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Searches for new resonances decaying to leptons, photons or jets with CMS

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A selection of resonance searches performed by the CMS Collaboration with LHC Run 2 data is presented. Those searches were done in many different final states, including the dijet, dilepton, multilepton, lepton and missing energy, diphoton, and pair-produced three-jet final states. In 2016-2018, CMS collected data corresponding to an integrated luminosity of 137 fb^{-1}, at a center-of-mass energy of 13 TeV. Some of the searches presented here use all of this data, while others only use part of it. No evidence of new physics was found, and thus 95% confidence-level (CL) limits were set on signal models. Supersymmetry and Grand Unified Theory (GUT) inspired models are tested, as well as benchmark models such as the Sequential Standard Model.

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1. Introduction

There are many open questions in fundamental physics, such as the nature of dark matter and dark energy, and the proper way to solve the incompatibility of the Standard Model (SM) and General Relativity at the highest energies. New physics theories going beyond the SM have been proposed to answer questions such as these, and they often predict the existence of new resonances. A large number of searches for new resonances have thus been performed recently in CMS, during LHC Run 2. There were analyses in a variety of final states: jets, leptons, lepton and missing energy, photons. No evidence of new physics was found, and thus 95% CL limits were set. CMS is a general-purpose particle detector built on one of the LHC's collision points. More information about its design and performance can be found in [1].

2. Dijet final states

Searches for new resonances in two-parton final states have been performed for invariant masses all the way from $\sim$ 10 GeV to almost 8 TeV. A high-mass dijet analysis [2] with full Run 2 data went public in 2019. It used a novel technique to model the QCD multijets background and considerably improved on the previous published results of CMS [3]. Figure 1 shows the results, and table 1 summarizes the excluded mass ranges for a range of different models, both for the previous CMS analysis and the new one. The latest CMS search for dijet events in the mass range 500-1600 GeV is found in the previously referenced [3].

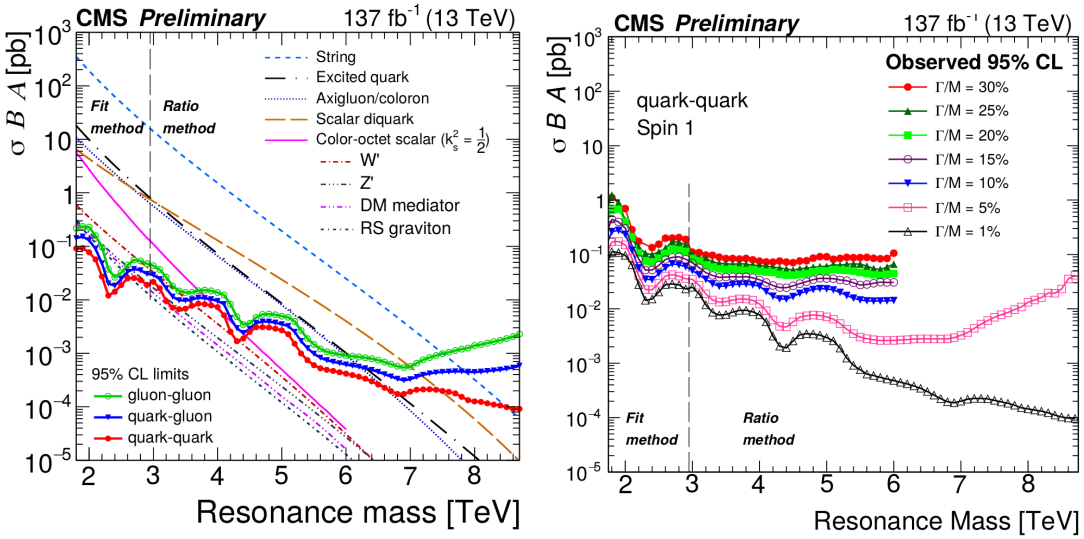

Figure 1: Exclusion plots for new dijet resonances, narrow on the left and broad on the right. The resonance mass is in the *x*-axis, while the *y*-axis shows the product of the cross-section, branching ratio and acceptance. 95% CL limits derived from data are shown separately for quark-quark, quark-gluon and gluon-gluon events. Predictions from many different new physics models are also shown [2].

Many analyses looked for boosted dijet events with masses below 500 GeV in Run 2 data. One was searching for a pseudoscalar boson coupling decaying to a $b\bar{b}$ pair [4], another for a Z' boson

decaying to quark-antiquark pairs [5], and another one for a leptophobic Z' [6]. The analyses had similar strategies: they search in each event for a large radius jet with a two-pronged substructure, recoiling against a high p_T object which triggered the data acquisition. An algorithm called the soft-drop mass algorithm removes soft and wide-angled contributions to the jet. Results for two of these analyses are presented in fig. 2.

Model	Excluded mass ranges (TeV)	
	Old	New
String resonances	<7.7	<7.9
Scalar diquarks	<7.2	<7.5
Axigluons/colorons	<6.1	<6.6
Excited quarks	<6.0	<6.3
Color-octet scalars	<3.4	<3.7
SM-like W'	<3.3	<3.6
SM-like Z'	<2.7	<2.9, 3.1-3.3
RS gravitons	<1.8, 1.9-2.5	<2.6
DM mediators	<2.6	<2.8

Table 1: Mass ranges excluded by data at 95% CL for high mass dijet resonances predicted by a variety of new physics models. The previous best CMS results ("old" [3]) are shown alongside the newest results [2].

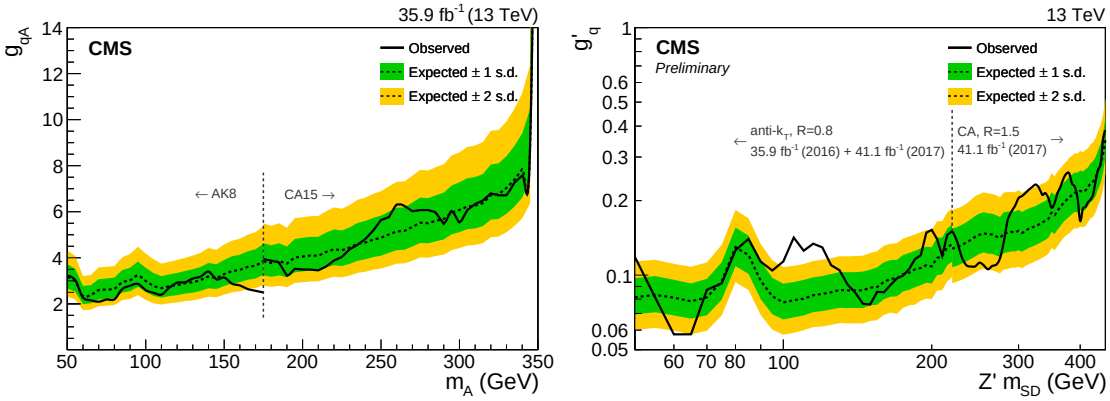

Figure 2: 95% CL exclusion plots in the (coupling, mass) plane for new low mass resonances in boosted searches. On the left: results from a search for (pseudo)scalar resonances in the $b\bar{b}$ final state [4], on the right: results from a search for vector resonances in the $q\bar{q}$ final state [6].

3. Pair-produced three-jet resonances

The CMS search for pair-produced three-jet resonances selects events with 6 jets in the final state, and groups them into two three-jet objects [7]. There are 20 different ways to classify 6 jets into such a grouping scheme, so even in a genuine signal event, finding the correct jet grouping is a non-trivial problem. This combinatorial noise and QCD multijet events are the main analysis

backgrounds. After event selection, the remaining background is fit to a smooth function in four different mass regions. The theoretical model tested is R-Parity Violating SUSY, limits are set on the gluino's mass and cross-section as shown in fig. 3.

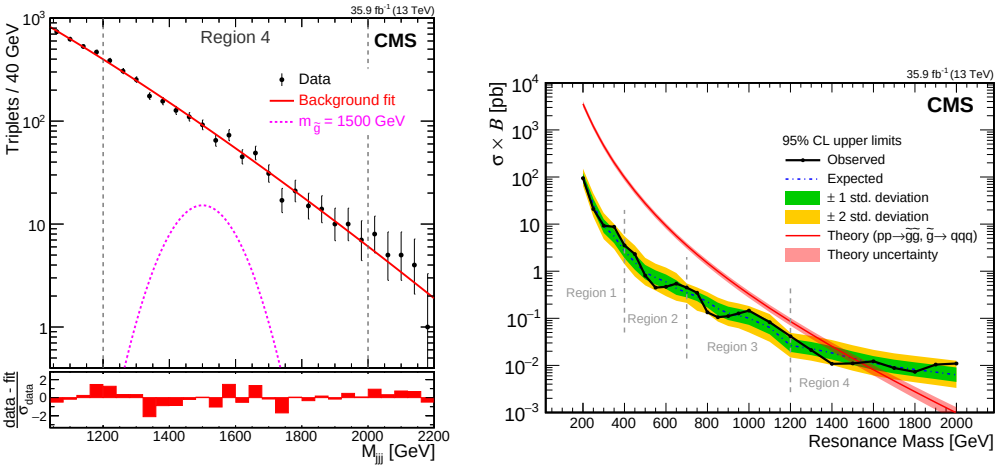

Figure 3: On the left, background fit to the data in the highest of the four mass regions (1200-2000 GeV) in the search for pair-produced three-jet resonances. A 1500 GeV RPV SUSY gluino signal is also depicted. On the right, the 95% CL exclusion plot in the (mass, cross section times branching ratio) plane, with observed and expected limits, as well as the RPV SUSY gluino model [7].

4. Dilepton searches

There are Run 2 CMS public results on high mass searches in dimuon (36.3 fb^{-1}) and dielectron (77.3 fb^{-1}) final states [8, 9]. Backgrounds with real leptons estimated from simulation and normalized to data, while the QCD multijets background is estimated by a data-driven method. The observed 95% CL lower limits on the resonance mass in the combined data[1] are 4.7 TeV for the Sequential SM Z' and 4.1 TeV for a superstring-GUT-inspired Z'_{ψ}.

5. Multilepton searches

A search for new light scalars and pseudoscalars produced in association with $t\bar{t}$ pairs was performed on events with three or more final state leptons [11]. The full Run 2 data was analyzed. Two different mass ranges, on either side of the Z mass window, are considered. The analysis is binned in the following discriminating variables: S_T (the scalar p_T sum of the leptons and missing energy), the number of b-jets, and the number of leptons. Limits on a scalar decaying to a dielectron pair are shown in fig. 4.

[1] More recent results went public in August [10].

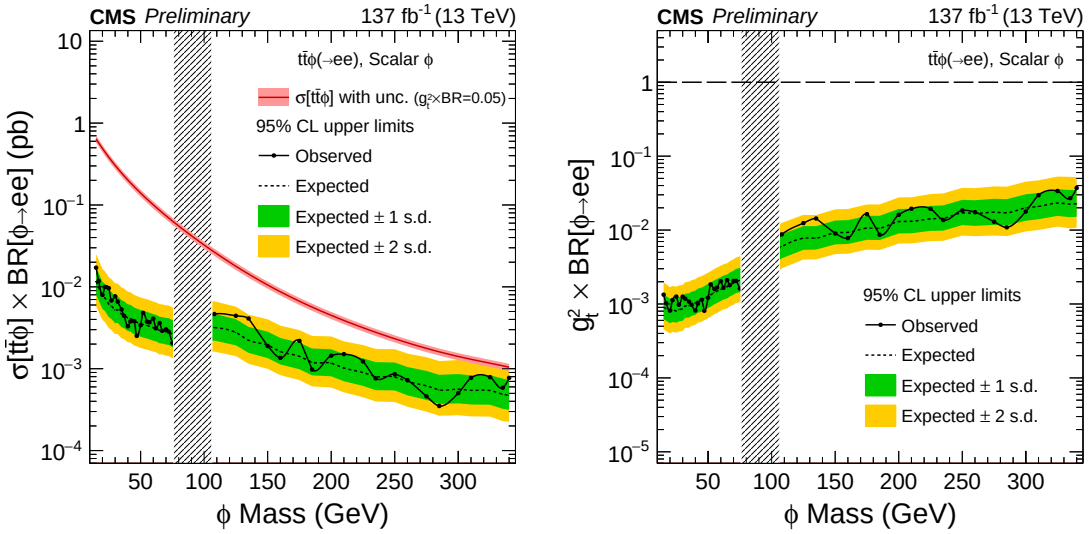

Figure 4: 95% CL limits on a scalar boson decaying to dielectron pair. The *x*-axis shows the scalar mass in both plots. On the left, the cross-section times branching ratio is shown, while on the right the *y*-axis depicts the product of the branching ratio to the square of the scalar's coupling to top quarks [11].

6. Lepton and missing transverse energy

Searches in final states with a lepton and missing transverse energy (MET) have been performed on 2016 data. One analysis looked for final states with tau leptons [12] and the other for final states with electrons or muons [13]. The final analysis variable in all cases is the invariant mass, in the transverse plane, of the lepton and the MET (called transverse mass $M_T(l, E_T)$). 95% CL lower limits on the mass of a SSM W' were derived: respectively 5.0, 4.9 and 4.0 TeV for the final states with electrons, muons, and taus.

7. Diphoton

A diphoton search in 2016 data can be found in [14]. The vertex is reconstructed by a MVA algorithm. The dominant background is formed by prompt SM diphoton events, which are fit to a smooth function of the diphoton mass. 95% CL lower mass limits on the first Kaluza-Klein excitation of spin-2 Randall-Sundrum (RS) gravitons are 2.3 (resp. 4.6) TeV for a coupling parameter of 0.01 (resp. 0.2).

8. Summary

A large variety of searches for new resonances were performed on LHC Run 2 data collected at CMS. All explored new parameter space and are either completely new or pushed further the limits of the previous analyses. New techniques are used to improve sensitivity and broaden scope of searches.

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