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

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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 $5.0 fb^{-1}$. 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[1].

2 Large Extra Dimensions (LED) Searches

In the framework of the ADD model proposed by **A**rkani-Hamed, **D**imopoulos, and **D**vali, 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 ($\gamma + \not{E}_{\mathrm{T}}$) and monojet (jet+$\not{E}_{\mathrm{T}}$) are the clean channels to search for existence of LED where $\not{E}_{\mathrm{T}}$ 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 $\not{E}_{\mathrm{T}} > 130$ GeV, while monojet uses $p_T^{jet} > 110$ GeV with $|\eta^{jet}| < 2.4$. Both analyses optmized 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 $5.0 fb^{-1}$ and $4.7 fb^{-1}$ of integrated luminosity respectively [2, 3].

[1]some of the results are recently updated with a slightly higher luminosity and are presented here

For a search in the diphoton channel, both γs are required to have $E_T > 70$GeV and $|\eta^{\gamma}| < 1.44$. The reducible backgrounds from QCD and γ+jets are estimated from data using the fake ratio method. The observed events yield and background expectations are compared in different ranges of $M_{\gamma\gamma}$ for any signal excess. A new lower limits of $2.3 - 3.8$ TeV is set by this analysis on the scale of LED for $2.2 fb^{-1}$ of data [4]. In the dilepton search isolated leptons are required to be $p_T^e > 35$ GeV(40 GeV for μ). The Drell-Yan production is the largest background here and is estimated from simulation and NLO corrections are applied. These corrections, along with the PDF uncertainties, dominate the systematic uncertainty for the background prediction [5]. The observed lmit on LED scale from this analysis is $2.5 - 3.8$ TeV for $n_D \geq 3 - 7$.

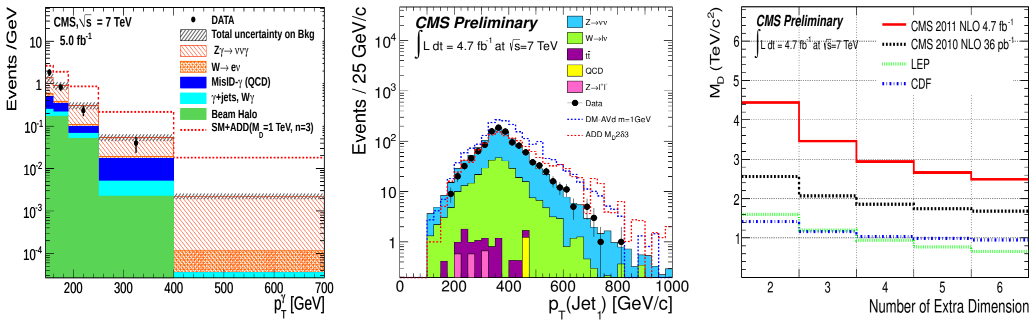

Figure 1: The p_T spectrum of γ from $\gamma + \not{E}_{\mathrm{T}}$ final state (left) and jet p_T distribution from jet+$\not{E}_{\mathrm{T}}$ final states(middle) after full selection. The observed limits for different n_D from monojet study are also shown(right).

3 Leptoquark Searches

The Standard Model shows a remarkable symmetry between quarks and leptons. This symmetry may imply a more fundamental relation between the two. It is natural to think of a theory which relates quarks and leptons and predicts new particles called leptoquarks which carry both lepton and baryon number.

CMS has searched for leptoquark production for first and second generation with $llqq$ (with branching fraction $\beta = 1.0$) and $l\nu qq$ ($\beta = 0.5$) final states production [6, 7, 8]. For this observation, the scaler sum of transverse momentum (S_T) of leptons and jets (and $\not{E}_{\mathrm{T}}$ for $l\nu qq$) is studied as the key variable (see Fig. 2). The main backgrounds comes from W/Z+jets and $t\bar{t}$ for first generation searches, and from Z/γ^*+jet and $t\bar{t} + VV$ for second generation searches. The new limits on M_{LQ} obtained from these analyses are 339 (384) GeV for $ee\nu\nu$ ($e\nu qq$) with $\sim 36pb^{-1}$, and 632 (523) GeV for $\mu\mu qq$ ($\mu\nu qq$) final state with $2.0 fb^{-1}$ of integrated luminosity. These limits are obtained for β or $\beta^2 \times \sigma$ as a function of M_{LQ}(see Fig. 2(right)).

In the search for third generation scalar leptoquarks, a final state with two tagged $b-$jets and $\not{E}_{\mathrm{T}}$ is analyzed [9]. A special variable called *razor*, designed to search for a pair of heavy particles, is used in this study. It is defined as ratio of $M_T^R = \sqrt{(E_{j1} + E_{j2})^2 - (p_z^{j1} + p_z^{j2})^2}$ and $M_R = \sqrt{\not{E}_{\mathrm{T}}(p_T^{\vec{j}1} + p_T^{\vec{j}2}) - \vec{\not{E}}_{\mathrm{T}}(p_T^{\vec{j}1} + p_T^{\vec{j}2})}$. The main background for this final state comes from SM heavy flavor multijets, $W/Z+$ heavy flavor jets, and $t\bar{t}$+jets production. This analysis is performed with $1.8 fb^{-1}$ of data collected at the beginning of 2011 and gives a lower bound of $M_{LQ} > 350$ GeV at 95%CL.

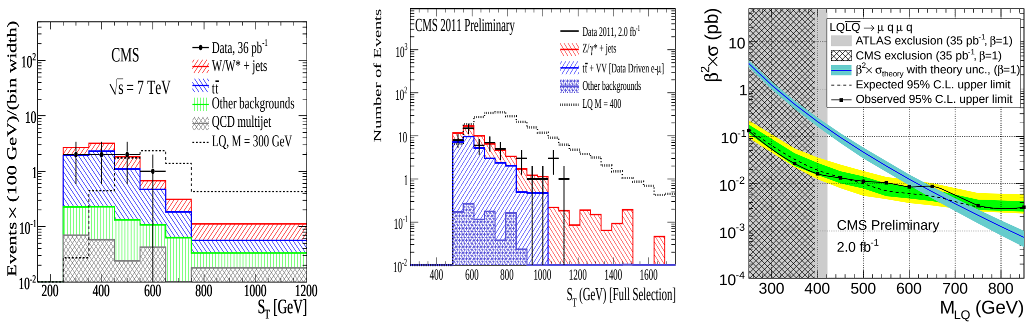

Figure 2: S_T distribution for $e\nu qq$ final state (left) and $\mu\mu qq$ final states (middle) for scalar leptoquark search. The signal expectation is also shown for a given leptoquark mass M_{LQ}. The limits for $\beta^2 \times \sigma$ as a function of M_{LQ} are also shown (right) from $\mu\mu qq$ 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 $t'\bar{t}'$ pair production search has been performed for the dilepton and lepton+jets final states. For the $t'\bar{t}' \to (l^+\nu b)(l^-\bar{\nu}\bar{b})$ 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 comparision 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 $t'\bar{t}'$ 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.

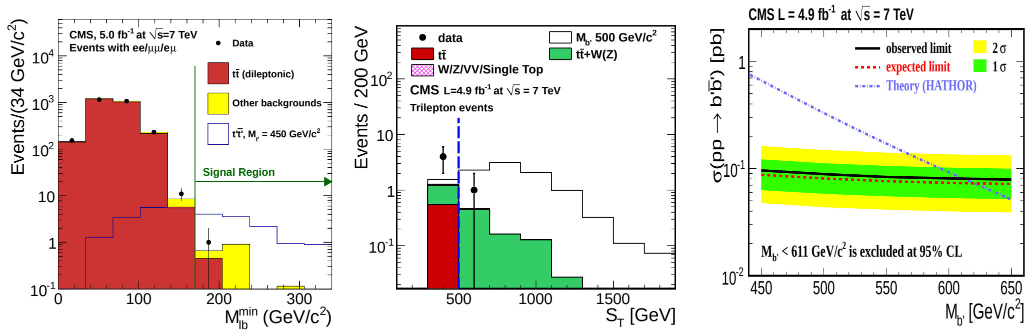

Figure 3: The M_{lb}^{min} spectrum of $b-$jet+lepton for t' search(left). The S_T distribution (middle) and cross section limits as a function of $M_{b'}$ (right) for trilepton search.

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 $p_T^l > 20$GeV and at least 1 b−jet ($p_T > 25$ 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 $S_T > 500$ 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 $Z(ll) + 1$−lepton+ ≥ 2−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 $M_D \geq 2.49 - 4.44$ 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 $M_{LQ} > 632$ (523) GeV for $\beta = 1.0$ (0.5). The CMS searches for heavy quarks have excluded $M_{t'}(M_{b'})$ below 560 GeV (611 GeV).

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