ELECTROWEAK STUDIES AND SEARCH FOR NEW PHENOMENA AT HERA

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Abstract

The H1 and ZEUS Collaborations measure the neutral current and charged current cross sections of deep inelastic electron-proton and positron-proton scattering at HERA at high four-momentum transfer squared, Q^2. Due to high precision and large kinematic coverage of the data, it is possible not only to extract proton parton density functions from the HERA data alone, but also to constrain electroweak parameters, such as the weak quark couplings to the Z boson. As no significant deviation from the Standard Model predictions was observed, limits were derived for different models of new physics: four-fermion contact interactions, models with large extra dimensions, a finite charge radius of the quark and models with leptoquark production or exchange. The only sizable deviation from the Standard Model predictions was reported by H1 Collaboration in the search for events with isolated high-p_T leptons and large missing transverse momentum. In the combined HERA I and HERA II e^+p data 18 events with hadronic transverse momentum $P_T^X > 25$ GeV were observed, whereas 7.8 ± 1.3 were expected. No corresponding excess was observed by the ZEUS collaboration.

1 Introduction

The HERA accelerator, built at DESY, Hamburg, allows us to study electron-proton and positron-proton collisions at the center of mass energies of up to 318 GeV. Scattering events are reconstructed in two omni-purpose detectors, H1 [1)] and ZEUS [2)], both equipped with silicon tracking, drift chambers, hermetic calorimetry and muon detector system. During the so called HERA I running phase (1994-2000) about 100 pb^{-1} of data were collected per experiment, mainly coming from e^+p collisions. After the collider upgrade in 2000-2001, resulting in significant increase of luminosity, over 300 pb^{-1} of data per experiment were collected in the so called HERA II phase (2002-2007). Moreover, spin rotators installed at the H1 and ZEUS interaction regions allow us to obtain longitudinal electron or positron polarization. With average lepton beam polarization of about 30-40% and significant increase of integrated data luminosity (especially of collected e^-p sample) HERA II has significantly extended the physics reach of experiments.

Presented in this contribution are selected results from H1 and ZEUS based on HERA II data analysis.

2 Electroweak studies

Deep inelastic neutral current scattering $ep \to eX$ at very high squared momentum transfer, Q^2, is sensitive to electroweak effects mainly due to the interference of photon and Z boson exchange which dominates over pure Z exchange effects in most of the kinematic range covered at HERA.

High Q^2 NC DIS cross section, neglecting contribution from longitudinal structure function F_L, can be written in terms of four structure functions F_2^0, xF_3^0, F_2^P and xF_3^P:

$$\frac{d^2\sigma^{\mathrm{NC}}(e^{\pm}p)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+F_2^0 \mp Y_-xF_3^0 + P_e\left(Y_+F_2^P \mp Y_-xF_3^P\right)\right] \qquad (1)$$

where: $Y_\pm = 1 \pm (1-y)^2$ and P_e is the lepton beam polarization. Access to electroweak effects is enabled by measuring charge and polarisation cross section differences by which the pure photon exchange part, giving the dominant contribution to the structure function F_2^0 is removed. Comparison of e^-p and e^+p cross sections, i.e. the measurement of charge asymmetry accesses xF_3^0 contributions which is dominated by the valence quark distributions at high Q^2 and lower x and is sensitive to the axial-vector weak quark couplings to the Z boson. The data on polarised cross section asymmetries, $A^{\pm}$, can be used to constrain the contribution from the F_2^P structure function, which is sensitive to d/u ratio at high-x and to the vector quark couplings.

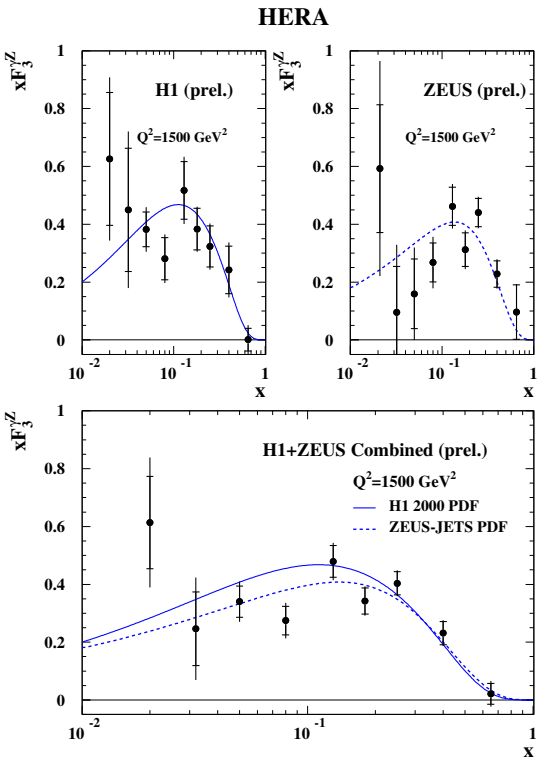

Figure 1: *Measurements of the structure function $xF_3^{\gamma Z}$ by the H1 Collaboration (top left), the ZEUS Collaboration (top right) and combined (bottom). The curves describe the Standard Model predictions as obtained in NLO QCD fits to the H1 inclusive data and to the inclusive and jet ZEUS data, respectively.*

The H1 and ZEUS experiments have measured neutral current DIS cross sections in both charge and both helicity states and the results were combined to improve statistical precision and sensitivity to electroweak effects [3]. Shown in fig.1 are the measurements of the structure function $xF_3^{\gamma Z}$ by the H1 and ZEUS Collaborations and the combined measurement. Results agree very well with the Standard Model predictions obtained from the NLO QCD fits to the inclusive data. Corresponding results on polarised cross section asymmetries, $A^{\pm}$, are shown in fig.2. Parity violation due to $\gamma - Z$ interference is clearly visible, in agreement with Standard Model expectations. This is the first observation of parity violation in neutral current $e^{\pm}p$ scattering at distances down to 10^{-18}m.

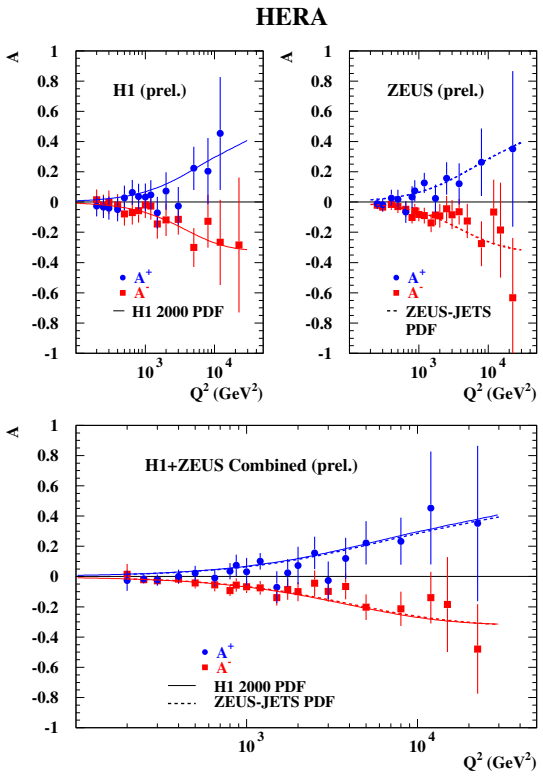

Figure 2: *Measurements of the polarisation asymmetries $A^{\pm}$ by the H1 Collaboration (top left), the ZEUS Collaboration (top right) and combined (bottom).*

The wide kinematic range covered, as well as their precision, allow the determination of the parton distribution functions of the proton from the HERA data alone. Recently, NLO QCD analysis performed by both collaborations were extended to fit electroweak parameters as well. In the ZEUS study [4] inclusive $e^{\pm}p$ cross section data and jet-production data from HERA I were combined with the new data on polarised electron scattering at HERA II to extract constraints on the weak couplings of the quarks. Results on the weak neutral current couplings of u and d quarks to the Z^0 boson are presented in fig.3. Corresponding results from the similar H1 analysis of HERA I data [5], as well as Tevatron and LEP limits are included for comparison. Perfect agreement with the Standard Model predictions is observed. Moreover, determinations of

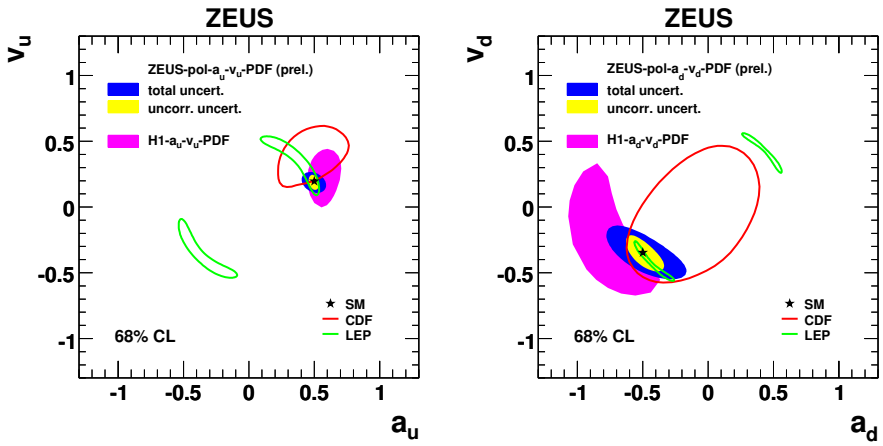

Figure 3: *Results at 68% C.L. on the weak neutral current couplings of u (left plot) and d (right plot) quarks to the Z^0 boson determined from the ZEUS analysis of HERA I and HERA II data. Results from H1 analysis of HERA I data and limits determined by the CDF and LEP experiments (open contours) are included for comparison. The stars show the expected SM values.*

the light-quark couplings at HERA turn out to be competitive in precision with those of the LEP experiments.

3 Search for new phenomena

3.1 Contact Interactions

New interactions between electrons and quarks involving mass scales above the center-of-mass energy can modify the deep inelastic $e^{\pm}p$ scattering cross section at high Q^2 via virtual effects, resulting in observable deviations from the Standard Model predictions. Many such interactions, such as processes mediated by heavy leptoquarks, can be modelled as four-fermion contact interactions. The ZEUS Collaboration applied a common method to search for four-fermion interactions, for graviton exchange in models with large extra dimensions, and for a finite charge radius of the quark [6]. Data on scattering of polarized electrons and positrons collected from HERA II were combined with electron and positron data from HERA I. No significant deviation from the Standard Model predictions was observed and 95% limits were derived for the relevant parameters of the models studied. For the contact-interaction models, limits on the effective mass scale, Λ (i.e. compositeness scale), ranging from 2 to 7.5 TeV

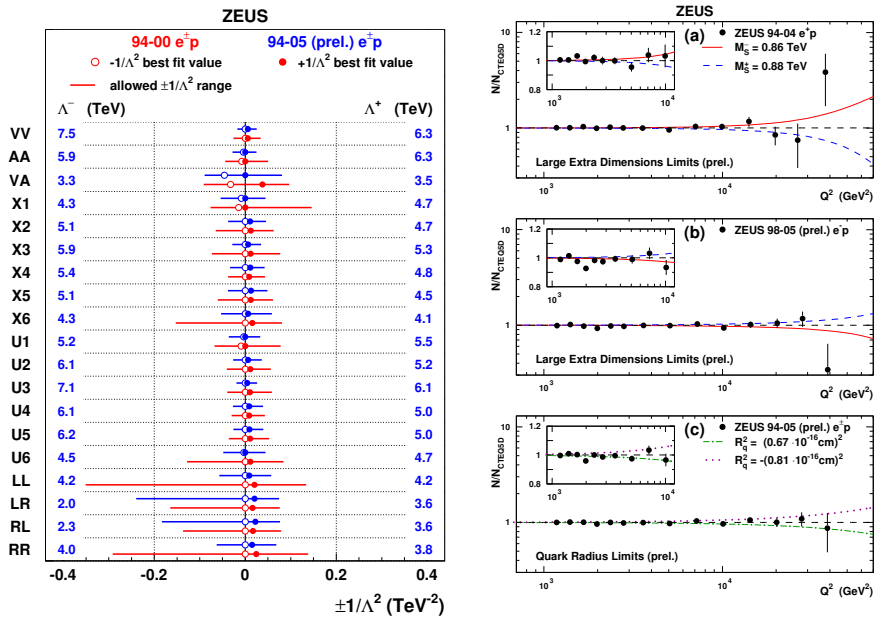

Figure 4: *Left plot: confidence intervals of* $\pm 1/\Lambda^2$ *at 95% C.L. for general CI scenarios studied by ZEUS. The numbers at the margins are the corresponding lower limits on the mass scale* Λ^- *and* Λ^+*. Right plot: ZEUS* e^+p *data (a) and* e^-p *data (b) compared with 95% C.L. exclusion limits for the effective Planck mass scale in models with large extra dimensions, and combined 1994-2000 data (c) compared with 95% C.L. exclusion limits for the effective mean-square radius of the electroweak charge of the quark.*

were obtained, as shown in fig.4(left). For models with large extra dimensions scales below 0.88 TeV (0.86 TeV) were excluded for positive (negative) coupling signs. A quark-charge radius larger than $0.67 \cdot 10^{-16}$cm was excluded, using the classical form-factor approximation. Comparison of ZEUS data with 95% C.L. exclusion limits for the effective Planck mass scale in models with large extra dimensions and the effective radius of the quark is shown in fig.4(right).

3.2 Leptoquarks

The *ep* collider HERA offers also the unique possibility to search for the resonant production of new particles which couple directly to a lepton and a parton. Leptoquarks, colour triplet bosons, which appear naturally in various unifying

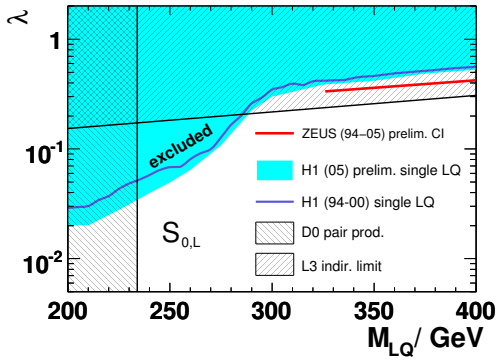

Figure 5: *H1 exclusion limits at 95% C.L. on the coupling as a function of the leptoquark mass for $S_{0,L}$ leptoquark. The indirect limits from ZEUS and L3 and the direct D0 limits are shown for comparison.*

theories beyond the Standard Model are such an example. The H1 Collaboration searched for scalar and vector leptoquarks coupling to first generation fermions using the ep scattering data collected by the experiment until 2005. With HERA II data sensitivity to leptoquarks with fermion number F=2 is significantly increased w.r.t. HERA I data. No evidence for the direct or indirect production of such particles is found in data samples with a large transverse momentum final state electron or with large missing transverse momentum. The results of the analysis are used to set constraints on leptoquark couplings. Exclusion limits at 95% C.L. on the Yukawa coupling of $S_{0,L}$ leptoquark, as a function of its mass are presented in fig.5. The indirect limits from ZEUS and L3 and the direct D0 limits are included for comparison. For leptoquark couplings of electromagnetic strength, F=2 leptoquarks with masses up to 276-304 GeV are ruled out.

3.3 Isolated leptons

Searches for events containing isolated high-p_T leptons (electrons or muons) and large missing transverse momentum were performed by the H1 and ZEUS collaborations in HERA I and HERA II $e^{\pm}p$ data. For HERA I data an excess of events compared to the SM prediction at large hadronic transverse momentum P_T^X was previously reported by the H1 Collaboration but not confirmed by ZEUS. Example of an event with an isolated electron, missing transverse momentum and a prominent hadronic jet found in the HERA II e^+p data col-

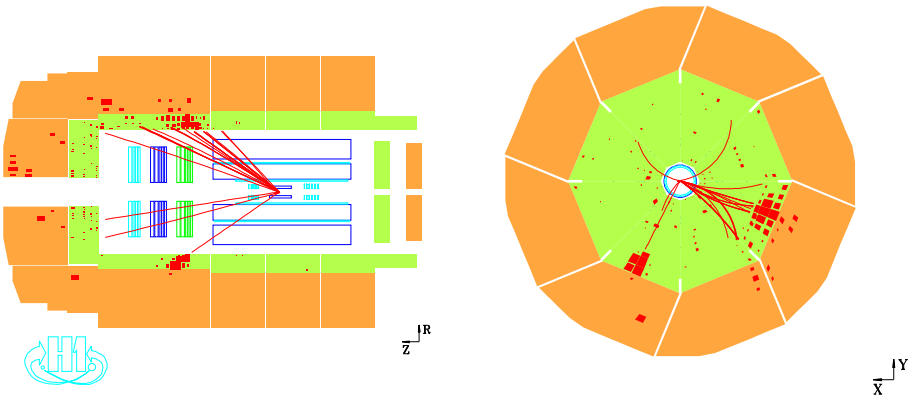

Figure 6: *Display of an event with an isolated electron, missing transverse momentum and a prominent hadronic jet in the HERA II e^+p data collected by the H1 experiment.*

lected by the H1 experiment is presented in fig.6. The main SM process that may produce events with this topology is the production of real W bosons via photoproduction with subsequent leptonic decay: $ep \to eW^{\pm}(\to l\nu)X$. The main SM background to events containing isolated electrons arises from neutral current events, whereas for events with an isolated muon the background arises from lepton pair production and charge current DIS events.

Figure 7 shows the distribution of the hadronic transverse momentum P_T^X for the e^-p and e^+p events selected from the H1 data [8]. Good agreement with Standard Model predictions is observed in low P_T^X region, where elastic $W^{\pm}$ production signal is expected. However, for e^+p data an excess of events over SM predictions is observed for large hadronic transverse momentum $P_T^X > 25$ GeV. In the combined HERA I and HERA II data 18 such events were observed by H1 experiment, corresponding to about 3σ excess over the Standard Model expectation of 7.8 ± 1.3. No such deviation was observed for e^-p data from H1. The ZEUS data are in good agreement with the model predictions: [9] for $P_T^X > 25$ GeV 4 e^+p events were observed in the combined HERA I and HERA II data compared to the SM expectation of 6.3. Summary of the H1 and ZEUS results on searches for events with isolated electrons or muons and missing transverse momentum at HERA is presented in tab.1.

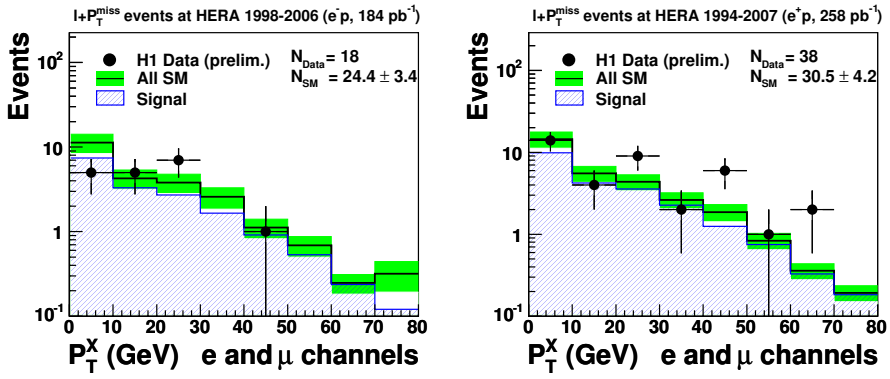

Figure 7: *Results of the search for events with isolated leptons and missing transverse momentum by the H1 Collaboration: hadronic transverse momentum distributions in the electron and muon channels, for the combined e^-p (left plot) and e^+p (right plot) data compared to the SM expectation (open histogram).*

4 Conclusions

With high luminosity and lepton beam polarisation at HERA II a new window for precise electroweak studies has been opened. H1 and ZEUS collaborations presented results on the charge and polarisation asymmetries in deep inelastic scattering. With high precision and large kinematic coverage of the data, NLO QCD analysis performed by both collaborations were extended to extract not only parton densities in the proton but to fit electroweak parameters as well. The obtained constraints on the light-quark couplings to the Z^0 boson are in good agreement with the Standard Model predictions and are competitive in precision with LEP measurements.

Precise measurements of deep inelastic $e^{\pm}p$ scattering at large Q^2 were also exploited to search for possible "new physics" beyond the Standard Model. As no significant deviation from the Standard Model predictions was observed, limits were derived for different models of new physics: four-fermion contact interactions, models with large extra dimensions, a finite charge radius of the quark and models with leptoquark production or exchange. The only sizable deviation from the Standard Model predictions was reported by the H1 collaboration in the search for events with isolated high-p_T leptons and large missing transverse momentum. In the combined HERA I and HERA II e^+p data 18 events with hadronic transverse momentum $P_T^X > 25$ GeV were observed, whereas 7.8 ± 1.3 were expected. However, no corresponding excess was observed by the ZEUS collaboration.

Table 1: *Summary of the H1 (upper table) and ZEUS (lower table) results on searches for events with isolated electrons or muons and missing transverse momentum at HERA. The number of observed events is compared to the SM prediction (observed/expected). The signal component of the SM expectation (W production) is given as a percentage in parentheses.*

H1 (prel.)	e channel	μ channel
$e^- p$ (184 pb^{-1})	$3/3.8 \pm 0.6$ (61%)	$0/3.1 \pm 0.5$ (74%)
$e^+ p$ (258 pb^{-1})	$10/4.1 \pm 0.8$ (75%)	$8/3.7 \pm 0.6$ (85%)
$e^\pm p$ (442 pb^{-1})	$13/7.9 \pm 1.4$ (67%)	$8/6.8 \pm 1.1$ (79%)

ZEUS (prel.)	e channel	μ channel
$e^- p$ (204 pb^{-1})	$5/3.8 \pm 0.6$ (55%)	$2/2.2 \pm 0.3$ (86%)
$e^+ p$ (228 pb^{-1})	$1/3.2 \pm 0.4$ (75%)	$3/3.1 \pm 0.5$ (80%)
$e^\pm p$ (432 pb^{-1})	$6/7.0 \pm 0.7$ (64%)	$5/5.3 \pm 0.6$ (82%)

HERA running is coming to an end soon. However, large samples of data have been collected by both experiments and are still being analyzed. Many more interesting results are still expected to emerge.

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