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Search for First Generation Leptoquarks at D0

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1. Introduction

Because of the limitations of the standard model (SM), several extensions have been proposed, among them supersymmetry (SUSY), grand unified theories, and string theory. Many of these extensions predict the existence of particles that directly connect the lepton and quark sectors. By combining leptons and quarks in multiplets of a larger symmetry group, they are expected to interact through new mediating bosons called leptoquarks (LQ) [1, 2]. Leptoquarks can either be scalar or vector fields. The analysis presented focuses on the search for scalar leptoquarks [3]. This search is independent of specific extensions of the SM because effective models are assumed for experimental searches for leptoquarks, . In $p\bar{p}$ collisions such as at the Tevatron collider, leptoquarks can be produced in leptoquark-antileptoquark pairs. Leptoquark pair production can occur via both, quark-antiquark annihilation and gluon-gluon fusion, although quark-antiquark annihilation dominates. The production cross section for scalar leptoquarks depends only on the strong coupling constant and on the leptoquark mass, and is known at next-to-leading order (NLO). Once produced, leptoquarks can decay to two final states: ℓq and $\nu q'$ (where $\ell = e,\ \mu$, or τ). It is assumed that in the low energy limit there is no intergenerational mixing. For first generation LQ pairs the final state will contain a pair of leptons (e or ν_e) and a pair of quarks (u or d). The analysis presented considers the case in which one leptoquark decays into a eq and the other to $\nu_e q'$. We define β as the branching ratio of a first generation leptoquark to decay to eq. Then the probability for a leptoquark to decay to $\nu_e q'$ is $(1-\beta)$, and the probability for a leptoquark pair to decay to the final state $eq\nu_e q'$ is $BR(LQLQ \to eq\nu_e q') = 2\beta(1-\beta)$. Therefore the probability to obtain $eq\nu_e q'$ in the final state becomes maximal for $\beta = 0.5$.

2. Experimental Setup and Simulation

The analysis is based on 5.4 fb^{-1} of $p\bar{p}$ collision recorded by the D0 detector during Run II at the Tevatron collider. The center of mass energy of the collider was $\sqrt{s} = 1.96$ TeV. The D0 detector is an all-purpose detector with a tracking system consisting of a silicon vertex detector and a fiber tracker in a 2 T magnetic field, a liquid argon calorimeter with a coverage up to $\eta = 4.2$ and a muon system with very high purity. A three level trigger system allows to select events of interested in which then lepton, quarks and missing energy are reconstructed. Details to detector and reconstruction can be found in [4]. Events must satisfy at least one trigger from the single-electron and electron plus jet trigger sets. For all data samples, trigger objects are required to match the reconstructed objects. The trigger efficiencies are measured in data and parametrized for specific lepton and jet identification criteria.

Scalar leptoquark pair Monte Carlo (MC) samples are generated using PYTHIA and are produced for different LQ masses between 200 and 360 GeV. Diboson (WW, WZ and ZZ) background processes are produced with PYTHIA as well, whereas $t\bar{t}$ and $V+$jets samples (with $V = W,\ Z$) are produced using the ALPGEN generator and then interfaced in PYTHIA for parton showering and hadronization. Single top production is simulated using COMPHEP. Signal and diboson production cross section processes are calculated with next-to-leading-order (NLO) accuracy and $V+$jets and $t\bar{t}$ at next-to-next-to-leading-order (NNLO) [5]. Instrumental background from QCD multijet production is estimated from data. The generated transverse momenta spectrum p_T of the Z boson is corrected according to the spectrum measured in data. The p_T spectrum of the W boson is corrected considering the differences between Z and W boson p_T spectra at NNLO.

3. Analysis

In the $eq\nu eq'$ final state one does not know a priori how to assign the jets to the leptoquark decaying to eq or $\nu eq'$. Therefore, to reconstruct the properties such as mass and p_T of the leptoquarks from the final products, an algorithm is needed to choose the best pairing. Although no requirement is placed on the jet multiplicity per event only the two highest momentum jets are used for the two possible combination of the leading jet either pairing with the electron or the neutrino. There are various ways to pair the objects, it has been found that it is most effective to minimize the difference between the transverse masses, $M_T = \sqrt{E_T^2 - \vec{p}_T^2}$. Here E_T and $\vec{p}_T$ are transverse energy and transverse momentum of the two leptoquarks. This pairing algorithm is 75% effective in finding the correct pairing assignment. Events are required to be consistent with the $LQ\overline{LQ} \to eq\nu q'$ process by selection one electron, large missing energy ($\not\!\!E_T$) and at least two jets. The electron has to exceed a minimum transverse momentum $p_T > 15$ GeV and to be within the central calorimeter region $|\eta| < 1.1$, $\not\!\!E_T > 15$ GeV, and at least two jets with $p_T > 20$ GeV and $|\eta_{\rm jet}| < 2.5$. Multijet (MJ) and instrumental background is suppressed by requiring $\not\!\!E_T/50 + M_T^{e\nu}/70 \geq 1$. Here $M_T^{e\nu}$ is the transverse mass between the electron and neutrino in GeV.

4. Analysis

Additional cuts are applied to reduce SM background processes. To minimize $V+$jets processes $M_T^{e\nu} > 110$ GeV is required. Because the longitudinal component of the neutrino momentum p_z is not measurable, we reconstruct only the visible mass m_{vis} of the decay $LQ \to \nu eq'$ as $M_{LQ} = M(\text{jet} + \nu_{vis})$. The four vector of ν_{vis} is given as $(\not\!p_x, \not\!p_y, 0, \not\!\!E_T)$. $\sum M_{LQ}$ is the sum of the invariant mass of the decay $LQ \to eq$ and the visible mass of the decay $LQ \to \nu_e q'$. By requiring $\sum M_{LQ} > 350$ GeV SM backgrounds are further suppressed. A third and last selection requirement is formed by applying a selection of $S_T > 450$ GeV. S_T is the scalar sum of the p_T of the electron, $\not\!\!E_T$ and the p_T of the two leading jets. All selection criteria have been optimized to achieve best expected sensitivity for $M_{LQ} = 260$ GeV. After each selection the number of expected and observed events agree reasonably well and are given along with the expected signal for $M_{LQ} = 260$ GeV in Tab. 1.

	Data	Total Background	Signal
Preselection	65992	65703 $\pm$ 5958	50 $\pm$ 7
$M_T^{e\nu} > 110$ GeV	990	986 $\pm$ 82	43 $\pm$ 5
$\sum M_{LQ} > 350$ GeV	64	55 $\pm$ 4	27 $\pm$ 4
$S_T > 450$ GeV	15	15 $\pm$ 1	24 $\pm$ 3

Table 1: Numbers of events for data and contributing processes after each selection requirement for $M_{LQ} = 260$ GeV and $\beta = 0.5$. Uncertainties include statistical contributions. The only.

Systematic uncertainties affecting only the normalization of the background and the signal efficiency include uncertainties on cross sections of signal (10%) and background (6% – 10%) processes, normalization of the MJ background (20%), integrated luminosity (6.1%), and lepton trigger and identification (4%). Uncertainties which also affect the differential distribution of S_T which is the quantity used to set the limits on LQ are due to the jet energy resolution and scale, jet identification efficiency, parton distribution functions, and the modeling of the jet p_T distribution of the dominant $W+$jets background. Their impacts are evaluated by repeating the analysis with values varied by ± 1 standard deviation (SD). Uncertainties on the jet p_T modeling. The Z-boson p_T distribution is modeled to match the distribution observed in data, taking into account the dependence on the number of reconstructed jets. To reproduce the W-boson p_T distribution in simulated events, the product of the measured Z-boson p_T spectrum and the ratio of W to Z-boson p_T distributions at NLO is used as correction [6, 7]. The difference between these distributions before and after corrections are taken as ± 1 SD bands.

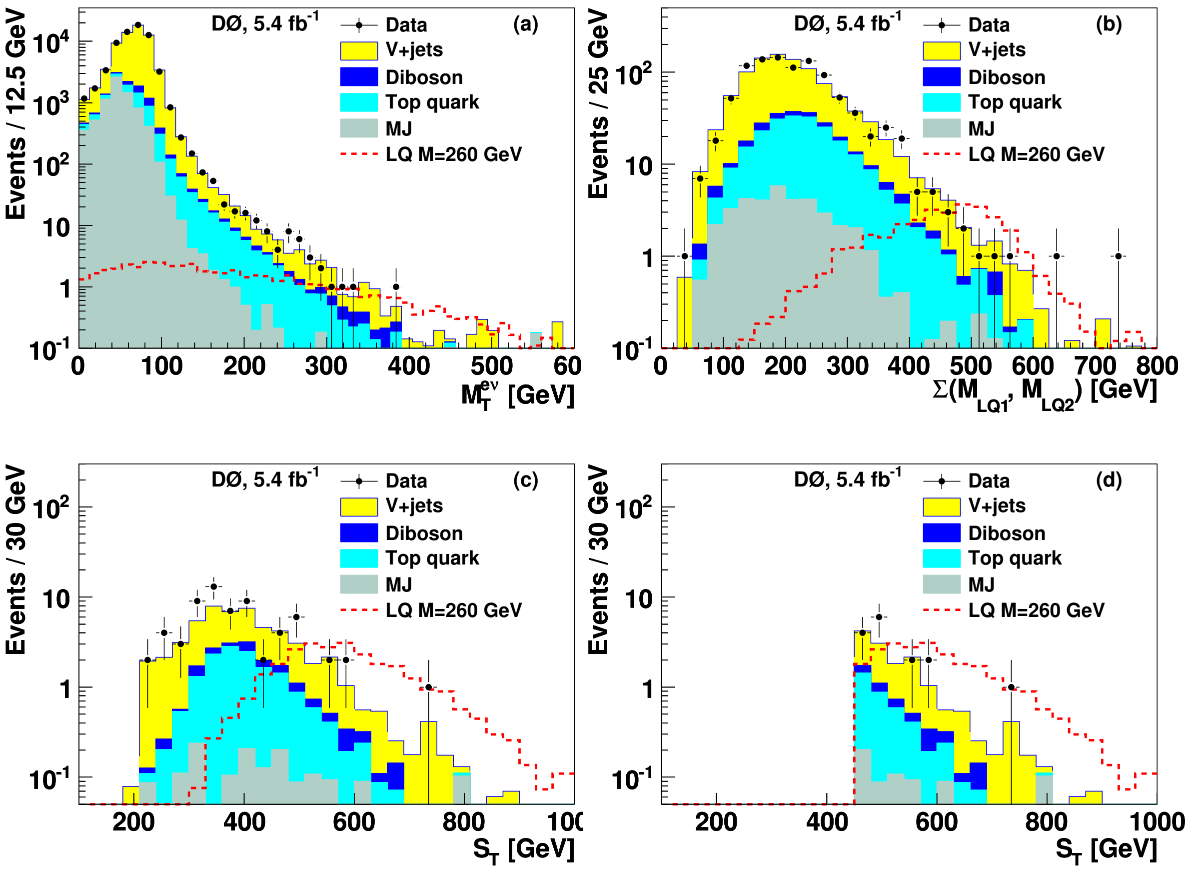

Figure 1: **(a)** $M_T^{e\nu}$ distribution after preselection **(b)** $\sum M_{LQ}$ for $M_T^{e\nu} > 110$ GeV **(c)** S_T for $M_T^{e\nu} > 110$ and $\sum M_{LQ} > 350$ GeV **(d)** S_T after final selection as used to set upper limits on LQ pair production

The distribution of S_T after all selection requirements is used as a discriminant to set an upper limit on LQ pair production cross section in the $eq\nu_e q$ final state. For each generated leptoquark mass the limit is calculated as 95% confidence level (C.L.) using the semifrequentist CL_s method based on a Poisson log-likelihood test statistic [8]. Signal and background normalizations and shape variations due to systematic uncertainties are incorporated assuming Gaussian priors. The best fit to the background distributions is evaluated by minimizing a profile likelihood function with respect to the observed data and various sources of uncertainty, maintaining all correlations among systematic uncertainties [9]. Limits on the cross section multiplied by the branching fraction and the theoretical LQ cross section for $\beta = 0.6$ are shown in Fig. 2 a). The limit on the LQ mass as a function of β is determined as shown in Fig. 2 b), and compared to the previous measurements from D0 [10], CMS [11, 12] and Atlas [13].

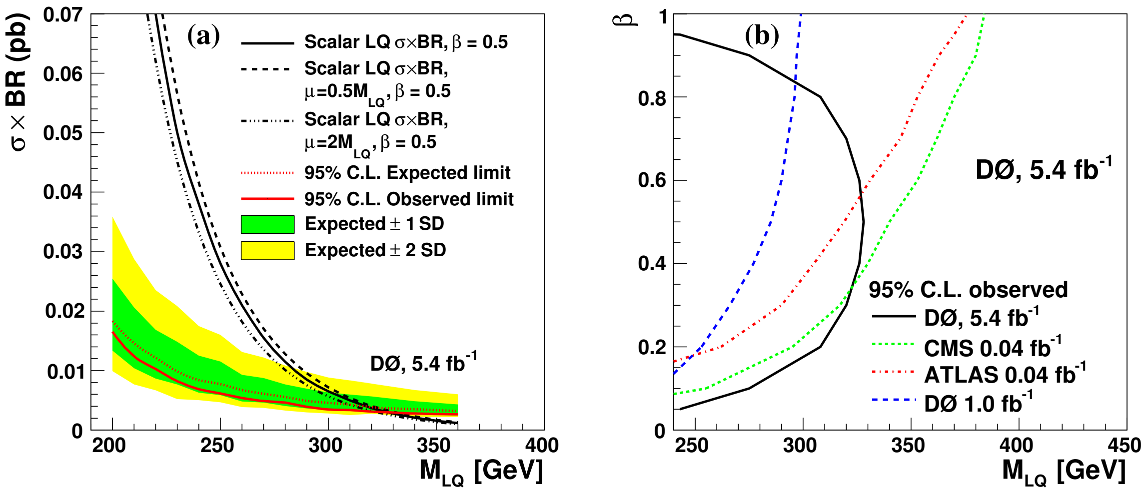

Figure 2: (a) Expected and observed upper limits calculated at the 95%C.L. on the LQ cross section as a function of M_{LQ} for a scalar leptoquark compared with the NLO prediction for $\beta = 0.5$. The NLO cross section is shown for different choices of the renormalization and factorization scales, $\mu = M_{LQ}$, $\mu = 2 \times M_{LQ}$, $\mu = 0.5 \times M_{LQ}$ **(b)** 95% C.L. observed limit for $\mu = M_{LQ}$ on the leptoquark mass as a function of β compared with the previous D0, CMS and Atlas results.

5. Summary

A search for scalar leptoquark pair production in the $eq\nu_e q'$ final state in 5.4 fb^{-1} of integrated luminosity of $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV has been performed. No signal has been observed and the production of first generation leptoquarks with $M_{LQ} < 326$ GeV of $\beta = 0.5$ are excluded at 95% C.L.

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