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SEARCHES FOR LEPTOQUARKS AND CONTACT INTERACTIONS AT HERA

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Results from leptoquark and contact interaction searches at HERA, based on the analysis of DIS event samples $e^{\pm}p \to e^{\pm}(\nu)X$, are reported. The data were collected by the H1 and ZEUS experiments from 1994 to 2000, at c.m. energies of 300 and 318 GeV, and correspond to a total integrated luminosity ~ 120 pb^{-1} for each experiment. No evidence for any signal of physics beyond Standard Model was found. Limits were derived on the leptoquark Yukawa coupling λ as a function of the leptoquark mass, the effective mass scale in $eeqq$ contact interactions, the effective Planck mass scale in models with large extra dimensions, and the effective quark charge radius. The results are compared to those obtained in direct and indirect searches at other colliders.

1 Leptoquarks

The ep collider HERA is an unique place to search for new particles coupling to a lepton-quark pair. Such particles, called leptoquarks (LQ), appear in many extensions of the Standard Model (SM). They carry both colour and a fractional electric charge as well as lepton and baryon number. In the general classification of leptoquark states proposed by Buchmüller, Rückl and Wyler (BRW) [1] there are 7 scalar and 7 vector leptoquarks. All of them can couple to an eq pair and can contribute to NC DIS events. In addition 4 states couple to both eq and νq and so can contribute to CC DIS.

Results of leptoquarks searches at HERA, based on the event samples collected by H1 and ZEUS experiments, were presented. The data was collected from 1994 to 2000, at c.m. energies, $\sqrt{s}$, of 300 and 318 GeV and correspond to a total integrated luminosity ~ 120 pb^{-1} per experiment. For masses up to $\sqrt{s}$, resonant LQ production dominates the cross section, if the LQ is produced from a valence quark (production of F=2 leptoquarks in e^-p scattering and F=0 in the e^+p case), yielding peaks in the lepton-jet invariant mass spectrum for the $e^{\pm}p \to e^{\pm}(\nu)X$ reactions. The u-channel exchange and interference terms become important for large leptoquark masses, $m_{LQ} > \sqrt{s}$, and can result in deviations of high-x NC and CC DIS cross sections from the SM predictions. Both, an increase or decrease of the cross section is possible, depending on the sign of the interference term.

Figure 1 shows the exclusion limits in the mass-coupling plane for a scalar LQ species with fermion numbers F=0(S_0^L) and F=2 ($S_{1/2}^R$), as obtained by H1 and ZEUS from analysis of NC and CC DIS events. The areas above the curves are excluded. H1 and ZEUS results are compared with limits from other experiments. The coupling independent LQ mass limits come from $p\bar{p}$ collision at the Tevatron [2],

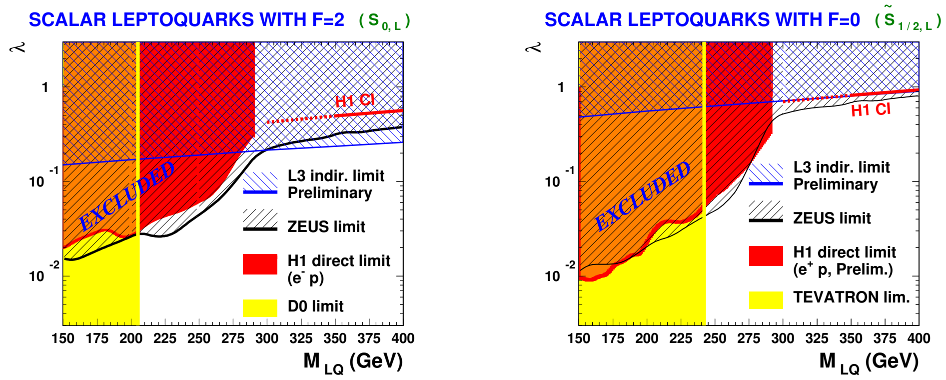

Figure 1. Comparison of excluded regions in the mass - coupling plane for the S_0^L and $S_{1/2}^R$ leptoquarks from HERA, Tevatron and LEP. Constraints on LQs with masses above $\sqrt{s}$ obtained from H1 Contact Interaction analysis, are shown as a dashed line in the rightmost part of each plot.

where leptoquark pairs can be produced via strong interactions ($p\bar{p} \to LQ\bar{LQ}X$). Indirect limits on leptoquarks couplings from LEP [3] have been obtained from limits on t-channel and u-channel contribution to quark-pair production ($e^+e^- \to q\bar{q}$). The leptoquark limits at HERA are complementary to Tevatron and LEP limits.

Figure 2 shows the Yukawa coupling λ limits as a function of the branching ratios (β) for $LQ \to eq$ (β_{eq}) and $LQ \to \nu q$, ($\beta_{\nu q}$) and as a function of the resonance mass. The limits were obtained for four scalar resonant states listed in [4] and for $\lambda = 0.1$ and for $\lambda = 0.3$, which corresponds to the electroweak (EW) coupling ($\lambda \approx \sqrt{4\pi\alpha_{EW}}$). The equivalent plots for vector resonant states are shown in [4]. For the e^+u and e^-d resonances νq decays are forbidden by charge conservation. The e^-u and e^+d resonances can decay to either eq or νq. The eq+νq limits, which assume $\beta_{\nu q} + \beta_{eq} = 1$, are largely independent of the branching ratio, and are typically in excess of 285 GeV for the EW coupling. The limits obtained using only the eq (or the νq) data set allow for decay modes other than eq and νq, so the eq and νq limits are applicable to a wider range of physics models than the combined $eq + \nu q$ results. Similar limits have been presented by the H1 collaboration for scalar e^-d and e^-u resonances [5]. For comparison, the limits on scalar resonances reported by the DØ experiment [6] at the Tevatron are also shown in Fig. 2.

2 Contact Interactions

Four-fermion $eeqq$ contact interactions (CI) are an effective theory, which allows us to describe, in the most general way, possible low energy effects in ep DIS coming from physics beyond Standard Model at much higher energy scales. Different CI scenarios are considered with different helicity and flavor structure. Contact interaction couplings, η, can be related to the effective mass scale Λ: $\eta = \pm 4\pi/\Lambda^2$.

No significant deviation of the HERA data from the SM prediction using the CTEQ5D parameterization of the proton PDF was observed. Therefore, limits on

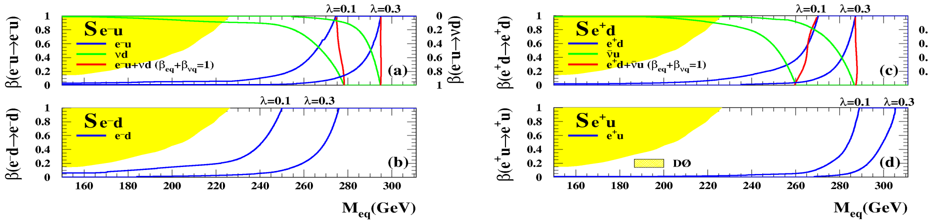

Figure 2. The constant-λ limits as a function of the branching ratios into eq and νq (shown on the left and right axes, respectively), and of the resonance mass (x axes), for the scalar resonant. The dotted line corresponds to limits set with only the $ep \to \nu X$ data set, the dashed line with only the $ep \to eX$ data set; the solid black line is the limit set using both data sets, assuming $\beta_{eq} + \beta_{\nu q} = 1$. For each limit curve, the area to the left of the curve is the excluded region. Results for the resonant states are shown for constant limit of $\lambda = 0.1$ and $\lambda = 0.3$. The shaded area in each plot shows the area excluded by the DØ experiment.

the mass scale parameters of the models are presented. The 95% C.L. lower limits on the compositeness scale Λ obtained by the H1 and ZEUS collaborations are presented in Table 1 and compared with limits from the Tevatron [7,8] and the LEP [9,10,11] experiments (where only the results from $e^+e^- \to q\bar{q}$ channel are quoted). HERA limits range from 1.6 TeV for the LL model to 6.2 TeV for the VV model. The results on the compositeness scale Λ from HERA are comparable to those obtained by other experiments, where they exist. For many models the HERA data set the only existing limits.

3 Large Extra Dimensions

In models with large extra dimensions, the strengths of the gravitational and electroweak interactions can become comparable at high energies. After summing the effects of graviton excitations in the extra dimensions, the graviton-exchange contribution to $eq \to eq$ scattering can be described as a contact interaction with an effective coupling strength of [12] $\eta_G = \lambda/M_S^4$, where M_S is an ultraviolet cutoff scale, expected to be of the order of the Planck scale in $4+n$ dimensions M_D, and the coupling λ is of order of unity. Since the sign of λ is not known *a priori*, both values $\lambda = \pm 1$ are considered.

95% C.L. lower limits on the mass scale parameter obtained by the H1 collaboration are: $M_S > 0.82$ TeV for $\lambda = +1$ and $M_S > 0.78$ TeV for $\lambda = -1$ [13]. In Figure 3 (left), effects of the graviton exchange on the Q^2 distribution of NC DIS events, corresponding to these limits, are compared with H1 e^+p and e^-p data. The limits are similar to those obtained by the ZEUS collaboration: $M_S > 0.78$ TeV for $\lambda = +1$ and $M_S > 0.79$ TeV for $\lambda = -1$ [14].

4 Quark Form factor

Possible quark substructure could also manifest itself as a finite spatial distribution of the quark charge. In the classical form factor approximation, $Q^2 \ll 1/R_q^2$, the SM predictions for the DIS cross sections are modified by a factor $(1 - \frac{1}{6}R_q^2 Q^2)^2$,

	ZEUS		H1		DØ		CDF		ALEPH		L3		OPAL	
Model	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+
LL	1.7	2.7	1.6	2.8	4.2	3.3	3.7	2.5	6.2	5.4	2.8	4.2	3.1	5.5
LR	2.4	3.6	1.9	3.3	3.6	3.4	3.3	2.8	3.3	3.0	3.5	3.3	4.4	3.8
RL	2.7	3.5	2.0	3.3	3.7	3.3	3.2	2.9	4.0	2.4	4.6	2.5	6.4	2.7
RR	1.8	2.7	2.2	2.8	4.0	3.3	3.6	2.6	4.4	3.9	3.8	3.1	4.9	3.5
VV	6.2	5.4	5.5	5.3	6.1	4.9	5.2	3.5	7.1	6.4	5.5	4.2	7.2	4.7
AA	4.7	4.4	4.1	2.5	5.5	4.7	4.8	3.8	7.9	7.2	3.8	6.1	4.2	8.1
VA	3.3	3.2	3.0	2.9										
X1	3.6	2.6			4.5	3.9								
X2	3.9	4.0												
X3	3.7	3.6	3.9	3.7	5.1	4.2			7.4	6.7	3.7	4.4	4.4	5.4
X4	5.1	4.8	4.4	4.4	4.4	3.9			4.5	2.9	5.2	3.1	7.1	3.4
X5	4.0	4.0												
X6	2.5	3.5			4.3	4.0								
U1	3.8	3.6												
U2	5.0	4.2												
U3	5.0	4.1									5.2	9.2		
U4	5.8	4.8									3.2	2.3		
U5	5.2	4.3												
U6	2.8	3.4												

Table 1. The 95% C.L limits on the compositeness scale, Λ, resulting from the H1 and ZEUS analysis. Each row of the table represents two scenarios corresponding to $\eta > 0$ (Λ^+) and $\eta < 0$ (Λ^-). The same coupling structure applies to d and u quarks, except for the models U1 to U6, for which the couplings for the d quarks are zero. Also shown are results obtained by the $p\bar{p}$ collider experiments DØ and CDF, and the LEP experiments ALEPH, L3 and OPAL. For the LEP experiments, limits derived from the channel $e^+e^- \to q\bar{q}$ are quoted.

where R_q is the root-mean-square radii of the electroweak charge of the quark, and electron is assumed to be point–like.

Comparable 95% C.L. upper limit on the effective quark-charge radius were obtained by the H1 collaboration ($R_q < 1.0 \cdot 10^{-16}$ cm) and the ZEUS collaboration ($R_q < 0.85 \cdot 10^{-16}$ cm). Cross section deviations corresponding to the ZEUS 95% C.L. exclusion limits for R_q, are compared with the ZEUS data in Figure 3 (right).

5 Conclusion

Results from leptoquark and contact interactions searches at HERA using the reaction $e^{\pm}p \to e^{\pm}(\nu)X$, are reported. No evidence for any signal of physics beyond Standard Model was found. Limits were derived on the leptoquarks Yukawa coupling λ as a function of the leptoquark mass. For $\lambda = 0.3$, corresponding to the EW coupling, LQ masses up to 398 GeV are excluded. Limits on the effective mass scale in $eeqq$ Contact Interactions range from 1.6 to 6.2 TeV. For the effective Planck scale in models with large extra dimensions, limits of about 0.8 TeV were obtained. The results from H1 and ZEUS experiments at HERA are comparable

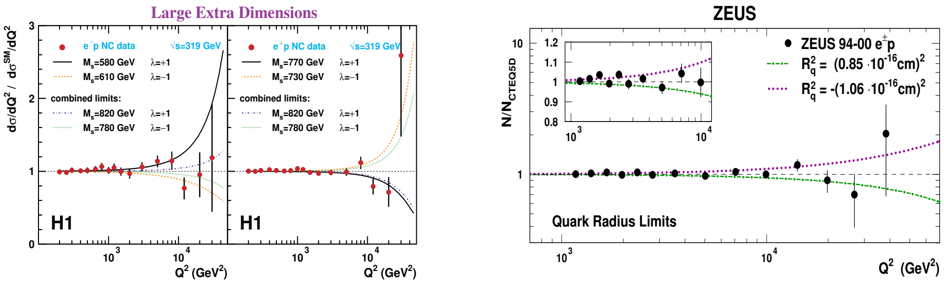

Figure 3. Combined 1994-2000 ZEUS data compared with 95% C.L. exclusion limits for the effective mean-square radius of the electroweak charge of the quark (right plot). H1 e^+p and e^-p data compared with 95% C.L. exclusion limits for the effective Planck mass scale in models with large extra dimensions, for positive (M_S^+) and negative (M_S^-) couplings (left plot). Results are normalized to the Standard Model expectations.

to those obtained in direct and indirect searches at other colliders.

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