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Search for Heavy Resonances with Leptons and Jets at CMS

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Additional heavy vector bosons such as the Z' and W' are predicted by a number of new physics models. So are leptoquarks, which are particles that carry both lepton and quark number. We present the latest results on heavy resonances and leptoquarks at CMS. Searches included are dilepton resonances, lepton + MET resonances, and lepton+jet resonances.

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1. Introduction

These proceedings describe searches by the CMS experiment [1] for several exotic new particles decaying to final states including leptons and jets. These new particles include resonances decaying to two charged leptons (Z') [2], resonances decaying to one charged lepton and one neutrino (W') [3], second generation leptoquarks (LQ_2) [4], and right-handed W bosons (W_R) decaying to heavy right-handed neutrinos (N_ℓ) and Standard Model leptons [5]. These proceedings serve only as a brief outline of each of these searches. The reader is encouraged to consult the cited physics analysis summaries for a more thorough overview of the results and the methods presented here. No significant deviation from Standard Model is observed in any of these analyses, so limits are set on the related models. The limits for all of these analyses are given in Table 1.

Model	Channel	Limit (GeV)
$Z'_{\rm SSM}$	Combined $(e+\mu)$	$m(Z'_{\rm SSM}) < 2960$
$Z'_{\rm GUT}$	Combined $(e+\mu)$	$m(Z'_{\rm GUT}) < 2600$
$W'_{\rm SSM}$	Combined $(e+\mu)$	$m(W'_{\rm SSM}) < 3350$
$W'_{\rm SSMO}$	Combined $(e+\mu)$	$m(W'_{\rm SSMO}) < 3600$
$W'_{\rm SSMS}$	Combined $(e+\mu)$	$m(W'_{\rm SSMS}) < 3100$
$W^2_{\rm KK}$ ($\mu = 0.05$ TeV)	Combined $(e+\mu)$	$m(W^2_{\rm KK}) < 1700$
$W^2_{\rm KK}$ ($\mu = 10.0$ TeV)	Combined $(e+\mu)$	$m(W^2_{\rm KK}) < 3700$
HNC Contact Int	e	$\Lambda < 13000$
HNC Contact Int	μ	$\Lambda < 10900$
LQ_2 ($\beta = 1.0$)	$LQ\overline{LQ} \to \mu\mu jj$	$m(LQ_2) < 1070$
LQ_2 ($\beta = 0.5$)	$LQ\overline{LQ} \to \mu\nu jj$	$m(LQ_2) < 785$
$W_{\rm R}$	Combined $(e+\mu)$	$m(W_{\rm R}) < 2800$

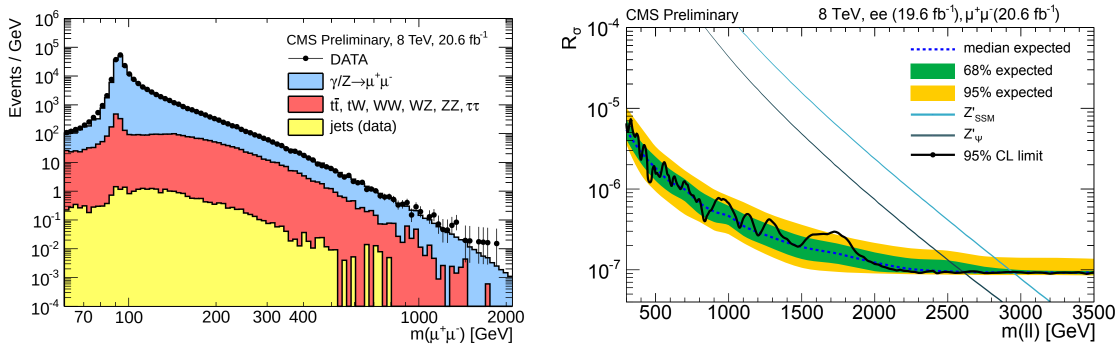
Table 1: Observed limits at 95% CL for the various models discussed in these proceedings

2. Search for dilepton resonances

Several models of new physics beyond the Standard Model predict the existence of narrow resonances decaying to dileptons at the TeV scale. These $Z'_{\rm SSM} \to \ell\ell$ resonances include the $Z'_{\rm SSM}$ predicted by the Sequential Standard Model (SSM) with Standard Model-like couplings [6] and the Z'_ψ predicted by grand unified theories [7]. An analysis of the dimuon and dielectron mass spectra has been carried out using these models as search benchmarks. The dilepton mass spectra for events having two well-isolated muons is shown in Figure 1a. The dominant Standard Model backgrounds include Drell-Yan Z/γ^* production, $t\bar{t}$ production, and multijet events where at least one jet is reconstructed as a lepton. The data were observed to be in good agreement with Standard Model predictions, so limits were set on both models. The combined limit for electron and muon events is shown in Figure 1b.

3. Search for lepton + MET resonances

Similarly, multiple models beyond the Standard Model predict processes with a final state



(a) (b)

Figure 1: (a) Comparison between expected and observed invariant dimuon mass spectrum from 8 TeV dataset from events with two isolated muons, (b) ratio of production cross section for Z'_{SSM} (Z'_{GUT}) over Z times branching fraction

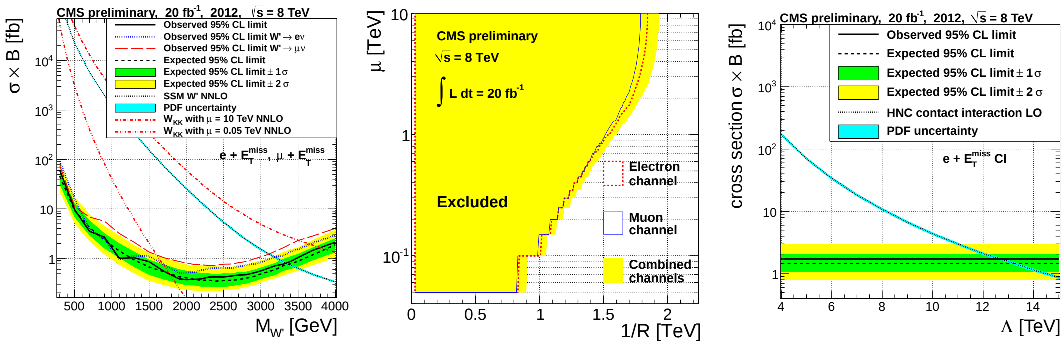
including one electron or muon and large missing transverse energy (E_T^{miss}). An analysis of the lepton and E_T^{miss} transverse mass (m_T) spectra has been carried out using three of these models as search benchmarks.

The first of these models is the the Sequential Standard Model (SSM) W'_{SSM} with Standard Model-like couplings [6] ($W'_{\mathrm{SSM}} \to \ell\nu$). Models where the W' boson interferes with the Standard Model W boson via same-sign (SSMS) and opposite-sign (SSMO) terms in the Lagrangian are also considered. Second, the analysis is intrepreted to consider a Universal Extra Dimension framework with bulk fermions (split-UED) [8, 9]. This model is based on an extended space-time with an additional compact fifth dimension of radius R. The split-UED parameter space is defined by $1/R$ and by μ, the bulk mass parameter of the fermion field in five dimensions. In the split-UED model, all Standard Model particles have Kaluza-Klein partners, and this analysis is interpreted as a search for the W partner, W^2_{KK}. Third, an interpretation of this analysis is made in the context of a four-fermion contact interaction. A Helicity-Non-Conserving Contact Interaction (HNC CI) model is considered whereby quarks and leptons are taken to be composite objects made up of fundamental consituents with a binding energy, Λ [10, 11].

Dominant Standard Model backgrounds include events from $W \to \ell\nu$, $t\bar{t}$, single top production, and multijets where a jet is reconstructed as a lepton. The data were observed to be in good agreement with the Standard Model prediction, so limits were set on all of the models listed above. The limits are shown in Figure 2.

4. Search for second generation leptoquarks

Several models describe heavy bosons carrying both lepton and baryon number that decay to muons and quarks (second generation leptoquarks, "LQ$_2$"). An analysis was performed to search for the pair production of second generation scalar leptoquarks under the minimal Buchmüller, Rückl, Wyler (mBRW) model in particular [12]. Under the mBRW model, second generation leptoquarks always decay to a muon and a quark or a neutrino and a quark. Along with the leptoquark mass, the mBRW model treats the branching fraction for the process $\beta = \mathrm{BR}(\mathrm{LQ}_2 \to \mu^\pm + \mathrm{q})$ as



(a) (b) (c)

Figure 2: (a) Cross section times branching fraction vs W' mass for SSM models with no interference, (b) excluded region in split-UED parameter space, (c) cross section times branching fraction vs binding energy Λ in an HNC CI model (electron channel),

a free parameter. This leads to two separate analyses to be used as benchmarks: one for which $\beta = 1$ ($\mu\mu jj$ final state) and one for which $\beta = 1/2$ ($\mu\nu jj$ final state). The largest background contributions with these final states come from W+jets (in the $\mu\nu jj$ analysis), Z/γ^*+jets (in the $\mu\mu jj$ analysis), and $t\bar{t}$ (in both analyses).

For the $\mu\mu jj$ analysis, events are selected that have two isolated, high-p_T muons and two high-p_T jets. For the $\mu\nu jj$ analysis, events are selected that have one isolated, high-p_T muon, two high-p_T jets, and large E_T^{miss}. After this basic selection has been applied, both analyses are optimized by selecting cuts that maximize sensitivity to signal discovery. The optimization is repeated for leptoquark mass hypotheses between 300 and 1200 GeV. In the case of the $\mu\mu jj$ analysis, cuts are optimized on the invariant mass of the two muons, the invariant mass of the lightest reconstructed leptoquark candidate, and S_T (the scalar sum of the p_T values of the two leading muons and the two leading jets). In the case of the $\mu\nu jj$ analysis, cuts are optimized on the transverse mass of the muon and the event E_T^{miss}, S_T (the scalar sum of the p_T values of the leading muon, the two leading jets, and the event E_T^{miss}), and the mass of the reconstructed leptoquark candidate.

Since there is good agreement between the Standard Model prediction and the data observed for the selections optimized for every leptoquark mass, lower limits are set on the leptoquark mass for both analyses. These limits are combined in the plane of β vs the leptoquark mass, and this combination is shown in Figure 3.

5. Search for heavy neutrinos and W_R bosons in a left-right symmetric model

Left-right symmetric extensions of the Standard Model (LRSM) [13, 14, 15, 16] were introduced to explain the origin of parity violation in weak interactions. By introducing a new symmetry group, LRSM introduces additional gauge bosons (including the right-handed $W_R^{\pm}$ and heavy right-handed neutrino states N_ℓ), which can explain non-zero left-handed neutrino mass via the see-saw mechanism [17]. An analysis was carried out to search for the process $pp \to W_R \to \ell N_\ell$, where $W_R \to \ell N_\ell$, followed by $N_\ell \to W_R^*$, followed by $W_R^* \to jj$. The final state is two leptons (electrons or muons in this analysis) and two jets ($\ell\ell jj$).

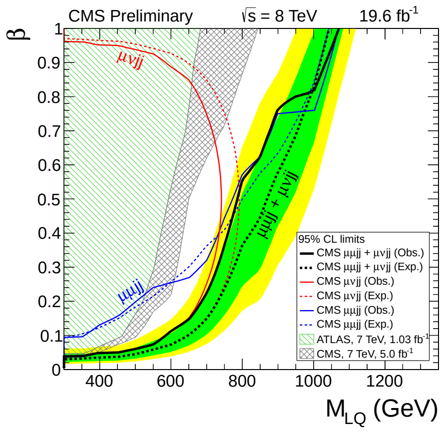
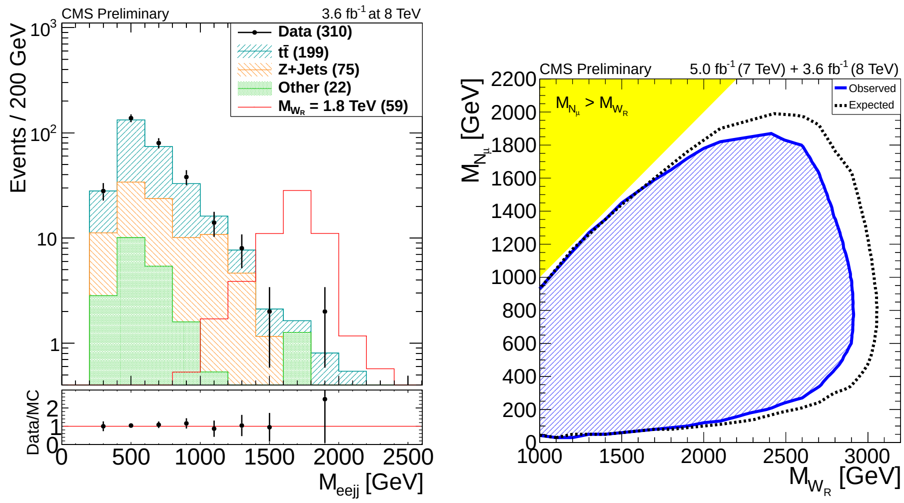


Figure 3: Excluded region in the parameter space of the mBRW model. M_{LQ} corresponds to leptoquark mass. β corresponds to the branching fraction for the process LQ $\rightarrow \mu^{\pm} + \text{q}$.



(a) (b)

Figure 4: (a) Comparison between expected and observed invariant mass spectrum from the two leading electrons and two leading jets in the event. Events come from the full 8 TeV dataset. (b) Region of 95% CL exclusion in the plane of M_{W_R} and M_{N_μ}. Events come from the combined 7 TeV and 8 TeV datasets.

The analysis is performed by analyzing the $\ell\ell jj$ invariant mass spectrum for events with two leptons with $M(\ell\ell) > 200$ GeV. The dominant backgrounds include Z/γ^*+jets and $t\bar{t}$. As shown in Figure 4a for the $eejj$ case, there is good agreement between the observed invariant mass spectrum and the invariant mass spectrum predicted by the Standard Model. As a result, limits are set using the statistical combination of the 7 TeV and 8 TeV datasets, as shown in Figure 4b.

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