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## Search for Leptoquarks and Technicolor at the Tevatron

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This note summarizes results on leptoquarks and technicolor searches at the Tevatron with a more particular focus on recent ones. Results on leptoquark pair production with leptoquark decays to  $q\nu$ ,  $qe$ ,  $q\mu$  and  $q\tau$  are given for an analysed luminosity up to  $5.2 \text{ fb}^{-1}$ . In most analyses, both leptoquarks decay identically leading to signatures of jets and missing transverse momentum or jets and charged leptons. Technicolor results are given with a particular emphasis on technirho decaying to  $WZ$  in a tripleton signature and on technirho decaying to a  $W$  and a technipion.

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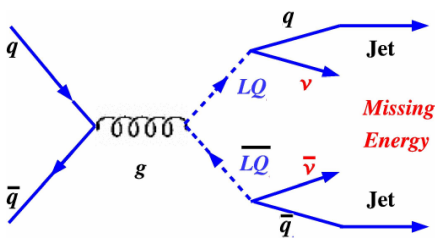
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\*Speaker.

The Fermilab Tevatron collides protons and anti-protons at a center of mass energy of 1.96 TeV. The CDF[1] and D0 [2] detectors record the collision products. At summer 2010, the Tevatron peak luminosity was  $\sim 3.5 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$  and both experiments had a recorded integrated luminosity of  $\sim 8 \text{ fb}^{-1}$ . As a hadronic collider, the Tevatron complex is very well suited to searches for hypothetical new particles interacting strongly. Among these, searches have been performed for leptoquarks and technicolor particles[3].

## 1. Leptoquarks

Leptoquarks (LQ) are hypothetical particles carrying both baryon number and lepton number. Most theoretically favored leptoquarks are QCD triplets and are either scalar or vector[3]. At the Tevatron, they are searched through gluon s-channel pair production (See Fig 1). For scalar leptoquarks, the corresponding cross section depends only on the LQ mass. For vector leptoquarks, the cross section depends also on two anomalous couplings  $\kappa_G$  and  $\lambda_G$  and is always higher than the scalar one for a given mass[4]. Hence lower limits on the scalar LQ mass hold true for the vector LQ mass as well.



**Figure 1:** Feynman diagram for the production of pairs of LQ

MET.

Each leptoquark can decay to  $q + \nu$  or  $q + l$  where  $q$  is a quark,  $\nu$  a neutrino and  $l$  a charged lepton. Lepton flavor violation and Flavour Changing Neutral Current set very strong constraints on LQ couplings to either two lepton families or two quark families[5, 6]. Tevatron searches assume a leptoquark couples to only one quark family and one lepton family. Experimental signature will then be either two jets + missing Transverse Momentum (MET) if both leptoquarks decay to  $q + \nu$ , two jets and two charged leptons of the same family or two jets, a charged lepton and

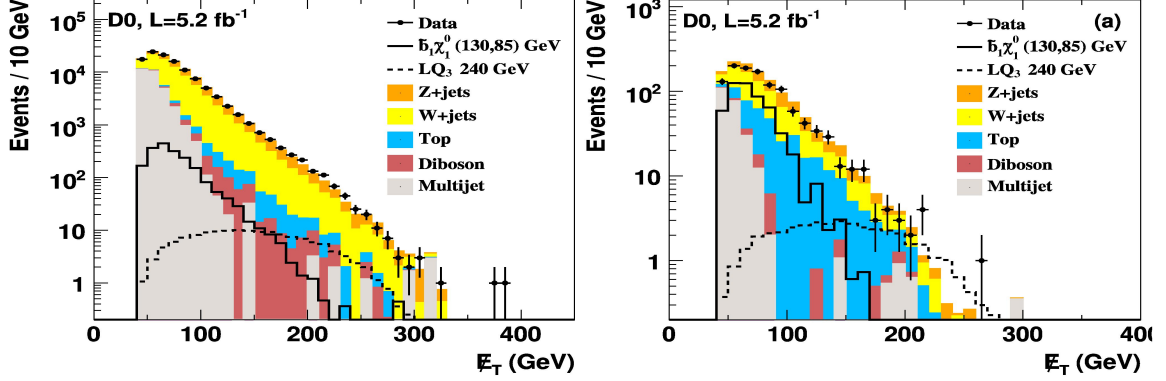
### 1.1 Jets+MET signatures

Signature	analysis	$H_T$	MET	
2jets+MET	low LQ mass	D0	150	75
		CDF	125	80
	high LQ mass	D0	300	125
		CDF	225	100
2b+MET	D0	40	60	

**Table 1:** Thresholds in GeV/c on  $H_T$  and MET for the 2jets+MET analyses.

The two jets+MET signature (See Fig. 1) has been searched for by CDF[7] (resp. D0[8]) with 2 (resp. 2.5)  $\text{fb}^{-1}$  of analysed data. Selected events should contain two jets with transverse momentum  $P_t > 30$  (resp. 35) GeV/c and pseudorapidity  $|\eta| < 1$  (resp. 0.8). A dedicated search of two  $b$ -jets+MET has been performed by D0[9] with 5.2  $\text{fb}^{-1}$  of analysed data. For this case, the two jets were required to be tagged as  $b$ -jets[10] and to have  $P_t > 20$  GeV/c. The two discriminating variables used to separate LQ signal from Standard Model (SM) background are the MET and  $H_T$  defined as the scalar sum of the two jets  $P_t$ . Their thresholds are summarized in Table 1. For the two  $b$ -quark+MET analysis, the  $b$ -tag requirement reduces the SM background by two orders of magnitude (Fig. 2) allowing relaxed cuts on  $H_T$  and MET. No deviation from SM prediction has

been observed and 95% Confidence Level (C.L.) lower limits have been set on the LQ masses assuming branching ratio  $BR(LQ \rightarrow qv) = 1$ . For  $LQ \rightarrow qv$  with  $q = u, d, s, c$ , these limits are  $187 \text{ GeV}/c^2$  for CDF and  $214 \text{ GeV}/c^2$  for D0. For  $LQ \rightarrow vb$ , the limit is  $247 \text{ GeV}/c^2$ .



**Figure 2:** Signal and SM MET distribution for the D0  $2b$ +MET analysis before (left) and after (right)  $b$ -tagging.

## 1.2 Jets+charged leptons signatures

When leptoquarks decay into a quark and a charged lepton, the discriminating variable is usually computed by doing the scalar sum of the two jets  $P_j$ , the charged leptons  $P_l$  and the MET if the experimental signature contains neutrinos. For the two jets+ two  $\tau$  signature, the MET comes from the neutrinos in the tau decay. CDF[11], using  $322 \text{ pb}^{-1}$  of analysed data has looked for this signature with one  $\tau$  decaying hadronically and one  $\tau$  decaying to either an electron or a muon. However, lower mass limits were only derived for vector leptoquarks and are  $251 \text{ GeV}/c^2$  for Minimal Coupling ( $\kappa_G = 1, \lambda_G = 0$ ) and  $317 \text{ GeV}/c^2$  for Yang-Mills coupling ( $\kappa_G = 0, \lambda_G = 0$ ). These limits are valid for  $BR(LQ \rightarrow q\tau) = 1$  with  $q = u, d, s, c, b$ . The signature two  $b$ + two  $\tau$  has been looked for by D0[12] using  $1.05 \text{ fb}^{-1}$  of analysed data. In the D0 analysis, one  $\tau$  should decay hadronically and the other should decay into a muon and two neutrinos. Among the two jets coming from LQ decays, at least one should be tagged as a  $b$ -jet. No events above SM expectation have been seen and a lower limit on the scalar LQ mass of  $210 \text{ GeV}/c^2$  has been derived for  $BR(LQ \rightarrow b\tau) = 1$ .

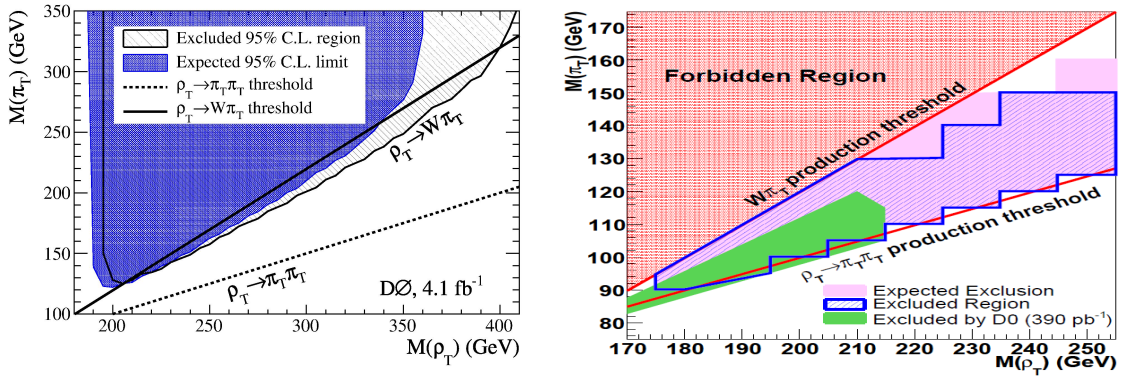
Searches for  $LQ \rightarrow q\mu$  and  $LQ \rightarrow qe$  with  $q = u, d, s, c, b$  have also been done. Most recent results are from D0 with  $1 \text{ fb}^{-1}$  of data[13, 14] and lead to lower mass limits for the scalar LQ of  $316 \text{ GeV}/c^2$  if  $BR(LQ \rightarrow q\mu) = 1$  and  $299 \text{ GeV}/c^2$  if  $BR(LQ \rightarrow qe) = 1$ . For muon and electron channels, the two jets+ $2l$  signature has been combined with the two jets+ $l$ +MET and two jets+MET signatures to derive lower limits on the LQ mass independantly of the branching fraction of the LQ into charged lepton or neutrino. These 95% C.L. limits are  $200 \text{ GeV}/c^2$  for leptoquarks decaying into second generation of leptons and  $214 \text{ GeV}/c^2$  for leptoquarks decaying into first generation of leptons.

## 2. Technicolor

The theory of technicolor has been proposed to offer a way to break dynamically the elec-

troweak symmetry[3]. For this, the theory adds a new QCD-like interaction that interacts with new fermions named technifermions. The non-abelian nature of the new interaction forces the technifermions to be confined and the creation of the technifermion condensate is used to break the electroweak symmetry down to electromagnetism. The theory, thus, predicts the existence of new observable particles, the technifermions condensates, which are for technifermions what the mesons are for quarks. By analogy with the mesons, these new particles are called technipion  $\pi_T$  (the lightest techniparticle), technirho  $\rho_T$ , techniomega  $\omega_T$ , ...

Compilations of existing limits on technicolor searches[3] are dominated by Tevatron results. A completely new search of a  $\rho_T$  decaying into a  $WZ$  pair[15] has been done by the D0 collaboration with  $4.2 \text{ fb}^{-1}$  of analysed data. This analysis covers the technicolor parameter space where the  $\rho_T$  mass  $m_{\rho_T}$  satisfies  $m_{\pi_T} < m_{\rho_T} < m_{\pi_T} + m_W$  where  $m_{\pi_T}$  and  $m_W$  are the  $\pi_T$  and  $W$  boson masses. The final state  $W$  and  $Z$  have been searched for in their leptonic decays leading to a tri-lepton final state. Only events with at least three central lepton ( $|\eta| < 2$  (muon) and  $|\eta| < 2.5$  (electron)) with  $P_t > 20 \text{ GeV}/c$  have been selected. The selected events should also have a MET higher than  $30 \text{ GeV}/c$  corresponding to the neutrino coming from the  $W$  decay. First, two leptons of the same generation with opposite charges are combined to form a  $Z$  candidate.  $Z$  candidates are kept if their invariant mass is between  $88 \text{ GeV}/c^2$  and  $102 \text{ GeV}/c^2$  for electronic decay and between  $70 \text{ GeV}/c^2$  and  $110 \text{ GeV}/c^2$  for muonic decay. Among the remaining lepton candidates, the one with the highest  $P_t$  is then combined with the MET to form a  $W$ -candidate. The  $W$  and  $Z$  candidates are then combined to form a  $\rho_T$  candidate. The final discrimination between the  $\rho_T$  signal and the SM background is done with the  $\rho_T$  candidate transverse mass. No signs of  $\rho_T$  has been found in the analysed data set and 95% C.L. excluded regions have been derived (Fig. 3).  $\rho_T$  masses between  $208 \text{ GeV}/c^2$  and  $408 \text{ GeV}/c^2$  are excluded if  $m_{\pi_T} < m_{\rho_T} < m_{\pi_T} + m_W$ .



**Figure 3:** 95% C.L. excluded region in the  $m_{\rho_T} - m_{\pi_T}$  plane for the D0  $\rho_T \rightarrow WZ$  analysis (left) and CDF  $\rho_T \rightarrow W\pi_T$  analysis (right).

If  $m_{\pi_T} + m_W < m_{\rho_T} < 2m_{\pi_T}$ , the  $\rho_T$  decays into a  $W$  and a  $\pi_T$ . CDF has searched for this signal with  $W \rightarrow (\mu/e)\nu$  and  $\pi_T \rightarrow b\bar{b}/b\bar{c}/b\bar{u}$  using  $1.9 \text{ fb}^{-1}$  of data[16]. In this analysis, a high  $P_t$  ( $> 20 \text{ GeV}/c$ ) central electron ( $|\eta| < 1.1$ ) or muon ( $|\eta| < 1$ ) is combined with a high MET ( $> 20 \text{ GeV}/c$ ) to form a  $W$  candidate. The combination is constrained to have the  $W$  mass. The  $\pi_T$  candidate is reconstructed from two jets with  $P_t > 20 \text{ GeV}/c$  and  $|\eta| < 2$  and with at least one of the jets tagged as a  $b$ -jet. The sensitivity of the analysis is optimized with cuts on the dijet mass and on

the difference between the reconstructed  $\rho_T$  mass and the sum of the reconstructed  $\pi_T$  mass with the  $W$  mass. The observed data are in agreement with the SM expectation. So 95% C.L exclusion limits have been derived and are shown on Fig 3. This analysis excludes  $180 \text{ GeV}/c^2 < m_{\rho_T} < 250 \text{ GeV}/c^2$  if  $95 \text{ GeV}/c^2 < m_{\pi_T} < 145 \text{ GeV}/c^2$ .

The techniparticles have also been looked for as resonances. CDF has measured the dijet mass distribution[17] with  $1.13 \text{ fb}^{-1}$  of analysed data. Good agreement between measurement and SM prediction is observed and the color-octet technirho ( $\rho_{T8}$ ) decaying into two jets has been excluded at 95% C.L. for masses between  $260 \text{ GeV}/c^2$  and  $1.1 \text{ TeV}/c^2$ . Limits on  $Z'$  mass in topcolor assisted technicolor have been set by looking at  $t\bar{t}$  resonances and are described elsewhere in these proceedings[18]. Older results are summarized in [3].

### 3. Outlook

Technicolor and leptoquarks have been searched in a wide range of final states at the Tevatron and have not yet been observed and numerous exclusion limits at 95% C.L have been set. However, the amount of data to be analysed by both D0 and CDF is still bigger than the amount of data used in the results described in this note. There are still opportunities for the Tevatron to shed more lights on these models before transferring the exploratory challenge to the LHC.

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