

Searches for Leptoquark Production at D0

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Abstract. Recent searches for leptoquark production in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV are presented using data samples with integrated luminosities up to 1 fb^{-1} recorded with the D0 detector.

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1 Introduction

Leptoquarks, hypothetical colored bosons which carry both lepton and quark quantum numbers and thus allow lepton-quark transitions, are predicted by numerous extensions of the standard model (SM) [1]. At hadron colliders, leptoquarks are predominantly produced in pairs via the strong coupling. Single leptoquarks can be produced via t -channel leptoquark exchange, which depends on the unknown leptoquark-lepton-quark coupling λ .

As the pair-production of scalar leptoquarks is a pure QCD process¹ which has been calculated to NLO [2], the cross-section depends only on the assumed leptoquark mass M_{LQ} . In case of vector leptoquarks, the pair-production cross section is generally much larger and additionally depends on unknown anomalous couplings. Furthermore, the cross section has only been calculated at LO. Therefore, all searches by the D0 experiment presented below assume scalar leptoquarks.

Leptoquarks could, in principle, decay into any combination of a quark and a lepton, but leptoquarks with masses as low as $\mathcal{O}(100 \text{ GeV})$ are only allowed to couple to one generation of quarks and leptons, since they otherwise would generate lepton number violation and sizable flavor-changing neutral currents. The branching fractions of the leptoquark decays into a charged lepton and quark or neutrino and quark are determined by the respective LQ - ℓ - q coupling. Thus, leptoquark pair-production can produce three characteristic final states: $\ell^+ \ell^- qq$, $\ell^\pm \nu qq$, and $\nu \nu qq$.

2 Pair-production of second generation scalar leptoquarks

Second generation scalar leptoquarks (LQ_2) were already searched for in the channel $LQ_2 \bar{L} \bar{Q}_2 \rightarrow \mu q \mu q$

using an integrated luminosity of 250 fb^{-1} [3]. In combination with previous D0 measurements lower mass limits of $M_{LQ_2} > 251 \text{ GeV}$ for $\beta = \mathcal{B}(LQ_2 \rightarrow \mu q) = 1$ and $M_{LQ_2} > 204 \text{ GeV}$ for $\beta = 1/2$ were set. All limits reported in this note are at 95% confidence level.

The first D0 search performed in Run II in the channel $LQ_2 \bar{L} \bar{Q}_2 \rightarrow \mu q \nu q$, which has maximal sensitivity for $\beta = 1/2$, is based on the Run IIa data set of 1 fb^{-1} [4]. The preselection required exactly one muon with large transverse momentum, $p_T > 20 \text{ GeV}$, reconstructed in a wide range of pseudorapidity, $|\eta| < 2$, large missing transverse energy, $\cancel{E}_T > 30 \text{ GeV}$, and at least two jets with transverse energies $E_T > 25 \text{ GeV}$ and $|\eta| < 2.5$. In addition, events with the \cancel{E}_T direction opposite in azimuth to the muon were removed, as they were likely due to badly reconstructed muons resulting in an overestimated \cancel{E}_T . The background consisted of W + jets, Z + jets (with a non-identified μ) and $t\bar{t}$ -production, which were estimated from simulation, and a small contribution of QCD multijet production, which was derived from data. The W + jets background was normalized to data at preselection level within a region of transverse mass $M_T(\mu\nu)$ dominated by W boson production.

The leptoquark signal was discriminated from the background using the muon-neutrino transverse mass $M_T(\mu\nu)$, the scalar transverse energy $S_T = E_T(\mu) + \cancel{E}_T + E_T(\text{jet}_1) + E_T(\text{jet}_2)$, the transverse mass $M_T(\nu j_1)$ constructed from \cancel{E}_T and the momentum of the leading jet, and the invariant mass of the muon jet combination closest to the assumed leptoquark mass. These selection requirements are motivated by the high leptoquark mass and consequently high transverse momenta of its decay products. For an assumed leptoquark mass $M_{LQ_2} = 200 \text{ GeV}$, six data events were selected with a background prediction of 6.4 ± 1.1 events, of which 50% were from W + jets production and the remainder from $t\bar{t}$, Z/γ^* + jets, and multijet production. The systematic error on the W + jet background prediction was found to be dominated by uncertainties in the jet energy scale and in the modeling of the jet transverse momentum shapes.

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¹ when neglecting the contribution from t -channel lepton exchange which is $\propto \lambda^2$

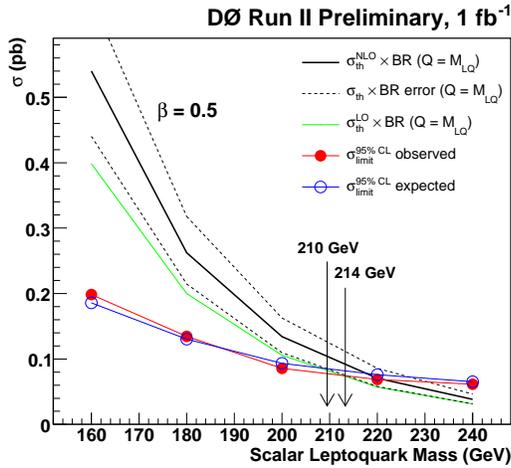


Fig. 1. Search for $LQ_2\overline{LQ}_2 \rightarrow \mu q\nu q$: comparison of the upper cross-section limit for the pair-production of second generation leptoquarks with the predicted cross section.

Upper limits on the cross section times branching ratio were obtained and compared to the NLO prediction reduced by its uncertainty to derive a leptoquark mass limit as shown in Fig. 1. From this analysis alone, a lower mass limit for scalar second generation leptoquarks of $M_{LQ_2} > 214$ GeV at $\beta = 0.5$ was set. The previous best limits were $M_{LQ_2} > 170$ GeV obtained in the $\mu\nu jj$ channel and $M_{LQ_2} > 208$ GeV from a combination with the $\mu\mu jj$ and $\nu\nu jj$ channels [5].

3 Single production of scalar leptoquarks

The production of single leptoquarks leads to final states consisting of two leptons and one jet. A search for single leptoquark production was performed using $\mu\mu j$ events reconstructed in a data sample of 300 fb^{-1} [6]. Despite their couplings to the second lepton generation, the leptoquarks were assumed to couple to the first quark generation, to avoid a suppression of the cross section due to the parton distribution functions. In the standard model there is no explicit connection between a given lepton generation with any of the three quark generations. The dominant background in this search was found to be from $Z/\gamma^* +$ jets production.

The event distribution in the two-dimensional plane given by the di-muon mass $M_{\mu\mu}$ and the E_T of the leading jet was used to define four signal bins. Those were combined with the three signal bins of the leptoquark pair-production search in the $\mu\mu jj$ channel [3], in order to derive upper cross section limits on the production of single leptoquarks. The limits are given in Fig. 2 for three different scenarios: (a) the only contribution in the signal region is from SM background and single leptoquark production, (b) pair-production contributes in addition with the assumption $\beta = 1/2$, and (c) as (b) but with $\beta = 1$. Lower limits on the leptoquark mass were derived assuming $\lambda = 1$. Compared to the search for leptoquarks which considered only

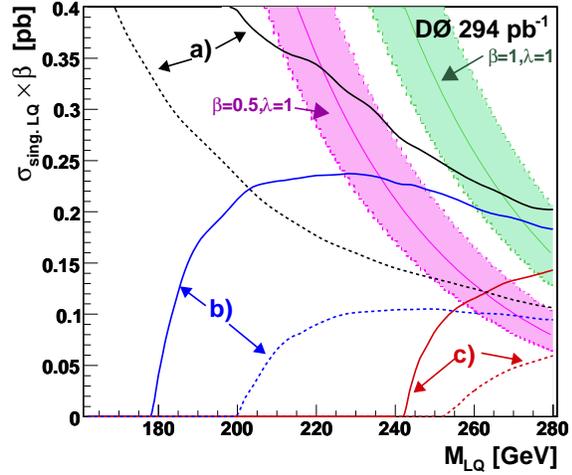


Fig. 2. Search for $\mu LQ \rightarrow \mu\mu q$: cross section limits for the production of single leptoquarks for the three scenarios described in the text, compared to the theoretical prediction.

pair-production (corresponding to $\lambda \ll 1$) the mass limits were improved to $M_{LQ} > 274$ GeV for $\beta = 1$ and to $M_{LQ} > 226$ GeV for $\beta = 1/2$, respectively.

4 Pair-production of third generation leptoquarks

Searches for the pair-production of third generation leptoquarks were performed in the $\tau b\tau b$ and $\nu b\nu b$ final states.

4.1 The $\tau\tau b\bar{b}$ final state

The search for $LQ_3\overline{LQ}_3 \rightarrow \tau b\tau b$ is based on the Run IIa data set of 1 fb^{-1} [7]. One of the taus was required to decay into a muon (τ_μ) and the other tau needed to decay hadronically (τ_h). Hadronic τ decays were reconstructed from calorimeter clusters and tracks and were separated into three types based on their decay. For each τ type a neural network was used for the discrimination against background. The b quark jets were identified using a neural network tagging algorithm with relatively loose conditions, corresponding to a b -tagging efficiency of 72% at a light quark misidentification rate of 6%. Subsamples with one and two b -tags, respectively, were defined.

The main background contribution were $t\bar{t}$, $Z/W +$ jets, and QCD multijet production. The contribution from the latter was estimated using like-sign $\tau_\mu\tau_h$ candidate events. The scalar sum of transverse energies $S_T = E_T(\mu) + E_T(\tau_h) + E_T(\text{jet}_1) + E_T(\text{jet}_2) + \cancel{E}_T$ was used as the main discriminant between the SM background and the leptoquark signal. The dominant systematic uncertainties were due to uncertainties in the cross sections of the background processes and in the b -tagging efficiency. Lower limits on the leptoquark mass were derived from the combination of the single-tag and double-tag subsamples (see Fig. 3). Assuming the

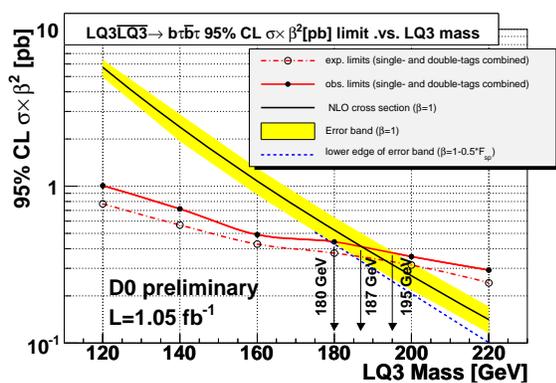


Fig. 3. Search for $LQ_3\overline{LQ}_3 \rightarrow \tau b\tau b$: observed and expected upper limit on the pair-production cross section compared to the theoretical prediction.

hypothetical leptoquark has charge-4/3, which implies a branching fraction $\mathcal{B}(LQ_3 \rightarrow \tau b) = 1$, a lower mass limit $M_{LQ_3} > 180$ GeV was set, which corresponds to an upper cross section limit of 0.42 pb. For charge-2/3 leptoquarks, decays into νt are allowed as well, albeit those are kinematically suppressed. Assuming equal leptoquark couplings to τb and νt , $\mathcal{B}(LQ_3 \rightarrow \tau b)$ hardly changes and the same mass limit was obtained.

Based on the same final state, the CDF collaboration previously published a search for the pair-production of third generation *vector* leptoquarks [8]. When including the uncertainty on the signal cross-section prediction, they obtained lower mass limits of $M_{LQ_3} > 294$ GeV and $M_{LQ_3} > 223$ GeV for the case of Yang-Mills couplings and the minimal couplings model, respectively. The latter corresponds to an upper cross-section limit of 0.61 pb.

4.2 The $b\overline{b}\cancel{E}_T$ final state

The D0 collaboration recently published a search for the pair-production of third generation scalar leptoquarks decaying into a neutrino and a b quark using 425 pb^{-1} of data collected with a missing transverse energy and a single-muon trigger [9]. Two selections based on the two different triggers were combined in the analysis. In both cases minimal requirements on the leading and second-leading jet E_T and on \cancel{E}_T were applied. Furthermore, two jets were required to be tagged as b jets with at least one of them by a jet lifetime probability algorithm based on the impact-parameters of the associated tracks. For the selection using the single-muon triggers, which is motivated by the semi-leptonic decays of B -mesons, one of the jets was required to be tagged with a soft-muon tagger.

The cuts on the final selection variables, \cancel{E}_T and scalar $H_T = \sum_{\text{jets}} E_T$, were optimized as function of the assumed leptoquark mass M_{LQ_3} . The main background sources were determined to be $t\overline{t}$, $W/Z + b\overline{b}$, and $W/Z + c\overline{c}$ production. The uncertainty on their contribution was found to be dominated by uncertainties on the cross-section predictions, on the jet energy calibration, and on the b -tagging efficiency. Assuming that

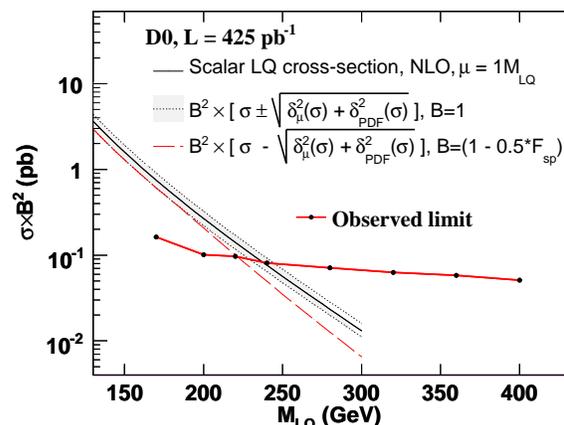


Fig. 4. Search for $LQ_3\overline{LQ}_3 \rightarrow \nu b\nu b$: upper limit on the pair-production cross section compared to the theoretical prediction.

the leptoquarks have charge-1/3 and that they decay exclusively in a neutrino and a b quark, a mass limit on third-generation leptoquarks of $M_{LQ_3} > 229$ GeV was derived as shown in Fig. 4. Taking into account leptoquark decays into τ and t quark as well and assuming equal couplings, a mass limit of $M_{LQ_3} > 221$ GeV was set.

5 Conclusions and perspectives

The D0 experiment at the Tevatron $p\overline{p}$ -collider has searched for single and pair-production of leptoquarks in a multitude of final states using data sets with up to 1 fb^{-1} . No indication for leptoquark production has been found and stringent limits, which are significantly improved compared to Run I, were set. Nearly 3 fb^{-1} of integrated luminosity has been recorded in summer 2007 and the experiment is expected to collect much larger data sets during the full period of Run II.

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