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SEARCH FOR PHYSICS BEYOND THE STANDARD MODEL AT ATLAS AND CMS

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On behalf of the ATLAS and CMS collaborations

Data taken in 2011 with the ATLAS and CMS detectors at the LHC have been used to search for physics beyond the Standard Model. Results are presented based on up to 5 fb^{-1} of $\sqrt{s} = 7$ TeV proton-proton collisions. No evidence of new physics is seen.

1 Introduction

In a very successful year of operation, the CERN LHC (Large Hadron Collider) delivered more than 5 fb^{-1} of proton-proton collisions at $\sqrt{s} = 7$ TeV to each of the ATLAS and CMS detectors in 2011. Results from BSM (beyond the Standard Model) searches with those detectors are summarized here. The emphasis here is on what both collaborations call *exotic* physics: new gauge bosons, fourth generation quarks, composite objects, extra dimensions (gravitons, black holes, ...), and other exotica. Searches for BSM physics in other areas are summarized elsewhere in these proceedings. Those include SM (Standard Model) measurements, top quark properties, heavy flavor measurements, searches for scalar (e.g. Higgs) bosons, and supersymmetry.

The discussion here is organized by final state with brief mention of how each search can be used to constrain a few benchmark models. Where space permits, cross section limit plots are also shown to give some idea of how the measurement can be used to constrain other models.

2 Results

At a hadron collider such as the LHC, the process to be studied must somehow couple to the incoming quarks or gluons. It is natural to search for final states comprised of these same partons, observed as jets in the detectors. Dijet resonances are signature for may many BSM models and include string balls, GUT (Grand Unified Theory) diquarks, excited quarks, W' and

Z'. Both collaborations search for these in 1.0 fb^{-1} of data. ATLAS sets limits $m_{q*} > 2.99$ TeV for excited quarks and $m_a > 3.32$ TeV for axigluons [1]. CMS limits include $m_s > 4.00$ TeV on string resonances and $m_{W'} > 1.51$ TeV on SSM W' production [2]. Additional sensitivity to new physics is obtained by looking at dijet angular distributions because BSM processes are often much more central. The standard search variable is $\chi = e^{|y_2 - y_1|}$ where y_1 and y_2 denote the rapidities of the two jets. Neither the ATLAS search [3] in 36 pb^{-1} nor the CMS search [4] in 2.2 fb^{-1} shows evidence for new physics. Figure 1 shows the ATLAS dijet resonance limits on a generic Gaussian signal and the CMS χ distribution. Both collaborations also search for pairs of dijets: ATLAS [5] in 36 pb^{-1} and CMS [6] in 2.2 fb^{-1}. The latter sets a limit $m_c > 580$ GeV on coloron production.

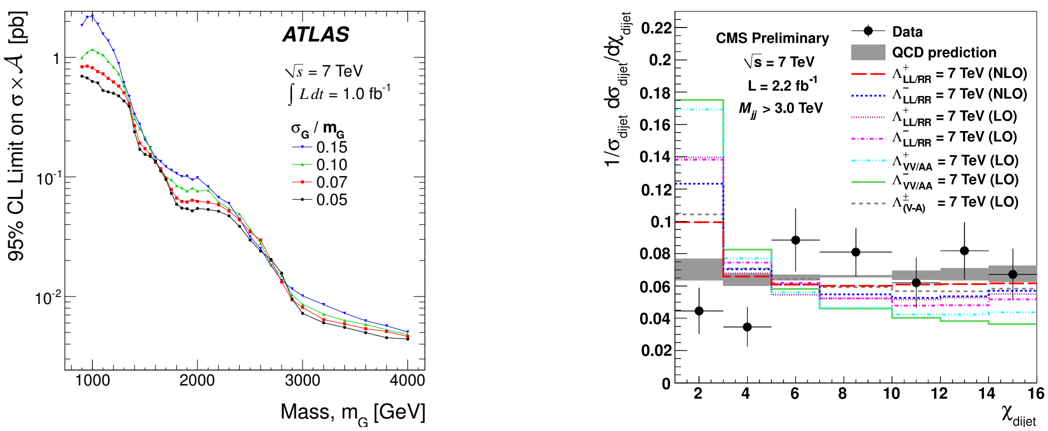

Figure 1: Dijet search results. Left is the ATLAS dijet resonance limit on a generic Gaussian signal with width varying from 5-15%. [1] Right is the CMS χ distribution showing much better agreement with SM than a series of contact interaction models. [4]

Total transverse energy is used to look for black holes and string balls as well as other new physics. The ATLAS search [7] in 1.0 fb^{-1} requires a lepton trigger. The CMS search [8] uses 4.7 fb^{-1} and sets mass limits of $m_{BH} > 3.8 - 5.2$ TeV on black hole production and $m_{SB} > 4.6 - 4.8$ TeV on the production of string balls. Cross section limits for both are shown in Fig. 2. In a pattern repeated throughout this report, the observed limits are found to be in good agreement with SM expectations.

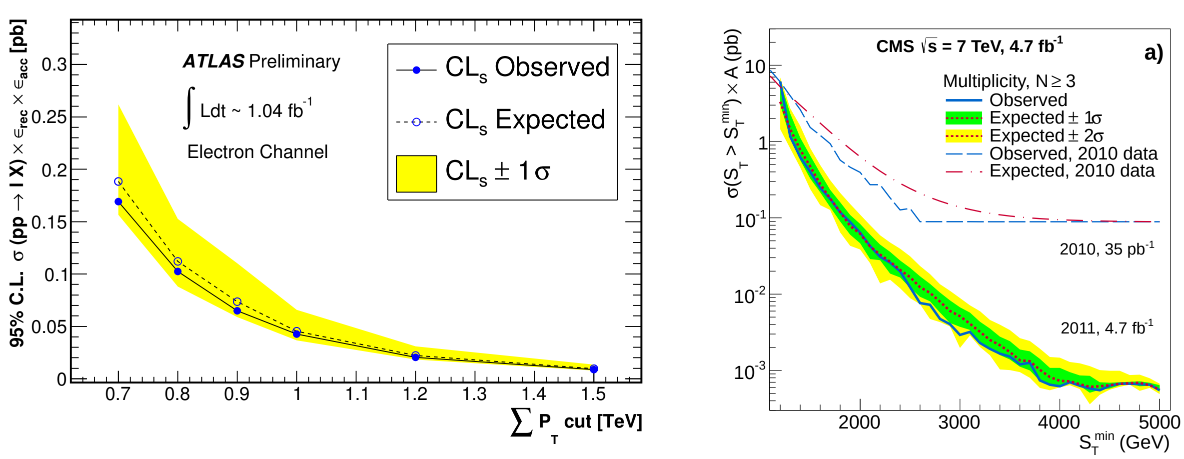

Figure 2: Example SM expected and observed cross section limits on total transverse energy reported by ATLAS [7] (left) and CMS [8] (right).

ATLAS and CMS both search for resonances in the dilepton (both electron and muon) spectrum. BSM physics signals include Z', graviton and technihadron. The ATLAS search [9] makes use of 5.0 fb^{-1} and sets mass limits $m_{Z'} > 2.11$ TeV on SSM Z' production and $M_G > 2.16$ TeV on RS1 graviton production for coupling strength $k/M_{pl} = 0.1$. The corresponding CMS limits [10] are $M_{Z'} > 1.94$ TeV and $M_G > 1.98$ TeV in 1.1 fb^{-1}. The CMS results were already updated to 5.0 fb^{-1} near the end of the Moriond meeting. Figure 3 shows the ATLAS and CMS cross section limits as a function of dilepton resonance mass.

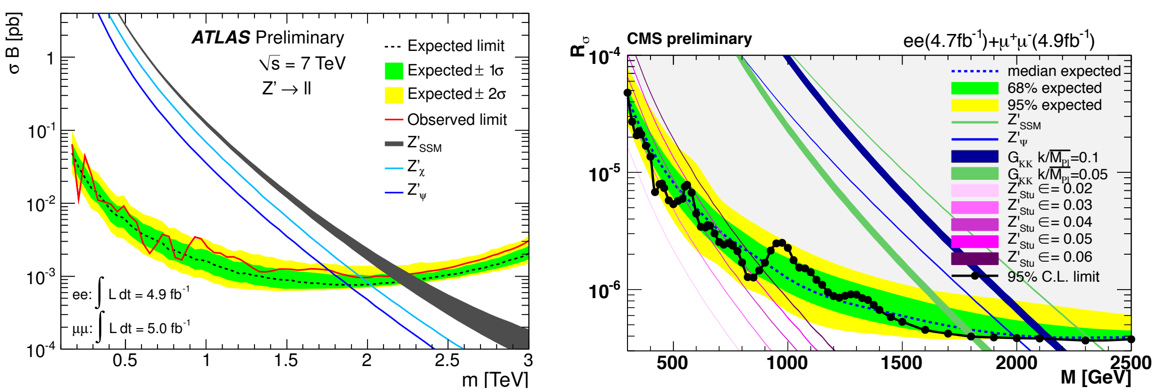

Figure 3: ATLAS [9] (left) and CMS [10] (right) expected and observed cross section limits on dilepton resonance as a function of mass.

The high-mass tail of the dilepton mass distribution is also searched for BSM physics. ATLAS uses 1.2 fb^{-1} to set limits on compositeness scale: $\Lambda > 8 - 10$ TeV. [11] CMS sets limits on the effective Planck scale, $M_S > 2.5 - 3.8$ TeV in the ADD model. [12]

ATLAS and CMS carry out many same-sign lepton and multilepton searches to search for a variety of new physics: doubly-charged Higgs [13,14,15] excited neutrinos [15], extra dimensions [16,14] and supersymmetry[17].

Both collaborations search for diphoton resonances as signature for extra dimensions. Using 2.1 fb^{-1}, ATLAS finds $M_G > 0.79 - 1.75$ TeV for the RS1 graviton and $M_D > 2.3 - 3.5$ TeV for the fundamental Planck scale in ADD [18]. With 2.2 fb^{-1}, CMS obtains $M_G > 0.86 - 1.84$ TeV for the same graviton and $M_S > 2.3 - 3.8$ TeV for the closely related effective Planck scale. [19]

ATLAS and CMS both search for $W' \to \ell\nu$. The ATLAS search is based on 1.0 fb^{-1} and obtains an SSM mass limit $m_{W'} > 2.2$ TeV [20]. The corresponding CMS limit is $m_{W'} > 2.5$ TeV [21] obtained with 4.7 fb^{-1}. Figure 4 shows the corresponding cross section limits as a function of W' mass. As usual, there is good agreement between the observed and expected limits.

Monojet events, where a high-p_{T} jet appears without objects to balance its transverse momentum, provide striking evidence of production of a non-interacting particle. ATLAS and CMS use such events to search for the production of an ADD graviton, e.g. in $gg \to gG$. Using 1.0 fb^{-1}, ATLAS sets limits on the fundamental Planck scale: $M_D > 3.4$ TeV for two extra dimensions and $M_D > 2.3$ TeV for four extra dimensions. [22] The corresponding CMS limits in 1.1 fb^{-1} are $M_D > 3.7$ and 2.7 TeV. [23] CMS has another monojet measurement [24] based on 4.7 fb^{-1} where a jet mass threshold is imposed and the signal is interpreted as $G^* \to ZZ \to (qq)(\nu\nu)$ to obtain cross section limits on the production of RS1 gravitons. The RS1 coupling strength is limited to $k/M_{Pl} < 0.21 - 0.29$ in the high-mass range $1.0 < M_{G^*} < 1.5$ TeV. Figure 5 shows the cross section limit as a function of mass and the limit as a function of coupling strength and mass.

In another paper in these proceedings, Steven Worm reports on a searches for dark matter based on update of the first CMS monojet analysis and a monophoton [25] search. The latter is also used to set a limit on the ADD fundamental Planck scale: $M_D \geq 1.59 - 1.66$ TeV for 3-6 extra dimensions.

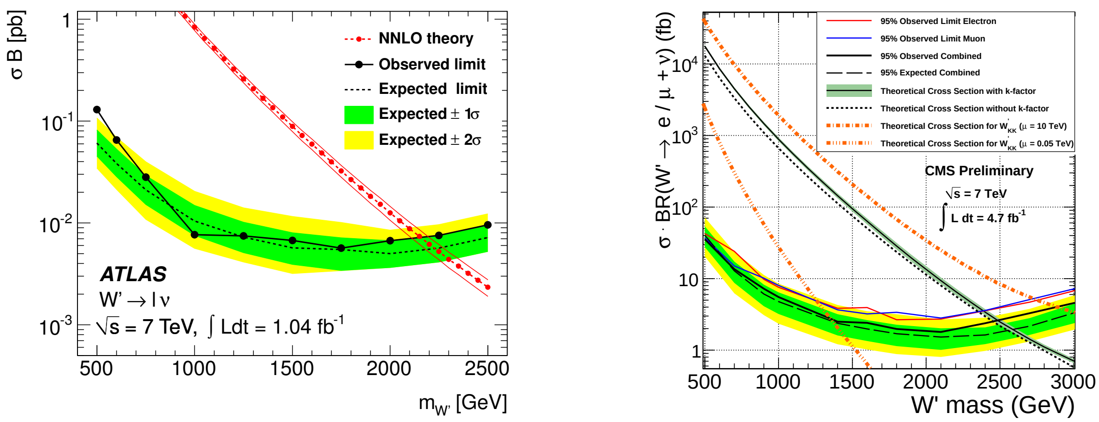

Figure 4: ATLAS [20] (left) and CMS [21] (right) cross section limits on $W' \to \ell\nu$.

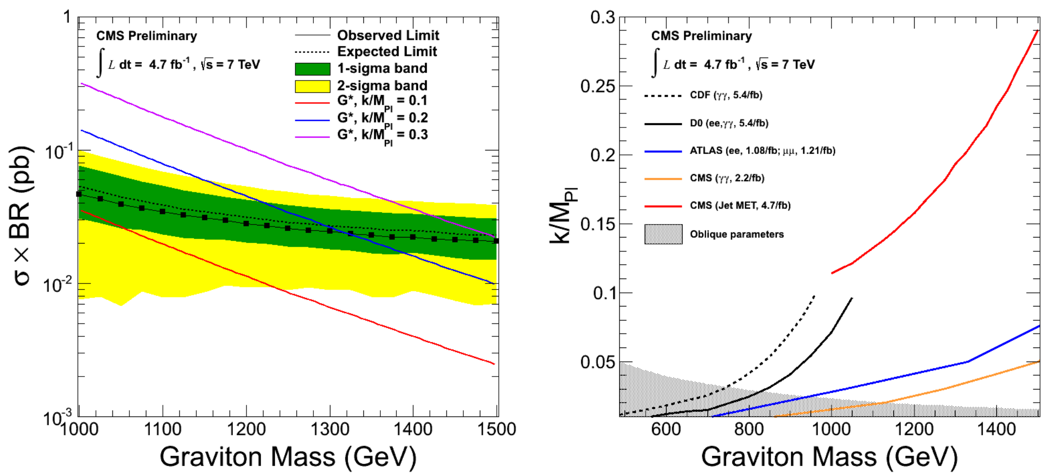

Figure 5: CMS $G^* \to ZZ \to (qq)(\nu\nu)$ monojet limits. [24] Left is the limit on cross section as a function of graviton mass and right is the two-dimensional limit in coupling strength vs. mass.

ATLAS and CMS also search for $t\bar{t}$ resonances. These can be a signature of Z' or KK (Kaluza-Klein) gluon production. ATLAS has a search [26] in 1.0 fb^{-1} that covers the low-mass range. CMS has a single-electron (plus jets) search [27] in 4.3 fb^{-1} and a single-lepton search [28] in 4.7 fb^{-1}. The latter sets leptophobic topcolor Z' mass limits of $m_{Z'} > 1.3$ TeV for a narrow resonance and $m_{Z'} > 1.7$ TeV for 10% width. It also sets a limit $m_{g_{KK}} > 1.4$ TeV for a KK gluon. CMS also has a $t\bar{t}$ resonance search in the all-jets channel using jet mass to identify W-bosons. [29] Figure 6 shows the jet mass spectrum spectrum and the one of the cross section limits as a function of mass. The KK gluon mass limit is $m_{g_{KK}} > 1.4 - 1.5$ TeV.

ATLAS has done a search for photon-jet resonances [30] in 2.1 fb^{-1}. The mass limit on excited quark production is $m_{q^*} > 2.46$ TeV.

ATLAS and CMS search for leptoquarks, pair-produced particles with resonant decay to either lq or νq with the branching fraction to the former denoted β. Searches are restricted to one generation, i.e. e, μ or τ. An ATLAS first-generation search [31] in the $eejj$ and $e\nu jj$ channels using 1.1 fb^{-1} sets mass limits $m_{LQ} > 660$ GeV for $\beta = 1$ and $m_{LQ} > 607$ GeV for $\beta = 0.5$. The limits in the $\beta - m_{LQ}$ plane are shown in Fig. 7. Second generation searches using the $\mu\mu jj$ and $\mu\nu jj$ channels have been performed by both ATLAS [32] in 1.0 fb^{-1} and CMS [33] in 2.0 fb^{-1}. Their respective mass limits are $m_{LQ} > 685$ and 632 GeV for $\beta = 1$ and $m_{LQ} > 594$

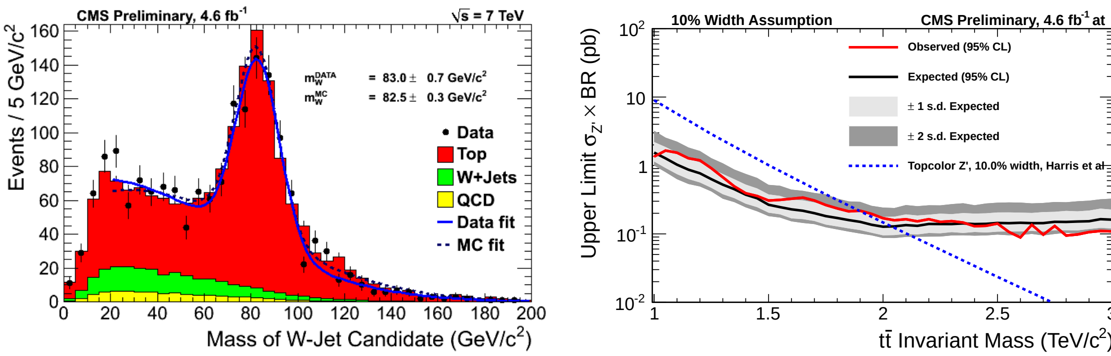

Figure 6: Jet mass spectrum (left) and example expected and observed limits on cross section as a function of mass (right) in the CMS all-jet $t\bar{t}$ resonance search.[29]

and 523 GeV for $\beta = 0.5$. CMS has performed a third-generation search[34] in 1.8 fb^{-1} in the $bb\nu\nu$ channel using razor variables and obtains the mass limit $m_{LQ} > 350$ GeV for $\beta = 0$. The limits in the $(1-\beta) - m_{LQ}$ plane are also shown in Fig. 7.

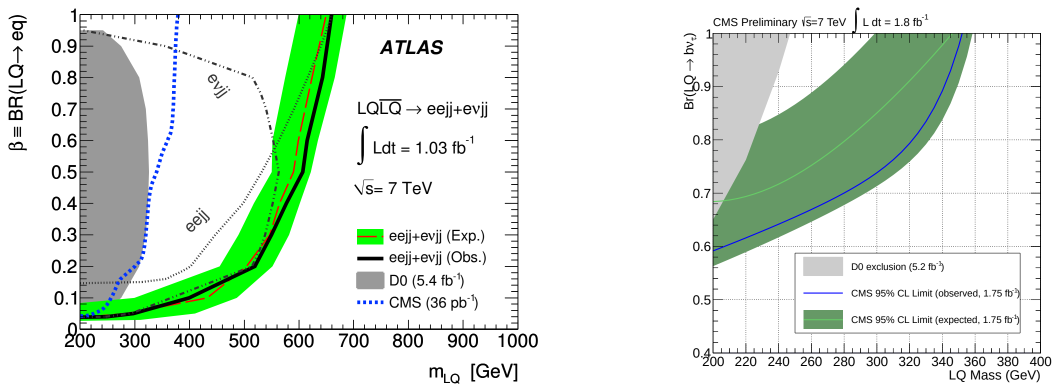

Figure 7: Expected and observed limits on leptoquark production. Left is the ATLAS first generation limit in the $\beta - m_{LQ}$ plane[31]. Right is the CMS third generation limit in the $(1-\beta) - m_{LQ}$ plane[34].

Both collaborations search for diboson resonances. The CMS search with $ZZ \rightarrow (qq)(\nu\nu)$ is discussed above. ATLAS has done a search with $ZZ \rightarrow llll$ and $ZZ \rightarrow lljj$ in 1.0 fb^{-1} and set a limit $m_G > 845$ GeV for the RS1 graviton with $k/M_{Pl} = 0.1$[35]. Searches for resonances in $WZ \rightarrow lll\nu$ have been carried out by ATLAS[36] in 1.0 fb^{-1}and CMS[37] in 1.1 fb^{-1}. Both are used to set limits on technicolor production, specifically two-dimensional limits on the masses of the π_T and ρ_T.

ATLAS has done a search for excited leptons looking for an $e\gamma$ resonance in $ee\gamma$ events and $\mu\gamma$ resonances in $\mu\mu\gamma$ events[38]. Figure 8 shows the two-dimensional limits on compositeness scale Λ and excited lepton mass m_{l^*}. Setting $\Lambda = m_{l^*}$, the mass limits are $m_{e^*} > 2.0$ TeV and $m_{\mu^*} > 1.9$ TeV.

Both collaborations search for heavy quarks, i.e. a fourth-generation pair of quarks. Here the heavy up-like quark is denoted T, the down-like partner B, and Q is used where the analysis is sensitive to either. Searches are preformed for both chiral, $T \rightarrow Wb$ and $B \rightarrow Wt$, and vector-like, $T \rightarrow Zb$ and $B \rightarrow Zt$, decays. In one search, the final-state Z is replaced with A_0, an unobserved neutral of arbitrary mass. Mass limits are summarized in table 1.

Both ATLAS and CMS search for a heavy neutrino N coupling to a right-handed boson W_R via the decay chain $qq \rightarrow W_R \rightarrow Nl \rightarrow W_R^* ll \rightarrow lljj$ leading to a mass resonance in both ljj

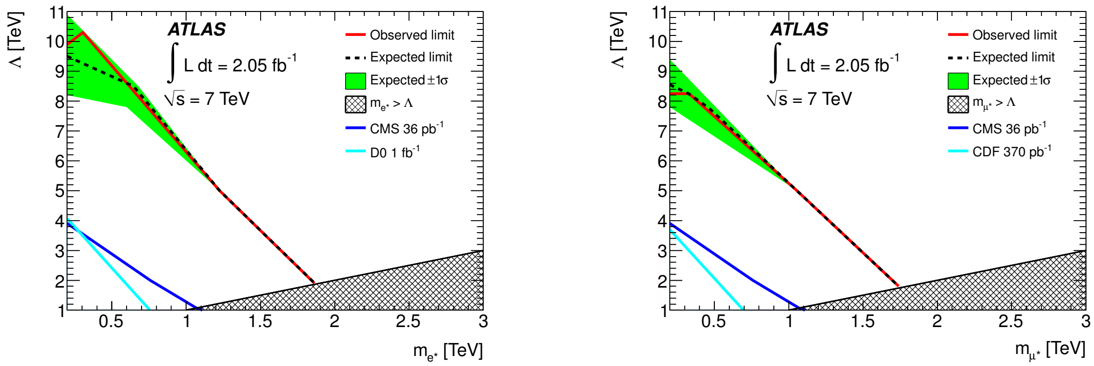

Figure 8: ATLAS expected and observed limits on excited electron (left) and excited muon (right) production.[38]

Table 1: Fourth generation quark searches and mass limits.

Exp.	Channel	$\int Ldt$ [fb^{-1}]	Mass limit
ATLAS[39]	$Qq \to Wqq'$	1.0	$m_Q > 900$ GeV
ATLAS[39]	$Qq \to Zqq'$	1.0	$m_Q > 760$ GeV
ATLAS[40]	$QQ \to (Wq)(Wq)$	1.0	$m_Q > 350$ GeV
CMS[41]	chiral $Q \to (Wb)X10$	1.1	$m_Q > 350$ GeV
ATLAS[42]	$TT \to (Wb)(Wb)$	1.0	$m_T > 404$ GeV
ATLAS[43]	$TT \to (tA_0)(tA_0) \to lX$	1.0	$m_T > 420$ GeV
CMS[44]	$TT \to (Wb)(Wb) \to llX$	4.7	$m_T > 552$ GeV
CMS[45]	$TT \to (Wb)(Wb) \to lX$	4.7	$m_T > 560$ GeV
CMS[46]	$TT \to (Zt)(Zt)$	1.1	$m_T > 475$ GeV
ATLAS[47]	$BB \to (Wt)(Wt) \to ljjjjjjX$	1.0	$m_B > 480$ GeV
ATLAS[48]	$BB \to (Wt)(Wt) \to l^{\pm}l^{\pm}X$	1.0	$m_B > 480$ GeV
CMS[49]	$BB \to (Wt)(Wt)$	4.6	$m_B > 600$ GeV

and $lljj$. The ATLAS search[50] in 2.1 fb^{-1} assumes similar masses for the heavy electron and muon neutrinos, and sets a mass limit $m_{W_R} > 2.3$ TeV for $(m_{W_R} - m_N) > 300$ GeV. A CMS search[51] in 0.24 fb^{-1} sets mass limits $m_{W_r} > 1.6$ TeV with a similar requirement on the mass difference. Figure 9 shows the two-dimensional mass limits for N and W_R.

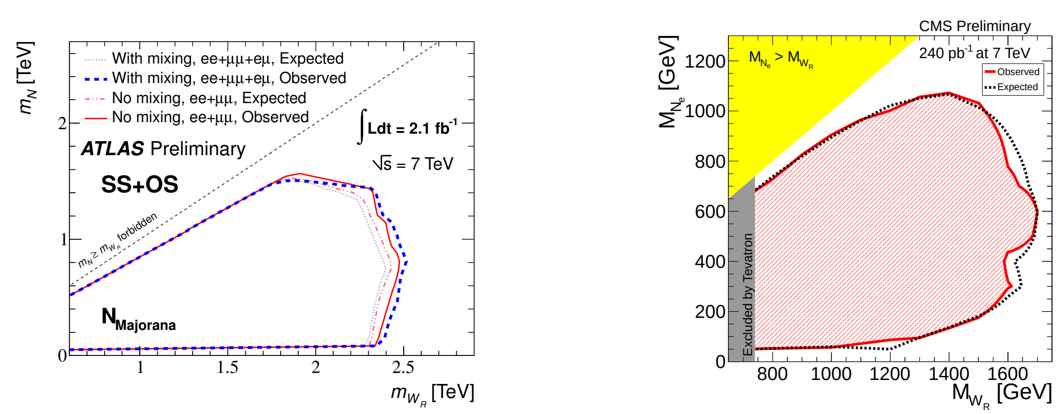

Figure 9: ATLAS[50] and CMS[51] expected and observed limits on the production of heavy right-handed W-bosons decaying to heavy neutrinos. Limits are a function of the new W and neutrino masses.

3 Conclusions

ATLAS and CMS have searched in a wide range of final states but have not (yet) found any evidence for physics beyond the standard model. Important constraints have been set on a variety of benchmark models. Published cross section limits can be used to restrict or rule out many more.

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