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Search for Leptoquark Pairs Decaying to $\nu\nu$ + $jets$ in $p\bar{p}$ Collisions at $\sqrt{s}$=1.8 TeV

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Abstract

We present the preliminary results of a search for leptoquark (LQ) pairs using (85.2 ± 3.7) pb^{-1} of $p\bar{p}$ collider data collected by the DØ experiment at the Fermilab Tevatron from 1994-1996. We observe no evidence for leptoquark production and set a limit on $\sigma(p\bar{p} \to LQ\overline{LQ} \to \nu\nu + jets)$ as a function of the mass of the leptoquark (M_{LQ}), assuming BR($LQ \to \nu q$)=100%. At the 95% confidence level, we exclude scalar leptoquarks for $M_{LQ} < 99$ GeV/c^2, and vector leptoquarks for $M_{LQ} < 178$ GeV/c^2.

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The observed symmetry between the lepton (l) and quark (q) sectors suggests the existence of a force connecting the two that is mediated by particles that couple directly to both leptons and quarks, and are therefore known as leptoquarks (LQ). Leptoquarks arise naturally as the vector bosons [1] or Higgs particles [2] of a Grand Unified Theory [1]; as composite particles [3]; as techniparticles [4]; or as R-parity violating supersymmetric particles [5].

Leptoquarks carry both color and fractional electric charge. The Fermilab Tevatron can produce pairs of leptoquarks through the strong process $p\bar{p} \to g \to LQ\overline{LQ} + X$ with a production cross section that is independent of the coupling for scalar leptoquarks, but not for vector leptoquarks. In this study, we consider the specific cases of Yang-Mills coupling (YM), Minimal Coupling (MC), and the coupling resulting in the minimal cross section (σ_{min}) [6].

Decay between generations is theoretically possible; however, the limits from flavor-changing neutral currents imply that leptoquarks of low mass ($\mathcal{O}$(Tev)) couple only within a single generation [7]. Decays of leptoquark pairs result in one of three possible final states: $l^{\pm}l^{\mp}qq$, $l^{\pm}\nu qq$, and $\nu\nu qq$. This analysis [8] studies the $\nu\nu qq$ final state, assuming BR($LQ \to \nu q$)=100%. In a previous analysis of this final state [9], DØ set limits of $M_{LQ} > 79$ GeV/c^2 for scalar leptoquarks, and $M_{LQ} > 145$ GeV/c^2, 160 GeV/c^2, and 205 GeV/c^2, for vector leptoquarks with couplings that yield the minimum cross section (σ_{min}), Minimal Couplings (MC), and Yang-Mills (YM) couplings, respectively [9]. The analysis presented here uses 10 times more data than the previous analysis. The CDF collaboration has conducted a search for second and third generation leptoquarks with BR($LQ \to \nu q$)=100% and set mass limits of 123 (148) GeV/c^2 for second (third) generation scalar leptoquarks and 171 (199) GeV/c^2 and 222 (250) GeV/c^2 for second (third) generation vector leptoquarks with MC and YM couplings, respectively [10].

The DØ detector [11] consists of three major subsystems: An inner detector for tracking charged particles; a uranium-liquid argon calorimeter for measuring electromagnetic and hadronic showers, and a muon spectrometer. The jets measured with the calorimeter have an energy resolution of approximately $\sigma(E)$=0.8$\sqrt{E}$ (E in GeV). We measure the missing transverse energy ($\not\!\!E_T$) by summing the calorimeter energy in the direction transverse to the beam. The measurement has a resolution of σ=1.08 GeV + 0.019($\Sigma|E_T|$) (E_T in GeV).

We use an event sample defined by the selection criteria: 2 jets with $E_T > 50$ GeV; $\not\!\!E_T >$ 40 GeV; $\Delta\phi(jet,\ \not\!\!E_T) > 30°$; and $\Delta\mathcal{R}(jet,\ jet) > 1.5$, where $\Delta\mathcal{R} = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$, η is the jet pseudo-rapidity, and ϕ is the jet azimuthal angle. These criteria select events with high trigger efficiency. Backgrounds arising from W or Z boson production are reduced by rejecting events with isolated muons or highly electromagnetic jets. We reduce cosmic ray backgrounds by rejecting events with jets containing little electromagnetic activity. The integrated luminosity after removing events corrupted by accelerator noise and detector malfunctions is 85.2 ± 3.7 pb^{-1}.

The backgrounds in the sample consist of events with jets produced in association with a W or a Z boson, and events from top quark and multijet production. We use Monte Carlo generators to simulate the topologies of events with W or Z bosons or top quarks, and a GEANT simulation of the detector to predict the acceptance of these events.

The W and Z backgrounds consist of processes containing only neutrinos and jets

($W \rightarrow \tau_h\nu + jet,\ Z \rightarrow \nu\nu\ +\ 2\ jets$), processes with unobserved charged leptons ($W \rightarrow l^{\pm}\nu\ +\ 2\ jets,\ Z \rightarrow \mu\mu\ +\ 2\ jets,\ Z \rightarrow \tau_h\tau_l\ +\ jet$), and processes in which an electron is misidentified as a jet ($W \rightarrow e\nu\ +\ jet,\ W \rightarrow \tau_e\nu\ +\ jet$). We use the PYTHIA Monte Carlo generator [12] to predict the acceptances of the W/Z + jet processes, and the VECBOS Monte Carlo generator [13] to predict the acceptances of the W/Z + 2 jets processes. We scale the generator cross sections to match the cross sections measured using the W and Z electronic decays.

The top background consists of $t\bar{t}$, $t\bar{b}$, and $\bar{t}b$ production, where the top quark decays to an unobserved charged lepton, a neutrino, and a jet. We use the DØ measured cross section for $t\bar{t}$ production [14] and the calculated next-to-leading order cross section for the other processes [15]. We use the HERWIG generator [16] to predict the acceptance of the $t\bar{t}$ process, and CompHEP [17] to predict the acceptances of the $t\bar{b}$ and $\bar{t}b$ processes.

The multijet background arises primarily from 2 sources: Vertex mismeasurement and jet energy loss. To reduce the number of events with mismeasured vertices, we use the central drift chamber (CDC) to associate charged tracks with each central high p_T jet. The tracks are used to determine the jet vertex position which is required to be no further than 15 cm from the event vertex position. The latter is determined using all of the tracks in the event. We reduce the number of events with significant jet energy loss by requiring that the angle between the $\not{E}_T$ and the jet with the second highest measured p_T be greater than 60°.

To predict the multijet background remaining in our sample, we use the sample of events whose jet vertex position deviates by 15 cm to 50 cm from the event vertex position. We normalize this sample to the event sample using a multijet dominated sample ($\Delta\phi(jet\ 2,\ \not{E}_T) < 60°$). The upper bound of 50 cm provides the best agreement between the background prediction and the data for events with $\not{E}_T$ between 30 GeV and 40 GeV, which is dominated by multijet events (Table I). Changing this value to 100 cm increases the multijet background prediction by 22% in this region, which we take as an estimate of the systematic error of the method. Table II shows the total expected background and the observed number of events for the 2 jets + $\not{E}_T$ data sample.

To model the characteristics of leptoquark production, we use scalar leptoquark events generated with PYTHIA and vector leptoquark events generated with CompHEP. The cross sections for scalar leptoquark production have been calculated to next-to-leading order [19], while those for vector leptoquark production have been calculated to leading order [20]. The calculations use a renormalization and factorization scale of μ=M$_{LQ}$, with theoretical uncertainties estimated by changing the scale to μ=M$_{LQ}$/2 and μ=2M$_{LQ}$. We use the lower cross section (μ=2M$_{LQ}$) in our optimization and in determining our mass limits.

The analysis is optimized for the production of 100 GeV/c^2 scalar leptoquarks and 200 GeV/c^2 vector leptoquarks, since leptoquarks with either of these masses would give a $\sim 2\sigma$ excess if they exist. We use the JETNET [18] neural network program, with the $\not{E}_T$ and $\Delta\phi(jet,\ jet)$ distributions as inputs for scalar leptoquarks, and the $\not{E}_T$ and second jet p_T distributions as inputs for vector leptoquarks. We show the neural network outputs and the chosen cuts for both of these masses in Fig. 1. The cuts are chosen to maximize the inverse of the fractional error in the signal:

$$n_\sigma = \frac{N_{lq}}{\sqrt{N_{lq}+N_{background}+\Delta N_{lq}^2+\Delta N_{background}^2}},$$

where N_{lq} and $N_{background}$ are the number of signal and background events, respectively, and ΔN_{lq} and $\Delta N_{background}$ are the associated uncertainties. We show the numbers of events after these cuts in Table III.

Event Sample	Number of Events
Multijet	162.8 ± 23.7
W, Z, and top	51.9 ± 7.0
Total background	214.7 ± 24.7
Data	224

TABLE I. The expected and observed numbers of events in the multijet dominated sample of $\not\!\!E_T$ between 30 GeV and 40 GeV.

Background	Number of Events
Multijet	$58.8 \pm 14.1 \pm 12.9$
$(W \to e\nu)\ +\ jet$	$51.9 \pm 7.0\ ^{+13.7}_{-8.9}$
$(W \to \tau\nu)\ +\ jet$	$46.3 \pm 5.0\ ^{+8.9}_{-7.7}$
$(Z \to \nu\nu)\ +\ 2\ jets$	$36.1 \pm 7.7\ ^{+9.0}_{-5.5}$
$(W \to \mu\nu)\ +\ 2\ jets$	$18.7 \pm 3.5\ ^{+4.2}_{-3.7}$
$t\bar{t} \to l^{\pm}\nu\ +\ 4\ jets$	$10.6 \pm 2.0 \pm 2.3$
$(W \to e\nu)\ +\ 2\ jets$	$8.3 \pm 2.5\ ^{+2.0}_{-2.5}$
$(W \to \tau\nu)\ +\ 2\ jets$	$5.6 \pm 1.7\ ^{+1.4}_{-0.8}$
$tb \to l^{\pm}\nu\ +\ 2\ jets$	$2.0 \pm 0.3 \pm 0.2$
$(Z \to \tau\tau)\ +\ jet$	$2.0 \pm 0.4\ ^{+0.6}_{-0.3}$
$(Z \to \mu\mu)\ +\ 2\ jets$	$1.7 \pm 0.4\ ^{+0.4}_{-0.3}$
Total background	$242.0 \pm 18.9\ ^{+23.3}_{-19.0}$
Data	231

TABLE II. The expected and observed numbers of events in the 2 jets + $\not\!\!E_T$ sample.

After applying the optimal cuts, we find that the observed number of events is consistent with the expected background, and that, consequently, we have found no evidence for leptoquark production. This null result yields the 95% confidence level cross section limit, as a function of leptoquark mass, shown in Fig. 2. We calculate the limit using a Bayesian method with a flat prior for the signal and Gaussian priors for background and acceptance uncertainties. The corresponding mass limits are 99 GeV/c^2 for scalar leptoquarks, and 178 GeV/c^2, 222 GeV/c^2, and 282 GeV/c^2 for vector leptoquarks with couplings corresponding to the minimum cross section σ_{min}, Minimal Coupling, and Yang-Mills coupling, respectively. We summarize the various DØ mass limits as a function of BR($LQ \to l^{\pm}q$) for first

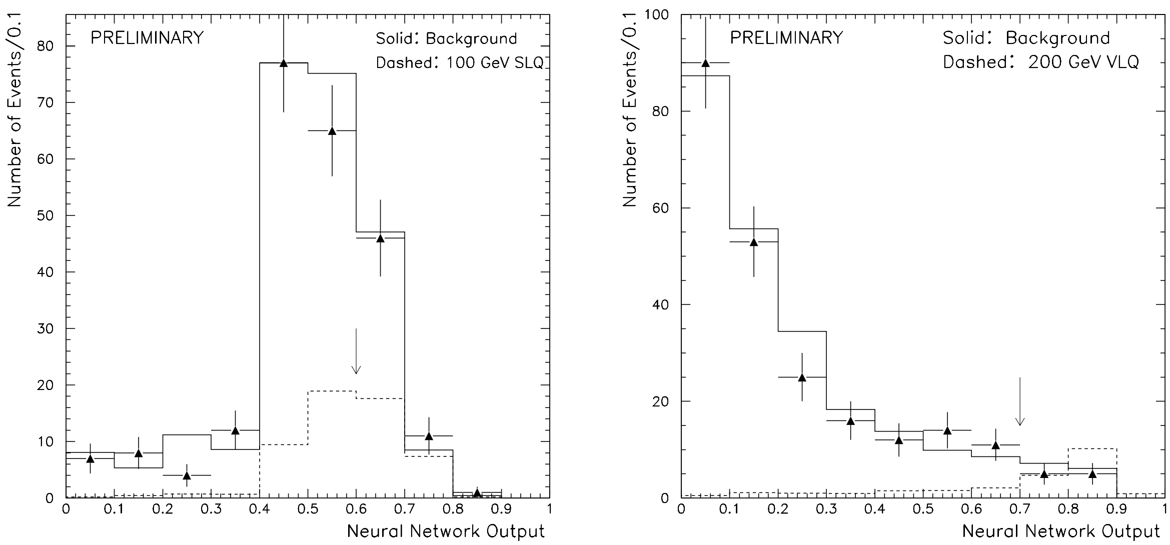

FIG. 1. The neural network output for the data, for background (solid), and for leptoquarks (dashed). We show the optimization for 100 GeV/c^2 scalar leptoquarks (left) and 200 GeV/c^2 vector leptoquarks with Minimal Coupling (right). We remove events to the left of the arrows.

Leptoquark	N_{data}	$N_{background}$	n_σ	$\sigma^{95\%}$ (pb)
100 GeV/c^2 Scalar	58	$56.0\,^{+8.1}_{-8.2}$	+2.1	10.8
200 GeV/c^2 Vector (MC)	10	$13.3\,^{+2.8}_{-2.6}$	+2.6	0.60

TABLE III. The data, the expected background, the number of σ excess that would be observed in the presence of a signal, and the 95% confidence level cross section limit.

generation scalar leptoquarks in Fig. 3 [9] and for second generation MC and YM vector leptoquarks [21] in Fig. 4. We note that the gap at low values of BR($LQ \rightarrow l^{\pm}q$) has been closed by this analysis.

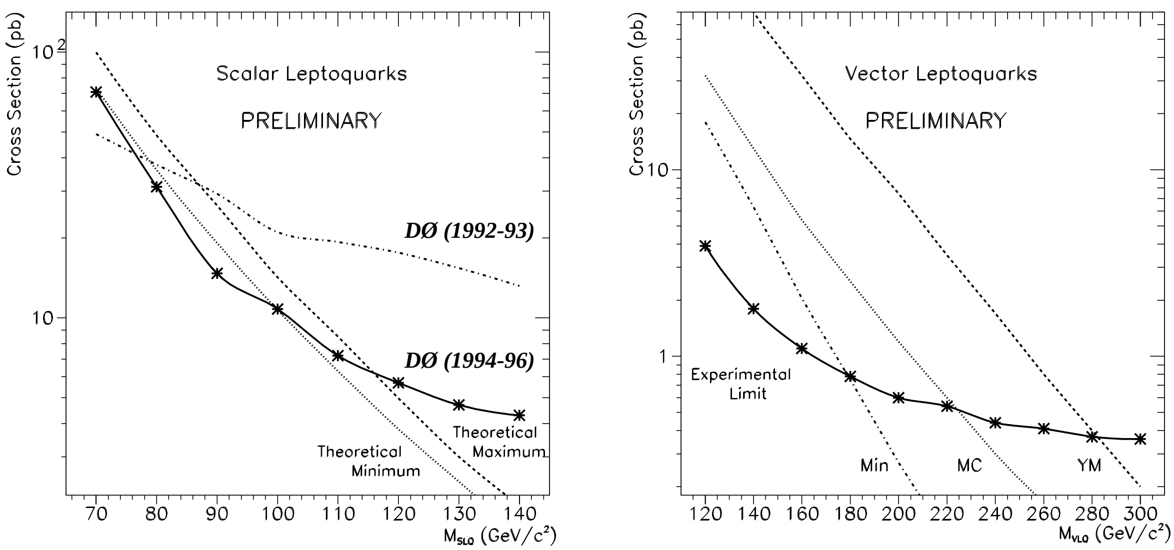

FIG. 2. The 95% confidence level cross section limits as a function of leptoquark mass. We show the mass limits for scalar (left) and vector (right) leptoquarks.

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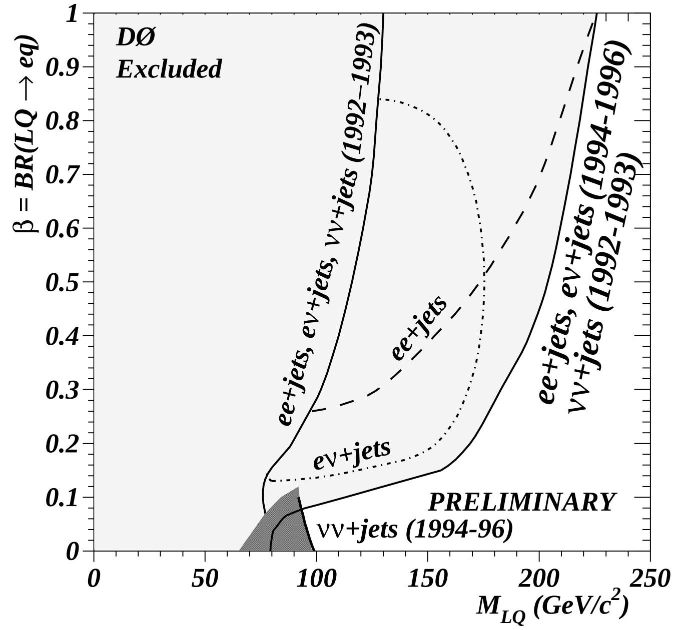

FIG. 3. The DØ excluded mass vs. BR($LQ \to eq$) region for first generation scalar leptoquarks. The dark region is excluded by this analysis.

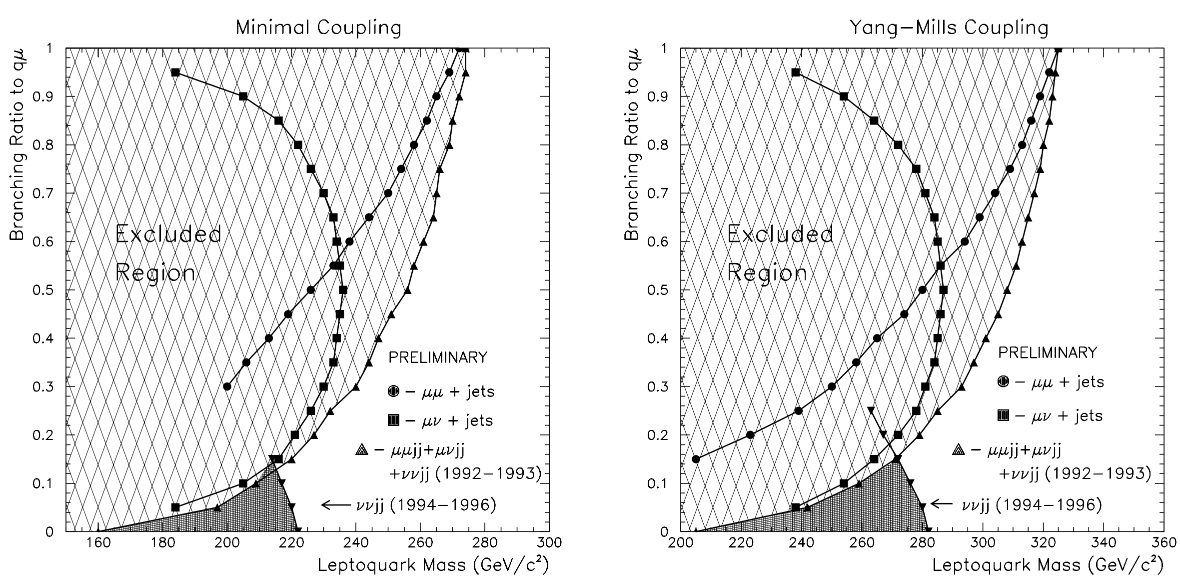

FIG. 4. The DØ excluded mass vs. BR($LQ \to \mu q$) region for second generation MC (left) and YM (right) vector leptoquarks. The dark regions are excluded by this analysis.

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