Sensitivity of the ZEUS Experiment to Contact Interactions at High Integrated Luminosities

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Abstract: The sensitivity of the ZEUS experiment to $eeqq$ contact interactions in neutral current deep inelastic scattering has been studied for future integrated luminosities as high as 1000 pb^{-1}.

1 Introduction

The electron–proton collider HERA is an ideal place for the study of neutral current deep inelastic scattering (NC–DIS), and by making precise measurements of the cross section, the ZEUS experiment can potentially detect the effects of physics beyond the Standard Model (SM). Many new physics processes that occur at mass scales greater than $\sqrt{s}$ (*e.g.* compositeness, leptoquarks, and new heavy bosons) may be detected at ZEUS as a contact term which modifies the DIS cross section. A 'contact term' is a simple four–fermion interaction where the propagator mass is so much larger than the energy available that the propagator is contracted to a point. The most general chirally invariant expression for $eeqq$ contact interactions adds terms to the Lagrangian of the form [1] $L = \eta_{ss'}(e_s \gamma e_s)(q_{s'} \gamma q_{s'})$ where $\eta_{ss'} = \pm g^2/2\Lambda^2_{ss'\pm}$ is the parameter for the coupling between lepton helicity s and quark helicity s', Λ is the mass scale of the process and the $\pm$ sign denotes constructive or destructive interference. Using this modified Lagrangian, a simple technique for setting limits is presented which is complimentary to previously published methods [2].

Assuming unpolarized beams and neglecting radiative corrections, the NC–DIS differential cross section can be expressed as the sum of the proton structure functions F_2 and F_3, which in turn are functions of the parton momentum distributions and SM quark couplings [5]. The contact term then causes additional terms (Eqs. 2-5) in F_2 and F_3 proportional to $\eta_{ss'}Q^2$: [2]

$$\begin{aligned}
\frac{d^2\sigma(e^\pm p)}{dxdQ^2} &= \frac{2\pi\alpha^2}{xQ^4}\left[[1+(1-y)^2]F_2(x,Q^2) \mp [1-(1-y)^2]xF_3(x,Q^2)\right] \qquad (1) \\
F_2 &= \sum_{flavor}\left[xq(x,Q^2)+x\bar{q}(x,Q^2)\right]\frac{1}{2}\left[\left|V_f^L\right|^2+\left|V_f^R\right|^2+\left|A_f^L\right|^2+\left|A_f^R\right|^2\right] \\
xF_3 &= \sum_{flavor}\left[xq(x,Q^2)-x\bar{q}(x,Q^2)\right]\left[V_f^L A_f^L - V_f^R A_f^R\right]
\end{aligned}$$

$$
\begin{aligned}
V_f^L &= e_f - (v_e + a_e) v_f P_Z + \frac{Q^2}{8\pi\alpha}(\eta_{LL} + \eta_{LR}) && (2)\\
V_f^R &= e_f - (v_e - a_e) v_f P_Z + \frac{Q^2}{8\pi\alpha}(\eta_{RL} + \eta_{RR}) && (3)\\
A_f^L &= -(v_e + a_e) a_f P_Z + \frac{Q^2}{8\pi\alpha}(\eta_{LL} - \eta_{LR}) && (4)\\
A_f^R &= -(v_e - a_e) a_f P_Z + \frac{Q^2}{8\pi\alpha}(\eta_{RL} - \eta_{RR}) && (5)\\
P_z &= \frac{1}{\sin^2\theta_W \cos^2\theta_W} \frac{Q^2}{Q^2 + M_Z^2} \\
v_i &= \frac{1}{2}\ T_i^3 - q_i \sin^2\theta_W \qquad\qquad a_i = \frac{1}{2}\ T_i^3
\end{aligned}
$$

where T_i^3 are the weak isospins ($+\frac{1}{2}$ for $i = u, \nu$, $-\frac{1}{2}$ for $i = d, e$) and q_i are the charges. At high Q^2, the contribution of the longitudinal structure function (F_L) to the cross section is very small, so it is ignored in this study.

The effect of the contact interaction on the cross section can be seen in Fig. 1, where the ratio of the differential cross section including a 1 TeV contact term to the SM only cross section for e^+p is shown as a function of Q^2. Since the valence quarks are the primary contributors at high Q^2, it is assumed that only the u and d quarks are involved in the contact interaction.

Additionally, if the quark has a finite size, then the cross section may be multiplied by a quark form factor. Assuming that the quark has charged constituents and that the electron is point-like, the cross section is modified to:

$$
\left(\frac{d\sigma}{dQ^2}\right)_{FORM} = \left(\frac{d\sigma}{dQ^2}\right)_{NC} \left(1 - \frac{1}{6} R^2 Q^2\right)^2
$$

where R is the effective radius of the quark and the factor of 6 is chosen by convention [6].

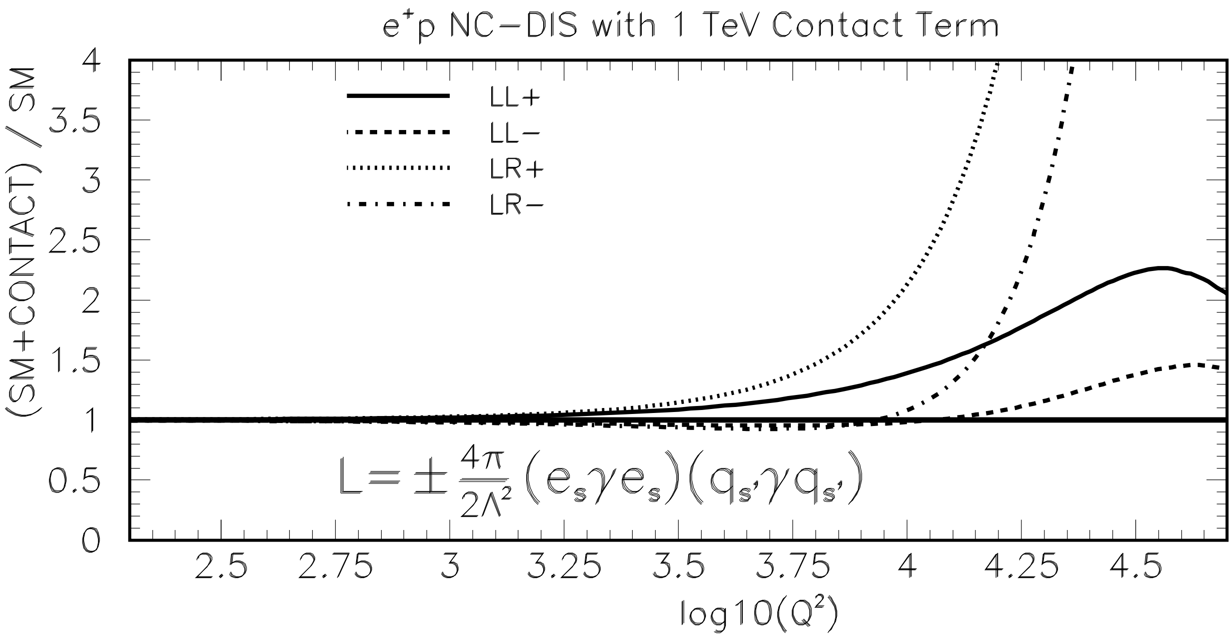

Figure 1: *Ratio of differential cross sections $\frac{d\sigma}{dQ^2}$(SM + CONTACT) to $\frac{d\sigma}{dQ^2}$(SM only) vs Q^2 calculated by integration of Eq. 1 over x for four different eeqq contact term couplings.*

2 Event Selection and Limits

The primary selection criteria for this analysis of the NC–DIS cross section are an isolated electron in the calorimeter with energy > 10 GeV, a matching track from the central tracking detector, and $Q^2 > 200$ GeV^2. Isolation and track matching requirements eliminate most of the photoproduction events with fake electrons, the primary background. Other requirements are energy and momentum conservation, $(E - P_z)$ and various non-ep background cuts (*e.g.* cosmic and halo muons, beam-gas). The effects of all cuts were studied using NC–DIS (Django [3]) and photoproduction (Herwig [4]) Monte Carlo. The efficiency with all cuts was found to be 80% and the background contamination less than 5%, decreasing for increasing Q^2. The 'double angle' method was used as an estimator for Q^2 because it is relatively insensitive to energy scale uncertainty. The overall systematic acceptance uncertainty is estimated to be 5%.

Both the contact term and the form factor have their strongest effect at high Q^2, so the simplest method to search for a signal is to look for an excess (or deficit) in the total number of events above some minimum Q^2 (Q^2_{MIN}), thus forming one bin in Q^2. The effect of a contact term or form factor has been simulated in this study by reweighting the DIS Monte Carlo event-by-event to the appropriate signal differential cross section, where the reweighting factor is $d\sigma(x,Q^2)_{SIGNAL}/d\sigma(x,Q^2)_{SM}$. The signal Monte Carlo is then used to determine the Q^2_{MIN} that maximizes the sensitivity to new physics.

A reduction in the SM cross section is expected in the presence of a quark form factor, so for setting limits it is necessary to define the *minimum* number of events N that are consistent with the number of observed events N_O with $Q^2 > Q^2_{MIN}$ at the 95% C.L. :

$$0.95 = \sum_{k=0}^{N_O} e^{-N} \frac{N^k}{k!}$$

This is just a modified version of the Poisson upper limit formulation [1], with the $1-\epsilon$ replaced by ϵ. Once N has been determined, R is varied until the number of events expected from the signal Monte Carlo matches N.

For the positive signal expected from contact interactions, Poisson statistics with background are used to determine the maximum number of signal events N that are consistent with N_b background events and N_O observed events with $Q^2 > Q^2_{MIN}$ at the 95% C.L. [1] Then Λ is varied until the number of events expected from the signal Monte Carlo equals N. Using this method and assuming that there is no significant deviation from the SM, the limits on the contact interaction mass scale Λ can be calculated for the eight lepton-quark couplings. The convention of setting $g^2 = 4\pi$ has been used [1] to determine the mass scale limits for integrated luminosities up to 1000 pb^{-1}. Four of the lepton-quark coupling limits are shown in Figs. 2a (e^-p) and 2b (e^+p). Similarly, the effective quark radius limits from the form factor analysis are plotted in Fig. 3.

In conclusion, it is clear from Figs. 2a and 2b that the e^-p measurement is particularly sensitive to the LL+ coupling while the e^+p measurement is most sensitive to the LR+ coupling. On the order of 500 pb^{-1} of each lepton species is neccessary to maintain limits that are competitive with $p\bar{p}$ experiments. Furthermore, if a signal is detected, the use of polarized beams may help to discern the chiral properties of the new interactions.

References

[1] Particle Data Group, *Phys. Rev.* D **54**, (1996).

[2] P. Haberl, *et al*, Proceedings *'Physics at HERA'*, eds. W. Buchmuller and G. Ingleman, 1133, DESY, Hamburg, 1992.

[3] DJANGO 1.0: G. Schuler and H. Spiesberger, *ibid.*, 1419.

[4] HERWIG 5.8: G. Marchesini *et al.*, Comput. Phys. Commun. **67**, 465 (1992).

[5] G. Ingelman and R. Rückl, *Phys. Lett.* B **201**, 369 (1988).

[6] G. Köpp, *et al.*, *Z. Phys.* C **65**, 545 (1995).

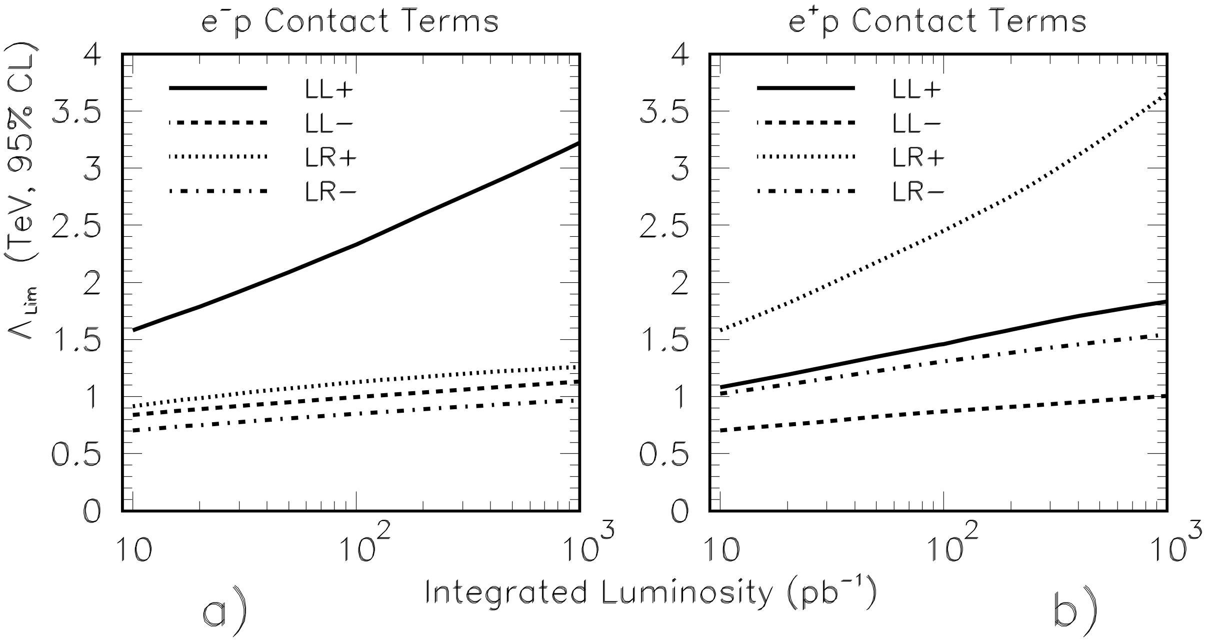

Figure 2: *Expected limits on the mass scale Λ with high integrated luminosities. Four different eeqq contact interaction couplings are shown using a) e^-p and b) e^+p Monte Carlo* [3].

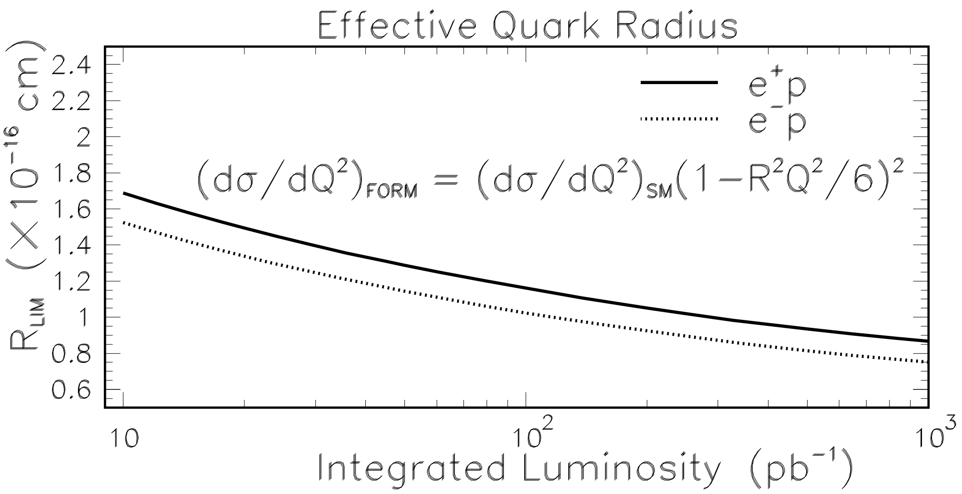

Figure 3: *Expected limits on the effective quark radius R with high integrated luminosities using e^-p (dotted line) and e^+p (solid line) Monte Carlo* [3].