exploring the parameters of the neutralino mass mixing matrix we find that such a branching holds within 10% for a large domain in the parameter space, e.g. for $\mu \lesssim -80$ GeV when $\tan\beta \lesssim 5$ and $M2 \lesssim 80$ GeV . The exclusion limits obtained represent an improvement of about a factor two compared

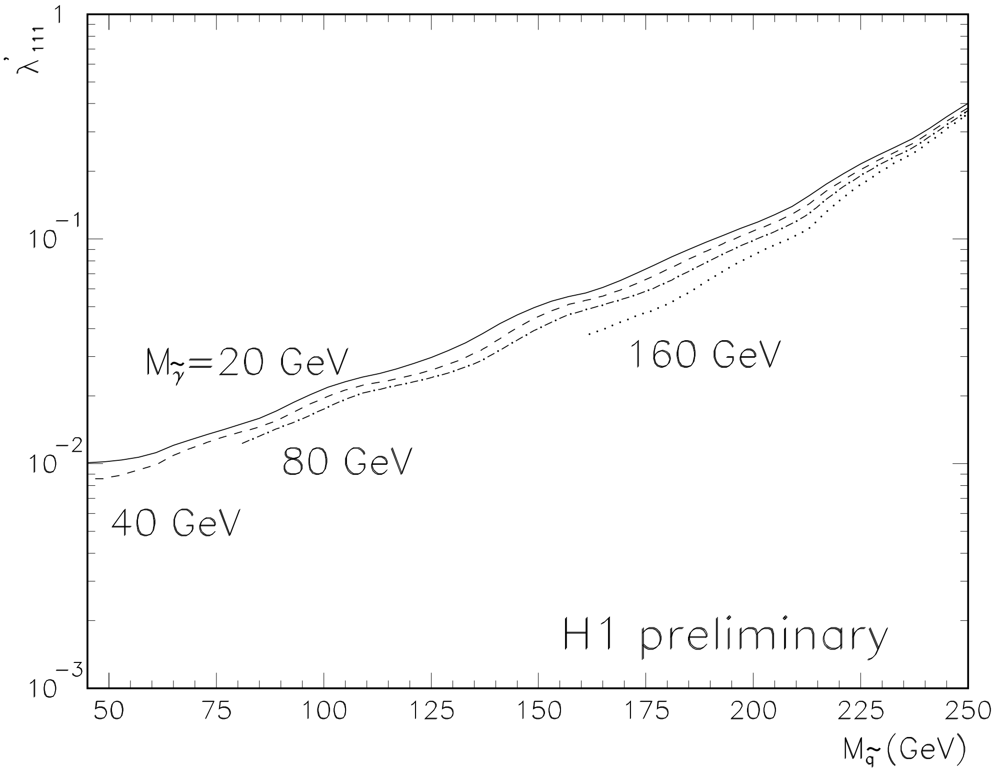

Figure 4: Exclusion upper limits at 95% CL for the coupling λ'_{111} as a function of squark mass for various fixed photino masses (regions above the curves excluded). The limits combine all charged and neutral decays of the $\tilde{d}$ and $\tilde{u}$.

to our previously published results [1]. Moreover, since we probe smaller values of λ'_{111}, the gauge decay branching of the squarks which leads to event topologies immediately distinguishable from those of leptoquarks dominates over a large fraction of the excluded domain. We are not aware of any other direct limit for λ'_{111} on squarks in $\not{R}_p$ SUSY besides the value of $M_{\tilde{q}} > 100$ GeV inferred in [10] from dilepton data of the Tevatron experiments.

Pair production of stop squarks:

For the simulation of stop pair production [11] in γ-gluon fusion, the resolved photon contribution [12] as well as the contribution from a Z boson exchange are neglected and the cross-sections are calculated in the Weizsacker-Williams approximation. The gluon density in the proton is taken from [13]. This choice constitutes the main source of systematic uncertainty.

The detection efficiencies for the signal of stop pair production after all selection cuts described in chapter 3 are found to vary from about 10% at 10 GeV to 30.5% at 30 GeV .

The exclusion limit obtained on the stop mass at 95% confidence level (CL) is shown in fig. 5. A stop lighter than 27 GeV is excluded at 95% confidence level. This limit does not depend upon the value of λ'_{13k} (as far as $\lambda'_{13k} \times \cos\theta_t > 10^{-4}$, below which value the decay into c and χ_1^0 cannot be neglected anymore). The angle θ_t is the mixing angle in the mass matrix of the stop (see for example [14]).

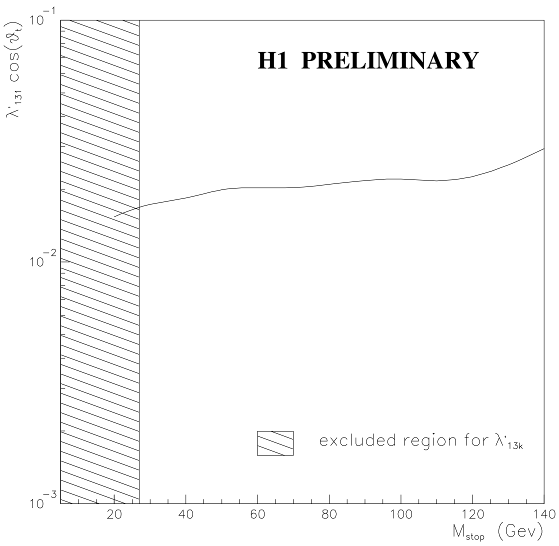

Figure 5: Exclusion limits for the coupling $\lambda'_{131} \times \cos\theta_t$ as function of the stop mass. The exclusion curve is obtained from the single stop production (region above the curve excluded). The hatched domain is excluded by the pair production search and concerns λ'_{13k} with $k = 1, 2, 3$.

If the coupling λ'_{131} dominates so that the stop can be singly produced in reactions of the type $e^+ + d \to \tilde{t}$, and with the restrictions given in [14], the search of the $\tilde{t}$ borrows from the analysis for $\not{R}_p$ decays of first generation squarks. We find that masses below 140 GeV are excluded at 95% CL for coupling strength of $(\lambda'_{131} \times \cos\theta_t)^2/4\pi \gtrsim 0.1\alpha_{em}$. As a comparison with other experiments, a $\tilde{t}$ lighter than 38 GeV is excluded at 95% CL from LEP data [15] for $\theta_t = 0$ from the width of the Z_0. But for θ_t close to the value for which the Z_0 decouples from the stop, $(0.7 < \theta_t < 1.4)$, there are no existing limit from LEP for $\not{R}_p$ stops.

5 Conclusions

We have searched for squarks from R-parity violating Supersymmetry in electron–proton scattering at HERA. No significant evidence for the production of squarks was found and mass dependent limits on the couplings were derived. The existence of first generation squarks at masses below 240 GeV is excluded at 95% confidence level for a strength of the Yukawa coupling λ'_{111} of $\lambda'^2_{111}/4\pi = \alpha_{em}$. The excluded domain in the mass-coupling plane for masses $\gtrsim$ 100 GeV has never been explored directly in other existing experiments.

Scalar stop squarks where searched in pair and single production modes. The existence of light scalar stops with λ'_{13k} couplings to light fermions is excluded for masses $5 < m_{\tilde{t}} <$ 27 GeV at 95% confidence level. Stop squarks with λ'_{131} couplings are excluded below 140 GeV at 95% confidence level for couplings ten times weaker than α_{em}.

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