Searches for leptoquark production at Tevatron

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Abstract. Recent searches for leptoquark production in $pp$ collisions at $\sqrt{s} = 1.96\text{ TeV}$ are presented using data samples with integrated luminosities up to $1\text{ fb}^{-1}$ recorded with the DØ and CDF detectors.

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 [2]. Single leptoquarks can be produced via t-channel leptoquark exchange, which depends on the unknown leptoquark-lepton-quark coupling $\lambda$.

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 $LQ-\ell-q$ coupling. Thus, leptoquark pair-production can produce three characteristic final states: $\ell^+\ell^-qq$, $\ell^\pm\nu qq$, and $\nu vqq$.

2. Pair-production of second generation scalar leptoquarks
The first DØ search performed in Run II in the channel $LQ_2LQ_2 \to \mu qq\nu$, which has maximal sensitivity for $\beta = B(LQ_2 \to \mu q) = 1/2$, is based on the Run IIa dataset of $1\text{ fb}^{-1}$ [3].

The background consisted of $W + \text{jets}$, $Z + \text{jets}$, $t\bar{t}$ and a small contribution of QCD multijet production. The leptoquark signal was discriminated from the background using the muon-neutrino transverse mass $M_T(\mu\nu)$, the scalar transverse energy $S_T = E_T(\mu) + E_T(jet_1) + E_T(jet_2)$, the transverse mass $M_T(\nu j_1)$ constructed from $E_T$ and the momentum of the leading jet, and the invariant mass of the muon jet combination closest to the assumed leptoquark mass.

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 $M_{LQ_2} > 214\text{ GeV}$ at $\beta = 0.5$ was set. All limits reported in this note are at 95% confidence level.
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 by DØ using $\mu\mu j$ events reconstructed in a data sample of 300 fb$^{-1}$ \cite{4}.

The dominant background in this search was found to be $Z/\gamma^{*} + \text{jets}$ 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 $jj$ channel \cite{5}, in order to derive upper cross section limits on the production of single leptoquarks.

Lower limits on the leptoquark mass were derived assuming $\lambda = 1$. Compared to the search for leptoquarks which considered only 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

4.1. The $\tau\tau bb$ final state

The DØ search for the pair-production of scalar leptoquarks in the $\tau\tau bb$ final state is based on the RunIIa data set of 1 fb$^{-1}$ \cite{6}. One of the taus was required to decay into a muon (\(\tau_{\mu}\)) and the other tau needed to decay hadronically (\(\tau_{h}\)). Hadronic $\tau$ decays were reconstructed from calorimeter clusters and tracks and were separated into three types based on their decay. For each $\tau$ 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. Subsamples with one and two $b$-tags, respectively, were defined.

The main background contribution were $t\bar{t}$, $Z/W + \text{jets}$, and QCD multi-jet production. The scalar sum of transverse energies $S_{T} = E_{T}(\mu) + E_{T}(\tau_{h}) + \mathcal{E}_{T}(\text{jet} \ _{1}) + E_{T}(\text{jet} \ _{2})$ was used as the main discriminant between the SM background and the leptoquark signal.

Lower limits on the leptoquark mass were derived from the combination of the single-tag and double-tag subsamples (see Fig. 2). Assuming the 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 $\nu t$ are allowed as well, albeit those are kinematically suppressed. Assuming equal leptoquark couplings to $\tau b$ and $\nu t$, $B(LQ_3 \to \tau b)$ hardly changes and the same mass limit was obtained.

The CDF collaboration previously published a search for the pair-production of third generation vector leptoquarks [7] based on 322 pb$^{-1}$ with similar final state, but including the $\tau$ decay into an electron. No $b$-tagging was required.

The main background contributions were $t\bar{t}$ and $Z/W+\text{jets}$ production. The discrimination between the leptoquark signal and the SM background was performed by using the number of jets and a likelihood based on two regions of the scalar sum of transverse energies $H_T = E_T(\mu) + E_T(\tau_b) + E_T(\text{jet}_1) + E_T(\text{jet}_2)$.

By comparing the upper cross-section limit with the nominal theory prediction, leptoquark masses up to 251 GeV were ruled out for the case of the minimal couplings model, and a lower limit of $M_{LQ_3} > 317$ GeV was set when considering the Yang-Mills couplings. 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 $\mathbf{\bar{b}bE_T}$ final state

The DØ 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 [8]. Two selections based on the two different triggers were combined in the analysis. Two tagged $b$-jets were required.

The main background sources were $t\bar{t}$, $W/Z + b\bar{b}$, and $W/Z + c\bar{c}$ production. Final selection cuts were based on the $E_T$ and scalar $H_T = \sum_{\text{jets}} E_T$.

Assuming that 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. Taking into account leptoquark decays into $\tau$ 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 DØ and CDF experiments at the Tevatron $p\bar{p}$-collider have 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. The integrated luminosity available at CDF and DØ during the summer 2007 is larger than 2.5 fb$^{-1}$. Both experiments are expected to collect much larger data sets for the full period of Run II.

References