Contact Interactions and Future Prospects for High Energy Physics

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Abstract

Data from HERA, LEP and the Tevatron, as well as from low energy experiments are used to constrain the scale of possible electron-quark contact interactions. Combined mass scale limits for specific one-parameter scenarios range from 5.1 to 18 TeV. Upper limits on possible effects to be observed in future HERA, LEP and Tevatron running are estimated.

1. Contact Interactions

Four-fermion contact interactions are an effective theory, which allows us to describe, in the most general way, possible low energy effects coming from "new physics" at much higher energy scales [1, 2, 3]. As strong limits have already been placed on the scalar and tensor terms [3], only the vector $eeqq$ contact interactions are considered in this study. They can be represented as additional term in the Standard Model Lagrangian [3]:

$$L_{CI} = \sum_{i,j=L,R} \eta^{eq}_{ij} (\bar{e}_i \gamma^{\mu} e_i)(\bar{q}_j \gamma_{\mu} q_j)$$

where the sum runs over electron and quark helicities. Couplings η^{eq}_{ij} describing the helicity and flavour structure of contact interactions can be related to the effective mass scale Λ: $\eta = \pm 4\pi/\Lambda^2$. In the presented analysis [4] 30 specific one-parameter CI scenarios are considered, assuming different relations between couplings η^{eq}_{ij}. All one-parameter models assume quark and lepton family universality. For most scenarios also $SU(2)_L \times U(1)_Y$ gauge invariance can be assumed, resulting in additional experimental constraints (see section 2).

The analysis takes also into account multi-parameter models, in which different couplings can vary independently. The most general model assumes that contact interactions couple only electrons to u and d quarks (8 independent couplings). All other couplings (for s, c, b, t, μ, τ) are assumed to vanish. In a model assuming $SU(2)_L \times U(1)_Y$ gauge invariance, the number of free model parameters is reduced from 8 to 7 ($\eta^{eu}_{RL} = \eta^{ed}_{RL}$). In addition the $eeqq$ contact interaction couplings can be related to $\nu\nu qq$ and $e\nu qq'$ couplings [5]. For this model lepton universality ($e=\mu$) and quark family universality ($u=c=t$ and $d=s=b$) are also assumed.

2. Mass scale limits

The global analysis [4] of $eeqq$ contact interactions combines relevant data from different experiments: ZEUS and H1 high-Q^2 NC DIS results; Tevatron data on high-mass Drell-Yan lepton pair production; LEP2 results on the hadronic cross-section $\sigma(e^+e^- \to q\bar{q}(\gamma))$, the heavy quark production ratios R_b and R_c, and the forward-backward asymmetries A^b_{FB}, A^c_{FB}, A^{uds}_{FB}; data from low-energy eN and μN scattering and from atomic parity violation (APV) measurements.

For models assuming $SU(2)_L \times U(1)_Y$ universality, additional constraints come from HERA e^+p CC DIS results, data on νN scattering, unitarity of the CKM matrix and electron-muon universality.

The combined data are consistent with the Standard Model predictions. The mass scale limits Λ^- and Λ^+ obtained from fitting one-parameter models to all available data are summarized in Table 1. For models not assuming $SU(2)_L \times U(1)_Y$ universality (only e/μ NC data used) the mass limits range from 5.1 to 11.7 TeV. With $SU(2)_L \times U(1)_Y$ universality (using also νN and CC data) the limits extend up to about 18 TeV.

For multi-parameter models, taking into account possible correlations between couplings, any contact interaction with a mass scale below 2.1 TeV (3.1 TeV when SU(2) universality is assumed) is excluded at 95% CL.

Table 1. 95% CL limits on the effective mass scales for different one-parameter contact interaction models. Results based on the combined electron/muon NC data (analysis not assuming SU(2) invariance) are compared to those corresponding to all available data (assuming SU(2) universality).

Model	95% CL mass scale limits [TeV]			
	e/μ NC data		All data	
	Λ^-	Λ^+	Λ^-	Λ^+
VV	9.8	10.7	9.6	11.4
AA	10.5	10.1	9.9	11.1
VA	6.6	6.2	6.3	8.0
X1	8.7	8.1	8.1	9.5
X2	8.2	8.4	7.8	9.6
X3	9.9	10.2	9.5	11.1
X4	5.7	5.2	6.0	5.4
X5	5.9	6.4	6.2	6.4
X6	6.2	5.8	6.2	5.8
U1	6.4	7.7	7.9	17.0
U2	6.9	9.1		
U3	8.5	11.7	8.6	18.2
U4	5.1	5.5		
U5	6.4	8.8	7.1	8.8
U6	7.0	5.6		

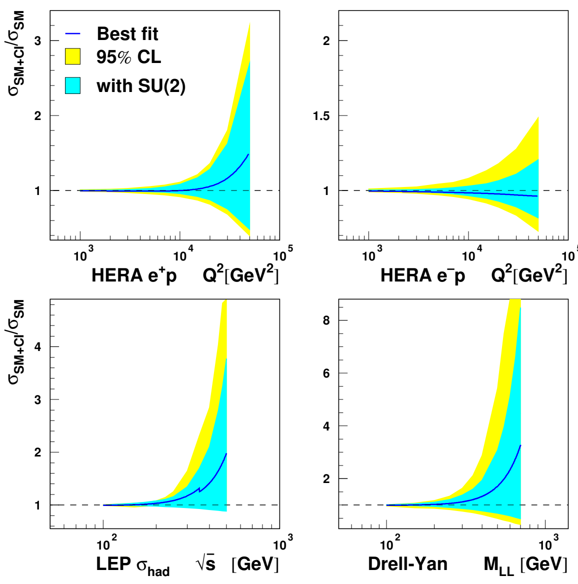

Figure 1. The 95% CL limit band on the ratio of predicted to the Standard Model cross-section for e^+p and e^-p NC DIS scattering at HERA, total hadronic cross-section at LEP/NLC and Drell-Yan lepton pair production at the Tevatron.

3. Future prospects

Probability function for the possible cross-section deviations from the Standard Model predictions is calculated as the weighted average over all contributing CI coupling combinations [4]. The results for high-Q^2 e^+p and e^-p NC DIS at HERA, for total hadronic cross-section at e^+e^- collisions and for Drell-Yan lepton pair production at the Tevatron are presented in Figure 1. The 95% CL limit bands on the ratio of predicted and the Standard Model cross-sections are shown for the general model and for the SU(2) model with family universality.

The allowed increase in the integrated e^+p NC DIS cross-section for $Q^2 > 15{,}000$ GeV^2 is about 40% for the general model and about 30% for the SU(2) model. In order to reach the corresponding level of statistical precision the HERA experiments would have to collect e^+p integrated luminosities of the order of 100-200 pb^{-1}.

Constraints on possible deviations from the Standard Model predictions are much stronger in the case of e^-p NC DIS. For the general model deviations larger than about 20% are excluded for $Q^2 > 15{,}000$ GeV^2 cross-section, whereas for the SU(2) model with family universality the limit goes down to about 7%. In such a case it would be very hard to detect contact interactions in future HERA e^-p running.

For the hadronic cross-section at LEP, for $\sqrt{s} \sim 200$ GeV, the possible deviations from the Standard Model are only about 8%. Significant cross-section deviations will be possible in the Next Linear Collider (NLC), for $\sqrt{s} > 300$ GeV. The largest cross-section deviations from the Standard Model predictions are still allowed at the Tevatron. For Drell-Yan lepton pair production, deviations of the cross-section at M_{ll}=500 GeV up to a factor of 5 are still not excluded.

References

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