Physics at high Q^2 with HERA II

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Abstract. The prospects of physics at high Q^2 in deep inelastic scattering at HERA after the upgrade in 2000/2001 are reviewed. With 1,000 pb^{-1} and polarized lepton beams, precision tests of electroweak physics are becoming possible and the search for physics beyond the standard model is expected to provide much improved limits.

1. Introduction

Major modifications of the HERA collider have been undertaken since the machine shutdown in September 2000 which are expected to yield 1,000 pb^{-1} of electron proton collisions during the next 5 to 6 years. The upgrade will also provide the technical prerequisites for experimentation with polarized electron or positron beams with up to 60 % degree of polarization. In addition, the construction period has been used by the experimental groups to install important detector improvements [1, 2].

An integrated luminosity of 1,000 pb^{-1} should be sufficient to open a new focus of physics analyses looking at processes with cross sections of the order of 1 pb and below. This is the typical value for the size of purely weak contributions in neutral and charged current (NC and CC) cross sections at large values of Bjorken x and momentum transfer Q^2. High luminosity will provide enough statistics to envisage precise tests of the electroweak interactions at high Q^2.

Also measurements of rare standard model processes, like the production of an additional gauge boson, are becoming possible. Low cross section processes provide interesting possibilities to look for deviations from standard model predictions and constitute important backgrounds for searches for physics beyond the standard model.

Improved measurements are expected for all aspects of deep inelastic scattering. For example, inclusive measurements will aim at the level of a 1 % precision in the determination of structure functions over large regions of x and Q^2, low-x and diffractive phenomena will be studied in much more detail, or heavy quark physics is expected to profit from improved detector components. The focus in this article is on aspects of electroweak physics and selected topics of searches for new physics [3].

2. Electroweak physics at large Q^2

The cross sections for NC and CC deep inelastic scattering at high Q^2, where the longitudinal structure function can be neglected, have the form

$$\left.\frac{\mathrm{d}^2\sigma}{\mathrm{d}x\mathrm{d}Q^2}\right|_{e^\pm} = K(x,Q^2)\left[\left(1+(1-y)^2\right)F_2 \mp \left(1-(1-y)^2\right)xF_3\right]. \qquad (1)$$

The structure functions are different for NC and CC scattering and contain two components for polarization-dependent and -independent lepton beams. The normalization factors are

$$K_{\mathrm{NC}} = \frac{2\pi\alpha^2}{x}\frac{1}{Q^4} \qquad \text{NC}, \qquad (2)$$

$$K_{\mathrm{CC}} = \frac{\pi\alpha^2}{4x\sin^4\theta_{\mathrm{W}}}\frac{1}{\left(Q^2+m_{\mathrm{W}}^2\right)^2} \qquad \text{CC}. \qquad (3)$$

Since the weak interactions violate parity and charge conjugation, the cross sections are different for electrons and positrons. Measurements at high Q^2 with both electron and positron beams are needed to determine xF_3. The early e^- data set of 0.54 pb^{-1} was already sufficient to demonstrate the unification of NC and CC cross sections at high Q^2 (Fig. 1 left) whereas $O(50)$ pb^{-1} of data collected until September 2000 are needed to turn the difference of e^+ and e^- cross sections (see Fig. 1 right) into a first measurement of xF_3 at high Q^2 [5].

At high Q^2 the cross sections depend on the electroweak parameters, in particular on the masses of the weak gauge bosons. Provided enough luminosity, one may envisage to interpret the measurements in terms of a determination of the electroweak parameters. There are different strategies, based on different ways to express the cross sections in

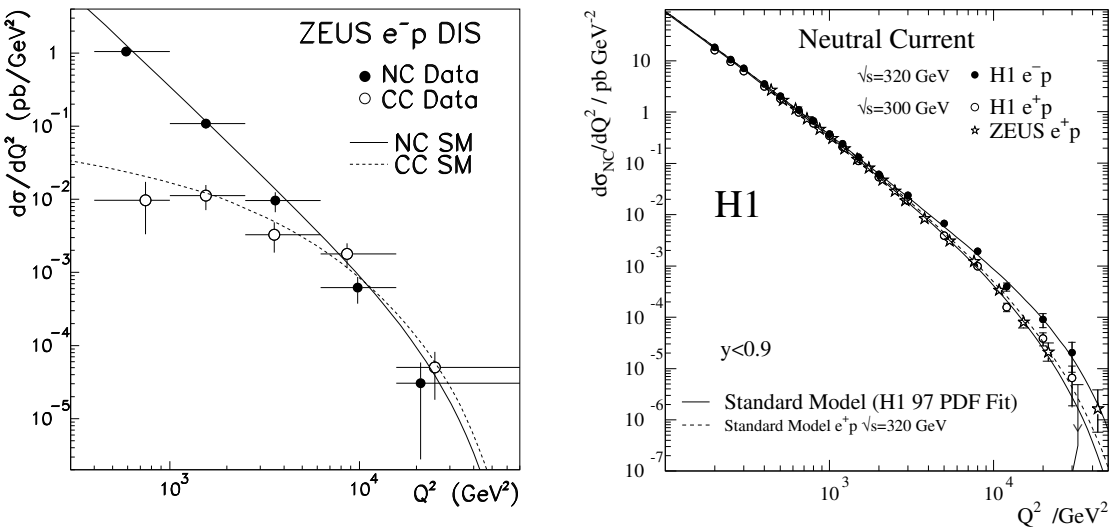


Figure 1. Comparison of NC and CC cross sections measured at HERA with 0.54 pb^{-1} e^-p data [4] (left) and of e^+ and e^- NC cross sections based on 36 pb^{-1} and 16 pb^{-1}, respectively (right) [5].

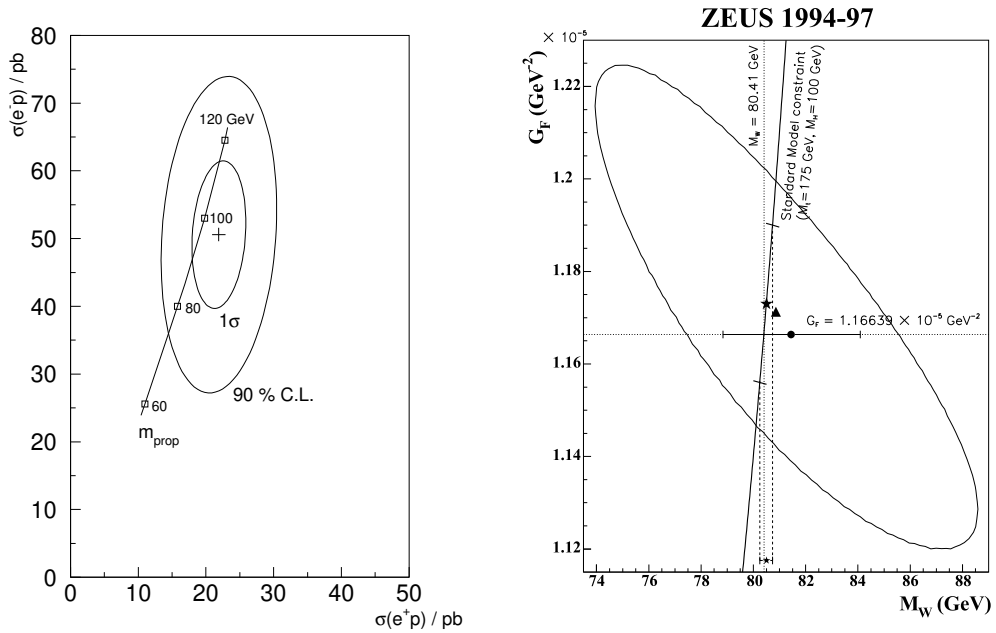


Figure 2. Possible strategies for an interpretation of DIS cross section measurements in terms of m_{W}: propagator mass fit to CC data for e^-p and e^+p scattering [6] (left) and fit of CC e^+p data to Eq. (5) with G_μ and m_{W} as free parameters [7].

terms of electroweak parameters and to take into account theoretical assumptions. For the CC cross section one can write

$$\left.\frac{\mathrm{d}\sigma}{\mathrm{d}Q^2}\right|_{\mathrm{CC}} = \frac{1}{\left(Q^2+m_{\mathrm{W}}^2\right)^2}\Phi(Q^2) \tag{4}$$

$$= \frac{1}{\left(Q^2+m_{\mathrm{W}}^2\right)^2}\frac{G_\mu^2 m_{\mathrm{W}}^4}{2\pi}\Phi'(Q^2) \tag{5}$$

$$= \frac{1}{\left(Q^2+m_{\mathrm{W}}^2\right)^2}\frac{\pi\alpha^2}{4\left(1-m_{\mathrm{W}}^2/m_{\mathrm{Z}}^2\right)^2}\Phi''(Q^2) \tag{6}$$

$$= \frac{1}{\left(Q^2+m_{\mathrm{W}}^2\right)^2}\frac{\pi\alpha^2}{4\sin^4\theta_{\mathrm{W}}}\rho_{\mathrm{CC}}^{1-\mathrm{loop}}(\alpha, m_{\mathrm{W}}, m_{\mathrm{Z}}, m_{\mathrm{t}}, \ldots)\Phi'''(Q^2) \tag{7}$$

The quantities Φ, Φ', ... in Eqs. (4)–(7) comprise all normalization factors not written explicitly and, in particular, the structure functions. A sufficiently precise knowledge of these functions is necessary in any case when trying to extract values for electroweak parameters from measured cross sections. Based on (4) which makes explicit only the dependence on the mass parameter entering the W-propagator (the "propagator mass"), H1 has shown to what extent standard model parameters can be tested already with the low luminosity of 2.7 pb^{-1} of e^+p and 0.36 pb^{-1} of e^-p data [6] (see Fig. 2, left). Taking into account also the measured normalization of the CC cross section, made explicit in Eq. (5) in terms of m_{W} and the Fermi constant G_μ, or in Eq. (6) in terms of m_{W} and m_{Z} (and α), one can perform a 2-parameter fit as done by ZEUS [7] (see Fig. 2 right). The variance of m_{W} resulting from a corresponding one-parameter fit

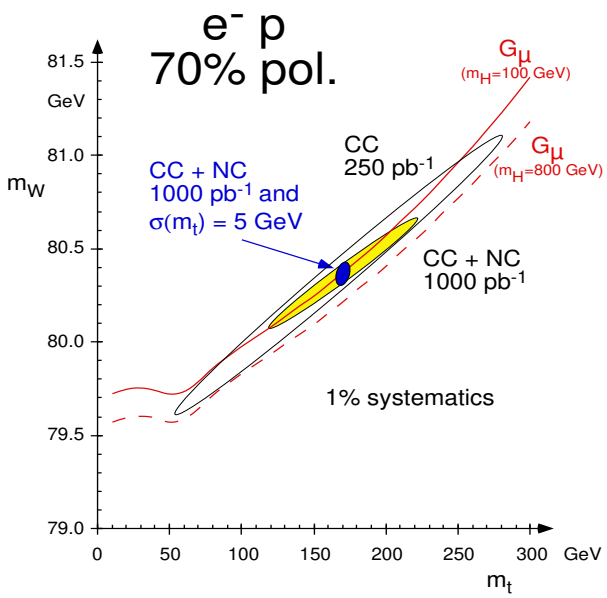


Figure 3. Prospects of a fit of future CC and NC data to the standard model predictions in terms of the parameters m_{W} and m_{t}. The outer ellipse assumes 250 pb^{-1} of CC e^-p data with $-70\,\%$ longitudinal polarization, the shaded ellipse combines 1,000 pb^{-1} of CC and NC data and the inner dark ellipse takes into account in addition to DIS data a direct measurement of m_{t} with precision ± 5 GeV. The standard model constraint due to the μ decay constant is also shown for two different values of m_{H} [8].

depends strongly on how the second parameter entering the normalization is restricted.

With a complete standard model calculation including one-loop electroweak radiative corrections, the cross sections depend on all standard model parameters. Two of them, the fine structure constant α and the Z boson mass m_{Z}, are known with high precision from other experiments. Other parameters are less important for an analysis of DIS cross sections; in particular the Higgs boson mass m_{H} enters only logarithmically in higher-order corrections. The two remaining most relevant parameters are the W boson mass m_{W} and the top mass m_{t}. The latter enters via self energy corrections which contain terms proportional to $m_{\mathrm{t}}^2/m_{\mathrm{W}}^2$. Therefore, cross section measurements can be interpreted, based on (7), as measurements of m_{W} and m_{t}. With 1,000 pb^{-1} of electron scattering data with degree of longitudinal polarization of $-70\,\%$, one can expect a precision, as shown in Fig. 3, of $\Delta m_{\mathrm{W}} \simeq 100$ MeV, provided that *i*) the standard model is assumed to be correct and the value of m_{t} is known with a precision of $\simeq O(5)$ GeV, and *ii*) systematic uncertainties can be kept at or below the level of 2 to 3 %. Structure function measurements at HERA itself have to provide a good understanding of the uncertainties due to parton distribution functions.

3. Electroweak physics with polarized beams

In the standard model, charged-current interactions proceed exclusively via left-handed currents, i.e. the CC cross section vanishes for right-handed electrons and left-

handed positrons. Tests of the helicity structure of CC interactions will come almost instantaneously when polarized beams are available. Two measurements with different polarizations for each lepton charge are sufficient to obtain limits on the CC cross sections for e^-_R and e^+_L which then may be translated into limits on the mass of new heavy W bosons with right-handed couplings.

With polarization available, one can perform four independent cross section measurements in NC scattering at HERA, i.e. for e^-_L, e^-_R, e^+_L, and e^+_R. Corresponding standard model predictions are shown in Fig. 4. Since different combinations of quark

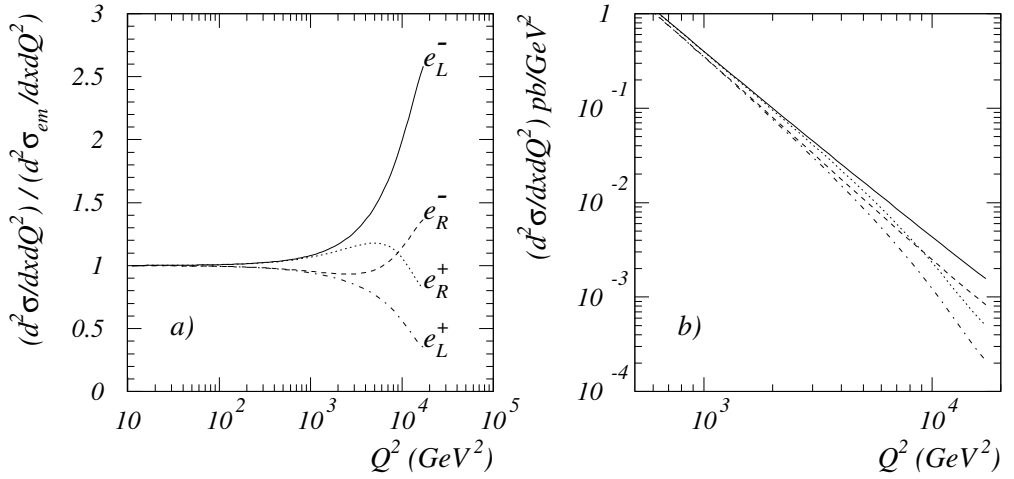


Figure 4. NC cross sections $\mathrm{d}\sigma/dx\mathrm{d}Q^2$ at $x = 0.2$ as a function of Q^2 for different charge and polarization assignments. The left part shows the cross sections normalized to the one-photon exchange which is independent of charge and polarization, the right part displays the absolute cross sections [9].

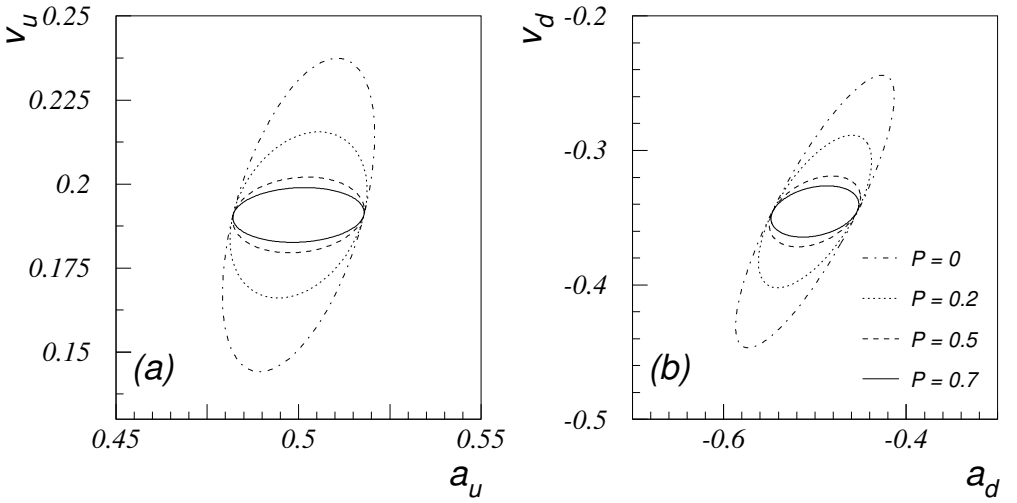


Figure 5. Fit to vector and axial-vector electroweak couplings of light quarks for *up*-quarks assuming fixed *down*-quark couplings (left) and for *down*-quarks assuming fixed *up*-quark couplings with different degree of longitudinal polarization [9].

flavors enter with different coupling constants into the cross sections, one can use these measurements to separately determine parton distribution functions for *up*- and *down*-type quarks, provided the electroweak couplings of quarks to the Z-boson are known. In turn, assuming values for parton distribution functions, one can extract information on these couplings. Figure 5 shows results of a simulated fit of data with 250 pb^{-1} per beam to vector and axial-vector couplings of the light quarks. Polarization is very important for such a measurement and helps to reduce the precision of vector-type couplings by a factor of roughly 5 compared to the case with unpolarized beams. Polarization is indispensable when attempting a four-parameter fit to both *up*- and *down*-type couplings. This is an important test of the electroweak standard model since independent measurements of the light quark couplings are scarce.

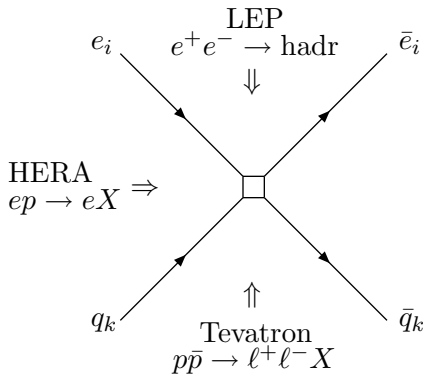
4. Search for New Physics

Higher luminosity implies the feasibility of measurements at higher values of Q^2. The first motivation to perform experiments at the frontier of high Q^2 is the search for new physics beyond the standard model. New physics may show up in the discovery of new particles which are predicted in many models, often connected with new symmetries, like in the minimal supersymmetric extension of the standard model. In classical unification scenarios, new phenomena are expected at the scale of order $O(10^{15})$ GeV. However, a few observations like the evidence for neutrino oscillations or the recent measurement of the anomalous magnetic moment of the muon have furnished again the hope that the scale of new physics is much closer to the present days' energies. New physics might, however, also involve new types of strong interactions. Manifestations of such kinds of scenarios are four-fermion contact interactions, excited fermions, or even novel types of contact interactions due to string effects at the scale of $O(1)$ TeV, realized in theories with large extra dimensions.

4.1. Contact interactions

The contact interaction (CI) scenario relevant for NC processes assumes that four-fermion processes are modified by additional terms in the interaction Lagrangian as shown in Fig. 6. Contact interactions may show up at low energies as a trace of compositeness. However, products of vector or axial-vector currents appear also naturally in models with new physics degrees of freedom like heavy gauge bosons, leptoquarks and others, with masses beyond the production threshold. Scalar or tensor interactions are strongly constrained.

Limits from single experiments at the Tevatron, HERA or LEP2 for models with one single parameter are typically in the order of several TeV and all present high-energy experiments have achieved limits in a very similar mass range despite of their different center-of-mass energies. Most recent limits from experiments at HERA range from 1.6 TeV for LL terms with negative interference to 9.2 TeV for VV contact terms



$$\mathcal{L}_{\rm CI} = \sum_{\substack{i,k=L,R \\ q=u,d,\cdots}} \eta^q_{ik} \frac{4\pi}{\left(\Lambda^q_{ik}\right)^2} \left(\bar{e}_i \gamma^\mu e_i\right) \left(\bar{q}_k \gamma_\mu q_k\right)$$

Figure 6. Four-fermion contact interaction.

with positive interference [10, 11]. Global fits [12, 13] taking into account additional data from LEP2, Tevatron, CCFR, as well as low-energy measurements of atomic parity violation, result in more stringent 95 %-CL limits for single-parameter models reaching values of up to 23 (12.5) TeV for Λ^u_{LL} with positive (negative) sign [13]. Increasing the luminosity at HERA from 100 to 1,000 pb^{-1} is expected to increase the limits on the CI scales Λ^q_{ik} in favourable cases by 50 % [14].

In the case of the observation of deviations from the standard model predictions, the combination of results obtained in different experiments and from measurements with polarized beams will be needed to identify the helicity structure of contact interaction terms [15] and to understand the underlying mechanisms.

4.2. Large Extra Dimensions

In the usual contact term scenario one considers interaction terms with mass dimension 6. Higher-dimension interactions are usually less important since they are suppressed by a higher power of the ratio of the center-of-mass energy and the mass scale characterizing these interactions. It is nevertheless interesting to study the effect of such terms in models where they are the dominating deviation from the standard model framework. The appearance of higher mass dimensions is one aspect of theories with large extra spatial dimensions emerging in low-scale compactified string theories [16].

A specific class of these theories would predict deviations from standard model cross sections through the exchange of gravitons and their Kaluza-Klein excitations [17]. The effect can be described with the help of dimension 8 NC contact interactions [18], but there would also exist electron-gluon contact terms. The relevant term for HERA physics coupling electrons e_i and quarks f_j with definite helicities i, j is of the form

$$\mathcal{L}_{\rm KK-eq} = \frac{\lambda}{M_{\rm S}^4} \Big\{ \bar{e}_1 \gamma_\mu e_2 \, \bar{f}_3 \gamma_\mu f_4 \left(p_2 - p_1\right) \cdot \left(p_4 - p_3\right) + \bar{e}_1 \gamma_\mu e_2 \, \bar{f}_3 \gamma_\nu f_4 \left(p_2 - p_1\right)^\nu \left(p_4 - p_3\right)^\mu \Big\} \; . \tag{8}$$

The novel interaction term which couples electrons to gluons reads

$$\mathcal{L}_{\mathrm{KK-eg}} = -\frac{4\lambda}{M_{\mathrm{S}}^4}\bar{e}_1\left[(p_1-p_2)_\mu\,\gamma_\nu + (p_1-p_2)_\nu\,\gamma_\mu\right] e_2 T^{\mu\nu}(k_1,k_2) \tag{9}$$

with a complicated tensor structure $T_{\mu\nu}$ depending on the momenta of the gluons. The coupling λ cannot be calculated unless the dynamics in the higher-dimensional theory is known. In particular, λ is cutoff sensitive and therefore the mass scale M_{S} is only an effective scale, not directly related to the size of extra dimensions. Lacking a better understanding, one usually assumes $\lambda = \pm 1$.

Large-Q^2 data from HERA can be used to set limits on the mass scale M_{S} [19, 20]. A recent analysis by ZEUS [11] found limits of 0.81 TeV (0.82 TeV) for positive (negative) signs. The limits obtained by H1 [10] depend, due to somewhat larger statistical fluctuations, on the choice of data sets using electrons or positrons or both: e^-p data (15.2 pb^{-1}) give $M_{\mathrm{S}} > 0.68$ (0.50) TeV for $\lambda = +1$ (-1) and e^+p data (81.5 pb^{-1}) $M_{\mathrm{S}} > 0.50$ (0.92) TeV for $\lambda = +1$ (-1), whereas the combined data set leads to $M_{\mathrm{S}} > 0.63$ (0.93) TeV for $\lambda = +1$ (-1).

With an integrated luminosity of 250 pb^{-1} for each lepton charge with left- and right-handed longitudinal polarization (i.e. 1 fb^{-1} in total), HERA could set limits slightly above 1 TeV and would thus be competitive with LEP2 after the complete data has been analyzed (1.1 TeV 95 % CL limit) and the run II Tevatron Drell-Yan data (1.3 TeV). A future e^+e^- linear collider would be sensitive to mass scales above 4 TeV and the LHC can be expected to shift the corresponding limit to 6.0 TeV [20].

4.3. R_p-violating supersymmetry and leptoquarks

The Lagrangian of a supersymmetric version of the standard model may contain a superpotential of the form

$$W_{\not{R}_p} = \lambda_{ijk} L_i L_j E_k^c + \lambda'_{ijk} L_i Q_j D_k^c + \lambda''_{ijk} U_i^c D_j^c D_k^c + \mu_i L_i H_2\,. \tag{10}$$

L_i and Q_i are the superfields for lepton and quark doublets and E_i^c, U_i^c, D_i^c the corresponding charge-conjugated ones for charged leptons, *up*- and *down*-quarks, respectively and i, j, k are generation indices. The separate contributions in $W_{\not{R}_p}$ violate lepton or baryon number conservation. Imposing symmetry under R-parity (defined as $R_p = (-1)^{3B+L+2S}$, $R_p = 1$ for particles, $R_p = -1$ for their superpartners) forbids the presence of $W_{\not{R}_p}$. The phenomenology of supersymmetry with R_p symmetry has been searched for at all present high energy experiments and experiments at HERA have obtained limits which are complementary to those obtained at the Tevatron [21, 22].

No good reason is known why the R_p-violating interactions should not be present. In contrast, they may rather be motivated by their analogy with the Higgs superpotential

$$W_{\mathrm{SUSY-Higgs}} = \lambda_{\mathrm{E},jk} H_1 L_j E_k^c + \lambda_{\mathrm{D},jk} H_1 Q_j D_k^c + \lambda_{\mathrm{U},ij} H_2 Q_i U_j^c + \mu H_1 H_2\,, \tag{11}$$

which contains the Higgs-superfields H_1 (coupling to down quarks) and H_2 (coupling to up quarks). Since H_1 and the lepton doublets L_i have the same weak isospin and

hypercharge, and insisting that H_1 and L_i should have similar interactions, the lepton-flavour violating terms in (10) would follow from (11). One may even speculate about a relation between the couplings appearing in (10) and (11) like $\lambda'_{ijk} = \lambda'_i \lambda_{\mathrm{D},jk}$ which would link lepton-number violating phenomena described by the coupling constants λ'_{ijk} to quark-flavour mixing contained in the $H_1 Q_j D^c_k$ term.

Many low- and high-energy experiments put limits on the couplings contained in $W_{\not R_p}$ [23]; however, they do not forbid interactions of the form $L_i Q_j D^c_k$ proportional to λ'_{ijk} in general, provided the λ''_{ijk} are chosen to be zero at the same time. The lepton-flavour violating $L_i Q_j D^c_k$ terms may be responsible for the generation of neutrino masses and mixings via one-loop diagrams [24]. In addition, with non-zero λ' couplings, squarks would appear as leptoquarks which can be produced on resonance in lepton-quark scattering at HERA.

In the generic leptoquark scenario one considers a broader theoretical basis which allows leptoquark states compatible with a few basic assumptions ($SU(3)\times SU(2)\times U(1)$ symmetry, renormalizability, B and L conservation, chirality of couplings, to mention the most important ones). This BRW-framework [25] leads to more allowed states than those occurring in the MSSM framework (vector states, for example). On the other hand, the BRW-framework is more restrictive since it assumes that there are no other new particles or interactions. Therefore, the branching fractions β_e for their decay to a charged lepton final state can only be 1, 0.5, or 0 and states which can be produced in eu or ed scattering having $\beta_e = 1$ are excluded by searches at the Tevatron for masses below 242 GeV [26]. Additional interactions, as present in the MSSM framework, allow for additional decay channels. If $\beta_e < 1$, the Tevatron bounds degrade and leptoquarks with masses above 200 GeV in scenarios with branching ratios $\beta_e \lesssim 0.7$ are not excluded by searches at the Tevatron. For small β_e, HERA limits supersede those from Tevatron and exclude states with masses up to 290 GeV at 95 % CL for Yukawa couplings $\lambda = e$ [27, 28]. Exclusion limits from HERA experiments also cover much larger mass values for small λ than those obtained from searches at LEP2.

As shown in Fig. 7 [29], exclusion limits for the coupling λ with a given LQ mass can be expected to be reduced by a factor of typically ~ 5 with 500 pb^{-1} of ep data, depending on the LQ type. To further extend the search to large LQ-masses and small Yukawa couplings, an increase of the center-of-mass energy of ep collisions (for example like at TESLA×HERA) would be needed. Again, in the case of a discovery, polarized beams are important to distinguish between various LQ scenarios (see Fig. 8 [30]).

In contrast to the generic leptoquark scenarios, squarks in the R_p-violating MSSM do not only decay into lepton-quark final states via their R_p-violating interactions but they can also decay into final states involving gauge bosons or gauginos. These R_p-conserving decays lead to a large number of interesting and distinct signatures (see [31] and references therein). Characteristically one expects multi-lepton and multi-jet final states. Searches at HERA have not found a signal and bounds on some of the λ' couplings have been derived from searches for the characteristic lepton + multi-jet final states which supersede previous exclusion limits [32, 33]. Measurements and

corresponding exclusion limits have also been interpreted in various versions of the MSSM as exclusion limits on the corresponding parameter sets. In particular for SUSY models where the sfermion and the gaugino sectors are not related, searches at HERA have extended beyond the reach of other collider experiments [32].

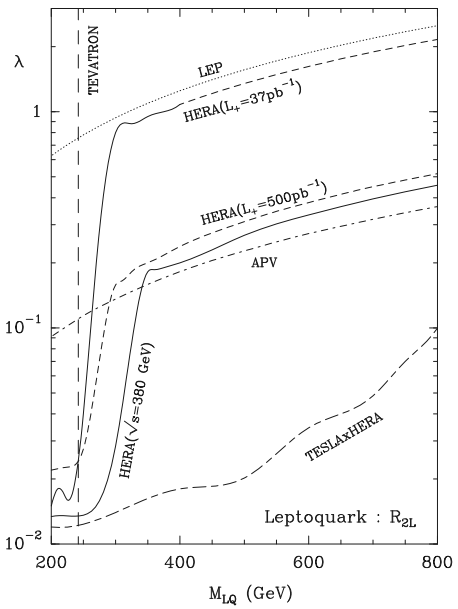


Figure 7. Discovery limits for a scalar leptoquark at various collider experiments [29].

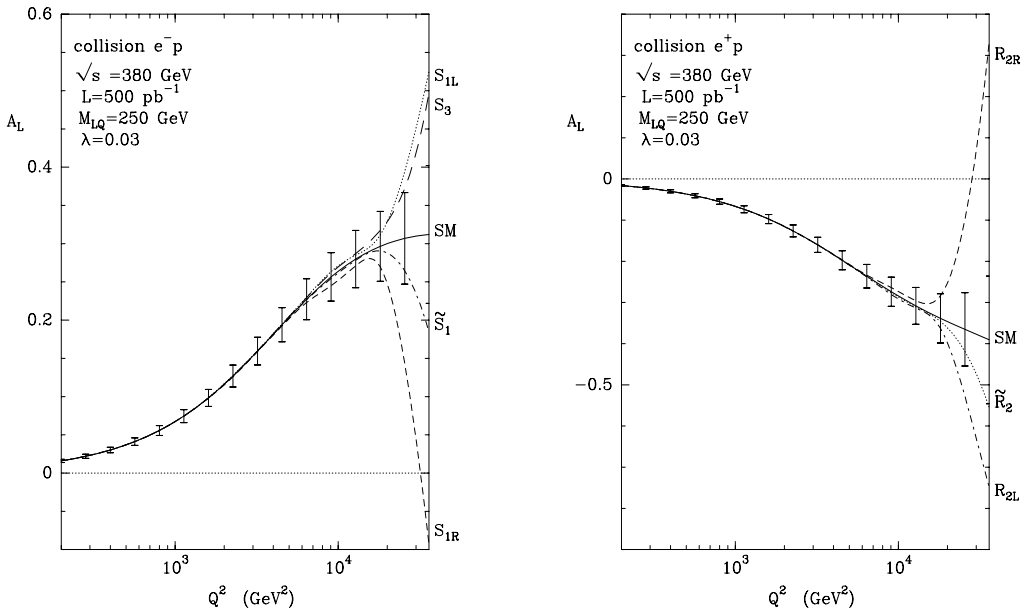


Figure 8. Spin asymmetries $A_{\rm L} = (\sigma(e^{\pm}_{\rm L}) - \sigma(e^{\pm}_{\rm R}))/\sigma(^{\pm}_{\rm unpol})$ for electrons (left) and positrons (right) predicted in various LQ scenarios with $m_{\rm LQ} = 250$ GeV, $\lambda = 0.03$. Solid lines correspond to the standard model predictions; the expected errors are shown assuming a luminosity of $250\,{\rm pb}^{-1}$ for each configuration of beam polarizations [30].

4.4. Lepton-flavour violation

If supersymmetry was realized with R_p-violating interactions, lepton-flavour violation could be observed even in the case when squarks are too heavy to be produced on resonance at HERA. In general, leptoquark states with intergenerational couplings could lead to the exotic signatures $ep \to \mu X$ or $ep \to \tau X$. Two examples for the corresponding processes are shown in Fig. 9. For high-mass leptoquarks, both s- and u-channel diagrams are important and can be described by a 4-fermion contact interaction with $\Lambda^{-2} = \lambda_{eq_i}\lambda_{\mu q_j}/M^2_{\rm LQ}$. Searches by H1 and ZEUS have excluded large values of corresponding couplings $\lambda_{eq_i}\lambda_{\mu q_j}$ and $\lambda_{eq_i}\lambda_{\tau q_j}$ [34, 35]. For a considerable number of possible combinations of lepton and quark flavours, especially for e–τ transitions, HERA limits are the best available, superseding low-energy exclusion limits [36]. In some cases, previous limits did not exist and HERA provides the first ones available. The search for lepton-flavour violating effects at collider experiments is extremely interesting in view of the possible connection to observations made in neutrino experiments (see for example [37]).

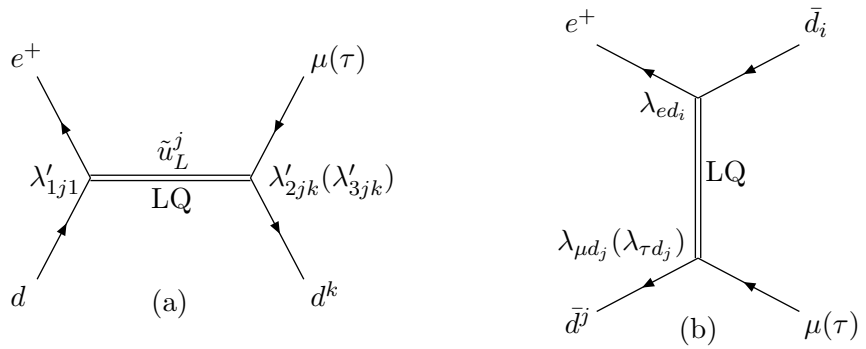


Figure 9. s-channel squark production as an example for the lepton-flavour violating process $e^+d \to \mu d$ through $\lambda'_{1j1}\lambda'_{2jk} \neq 0$ (a) and lepton-flavour violation induced through the exchange of a generic leptoquark with intergenerational couplings in the u-channel (b).

R_p violation was also invoked as a possible explanation of the observation of events with an isolated μ and large missing transverse momentum [38] (see also [39]) in e^+p scattering. Events with muons and missing transverse momentum can originate from W production followed by the decay $W \to \mu\nu_\mu$. Their observed number at H1 is, however, larger than expected from the standard model. Moreover, their kinematic properties are atypical for W production. An explanation in terms of anomalous $WW\gamma$ couplings additionally has to face limits from Tevatron, LEP2 and ZEUS [40] and leaves the question open why a similar excess of events is not seen in $e + \not{p}_T$ events.

$\mu + \not{p}_T$ events would be expected if R_p-violation did lead to on-resonance production of a stop quark $\tilde{t}$ at HERA. The most realistic scenarios require the presence of R_p-conserving decays, for example $\tilde{t} \to \tilde{b}W$, or cascade decays involving charginos $\tilde{t} \to \tilde{\chi}^+_1 b$ followed by $\tilde{\chi}^+_1 \to \tilde{\chi}^0_1 W^+(\to \mu^+\bar{\nu}_\mu)$ or $\tilde{\chi}^+_1 \to \nu_\ell \tilde{\ell}^0(\to \mu^+\bar{\nu}_\mu)$. In all cases, some fine-tuning of mass and coupling parameters is necessary and other final states are predicted.

Moreover, in order to obtain an appreciable number of events, all known mechanisms require the on-resonance production of a stop. In this case the corresponding events would have characteristic kinematic properties which could be checked experimentally. At present there is no convincing explanation for the experimental observation made by H1. Since only H1, but not ZEUS [40], has found an excess of this kind of events, it is obvious that statistical fluctuations play a role. Which of the two experiments has suffered from a statistical fluctuation will be one of the exciting questions of the awaited high-luminosity run of HERA II.

5. Concluding remarks

Deep inelastic scattering experiments are a good place to search for many scenarios of new physics. Limits on leptoquark or squark masses and their Yukawa or R-parity violating couplings, and limits on various mechanisms leading to lepton-flavour violating interactions, can be obtained at HERA which will stay superior to those from other experiments in many cases: HERA remains the best machine for this kind of search.

The search for new physics effects relies in most cases on reliable predictions from the standard model. In deep inelastic scattering this includes the necessity to know parton distribution functions as precisely as possible. It is therefore mandatory to combine the information from all available different experiments in order not to run the risk of confusing modifications of parton distributions with signs of new physics. With this in mind, the huge amount of data expected from HERA experiments in the future is guaranteed to play an indispensable role in the search for new physics.

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