SEARCH FOR CONTACT INTERACTIONS AND LEPTON FLAVOUR VIOLATION AT HERA

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In the years 1993-2000 the two experiments H1 and ZEUS at the ep collider HERA each have accumulated a luminosity of approximately 130 pb^{-1} at center of mass energies of $300 - 320$ GeV. The data are used to search for physics beyond the Standard Model. No significant deviation of the measured cross section $d\sigma/dQ^2$ from the Standard Model expectation is observed. In the framework of contact interactions this result is expressed as limits on mass scales for compositeness models or limits on leptoquark masses. Furthermore searches for lepton flavour violating processes $ep \to lX$ ($l = \mu, \tau$) are performed. No excess above the expectations from the Standard Model is observed. Limits on the Yukawa coupling λ_{lq} as function of leptoquark mass are derived.

1 Introduction

At the ep collider HERA the detailed study of the process of Deep Inelastic Scattering (DIS) provides sensitivity to new physics. At large values of the square of momentum transfer from the electron to the proton, Q^2, deviations of the observed cross section from the Standard Model (SM) expectation could occur due to the interference of the exchange of γ, Z^0 (neutral current, NC) or W (charged current, CC) with new particles. For masses below the center-of-mass energy of HERA new particles can be resonantly produced in the s-channel while at higher mass values also the u-channel contributes. The data presented here have been taken in the years 1993-2000 by the two collider experiments H1 and ZEUS. In this period each experiment accumulated about 16 pb^{-1} of e^-p and up to about 115 pb^{-1} of e^+p data at center of mass energies of $300 - 320$ GeV.

2 Contact Interactions

For masses of the exchanged particle well above the center-of-mass energy the reaction can be described by a four-fermion pointlike interaction. In the general case the effective Lagragian is given by:

$$\mathcal{L}_V = \sum_{q=u,d} \sum_{a,b=L,R} \eta^q_{ab} (\bar{e}_a \gamma^\mu e_a)(\bar{q}_b \gamma_\mu q_b) \quad (1)$$

with $\eta^q_{ab} = \epsilon^q_{ab} \frac{4\pi}{\Lambda^2}$. Λ denotes the mass scale of the interaction. Here, only vector terms are considered because very stringent limits already exist for tensor and $(\bar{e}e)(\bar{q}q)$-scalar couplings. This formalism can be used to describe a variety of different models like e.g. compositeness, leptoquarks. Deviations of the measured cross section from the DIS expectation can also be interpreted in terms of quark-substructure or large extra dimensions[1].

2.1 Compositeness

Depending on the chiral structure of the model under study only some of the terms in eq.1 may contribute. Fig.1 shows the ratio of the measured differential cross section $d\sigma/dQ^2$ to the SM expectation separately for e^-p and e^+p data from H1[2]. Possible deviations from the SM would manifest themselves as deviations from unity, in particular at high values of Q^2. Depending on the chiral structure of the model and on the value of the scale parameter Λ, the data are expected to follow different lines. H1 and ZEUS used all the

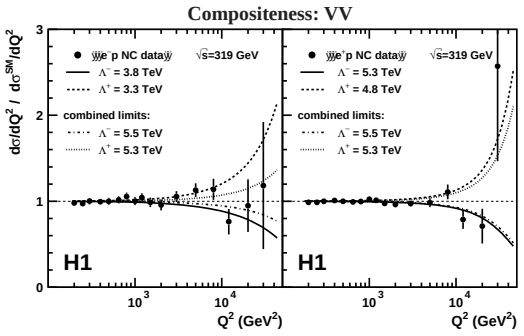

Figure 1. NC cross section $d\sigma/dQ^2$ at $\sqrt{s} = 319$ GeV normalised to the Standard Model expectation. H1 e^-p (left, $\mathcal{L} = 16.4$ pb^{-1}) and e^+p (right, $\mathcal{L} = 65.2$ pb^{-1}) scattering data are compared with curves corresponding to 95% C.L. exclusion limits obtained from each data set and from the combined data for VV compositeness scales Λ^+ and Λ^-. The errors represent only statistics and uncorrelated experimental systematics.

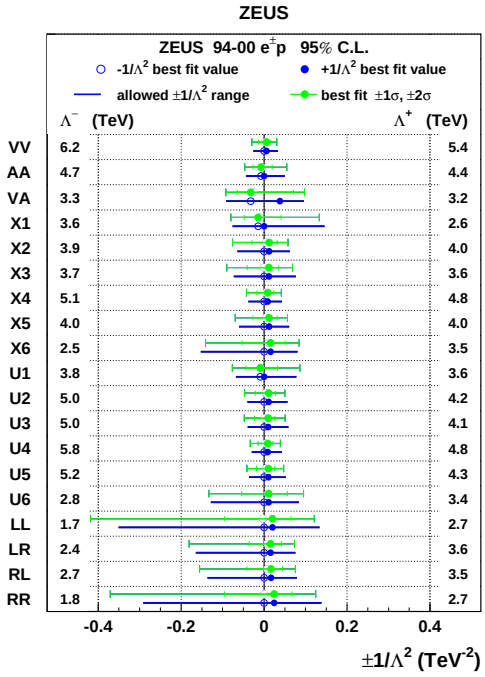

Figure 2. Confidence intervals of $\pm 1/\Lambda^2$ at 95% C.L. for general contact interaction scenarios. Numbers at the right (left) margin are the corresponding lower limits on the mass scale Λ^+ (Λ^-). The best fit values for the coupling are represented by light filled circles together with their $\pm 1\sigma$ and $\pm 2\sigma$ errors indicated by bars.

HERA I data to investigate a large variety of compositeness models. As an example for a specific model fig.1 shows in addition to the H1 data expectations for the VV model which corresponds to the case where all $\epsilon_{ab} = +1$. As can be seen from this example e^-p and e^+p data provide complementary sensitivity and despite its much lower luminosity the e^-p data help to improve the limits as shown by the curves resulting from the combined analysis of both data sets. No significant deviation from the SM were observed in the H1 and ZEUS data. For all models studied the best fit value for $1/\Lambda^2$ was found to be consistent with being 0 within the 2σ error band. Therefore 95% C.L. lower limits for the scale parameter Λ have been derived (see fig.2 for the ZEUS results[3]) and are found to be in the range $\Lambda < 1.7 - 6.2$ TeV depending on the model. The obtained HERA limits are comparable and in several cases more stringent than corresponding limits obtained at LEP and Tevatron.

2.2 Leptoquarks

Leptoquarks appear in many extentions of the SM. These are color triplet scalar or vector bosons which carry both lepton and baryon number and have non-integer electric charge. In the so-called Buchmüller-Rückl-Wyler model[4] seven scalar and seven vector leptoquarks are introduced which are characterized by the fermion number $F = L+3B$. F is a conserved quantum number and can assume values $F = 0, \pm 2$. Due to the dominant coupling to the valence quarks in the proton e^+p (e^-p) data provide sensitivity mainly to leptoquarks with $F = 0$ (2). For large leptoquark masses, M_{LQ}, the leptoquark coupling λ_{LQ} to the eq pair and the contact interaction coefficient η^q_{ab} are related via: $\eta^q_{ab} = \epsilon^q_{ab}\lambda^2_{LQ}/M^2_{LQ}$.

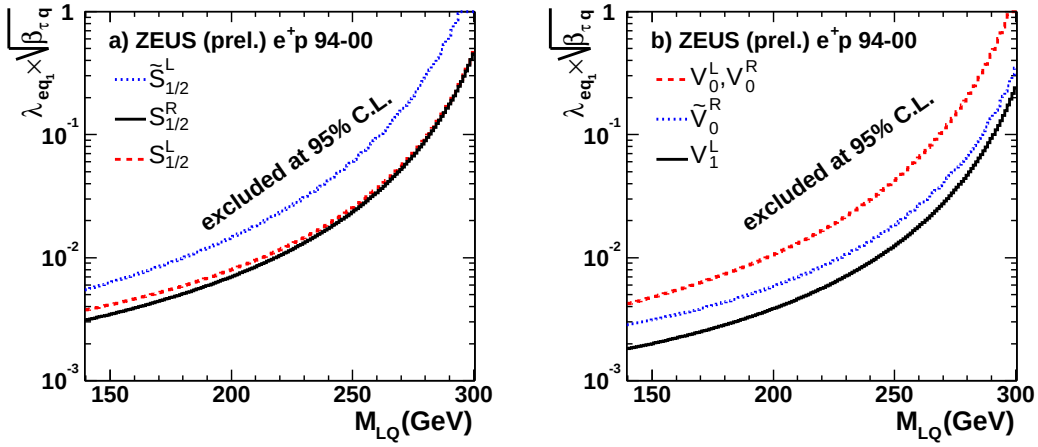

Figure 3. 95 % C.L. limits on $\lambda_{eq_1} \times \sqrt{\beta_{\tau q}}$ for scalar (left) and vector (right) leptoquarks with $F = 0$ obtained from e^+p data of ZEUS in the τ-channel.

Therefore, since no deviations from the SM have been observed in the data, lower limits on the ratio M_{LQ}/λ_{LQ} in the range $0.3-1.4$ TeV have been derived[2,3]. For seven out of the 14 leptoquarks the HERA limits are more stringent than the corresponding limits from LEP. The best limits are obtained for the vector leptoquarks V_1^L (1.36 TeV) and $\tilde{V}_{1/2}^L$ (1.06 TeV).

3 Lepton Flavour Violation

The observation of neutrino oscillations suggests that conservation of lepton flavour number might be violated also in the charged lepton sector. However for charged leptons strong limits exist from the study of rare decays etc., in particular for transitions between the first and the second generation. Lepton Flavour Violation (LFV) could occur if leptoquarks would exist which have non-zero couplings to different generations of leptons and quarks.

At HERA LFV interactions could be observed in the reaction $ep \to lX$, where the lepton l is a μ or a τ. These very simple event topologies are almost background free and their observation would clearly signal physics beyond the Standard Model. ZEUS[5] and H1[6] have both searched for events with an isolated high-p_t μ, back-to-back and balanced in p_t with the jet of the hadronic final state. After the final event selection no events remain in the data samples corresponding to 130 pb^{-1} (66 pb^{-1}) in the case of the ZEUS (H1) analysis with 0.86 (0.74) events expected from Standard Model processes. The same data samples were also used to search for events containing a high momentum isolated τ balanced by a jet in azimuth. The hadronic decay of a high-p_t τ leads to the typical signature of a high-p_t "pencil-like" jet, which is characterized by its narrow shape and low track multiplicity. These and a number of other properties are exploited for the definition of dedicated τ finders. Neutrinos from the decay of the τ are boosted in the direction of the τ-jet leading to the additional requirement of missing transverse momentum aligned with the τ-jet candidate. The ZEUS results includes in addition the analysis of

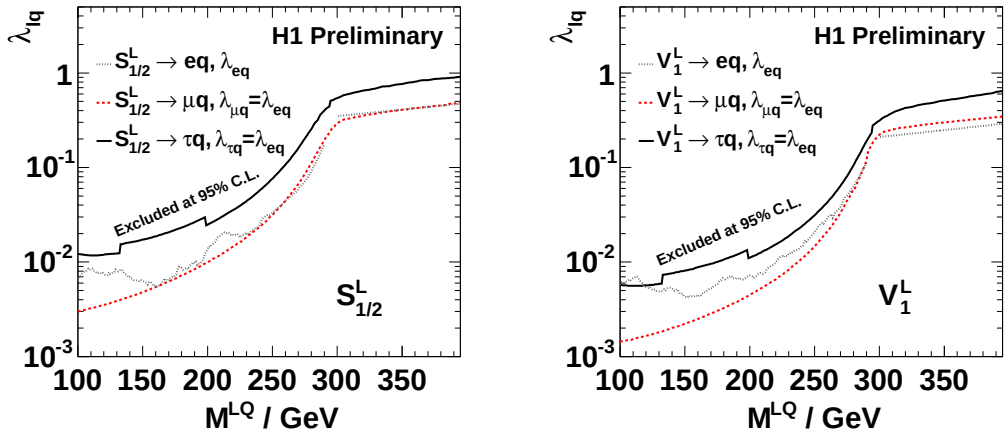

Figure 4. Limit on coupling strength λ_{lq} at 95% C.L. for $S^L_{1/2}$ (left) and V^L_1 (right) decaying into leptons of the first, second and third generation. Equal leptoquark coupling strength to eq and μq or τq is assumed.

the leptonic τ-decay modes $\tau \to \mu\bar{\nu}_\mu\nu_\tau$ and $\tau \to e\bar{\nu}_e\nu_\tau$. H1 finds one candidate τ-event while 0.56 events are expected from NC DIS and photoproduction. ZEUS sees no event with a SM expectation of 1.7 events.

Since no evidence has been found for lepton flavour violation exclusion limits for Yukawa coupling constants λ_{lq} can been derived. For masses $M_{LQ} < \sqrt{s}$ the narrow width approximation yields $\sigma^{NWA} \propto \lambda^2_{eq}\beta_{lq}$. As an example fig. 3 compares limits on the product of coupling constant times square root of branching ratio for various $F = 0$ low mass leptoquark types as obtained from the ZEUS τ-channel analysis. Assuming a coupling of electromagnetic strength ($\lambda^{em} = 0.3$) masses below $\simeq 280 - 300$ GeV can be excluded depending on the leptoquark type. A comparison to indirect constraints from low energy experiments (LFV B-, τ-, K-decays) shows that some of the τ-limits of ZEUS are more stringent for leptoquark masses below $\simeq 260 - 290$ GeV.

Due to the steeply falling quark distributions inside the proton towards higher momentum fractions the experimental sensitivity drops at higher masses, however some sensitivity extends even beyond the kinematic limit of HERA if the finite width of the leptoquark and the u-channel leptoquark exchange are taken into account. In fig. 4 resulting limits from the H1 μ- and τ-analyses and from a search for non-LFV leptoquarks[7] are compared. As expected the limits connect at high masses to the corresponding limits from the contact interaction analysis. The high selection efficiency and very low background level for the μ-channel lead to an enhanced sensitivity compared to the e- and τ-channels.

References

1. E. Kajfasz, Extra Dimension Search at $p\bar{p}$ and ep Colliders, these proceedings.
2. H1 Coll., C. Adloff et al., *Phys. Lett.* B **568**, 35 (2003);
   H1 Coll., Abstr. **12-0158**, ICHEP04
3. ZEUS Coll., S. Chekanov et al., *Phys. Lett.* B **591**, 23 (2004);
   ZEUS Coll., Abstr. **12-0228**, ICHEP04
4. W. Buchmüller, R. Rückl and D. Wyler, *Phys. Lett.* B **191**, 442 (1987). Erratum in *Phys. Lett.* B **448**, 320 (1999).
5. ZEUS Coll., Abstr. **12-0255**, ICHEP04
6. H1 Coll., Abstr. **12-0766**, ICHEP04
7. H1 Coll., Abstr. **185**, LP2003, Fermilab