# Searches for Leptoquark production in $p\bar{p}$ collisions at the DØ experiment

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**Abstract.** We report on searches for the production of scalar and vector leptoquarks in $p\bar{p}$ collisions at the Tevatron collider, which are based on integrated luminosities of up to 2.5 fb$^{-1}$ collected with the DØ detector. Searches for the pair-production of leptoquarks of all three generations have been performed using the $LQ\overline{LQ} \to l^+l^-q\bar{q}$, $\to l^\pm \nu q\bar{q}$, and $\to \nu\bar{\nu}q\bar{q}$, $\to \tau b\tau b$ final states. Upper limits on the production cross sections are given and are used to derive lower limits on the leptoquark masses as a function of the branching fraction $\beta$ of the Leptoquark in a charged lepton and a quark and for different couplings.

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## INTRODUCTION

The apparent symmetry between the quark and leptons sectors has motivated the development of several extensions of the Standard Model (SM) in which lepton-quark interactions may be mediated by new gauge bosons [1], called Leptoquarks. The Leptoquarks (LQs) which appear in such exotic models carry both lepton and quark flavors, an electric charge and a spin. For spin-0 LQs, the production cross section only depends on the LQ mass and on the center-of-mass collision energy; while for spin-1 LQs, it is also function of so-called "anomalous" couplings [2]. At hadron colliders, Leptoquarks can either be pair-produced via the strong interaction or a single leptoquark can be produced in association with a lepton via the hypothesized leptoquark-lepton-quark coupling. Moreover, three generations of LQs are predicted, each one couples to the fermions from the corresponding generation. Cross-generational couplings are not excluded in theory, but strongly suppressed by experiments, and consequently we will consider generational couplings only. Are also excluded the $l-l-$LQ or $q-q-$LQ interactions, cases which could eventually allow protons to decay. Since there are two decay modes, depending on the charge of the lepton, for the pair-produced LQs arise three types of analysis channels: $LQ\,\overline{LQ} \to llqq$, $LQ\,\overline{LQ} \to l\nu qq$ and $LQ\,\overline{LQ} \to \nu\nu qq$. Then if $\beta$ is the total branching ratio of the LQ into a charged lepton and a quark, and $(1-\beta)$ the branching ratio of $LQ \to \nu q$, the total branching fraction of the three decay channels are $\beta^2$, $2\beta(1-\beta)$ and $(1-\beta)^2$ respectively. The first two channels benefit from the visible energy of the charged leptons in the detector, and the analysis performance relies on the reconstruction of the isolated deposits in the calorimeters. While in absence of charged leptons, variables such as the topology of events with jets and missing transverse energy in the final state are preferred in such analyses.

The Tevatron is the proton-antiproton collider of the Fermi National Accelerator Laboratory. It is today the world's most powerful particle accelerator, with a center-of-mass energy $\sqrt{s} = 1.96$ TeV. Associated to its good performances, the data taking efficiency of the DØ detector is close to 100%. The DØ detector [3] presents a usual concentric constitution of multipurpose detectors. It comprises a central tracking volume with a silicon microstrip vertex detector and a scintillating fiber tracker located within a 2 T superconducting solenoidal magnet, a uranium/liquid-argon calorimeter, and a surrounding muon system composed of tracking chambers and scintillators.

The Tevatron experiments devote an important part of their program to searches for signatures of new phenomena which could be at their reach in few inverse femtobarns of data. In this article, we will focus on most recent results of searches for Leptoquarks at DØ, obtained with integrated luminosities of up to 2.5 fb$^{-1}$.

## SEARCHES FOR FIRST-GENERATION LEPTOQUARKS

A search for first-generation Leptoquarks in the $eejj$ final state has been performed at DØ, in a data sample corresponding to a luminosity of about 1 fb$^{-1}$. From a previous analysis on 252 pb$^{-1}$ of data, first-generation scalar LQs with a mass below 241 GeV/$c^2$ are ruled out. In the most recent analysis, the main backgrounds are instrumental background (QCD "multijet" events faking leptons in the final state) and electroweak standard processes such as $Z/\gamma^* \rightarrow ee$ produced in association with jets or $t\bar{t} \rightarrow bW(l\nu)bW(l\nu)$. The contribution of electroweak processes is estimated relying on Monte Carlo simulation, while the QCD background is extracted from data. Events containing two electrons candidates and two jets, with high transverse energy ($E_T$) are selected. The normalization of the simulated background to the data is based on the dielectron invariant mass ($M_{ee}$) distribution, and controlled on the scalar tranverse energy spectrum $S_T$, sum of the transverse energy of the four objects in the final state. In order to reduce the main background contributions, criteria are applied on the $M_{ee}$ and $S_T$ variables and optimized so as to minimize the expected production cross section. The number of observed events agrees with Standard Model expectations; limits on the cross section times branching fraction are set on the production of scalar and vector leptoquark pairs decaying to the e+jet final state as a function of the leptoquark mass. The limits are interpreted as mass limits and exclude leptoquarks with masses less than 292 GeV/$c^2$ for scalar leptoquarks and from 350 to 458 GeV/$c^2$ for three types of vector leptoquarks, depending on the $LQ-l-q$ coupling (Minimal Coupling MC, Yang-Mills YM and Minus-Minus MM). The four results are shown on figure 1. These results have been combined with a search for first-generation LQs at DØ in the $e\nu jj$ channel, where one LQ decays into a neutrino and a quark, in a dataset of 1 fb$^{-1}$ equivalent luminosity.[1].

A search for LQ in a jet plus missing $E_T$ topology has been published recently [4] and

[1] The combination of the two channels has been accepted for publication after the conference: Physics Letters B (2009), doi:10.1016/j.physletb.2009.10.016

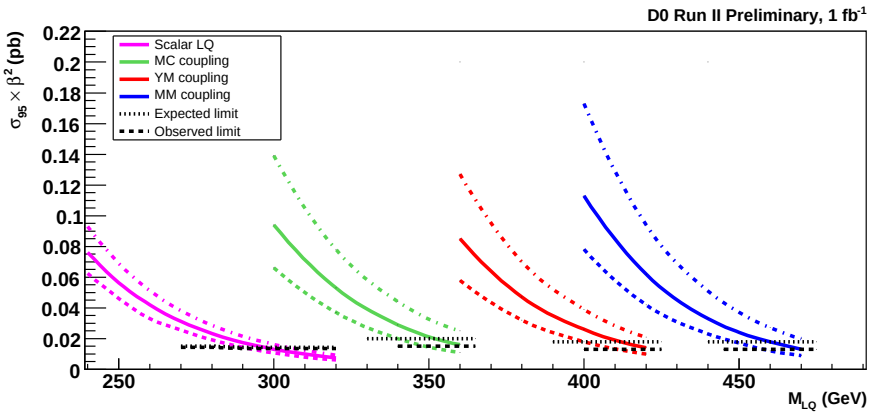


**FIGURE 1.** Cross sections at 95% C.L. times branching ratio as a function of the LQ1 mass for the four different couplings considered and with $\beta = 1$. The vector and scalar LQ cross sections are drawn for different values of the renormalization and factorization scale: $M_{LQ}$ (solid line), $M_{LQ}/2$ (dot-dashed line) and $2M_{LQ}$ (dashed line). The horizontal black lines correspond to the expected and observed limit cross section for each coupling.

performed on a 2.5 fb$^{-1}$ dataset. The main physical background in this channel is the $Z \to \nu\nu$ +jets process. Contributions from $W \to l\nu$ +jets processes are suppressed using a veto on isolated leptons. Events are required to have at least two jets with high $E_T$ and high missing transverse energy. The selection cuts are then optimized for a low and high LQ mass. Since no excess of data with respect to the SM predictions is observed, a limit is set on a LQ production cross section interpreted for $\beta = 0$ as a limit on the LQ mass at 214 GeV/$c^2$ (see fig. 2). This analysis also allows to set a limit on T-odd quarks production cross section.

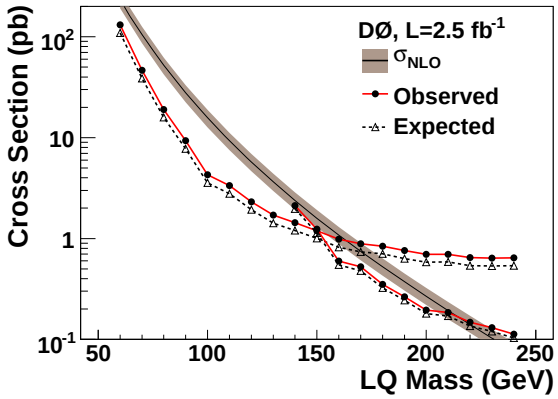


**FIGURE 2.** Cross sections at 95% C.L. as a function of the LQ mass, with $\beta = 0$.

## SEARCHES FOR SECOND-GENERATION LEPTOQUARKS

The most recent search at DØ for second-generation LQs is a combination of the $\mu\mu jj$ and $\mu\nu jj$ channels, performed on 1 fb$^{-1}$ dataset [5]. For the $\mu\mu jj$ channel, the main background contribution comes from the $Z/\gamma^* \rightarrow \mu\mu$ +jets. Events which have at least two muons and two jets with high $E_T$ are selected. Cuts on $S_T$, on the dimuon invariant mass $M_{\mu\mu}$ and on the muon-jet invariant mass $M_{\mu j}$ are used as inputs of a multivariate analysis tool (kNN) in order to set an upper limit on the cross section. For the $\mu\nu jj$ channel, a similar approach is considered. Events are selected so as to contain one muon, two jets and high missing transverse energy. Here again, data are found consistent with the SM predictions and kNN is used to set a limit on the production cross section of a second-generation LQ, based on the input variables $S_T$, $M_{\mu\nu}$, $M_{\nu j}$ and $M_{\mu j}$. Figure 3 represents the combination of the two channels: if $\beta = 1$, second-generation LQs with a mass below 316 GeV/$c^2$ are ruled out. If $\beta = 0.5$, the lower limit on the leptoquark mass is 270 GeV/$c^2$.

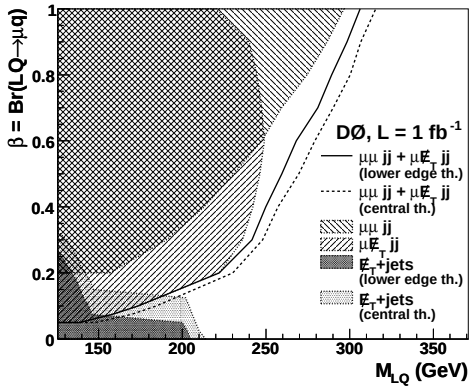


**FIGURE 3.** Combination of the LQ2 decay channels in the ($\beta$, M$_{LQ}$) plane (right).

## SEARCHES FOR THIRD-GENERATION LEPTOQUARKS

In the third generation, a search for leptoquarks at DØ [6] has been performed in the final state consisting of two tau candidates and two b quark jets. One tau lepton is supposed to decay leptonically ($\tau_1 \rightarrow \mu\nu\nu$) and the other hadronically ($\tau_2 \rightarrow$h$^{\pm}\nu$). Here, the dominant sources of physical background are $W$ or $Z$ bosons produced together with light jets, and top quark production. Their estimation relies on Monte Carlo simulation. Background contributions from QCD multijet production and light flavor jets misidentified as b-jets are extracted from data. Events are required to have two tau candidates and two jets with high $E_T$. The tau candidates are identified using a neural network based on reconstructed tracks and calorimeter informations. Then, jets are subjected to a b-tagging algorithm and events divided into two subsamples, one with exactly one tagged $b$ jet and the other with $\geq 2b$ jet tags. No excess has been observed above the SM expectations. The $S_T$ spectrum is used to set lower limits on a LQ3 mass at 210 GeV/$c^2$

for $\beta = 1$. When the decay LQ3 $\rightarrow \nu t$ becomes kinematically possible, with the inclusion of a phase space factor, the cross section times branching ratio for the charge 2/3 LQ3 $\rightarrow \tau b$ decreases; in this case, the limit on the LQ3 mass is found at 207 GeV/$c^2$.

It is also interesting to mention that the best limits on a vector LQ3 mass to date, have been obtained by the CDF Collaboration [7] from a dataset corresponding to 322 pb$^{-1}$ of integrated luminosity. In this analysis, the pair-produced third-generation vector leptoquarks (VLQ3) are assumed to both decay into a b quark and a tau lepton, and yield two jets from the b quarks, an electron or muon from a leptonically decaying tau, and a hadronically decaying tau. Assuming Yang-Mills and minimal couplings of the VLQ3 with the fermions, and a branching ratio BR(VLQ3 $\rightarrow b\tau$) = 1, the limits on the VLQ3 pair-production cross section are interpreted as lower limits at 95% C.L. on a VLQ3 mass for the two couplings at 317 GeV$/c^2$ and 251 GeV$/c^2$ respectively.

## CONCLUSION

An intense search for Leptoquarks of the three generations in all the decay modes has been performed throughout the data taking period at Tevatron, and we presented here the most recent results from the DØ Collaboration. No evidence of Leptoquarks, indicating the existence of new physics, has been observed in data samples corresponding to 1 to 2.5 fb$^{-1}$ of integrated luminosity. But with more than 6 fb$^{-1}$ now collected at Tevatron and later at LHC, LQ searches, as part of the hunt for New Phenomena, have without any doubt, a very promising future.

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