LEPTOQUARKS AND CONTACT INTERACTIONS FROM A GLOBAL ANALYSIS

A. F. ŻARNECKI
Institute of Experimental Physics, Warsaw University,
Hoża 69, 00-681 Warszawa, Poland
E-mail: zarnecki@fuw.edu.pl

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. Some models are found to describe the existing experimental data much better than the Standard Model. The possibility of scalar or vector leptoquark contribution is studied using the Buchmüller-Rückl-Wyler effective model. Increase in the global probability observed for scenarios including S_1 or $\tilde{V}_0$ leptoquark production/exchange corresponds to more than a 3σ effect. Assuming that a real leptoquark signal is observed, calculated is an allowed region in the $\lambda - M$ plane.

1 Introduction

In the global contact interaction analysis presented last year[1,2] data from both collider and low energy experiments were used to constrain the mass scale of possible new electron-quark contact interactions. No indication for possible deviations from the Standard Model predictions was found at that time.

Presented in this paper are results from the updated analysis, which includes new experimental data. Most important are the new results from the atomic parity violation (APV) measurements in cesium.[3] After the theoretical uncertainties have been significantly reduced, the measured value of the cesium weak charge is now 2.5σ away from the Standard Model prediction. Also the new hadronic cross-section measurements at LEP2, for $\sqrt{s}$=192–202 GeV, are on average about 2.5% above the predictions.[4] This is only about 2.3σ effect, but has an important influence on the analysis.

2 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. Vector *eeqq* contact interactions can be represented as an additional term in the Standard Model Lagrangian:

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

Table 1: Mass scale limits for different contact interaction models.

Coupling	95% CL exclusion limit TeV							
	General approach				One-parameter models			
	1^{st} gen.		3 gen.		1^{st} gen.		3 gen.	
	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+
η^{ed}_{LL}	5.3	4.4	6.7	7.2	28.6	8.4	30.5	8.9
η^{ed}_{LR}	2.4	3.0	3.6	3.8	19.2	7.6	19.5	7.5
η^{ed}_{RL}	3.5	3.7	4.3	4.2				
η^{ed}_{RR}	2.8	3.5	4.0	5.9	8.0	18.1	8.8	17.4
η^{eu}_{LL}	4.9	4.6	6.0	8.2	12.5	18.7	11.8	21.4
η^{eu}_{LR}	4.3	3.4	5.0	4.8	17.4	7.5	17.3	7.8
η^{eu}_{RL}	3.5	3.7	4.3	4.2				
η^{eu}_{RR}	4.0	3.8	4.9	4.7	6.9	19.7	7.0	21.2
VV					6.5	11.1	8.2	15.1
AA					5.7	6.3	10.5	11.7
VA					4.5	4.6	5.7	7.8

where the sum runs over electron and quark helicities. Couplings η^{eq}_{ij} describe the helicity and flavor structure of contact interactions. Non vanishing couplings can be related to the effective mass scale Λ: $\eta = \pm 4\pi/\Lambda^2$.

In the presented analysis different CI scenarios are considered. The so called first-generation models assume that contact interactions couple only electrons to u and d quarks. In the three-generation model lepton universality (e=μ) and quark family universality (u=c=t and d=s=b) is assumed. Assuming $SU(2)_L \times U(1)_Y$ gauge invariance, there are 7 independent couplings (η^{eu}_{RL}=η^{ed}_{RL}). In the most general approach different couplings are allowed to vary independently, whereas in the so called one-parameter scenarios only one coupling (or given combination of couplings [1]) is allowed to be non-zero.

The analysis combines relevant data from HERA, Tevatron and LEP2, results from low-energy eN, μN and νN scattering experiments, constraints on the CKM matrix unitarity and electron-muon universality, and the atomic parity violation measurements.[5] The global probability function $\mathcal{P}(\eta)$ describes the probability that the data come from the model described by the coupling η. It is defined in such a way that the Standard Model probability $\mathcal{P}_{SM} \equiv 1$.

The best description of all data is obtained for three-generation model with $e_L d_L$ type coupling. Increase in the global probability $\mathcal{P}(\eta)$ corresponds to 3.8σ deviation from the Standard Model. The mass scale resulting in the best description of the data is $\Lambda^{ed}_{LL} = 13.2 \pm 1.8$ TeV ($10.3 < \Lambda^{ed}_{LL} < 21.9$ TeV on 95% CL). Mass scale limits $\Lambda^{\pm}$, corresponding to the global probability equal to 5% of the Standard Model probability ($\mathcal{P}(\Lambda^{\pm}) = 0.05\ \mathcal{P}_{SM}$) are presented in Table 1.

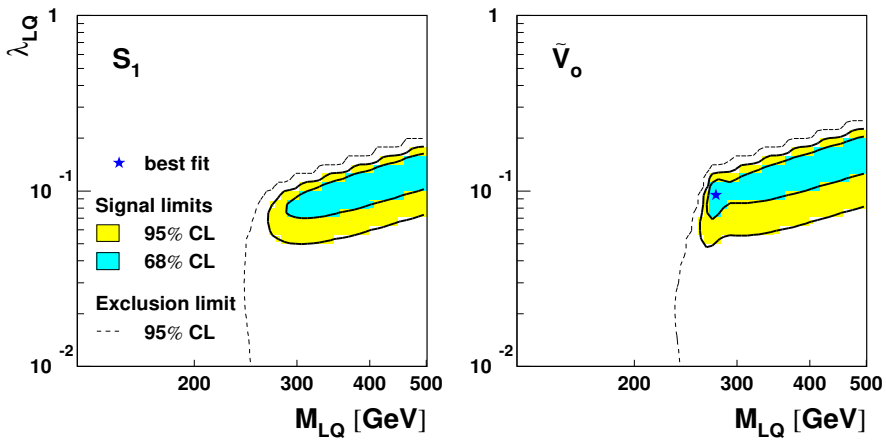

Figure 1: Signal limits on 68% and 95% CL for S_1 and $\tilde{V}_o$ leptoquarks. Dashed lines indicate the 95% CL exclusion limits. For $\tilde{V}_o$ model a star indicates the best fit parameters. For S_1 model the best fit is obtained in the contact interaction limit $M_{LQ} \to \infty$.

3 Leptoquarks

In a recent paper[5] available data were also used to constrain Yukawa couplings and masses for scalar and vector leptoquarks using the Buchmüller-Rückl-Wyler effective model.[6] In the limit of very high leptoquark masses, constraints on the coupling to the mass ratio were studied using the contact interaction approximation.[7] The best description of the data is obtained for the S_1 and the $\tilde{V}_o$ leptoquarks[a] with $\lambda_{LQ}/M_{LQ} \sim 0.3$ TeV^{-1}. Increase in the global probability corresponds to more than 3σ deviation from the Standard Model.

Constraints on the leptoquark couplings and masses were studied also for finite leptoquark masses, with mass effects correctly taken into account. Shown in Figure 1 are the 95% exclusion limits as well as the 68% and 95% CL signal limits for S_1 and $\tilde{V}_o$ leptoquarks. The best description of the data for the $\tilde{V}_o$ model is obtained for $M_{LQ} = 276 \pm 7$ GeV and $\lambda_{LQ} = 0.095 \pm 0.015$.

Table 2 summarizes the results of the global leptoquark analysis.[5] For all models the 95% CL exclusion limits are given both for λ_{LQ}/M_{LQ} (upper limit) and for M_{LQ} (lower limit). For models which describe the existing experimental data better than the Standard Model the maximum value of the global probability $\mathcal{P}_{max}$ and the corresponding coupling to the mass ratio $(\lambda_{LQ}/M_{LQ})_{max}$ are included. 95% CL signal limits for λ_{LQ}/M_{LQ} and M_{LQ}, corresponding to $\mathcal{P}(\lambda_{LQ}, M_{LQ}) > 0.05\ \mathcal{P}_{max}$, are given for models with $\mathcal{P}_{max} > 20$.

[a] The nomenclature follows the so-called Aachen notation.[8]

Table 2: Results of the global leptoquark analysis: the 95% CL exclusion limits on the leptoquark coupling to the mass ratio λ_{LQ}/M_{LQ} (upper limit) and the leptoquark mass M_{LQ} (lower limit), the coupling to the mass ratio $(\lambda_{LQ}/M_{LQ})_{max}$ resulting in the best description of the experimental data and the corresponding model probability $\mathcal{P}_{max}$, and the 95% CL signal limits on λ_{LQ}/M_{LQ} and M_{LQ}, for models with $\mathcal{P}_{max} > 20$.

Model	95% CL excl. limits		best description		95% CL signal limits	
	$\frac{\lambda_{LQ}}{M_{LQ}}$ TeV^{-1}	M_{LQ} GeV	$\left(\frac{\lambda_{LQ}}{M_{LQ}}\right)_{max}$ TeV^{-1}	$\mathcal{P}_{max}$	$\frac{\lambda_{LQ}}{M_{LQ}}$ TeV^{-1}	M_{LQ} GeV
$S_\circ^L$	0.27	213				
$S_\circ^R$	0.25	242				
$\tilde{S}_\circ$	0.28	242				
$S_{1/2}^L$	0.29	229				
$S_{1/2}^R$	0.49	245	0.32 ± 0.06	35.8	0.09–0.44	258
$\tilde{S}_{1/2}$	0.26	233				
S_1	0.41	245	0.28 ± 0.04	367.	0.15–0.36	267
$V_\circ^L$	0.12	230				
$V_\circ^R$	0.44	231	0.28 ± 0.07	11.7		
$\tilde{V}_\circ$	0.52	235	0.34 ± 0.06	122.	0.16–0.46	259
$V_{1/2}^L$	0.47	235	0.30 ± 0.06	31.7	0.08–0.42	254
$V_{1/2}^R$	0.13	262				
$\tilde{V}_{1/2}$	0.47	244	0.30 ± 0.07	14.8		
V_1	0.14	254				

Acknowledgments

This work has been partially supported by the Polish State Committee for Scientific Research (grant No. 2 P03B 035 17).

References

1. A.F. Żarnecki *Euro. Phys. J.* C **11**, 539 (1999).
2. A.F. Żarnecki *Nucl. Phys. Proc. Suppl.* **79**, 158 (1999).
3. S.C. Bennett and C.E. Wieman, *Phys. Rev. Lett.* **82**, 2484 (1999).
4. LEP Electroweak Working Group, C.Geweniger *et al*, LEP2FF/00-01.
5. A.F. Żarnecki hep-ph/0003271.
6. W.Buchmüller, R.Rückl and D.Wyler, *Phys. Lett.* B **191**, 442 (1987); Erratum: *Phys. Lett.* B **448**, 320 (1999).
7. J.Kalinowski *et al*, *Z. Phys.* C **74**, 595 (1997).
8. A.Djouadi, T.Köhler, M.Spira, J.Tutas, *Z. Phys.* C **46**, 679 (1990).