

# Searches for Large Extra Dimensions, Leptoquarks and Heavy Quarks at CMS

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DOI: <http://dx.doi.org/10.3204/DESY-PROC-2012-02/222>

We present results from several searches for physics beyond the standard model involving large extra dimensions, leptoquarks, and heavy quarks at  $\sqrt{s} = 7$  TeV with the CMS experiment. Many different final states are analyzed using the data collected in 2010 and 2011 corresponding to an integrated luminosity up to  $5.0fb^{-1}$ . The results are used to set new limits on the scale of large extra dimensions and on the masses of leptoquarks and heavy quarks.

## 1 Introduction

The CMS experiment has been designed to look for new physics beyond the Standard Model(SM). This includes searches for large extra dimensions, leptoquarks and heavy quarks production. The measurements described here were performed using data recorded by the CMS detector [1] at the LHC in 2010 and 2011<sup>1</sup>.

## 2 Large Extra Dimensions (LED) Searches

In the framework of the ADD model proposed by Arkani-Hamed, Dimopoulos, and Dvali, the gravitational and gauge interactions unify at the electroweak scale so that there is only one fundamental length scale. The observed weakness of gravity is explained as a consequence of the universe having “large” (mm) extra dimensions, where gravity could propagate. The number of extra dimensions ( $n_D$ ) and the effective scale ( $M_D$ ) are the main parameters of the ADD model.

The ADD model predicts a number of possible signatures within the reach of LHC. Production of monophoton ( $\gamma + \cancel{E}_T$ ) and monojet (jet+ $\cancel{E}_T$ ) are the clean channels to search for existence of LED where  $\cancel{E}_T$  originate from graviton as it escapes detection. If LED exists, it will manifest itself as an excess of events in the previously mentioned final states. The monophoton study is done in the phase space defined by  $p_T^\gamma > 145$  GeV,  $|\eta^\gamma| < 1.44$  and  $\cancel{E}_T > 130$  GeV, while monojet uses  $p_T^{jet} > 110$  GeV with  $|\eta^{jet}| < 2.4$ . Both analyses optimized their selections for better sensitivity and used other vetoes to reduce potential background contributions mainly arising from QCD and  $W/Z + X$  production [2, 3]. Figure 1 shows  $p_T$  distributions from these analyses after the full selection criteria is applied. The new lower limits from monophoton and monojet studies are 1.64 – 1.73 TeV ( $n_D = 3 - 6$ ), 2.49 – 4.44 TeV ( $n_D = 2 - 6$ ) at 95%CL with  $5.0fb^{-1}$  and  $4.7fb^{-1}$  of integrated luminosity respectively [2, 3].

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<sup>1</sup>some of the results are recently updated with a slightly higher luminosity and are presented here



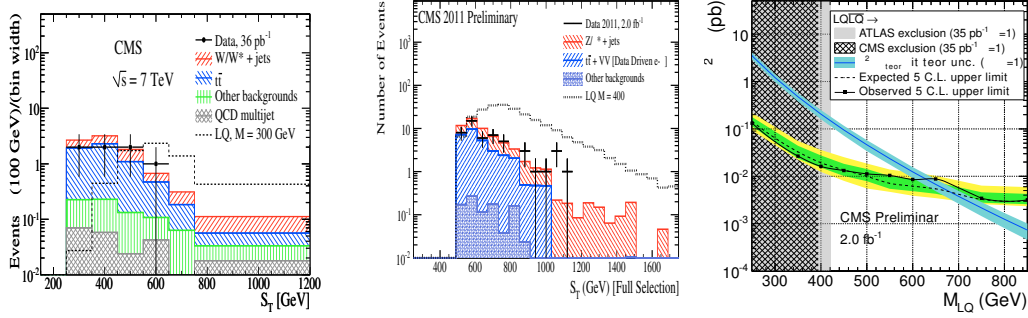


Figure 2:  $S_T$  distribution for  $evqq$  final state (left) and  $\mu\mu qq$  final states (middle) for scalar leptoquark search. The signal expectation is also shown for a given leptoquark mass  $M_{LQ}$ . The limits for  $\beta^2 \times \sigma$  as a function of  $M_{LQ}$  are also shown (right) from  $\mu\mu qq$  channel.

## 4 Heavy Quark Searches

An obvious extension of SM is the prediction of a new generation of heavy quarks. The presence of such heavy quarks could solve some of the known problems of particle physics. For example, the existence of such a new generation could enhance the  $CP$  violation by a large factor and hence could explain the observed matter-antimatter asymmetry in the universe.

The  $t't'$  pair production search has been performed for the dilepton and lepton+jets final states. For the  $t't' \rightarrow (l^+\nu b)(l^-\bar{\nu}\bar{b})$  production search the mass of “ $b$ -jet+lepton” is reconstructed from different  $b$  and  $l$  combinations. The lowest mass ( $M_{lb}^{min}$ ) of these combinations is considered for a comparison of the SM prediction with data. The main backgrounds  $t\bar{t}$  tends to accumulate at lower  $M_{lb}^{min}$  values thus providing a way to reduce it by a large fraction [10] (see Fig. 3 (left)). The signal region is defined by  $M_{lb}^{min} > 170$  GeV. For the lepton+jets final state the  $H_T (= p_T^l + p_T^{miss} + \sum p_T^{jet})$  and reconstructed mass from kinematical fit ( $M_{fit}$ ) are used as discriminating variables. Here the  $t't'$  signal is expected to be at high  $H_T$  while the SM  $t\bar{t}$  ends up at low  $H_T$  and  $M_{fit}$  values [11]. The new limit of  $M_{t'} > 557$  (560) GeV is obtained from dilepton (lepton+jets) final state with  $5.0 fb^{-1}$  ( $4.9 fb^{-1}$ ) of integrated luminosity.

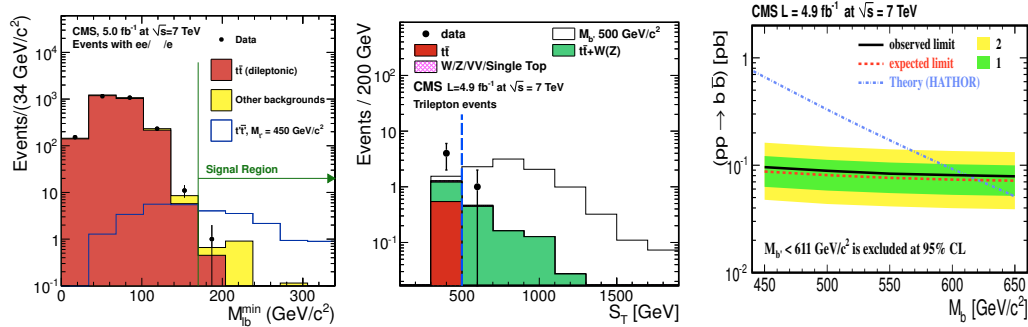


Figure 3: The  $M_{lb}^{min}$  spectrum of  $b$ -jet+lepton for  $t'$  search (left). The  $S_T$  distribution (middle) and cross section limits as a function of  $M_{b'}$  (right) for tripleton search.

The  $b'\bar{b}'$  pair production searches are done with 3-leptons+2-jets or same sign 2-lepton+4 jets final states with very low SM background. The event selection requires  $p_T^l > 20\text{ GeV}$  and at least 1  $b$ -jet ( $p_T > 25\text{ GeV}$ ). The  $S_T$  distribution is examined for any  $b'$  signal in the  $S_T$  region above the SM prediction (see Fig. 3). A final selection of  $S_T > 500\text{ GeV}$  is used to reduce the  $t\bar{t}$  background [12]. Based on this study the  $b'$  are excluded with mass below 611 GeV at 95%CL.

Inclusive search for  $t'$  and  $b'$  are also done and details can be found in Ref. [13]. The pair production of vector-like heavy quarks with  $T \rightarrow tZ$  has been studied at CMS assuming a 100% branching fraction. This analysis is performed for a final state of  $Z(l\bar{l}) + 1\text{-lepton} + \geq 2\text{-jets}$ . A more detail of the analysis can be found in Ref. [14].

## 5 Conclusion

The lower limits on the large extra dimension scale in the ADD framework are extended to  $M_D \geq 2.49 - 4.44\text{ TeV}$  for  $n_D = 2 - 6$  from the monojet study. The search for leptoquarks for second generation at CMS have set new lower bound of  $M_{LQ} > 632\text{ (523) GeV}$  for  $\beta = 1.0\text{ (0.5)}$ . The CMS searches for heavy quarks have excluded  $M_{t'}(M_{b'})$  below 560 GeV (611 GeV).

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