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Leptoquark Searches at the Tevatron

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LEPTOQUARK SEARCHES AT THE TEVATRON

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We present recent results of searches for leptoquarks at the two Tevatron collider experiments, CDF and D0 at Fermilab. Described here are results from direct leptoquark searches in all three generations, and indirect searches for Pati-Salam leptoquarks using rare B_s^0 and B_d^0 decay signatures.

1 Introduction

Leptoquarks belong to a class of particles carrying both color and lepton quantum numbers which mediate transitions between quarks and leptons. Leptoquarks do not exist within the Standard Model but appear in many SM extensions which predict a symmetry between quarks and leptons at a fundamental level [1,2,3]. The Tevatron, a $p\bar{p}$ collider with the currently highest center of mass energy in the world($\sqrt{s}$ =1.8TeV), is in a unique position to search for existences of leptoquarks directly [4]. We have performed direct searches for pair production of leptoquarks for all three generations at the Tevatron. At CDF we have also searched for Pati-Salam leptoquarks [1] via rare decay modes of B_s^0 and B_d^0. These two, direct and indirect searches are fundamentally different and they are described in the following two sections. All limits quoted in this paper are at 95% confidence level.

2 Direct Search for Pair Produced Leptoquarks

Leptoquark masses and coupling strengths are severely constrained by experimental bounds on rare processes, so one has to make the following assumptions about the properties of leptoquarks and their couplings to allow masses which are directly observable in collider experiments:

1. to evade mass bounds from proton decay, lepton and baryon number have to be conserved;
2. to prevent leptoquark-induced FCNC, leptoquarks are generally assumed to link, through an unknown coupling strength, quark and lepton multiplets of the same generation, and
3. to avoid LQ contributions to the helicity suppressed $\pi \rightarrow e\nu$ decay, the couplings have to be chiral.

CDF has searched for pair production of leptoquarks in the dilepton plus dijet channels ($LQ\overline{LQ} \rightarrow l^+l^-jj$) for all three lepton generations. D0 has searched for the signatures l^+l^-jj and $l^\pm\nu jj$ in the electron and muon channels. The following three subsections summarize the results from each generation leptoquark direct searches.

2.1 First Generation Leptoquark (LQ1) Searches

In the 88/89 run [5], CDF set a first generation scalar leptoquark mass limit of $M_{LQ1} > 113$ GeV/c^2 for $\beta = 1$ and $M_{LQ1} > 80$ GeV/c^2 for $\beta = 0.5$, where β is the branching ratio for a leptoquark decaying to a charged lepton and quark. Since then, HERA has improved [6,7] the first generation limits. However, their limits depend on the coupling strength λ. At hadron colliders on the other hand the production cross section depends only very weakly on λ. D0 has searched [8] for the signatures $eejj$ and $e\nu jj$ using data sets corresponding to $14pb^{-1}$. The results are shown in Figure 1. A first generation scalar leptoquark with mass less than 130 (116) GeV/c^2 for $\beta = 1(0.5)$ is excluded.

2.2 Second Generation Leptoquark (LQ2) Searches

D0 has searched [9] for the signatures $\mu\mu jj$ and $\mu\nu jj$ using data sets corresponding to $12pb^{-1}$. The results are shown in Figure 2. D0 excludes a second

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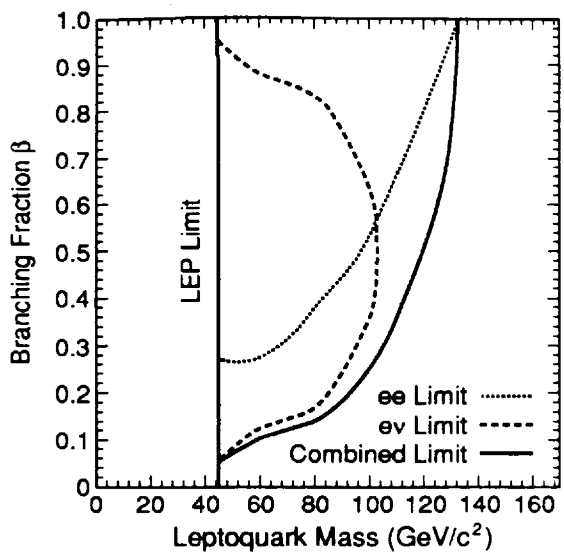

Figure 1: LQ1 excluded region in branching fraction vs. LQ1 mass plane. (D0 experiment)

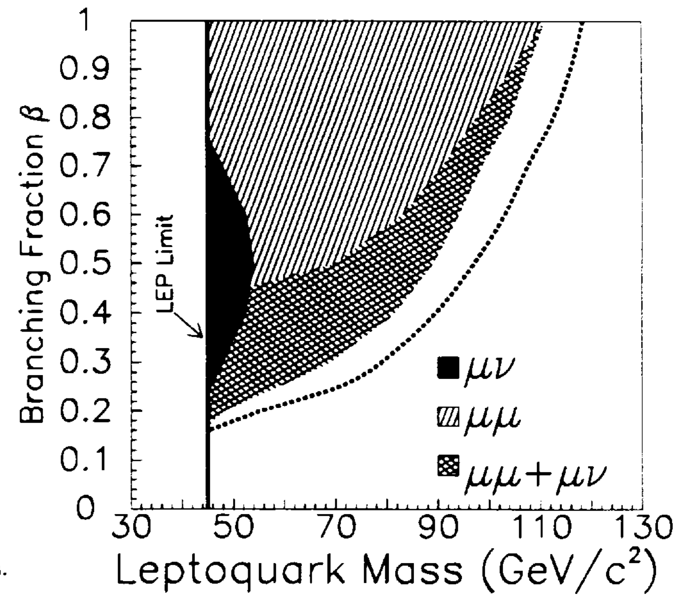

Figure 2: LQ2 excluded region in branching fraction vs. LQ2 mass plane. (D0 experiment)

generation scalar leptoquark with mass less than 111 (89) GeV/c^2 for $\beta = 1.0(0.5)$

At CDF, to search for LQ2 ($LQ_2\overline{LQ_2} \rightarrow \mu^+\mu^- jj$) we require 2 isolated μ with $P_T > 20$ GeV/c and 2 jets with $E_T > 20$ GeV, events in the Z^0- mass region ($75 < m_{\mu\mu} < 105\ GeV/c^2$) are excluded. Analysing $\approx 70pb^{-1}$ of data we observe 4 events where 4.8 background events, mainly from Drell Yan, are expected. With this we set limits and obtain $M_{LQ2} > 180$ GeV/c^2 for $\beta = 1$ and $M_{LQ2} > 140$ GeV/c^2 for $\beta = 0.5$. Figure 3 shows the limit on $\sigma \cdot \beta^2$ as a function of LQ2 mass.

2.3 Third Generation Leptoquark (LQ3) Searches

CDF has searched for LQ3 [10]. To search for third generation leptoquarks (LQ3) ($LQ_3\overline{LQ_3} \rightarrow \tau^+\tau^- jj$) we require one of the τ's to decay to e or μ with $P_T > 20$ GeV/c, the lepton is required to be isolated and the $\not{E}_T$ was required to point within 50^0 of the lepton direction. The other τ decays hadronically and is identified by requiring that there be 1 or 3 tracks within a 10^0 cone about the jet axis and no other tracks above 1 GeV/c between the 10^0 cone and a 30^0 cone. In addition we require 2 jets with $E_T > 20$ GeV. No b-tag is required. We observe 1 event in $110pb^{-1}$ of data surviving all LQ3 cuts with an estimated background of $2.4^{+1.2}_{-0.6}$ events (mainly from $Z^0 \rightarrow \tau^+\tau^- + jets$). For scalar leptoquarks we set a limit at $M_{LQ3} > 99\ GeV/c^2$. We also considered vector leptoquarks with "anomalous chromomagnetic moments" parameterised by κ. For this type of leptoquark assuming $\beta = 1$, the limits are $M_{LQ3} > 170$ GeV/c^2 and $M_{LQ3} > 225$ GeV/c^2 for κ=0 and $\kappa = 1$ respectively. The results are summarised in Figure 4.

3 Indirect Search for Leptoquarks (Search for the decays $B_s^0 \rightarrow e\mu$ and $B_d^0 \rightarrow e\mu$)

Within the Pati-Salam model [1], which is based on the SU(4)$_c$ group, the lepton number is regarded as the fourth "color". At some high-energy scale, the group SU(4)$_c$ is spontaneously broken to SU(3)$_c$, liberating the leptons from the influence of the strong interaction and breaking the symmetry between quarks and leptons. This model predicts a heavy spin-one gauge boson with non-chiral couplings called the Pati-Salam boson. The lepton and quark components in this kind of leptoquark are not necessarily from the same generation as pointed out in [11]. This would make decays like $B_s^0 \rightarrow e\mu$ and $B_d^0 \rightarrow e\mu$ possible. Setting limits on the branching ratio of these rare processes can

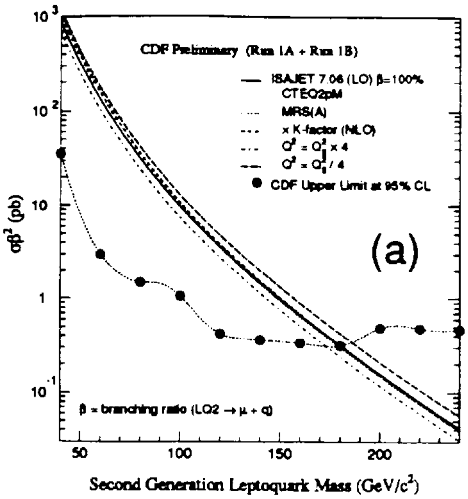

Figure 3: The limit on the LQ2 cross section is shown as a function of LQ2 mass (CDF experiment).

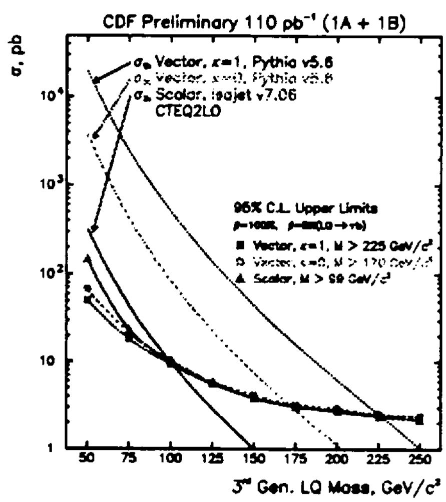

Figure 4: The limit on the LQ3 cross section is shown as a function of LQ3 mass. (CDF experiment)

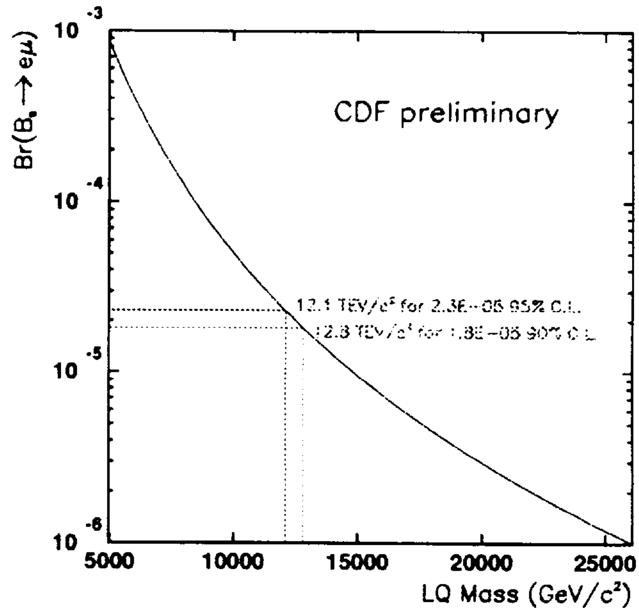

Figure 5: Pati-Salam leptoquark mass limit (CDF experiment)

probe masses in the multi-TeV range, i.e. masses not accessible directly. CDF has searched for the decays $B_s^0 \to e\mu$ and $B_d^0 \to e\mu$ using $\approx 90\ pb^{-1}$ of Run Ib data. We select events with an oppositely charged $e\mu$-pair, the electron with $E_T > 5.0$ GeV and the muon with $P_T > 2.5$ Gev/c. In addition we required the proper decay length: $c\tau > 200\mu m$ and that the momentum of the $e\mu$ pair points back to the primary vertex. We find no B_d^0 candidates in a mass window ($\pm 3\sigma$ of our mass resolution) of 5.174-5.384 GeV/c^2 and one B_s^0 candidate in a mass window of 5.270-5.480 GeV/c^2. We set preliminary limits at $\mathrm{Br}(B_s^0 \to e\mu) < 2.3 \times 10^{-5}$ and $\mathrm{Br}(B_d^0 \to e\mu) < 4.4 \times 10^{-6}$ after systematic uncertainties have been included. From this we derive a limit on the mass of a certain Pati-Salam leptoquark of 12.1 TeV/c^2 for the B_s and 18.3 TeV/c^2 for the B_d.

4 Summary

At the Tevatron, we have performed direct searches for pair production of leptoquarks for all three generations. D0 excludes a first generation scalar leptoquark with mass less than 130 (116) GeV/c^2 for $\beta = 1(0.5)$ using $14pb^{-1}$ of data. CDF excludes a second generation scalar leptoquark with mass less than 180 (140) GeV/c^2 for

$\beta = 1(0.5)$ using $70pb^{-1}$ of data. CDF sets a scalar LQ3 mass limit at $M_{LQ3} > 99\ GeV/c^2$ and vector leptoquark mass limits at $M_{LQ3} > 170$ GeV/c^2 and $M_{LQ3} > 225$ GeV/c^2 for κ=0 and $\kappa = 1$ respectively. CDF also performed indirect leptoquark search via $B_s^0 \rightarrow e\mu$ and $B_d^0 \rightarrow e\mu$ decay. We set preliminary mass limits of a certain Pati-Salam leptoquark of 12.1 TeV/c^2 for the B_s and 18.3 TeV/c^2 for the B_d.

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