Eur Phys J C **33**, s01, s755–s757 (2004)
Digital Object Identifier (DOI) 10.1140/epjcd/s2003-03-814-8

EPJ C direct
electronic only

Search for leptoquark production and lepton flavour violation

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Received: 1 November 2003 / Accepted: 11 November 2003 /
Published Online: 2 December 2003 –

Abstract. Direct and indirect leptoquark searches performed at LEP, HERA and the Tevatron are reviewed. No signal of leptoquark production or exchange is observed. Complementary limits are obtained from different processes and different experiments.

PACS. 13.85.Rm Limits on production of particles

1 Introduction

Leptoquarks are hypothetical bosons which couple to a lepton and a quark via a Yukawa coupling (denoted λ). Because they carry color and electroweak charge, they could be pair produced in strong or electroweak interactions, at $p\bar{p}$ or e^+e^- colliders. They could also be singly produced in a lepton-quark collision, via the Yukawa coupling.

The model of Buchmüller, Rückl and Wyler[1] (BRW), in which leptoquarks couple to a single generation of SM fermions via chiral Yukawa couplings which are invariant under $SU(3)\times SU(2)\times U(1)$, is commonly used to classify possible leptoquark species. In the BRW model, baryon and lepton numbers (B and L) are conserved; there exist fourteen possible leptoquark species characterized by the chirality of the coupling, the spin ($J = 0$ or 1), the weak isospin (T =0, 1/2, or 1), and the fermion number, $F = 3B+L = 0$ or 2. In this paper leptoquark states are named according to the so-called Aachen notation [2].

2 Search for leptoquark pair-production

Leptoquark pair production in $p\bar{p}$ collisions at the Tevatron is dominated by the gg fusion mechanism. The cross section does not depend on the leptoquark isospin, charge or Yukawa coupling. Therefore general limits on the scalar and vector leptoquark masses can be set, depending only on the leptoquark generation and assumed branching fractions. Both CDF and D0 collaborations presented new results from the leptoquark searches based on the data collected in Tevatron Run II [3,4]. Although the integrated luminosities of the considered data samples ($41pb^{-1}$ for D0 and about $74pb^{-1}$ for CDF) are much smaller, the obtained mass limits are comparable to Run I results [5,6,7,8], mainly due to the increase in the leptoquark production cross section for the higher Run II center-of-mass energy by about 30–40%. New limits for first generation scalar leptoquark masses range from 107 GeV for $\beta = BR(LQ \to l^\pm q) = 0$ to 230 GeV for $\beta = 1$ [3]. For second generation, a limit on scalar leptoquark mass of 157 GeV ($\beta = 1$) is obtained [4].

Leptoquark pair production at LEP is dominated by the s-channel γ and Z° exchange contributions. The production cross section is not sensitive to the Yukawa coupling, but does depend on the leptoquark isospin and charge. New limits on the leptoquark masses from the search for the leptoquark pair production at LEP were presented by OPAL [9]. The limits range from 89 to 102 GeV depending on the leptoquark generation, leptoquark type and the assumed branching fractions.

3 Search for single leptoquark production

Single production of first-generation leptoquarks in $e^\pm\gamma$ interactions at LEP was studied by OPAL [10]. The dominant contribution to the cross section is expected from diagrams with photon splitting, $\gamma \to q\bar{q}$, and from resolved photon processes. The cross section for single leptoquark production is proportional to the leptoquark Yukawa coupling, λ. Assuming electroweak coupling strength, $\lambda = \sqrt{4\pi\alpha}$, mass limits between 183 and 202 GeV are obtained [10]. As both eq and νq decay channels are considered, limits depend weakly on the assumed branching fractions.

Searches for the single leptoquark production were also performed at HERA. Processes with production or exchange of first-generation leptoquarks would contribute to the measured neutral current (NC) or charged current (CC) deep inelastic scattering (DIS) events. The leptoquark signal can be distinguished from the large SM background by studying 2-dimensional event distributions in invariant eq mass and scattering angle. Both H1 [12] and ZEUS [13] presented limits on the leptoquark Yukawa coupling as a function of the leptoquark mass, for different

[a] supported by the Polish State Committee for Scientific Research, grant no. 2 P03B 07022

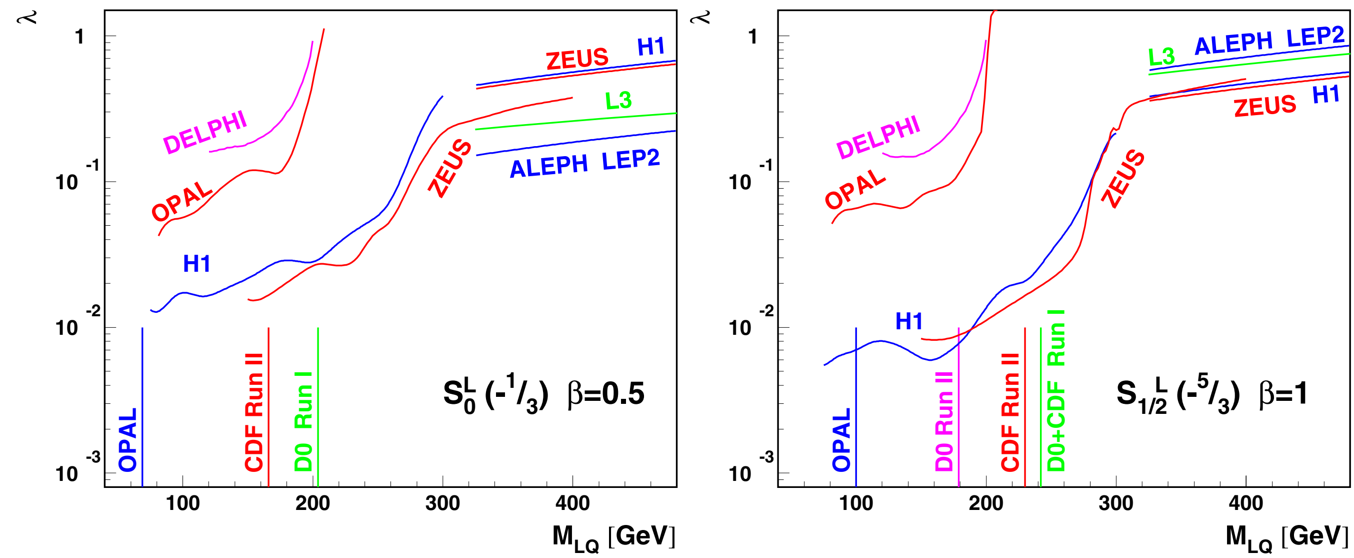

Fig. 1. Direct and indirect leptoquark limits for first-generation leptoquark models S_0^L and $S_{1/2}^L$. Limits from pair production at the Tevatron [3,4,6,8] and LEP [9], single production at LEP [10,11] and HERA [12,13] and virtual effects at LEP [14,15,16] and HERA [17,18] are compared

leptoquark models, based on data collected in 1994-2000. For leptoquarks with $\beta = 0.5$, significant improvement of the coupling limits is obtained from a combined analysis of NC and CC DIS samples. For $\lambda = \sqrt{4\pi\alpha}$, mass limits between 273 and 386 GeV are obtained [13].

4 Search for effects of virtual leptoquark exchange

Virtual leptoquark exchange can contribute to the measurement of DIS cross sections at HERA, quark-pair production at LEP or Drell-Yan cross section at the Tevatron even for leptoquark masses $M_{LQ} \gg \sqrt{s}$. The L3 collaboration presented new limits on the leptoquark Yukawa couplings derived from hadronic cross section measurements at LEP. For $\lambda = \sqrt{4\pi\alpha}$, mass limits up to 375 GeV (for scalar leptoquarks) and 557 GeV (for vector leptoquarks) are obtained [14]. In Table 1, the L3 limits on the mass to the Yukawa coupling ratio for first-generation leptoquarks are compared with new H1 limits [17] and older limits from other experiments [18,15,16].

Direct and indirect leptoquark limits coming from Tevatron, LEP and HERA, for first-generation leptoquark models S_0^L and $S_{1/2}^L$, are compared in Fig. 1. The strongest limits on the leptoquark pair production still come from Tevatron Run I, whereas single production and virtual effects are best constraint by HERA and LEP measurements.

5 Search for lepton flavour violation

In the general case, production or exchange of leptoquarks coupling to different fermion generations could result in processes with lepton flavour violation (LFV). The ZEUS collaboration searched for production of leptoquarks in $e^+p \to \tau\ X$ decay channel. No candidate events were found in the ZEUS 1999-2000 data [19]. Assuming $\lambda_{eq_\alpha} = \lambda_{\tau q_\beta} = \sqrt{4\pi\alpha}$ mass limits for LFV mediating leptoquarks with fermion number $F = 0$ range from 276 to 299 GeV.

A search for LFV processes was also reported by OPAL [20]. Upper cross section limits for LFV processes were obtained from an analysis of data collected at $\sqrt{s}$ =189–

Table 1. 95% C.L. limits on the mass to the coupling ratio, M_{LQ}/λ_{LQ}, for first-generation leptoquarks. Limits from H1 and ZEUS are calculated in the high leptoquark mass approximation, whereas LEP limits are taken at $\lambda = \sqrt{4\pi\alpha_{em}}$

Model	M_{LQ}/λ limit [TeV]				
	H1[17]	L3[14]	ZEUS[18]	ALEPH[15]	LEP2[16]
S_0^L	0.71	1.24	0.75	2.13	2.16
S_0^R	0.64	0.88	0.69	0.41	1.72
$\tilde{S}_0^R$	0.33	0.40	0.31	0.57	0.67
$S_{1/2}^L$	0.85	0.37	0.91	0.53	0.59
$S_{1/2}^R$	0.37	0.52	0.69	0.61	0.77
$\tilde{S}_{1/2}^L$	0.43	-	0.50	-	-
S_1^L	0.49	0.89	0.55	1.48	1.19
V_0^L	0.73	1.84	0.69	2.59	3.03
V_0^R	0.58	0.53	0.58	0.49	0.55
$\tilde{V}_0^R$	0.99	1.25	1.03	1.29	1.62
$V_{1/2}^L$	0.42	0.84	0.49	0.81	1.00
$V_{1/2}^R$	0.95	0.71	1.15	0.68	0.75
$\tilde{V}_{1/2}^L$	1.02	0.55	1.26	0.55	0.58
V_1^L	1.36	1.73	1.42	1.98	2.18

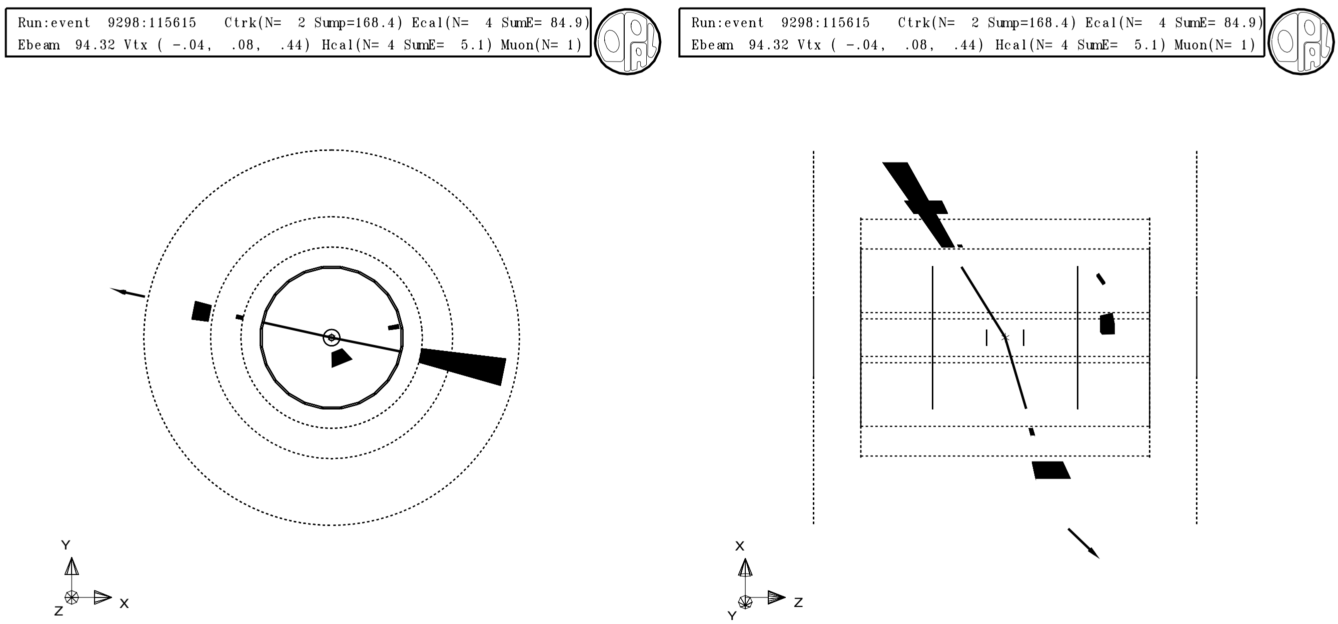

Fig. 2. An $r-\phi$ (*left plot*) and $r-\theta$ (*right plot*) view of the $e^+e^- \to e\mu$ candidate event from OPAL, $\sqrt{s}$=189 GeV

209 GeV. The agreement between the data and SM predictions is very good, except for one $e^+e^- \to e\mu$ candidate event remaining after the final selection cuts, compared to the background expectation of 0.019. The candidate event is presented in Fig. 2.

6 Summary

Leptoquark searches were performed at LEP, HERA and the Tevatron. No signal of leptoquark production or exchange is observed. Complementary limits on leptoquark masses and couplings are obtained from different processes measured at different experiments. Strongest limits come from leptoquark pair production at the Tevatron, single production at HERA and precision measurements at LEP.

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