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Searches for heavy resonances at the LHC

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Abstract

Searches for heavy resonances at the LHC during Run I are presented. This talk focuses on the searches performed by the ATLAS and CMS experiments, covering a variety of final state topologies.

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SEARCH FOR HEAVY RESONANCES AT THE LHC

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Searches for heavy resonances at the LHC during Run I are presented. These proceedings focus on the searches performed by the ATLAS and CMS experiments, covering a variety of final state topologies.

1 Introduction

The ATLAS [1] and CMS [2] experiments are located at the LHC, a 27 km *pp* circular collider at CERN, Geneva Switzerland. Both have searched for new physics involving resonances in a wide variety of final states. In these proceedings I present these searches on behalf of the ATLAS and CMS Collaborations.

The pseudorapidity, η, is defined in terms of the angle with the beam axis, θ, as $\eta = -\log\tan\theta/2$. Typical pseudorapidity ranges for electrons are $|\eta| < 1.37$ or $1.52 < |\eta| < 2.47$ for ATLAS, and $|\eta| < 1.442$ or $1.56 < |\eta| < 2.5$ for CMS, where the excluded regions are the "transition" regions between the detector barrel and endcap. Typical pseudorapidity ranges for muons are $|\eta| < 2.5$ for ATLAS and $|\eta| < 2.4$ for CMS.

2 Resonances with dilepton, diphoton, and dijet final states

Dilepton and diphoton searches have typically simple final states with smoothly falling backgrounds. In the dilepton searches the E_T thresholds for the leading (subleading) electrons are 40 (30) GeV for ATLAS and 35 (35) GeV for CMS. Dominant systematic uncertainties are due to PDFs for background modeling, and lepton scale factors. Typical uncertainties are of the order of 5%. For the dilepton searches ATLAS sets a combined limit of $Z'_{SSM} > 2.90$ TeV [3], and CMS sets a combined limit of $Z'_{SSM} > 2.90$ TeV [4]. These results are shown in figure 1 (left).

ATLAS and CMS search for resonances in the diphoton final state. The E_T thresholds for photons for ATLAS (CMS) are 50 (80) GeV. CMS require the photons to be located in the barrel region of the detector and require $m(\gamma\gamma) > 300$ GeV. Dominant systematic uncertainties come from PDFs for background modeling, photon reconstruction efficiency, and luminosity. In the context of a Randall-Sundrum graviton model with $k/M_{Pl} = 0.1$ ATLAS sets a limit of $m(G_{RS}) > 2.66$ TeV [5] and CMS sets a limit of $m(G_{RS}) > 2.78$ TeV [6]. These results are shown in figure 1 (center).

Both ATLAS and CMS search for resonances in the dijet final state, which can be interpreted using many different models. The E_T thresholds for ATLAS (CMS) are 50 (30) GeV, and pseudorapidity ranges for ATLAS (CMS) of $|\eta| < 2.8$ ($|\eta| < 2.5$). ATLAS requires $m(jj) > 250$ GeV and $1/2(\eta(j_1) - \eta(j_2)) < 0.6$, while CMS requires $m(jj) > 890$ GeV. Dominant systematic uncertaintes are due to jet energy scale, jet energy resolution, and luminosity. In the context of a W' boson ATLAS sets a limit of $m(W') > 2.45$ TeV and CMS sets a limit of

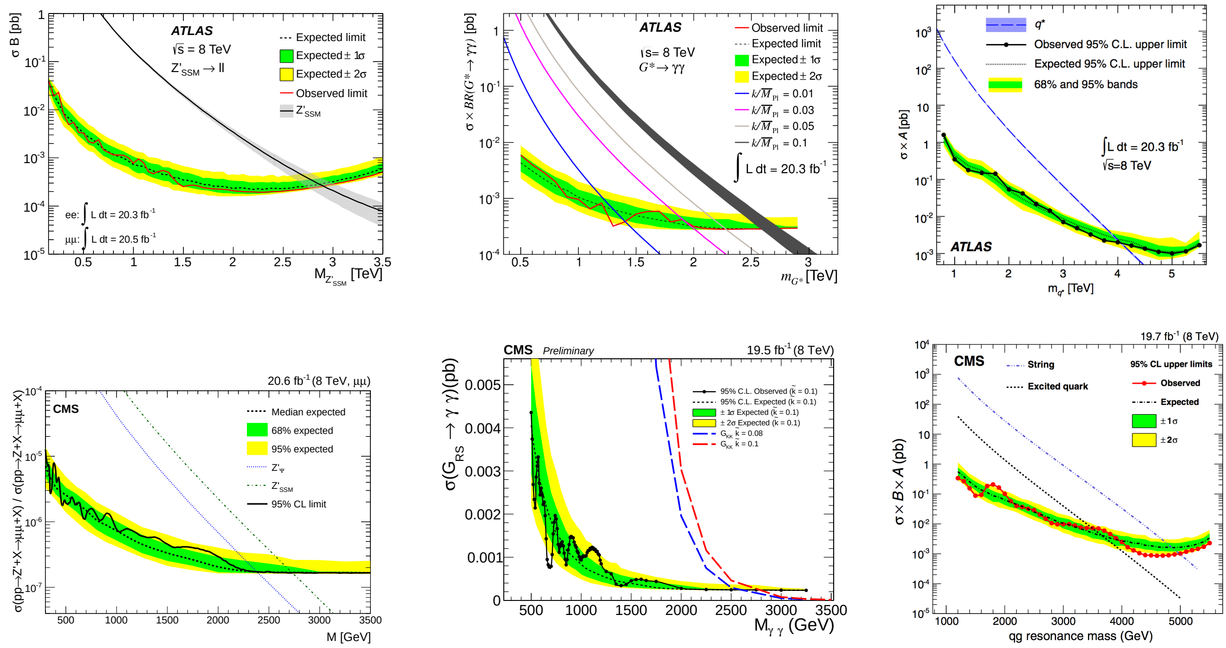

Figure 1 – Limits of the dilepton [3 4] (left), diphoton [5 6] (center) and dijet [7 8] (right) searches for the ATLAS (top) and CMS (bottom) experiments.

$m(W') > 2.2$ TeV, while in the context of a qg final state ATLAS sets a limit of $m(qg) > 4.06$ TeV [7] and CMS sets a limit of $m(qg) > 5.0$ TeV [8]. These results are shown in figure 1 (right).

3 Resonances with top quarks

As the mass limits of searches have become higher the reconstruction of top quarks in the boosted regime has become a very important aspect of new analysis techniques. For boosted decays this requires the identification of "top-jets". Top-jets are identified using dedicated top-tagging algorithms, which exploit variables related to jet substructure, and subjettiness variables, $\tau_n = \sum_i p_T^i \min(\Delta R_{1,i} \ldots \Delta R_{N,i}) / \sum_i p_T^i R_0$, where the index i represents subjets in the top-jet, $\Delta R_{m,i}$ is the relative separation in $\Delta R^2 = \Delta\eta^2 + \Delta\phi^2$ between the i-th jet axis and the m-th track within the jet, p_T^i is the transverse momenta of the subjets, and R_0 is a characteristic jet radius. The ratios τ_i/τ_j can be used to discriminate between different subjet topologies. ATLAS and CMS have detailed descriptions of their respective algorithms [9], [10].

ATLAS and CMS investigate vector-like top quark (T) scenarios, with the decay $T \to tH$, where H is the Standard Model scalar boson. Dominant systematic uncertainties include QCD estimates, flavour tagging, jet energy corrections and H boson tagging. ATLAS sets a limit of $m(T) > 855$ GeV [11], and CMS sets a limit of $m(T) > 745$ GeV [10]. These results are shown in figure 2 (left).

CMS searches for leptoquarks decaying into a $t\tau$ final state. The selections applied depend on the category of event, with typical selections of lepton transverse momenta satisfying $p_T^\ell > 15 - 35$ GeV, and $E_T^{jets} > 30 - 40$ GeV. Dominant systematic uncertainties include t reconstruction, pileup, and background estimation. CMS obtains the limit $m(LQ \to t\tau) > 685$ GeV [12].

Both ATLAS and CMS search for W' boson decaying via $W' \to tb$. Dominant systematic uncertainties come from $t\bar{t}$ production, and top-tagging. ATLAS sets a limit of $m(W'_R) > 1.92$ TeV [9 13], and CMS sets a limit of $m(W'_R) > 2.15$ TeV [14], where W'_R is a right-handed massive W-like boson. These results are shown in figure 2 (center).

ATLAS and CMS search for $t\bar{t}$ resonances in the context of a variety of Z' models which can preferentially couple to top quarks, including a narrow leptophobic topcolor Z' resonance.

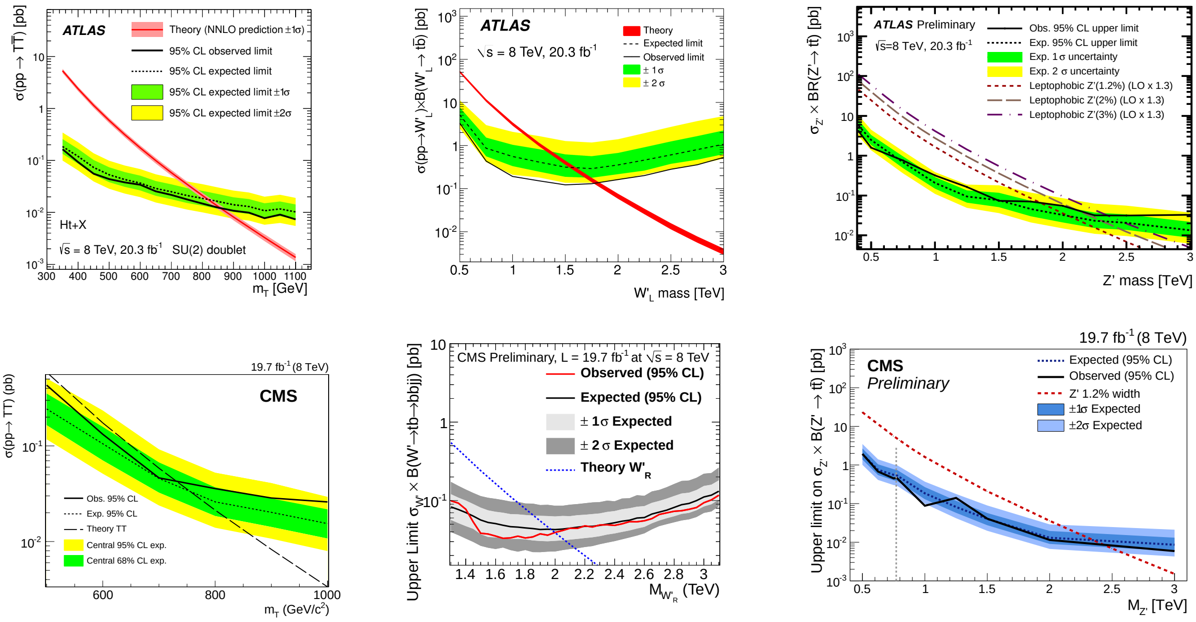

Figure 2 – Limits of the $T \to tH$ [11 10] (left), $W' \to tb$ [9 13 14] (center), and $Z' \to t\bar{t}$ [15 16] (right) searches for the ATLAS (top) and CMS (bottom) experiments.

Kinematic selections depend upon the final state for the CMS analyses, with E_T (p_T) thresholds for electrons (muons) in the range $20-85$ GeV, and E_T thresholds for jets in the range $50-100$ GeV, with top-tagging where appropriate. For the ATLAS analyses the E_T (p_T) threshold for electrons (muons) is 25 GeV, and 25 GeV (300 GeV) for anti-kT $\Delta R = 0.4$ ($\Delta R = 0.1$) jets. Leading systematic uncertainties are due to jet energy scales, $t\bar{t}$ normalisation, parton showering and fragmentation, and luminosity. No excess is seen, with ATLAS setting a limit of $m(Z') < 0.4$ TeV or $m(Z') > 1.8$ TeV [15], and CMS setting a limit of $m(Z') > 2.4$ TeV [16]. These results are shown in figure 2 (right).

4 Resonances with vector boson final states

There is a wide range of possible final states for resonances decaying via vector bosons, and both ATLAS and CMS have rich physics programs for these modes. These include a benchmark model of $W' \to WZ \to \ell\nu\ell\ell$. For ATLAS the E_T thresholds for leading (subleading) electrons are 40 (30) GeV, and the p_T threshold for muons is 25 GeV. For CMS the E_T threshold for Z electrons is 35 GeV, and the p_T thresholds for Z muons are 25 (10) GeV, where the first (second) threshold for the Z muons is for the leading (subleading) muon, while the E_T thresholds for W electrons is 20 GeV, and the p_T threshold for W muons is 20 GeV. Dominant systematic uncertainties are due to lepton scale factors, simulation statistics, trigger efficiency, missing transverse energy resolution, and luminosity. ATLAS sets limits of $m(W') > 1520$ GeV [17] and CMS sets limits of $m(W') > 1550$ GeV [18]. These results are shown in figure 3.

Addendum: The ATLAS collaboration released results showing excesses at a mass of around 2 TeV in the topology $X \to VV \to qqqq, V = W, Z$, using jet grooming techniques. The most significant local excess was of 3.5σ in the WZ final state. These results were not released early enough to be included in this talk [19].

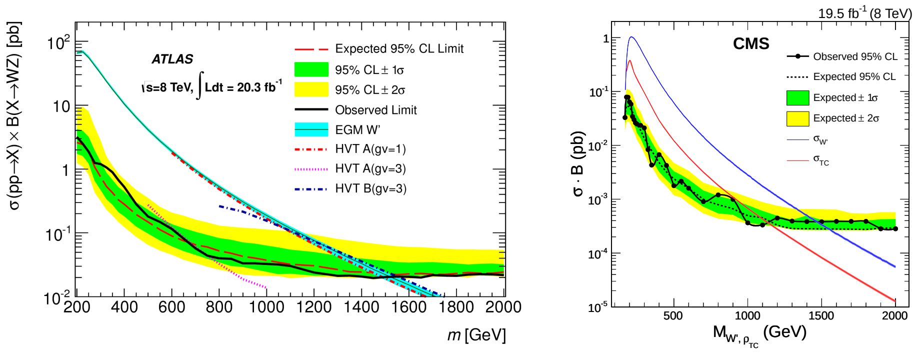

Figure 3 – Limits of the WZ searches for the ATLAS [17] (left) and CMS [18] (right) experiments.

5 Conclusion

The ATLAS and CMS collaborations have studied many final states in the search for massive resonances. They have probed new parameter space setting unprecedented limits in the range of TeV. The experiments have rich programs of physics diverse searches, which have so far not found any new exotic particles.

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