HERA DATA AT HIGH Q^2: A SIGN OF NEW PHYSICS?*

H. SPIESBERGER

Fakultät für Physik, Universität Bielefeld
D-33501 Bielefeld, Germany

(Received October 30, 1997)

I review theoretical interpretations of the recently observed excess of high-Q^2 events in deep-inelastic positron-proton scattering at HERA, concentrating on scenarios with leptoquarks or squarks with R-parity violating couplings.

PACS numbers: 12.60. Jv, 13.85. Rm, 14.80. -j

1. The data

Both HERA experiments, H1 [1] and ZEUS [2], have reported the observation of an excess of events in deep-inelastic positron-proton scattering at large values of Bjorken-x and momentum transfer Q^2, relative to the expectation in the standard model. Including the new data presented recently at the 1997 Lepton-Photon Symposium [3] and the International Europhysics Conference on High Energy Physics [4], H1 and ZEUS each observe 18 neutral current (NC) events at $Q^2 > 1.5 \cdot 10^4$ GeV^2, while H1 expects 8.0 ± 1.2 and ZEUS about 15 events. At H1, the excess is concentrated in the rather narrow mass range 187.5 GeV $\leq M = \sqrt{xs} \leq$ 212.5 GeV where 8 events are observed with 1.53 ± 0.29 expected. However, in the same region, ZEUS finds roughly the expected number of events. Conversely, in the region $x > 0.55$, $y = Q^2/M^2 > 0.25$ where ZEUS finds 5 events with 1.51 ± 0.13 expected, H1 observes no excess. Fig. 1 shows the H1 and ZEUS results for the integrated cross section with a lower cut on Q^2, $\sigma_{NC}(Q^2 > Q^2_{\rm min})$ [3]. The data are above the standard model expectation by a factor of about 2 to 10, corresponding to about 2 standard deviations for $Q^2 \geq 15,000$ GeV^2.

* Presented at the XXI School of Theoretical Physics "Recent Progress in Theory and Phenomenology of Fundamental Interactions", Ustroń, Poland, September 19–24, 1997.

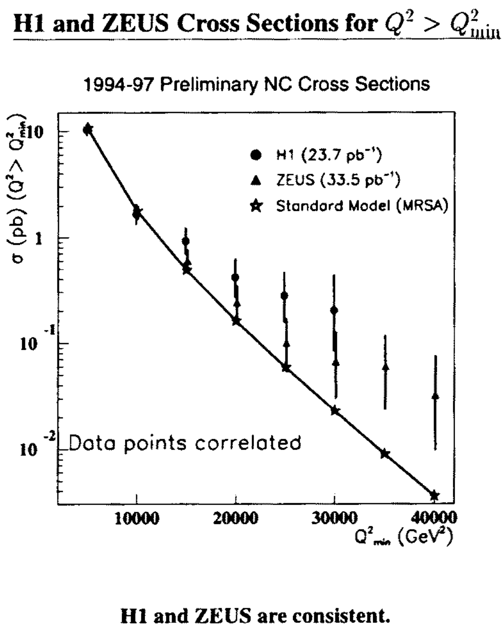

Fig. 1. H1 and ZEUS neutral current scattering cross sections for $Q^2 > Q^2_{\rm min}$ [3].

A surplus of events is also observed in charged current (CC) scattering, although with smaller statistical significance. At $Q^2 > 10^4$ GeV^2, H1 and ZEUS together find 28 events and expect 17.7 ± 4.3. Moreover, recently H1 reported also on the observation of 4 events with high-energetic muons in the final state where 0.4 are expected from leptonic decays of a W produced in e^+p scattering [4].

The clustering of the H1 NC events at a fixed value of $M = \sqrt{xs}$ could indicate the production of a resonance with leptoquark quantum numbers and mass $M \simeq 200$ GeV. On the other hand, ZEUS has 4 events clustered at a somewhat higher mass $M \simeq 225$ GeV. A direct comparison of event distributions of the two experiments is, however, difficult since H1 and ZEUS prefer different methods for the reconstruction of kinematic variables with different sensitivities to radiative effects and detector smearing. Given the experimental mass resolution of 5 and 9 GeV, respectively, it appears nevertheless unlikely that both signals come from a single narrow resonance [3, 5]. Rather, the excess may be a continuum effect reminiscent of contact interactions. Although the anomalous number of events is not large enough to clearly exclude statistical fluctuations as the origin of the effect, and despite of the puzzling differences among the H1 and ZEUS data, it is important to investigate possible interpretations within and beyond the standard model.

Leaving aside very small uncertainties in electroweak parameters and radiative corrections [1, 2], the main theoretical uncertainty on the high-Q^2 cross sections in the standard model comes from the structure functions. The latter are obtained by extrapolation of measurements at lower Q^2 using next-to-leading order evolution equations. For presently available parametrizations the HERA collaborations have estimated an uncertainty of about 7 % from this source [1, 2]. Attempts [6] to add to the conventional parton densities a new valence component at very large x but low Q^2, and to feed down this enhancement to lower x by evolution to very high Q^2, fail to increase the cross sections by a sufficient amount because of the constraints put by the fixed-target data. Explanations based on a strong intrinsic charm component [7] produced by some nonperturbative effect do not seem to be more successful. In fact, up to this day no standard model mechanism is known which could explain the observed surplus of events. Moreover, no sign of a deviation from the perturbative evolution of structure functions in QCD up to $Q^2 \simeq 10^4$ GeV^2 has so far been found in the data. Whatever mechanism is responsible for the HERA anomaly, it must have quite a rapid onset.

Therefore, if the excess is not a statistical fluctuation, it is very likely produced by some new physics beyond the standard model. Then the question arises whether one is dealing with a (not necessarily single) resonance or with a continuum effect. For a wide class of models, the latter can be parametrized with the help of contact interactions [8]. Recent analyses have shown that contact terms with a mass scale Λ of the order of 3 TeV [9] could explain the observed excess of events at large Q^2. Low-energy bounds from atomic parity violation experiments can be avoided by choosing parity-conserving combinations of contact terms [10]. However, measurements of the Drell–Yan cross section at the Tevatron put strong bounds on Λ [11] and leave only a small window open for an interpretation in terms of contact interactions[1]. In the following, I give a brief overview of the main hypotheses for resonance production.

2. Leptoquarks

The most exciting speculation is the one of a possible discovery of a new particle. Being supposedly produced as an s-channel resonance in e^+q or $e^+\bar{q}$ collisions, this new member of the particle zoo must be a boson and carry simultaneously lepton and quark quantum numbers. Such species are generically called leptoquarks.

---

[1] For more details, in particular concerning charged current scattering, see the contribution by F. Cornet [12] in these proceedings.

Leptoquarks appear in extensions of the standard model involving unification, technicolor, compositeness, or R-parity violating supersymmetry. In the generally adopted framework described in Ref. [13], they are assumed to have Yukawa-type couplings to lepton-quark pairs which are taken to be dimensionless and SU(3)× SU(2)×U(1) symmetric. Moreover, they are assumed to conserve lepton and baryon number in order to avoid rapid proton decay, to be non-zero only within one family in order to exclude FCNC processes beyond the CKM mixing, and chiral in order to avoid the very strong bounds from leptonic pion decays. The allowed states can be classified according to spin, weak isospin and fermion number. They are summarized in Table I.

The Yukawa couplings of scalar and vector leptoquarks are described by the effective Lagrangeans

$$\begin{aligned} \mathcal{L}^S_{\rm eff} &= (g_{\rm L}\bar{q}^c_{\rm L} i\tau_2 l_{\rm L} + g_{\rm R}\bar{u}^c_{\rm R} e_{\rm R})\, S_0 + g_{\rm R}\bar{d}^c_{\rm R} e_{\rm R}\tilde{S}_0 + g_{\rm L}\bar{q}^c_{\rm L} i\tau_2 \vec{\tau} l_{\rm L}\vec{S}_1 \\ &\quad + (g_{\rm L}\bar{u}_{\rm R} l_{\rm L} + g_{\rm R}\bar{q}_{\rm L} i\tau_2 e_{\rm R})\, S_{1/2} + g_{\rm L}\bar{d}_{\rm R} l_{\rm L}\tilde{S}_{1/2}, \qquad (1) \\ \mathcal{L}^V_{\rm eff} &= (g_{\rm L}\bar{d}^c_{\rm R}\gamma_\mu e_{\rm L} + g_{\rm R}\bar{q}^c_{\rm L}\gamma_\mu e_{\rm R})\, V^\mu_{1/2} + g_{\rm L}\bar{u}^c_{\rm R}\gamma_\mu l_{\rm L}\tilde{V}^\mu_{1/2} \\ &\quad + (g_{\rm L}\bar{q}_{\rm L}\gamma_\mu l_{\rm L} + g_{\rm R}\bar{d}_{\rm R}\gamma_\mu e_{\rm R})\, V^\mu_0 + g_{\rm R}\bar{u}_{\rm R}\gamma_\mu e_{\rm R}\tilde{V}^\mu_0 \\ &\quad + g_{\rm L}\bar{q}_{\rm L}\vec{\tau}\gamma_\mu l_{\rm L}\vec{V}^\mu_1 . \qquad (2) \end{aligned}$$

Here, c denotes charge conjugation, $q_{\rm L}$ and $l_{\rm L}$ denote the left-handed quark and lepton doublets, and $u_{\rm R}$, $d_{\rm R}$ and $e_{\rm R}$ the right-handed quark and lepton fields.

With the above couplings the resonance cross section in ep scattering is given by

$$\frac{d\sigma}{dy} = \frac{\pi}{4s}\lambda^2 q_f(M^2/s, \mu^2) \times \begin{cases} 1 & \text{for scalars,} \\ 6(1-y)^2 & \text{for vectors.} \end{cases} \qquad (3)$$

$q_f(x, \mu^2)$ is the density of quarks (or antiquarks) with flavour f in the proton. The relevant scale μ is expected to be of order M. Obviously, leptoquarks with fermion number $F = 0\,(2)$ are dominantly produced from valence quarks in e^+q (e^-q) fusion. Scalar and vector states can be identified by the different dependence of their production cross sections on the electron scattering angle θ^*, $\cos\theta^* = 1 - 2y$, in the eq center-of-mass frame. The coupling λ for each leptoquark species is determined by the Yukawa couplings $g_{L,R}$ as shown in Table I.

TABLE I

Scalar (S) and vector (V) leptoquarks, their electric charges Q, decay modes, branching ratios into charged lepton + jet channels, and Yukawa couplings. Given are also the most stringent low-energy bounds and the couplings deduced from the 1994-96 HERA data [15]. Inclusion of the 1997 data decrease the couplings by about 15%. Also shown are the possible assignments of squarks with R-parity violating couplings.

LQ		Q	Decay Mode	BR $e^{\pm}\, j$	Coupling $\lambda_{\mathrm{L,R}}$	Limits Ref. [14]	HERA estimates
S_0	$\tilde{d}_{\mathrm{R}}$	$-1/3$	$e_{\mathrm{L}}u$	$\frac{1}{2}$	g_{L}	$g_{\mathrm{L}} < 0.06$	0.40
			$\nu_{\mathrm{L}}d$		$-g_{\mathrm{L}}$		
			$e_{\mathrm{R}}u$	1	g_{R}	$g_{\mathrm{R}} < 0.1$	0.28
$\tilde{S}_0$		$-4/3$	$e_{\mathrm{R}}d$	1	g_{R}	$g_{\mathrm{R}} < 0.1$	0.30
S_1		$+2/3$	$\nu_{\mathrm{L}}u$	0	$\sqrt{2}g_{\mathrm{L}}$		–
		$-1/3$	$\nu_{\mathrm{L}}d$	$\frac{1}{2}$	$-g_{\mathrm{L}}$	$g_{\mathrm{L}} < 0.09$	0.40
			$e_{\mathrm{L}}u$		$-g_{\mathrm{L}}$		
		$-4/3$	$e_{\mathrm{L}}d$	1	$-\sqrt{2}g_{\mathrm{L}}$		0.21
$V_{1/2}$		$-1/3$	$\nu_{\mathrm{L}}d$	0	g_{L}	$g_{\mathrm{L}} < 0.09$	–
			$e_{\mathrm{R}}u$	1	g_{R}		0.30
		$-4/3$	$e_{\mathrm{L}}d$	1	g_{L}	$g_{\mathrm{R}} < 0.05$	0.32
			$e_{\mathrm{R}}d$		g_{R}		0.32
$\tilde{V}_{1/2}$		$+2/3$	$\nu_{\mathrm{L}}u$	0	g_{L}	$g_{\mathrm{L}} < 0.09$	–
		$-1/3$	$e_{\mathrm{L}}u$	1	g_{L}		0.32
$S_{1/2}$		$-2/3$	$\nu_{\mathrm{L}}\bar{u}$	0	g_{L}	$g_{\mathrm{L}} < 0.1$	–
			$e_{\mathrm{R}}\bar{d}$	1	$-g_{\mathrm{R}}$		0.052
		$-5/3$	$e_{\mathrm{L}}\bar{u}$	1	g_{L}	$g_{\mathrm{R}} < 0.09$	0.026
			$e_{\mathrm{R}}\bar{u}$		g_{R}		0.026
$\tilde{S}_{1/2}$	$\bar{\tilde{d}}_{\mathrm{L}}$	$+1/3$	$\nu_{\mathrm{L}}\bar{d}$	0	g_{L}	$g_{\mathrm{L}} < 0.1$	–
	$\bar{\tilde{u}}_{\mathrm{L}}$	$-2/3$	$e_{\mathrm{L}}\bar{d}$	1	g_{L}		0.052
V_0		$-2/3$	$e_{\mathrm{L}}\bar{d}$	$\frac{1}{2}$	g_{L}	$g_{\mathrm{L}} < 0.05$	0.080
			$\nu_{\mathrm{L}}\bar{u}$		g_{L}		
			$e_{\mathrm{R}}\bar{d}$	1	g_{R}	$g_{\mathrm{R}} < 0.09$	0.056
$\tilde{V}_0$		$-5/3$	$e_{\mathrm{R}}\bar{u}$	1	g_{R}	$g_{\mathrm{R}} < 0.09$	0.027
V_1		$+1/3$	$\nu_{\mathrm{L}}\bar{d}$	0	$\sqrt{2}g_{\mathrm{L}}$		–
		$-2/3$	$e_{\mathrm{L}}\bar{d}$	$\frac{1}{2}$	$-g_{\mathrm{L}}$	$g_{\mathrm{L}} < 0.04$	0.080
			$\nu_{\mathrm{L}}\bar{u}$		g_{L}		
		$-5/3$	$e_{\mathrm{L}}\bar{u}$	1	$\sqrt{2}g_{\mathrm{L}}$		0.019

Having only couplings to standard model particles, leptoquarks decay exclusively to lepton-quark pairs. The partial width per channel is given by

$$\Gamma = \frac{a}{16\pi}\lambda^2 M = 350\,\text{MeV}\,a\left(\frac{\lambda}{e}\right)^2\left(\frac{M}{200\,\text{GeV}}\right), \qquad (4)$$

a being 1 for scalars and 2/3 for vectors. Hence, leptoquarks are very narrow for masses in the range accessible at HERA, and for couplings weaker than the electromagnetic coupling strength $e = \sqrt{4\pi\alpha}$.

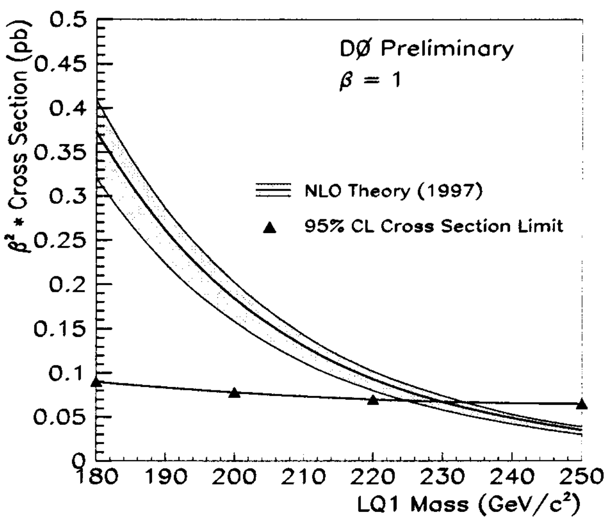

Fig. 2. The 95 % CL limit on the production cross section times branching ratio $\beta = B_{eq}$ from [16]. The band shows the NLO theoretical prediction [25].

The leptoquark masses and couplings are constrained by high-energy data. Direct searches for leptoquarks have been performed at the Tevatron, at HERA and at LEP. Recently, both experiments, CDF and D0, have improved their mass limits for scalar leptoquarks considerably. D0 excludes first generation leptoquarks with masses below 225 GeV assuming a branching ratio $B_{eq} = 1$ for decays into $e^{\pm}$ and a jet (see Fig. 2, [16]), whereas CDF quotes a limit of 213 GeV [17] (all mass limits are at 95 % CL). For branching ratios less than one, the limits are weaker, *e.g.*, $M > 176$ GeV for $B_{eq} = 0.5$ [16]. The bounds on vector states are even stronger: 298 GeV for $B_{eq} = 1$ and 270 GeV for $B_{eq} = 0.5$ [18]. The corresponding bounds on second and third generation scalar leptoquarks are $M > 184$ GeV for $B_{\mu q} = 1$ and $M > 98$ GeV for $B_{\tau q} = 1$, respectively [19]. The above constraints follow from pair-production mainly by $q\bar{q}$ annihilation, and are therefore practically independent of the unknown Yukawa coupling λ. In contrast, the mass limits obtained at HERA depend on λ and the quantum numbers specified in Table I. For $\lambda = e$ they range from 207 to 272 GeV [20]. These limits are lowered by about 50 GeV if $\lambda = 0.1$. Finally, the most stringent but again λ-dependent mass bound at LEP2 comes from the search for single-leptoquark production and excludes masses below 131 GeV assuming $\lambda > e$ [21]. The mass limits from leptoquark pair production [22] roughly reach half of the center-of-mass energy $\sqrt{s}$, and are thus much weaker than the Tevatron bounds.

Indirect bounds on Yukawa couplings and masses can be derived from t/u-channel LQ-exchange in $e^+e^- \rightarrow q\bar{q}$ [23], and from low-energy data [14]. From the very recent analysis by OPAL (see Fig. 3) we infer upper limits on λ between 0.2 and 0.7 assuming $M = 200$ GeV. However, the most restrictive bounds come from atomic parity violation and lepton and quark universality, at least for first generation leptoquarks and chiral couplings. The maximum allowed couplings for $M = 200$ GeV are given in Tab. I [15].

In order to explain the observed excess of high-Q^2 events at HERA by the production and decay of a 200 GeV leptoquark, one roughly needs $\lambda \simeq e$ for $F = 2$ states and $\lambda \simeq e/10$ for $F = 0$. The factor 10 difference in λ simply reflects the factor 100 difference in the sea and valence quark densities in the region of x and Q^2 where the signal resides. Similarly, the coupling of $F = 0$ leptoquarks to the d quark has to be two times larger than the coupling to the u quark in order to compensate the factor four difference in the corresponding quark densities. These simple rules of thumb describe the main pattern in the couplings found in detailed analyses [24], and shown in the last column of Table I.

Whereas the coupling strength λ required for $F = 0$ leptoquarks is compatible with all existing bounds, the coupling necessary for $F = 2$ leptoquarks is already excluded by the low-energy constraints, and also at the borderline of getting in conflict with LEP2 data. Moreover, with such strong couplings, $F = 2$ leptoquarks should have shown up in e^-p scattering at HERA [26], where they can be produced off the valence quark component, despite of the low luminosity of the previous e^-p run. Since vector leptoquarks cannot be made responsible for an excess of events at $M \simeq 200$ to 225 GeV because of the high Tevatron mass bounds, only the two scalar doublets $S_{1/2}$ and $\tilde{S}_{1/2}$ remain from the whole Table I as a possible interpretation. However, also these solutions have difficulties. Firstly, the Tevatron mass limits require scalar leptoquarks of the first generation with $M \simeq 200$ GeV to have branching ratios into $e + jet$ final states less than about 0.7, whereas in the simple framework considered in Table I, $S_{1/2}$ and $\tilde{S}_{1/2}$ are expected to have $B_{eq} = 1$. Secondly, the scalar doublets cannot give rise to CC events.

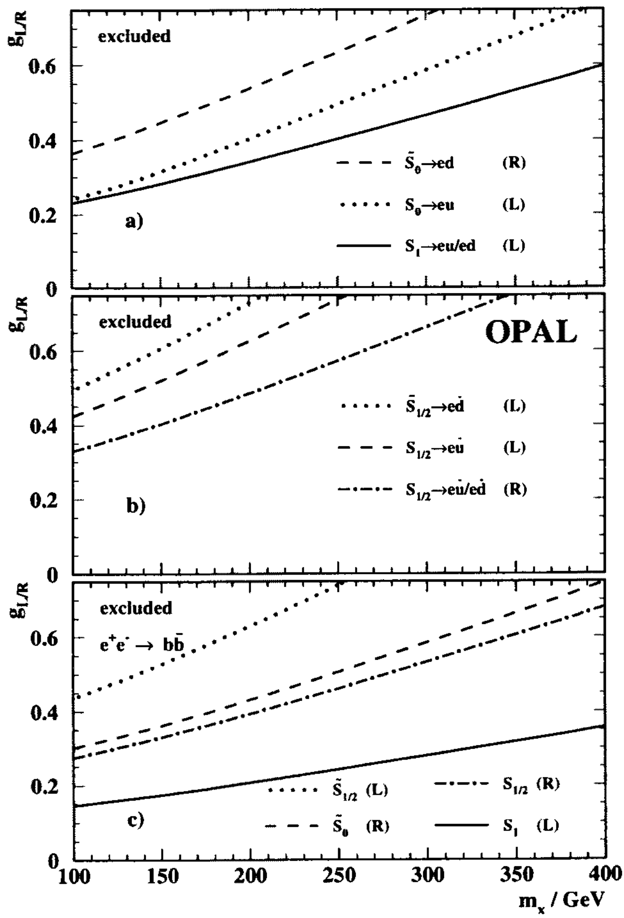

Fig. 3. OPAL 95 % confidence exclusion limits on g_L or g_R as a function of the mass m_X for scalar leptoquarks. (a) and (b) show limits on leptoquark couplings to a single quark family, derived from the hadronic cross sections. (c) shows limits on leptoquark couplings to b quarks only, derived from the $b\bar{b}$ cross sections. The excluded regions are above the curves in all cases. The figure is taken from Ref. [23] where similar exclusion limits for vector leptoquarks can also be found.

Thus it seems that the leptoquark interpretation of the HERA high-Q^2 events points to more complicated and maybe more realistic scenarios. Several possibilities have been suggested allowing for $B_{eq} < 1$ and, at the same time, providing CC final states: leptoquarks with interfamily couplings [27, 28], leptoquark mixing [29], LQ models with additional vector-like fermions [30], and squarks with R-parity violating couplings [31].

3. Squarks

Supersymmetry with R-parity violation provides an attractive theoretical framework in which squarks can have direct couplings to lepton-quark pairs, and therefore act as leptoquarks. However, because of the usual R-parity conserving interactions one naturally expects the branching ratio for $\tilde{q} \to e + jet$ to be smaller than unity. In addition, one can get CC-like final states, *e.g.*, through the decay chain $\tilde{q} \to q\chi \to q\nu + \cdots$, χ being either a neutralino or chargino. Thus it appears possible to avoid the two main problems encountered in the simplest leptoquark models.

TABLE II

Low-energy constraints on R-parity violating couplings $\lambda'_{ijk} < C\,(M_{\tilde{q}}/200\,\mathrm{GeV})^n \times (m_{\tilde{g}}/1\,\mathrm{TeV})^m$ relevant for e^+p scattering [33]. The limit on λ'_{123} from $D-\overline{D}$ mixing, marked by *, involves quark mixing and is thus more model dependent.

ijk	C	n,m	source
111	0.004	$2,\frac{1}{2}$	ν-less $\beta\beta$ decay
112 113	0.04	1,0	CC universality
121 131	0.07	1,0	atomic P-violation
122 133	0.08 0.003	$\frac{1}{2}$,0	ν_e mass
123	0.52 0.28	1,0 $\frac{1}{2}$,0	F – B asymmetry $D-\overline{D}$ mixing*
132	0.68	1,0	R_e (Z_0)

In the minimal supersymmetric extension of the standard model, one can have a renormalizable, gauge invariant operator in the superpotential that couples squarks to quarks and leptons:

$$W_{\not{R}} = \lambda'_{ijk} L^i_{\mathrm{L}} Q^j_{\mathrm{L}} \overline{D}^k_{\mathrm{R}}\,. \tag{5}$$

Here, L and Q denote doublets of lepton and quark superfields, respectively, D stands for singlets of d-quark superfields, and i, j, and k are generation indices. This interaction term violates global invariance of R-parity, defined as $R = (-1)^{3B+L+2S}$ which is $+1$ for particles and -1 for superpartners. In general, there are other R-odd operators in the superpotential that couple sleptons to leptons and squarks to quarks. Together, they may induce rapid proton decay. This can be avoided by requiring conservation of R-parity, or a strong hierarchy in the various couplings. Generally, these two options lead to very different phenomenology.

Expanding the superfields in (5) in terms of matter fields, one finds interaction terms which allow for resonance production of squarks at HERA [32]:

$$e^+ d^k_{\rm R} \to \tilde{u}^j_{\rm L}\,, \qquad (\tilde{u}^j = \tilde{u}, \tilde{c}, \tilde{t})\,, \tag{6}$$

$$e^+ \bar{u}^j_{\rm L} \to \bar{\tilde{d}}^k_{\rm R}\,, \qquad (\tilde{d}^k = \tilde{d}, \tilde{s}, \tilde{b})\,. \tag{7}$$

The cross sections are determined by the coupling constants λ'_{1jk}. Similarly as the leptoquark Yukawa couplings $\lambda_{L,R}$ from Table I, these couplings are strongly constrained by existing data. The relevant bounds are summarized in Table II. As already pointed out, since the excess of events was observed in e^+p but not in e^-p scattering, the process of class (7) involving the $\bar{u}$ sea is unlikely. Moreover, the coupling strength $\lambda'_{11k} \simeq e$, required for

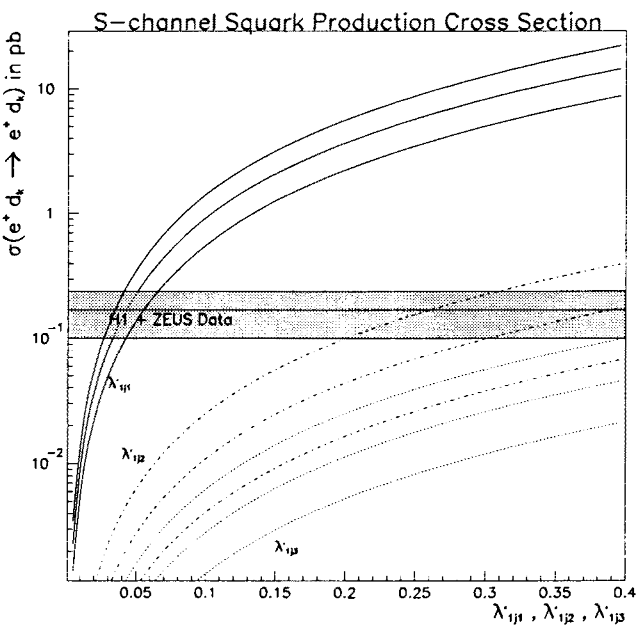

Fig. 4. Cross section for $e^+d_k \to \tilde{u}_j \to e^+d_k$ as a function of the coupling λ'_{1jk} for d valence quarks (full), s quarks (dash-dotted) and b quarks (dotted) assuming $B_{eq} = 1$. The curves from top to bottom correspond to $M_{\tilde{u}_j} = 200$, 210, and 220 GeV. The shaded region shows the excess cross section $\sigma_{exp} = (0.17 \pm 0.07)$ pb from the 1994–96 HERA data for $Q^2 > 20,000$ GeV^2 (from Ref. [36]).

production off sea quarks, is incompatible with the existing bounds. This also applies to the $e^+\bar{c}$ channel with the marginal exception of the subprocess $e^+\bar{c} \to \bar{\tilde{t}}$ [36]. The top sea plays no role. Turning to the processes of class (6), one finds three possible explanations of the HERA anomaly [31][2]:

$$e^+d \to \tilde{c} \quad (\lambda'_{121}), \tag{8}$$
$$e^+d \to \tilde{t} \quad (\lambda'_{131}), \tag{9}$$
$$e^+s \to \tilde{t} \quad (\lambda'_{132}). \tag{10}$$

The corresponding cross sections are plotted in Fig. 4 for $M_{\tilde{q}} = 200$ to 220 GeV, and setting $B_{eq} = 1$. As can be seen, within the limits on λ' quoted in Tab. II one can still afford branching ratios for $\tilde{c}, \tilde{t} \to e^+d$ below 0.7, necessary in order to avoid the D0/CDF mass bounds. Studies [34, 37] have shown that one can indeed find allowed regions in the supersymmetry parameter space in which $B_{eq} < 0.7$. This is exemplified in Fig. 5 for $B(\tilde{t} \to e^+d)$. However, there is not too big a room for a consistent squark interpretation of the HERA anomaly.

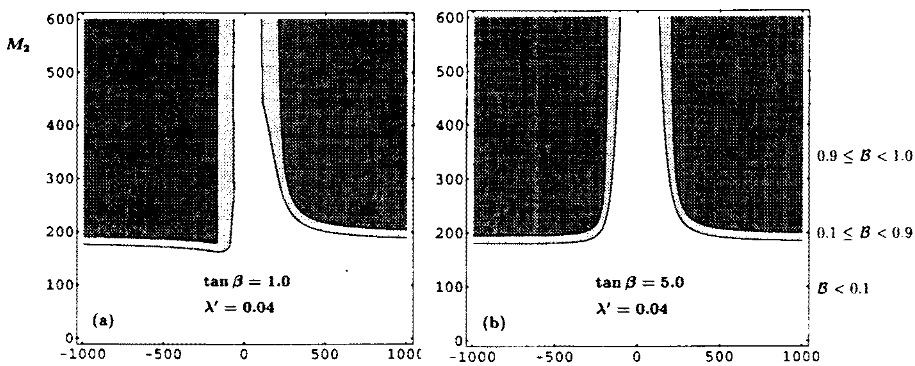

Fig. 5. Contours of $B(\tilde{t} \to e^+d)$ in the $\mu - M_2$ plane assuming vanishing stop left-right mixing. The LEP2 bound of 85 GeV for the chargino mass is taken into account. From Ref. [34].

Note that the NC events from $\tilde{t}, \tilde{c} \to e^+d$ have the same visible particles as the DIS-NC events. This is not expected for the CC events originating from cascade decays of squarks on the one hand, and DIS-CC events on the other.

Finally, the difficulty to interpret the excess of events as a single resonance effect may also find a reasonable solution [38]. In the MSSM, each fermion has two superpartners which mix in general. In the case of stop,

[2] For a discussion of the strange stop scenario see in particular Ref. [35]

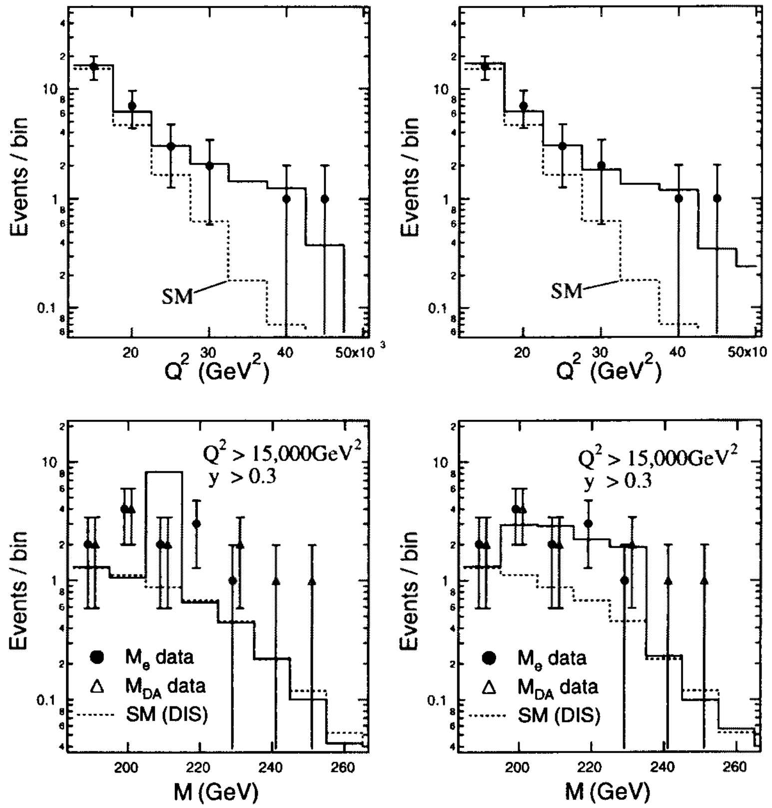

Fig. 6. Distributions in $M = \sqrt{xs}$ of the 1994 - 96 HERA data (combined H1 and ZEUS) in comparison with the distributions in a single stop scenario (left, $M_{\tilde{t}} = 210$ GeV, $\lambda'_{131} = 0.04$) and in a mixed left-right stop scenario (right, $M_{\tilde{t}_1} = 205$ GeV, $M_{\tilde{t}_2} = 225$ GeV, $\theta_t = 0.95$, $\lambda'_{131} = 0.045$). From Ref. [38].

this mixing may be sizeable and lead to two mass eigenstates with a small but pronounced mass difference. Such a case is illustrated in Fig. 6. The resulting mass distribution can apparently mimic a continuum effect.

4. Conclusions

For the time being, it is an open question whether or not the excess of high-Q^2 events observed at HERA is a statistical fluctuation or a physical effect. If it is a real signal, then it very likely originates from new physics beyond the standard model. Making this assumption, the present data slightly favour some continuum mechanism, but do not yet allow to rule out a resonance effect. Both kinds of interpretations are tightly constrained by measurements at LEP2 and the Tevatron, as well as by low-energy data. These bounds rule out the simplest leptoquark scenarios and do also not leave much room for the squark interpretation. Particularly difficult would be the explanation of an excess of CC events. At any rate, if the excess of high-Q^2 events is confirmed by future data it is likely that related signals will soon show up in other experiments [39].

I wish to thank J. Kalinowski, R. Rückl and P. Zerwas for the fruitful collaboration on the subject of this talk, and T. Kon for providing me with an updated version of Fig. 6. This work was supported by the Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie, Bonn, Germany, Contract 05 7BI92P (9). I also want to thank K. Kołodziej for his kind invitation to and hospitality at the workshop.

REFERENCES

[1] C. Adloff *et al.*, H1 Collaboration, *Z. Phys.* **C74**, 191 (1997).

[2] J. Breitweg *et al.*, ZEUS Collaboration, *Z. Phys.* **C74**, 207 (1997).

[3] B. Straub, Talk presented at the XVIII International Symposium on Lepton Photon Interactions, July 28–August 1, 1997, Hamburg.

[4] E. Elsen, Talk presented at the International Europhysics Conference on High Energy Physics, August 19–26, 1997, Jerusalem.

[5] U. Bassler and G. Bernardi, DESY 97-136 (hep-ex/9707024).

[6] S. Kuhlmann, H.L. Lai, W.K. Tung, hep-ph/9704338; K.S. Babu, C. Kolda, J. March-Russell, F. Wilczek, hep-ph/9705399;

[7] J.F. Gunion, R. Vogt, hep-ph/9706252; W. Melnitchouk, A.W. Thomas, hep-ph/9707387.

[8] R. Rückl, *Phys. Lett.* **B129**, 363 (1983); *Nucl. Phys.* **B234**, 91 (1984); P. Haberl, F. Schrempp, H.-U. Martyn, in the Proceedings, *Physics at HERA*, eds W. Buchmüller and G. Ingelman, Hamburg, 1991.

[9] K.S. Babu, C. Kolda, J. March-Russell, F. Wilczek, *Phys. Lett.* **B402**, 367 (1997); V. Barger *et al.*, *Phys. Lett.* **B404**, 147 (1997), hep-ph/9707412; N. Di Bartolomeo, M. Fabbrichesi, *Phys. Lett.* **B406**, 237 (1997); N.G. Deshpande, B. Dutta, X.-G. He, hep-ph/9705236; F. Cornet, J. Rico, hep-ph/9707299.

[10] A. Deandrea, hep-ph/9705435.

[11] V. Barger *et al.*, hep-ph/9707412; X. Wu, Talk presented at the International Europhysics Conference on High Energy Physics, August 19–26, 1997, Jerusalem.

[12] F. Cornet, these proceedings.

[13] W. Buchmüller, R. Rückl, D. Wyler, *Phys. Lett.* **B191**, 442 (1987).

[14] M. Leurer, *Phys. Rev.* **D49**, 333 (1994); *Phys. Rev.* **D50**, 536 (1994); S. Davidson, D. Bailey, B. Campbell, *Z. Phys.* **C61**, 613 (1994).

[15] J. Kalinowski, R. Rückl, H. Spiesberger, P.M. Zerwas, *Z. Phys.* **C74**, 595 (1997).

[16] B. Abbott *et al.*, D0 Collaboration, FERMILAB-PUB-97/252-E (hep-ex/9707033).

[17] F. Abe *et al.*, CDF Collaboration, FERMILAB-PUB-97/280-E.

[18] J.A. Valls, FERMILAB-CONF-97/135-E, XXXII Rencontres de Moriond, QCD and Hadronic Interactions, Les Arcs, France, 1997.

[19] F. Abe *et al.*, CDF Collaboration, *Phys. Rev. Lett.* **78**, 2906 (1997); *Phys. Rev. Lett.* **75**, 1012 (1995); B. Abbott *et al.*, D0 Collaboration, paper 109 submitted to the International Europhysics Conference on High Energy Physics, Jerusalem, 1997.

[20] S. Aid *et al.*, H1 Collaboration, *Phys. Lett.* **B369** 173 (1996); M. Derrick *et al.*, ZEUS Collaboration, *Phys. Lett.* **B306**,173 (1993); *Z. Phys.* **C73**, 613 (1997).

[21] OPAL Collaboration, paper LP138 submitted to the XVIII International Symposium on Lepton-Photon Interactions, Hamburg, 1997.

[22] B. Adeva *et al.*, L3 Collaboration, *Phys. Lett.* **B261**, 169 (1991); G. Alexander *et al.*, OPAL Collaboration, *Phys. Lett.* **B263**, 123 (1991); P. Abreu *et al.*, DELPHI Collaboration, *Phys. Lett.* **B316**, 620 (1993).

[23] K. Ackerstaff *et al.*, OPAL Collaboration, CERN-PPE/97-101.

[24] G. Altarelli *et al.*, hep-ph/9703276; J. Blümlein, *Z. Phys.* **C74**, 605 (1997); J. Kalinowski, R. Rückl, H. Spiesberger, P.M. Zerwas, *Z. Phys.* **C74**, 595 (1997); K.S. Babu, C. Kolda, J. March-Russell, F. Wilczek, *Phys. Lett.* **B402**, 367 (1997); J.L. Hewett, T.G. Rizzo, hep-ph/9703337; Z. Kunszt, W.J. Stirling, *Z. Phys.* **C75**, 453 (1997).

[25] M. Krämer, T. Plehn, M. Spira, P.M. Zerwas, *Phys. Rev. Lett.* **79**, 341 (1997).

[26] S. Aid *et al.*, H1 Collaboration, *Phys. Lett.* **B369**, 173 (1996).

[27] Z. Kunszt, W.J. Stirling, *Z. Phys.* **C75**, 453 (1997).

[28] G. Altarelli, G.F. Giudice, M.L. Mangano, hep-ph/9705287.

[29] K.S. Babu, C. Kolda, J. March-Russell, hep-ph/9705414.

[30] J.L. Hewett, T.G. Rizzo, hep-ph/9708419.

[31] D. Choudhury, S. Raychaudhuri, *Phys. Lett.* **B401**, 54 (1997); G. Altarelli *et al.*, hep-ph/9703276; H. Dreiner, P. Morawitz, hep-ph/9703279; J. Kalinowski, R. Rückl, H. Spiesberger, P.M. Zerwas, *Z. Phys.* **C74**, 595 (1997); T. Kon, T. Kobayashi, hep-ph/9704221; J. Ellis, S. Lola, K. Sridhar, hep-ph/9705416; T. Kon, T. Matsushita, T. Kobayashi, hep-ph/9707355; M. Carena *et al.*, hep-ph/9707458.

[32] J.L. Hewett, Proceedings, *1990 Summer Study on High Energy Physics – Research Directions for the Decade* (Snowmass 1990), ed. E. Berger, World Scientific, Singapore 1992; T. Kon, K. Nakamura, T. Kobayashi, *Z. Phys.* **C45**, 567 (1990); *Acta Phys. Pol.* **B21**, 315 (1990); J. Butterworth, H. Dreiner, *Nucl. Phys.* **B397**, 3 (1993); H. Dreiner, E. Perez, Y. Sirois, hep-ph/9703444.

[33] H. Dreiner, hep-ph/9707435, and references therein.

[34] G. Altarelli *et al.*, hep-ph/9703276.

[35] J. Ellis, S. Lola, K. Sridhar, hep-ph/9705416.

[36] H. Dreiner, P. Morawitz, hep-ph/9703279.
[37] D. Choudhury, S. Raychaudhuri, *Phys. Lett.* **B401**, 54 (1997).
[38] T. Kon and T. Kobayashi, hep-ph/9704221 (to appear in *Phys. Lett.* **B**).
[39] J. Kalinowski, these proceedings.