Search for Leptoquarks, Excited Leptons and Technicolor at the LHC

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The ATLAS and CMS experiments at the Large Hadron Collider (LHC) will soon search for physics phenomena that are not predicted by the Standard Model. Technicolor, Compositeness and GUT-based models are rich in high-

leptons and could be studied in such final states. This contribution shows studies that indicate that a 5 \sigma discovery of a 500 GeV leptoquark could occur with 100 pb^{-1} of integrated luminosity. Technicolor predicted particles could be seen with 4 fb^{-1} of integrated luminosity and, excited electron could be detected with 300 fb^{-1} of integrated luminosity.

1. INTRODUCTION

The Large Hadron Collider (LHC) will soon open up a new energy scale that will directly probe for physical phenomena outside the framework of the Standard Model (SM). Many Grand Unification inspired extensions of the SM introduce new, very heavy particles such as leptoquarks. The finite number of fermion generations in the SM could be explained by composite models thereby giving rise to excited fermions such as excited electrons. The mechanism of electroweak symmetry breaking (EWSB) in the SM is based on a purely weakly-interacting Higgs sector in which, the mass of the Higgs boson, itself, is unstable because of quadratic divergences due to loop corrections. This mechanism could as well be explained in the context of strong dynamics, e.g. Technicolor model.

In this work, we discuss the discovery potential of ATLAS and CMS experiments at the LHC to these new particles.

2. SEARCH FOR SCALAR LEPTOQUARKS WITH ATLAS

Leptoquarks (LQ) are hypothetical bosons carrying both quark and lepton quantum numbers, as well as fractional electric charge. Leptoquarks could, in principle, decay into any combination of any flavor lepton and any flavor quark. Experimental limits on lepton number violation, flavor-changing neutral currents, and proton decay favor three generations of leptoquarks. In this scenario, each leptoquark couples to a lepton from the same SM generation and a quark. Leptoquarks can either be produced in pairs by the strong interaction or in association with a lepton via the leptoquark-quark-lepton coupling. Figure shows Feynman diagrams for pair production of leptoquarks at the LHC.

This contribution describes the search strategy for leptoquarks decaying to either an electron and a quark or a muon and a quark leading to final states with two leptons and at least two jets. The branching fraction of a leptoquark to a charged lepton and a quark is denoted as \beta^1.

The signal has been studied using Monte Carlo (MC) samples for first generation (1st gen.) and second generation (2nd gen.) scalar leptoquarks simulated at four masses of 300 GeV, 400 GeV, 600 GeV, and 800 GeV with the MC generator at 14 TeV pp center-of-mass energy. The next to leading order (NLO) cross section for the above simulated signal decreases with leptoquark mass from a few pb to a few fb with mass point of 400 GeV at (2.24\pm0.38) pb.

1\beta = 1 would mean that leptoquarks do not decay into quarks and charge-neutral leptons, neutrinos.
Signal reconstruction requires selection of two high quality leptons and at least two jets. Each signal jet and lepton candidate is required to have \( p_T > 20 \text{ GeV} \). This helps to suppress low \( p_T \) background predicted by the SM. Leptons are required to have pseudorapidity \( |\eta| \) below 2.5, which is the inner detector’s acceptance, whereas jets are restricted to \( |\eta| < 4.5 \) to suppress backgrounds from underlying event and minimum bias events that dominate in the forward region of the detector. In addition, leptons are required to pass identification criteria, which, in case of electrons, are based on electromagnetic-shower shape variables in the calorimeter and, in the case of muons, are based on finding a common track in the muon spectrometer and the inner detector together with muon isolation requirement in the calorimeter. Electron candidates are also required to have a matching track in the inner detector. Furthermore, it is also required that signal jet candidates are spatially separated from energy clusters in the electromagnetic calorimeter that satisfy electron identification criteria. Finally, a pair of leptoquark candidates are reconstructed from lepton-jet combinations. Given the fact that these four objects can be combined to give two pairs, the pair that has minimum mass difference between the two leptoquark candidates is assumed to be the signal.

The main backgrounds to the signal come from \( t\bar{t} \), and \( Z/DY+\text{jets} \) production processes. Multijet production where two jets are misidentified as electrons, represents another background to dielectron(1st gen.) channel. In addition, minor contributions arise from diboson production. Other potential background sources, such as single-top production, were also studied and found to be insignificant.

The backgrounds are suppressed and the signal significance is enhanced by taking advantage of the fact that the final states in signal-like events have relatively large \( p_T \). A scalar sum of transverse momenta of signal jets and lepton candidates, denoted by \( S_T \), helps in reducing the backgrounds while retaining most of the signal. The other variable used to increase the signal significance is the invariant mass of the two leptons, \( M_{ll} \). The distributions of these two variables are shown in Figure 2.

After applying optimized selection on these two variables, \( S_T \) and \( M_{ll} \), relative contribution of the background processes from \( t\bar{t} \), \( Z/DY \), diboson and multijet is 22%, 7%, 0.4% and 18%, respectively.

ATLAS’s sensitivity to leptoquark signal with an integrated pp luminosity of 100 pb\(^{-1}\) is summarized in Figure 3. The results include systematic uncertainty of 50%. Trigger is based on a single high-\( p_T \) lepton and is about 97% efficient with respect to the offline reconstruction of the signal events. ATLAS is sensitive to leptoquark masses of about 565 GeV and 575 GeV for 1st and 2nd generations, respectively, at the given luminosity of 100 pb\(^{-1}\).

\[^2\]E_T^{iso}/p_T^\mu \leq 0.3\text{, where } p_T^\mu\text{ is muon candidate’s transverse momentum and } E_T^{iso}\text{ is energy detected in the calorimeters in a cone of } \Delta R=\sqrt{(\Delta \eta^2 + \Delta \phi^2)}=0.2\text{ around muon candidate’s reconstructed trajectory.}
Figure 2: $S_T$ (left) and $M_{ee}$ of the selected electron pair after $S_T$ selection (right) in 1st gen. leptoquark MC events ($m_{LQ} = 400$ GeV). Both distributions are normalized to 100 pb$^{-1}$ of integrated $pp$ luminosity.

Figure 3: 5σ discovery potential for 1st and 2nd gen. 400 GeV scalar leptoquark versus $\beta^2$, with and without background systematic uncertainty (left). Minimum $\beta^2$ of scalar leptoquark versus leptoquark mass at 100 pb$^{-1}$ of integrated $pp$ luminosity at 5σ (background systematic uncertainty is included) (right).

3. EXCITED LEPTONS AT ATLAS

Composite models[3] predict the existence of quarks and leptons as bound states of three fermions or a fermion and a boson. The single production of excited electrons through contact interaction at the LHC has been studied in ATLAS [9, 10] using MC samples simulated with PYTHIA and fast simulation of the ATLAS detector [11]. Excited electrons can decay either via contact interaction or via an intermediate gauge boson. The final states studied include ee$\gamma$, eee, and ejj. Figure 4 shows the results for eee channel. This study predicts that singly-produced excited

Figure 4: Invariant mass of excited electron candidate from three electrons (left). Excited electron signal significance shown for different mass hypothesis as a function of compositeness scale $\Lambda$ and (right). Both plots (ATLAS study) are for an integrated $pp$ luminosity of 300 fb$^{-1}$
electrons could be detected at the LHC with masses up to 3-4 TeV for $\Lambda = 6$ TeV, where $\Lambda$ is the compositeness scale.

4. TECHNICOLOR AT CMS

Technicolor is an alternate mechanism of EWSB. It is based on strong symmetry breaking that introduces Goldstone bosons in the form of technipions that eventually provide masses to $W^\pm$ and $Z^0$ bosons. To be consistent with the observations explained by the SM, this hypothesis requires technicolor gauge couplings to evolve very slowly and predicts lightest technicolor resonances to have masses below a TeV. One of such light resonances studied at CMS is technirho($\rho_{TC}$), predicted by Technicolor Straw Man Model (TCSM).

The $\rho_{TC}$ analysis [12] is performed in $3l + E_T$ final state arising from decay channel $\rho_{TC} \rightarrow W + Z$. The signal is simulated with Pythia and fast simulation of the CMS detector [13]. Figure 5 shows CMS sensitivity to Technicolor in technipion and technirho mass phase space for $4 \text{fb}^{-1}$ of integrated $pp$ luminosity.

![Figure 5: 5σ sensitivity curves (CMS study) for various integrated luminosities (left); sensitivity curve for 4 fb$^{-1}$ of integrated luminosity: the dotted (dashed) curve shows the sensitivity (90% C.L. signal upper limit), systematic uncertainties included.](image)

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