PHYSICS BEYOND THE STANDARD MODEL AT HERA*

F. CORNET AND J. RICO

Depto. de Física Teórica y del Cosmos, Universidad de Granada
E-18071 Granada, Spain

This talk is divided in two parts. In the first one we discuss the signals of the Minimal Supersymmetric Standard Model through the production of $\tilde{e}\tilde{q}$. The second part is devoted to contact terms. The bounds on the mass scale Λ obtained from atomic parity violation experiments and from LEP are reviewed. Afterwards, we show that the excess of events at high Q^2 observed at HERA could be explained in terms of these contact terms.

PACS numbers: 12.38. Qk, 12.60. Jr, 13.85. Rm, 14.80. –j

1. Introduction

The potential of HERA to discover some hints of Physics Beyond the Standard Model has been an important subject in all the studies and workshops on the HERA physics potential. In a single talk we cannot cover all the work that has been done in all these years. Rather, we refer to the interested readers to an early report on the subject [1] and to the proceedings of the workshops on HERA physics [2–4] as well as to the references therein.

HERA is an *ep* collider with a 27.5 GeV electron (or positron) beam and an 820 GeV proton beam that gives a center of mass energy of 300 GeV. This energy allows to probe the proton down to distances $O(10^{-16})$cm. The total luminosities collected up to now by each experiment are 23.7 pb^{-1} (H1) and 33.5 pb^{-1} (ZEUS). An upgrade in luminosity is planned for the year 2000. The hope is to reach a yearly integrated luminosity of order 150 pb^{-1}. This, obviously, would improve very much the potential to discover signals of new physics.

The peculiar initial state at the partonic level, eq or eg, forces most of the effects of new physics to appear through a t-channel exchange of new particles (this is the case for new gauge bosons [5]) or in associate production. The only particles that can be produced in the s-channel are leptoquarks or leptoquark-like, $i.e.$ particles that couple to a quark and a lepton (such as squarks in R-parity violating SUSY).

Recently, both experiments at HERA, H1 and ZEUS, have announced the observation of an excess of events with respect to the Standard Model prediction at very high Q^2 [6–8] in e^+p neutral current and charged current deep inelastic scattering. Each experiment observe 18 $e^+p \rightarrow e^+X$ events with $Q^2 > 15000$ GeV^2, while only 8 are expected at H1 and 15 at ZEUS. In charged current deep inelastic scattering, H1 observes 6 events with $Q^2 > 15000$ GeV^2 and expects 3, while ZEUS observes 5 events with the same Q^2_{min} and expects 2. We will not elaborate any longer on the kinematics of these events because an updated description of the experimental situation can be found in Spiesberger's talk in this school [9]. In this talk you can also find a discussion on the attempts to explain the excess of events within the standard model, modifying the proton structure functions [10]. However, none of the proposed modifications produces an increase in the cross-section large enough to explain the data. Thus, if we assume that the large number of events observed is not a statistical fluctuation, we have to invoke some new physics to explain it. Three main ideas have been proposed: the s-channel production of a leptoquark [11], the s-channel production of an squark within R-parity violating SUSY [12] and the presence of a non-resonant, four-fermion contact interaction [13]. We refer the reader to the talks of Spiesberger [9] and Kalinowski [14] for a detailed discussion of the first two possibilities. In the third section of this talk, we will present the contact term interpretation.

The structure of this talk is the following. After this introduction we will present a summary of the work that were performed in the last HERA workshop studying the signals you can expect from the Minimal Supersymmetric Standard Model (MSSM), with R-parity conservation. The third section will be devoted to contact interactions, both in neutral current and charged current deep inelastic scattering. Finally, we will finish with a brief summary[1].

2. Minimal Supersymmetric Standard Model

Supersymmetry (SUSY) is one of the main candidates for physics beyond the Standard Model. A very clear signature of the new fermion-boson

---

[1] The signals of a non-standard light Higgs boson at HERA has been presented by Krawczyk at this school.

symmetry is the doubling of particles. Each particle in the Standard Model is predicted to have, at least, a superpartner which differs in half a unit of spin from the standard particle. The discovery of these superpartners would provide an unequivocal proof of SUSY. There has been intensive search for them but, up to now, no superpartner has been found. HERA should contribute in this search and there has been some studies on the sensitivity that can be expected for different processes. In this talk, we will concentrate on the Minimal Supersymmetric Standard Model with R-parity conservation.

The most promising process in ep collisions is associate production of selectron and squark [15–18]

$$ep \rightarrow \tilde{e}\tilde{q}X. \tag{1}$$

It proceeds through neutralino t-channel exchange. Normally, the exchange of the lightest neutralino would give the largest contribution, unless it turns out to be a higgsino. In this case the smallness of the higgsino couplings to the electron and the light quarks in the proton suppresses its contribution in front of the exchange of heavier neutralinos with larger couplings. The net effect is that in the case that the lightest neutralino is dominated by a higgsino, the cross-section for the process (1) is too small to be measured at HERA.

The masses and couplings of the neutralinos depend on the parameters: M_1, M_2, μ and $\tan\beta = \dfrac{v_2}{v_1}$, that are the U(1) and SU(2) gaugino masses, the higgsino mass parameter and the ratio between the vacuum expectation values of the two Higgs doublets, respectively. The two gaugino masses are related in Grand Unified Theories through:

$$M_1 = \tfrac{5}{3}\tan^2\theta_W M_2 \,. \tag{2}$$

The cross-section for the process (1) depends on the sum of the selectron and squark masses and on the gaugino mass parameter, say M_2, but depends very weakly on each independent sfermion mass and $\tan\beta$. Moreover, since the higgsino contribution is suppressed, $\sigma(ep \rightarrow \tilde{e}\tilde{q}X)$ depends also very weakly on μ in the accessible region of the parameter space.

The produced sfermions decay into the corresponding fermions and a neutralino, or another fermion and a chargino:

$$
\begin{aligned}
\tilde{e} \rightarrow e\chi_i^0 \quad & i = 1,\ldots 4 \quad & \tilde{e} \rightarrow \nu\chi_i^{\pm} \quad & i = 1, 2 \\
\tilde{q} \rightarrow q\chi_i^0 \quad & i = 1,\ldots 4 \quad & \tilde{q} \rightarrow q'\chi_i^{\pm} \quad & i = 1, 2 \,.
\end{aligned}
\tag{3}
$$

We will assume that the lightest neutralino (χ_1^0) is the lightest SUSY particle. Since R-parity is assumed to be conserved χ_1^0 is, thus, a stable particle

that once it is produced will escape the detector as missing energy. The decay channel into the lightest neutralino provides the clearest signature for selectron squark production. The optimal situation to search for the process (1) is that only χ_1^0 is lighter than the sfermions and the other neutralinos and charginos are heavier than the sfermions. If this is not the case and decays into another neutralinos and charginos are kinematically allowed, these χ_i^0 with $i > 1$ and $\chi_i^\pm$ would chain-decay into fermions and χ_1^0. The final state, thus, would contain a large number of fermions and missing energy. Since this final state is much more difficult to search for than the simple decay channel $\tilde{f} \to f\chi_1^0$, the analysis performed in Ref. [18] has been done searching only for this latter decay channel. The contribution from the other channels has been taken into account via the corresponding decrease of the branching ratio into $f\chi_1^0$. The value of this branching ratio can again be calculated in terms of the same parameters discussed above.

A systematic survey of the parameter space was performed in Ref. [18] allowing the parameters $M_{\tilde{e}}$, $M_{\tilde{q}}$ and M_2 to vary within the bounds $45 \le M_{\tilde{e}}, M_{\tilde{q}} \le 160$ GeV and $0 \le M_2 \le 200$ GeV for the extreme values of $\mu = -300$ GeV, and 300 GeV, assuming that the partners of the right and left-handed fermions have the same mass. The values of $\tan\beta$ were taken to be $\tan\beta = 1.41$ and 35^2. The exclusion region in the plane $(M_{\tilde{e}} + M_{\tilde{q}})/2, M_2$ are shown in Fig. 1 for $\tan\beta = 1.41$ and $\mu = -300$ GeV (χ_1^0 is photino-like). The smallest triangle is the region already excluded by LEP1 and two integrated luminosities have been assumed: 100 pb^{-1} and 500 pb^{-1}. The diagonal line is the limit where χ_1^0 has the same mass as the selectron or squark. The kink you can see for small M_2 values is due to loss in sensitivity caused by the opening of sfermion decay channels other that $\tilde{f} \to f\chi_1^0$.

We have already stated that the cross-section depends very weakly on μ and $\tan\beta$. Thus, the bounds shown in Fig. 1 also depend weakly on those parameters. For instance, changing $\tan\beta$ from 1.41 (shown in the figure) to $\tan\beta = 35$ the bound on M_2 only gets around 10 GeV higher and changing $\mu = -300$ GeV to $\mu = 300$ GeV (i.e. going from a photino-like to $\tilde{Z}$-like lightest neutralino), the bounds on $(M_{\tilde{e}} + M_{\tilde{q}})/2$ are also around 10 GeV higher. Finally, relaxing the GUT relation (2) does not change the results as long as the mass of the lightest neutralino (which is the parameter that really enters in the cross-section calculation) is not changed.

The bounds shown in Fig. 1 for M_2 are more stringent than the ones that can be obtained at LEP2 in chargino searches. However, if χ_1^0 is $\tilde{Z}$-like ($\mu = 300$ GeV) the bound that can be obtained at LEP2 becomes stronger than the ones discussed here. The sensitivity of HERA to selectron and

---

^{2} Some experimental bounds have already been obtained for this process by H1 [19] and ZEUS [20]. However, the total integrated luminosity collected up to now is too small to allow for competitive bounds.
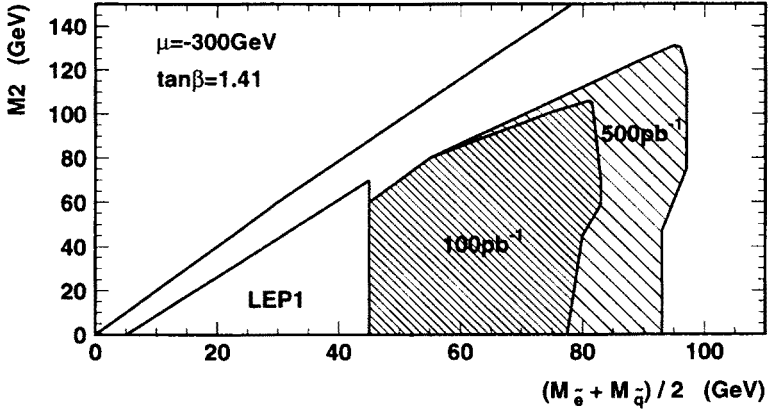
Fig. 1. Exclusion limits for HERA from the process $ep \rightarrow \tilde{e}\tilde{q}X$ at 95% C.L. assuming two integrated luminosities 100 pb^{-1} and 500 pb^{-1}. The small triangle is the region already excluded by LEP1 and the diagonal line is the limit where the lightest neutralino has the same mass as the selectron or squark. Figure taken from Ref. [18].

squark masses turns out to be very similar to the one of LEP2. However, it is interesting to note that the production mechanisms are completely different. In such a way that if a signal is found measurements at both colliders complement in the study of the Minimal Supersymmetric Standard Model parameters. The squark production cross-section at TEVATRON is very large. However, in order to have a clear signal one has to cut in the mass of χ_1^0. At HERA, instead, you can be sensitive to larger values of this mass.

3. Contact terms

The low energy effects of physics beyond the SM, characterized by a mass scale Λ much larger than the Fermi Scale can be parametrized in a very general way in terms of a non-renormalizable, effective lagrangian. In this lagrangian all the operators are organized according to their dimensionality in such a way that the higher dimension operators are suppressed by powers of $\frac{1}{\Lambda}$. Since the momenta involved in present experiments are much lower than Λ one expects the lower dimension operators to give the bulk of the new physics effects. The relevant lagrangian for ep scattering, including dimension 6, four-fermion operators is[3]:

$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_V,\tag{4}$$

---

[3] Terms with scalar currents can also contribute to this order, but we will not consider them here.

where $\mathcal{L}_{SM}$ is the SM lagrangian and $\mathcal{L}_V$ is given by:

$$
\begin{aligned}
\mathcal{L}_V = {}& \eta_{LL}^{(3),q}(\bar{l}\gamma_\mu\tau^I l)(\bar{q}\gamma^\mu\tau^I q) + \eta_{LL}^{(1),q}(\bar{l}\gamma_\mu l)(\bar{q}\gamma^\mu q) \\
& + \eta_{LR}^u(\bar{l}\gamma_\mu l)(\bar{u}\gamma^\mu u) + \eta_{LR}^d(\bar{l}\gamma_\mu l)(\bar{d}\gamma^\mu d) \\
& + \eta_{RL}^q(\bar{e}\gamma_\mu e)(\bar{q}\gamma^\mu q) \\
& + \eta_{RR}^u(\bar{e}\gamma_\mu e)(\bar{u}\gamma^\mu u) + \eta_{RR}^d(\bar{e}\gamma_\mu e)(\bar{d}\gamma^\mu d) .
\end{aligned}
\tag{5}
$$

The SU(2) doublets $l = (\nu, e)$ and $q = (u, d)$ denote left-handed fields ($Ll = l, Lq = q,$ with $L = \frac{1-\gamma_5}{2}$) and the SU(2) singlets e, u and d represent right-handed electron, up-quark and down-quark ($Re = e, Ru = u,$ $Rd = d,$ with $R = \frac{1+\gamma_5}{2}$). It is customary to replace the coefficients η by a mass scale Λ:

$$
\eta = \frac{\varepsilon g^2}{\Lambda^2},
\tag{6}
$$

with $\varepsilon = \pm 1$ taking into account the two possible interference patterns. Λ is interpreted as the mass scale for new physics in the strong coupling regime, *i.e.* with

$$
\frac{g^2}{4\pi} = 1.
\tag{7}
$$

The lagrangian in Eq. (5) modifies both, the neutral current and the charged current cross-sections. We will now discuss both cases.

3.1. Neutral currents

Contact terms have been proposed as a possible explanation for the excess of events at high Q^2 observed at HERA [13]. With the new data the first indications towards a resonance structure in the events seem to disappear, thus giving more strength to the contact term hypothesis. The cross-sections for the processes $e^- p \to e^- X$ and $e^+ p \to e^+ X$ receive contributions from all the terms in the $O(p^6)$ lagrangian. However, there is an important difference between both cross sections. The contributions from the LR and RL contact terms are suppressed in the e^- cross-section, while they give the largest contribution to the e^+ cross-section [21–23]. This can be explicitly seen in Fig. 2 where we show

$$
F(x, Q^2) = \frac{sx^2y^2 \dfrac{d\sigma}{dx dQ^2}}{2\pi\alpha^2(1 + (1-y)^2)}
\tag{8}
$$

for $x = 0.3$ as a function of Q^2 for the six models we are considering with $\varepsilon = 1$ and $\Lambda = 3\,\text{TeV}$. The variable y is defined as usual: $y = \dfrac{Q^2}{sx}$. Although,

we have shown in the figure only a value of x this is true for all the interesting values of Q^2 and x.
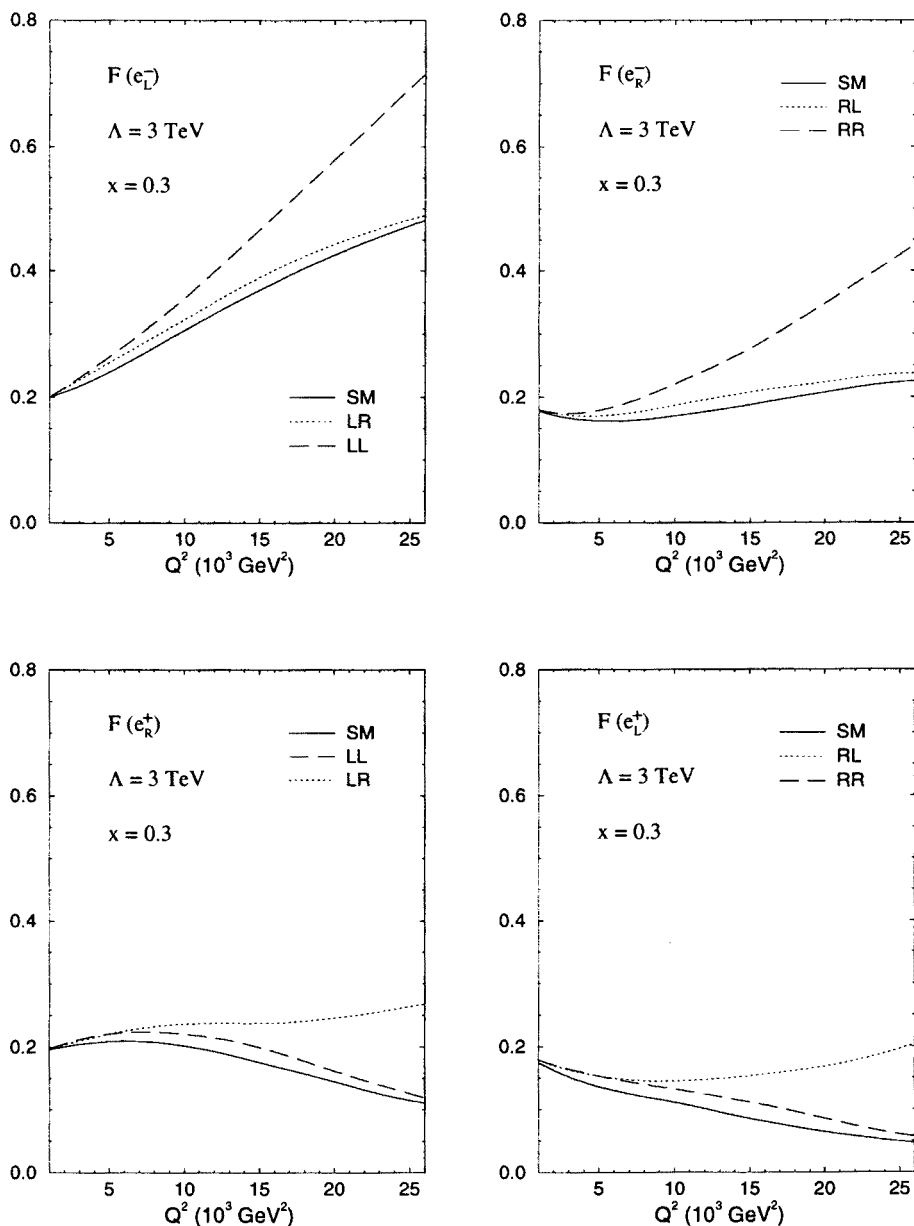

Fig. 2. Structure functions F defined in the text, see Eq. (8), for polarized electron and positron beams. Notice that LR and RL contact terms give a small contribution to the electron cross-section, but a large one to the positron cross-section

There are, certainly, constrains on the values of Λ from present experiments. Recently OPAL has published bounds on Λ from measurements at LEP with a center of mass energy $\sqrt{s} = 130 - 136$ GeV and 161 GeV [24]. This bounds are shown in Table I. Also atomic parity violation measurements provide bounds on Λ. There, you measure the weak charge given by:

$$Q_W = -2\left[\left(-\frac{1}{2} + \frac{4}{3}\sin^2\theta_W\right)(2Z+N) + \left(\frac{1}{2} - \frac{2}{3}\sin^2\theta_W\right)(2N+Z)\right] \\ -\frac{1}{\sqrt{2}G_F}\left[(2Z+N)\,\Delta\eta^{eu} + (2N+Z)\,\Delta\eta^{ed}\right],$$

$$(9)$$

where N and Z are the number of neutrons and protons, respectively, in the nucleus. The first term in the right hand side is the SM contribution and

$$\Delta\eta^{eq} = \eta^{eq}_{\mathrm{RR}} - \eta^{eq}_{\mathrm{LL}} + \eta^{eq}_{\mathrm{RL}} - \eta^{eq}_{\mathrm{LR}}. \qquad (10)$$

The most stringent bounds on the mass scales can be obtained from the Q_W measurements in $^{133}_{55}$Cs:

$$Q_W = -71.04 \pm 1.81 \qquad (11)$$

that should be compared with the SM prediction, $Q_W = -73.04$. Assuming that only one of the operators in the lagrangian contributes, the bounds on Λ range between 7.4 TeV and 12.3 TeV [25]. These values are too high to give a sensible modification of the SM cross-section at HERA. However, these bounds can be easily avoided taking the appropriate combinations of contact terms. Notice that this is not fine tuning, but just determining the chiral structure of the new physics couplings.

TABLE I

Lower bounds on the contact term mass scale obtained by the OPAL collaboration [24].

	Λ^- (TeV)	Λ^+ (TeV)
LL	2.1	2.5
RR	2.3	2.1
LR	2.2	2.1
RL	2.6	2.1

The low energy bounds on the mass scale still allow for values that clearly are in better agreement with the experimental data than the SM predictions. As an example we show in Fig. 3 the integrated cross-section as a function of the minimum Q^2 for the Standard Model (solid line) and for an

eu contact term with $\Lambda_{LR} = \Lambda_{\rm RL} = 3$ TeV, which avoids the atomic parity violation bounds. Since only the LR and RL contact terms are assumed to contribute to the cross-sections, the effects on the electron cross-section are smaller than the ones in the positron cross-section, in such a way that with the accumulated integrated luminosity no observable deviation from the SM prediction is expected.
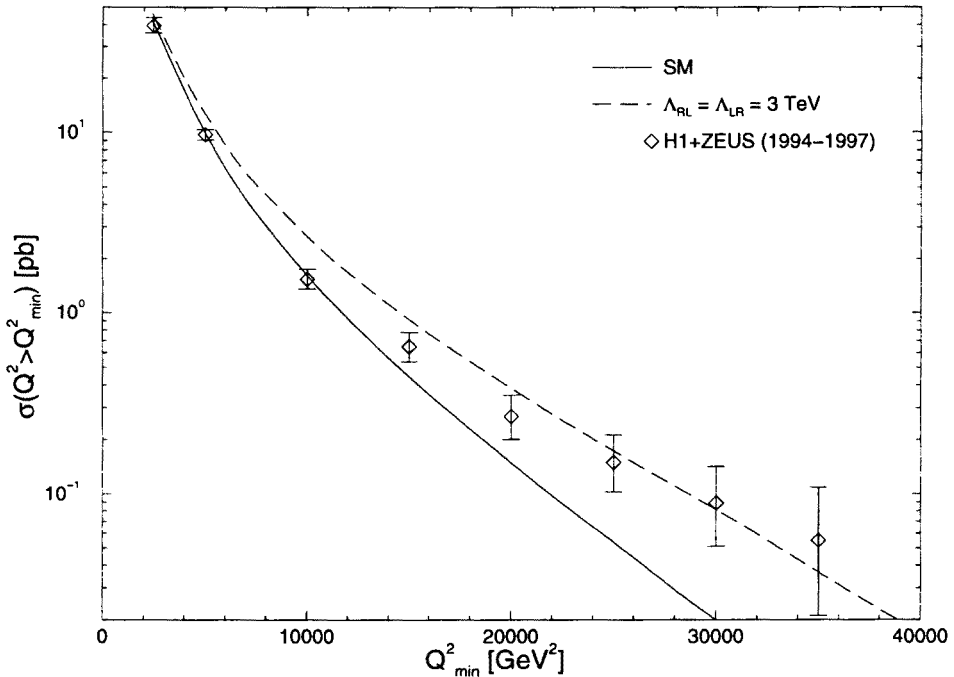

Fig. 3. Cross-section for $e^+p \to e^+X$ for $Q^2 \geq Q^2_{\rm min}$ as a function of $Q^2_{\rm min}$ in the Standard Model (solid line) and with an eu contact term with $\Lambda_{\rm RL} = \Lambda_{LR} = 3$ TeV. The combined experimental data from H1 and ZEUS are also shown.

3.2. Charged currents

The charged current cross-sections also receive contributions from contact terms [26]. The difference with the neutral current case is that now only the first term in Eq. (5) contributes.

There are no direct experimental bounds on $\Lambda_{LL}^{(3)}$. The bounds on Λ_{LL} discussed in the previous section do not apply directly because in neutral current processes one is actually measuring the combination:

$$\Lambda_{LL} = \Lambda_{LL}^{(3)} + \Lambda_{LL}^{(1)}. \tag{12}$$

It is, thus, important to measure both channels to disentangle the contributions from both terms in the lagrangian (5). An indirect bound, $\Lambda_{LL}^{(3)} > 10$ TeV can be found from the unitarity of the CKM matrix [27]. This bound assumes that only the first family is sensitive to contact terms.

The cross sections for $e^-p \to \nu X$ and $e^+p \to \bar{\nu} X$ can be obtained in a straightforward way :

$$\frac{d^2\sigma_{e^-p \to \nu X}}{dQ^2 dx} = \frac{1}{\pi} \left(\frac{G_F}{\sqrt{2}} \frac{M_W^2}{Q^2 + M_W^2} - \frac{\pi}{2} \frac{\varepsilon}{\Lambda_{LL}^{(3)2}} \right)^2$$
$$\times \sum_{i=1}^{2} \left[u_i(x, Q^2) + (1-y)^2 \bar{d}_i(x, Q^2) \right], \tag{13}$$

$$\frac{d^2\sigma_{e^+p \to \bar{\nu} X}}{dQ^2 dx} = \frac{1}{\pi} \left(\frac{G_F}{\sqrt{2}} \frac{M_W^2}{Q^2 + M_W^2} - \frac{\pi}{2} \frac{\varepsilon}{\Lambda_{LL}^{(3)2}} \right)^2$$
$$\times \sum_{i=1}^{2} \left[\bar{u}_i(x, Q^2) + (1-y)^2 d_i(x, Q^2) \right]. \tag{14}$$

The contact term increases (decreases) the cross-sections for $\varepsilon = -1$ $(+1)$ and the effects are larger for large values of Q^2 and x.

We have performed a χ^2 fit to the Q^2 distributions obtained by H1 and ZEUS presented by Elsen in Ref. [8][4]. The fit to the H1 data does not improve with the inclusion of a contact term. There is an excess of events at high Q^2 but at low Q^2 the SM prediction lies above (although within one standard deviation) the measured cross-section. The inclusion of a contact term can improve the agreement between theory and experiment at high Q^2, but also produces a small increase in the cross-section at low Q^2 that spoils the quality of the fit. Thus from the H1 data one can only obtain the following 95 % C.L. bounds on the mass scale:

$$\Lambda_{LL}^{(3)+} \geq 3.5 \, \text{TeV} \quad \Lambda_{LL}^{(3)-} \geq 3.4 \, \text{TeV} \quad \text{(From H1 1994-97 data)}. \tag{15}$$

---

[4] A similar fit to the electron and positron data obtained before 1997 can be found in Ref. [26].

The situation is very different for the ZEUS data. Using the 1994-97 data we now obtain a value for $\eta_{LL}^{(3)}$ that is not compatible (within one standard deviation) with zero, namely:

$$\eta_{LL}^{(3)} = -0.6 \pm 0.4 \, \text{TeV}^{-2} \quad i.e. \quad \Lambda_{LL}^{(3)-} = 4.6_{-1.1}^{+3.3} \, \text{TeV} \qquad (16)$$

We have also made a similar fit to the x distribution measured by ZEUS obtaining again a non-zero value for $\eta_{LL}^{(3)}$ compatible with the previous one:

$$\eta_{LL}^{(3)} = -0.48_{-0.33}^{+0.27} \, \text{TeV}^{-2} \quad i.e. \quad \Lambda_{LL}^{(3)-} = 5.1_{-1.0}^{+4.0} \, \text{TeV}. \qquad (17)$$

These results have been obtained using the MRSA parton density parameterization [28] and the mass of the W boson has been fixed to the value given by the Particle Data Book: $M_W = 80.33 \pm 0.15$ GeV [29]. We have checked that the results of the fits do not change in an appreciable way when moving the mass of the W within its experimental error.

4. Summary

There has been a lot of work during the last years on the capabilities of HERA to search for physics beyond the Standard Model. In particular, after the publication of the excess of events at high Q^2 observed by the two experiments, H1 and ZEUS, the number of papers trying to explain them in terms of new physics has exploded. Since we cannot cover everything in a single talk we have concentrated on two subjects: search for the Minimal Supersymmetric Standard Model with R-parity conservation and the effects of contact terms in neutral and charged current processes. Other interpretations of the excess of events in terms of leptoquark production and squark production in R-parity breaking supersymmetry have been discussed in other talks at this school [9, 14].

The most promising process to search for R-parity conserving SUSY is the associate production of a selectron and an squark, with these sfermions decaying into the corresponding fermions and the lightest neutralino. The experimental signature would be a final state containing an electron, a jet and missing energy. We have shown the exclusion bounds that can be obtained at HERA assuming an integrated luminosity of 100 and 500 pb^{-1}. These bounds turn out to be competitive and complementary to the ones that can be obtained at LEP and TEVATRON.

It is not clear for the moment whether the excess of events observed at HERA in neutral and charged current processes is really a signal of new physics or just a statistical fluctuation. In case it is a signal for new physics it is difficult to explain it in terms of the production of a single resonance.

Instead it can be explained in terms of contact terms, *i.e.* dimension 6 four-fermion operators. The contact terms required to improve the agreement between the theoretical predictions and the observed number of events with respect to the SM predictions are compatible with low energy constraints, such as atomic parity violation measurements, and high energy bounds from LEP and TEVATRON.

REFERENCES

[1] R.J. Cashmore *et al.*, *Phys. Rep.* **122**, 275 (1985).

[2] Proceedings of the HERA Workshop, Ed. R.D. Peccei. DESY, Hamburg, 1988.

[3] Proceedings of the Workshop Physics at HERA, Eds. W. Buchmüller and G. Ingelman, DESY, Hamburg 1992.

[4] Proceedings of the Workshop Future Physics at HERA, Eds. G. Ingelman, A. De Roeck, R. Klanner, DESY, Hamburg 1996.

[5] F. Cornet, R. Rückl, *Phys. Lett.* **B184**, 263 (1987); S. Capstick, S. Godfrey, *Phys. Rev.* **D35**, 3351 (1987); P. Haberl *et al.* in [3], V.2, p.980; H.-U. Martyn *et al.* in [3], V.2, p.987.

[6] H1 Coll., *Z. Phys.* **C74**, 191 (1997).

[7] ZEUS Coll., *Z. Phys.* **C74**, 207 (1997).

[8] For an update of the analysis including the data from 1994 to 1997, see: B. Straub, New Results from Neutral and Charged Current Scattering at High Q^2 from H1 and ZEUS, to appear in the Proceedings of the XVIII International Symposium in Lepton Photon Interactions, Hamburg, Germany, July 1997. E. Elsen, New High Q^2 Results in ep collisions at HERA, to appear in Proceedings of the Int. Europhysics Conference on High Energy Physics, Jerusalem, Israel, August 1997.

[9] H. Spiesberger, *Acta Phys. Pol.* **28B**, 2407 (1997).

[10] S. Kuhlmann, H.L. Lai, W.K. Tung, hep-ph/9704338. K.S. Babu, C. Kolda, J. March-Russell, F. Wilczek, *Phys. Lett.* **B408**, 268 (1997). J.F. Gunion, R. Vogt, hep-ph/9706252. W. Melnitchouk, A.W. Thomas, hep-ph/9707387.

[11] G. Altarelli, J. Ellis, G.F. Giudice, S. Lola, M.L. Mangano, 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). M. Suzuki, hep-ph/9703316. G.K. Leontaris, J.D. Vergados, hep-ph/9703338. Z. Kunzst, W.J. Stirling, *Z. Phys.* **C75**, 453 (1997). T. Plehn *et al.*, *Z. Phys.* **C74**, 611 (1997). D. Friberg, E. Norrbin, T. Sjöstrand, *Phys. Lett.* **B403**, 329 (1997).

I. Montvay, *Phys. Lett.* **B407**, 22 (1997). S.F. King, G.K. Leontaris, hep-ph/9704336. J. Elwood, A. Faraggi, hep-ph/9704363. B. Dutta, R. Mohapatra, S. Nandi, hep-ph/9704428. S. Jadach, W. Placzek, B.F.L. Ward, hep-ph/9705395. K.S. Babu, C. Kolda, J. March-Russell, *Phys. Lett.* **B408**, 261 (1997). J. Ellis, S. Lola, K. Sridhar, *Phys. Lett.* **B408**, 252 (1997). S. Jadach, B.F.L. Ward, Z. Was, hep-ph/9705429. A. Blumhofer, B. Lampe, hep-ph/9706454. E. Keith, E. Ma, hep-ph/9707214. N.G. Deshpande, B. Dutta, hep-ph/9707274.

[12] D. Choudhury and S. Raidchaudhuri, *Phys. Lett.* **B401**, 54 (1997). H. Dreiner, P. Morawitz, hep-ph/9703279. J. Kalinowski, R. Rückl, P.M. Zerwas, *Phys. Lett.* **B406**, 314 (1997). T. Kon, T. Kobayashi, hep-ph/9704221. R. Barbieri, A. Strumia, Z. Berezhiani, *Phys. Lett.* **B407**, 250 (1997). G.F. Giudice, R. Ratazzi, hep-ph/9704339. A.S. Belyaev, A.V. Gladyshev, *Phys. Lett.* **B406**, 321 (1997). J. Kalinowski, hep-ph/9706203. J.E. Kim, P. Ko, hep-ph/9706387. A.S. Joshipura, V. Ravindran, S.K. Vempati, hep-ph/9706482. M. Frank, H. Hamidian, hep-ph/9706510. M. Guchait, D.P. Roy, hep-ph/9707275. T. Kon, T. Matsuhita, T. Kobayashi, hep-ph/9707355.

[13] V. Barger, K. Cheung, K. Hagiwara, D. Zeppenfeld, hep-ph/9703311, *Phys. Lett.* **B** (in press). A. Nelson, *Phys. Rev. Lett.* **78**, 4159 (1997). N. Bartolomeo, M. Fabrichesi, *Phys. Lett.* **B406**, 237 (1997). W. Buchmüller, D. Wyler, *Phys. Lett.* **B407**, 147 (1997). N.G. Deshpande, B. Dutta, Xiao-Gang He, *Phys. Lett.* **B408**, 288 (1997). M.C. Gonzalez-García, S.F. Novaes, *Phys. Lett.* **B407**, 255 (1997). S. Godfrey, *Mod. Phys. Lett.* **A12**, 1859 (1997). L. Giusti, A. Strumia, hep-ph/9706298. C. Kao, X.-G. He, B. McKellar, hep-ph/9707227.

[14] J. Kalinowski, *Acta Phys. Pol.* **28B**, 2423 (1997).

[15] L. Stanco, in [2] Vol. 2 p.889.

[16] A. Bartl, M. Drees, W. Majerotto, B. Mösslacher in [3] Vol. 2 p.1118.

[17] Y. Eisenberg, U. Karshon, A. Montag, G.D. Wolf, in [3] Vol. 2 p.1124.

[18] P. Schleper, in [4] Vol. 1 p.275.

[19] H1 Coll., *Phys. Lett.* **B380**, 461 (1996).

[20] V.A. Noyes, hep-ex/9707037.

[21] R. Rückl, *Phys. Lett.* **B129**, 363 (1983); *Nucl. Phys.* **B234**, 91 (1984).

[22] F. Cornet, Proc. of the XV Winter Meeting on Fundamental Physics, Sevilla, Spain, 1987. Eds. F. Barreiro, J.L. Sánchez Gómez. World Scientific, Singapore, 1988, p.209.

[23] P. Haberl, H.U. Martyn, F. Schrempp, Proc. of the Workshop Physics at HERA, Hamburg 1991. Eds. W. Büchmuller, G. Ingelman, DESY, Hamburg 1992, p.1133.

[24] OPAL Collab., *Phys. Lett.* **B391**, 221 (1997).

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

[26] F. Cornet, J. Rico, hep-ph/9707299, *Phys. Lett.* **B**, in press.

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

[28] A.D. Martin, R.G. Roberts, W.J. Stirling, *Phys. Rev.* **D50**, 6734 (1994).

[29] *Particle Data Group, Phys. Rev.* **D54**, 1 (1996).