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R-Parity Violation at HERA?

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Abstract

We examine the possibility that the high-Q^2 events seen at HERA are due to the production and decay of squarks of R-parity-violating supersymmetry. The relevant R-parity-violating coupling(s) is (are) identified and shown to lie between 0.03 and 0.26. Consequences of such a coupling at other experiments, such as the LEP and the Tevatron, are discussed.

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Recent reports of excess high-Q^2 events in both the H1 [1] and ZEUS [2] detectors at HERA are of considerable interest, since they correspond to possible leptoquark sightings. The H1 Collaboration [1] has reported 12 neutral current (NC) events with $Q^2 > 15000$ GeV^2 for an integrated luminosity of 14.2 pb^{-1} against a Standard Model (SM) deep inelastic scattering (DIS) background of 4.7 ± 0.76 events. The fluctuation probability for this is 9×10^{-3}. The ZEUS Collaboration [2] has reported 5 NC events with $Q^2 > 20000$ GeV^2 for an integrated luminosity of 20.1 pb^{-1} against a Standard Model background of 0.9 ± 0.08 events, for which there is a fluctuation probability of 1.4×10^{-2}. The excess events appear to indicate a resonance of mass around 200 GeV. A confirmation would point emphatically to new physics since leptoquark fields — vector or scalar — are not present in the SM. Vector leptoquarks arise naturally in Grand Unified Theories (GUTs) [3], but these are constrained by the proton lifetime to be very heavy — far beyond the reach of HERA energies. Relatively light vector leptoquarks may still exist in certain models, but these are not readily amenable to coupling constant unification [4]. On the other hand, scalar leptoquarks — arising from Higgs multiplets — are generically free from such constraints. Most such models, however, suffer from a major conceptual drawback, namely the lack of a satisfactory explanation for the large mass hierarchies in the theory. The presence of a light leptoquark accessible at HERA merely aggravates this problem. In contrast, the best known answer to the problem of mass hierarchies is provided by supersymmetry [5], which is also known to facilitate coupling constant unification [6]. It seems, therefore, that one will eventually require supersymmetry as well as grand unification in order to have a satisfactory theory involving the presence of elementary leptoquarks. However, before looking for an explanation of the HERA events within the framework of any supersymmetric GUT, it is interesting to ask if these events can be accommodated within the minimal supersymmetric extension of the Standard Model (MSSM) [5], which is a simpler construction.

In its usual formulation, the MSSM respects the global conservation laws for the baryon number B and lepton number L, which are valid in the SM. More conventionally represented as conservation of R-parity, $R_p \equiv (-1)^{3B+L+2S}$, where S is the intrinsic spin [7], this feature immediately precludes leptoquark-like interactions. However, this symmetry was originally imposed *ad hoc* and has no compelling theoretical motivation. It is thus important to investigate the consequences of possible R_p-violating terms [8, 9] in the Lagrangian. This assumes particular significance in view of the fact that it would allow the squarks to have leptoquark-like interactions. A broken R-parity ($\not{R}_p$) would also imply that the lightest supersymmetric particle (LSP) is no longer stable: search strategies and existing bounds on MSSM masses and couplings need to be modified accordingly.

While it is possible to have both L-violating and B-violating $\not{R}_p$ terms, non-observation of proton decay imposes very stringent conditions on their simultaneous presence [10]. Assuming that the baryon-number-violating terms are identically zero [11] helps evade this constraint in a natural way, apart from rendering simpler the cosmological requirement of the survival of GUT baryogenesis through to the present day. This survival can then be assured if at least one of the lepton numbers L_i is conserved over cosmological time scales [12].

We thus concentrate on the L-violating part of the superpotential, which can be written (with the MSSM superfields in usual notation) as

$$\mathcal{W} = \frac{1}{2}\lambda_{ijk} L_i L_j \overline{E_k} + \lambda'_{ijk} L_i Q_j \overline{D_k}, \tag{1}$$

where $\lambda_{ijk} = -\lambda_{jik}$, with i, j, k being family indices. Since we are interested in processes involving quarks, we shall further restrict ourselves to the λ'-type couplings only. The absence of λ_{ijk} couplings can be assured by the imposition of suitable discrete symmetries [11]. Neglecting quark mixing effects, the interaction Lagrangian can then be expressed as

$$\begin{aligned} \mathcal{L}_{\lambda'} \;=\; -\lambda'_{ijk} \Big[& \tilde{\nu}_{iL} \overline{d_{kR}} d_{jL} + \tilde{d}_{jL} \overline{d_{kR}} \nu_{iL} + \tilde{d}^\star_{kR} \overline{(\nu_{iL})^c} d_{jL} \\ & - \tilde{e}_{iL} \overline{d_{kR}} u_{jL} - \tilde{u}_{jL} \overline{d_{kR}} e_{iL} - \tilde{d}^\star_{kR} \overline{(e_{iL})^c} u_{jL} \Big] + \text{h.c.} \end{aligned} \tag{2}$$

Clearly, while the sleptons and sneutrinos behave rather like charged and neutral Higgses in a non-minimal model, the squark coupling mimics that of leptoquarks.

Given the above couplings, the processes of interest at HERA are [13, 14, 15]

$$e^+ + d_k \longrightarrow \tilde{u}_{jL} \longrightarrow e^+ + d_k \tag{3a}$$

$$e^+ + \bar{u}_j \longrightarrow \overline{\tilde{d}_{kR}} \longrightarrow e^+ + \bar{u}_j \;, \tag{3b}$$

and, of the 27 possible λ's, only nine (λ'_{1jk}) are relevant to our discussion. If one admits the possibility that more than one of these couplings may be non-zero, *tree-level* flavour-changing NCs are introduced and the bounds on most of the *products* are very severe [16]. More conservative bounds are obtained under the simplifying assumption that only one of these couplings may be non-zero. The relevant 2σ bounds (with their sources) are :

$$\begin{array}{llll} \lambda'_{11k} \lesssim 0.03\,(m_{\tilde{d}_{kR}}/100\,\text{GeV}) & & \text{Charged current universality [17]}, \\ \lambda'_{111} \lesssim 10^{-4}\, m_{\tilde{q}} m_{\tilde{g}}^{1/2}/(100\,\text{GeV})^{3/2} & & \text{Neutrinoless double } \beta\text{-decay [18]}, \\ \lambda'_{12k} \lesssim 0.4\,(m_{\tilde{d}_{kR}}/100\,\text{GeV}) & & \text{D-decays [19]}, \\ \lambda'_{122} \lesssim 0.03\,(m_{\tilde{s}}/100\,\text{GeV}) & & \nu_e\text{-Majorana mass [20]}, \\ \lambda'_{13k} \lesssim 0.63\,(m_{\tilde{d}_{kR}}/100\,\text{GeV}) & & \text{D-decays [21]}, \\ \lambda'_{133} \lesssim 0.03\,(m_{\tilde{b}}/100\,\text{GeV}) & & \nu_e\text{-Majorana mass [20]}, \\ \lambda'_{1j1} \lesssim 0.26\,(m_{\tilde{q}_{jL}}/100\,\text{GeV}) & (1\sigma) & \text{Atomic parity violation [17]}. \end{array} \tag{4}$$

Now, of the nine couplings λ'_{ijk}, only for three (λ'_{1j1}) can a valence quark in the proton participate in the production mechanism (eq.(3a)). For all other couplings, a sea-quark must appear in the initial state. As the data [1, 2] seem to indicate a moderately large value for the parton momentum fraction, the corresponding sea-quark densities are rather small. An explanation of the data would then need a large value of the corresponding λ', which is already ruled out by the constraints of eq.(4).

Of the three that are left, λ'_{111} has already been constrained to be too small to be relevant. Consequently, we are left with two possible couplings and hence scenarios, namely :

$$\lambda'_{121} \quad : \quad e^+ + d \longrightarrow \tilde{c}_L \longrightarrow e^+ + d \tag{5a}$$

and

$$\lambda'_{131} \quad : \quad e^+ + d \longrightarrow \tilde{t}_L \longrightarrow e^+ + d, \tag{5b}$$

so that the HERA NC events could be signals for the production of a left-handed scalar charm or stop. The major difference between these signals and those for a leptoquark (of the same mass and quantum numbers) lies in the fact that these squarks can have other (R_p-conserving) decay modes into quarks and charginos/neutralinos. This would show up either through the branching ratio or the width of the resonance [22].

Until now, we have considered only the $T_3 = \frac{1}{2}$ component of the squark doublet. However, the masses of the two isospin components are related, with the splitting determined by the corresponding quark masses and the $SU(2)_L$-breaking D-term [5]:

$$m^2_{\tilde{b}_L} = m^2_{\tilde{t}_L} - m_t^2 + m_b^2 - m_W^2 \cos 2\beta \ ,$$

and similarly for the $(\tilde{c}_L, \tilde{s}_L)$ pair. This implies the presence of at least one more relatively low-lying squark state ($\tilde{s}_L$ is somewhat heavier than $\tilde{c}_L$ while $\tilde{b}_L$ is somewhat lighter than $\tilde{t}_L$). A possible consequence is an extra contribution [23] to $\delta\rho \equiv 1 - m_W^2/m_Z^2 \cos^2\theta_W$. It is easy to check that the contribution due to $(\tilde{c}_L, \tilde{s}_L)$ is much smaller than the experimental errors [24]. For the stop solution, though, this constraint is non-trivial, especially for lighter stop masses within the (180–220) GeV range. As an example, for $m_{\tilde{t}_L} = 180$ GeV and $m_t = 170$ GeV, one needs[1] $\tan\beta \gtrsim 4$ for consistency with $\delta\rho$ at the 1σ level. This also implies that the $\tilde{b}_L$ would be just beyond the energy range of LEP2.

As far as HERA is concerned, the two processes (5a & 5b) are almost identical, the only major difference being the fact that the neutralino decay modes of the stop are greatly suppressed by phase-space considerations. Consequently, for most of our analysis, we shall consider (5a) to be the representative process and will highlight differences only where they are crucial.

While the production cross section for squarks is obviously quadratic in λ', the subsequent decay can be more complicated. If R-parity is violated, the squark may indeed be the LSP without contradicting any phenomenological bounds. In this case, it would be virtually indistinguishable from a leptoquark coupling to left-handed electrons and the right-handed d-quark. However, we do not make any such assumption and allow the squark ($\tilde{q}_L = \tilde{c}_L$ or $\tilde{t}_L$) to have R_p-conserving decays :

$$\begin{aligned} \tilde{q}_L &\longrightarrow q + \tilde{\chi}^0_j \ , \\ \tilde{q}_L &\longrightarrow q' + \tilde{\chi}^\pm_j \ . \end{aligned} \tag{6}$$

[1]This applies for the case of vanishing left-right squark mixing. In the presence of mixing, the constraint may be considerably relaxed.

The various branching fractions depend on both the size of λ' and the quark-squark-gaugino coupling as well as on the gaugino masses. Under the assumption of gaugino mass unification in the electroweak sector, the latter are determined in terms of three parameters: the gaugino mass term M_2 in the $SU(2)_L$ sector, the higgsino mixing parameter μ and $\tan\beta$, the ratio of the Higgs vacuum expectation values. Any explanation of the HERA events within the framework of R_p-violating supersymmetry must, therefore, consider the constraints that can already be imposed on the parameter space from LEP data. Now, if R-parity is violated, most of the usual bounds do not hold any longer unless further assumptions are made. In fact, with our choice of a non-zero λ', the only relevant constraint (in the M_2–μ plane) is the one derived from the *total width* of the Z [25]:

$$\sum_{i,j=1}^{2} \Gamma(Z \to \tilde{\chi}_i^+ \tilde{\chi}_j^-) + \sum_{i,j=1}^{4} \Gamma(Z \to \tilde{\chi}_i^0 \tilde{\chi}_j^0) \lesssim 23.1 \text{ MeV} . \tag{7}$$

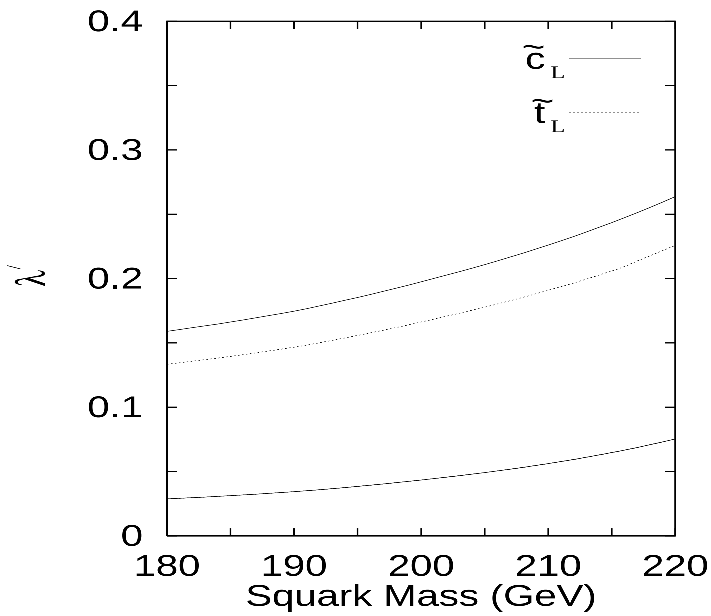

Figure 1: *The range in λ' that can account for the HERA events as a function of the squark mass. The minimum value is common to the two pairs $(\tilde{c}_L, \lambda'_{121})$ and $(\tilde{t}_L, \lambda'_{131})$. The spread accounts for all values of $(M_2, \mu, \tan\beta)$ consistent with the LEP constraint (7).*

We make a simple parton-level Monte Carlo simulation of the process $e^+p \to \tilde{c}_L/\tilde{t}_L + X \to e^+d + X$ at HERA energies using acceptance cuts and selection criteria closely modelled on those adopted for the NC signal by the H1 Collaboration [1]. Like them, we use the MRS(H) [26] distributions for the parton densities inside the proton, although we have checked that our results are not very sensitive to the particular structure functions being used. For a given value of the squark mass, we determine all values of the $\not{R}_p$-coupling λ'_{1j1} $(j = 2, 3)$, which can yield the observed excess of $12 - (4.7 \pm 0.76) \approx 7$ events in 14.2 pb^{-1} of data [1]. A value of λ'_{1j1} is deemed acceptable if we can find a set of values of $M_2, \mu, \tan\beta$ in the ranges $(0 < M_2 < 1 \text{ TeV}), (-1 \text{ TeV} < \mu < 1 \text{ TeV}), (1 < \tan\beta < 50)$, which is consistent with the LEP1 bounds and for which the required number of events is predicted. Our results are shown in Fig. 1 where solid (dotted) lines show, for each value of the squark mass, the upper and lower permissible values of λ'_{1j1} for $j = 2$ (3). The lower bounds are the same for the two cases; this corresponds to the fact that a small coupling requires a large branching ratio into $e^+ + d$, which is only possible if both charginos and neutralinos are very heavy, irrespective of the mass of the quark in the decay products. Another consequence of this fact is that the dependence of the allowed range in coupling is minimally dependent on $\tan\beta$. Thus, even if low values of $\tan\beta$ are disallowed by the ρ-parameter constraint for stops, the curves remain unchanged. It is interesting that the coupling cannot be smaller that 0.03 or larger than 0.26 (0.22) for $\tilde{c}_L$ ($\tilde{t}_L$) production to be the explanation of the HERA events. This result is consistent with the earlier bounds given by the H1 Collaboration [15] based on 2.8 pb^{-1} of data.

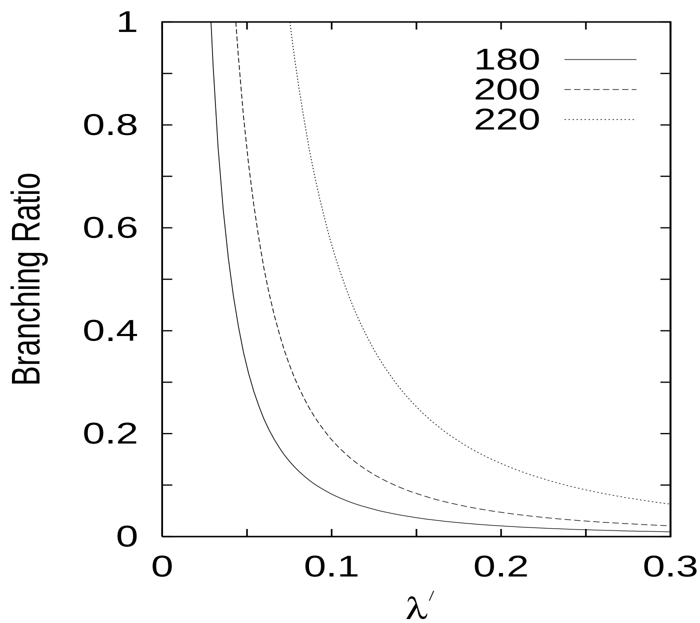

Figure 2: *The R_p-violating branching fraction for the squark as a function of the coupling for three different values of the squark mass (marked, in GeV).*

In Fig. 2, we exhibit the branching fraction of $\tilde{u}_{iL} \to e^+ + d$ $(i = 2, 3)$ required to explain the H1 events for $Q^2 > 15000\ \mathrm{GeV}^2$ as a function of the relevant λ', for three representative values of the squark mass. These curves tell us that for reasonably large values of the coupling the branching ratio must be rather small, *i.e.* 0.25 or less (unless the squark mass is at the lower end of the range). This immediately points to the conclusion that there should be a large cross-section for the squark in question to decay to charginos or neutralinos, which, in turn, should be expected to have decays leading to recognizable signals. Thus, under the assumption that only one R-parity-violating coupling is non-zero, the lightest neutralino will decay into two quarks and an electron/neutrino. For example,

$$\lambda'_{121} \quad : \quad \chi_1^0 \to c\bar{d}e^- \ , \ s\bar{d}\nu_e \tag{8}$$

as well as the conjugate modes. The situation is analogous for λ'_{131}, except for the fact that the decay proceeds only through the $\bar{d}\chi_1^0\tilde{d}$ and $\bar{b}\chi_1^0\tilde{b}$ couplings. Chargino decay is more complicated. Apart from the R_p-violating decay (isospin analogue of the process in eq.(8)), it could decay into two SM fermions and χ_1^0 with the last-mentioned then decaying as above. The ratio of the R_p-conserving and R_p-violating decay modes is determined by both the size of λ' and the gaugino content of the chargino, and the chargino–neutralino mass splitting. These issues have been studied in detail in ref. [15], for an integrated luminosity of 2.8 pb^{-1} with the conclusion that such cascade decays of a squark in the (180–220) GeV range cannot be recognized above the background for $\lambda \lesssim \sqrt{4\pi\alpha}$ (≈ 0.31 at HERA energies). Since this is precisely the region of the parameter space that we are interested in, we may safely conclude that *published* constraints from HERA [15] do not rule out any part of the parameter space shown in Fig. 1. On the other hand, *with the higher luminosity accumulated since then, it may well be possible to observe such signals.* If, indeed, such signals are seen, the signals will be able to clearly distinguish R_p-violating signals from those of leptoquarks. Non-observation would not rule out the $\not{R}_p$ option, but would restrict us to the lowest range of λ' for which the decay mode is practically indistinguishable from that of a leptoquark.

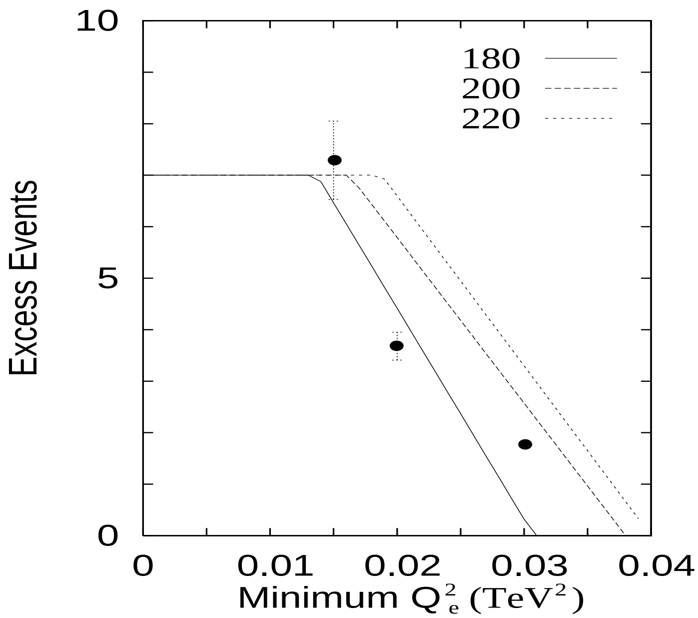

Figure 3: *The number of high Q^2 events due to squark production as a function of the minimum Q^2 used to bin the e^+, for three representative squark masses (marked, in GeV). The H1 data [1] are also shown.*

The hypothesis that the excess in high-Q^2 events is due to resonant production of a particle with leptoquark-like interactions is subjected to a simple test by the data presented by the H1 Collaboration [1] for different cuts on the minimum Q^2. They observe an excess over DIS predictions of approximately 7, 4 and 2 events, for $Q^2 > 15000, 20000, 30000\,\mathrm{GeV}^2$, respectively. This is also consistent with the excess observed by the ZEUS Collaboration [2], given their slightly higher luminosity. In Fig. 3 we illustrate our predictions for squark production in R_p-violating supersymmetry, as a function of the cut on minimum Q^2, normalized to 7 events, which agrees with the H1 excess for $Q^2 > 15000\,\mathrm{GeV}^2$. As before, solid, dashed and dotted lines correspond to squark masses of 180, 200, 220 GeV. The flatness of the initial part of the curve and its linear decrease thereafter are indicative of the relative smallness of the t-channel contribution. This is as expected, since it arises from a heavy sea-quark (c or t) and is a non-resonant process. It is clear from the figure that the observations seem to favour somewhat lower values of the squark mass within the range of interest. However, for such low statistics, any such statement must be made with a great degree of caution.

We have also examined the implications of an R-parity-violating solution, for the charged current (CC) excess seen by the H1 Collaboration [1]. This is rather hard to explain from direct squark decays. As the neutralino always decays within the detector for the allowed range of λ' couplings, the only possibility is to have the following process

$$e^+ + p \to \tilde{c}_L + X \to c + \tilde{\chi}_i^0 + X \to c + s\bar{s}\nu(\bar{\nu}) + X \ , \tag{9}$$

where the neutralino decay takes place through a virtual $\tilde{s}_L$ squark, which has to be close in mass (see above) to the $\tilde{c}_L$. Both the lightest and next-to-lightest neutralinos may participate in this process. The final state would be purely hadronic (mostly with more than one jet) with missing momentum, arising from the neutrino. A parton-level Monte Carlo analysis shows that for the greater part of the MSSM parameter space the final state neutrino is rather soft. In fact, two thirds or more of the events are lost because of the selection cut of 50 GeV on the missing momentum which has been imposed by the H1 Collaboration. For values of λ' consistent with the NC data, the branching ratio of the $\tilde{c}_L$ to neutralinos can be as high as 70%. For the same set(s) of parameters, the branching ratio for the $cs\bar{s}\nu(\bar{\nu})$ mode is around 40%. Convoluting these with the production cross-section, we predict up to 3 excess events in the CC sample for $Q^2 > 15000$ GeV^2, depending on the choice of the point in the parameter space. The excess drops rather sharply for $Q^2 > 20000$ GeV^2, however, which does not seem to agree well with the trend of the H1 data. Pushing the comparison further is not very meaningful in view of the low statistics. It is also noteworthy that the ZEUS Collaboration [2] has not reported any CC events, although their luminosity is somewhat higher. A full investigation must, therefore, await more data. Meanwhile we can say with some certainty that a charged current excess at the level observed so far can be accommodated quite easily within our $\not{R}_p$-scenario.

It may be said, therefore, that the observed excess in high-Q^2 events at HERA can be simply explained by squark production in R_p-violating supersymmetry. However, unless a further search for chargino/neutralino decay modes of these squarks is made and actual signals found, it will be difficult to decide whether the present signals are those arising from leptoquarks or squarks. We turn, therefore, to other possible consequences of the proposed scenario, with special emphasis on those that might distinguish it from the leptoquark alternative. We make the conservative assumption that no other supersymmetric particle would be discovered directly.

We start with LEP1 results on $R_b \equiv \Gamma(Z \to b\bar{b})/\Gamma(Z \to \text{hadrons})$. This is of relevance only to the $(\tilde{t}_L,\ \lambda'_{131})$ solution. It might be argued that a relatively light stop could contribute significantly to this ratio, especially if the chargino were light too. One must remember, however, that we are dealing with $\tilde{t}_L$ and the effect is smaller compared to that for $\tilde{t}_R$. Explicit computations show that the extra contribution is of the order of 10^{-5} to 10^{-4} and hence is consistent with the observations [27]. If we assume a degenerate $(\tilde{t}_L, \tilde{t}_R)$ pair (this does not affect the HERA signal), one can get a contribution as large as 10^{-3}, which is also consistent with observations. The contribution due to the λ'_{131} coupling itself is small [21]. The situation for R_ℓ is similar [21]. For $\lambda'_{131} \sim 0.25$ or less, the excess contribution is always well within the experimental errors at 1σ. Essentially, contributions to both R_b and R_ℓ are severely suppressed by a squark mass in the 200 GeV ballpark. Thus precision measurements at LEP1 will not help to confirm or deny our hypothesis.

Since these squarks are too heavy to be produced at LEP2, one could only consider virtual effects. A relevant process is $e^+e^- \to c\bar{c}$. A non-zero λ'_{121} leads to an additional (t-channel) diagram. A study of the angular distribution of the charm jets may rule out the high λ'_{121} end of the parameter space [28]. It is only fair to point out, however, that this is just the range where further searches at HERA itself may be effective.

At the Tevatron, there is enough energy to produce a pair of these squarks. Both R_p-conserving and R_p-violating processes will contribute. The cascade decay modes (through charginos and neutralinos) have been studied in the literature [29] in fair detail. The upshot of these is that squark masses and couplings of the magnitudes conceived of here would not lead to signals distinguishable from the background. On the other hand, direct decay into e^+d (in common with the leptoquark signal) will give rise to two hard jets and a dielectron pair. This signal might be of significance [30], especially for low values of λ'. However, in view of the large SM backgrounds, a detailed and separate study seems to be called for [31].

Virtual effects at the Tevatron are not likely to be a decisive discriminator. A non-zero λ'_{131} will enhance the $t\bar{t}$ production cross-section, but the relatively large errors in the cross-section measurement [32] do not allow us to probe $\lambda'_{131} \lesssim 0.3$ unless the selectron is light enough to be seen at LEP2 [33]. The analogous process for λ'_{121} would result in an enhancement of the large-p_T dijet rates. An improvement in the angular measurement [34] of the pure dijet spectrum could, in principle, rule out the large λ'_{121} end of the parameter space. This, however, is unlikely to substantially improve upon the bounds derivable from $c\bar{c}$ production at LEP2. Moreover, as pointed out already, this range of values of λ' can probably be probed at HERA itself. Dilepton production, on the other hand, can probe both the couplings [35], but would not be able to distinguish between them or from the leptoquark alternative. Thus, although they are certainly worth a detailed investigation, one cannot expect immediate confirmation or otherwise from virtual effects.

Another interesting possibility, which arises in models with R_p-violation, is that of single squark production at the Tevatron, the process relevant to the present investigation being $g + d \to \tilde{u}_{jL} + e^-$, where $j = 2, 3$. With the squark decaying through the $\not{R}_p$ interaction, we are led to the signal $p + \bar{p} \to e^+ + e^- + \text{jet} + X$. However, as Fig. 2 shows, choosing a large value of λ' to get a sizeable cross-section here is more than offset by the HERA requirement of a small branching ratio of the squark to e^+d. As a result, the signal is strongly suppressed and is not likely to be distinguishable above the SM background. It may still be possible to detect signals of the chargino or neutralino decay modes of the squark (as at HERA), especially with added luminosity, such as will be available with the commissioning of the Main Injector. Eventually, perhaps, CDF/D0 will be in a position to confirm the signal or, at least, rule out parts of the parameter space.

In summary, then, we have investigated the possibility that the excess high-Q^2 events observed at HERA are due to the production of squarks of R-parity-violating supersymmetry. We have shown that in view of low-energy constraints, this is acceptable only if one of the couplings $\lambda'_{121}, \lambda'_{131}$ is non-zero, so that the produced particle must be a left-handed scalar charm or stop. The coupling must lie between 0.03 and 0.26 for the first option and 0.03 and 0.22 for the second, depending on the mass of the squark, which, according to the data, must lie around 200 GeV with an uncertainty of about 10%. It turns out that, for a large range of these couplings, large branching ratios of the produced squark into charginos and neutralinos are predicted. Decays of the latter should lead to distinctive signals at HERA. On the other hand, small values of the $\not{R}_p$-violating coupling would make it extremely difficult to distinguish squark signals from those arising from leptoquarks of similar masses and couplings. We also show that confirmation (or otherwise) of our hypothesis at the two running high-energy facilities, LEP and the Tevatron, is unlikely to be immediately forthcoming, although we might expect some results from the Tevatron eventually with higher luminosities. The supersymmetric solution would thus remain a valid and exciting hypothesis to explain the HERA events, and we look forward to new results in this area in the near future.

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