SEARCH FOR HIGH-MASS RESONANCES AND OTHER EXOTICA AT THE LHC

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With the discovery of the Standard Model Scalar boson by the ATLAS and CMS collaborations, all the constituents of the Standard Model (SM) of particle physics have been observed. Despite its success, the SM leaves many questions unanswered and that has inspired many models of physics beyond the SM. These models predict a wide range of new phenomena that is accessible at the LHC. This talk presents recent results from searches by the ATLAS and CMS collaborations for new phenomena with emphasis on processes that involve new massive resonances.

1 Introduction

The Standard Model (SM) of particle physics provides an excellent description of high-energy physics experimental data. At this time, there are no significant discrepancies between data and the SM. If the "Higgs-like" boson recently discovered by ATLAS [1] and CMS [2] proves to be the SM scalar, all the constituents of the SM will have been observed. Despite its success, the SM leaves many questions unanswered, including the nature of dark matter, the number of generations and the hierarchy problem. As a result, numerous Beyond-the-SM (BSM) theories have been proposed that seek to answer one or more of these questions. Many BSM models predict new phenomena at the TeV scale that would be accessible to experiments at the LHC.

This talk presents the results of searches for BSM resonances, essentially looking for bumps on smooth SM backgrounds. A few words about the conventions used for the following: for final states involving leptons, the notation ℓ will refer to electrons or muons. In addition, all limits are quoted at the 95% CL.

2 High-Mass Dilepton Resonances

Many BSM models predict the existence of new bosons, including various versions of a Z' (for example, from the Sequential SM (SSM) [3] or E_6 inspired models [4]) and Randall-Sundrum gravitons [5] G^*. ATLAS and CMS have searched for heavy narrow neutral resonances in the dilepton final state (e^+e^- or $\mu^+\mu^-$). The searches are based on the $\sqrt{s} = 8$ TeV data from 2012, the integrated luminosity used is 20 fb^{-1} and 21 fb^{-1} for ATLAS and CMS, respectively. The search strategy is to look for an excess in the dielectron and dimuon invariant mass distributions. Figure 1 (left) shows the dimuon mass spectrum from CMS while Fig. 1 (right) shows the dielectron mass distribution from ATLAS along with the expected signal from a SSM Z' for two Z' masses. Good agreement between the data and the SM background estimate is observed and limits on new bosons are set. For the benchmark SSM model, Z' bosons with masses below 2.96 TeV are excluded by CMS [7], the lower limit set by ATLAS [6] is 2.88 TeV.

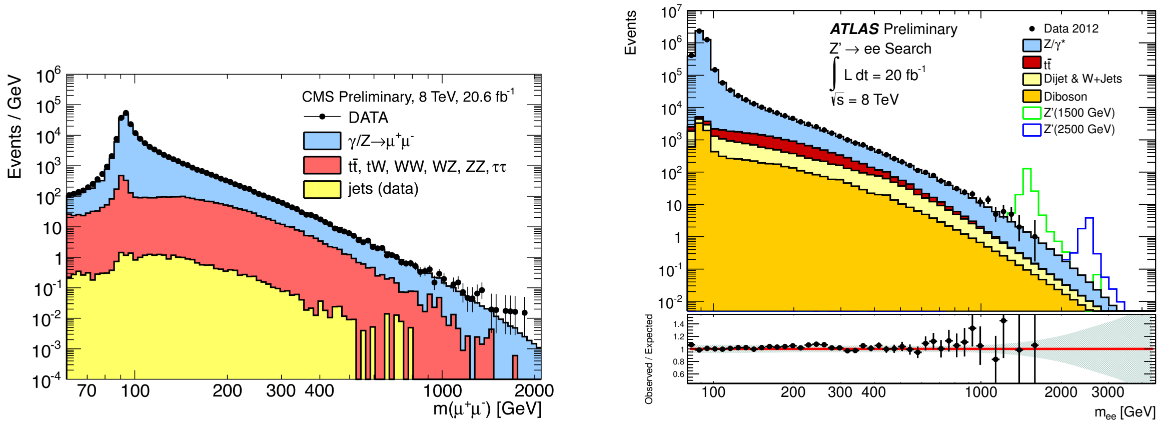

Figure 1: The CMS dimuon [7] (left) and ATLAS dielectron [6] (right) invariant mass distributions. The dots represent the data while the filled histograms show the expected SM backgrounds. The open histograms (right) illustrate the signal for a Z' with mass of 1.5 TeV or 2.5 TeV.

3 $W' \to$ Lepton + MET

The charged final-state counterpart to the dilepton searches presented in Section 2 are searches for heavy resonances decaying to a lepton (e or μ) plus missing transverse energy. The discriminant is the transverse mass M_T distribution. Examples of signal models include various versions of the W' (for example, the Sequential SM (SSM) [3]), chiral boson excitations W^* [8], or resonances predicted by Universal Extra Dimension (UED) models [9,10]. The new CMS results [11] are based on 20 fb^{-1} of $\sqrt{s} = 8$ TeV data from 2012. Figure 2 (left) shows the M_T spectrum for the electron channel. Good agreement is observed between the data and the SM background estimate and limits on new bosons are set. For the benchmark SSM model, CMS excludes W' bosons with masses below 3.35 TeV. A published result from ATLAS based on $\sqrt{s} = 7$ TeV data from 2011 placed a mass limit at 2.55 TeV [12]. CMS extends their analysis to set limits on the parameters of the split-UED model, see Fig.2 (right).

4 Type III Seesaw Model Heavy Leptons

Seesaw models provide a natural explanation for the light masses of the observed SM neutrinos through the addition of new massive particles and the seesaw mechanism. In the Type III seesaw models [13,14,15], the new heavy states couple to gauge bosons which allows a large enough production cross section for observation at the LHC. CMS has published results based on $\sqrt{s} = 7$ TeV data from 2011 placing mass limits on heavy leptons for several branching fraction scenarios [17]. ATLAS has a new search for pair production of heavy leptons $N^{\pm}N^0$ using 6 fb^{-1} of $\sqrt{s} = 8$ TeV data from 2012 [16]. The search is in the 4-lepton final state where $N^0 \to W^{\pm}\ell^{\mp}$ and $N^{\pm} \to Z\ell^{\pm}$ followed by $Z \to \ell\ell$. The discriminant is the $N^{\pm}$ mass $m_{Z(\ell\ell)\ell'}$, see Fig. 3 (left) which shows good agreement of the data with the SM background prediction. Limits are set as a function of heavy lepton mass m_N and the product of branching fractions (BFs), see Fig. 3 (right). Using a theoretically favored product of BFs, ATLAS sets lower limit on m_N of 245 GeV, the limit rises to 350 GeV in the case where the product of BFs is unity.

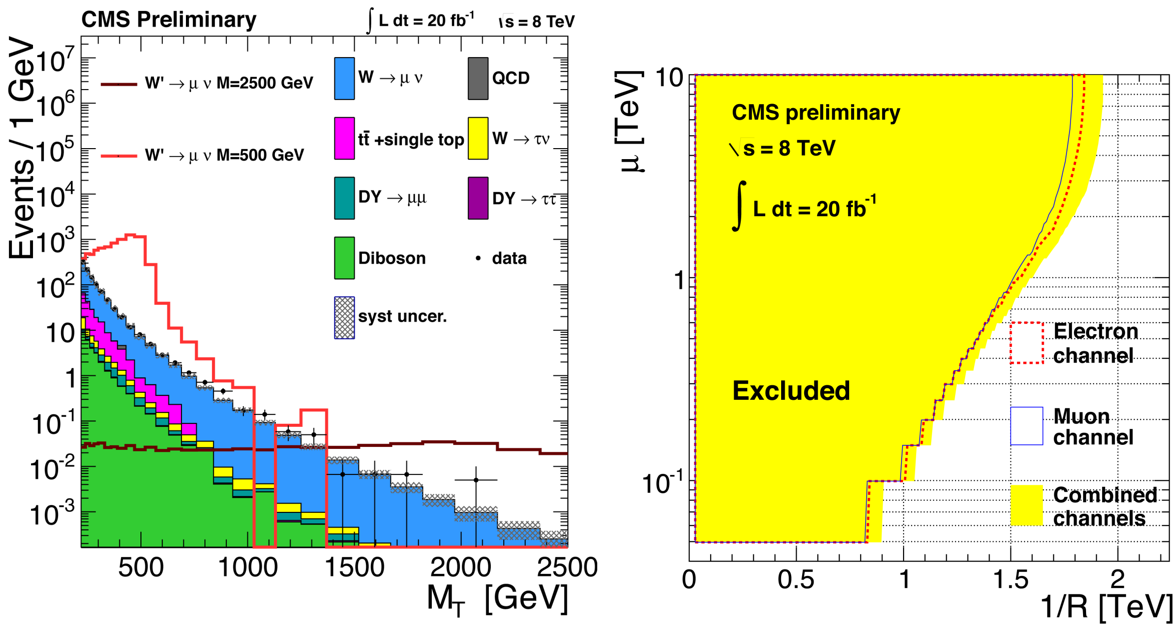

Figure 2: (Left) The M_T distribution for the electron channel from CMS [11]. The dots represent the data while the filled histograms show the expected SM backgrounds. (Right) Exclusion limits on the split-UED model parameters μ and 1/R derived from the W' mass limits.

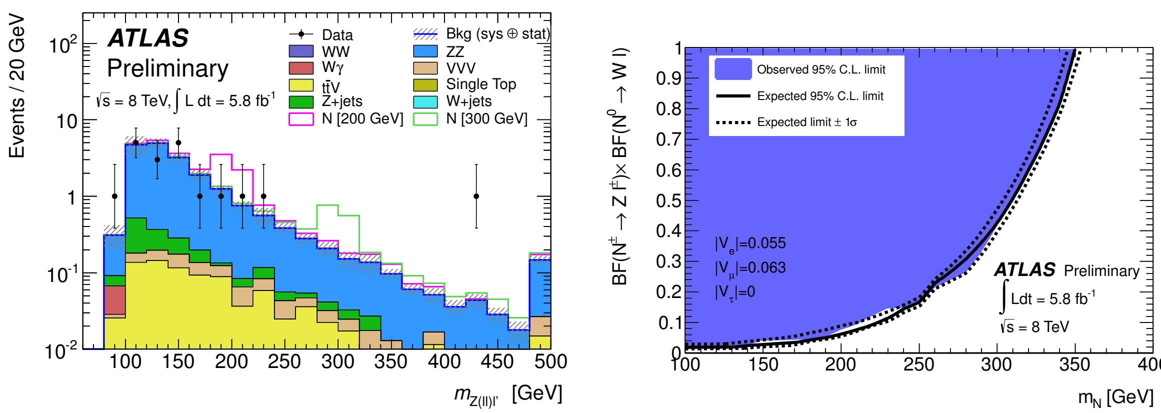

Figure 3: (Left) The invariant mass $m_{Z(\ell\ell)\ell'}$ from ATLAS [16]. The dots represent the data while the filled histograms show the expected SM backgrounds. (Right) Exclusion limits on Type III heavy leptons N in the product branching-fraction vs. m_N plane.

5 Resonant $WZ \to 3\ell + \nu$ Production

Many BSM models of electroweak symmetry breaking predict new diboson resonances. Examples include extended gauge model (EGM) [3] W' bosons and spin-1 technihadron states from low scale technicolor (LSTC) [18]. A new analysis from ATLAS looks for resonances in the $WZ \to 3\ell + \nu$ channel using 13 fb^{-1} of $\sqrt{s} = 8$ TeV data from 2012 [19]. The discriminant is the WZ mass M_{WZ} shown in Fig. 4 (left). The data is fully consistent with the SM background expectation and ATLAS sets a lower limit on the EGM W' mass of 1.18 TeV. A published result from CMS based on $\sqrt{s} = 7$ TeV data from 2011 places a W' mass limit at 1.14 TeV [20]. The ATLAS search results are also used to set limits on the masses of the π_T and ρ_T particles predicted by the LSTC model, see Fig. 4 (right).

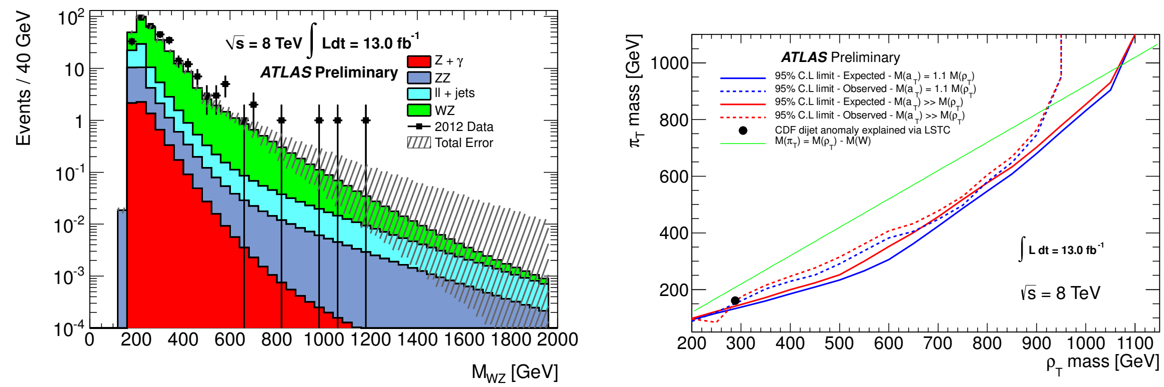

Figure 4: (Left) The invariant mass M_{WZ} from ATLAS [19]. The dots represent the data while the filled histograms show the expected SM backgrounds. (Right) Exclusion limits on technihadrons predicted by the LSTC model in the M_{π_T} vs. M_{ρ_T} plane.

6 Resonant ZZ Production

ATLAS and CMS have searched for bulk Randall-Sundrum (RS) gravitons [21] G^* that decay to the ZZ final state where one Z decays hadronically ($Z \to jj$) and the other leptonically ($Z \to \ell\ell$). The recent analysis from ATLAS [22] is based on 7 fb^{-1} of $\sqrt{s} = 8$ TeV data from 2012 and illustrates the trend of LHC experiments towards using special particle ID for highly boosted objects. To retain good efficiency at high G^* masses, ATLAS splits the analysis into two regimes: lower M_{G^*} where the jets from the $Z \to jj$ decay are both identified (i.e. "resolved") and higher M_{G^*} where the jets are merged in to a single object. Figure 5 shows the ZZ invariant mass distribution for both regimes along with an example G^* signal. ATLAS uses the distributions to exclude gravitons with masses below 850 GeV for the choice of RS model parameter $k/M_{Pl} = 1.00$. CMS published a graviton mass limit of 610 GeV using $\sqrt{s} = 7$ TeV data from 2011 under the assumption that $k/M_{Pl} = 0.50$ [23].

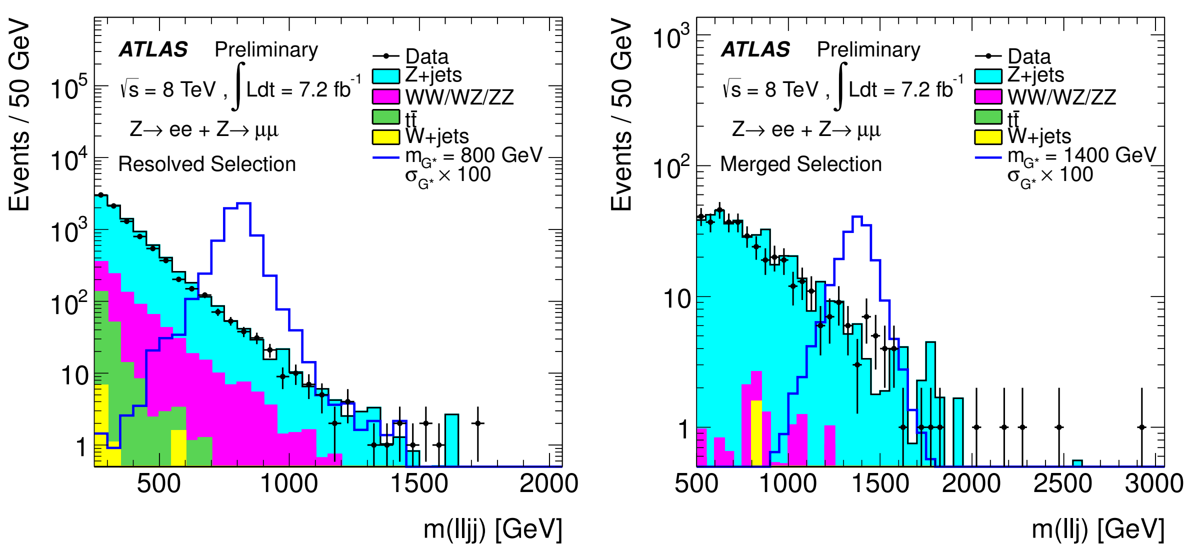

Figure 5: ZZ invariant mass distribution from ATLAS [22] when the jets from the decay $Z \to jj$ are resolved (left) or merged (right).

7 Dijet Resonances

A wide variety of narrow s-channel dijet resonances are predicted by BSM models. Examples include excited quarks q^* [24,25], W' and Z' bosons, and RS gravitons. ATLAS and CMS have new results from searches based on $\sqrt{s} = 8$ TeV data from 2012, the integrated luminosity used is 13 fb^{-1} and 20 fb^{-1} for ATLAS and CMS, respectively. The discriminant is the dijet mass, shown in Fig. 6. Both experiments look for excesses in the data compared to a four parameter fit to the dijet mass distribution. With no significant deviations observed, limits on BSM resonance production are set. Both experiments address q^* production, CMS excludes excited quarks with masses below 3.50 TeV (with an expected limit of 3.75 TeV) [27] while the ATLAS limit is 3.84 TeV (with an expected limit of 3.70 TeV) [26]. CMS sets mass limits on an additional seven more models while ATLAS places limits on $\sigma \times BF \times$ acceptance for any model whose signal is a Gaussian dijet mass peak.

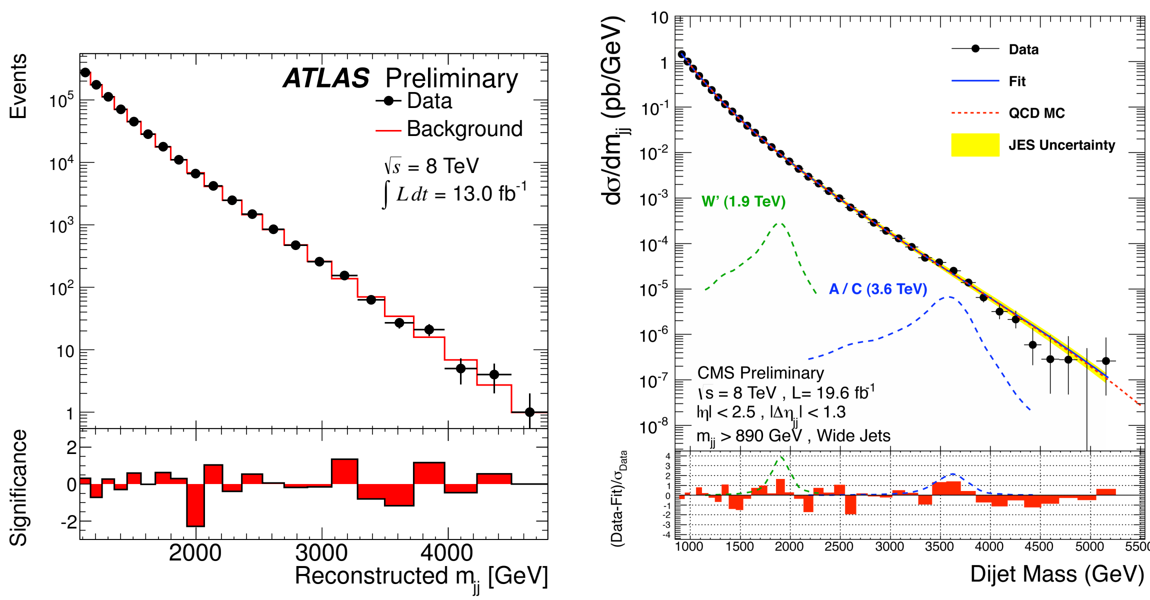

Figure 6: Dijet invariant mass distribution from ATLAS [26] (left) and CMS [27] (right).

8 Conclusions

Searches for new phenomena by ATLAS and CMS are probing the TeV energy scale. So far, the SM has proved remarkably resilient and no evidence for BSM physics has yet been uncovered at the LHC. Nonetheless, this is only the beginning. In the near term, results using the full LHC Run 1 datasets are starting to appear and a sample was presented here. In the medium term, the LHC BSM physics reach will be greatly extended by the increase in beam energy and intensity expected for Run 2.

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