Leptoquark Searches at the Tevatron

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ABSTRACT

This article summarizes the status of the Tevatron Run II searches for leptoquarks in $p\bar{p}$ collisions at $\sqrt{s} = 1.96\text{ TeV}$. The analyses discussed use datasets with integrated luminosities ranging from 72 pb$^{-1}$ to 200 pb$^{-1}$.

1. Introduction

The existence of leptoquarks (LQ), color triplet bosons with lepton and quark quantum numbers, is predicted by several extensions of the Standard Model [1]. Limits on the proton lifetime, lepton flavor violating decays, and flavor changing neutral currents lead to the assumption that the leptoquarks exist in three generations each coupling only to one lepton and one quark generation. At hadron colliders leptoquark pairs can be produced via the strong interaction. The production cross section of scalar leptoquarks is therefore practically model independent. Each leptoquark can either decay into a quark and a charged lepton or into a quark and a neutrino. The branching ratio $\beta$ of the leptoquark to decay into a charged lepton and a quark depends on the details of the model. The limits will therefore be given either as a function of $\beta$ or for fixed values of $\beta$. The combinations of the two leptoquark decays lead to distinctive topologies which will be discussed in the following sections. Since the region of interest for leptoquark masses is typically of the order of 200 GeV or higher the decay products of the leptoquarks will have high energies. If both leptoquarks decay into charged leptons one will observe two leptons of the same flavor and two highly energetic jets. If one leptoquark decays into a charged lepton and the other into a neutrino one will observe two jets, one lepton, and missing transverse energy. Finally if both leptoquarks decay into neutrinos one will observe two jets and missing transverse energy.

2. First generation leptoquarks

2.1. Two jets and two electrons

If both leptoquarks decay into a quark and an electron one will observe two high energetic electrons and two jets. The basic selection for the preliminary DØ analysis are two jets with transverse energy $E_T > 20\text{ GeV}$ and two electrons with transverse energy $E_T > 25\text{ GeV}$. The main backgrounds are due to electron pairs from $Z$-decays and Drell-Yan events with two additional jets, and to events where jets are misidentified as electrons. (In order to maintain a very high signal efficiency the DØ analysis uses loose electron selection criteria.) The background can be suppressed by vetoing on the $Z$ mass.
region in the electron pair mass and by exploiting the high energy of the objects with a cut on the scalar sum $S_T$ of the transverse energies of the electrons and jets (see Fig. 1): $S_T = E_T(e_1) + E_T(e_2) + E_T(j_1) + E_T(j_2)$.

Figure 1: Comparison of the electron pair mass and the $S_T$ distribution between the data and the expected background. The $S_T$ distribution is shown after applying a Z-veto cut. The dot-dashed histogram in the $S_T$ plot is the expectation for a 240 GeV leptoquark signal. The shading represents the uncertainty on the total background. Comparison of the 95% confidence limit on the production cross section of 1st generation leptoquarks with the theoretical NLO cross section [2]. The dashed lines indicate the change in the NLO prediction if the renormalization and factorization scales are changed from $M_{LQ}$ to $2M_{LQ}$ and to $M_{LQ}/2$.

After all cuts the DØ analysis observes 0 events while 0.4 ± 0.1 events are expected from background. The typical efficiency is about 30%. Since no significant excess is observed a limit on the production cross section times branching ratio can be calculated and compared to the expected cross section (see Fig. 1). From this comparison DØ derives a preliminary limit on the mass of scalar leptoquarks of:

$$M_{LQ}^{\text{scalar}} (1\text{st \, gen}) > 238 \text{ GeV} \quad \text{(DØ preliminary, 175 pb}^{-1}, \beta = 1) \quad (1)$$

at 95% confidence level. The corresponding preliminary limit obtained by CDF with a similar analysis is:

$$M_{LQ}^{\text{scalar}} (1\text{st \, gen}) > 230 \text{ GeV} \quad \text{(CDF preliminary, 175 pb}^{-1}, \beta = 1). \quad (2)$$

2.2. Two jets, one electron, and missing energy

If one of the two leptoquarks decays into a neutrino and a quark and the other into an electron and a quark one will observe two jets, an electron, and missing energy due to the unobserved neutrino. The main background in this case are events with a W and two additional jets, and events where a jet or photon is misidentified as an electron. DØ uses a pre-selection of events with two jets with $E_T > 25 \text{ GeV}$, one electron with $E_T > 35 \text{ GeV}$, and missing transverse energy $E_{\text{miss}}^{\text{T}} > 25 \text{ GeV}$. Events containing W decays are vetoed by requiring that the transverse mass of the electron and the neutrino (estimated from the missing energy) be larger than 130 GeV. The high energy of the leptoquark decay products is again exploited by a cut on the scalar sum of the four
objects $S_T = E_T(e_1) + E_T^{miss} + E_T(j_1) + E_T(j_2)$. The preliminary limits on the leptoquark mass for $\beta = 0.5$ are:

$$M_{LQ}^{scalar} (1^{st} \text{ gen}) > 194 \text{ GeV}( \text{DØ preliminary, 175 pb}^{-1}, \beta = 0.5),$$

(3)

$$M_{LQ}^{scalar} (1^{st} \text{ gen}) > 166 \text{ GeV}( \text{CDF preliminary, 72 pb}^{-1}, \beta = 0.5).$$

(4)

2.3. Two jets and missing energy

If both leptoquarks decay into a neutrino and a quark only two jets and missing energy are observed. The CDF analysis requires two jets with $E_T > 20 \text{ GeV}$ and missing transverse energy above 60 GeV. After all cuts 124 events are observed with an expected background of 118 ± 14 events. For $\beta = 0$ this excludes scalar leptoquarks in the mass range between 78 GeV and 117 GeV at 95% confidence level (see Fig. 2). This limit is independent of the leptoquark generation.

![CDF Run II Preliminary](image)

Figure 2: Missing transverse energy in the leptoquark signal region. Comparison of the 95% confidence limit on the production cross section of leptoquarks with the theoretical NLO cross section.

2.4. Combination

Fig 3 shows the 95% confidence level lower limit on the mass of a first generation scalar leptoquark as a function of decay probability $\beta$ of the leptoquark into an electron and a quark. In particular for $\beta = 0.5$ DØ finds:

$$M_{LQ}^{scalar} (1^{st} \text{ gen}) > 213 \text{ GeV}( \text{DØ preliminary, 175 pb}^{-1}, \beta = 0.5).$$

(5)

3. Second generation leptoquarks

For second generation leptoquarks both collaborations have studied the case where both leptons decay into a muon and a quark. The main backgrounds are $Z$ decays and Drell-Yan events with two additional jets. The CDF analysis uses a pre-selection of two
muons with $p_T > 25$ GeV and two jets with $E_T^1 > 30$ GeV and $E_T^2 > 15$ GeV. Events with a muon pair mass of $M_{\mu\mu} < 15$ GeV or $75$ GeV $< M_{\mu\mu} < 105$ GeV are vetoed. The background is finally reduced by a two dimensional cut on $E_T(j_1) + E_T(j_2)$ and $p_T(\mu_1) + p_T(\mu_2)$.

The preliminary results are:

$$M_{LQ}^\text{scalar (2nd gen)} > 241 \text{ GeV} \quad \text{(CDF preliminary, 198 pb}^{-1}, \beta = 1.)$$ (6)

$$M_{LQ}^\text{scalar (2nd gen)} > 186 \text{ GeV} \quad \text{(DØ preliminary, 104 pb}^{-1}, \beta = 1.)$$ (7)

4. Conclusions

Hadron colliders where leptoquarks can be produced in pairs via the strong interaction are good places to search for leptoquarks. The large energies of the decay products of the leptoquarks provide clear signatures which can be distinguished from the background. Both DØ and CDF have searched for first and second generation leptoquarks, but no evidence for leptoquarks has been found. Therefore preliminary limits on the leptoquark mass are presented. These limits surpass the Run I limits.

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6. References

[1] D. Acosta and S. Blessing, Annu. Rev. Nucl. part. Sci. 49, 389(1999), and references therein.

[2] M. Kramer et. al., Pair Production of Scalar Leptoquarks at the Fermilab Tevatron, Phys. Ref. Lett. 79, 341(1997).