Search for Leptoquarks

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This talk summarizes the status of Leptoquark searches performed at Tevatron, LEP and HERA. Prospects for Leptoquark searches at future colliders at LHC and TESLA are given.

1. Introduction

In many extensions of the Standard Model (SM) new particles are predicted which carry both lepton and baryon number - leptoquarks (LQ). LQs might have masses as low as the electroweak scale. Therefore they have been directly searched for in high energy collider experiments. In the BRW model [1] LQs are assumed to respect $SU(3) \times SU(2) \times U(1)$ symmetry. Several isospin multiplets can be constructed with fermion number $F = \pm 2$ or $F = 0$ depending on their couplings to matter and antimatter, and with spin 0 (scalar) or spin 1 (vector).

The coupling between LQs and fermions is given by the Yukawa coupling λ. In the most general model couplings of LQs to different fermion generations can mix and therefore would lead to FCNC and LFV processes. In low energy experiments the existence of LQs can be indirectly tested by interpreting results in the four-fermion contact interaction model. Constraints are obtained from the proton lifetime, rare decays (e.g. neutrinoless double beta decay), atomic parity violation and search for FCNC processes. LQs are not allowed to have diquark couplings and have to be chiral particles, i.e. $\lambda_L \lambda_R \approx 0$. The ratio of LQ mass over Yukawa coupling m_{LQ}/λ has to be above about 1 TeV in general and above 1-100 TeV for flavor changing couplings.

Recent experiments on the anomalous magnetic moment of the muon Δa_μ [2][1] and on the atomic parity violation in Cs [4] which showed slight deviations from the SM expectation have been interpreted in the framework of new LQs by [5,6]. These deviations would be in agreement with the expectation from LQs of mass about 1 and 1-2 TeV, respectively.

[1]Recent calculations of Δa_μ discovered a sign error in the pseudoscalar pole contribution, which reduces the deviation [3].

2. Direct Searches

In the following the status of experimental searches for first or second generation LQs at high energy colliders is summarized. Flavor-changing processes induced by LQs are not discussed here (for a more general overview on flavor-changing processes see [7])

2.1. Tevatron

At the Tevatron collider protons and antiprotons are collided at a center of mass energy of 1.8 TeV. LQs of all generations would be dominantly pair-produced independent of the Yukawa couplings. Limits obtained by a search for a first-generation vector LQ performed at the D0 experiment [8] are shown in Fig. 1. LQs with a branching ratio BR($LQ \to eq, \nu q$) = 1/2 were considered in the BRW model by combining the searches for the resulting $eejj$, $e\nu jj$ and $\nu\nu jj$ channels. The results were compared with different assumptions on the LQ-LQ gauge couplings: Yang Mills, minimal vector, minimal cross section couplings. Depending on the model 95% CL limits have been set in the range 230-340 GeV. In a recent publication similar limits were obtained

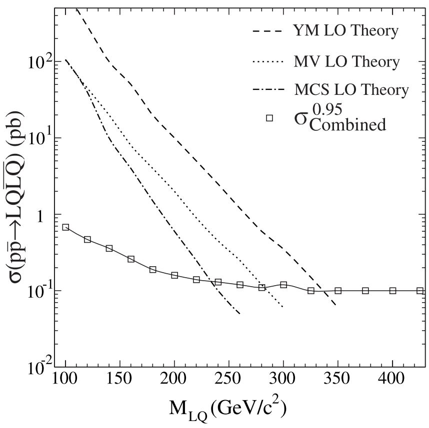

Figure 1. The 95% CL upper limits on cross sections for first generation vector LQ pair production as function of the LQ mass and comparison with LO predictions from different models [8].

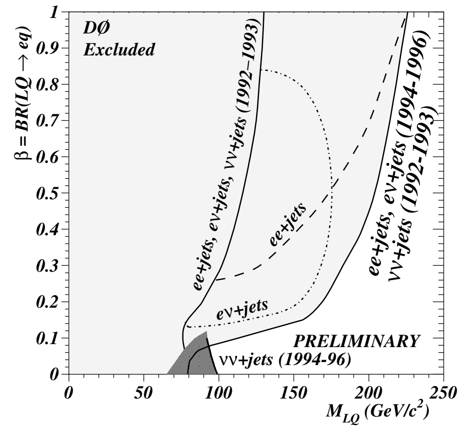

Figure 2. The 95% CL lower limit on the mass of first-generation scalar LQs as a function of the Branching Ratio β for the individual $eejj$, $e\nu jj$, and $\nu\nu jj$ channels, and for the combined analysis [8].

from a search for the $\nu\nu jj$ channel alone assuming $\mathrm{BR}(LQ \to \nu q) = 1$ [9].

The results of a search for pair production of a first-generation scalar LQ is summarized in Fig. 2. LQs are here interpreted in a more general model with arbitrary branching ratios into eq and νq. For branching ratios with a dominant decay into $eejj$ masses below about 225 GeV, for branching ratios with a dominant decay into $\nu\nu jj$ masses below about 95-100 GeV are excluded.

Searches for second generation vector LQs yielded due to the cleaner signature of muons in the final state higher mass limits. Depending on the branching ratio into muon and neutrino masses above about 270-320 GeV were excluded.

2.2. LEP

In e^+e^- collisions LQs can be tested in both pair production and single production. In pair production the sensitivity is limited to half the center of mass energy $m_{LQ} < \sqrt{s}/2$. Therefore mass exclusion limits obtained at LEP II [10] of the order of 100 GeV are not competitive with those obtained by Tevatron. In single production LQs can be created up to the full center of mass energy. LQs are mainly photo-produced and the cross section depends quadratically on the Yukawa coupling λ. Searches have been performed [11] for several types of LQs in different decay channels. Limits on λ of the order 0.1-1 were obtained in the mass range 100-189 GeV for scalar and vector LQs.

2.3. HERA

At the electron(positron)-proton collider HERA LQs can be resonantly produced in $e^{\pm}q$ interactions up to the center of mass energy of $\sqrt{s} = 318$ GeV for not too small values of λ. The main background is due to genuine neutral current (NC) and charged current (CC) deep inelastic scattering processes. Different types of LQs can in principle be tested by switching the lepton beam charge and by studying the decay distributions of LQs. The latter has been exploited to discriminate against SM background and to enhance sensitivity. The distribution of reconstructed invariant masses as measured by the H1 experiment is shown in Fig. 3. Optimization cuts have been applied to enhance the sensitivity for scalar LQs.

An excess found earlier at masses of about

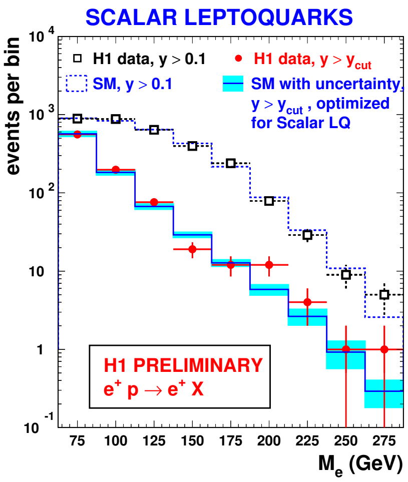

Figure 3. Distribution of *positron-jet* invariant masses measured by the H1 experiment. The open squares show all data, the full points show the data after applying an angular optimization cut for *scalar LQs*. The lines indicate the expectation from the SM

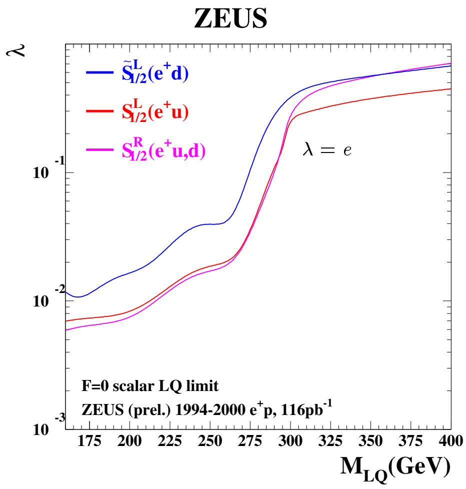

Figure 4. 95% CL exclusion limits of scalar LQs as function of the mass calculated in the BRW model. Yukawa couplings above the curves are excluded.

200 GeV in the data taken from 1994-1997 by the H1 and ZEUS collaborations [12] was not confirmed by the most recent data. The slight excess at 200 GeV in Fig. 3 is still a remaining effect of the early HERA excess.

Similar results obtained by the ZEUS collaboration from data taken in e^+p scattering have been interpreted in the BRW model. Limits are shown in Fig. 4 considering different types of $F = 0$ scalar LQs. For LQ masses above 200 GeV Yukawa couplings of the order 0.01 can be excluded almost up to the center of mass energy. For Yukawa couplings of electromagnetic strength $\lambda = e \approx 0.3$ scalar LQs up to about 290-300 GeV are excluded.

The exclusion limit obtained by the H1 experiment in a more general model with an arbitrary branching ratio into electron and neutrino of a $F = 2$ scalar LQ is shown in Fig. 5. Due to the combination of the NC and CC channels the limits, which are shown for three different assumptions on λ, are almost independent of the branching ratio.

3. Contact Interaction

In the framework of four-fermion contact interactions additional LQ couplings can be studied at different colliders by testing the $\ell\ell qq$ vertex at high scales (e.g. Q^2). By adding to the SM Lagrangian an extra term with positive or negative interference $\varepsilon = \pm 1$ for the contact interaction deviations from the SM can be interpreted as function of M/λ [2] with M being the mass scale.

The H1 and ZEUS experiments at HERA have fitted various LQ hypotheses to the NC data taken at HERA I. Lower limits at 95% CL on M/λ for two specific LQs are shown in Fig. 6. Typical limits for different types of LQs obtained at HERA are in the range $0.5 - 1.3$ TeV [13,14].

Similarly, different kinds of contact interactions were fitted to the two-fermion final state cross sections at LEP II. The resulting 95% CL limits as obtained by the OPAL collaboration [15] for different chiral couplings are shown in Fig. 7. The limits are given here as lower limit on Λ/g with $g = \sqrt{4\pi}$ for both constructive and destructive interference with the SM processes. The limits

[2] often the convention Λ/g is used

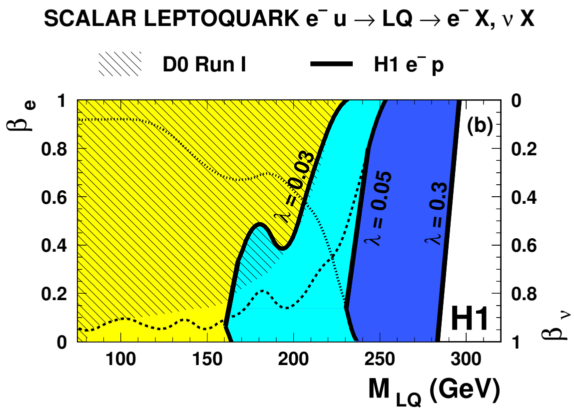

Figure 5. 95% CL mass exclusion limits of a $F = 2$ scalar LQ as function of the branching ratio $\mathrm{BR}(LQ \to eq)$. The limits are shown for three different example Yukawa couplings.

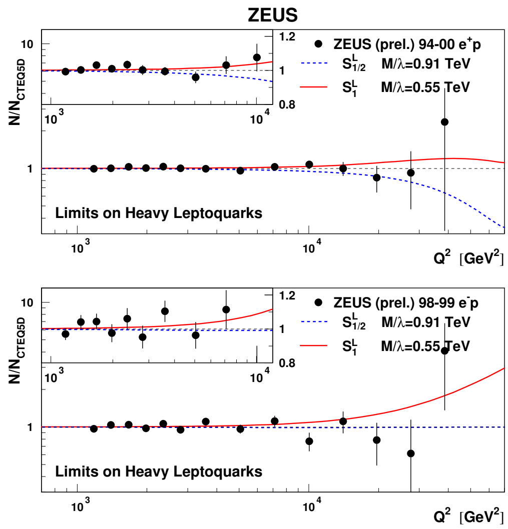

Figure 6. 95% CL Limits on LQs. The full lines show limits of two specific LQs obtained by a simultaneous fit to e^+p and e^-p scattering data as function of Q^2 [13].

on $q\bar{q}$ final states can also be interpreted in LQ models resulting in mass limits similar to those obtained at HERA.

4. Summary

The current status of first-generation LQ searches is summarized in Fig. 8 for two specific scalar LQ examples. The plot shows excluded regions as function of the LQ mass and its coupling as obtained by direct and indirect searches performed at Tevatron, HERA and LEP. Tevatron searches are independent of the Yukawa coupling while HERA searches have a higher mass reach for not too small Yukawa couplings. LQs at very high masses above 300 GeV are only constrained from indirect searches performed at HERA and LEP.

5. Outlook

Both HERA and Tevatron were upgraded in order to produce more luminosity. In the next years before LHC and TESLA come to operation an exciting competition between HERA and Tevatron in scalar LQ searches up to 300 GeV is expected. In case of a discovery HERA has the possibility by using different beam charges and by exploiting the newly available longitudinally polarized $e^\pm$ beam to determine the LQ type. For not too small Yukawa couplings LQs may be tested with higher sensitivity in indirect searches at the TeV scale. This region will be directly probed by LHC were resonances up to about 1.5 TeV can be found [16]. The successor of LEP, TESLA, will be able to probe LQs up to about 350 GeV. In case of a discovery TESLA will have the possibility to determine precisely the LQ type, its mass and its couplings [17].

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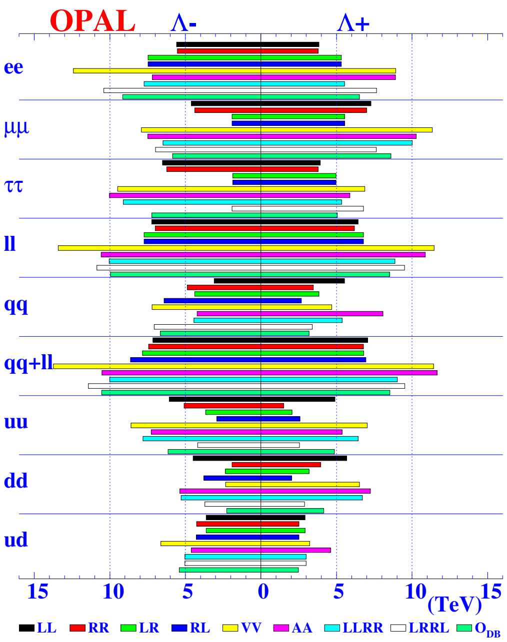

Figure 7. 95% limits on an effective contact interaction with a mass scale Λ for different final state topologies [15].

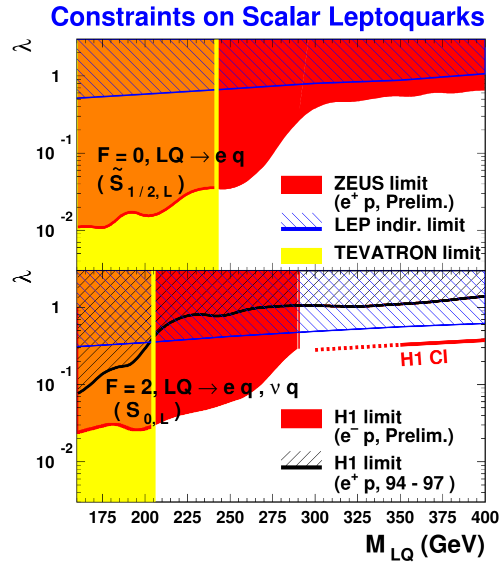

Figure 8. 95% Limits from LQ searches obtained from collider experiments at Tevatron, HERA and LEP on λ as function of the LQ mass.

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