

Search for contact interactions in inclusive ep scattering at HERA

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The high-precision HERA data are used to search for Beyond the Standard Model contributions to electron-quark scattering in the framework of $eeqq$ contact interactions (CI). Combined measurements of the inclusive deep inelastic cross sections in neutral and charged current ep scattering are considered, corresponding to a luminosity of around 1 fb^{-1} . The analysis of the inclusive ep data is based on the simultaneous fits of parton distribution functions together with contributions of CI couplings to ep scattering. Results are presented for different general CI scenarios and heavy leptoquarks with expected 95% C.L. limits on the CI mass scales in the 10 TeV range.

*The 39th International Conference on High Energy Physics (ICHEP2018)
4-11 July, 2018
Seoul, Korea*

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1. Introduction

The ZEUS collaboration has used the HERA combined measurement of inclusive cross sections [1] to set limits on possible deviations from the Standard Model due to a finite radius of the quarks [2]. A new approach to the beyond the Standard Model analysis was used, based on the simultaneous fits of parton distribution functions together with contributions of “new physics” processes. This is the only method to properly take into account the possibility that the PDF set may already have been biased by partially or totally absorbing previously unrecognised BSM contributions. The details of this procedure are described in [2]. In the analysis presented here, the new procedure to set limits on the BSM model contributions is applied to other CI scenarios. This work supersedes the results presented in [3] and extends the analysis presented there to more scenarios.

2. Models for new physics

Four-fermion contact interactions (CI) represent an effective theory which describes low-energy effects due to physics at much higher energy scales. The CI approach is not renormalizable and is only valid in the low-energy limit. Vector contact interaction currents considered here are represented by additional terms in the Standard Model Lagrangian:

$$\mathcal{L}_{CI} = \sum_{\substack{i,j=L,R \\ q=u,d,s,c,b}} \eta_{ij}^{eq} (\bar{e}_i \gamma^\mu e_i) (\bar{q}_j \gamma_\mu q_j), \quad (2.1)$$

where the sum runs over electron and quark helicities and quark flavors. The couplings η_{ij}^{eq} describe the helicity and flavor structure of contact interactions.

For the general contact interaction scenarios considered here, it was assumed that all up-type quarks have the same contact-interaction couplings, and a similar assumption was made for down-type quarks, leading to eight independent couplings, η_{ij}^{eq} , with $q = u, d$. A set of one-parameter scenarios were defined by eight coefficients, ε_{ij}^{eq} , each of which may take the values ± 1 or zero, see Table 1, and the coupling strength η . The couplings are given by the formula:

$$\eta_{ij}^{eq} = \varepsilon_{ij}^{eq} \eta = \varepsilon_{ij}^{eq} \frac{4\pi}{\Lambda^2}.$$

Leptoquarks (LQ) appear in certain extensions of the SM that connect leptons and quarks; they carry both lepton and baryon numbers and have spin 0 or 1. According to the general classification proposed by Buchmüller, Rückl and Wyler [4], there are 14 possible LQ states: seven scalar and seven vector. In the limit of heavy LQs ($M_{LQ} \gg \sqrt{s}$), the effect of s - and t -channel LQ exchange is equivalent to a vector-type $eeqq$ contact interaction¹. The effective LQ coupling, η_{LQ} , is given by the square of the ratio of the leptoquark Yukawa coupling, λ_{LQ} , to the leptoquark mass, M_{LQ} , and the contact-interaction couplings of the Lagrangian (2.1), η_{ij}^{eq} , can be then written as:

$$\eta_{ij}^{eq} = a_{ij}^{eq} \cdot \eta_{LQ} = a_{ij}^{eq} \left(\frac{\lambda_{LQ}}{M_{LQ}} \right)^2,$$

where the coefficients a_{ij}^{eq} depend on the LQ species and are twice as large for vector as for scalar leptoquarks.

¹For the invariant mass range accessible at HERA, $\sqrt{s} \sim 300$ GeV, heavy LQ approximation is applicable for $M_{LQ} > 400$ GeV.

HERA $e^\pm p$ 1994-2007 data

Coupling structure Model $[\epsilon_{LL}, \epsilon_{LR}, \epsilon_{RL}, \epsilon_{RR}]$		95% C.L. limits (TeV)				p_{SM} (%)
		Measured		Expected		
		Λ^-	Λ^+	Λ^-	Λ^+	
LL	[+1, 0, 0, 0]	18.9	4.5	5.9	6.3	6.6
RR	[0, 0, 0, +1]	27.2	4.4	5.7	6.1	5.5
LR	[0, +1, 0, 0]	5.0	7.1	5.7	6.3	34
RL	[0, 0, +1, 0]	5.4	6.3	5.6	6.5	41
VV	[+1, +1, +1, +1]	14.7	9.7	11.2	11.4	26
AA	[+1, -1, -1, +1]	-	5.0 - 11.1	7.9	7.8	0.6
VA	[+1, -1, +1, -1]	3.76	-	4.2	4.2	5.8
		-	3.6 - 10.2			2.8
X1	[+1, -1, 0, 0]	-	3.5 - 6.8	5.4	5.5	0.4
X2	[+1, 0, +1, 0]	10.1	6.9	7.8	8.3	24
X3	[+1, 0, 0, +1]	24.4	6.3	8.3	8.7	6.7
X4	[0, +1, +1, 0]	7.4	9.4	8.0	8.6	38
X5	[0, +1, 0, +1]	10.1	6.9	7.7	7.7	27
X6	[0, 0, +1, -1]	3.4 - 6.0	-	5.3	5.5	0.3

Table 1: Relations between couplings $[\epsilon_{LL}, \epsilon_{LR}, \epsilon_{RL}, \epsilon_{RR}]$ for the compositeness models and the upper 95% C.L. limits on the compositeness scale, Λ , corresponding to the central 90% C.L. intervals on the CI coupling obtained from the ZEUS analysis of the HERA inclusive data. Also shown are the expected limits, and the probability of SM to result in the best-fit coupling value greater than that observed for the data, p_{SM} . Λ^+ and Λ^- limits correspond to the scenarios with positive and negative coupling values, respectively. The same coupling structure applies to all quarks. For AA, VA, X1 and X6 models, ranges of compositeness scale values corresponding to the central 90% C.L. coupling interval are given.

3. Results

The 95% C.L. limits on the compositeness scale Λ for different CI models are summarized in Table 1. For most of the considered CI scenarios improved description of the HERA data is obtained either for positive or for negative coupling values. Only in case of the VA model two minima are observed in the χ^2 dependence on coupling value, one for positive and one for negative couplings. As different coupling signs correspond to distinct scenarios, we calculate two confidence intervals for the VA model, separately for negative and positive couplings.

The limits on the ratio of the Yukawa coupling to the leptoquark mass, λ_{LQ}/M_{LQ} , corresponding to the central 90% C.L. coupling intervals, are summarized in Table 2 together with the coefficients a_{ij}^{eq} describing the CI coupling structure. For two models, S_1^L and V_\circ^R , significant improvement in the description of HERA data can be obtained and probability of reproducing the fit result with Standard Model replicas, p_{SM} , is below 5%, which means that $\eta_{LQ} = 0$ (corresponding to the Standard Model) is outside the central 90% C.L. interval. For both models the range of λ_{LQ}/M_{LQ} values is given, corresponding to the central 90% C.L. η_{LQ} interval. Also for \tilde{S}_\circ^R and V_\circ^L models ²

²Please note that \tilde{S}_\circ^R is related to V_\circ^R model, corresponding to the same CI coupling structure, but with different sign.

HERA $e^\pm p$ 1994-2007 data

Model	Coupling Structure	λ_{LQ}/M_{LQ} (TeV^{-1})		p_{SM} (%)
		95% C.L. limits		
		Measured	Expected	
S_\circ^L	$a_{LL}^{eu} = +\frac{1}{2}$	0.27	0.56	8.4
S_\circ^R	$a_{RR}^{eu} = +\frac{1}{2}$	1.02	0.72	5.9
\tilde{S}_\circ^R	$a_{RR}^{ed} = +\frac{1}{2}$	-	1.71	1.8
$S_{1/2}^L$	$a_{LR}^{eu} = -\frac{1}{2}$	0.80	0.76	42
$S_{1/2}^R$	$a_{RL}^{ed} = a_{RL}^{eu} = -\frac{1}{2}$	0.99	0.92	37
$\tilde{S}_{1/2}^L$	$a_{LR}^{ed} = -\frac{1}{2}$	1.51	1.39	41
S_1^L	$a_{LL}^{ed} = +1, a_{LL}^{eu} = +\frac{1}{2}$	0.78-1.16	0.62	< 0.01
V_\circ^L	$a_{LL}^{ed} = -1$	-	0.44	0.4
V_\circ^R	$a_{RR}^{ed} = -1$	0.56-1.44	0.99	1.8
\tilde{V}_\circ^R	$a_{RR}^{eu} = -1$	0.16	0.53	6.3
$V_{1/2}^L$	$a_{LR}^{ed} = +1$	1.11	1.29	38
$V_{1/2}^R$	$a_{RL}^{ed} = a_{RL}^{eu} = +1$	0.53	0.57	39
$\tilde{V}_{1/2}^L$	$a_{LR}^{eu} = +1$	0.47	0.49	42
V_1^L	$a_{LL}^{ed} = -1, a_{LL}^{eu} = -2$	0.39	0.35	31

Table 2: Coefficients a_{ij}^{eq} defining the effective leptoquark couplings in the contact-interaction limit, $M_{LQ} \gg \sqrt{s}$, limits on the Yukawa coupling to the leptoquark mass ratio, λ_{LQ}/M_{LQ} , corresponding to the central 90% C.L. intervals on the LQ coupling obtained from the presented analysis, and the probability of SM to result in the best-fit coupling value greater than that observed for the data, p_{SM} , for different models of scalar (upper part of the table) and vector (lower part) leptoquarks. For \tilde{S}_\circ^R and V_\circ^L models limit values are not given as the confidence intervals cover unphysical (negative) coupling values only. For S_1^L and V_\circ^R models ranges of values corresponding to the central 90% C.L. η_{LQ} intervals is given.

probability below 5% is obtained, but the confidence interval covers unphysical (negative) coupling values only so limit values are not given.

References

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