DESY 97-097
IFT 4/97

DESY 97-097
IFT 4/97

New Physics at HERA: Implications for e^+e^- Scattering at LEP2

J. Kalinowski

Deutsches Elektronen-Synchrotron DESY, D-22607 Hamburg
and
Institute of Theoretical Physics, Warsaw University, PL-00681 Warsaw

hep-ph/9706203 31 May 1997

Abstract

The impact of virtual leptoquark or R-parity breaking squark exchange as well as generic contact interactions on the production of quark–antiquark pairs in e^+e^- annihilation, in particular at LEP2, is summarized. An exciting possibility of sneutrino formation in e^+e^- scattering is also mentioned.

Talk presented at the 5th International Workshop on "Deep Inelastic Scattering and QCD" (DIS '97), Chicago, Illinois, USA, April 14-18, 1997.

New Physics at HERA: Implications for e^+e^- Scattering at LEP2

J. Kalinowski

Deutsches Elektronen-Synchrotron DESY, D-22607 Hamburg
and
Institute of Theoretical Physics, Warsaw University, PL-00681 Warsaw

Abstract. The impact of virtual leptoquark or R-parity breaking squark exchange as well as generic contact interactions on the production of quark–antiquark pairs in e^+e^- annihilation, in particular at LEP2, is summarized. An exciting possibility of sneutrino formation in e^+e^- scattering is also mentioned.

Recently both HERA experiments reported an excess of events in positron–proton scattering at very high Q^2 values []. Unambiguous interpretation of these events is not possible at present due to limited statistics. Nevertheless, interesting explanations in terms of new physics, either as contact terms in the effective Lagrangian or leptoquarks (LQ) and/or squarks with R-parity violating couplings ($\tilde{q}$) with masses $m_{LQ/\tilde{q}} \sim 200$ GeV, have been studied in detail. If true, a large variety of phenomena are expected to be observed experimentally in other reactions. If leptoquarks/squarks exist, they can be pair produced in $p\bar{p}$, e^+e^- and $\gamma\gamma$ collisions; single production with leptons or quarks can also be explored in these and other reactions. Below the production threshold, indirect effects generated by the exchange of virtual $LQ/\tilde{q}$, or by contact terms, are important means to explore the nature of these new physics interpretations. A general classification of leptoquarks respecting the SM symmetries has been presented in Ref. [], assuming baryon- and lepton-number conserving, family diagonal and chiral Yukawa couplings to lepton–quark pairs to avoid restrictions derived from proton decay and low-energy experiments. Only a small subset of these states is realized in supersymmetric theories with R-parity breaking coupled via a term $\lambda'_{ijk} L^i_L Q^j_L \bar{D}^k_R$ in the superpotential.

The interpretation of HERA data in terms of contact interactions, leptoquarks or squarks have been summarized in separate talks []. In this talk implications of possible interpretations of HERA events on $e^+e^- \to q\bar{q}$ annihilation [] are summarized. This process is mediated by γ, Z exchanges in the s-channel, and $LQ/\tilde{q}$ exchanges in the t/u-channels; $LQ/\tilde{q}$ with the fermion

© 1997 American Institute of Physics

number $F = 0$ are exchanged in the t-, with $F = 2$ in the u-channel. Both scalar (S_I) and vector (V_I) leptoquarks of isospin I, and squarks ($\tilde{q}$) are considered.

After the Fierz transformation, the t/u-channel $LQ/\tilde{q}$ exchange amplitudes in $e^+e^- \to q\bar{q}$ generate only *(lepton vector current)*$\times$*(quark vector current)* terms in addition to the standard s-channel amplitudes. This leads to a convenient representation of the matrix elements including a transparent interference pattern of $LQ/\tilde{q}$ with SM γ/Z exchanges. Leptoquarks with $I = 0, 1$ contribute to equal-helicity LL and RR amplitudes, while leptoquarks with $I = 1/2$ contribute to opposite-helicity amplitudes RL and LR, where the first (second) index denotes the helicity of incoming electron (outgoing quark). All $F = 0$ leptoquarks/squarks contribute with the same positive sign, all $F = 2$ with the negative sign. For a given F, the sign of the interference with γ/Z exchange is determined by the sign of the generalized charges $Q^{eq}_{ik} = e^2\, Q_e Q_q + g^e_i g^q_k/(1 - m^2_Z/s)$, $i, k = L, R$. In the energy range of LEP2 they are negative for u-quarks and positive for d-quarks, except Q^{ed}_{RL} which is negative. [The left/right Z charges of the fermions are defined as $g^f_L = e\,(I^f_3 - s^2_W Q_f)/s_W c_W$, $g^f_R = -e\, s^2_W Q_f/s_W c_W$ with $s_W = \sin\Theta_w$, $c_W = \cos\Theta_w$].

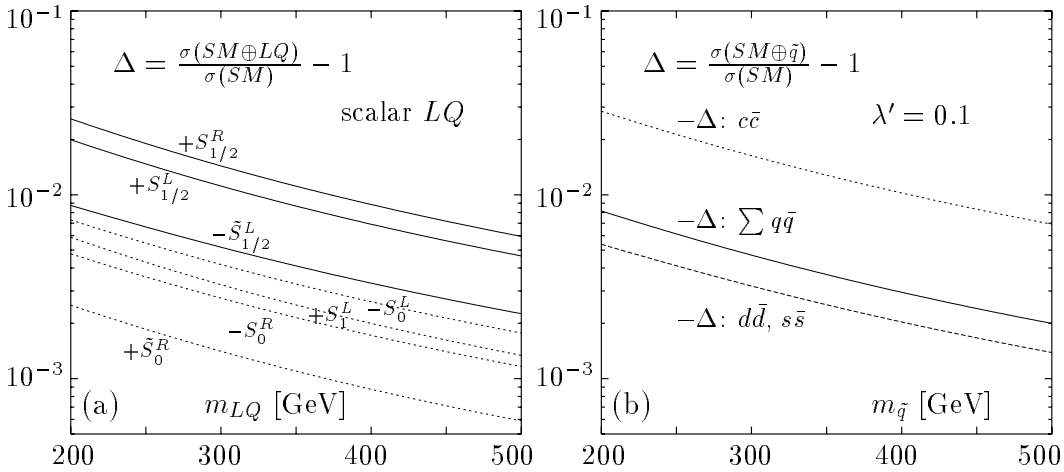

FIGURE 1. Impact of (a) leptoquark [solid lines scaled by factor 10], (b) squark exchange in $e^+e^- \to q\bar{q}$ for $\sqrt{s} = 192$ GeV [adapted from J. Kalinowski et al., DESY 97-038, hep-ph/9703288].

If the HERA events are interpreted as the signal of $LQ/\tilde{q}$ production with $F = 0$ generated in e^+–valence-quark collisions, the Yukawa coupling is of the order 0.05, *i.e.* $\sim e/10$. Then the t/u-channel exchange of a leptoquark affects the $e^+e^- \to u\bar{u}$ or $e^+e^- \to d\bar{d}$ parton cross sections generally only at the level of a percent (up to 10 % for V_0 and V_1). Summing up all parton channels, the impact is slightly smaller. In Fig.1a the sensitivity of the total hadronic e^+e^- cross section to the entire ensemble of scalar leptoquarks (superscripts in the

figure denote the chirality of the Yukawa coupling) is shown for the Yukawa coupling $g_{LQ} = 0.1$ (similar effects are found for vector leptoquarks). For small enough couplings and large enough masses the curves scale in g^2_{LQ}/m^2_{LQ}. Both constructive and destructive interference effects, depending on the type of quarks in the final state, are expected. The impact of $I = 0$, 1 leptoquarks on the hadronic cross section is larger than the impact of $I = 1/2$ leptoquarks. In the SUSY interpretation, the HERA events are either $\tilde{c}$ or $\tilde{t}$ production processes with λ'_{121} or $\lambda'_{131} \sim 0.05$, respectively. Their impact on $e^+e^- \to q\bar{q}$ is shown in Fig.1b for the total hadronic cross section (solid line). The impact on the charm quark production $e^+e^- \to c\bar{c}$ is larger (dotted line), while it is smaller for the down quarks, $e^+e^- \to d\bar{d}$ (dashed line).

Single leptoquark (with $F = 2$) production out of the sea in positron scattering at HERA requires larger couplings, of order e. For such couplings leptoquarks with masses $\sim$ 200 GeV are excluded by earlier e^-p data and low-energy limits. In SUSY one can assume $\lambda'_{132} \neq 0$ which leads to $e^+s \to \tilde{t}$, or $\lambda'_{123} \neq 0$ which gives rise to $e^+\bar{c} \to \tilde{b}^*$ and/or $e^+b \to \tilde{t}$ processes. The impact of the former case on strange quark production at LEP2 is shown in Fig.1b.

Note, that in all SUSY cases we observe only destructive interference pattern. Also in contrast to genuine leptoquarks, squarks can decay via a large number of R-parity conserving modes: $\tilde{q} \to q\chi$ with χ being either a neutralino or a chargino. If these decays are non-negligible, the couplings λ' would be correspondingly larger, implying a larger impact on e^+e^- processes.

For large masses, the exchange of leptoquarks/squarks can be described by contact interactions. Depending on the $LQ/\tilde{q}$ type, different helicity combinations of lepton and quark currents are affected differently in either $u\bar{u}$ or $d\bar{d}$ final states. Potentially large effects can be expected for e^+e^- annihilation to hadrons for the scales $\Lambda \sim 2$ TeV. Present analyses of hadron production at LEP2 set limits to Λ already at the level of about 1.5 to 2.5 TeV [].

In addition to the lepton-quark-quark superfield term $\lambda'_{ijk}L^i_L Q^j_L \bar{D}^k_R$, the R-breaking part of the 0 0 superpotential may involve also the interaction of three lepton superfields $\lambda_{ijk}L^i_L L^j_L \bar{E}^k_R$. Both couplings λ and λ' violate lepton number. The interpretation of the HERA events by R-parity breaking SUSY interactions involves at least one of the couplings λ'. This invites to speculations that some of the couplings λ may also be non-zero and that other supersymmetric particles, sleptons, may exist in a similar mass range. They would influence purely leptonic processes at LEP2. Most exciting of course would be the direct formation of sneutrinos $e^+e^- \to \tilde{\nu}$ and its impact on Bhabha scattering. This is illustrated in Fig.2, for both (a) virtual 0 s-channel $\tilde{\nu}_\tau$ exchange for $m_{\tilde{\nu}_\tau}$ exceeding the LEP2 energy, and (b) resonance formation. The effect should be also seen in other decay modes of $\tilde{\nu}_\tau$ [].

In summary: While the effect of $F = 0$ $LQ/\tilde{q}$ on $e^+e^- \to q\bar{q}$ process at LEP2 is small, the $F = 2$ leptoquarks may lead to observable effects, or

at least more stringent bounds on the Yukawa couplings or contact terms can be established. If sleptons do exist in the mass range of 200 GeV, the effect of sneutrino exchanges at LEP2 could be very large. Most exciting is the prospect that sneutrinos would manifest themselves through resonance formation in e^+e^- collisions.

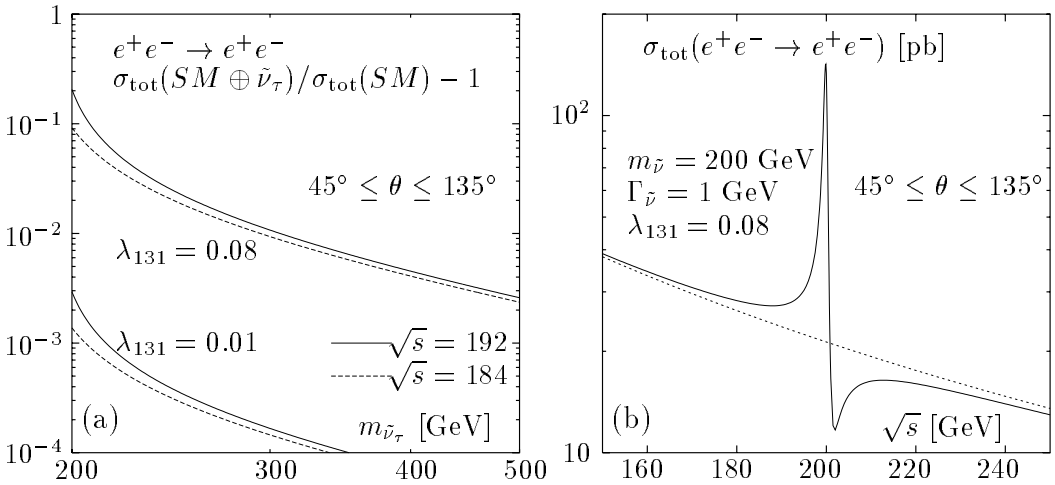

FIGURE 2. Effect of sneutrino $\tilde{\nu}_\tau$ exchange on the cross section for Bhabha scattering [adapted from J. Kalinowski et al., DESY 97-044, hep-ph/9703436].

REFERENCES

1. H1 Collab., C. Adloff *et al.*, *Z. Phys.* **C74** (1997) 191; ZEUS Collab., J. Breitweg *et al.*, *Z. Phys.* **C74** (1997) 207; and talks by T. Carli, and by F. Zarnecki, these proceedings.
2. W. Buchmüller, R. Rückl and D. Wyler, *Phys. Lett.* **B191** (1987) 442.
3. Talks by J. Blümlein, by D. Zeppenfeld and by S. Lola, these proceedings.
4. D. Choudhury and S. Raychaudhuri, CERN-TH/97-26 (hep-ph/9702392); G. Altarelli *et al.*, CERN-TH/97-40 (hep-ph/9703276); H. Dreiner and P. Morawitz, RAL preprint (hep-ph/9703279); M. Doncheski and S. Godfrey, OCIP-C-97-02 (hep-ph/9703285);. J. Kalinowski, R. Rückl, H. Spiesberger and P.M. Zerwas, DESY 97-038 (hep-ph/9703288), and DESY 97-044 (hep-ph/9703436); J.L. Hewett and T.G. Rizzo, SLAC-PUB-7430 (hep-ph/9703337); M.C. Gonzalez-Garcia and S.F. Novaes, (hep-ph/9703346); N. Di Bartolomeo and M. Fabbrichesi, (hep-ph/9703375); S. Jadach, B.F.L. Ward and Z. Was, CERN-TH-97-48 (hep-ph/9704241); A.S. Belyaev and A.V. Gladyshev, (hep-ph/9704343).
5. P. Mättig, Proceedings, *International Conference on High Energy Physics* (Warsaw 1996); OPAL physics note PN 280.
6. H. Dreiner and S. Lola, Proceedings, DESY 96-123D (1996) 435; J. Erler, J.L. Feng and N. Polonsky, *Phys. Rev. Lett.* **78** (1997) 3063.