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Top partners and compositeness at LHC

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A review of the last results with the data collected by the ATLAS and CMS experiments during 2011-2012 runs at the LHC is presented. The focus is on exotic searches for top partners and compositeness, with various reconstruction and analysis techniques.

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1. Introduction

The simplest and more natural extension to the standard model (SM) of particle physics consists in considering a fourth family of leptons and quarks [1]. To be consistent with the precision electroweak measurements, they should be strongly produced, and couple mainly to the third family. A sequential chiral fourth family might enhance the SM Higgs production in gluon fusion, but the decay mode $H \rightarrow \gamma\gamma$ is also suppressed. The presence of a fourth generation heavy Dirac neutrino might open invisible Higgs decays, reducing all branching ratios by a common factor [2]. Furthermore, a fourth family can be accomodated in models with an extended Higgs sector (Ex. Two-Higgs-Doublet models) [3]. A fourth family might also consist of vector like quarks, that have the same chiral transformation under electroweak group. A mass term in the lagrangian would be then allowed, cancelling Higgs quadratic divergences. Vector-like quarks can appear as singlet, doublet, triplet with possible charges +5/3, -4/3. The decay modes include final states with a boson (H, W, Z) and a third generation quark, with different channels opened: all three decay modes can be sizable for a singlet, while only Hq, and Zq are natural for a doublet [4].

According to the present knowledge, quarks and leptons are probed to be elementary particles up to scales of 10-15 TeV. Nevertheless, the SM of particle physics, albeit very successful, provides no explanation for the three generation structure of the fermion families. Attempts to explain the observed hierarchy (number of generations, charges, masses of quarks and leptons) have led to a family of models, the so called compositeness models, postulating that quarks and leptons might be composite objects of fundamental constituents [5–11]. Their hypothetic fundamental constituents are called "preons" and they are bound by an asymptotically free gauge interaction that becomes strong at a characteristic scale Λ. Compositeness models predict the existence of excited states of quarks (q^*) and leptons (l^*) at the characteristic scale of the new binding interaction. Since these excited fermions couple to the ordinary SM fermions, they can be produced via contact interactions in collider experiments and subsequently decay radiatively to ordinary fermions through the emission of a W/Z/g boson or via contact interactions to other fermions. The excited leptons can also be produced via gauge mediated interactions as well.

2. Top partners

In order to exclude different models, various signatures were used, in particular with one or more leptons (electrons or muons) in combination with various number of jets.

Latest results from CMS present a combined search of bottom-like and top-like quarks produced in different combinations t'$\bar{\text{t}}$', b'$\bar{\text{b}}$', t'b, b't, t'b'. The final states were classified according to the number of W-boson and lepton candidates. A combined fit to all the channels allowed the CMS Collaboration to set an observed mass limit at 685 GeV with a 95% confidence level (CL). The effect of a split in mass of 25 GeV, between the t' and b' quarks, was

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also investigated, translating in a shift of +/-20 GeV in the final limit value. This analysis was performed on 5.0 fb^{-1} of proton-proton collisions at 7 TeV [12].

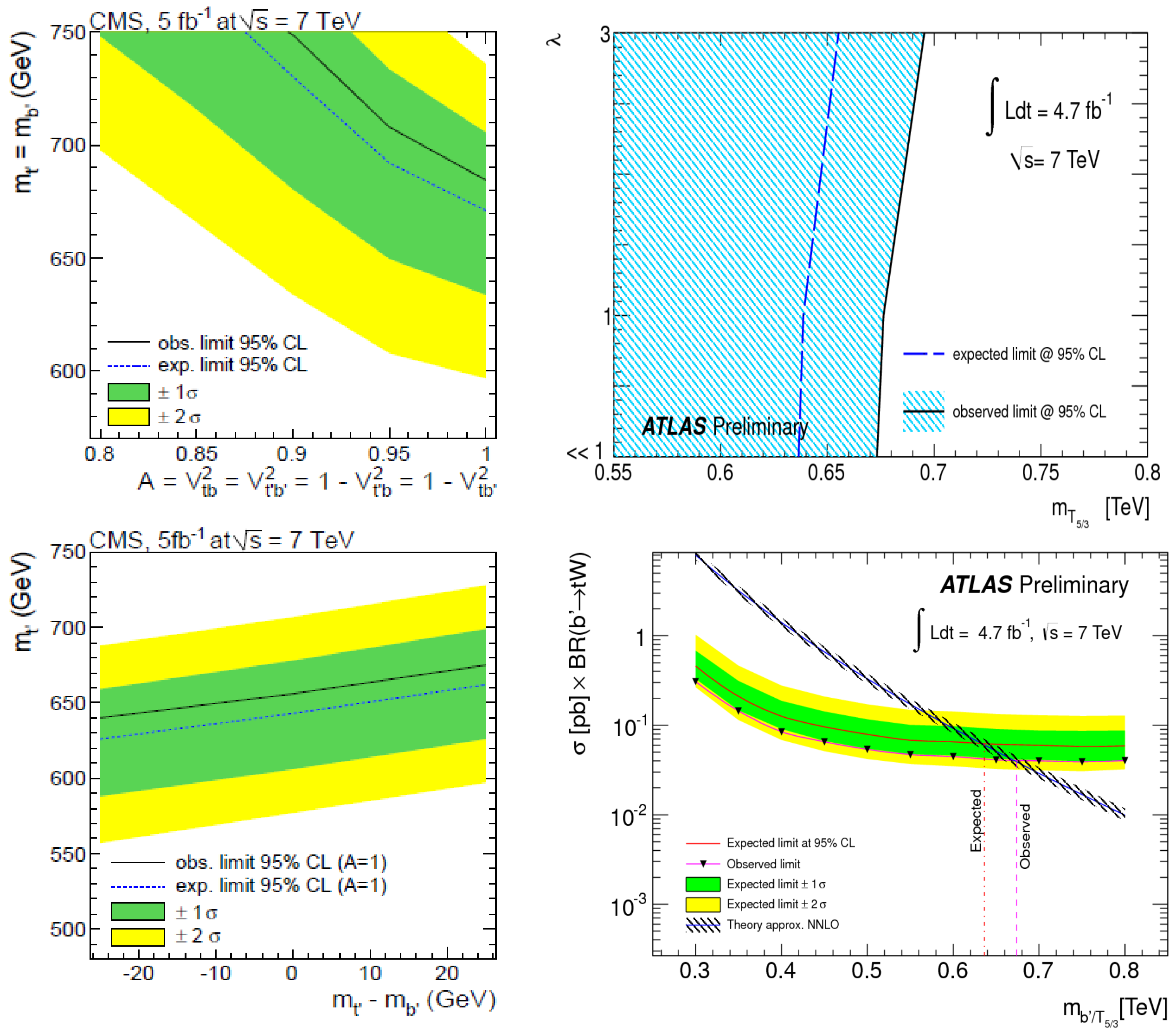

Figure 1. On the top left, the mass limit for a fourth generation quark. The effect of a split in mass, between the t' and b' quarks, it is shown on the bottom left [12]. On the top right, the mass limit for a T5/3 quark, for different λ couplings. On the bottom right, the mass limit on the pair production of b' or T5/3 quarks [13].

ATLAS performed a search on same-sign dilepton events, plus at least two jets and missing energy, with a cut and count analysis to set limits on various models: pair production of chiral b', single and pair production of a vector-like top partner of charge 5/3, decaying in Wt final state, and four tops final state production. Chiral b' quarks or a $T^{5/3}$ produced in pair with mass below 670GeV are excluded at 95% CL. The $T^{5/3}$ quark is excluded at 680GeV (700GeV) according to the coupling λ=1 (λ=3). The upper limit on the four tops cross section is 61fb. The analysis was performed using 4.7 fb^{-1} of proton-proton collisions at 7 TeV [13]. The limit plots for this and the previous analysis are reported in Figure 1.

CMS dedicates a full analysis to the $T^{5/3}$ quark in the two same-sign leptons plus jets final state. Assuming a $B^{-1/3}$ mass greater than $T^{5/3}$ mass, and 100% branching ratio in the Wt final state, the observed mass limit on $T^{5/3}$ has been pushed to 770 GeV. The analysis was performed using 19.6 fb^{-1} of proton-proton collisions at 8 TeV [14].

The lepton plus jets final state is used by both ATLAS and CMS to investigate new quarks pair production. CMS searches for Wt and Zt final states, with at least one W decaying leptonically, and the other bosons decaying hadronically. To reconstruct the event CMS requires at least one electron or muon, missing transverse momentum, at least four high momenta jets, at least one tagged as coming from a b quark. The presence of new signal is tested fitting the data to the distribution of ST, the scalar sum of transverse energy of leptons and jets, as a function of jet multiplicity. The observed mass limit is 675 GeV for a quark entirely decaying into Wt, and 625 GeV for a quark entirely decaying into Zt. The analysis was performed using 5 fb^{-1} of proton-proton collisions at 7 TeV [15].

ATLAS makes two searches focused on pair production of a vector like top partner in the lepton plus jets final state [16-17]. We focus here on the most recent, looking into the t' to Ht final state, but sensitive to mostly all the decay combinations (HtHt, ZtHt, WbHt, ZtZt, WbZt). Requiring at least six jets, three signal regions are defined, based on the number of b-tagged jets (2, 3, or more). A simultaneous fit is performed to all the signal regions to extract the mass limit. For the singlet (doublet) benchmark model, the observed mass limits at 95% CL were set at 709 (640) GeV. In Figure 2 the limits are presented in 2D plots, showing the different branching ratio hypothesis in the two axes.

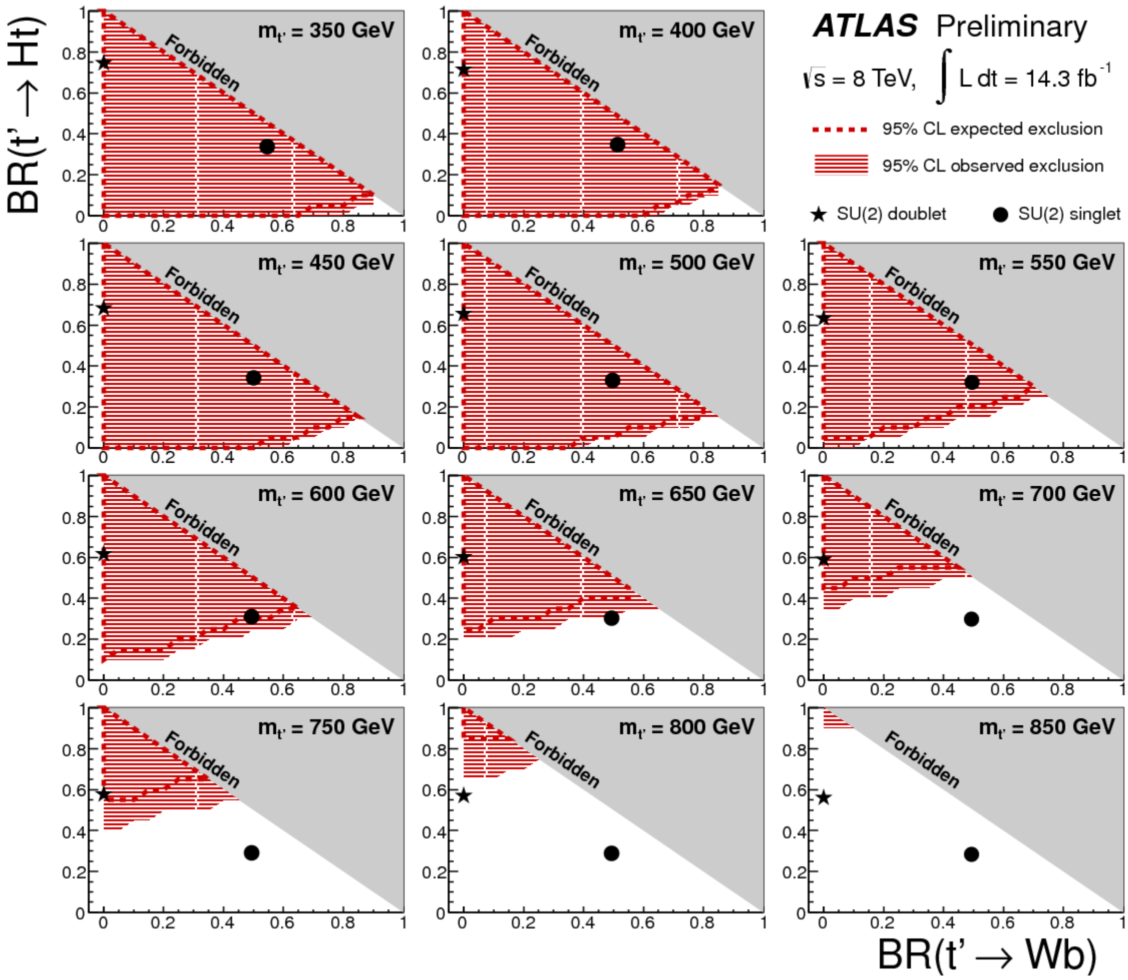

Figure 2. Observed and expected exclusion contours as a function of the branching ratios into Wb and Ht. Each plot represents a mass point hypothesis for the vector like top partner [17].

3. Compositeness Results

CMS experiment collaboration presents the most updated results of a search for compositeness in electrons and muons using a data sample of pp collisions at a center-of-mass energy $\sqrt{s}$ = 7 TeV collected with the detector at the LHC and corresponding to an integrated luminosity of 5.0 fb^{-1} [18]. Excited leptons are assumed to be produced via contact interactions in conjunction to a standard model lepton and a photon, yielding a final state with two energetic leptons and a photon. The analysis shows that the signal is distributed along two mutually perpendicular narrow bands in the lower and higher invariant mass (M^{Min} and M^{Max}) plane, as evident from Figure 3, and this shape determines the final selection cuts as outlined in the analysis.

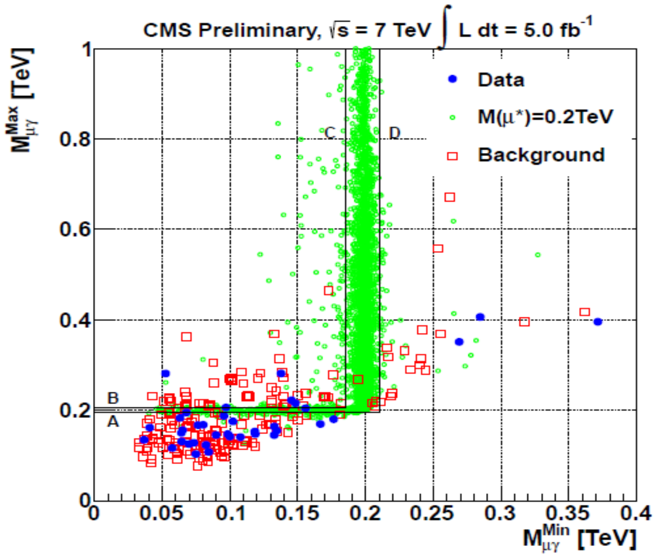

Figure 3: Distribution of M^{Min} and M^{Max} for the excited muon analysis. The blue solid circles, the red squares and the green solid circles correspond to the observed data, the background distribution and the signal distribution, respectively. The optimized selection boundaries are shown for an excited lepton mass of 0.2 TeV. The sample is normalized to 5 fb^{-1} of integrated luminosity.

The number of events observed in data is consistent with that expected from the standard model,thus the 95% confidence upper limits for the cross section for the production and decay of excited electrons (muons) have been set. For each excited lepton mass, the excluded cross section can be associated with a value for the new interaction scale. Excited leptons (electrons or muons) with masses below 1.9 TeV are excluded for the case where the contact interaction scale equals the excited lepton mass the scale of contact interaction. Production cross sections higher than 1.48 to 1.24 fb (1.31 to 1.11 fb) are excluded at the 95% CL for e^* (μ^*) masses ranging from 0.6 to 2 TeV as reported in Figure 4. These limits are the most stringent published to date.

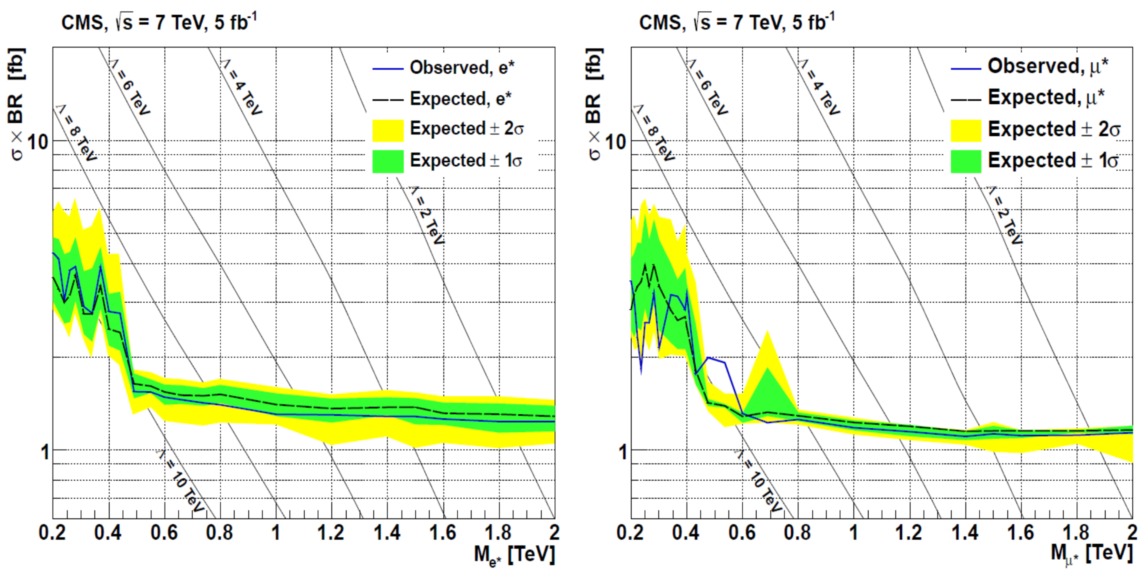

Figure 4: CMS expected and observed 95% CL upper limits on the cross section of the studied channel for the different excited electron (left) and muon (right) mass points, using the CLs method. The black solid lines correspond to the excited lepton LO cross sections times branching ratio for different Λ scales. The one (two) standard deviation uncertainty bands are shown in green (yellow).

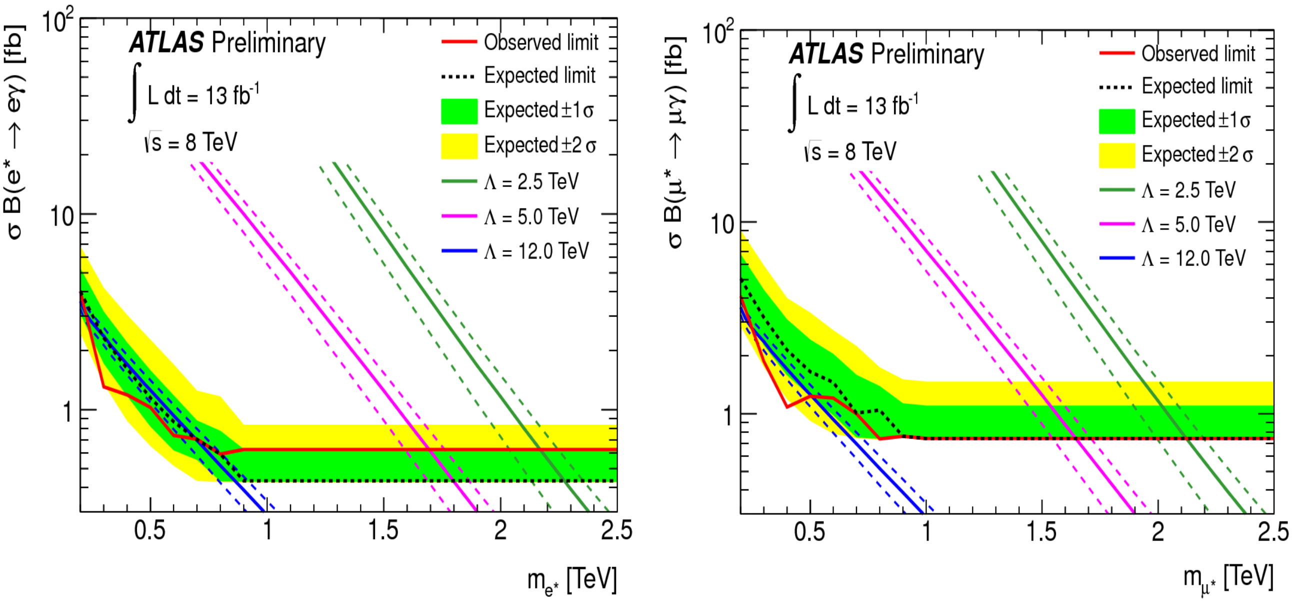

Figure 5: ATLAS experiment cross section times branching ratio limits at 95% CL as a function of the e^* (left) and μ^* (right) mass. Theoretical predictions for e^* and μ^* produced for three different compositeness scales are shown, as well as the theoretical uncertainties from renormalization and factorization scales and PDFS.

The ATLAS detector at the LHC is used to search for excited electrons and excited muons in the electromagnetic radiative decay channel $l^* \rightarrow l\gamma$ as well [19]. The analysis is performed using 13.0 fb^{-1} of pp collisions recorded in 2012 at a center-of-mass energy of 8 TeV. No evidence for excited leptons is found, and limits are set on the compositeness scale as a function of the excited lepton mass. Both excited electron and excited muon masses below 2.2 TeV are excluded at 95% CL. Since the analysis uses a larger dataset with a higher center-of-mass energy, ATLAS limit is more stringent of the one obtained by CMS (Figure 5).

In the contest of compositeness models the existence of new massive objects such as excited quarks (q^*), that couple to quarks or antiquarks (q) and gluons (g), is predicted, thus resulting in resonances in the dijet mass spectrum. Both CMS ([20]) and ATLAS ([21]) detectors have reported results on the search of such resonances, in the contest of specific models of narrow s-channel dijet resonances.

A search for narrow resonances decaying into a pair of jets has been performed by CMS using 19.6 fb^{-1} of pp collisions at $\sqrt{s}$ = 8 TeV. The dijet invariant mass distribution has been measured to be a smoothly falling distribution, as expected within the standard model. In the analyzed data sample there is no significant evidence for new particle production. Observed and expected 95% CL exclusions on the mass of resonances for exited quarks model are set by CMS experiment to be [1.20,3.50] and [1.20,3.75] as shown in figure 6.

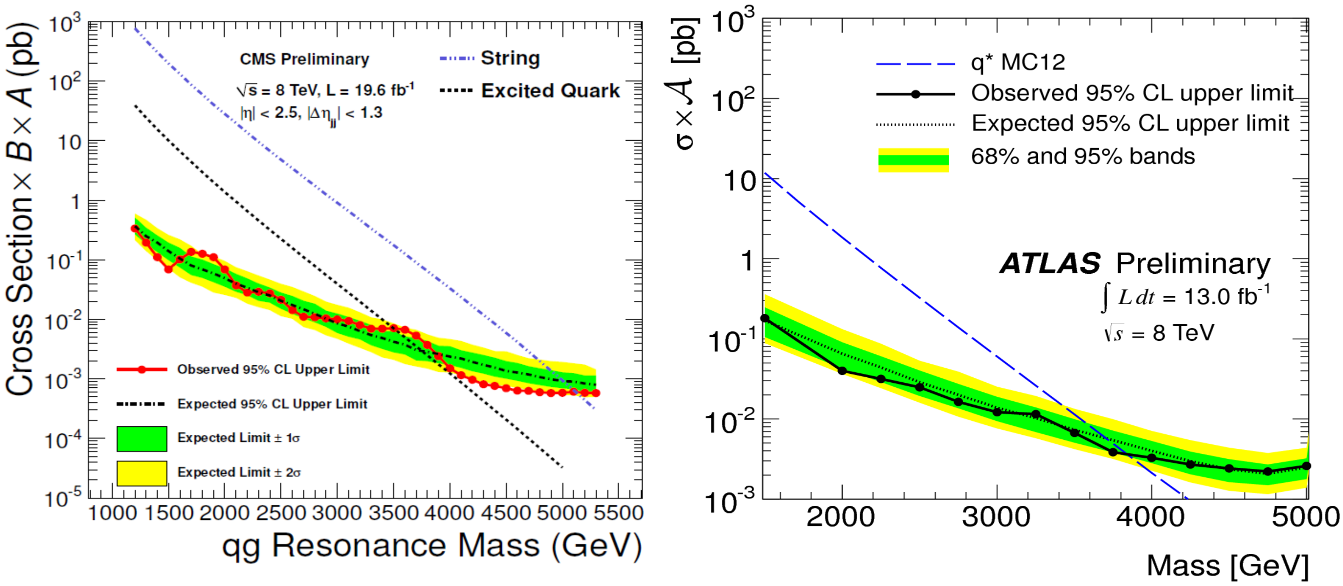

Figure 6: Left: Observed and expected 95% CL upper limits on cross section for resonances decaying into qg final state for CMS experiment (left) and ATLAS experiment (right) 95% C.L., as a function of dijet resonance mass (red for CMS and black filled circles for ATLAS). The black dotted curve shows the expected 95% C.L. upper limit and the green (darker) and yellow (lighter) bands represent the 68% and 95% contours of the expected limit, respectively.

The dijet mass distribution produced in LHC proton-proton collisions at a centre-of-mass energy $\sqrt{s}$ = 8 TeV has been studied with the ATLAS detector using 2012 data with an integrated luminosity of 13 fb^{-1}, reaching dijet masses up to ∼ 4.69 TeV. No resonance-like features have been observed in the dijet mass spectrum. A new 95% C.L. lower limit on the mass of excited quarks has been set at 3.84 TeV as shown in Figure 6 [21].

4. Conclusions

A plethora of forth generation and compositness models searches have been performed by both ATLAS and CMS detectors. No evidence for new physics have been found. Analysis must be finalized now with the full datasets available for 2012 data, nevertheless luminosity is not a game changer and limits are expected to improve slightly.

For Run II data analysis these searches need to be prepared for increased center-of-mass energy, therefore pile-up conditins and triggers must be carefully studied and proposed.

To optimize the analysis, model-independent analysis have been proposed, with a classification based on final state objects.

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