Search for heavy Resonances in Two-Particle Final States with Leptons, Jets and Photons at CMS

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At the LHC, the production of heavy resonances decaying into a pair of particles can be probed at unprecedented centre-of-mass energies. Two-particle resonances are predicted in a variety of BSM models and can be searched for in a largely model-independent fashion. Results from searches for resonances in final states with leptons, jets and photons based on the full dataset of 20 fb^{-1} taken by the CMS detector in 2012 in proton-proton collisions at a centre-of-mass energy of 8 TeV are presented. They are interpreted in terms of various theories of BSM physics ranging from generic heavy resonances such as the Z' to excited quarks or Randall-Sundrum gravitons. In the absence of a significant deviation from the expected SM background, 95% CL limits are set on model parameters of the theories under study.

1 Introduction

Searches for heavy resonances constitute an important part of the effort devoted to the test of beyond the Standard Model (BSM) physics carried out by the CMS collaboration at the LHC [1]. This note can only present an excerpt of the full program and is therefore restricted to three exemplary analyses with singly produced resonances which decay into a pair of reconstructed objects. The common feature of these searches is the distinct signal shape of the resonance on top of smoothly falling backgrounds. This leads to shape-based searches which are robust against deviations in the background spectrum in the region of high invariant mass of the two-object system.

2 Dilepton resonances

The search for narrow dilepton resonances in the dimuon and dielectron final states [2] focuses on the mass range above $M_{\ell\ell} = 200$ GeV, well above the Z peak. The interpretation of the results is carried out in terms of different spin-1 Z' signal models. With an invariant mass resolution of about 1% in the dielectron channel above $M_{ee} = 500$ GeV and 4% ($M_{\mu\mu} = 1$ TeV) to 9% ($M_{\mu\mu} = 3$ TeV) in the dimuon channel, the CMS detector is well-suited for the task of finding TeV-scale dilepton resonances. The selection of dimuon events is based on a dataset satisfying a single-muon trigger requirement with a central muon within $|\eta| < 2.1$ and $p_T > 40$ GeV. Two isolated muons, which satisfy identification criteria optimized for the efficient selection of

muons at high p_T, with $p_T > 45$ GeV and $|\eta| < 2.4$ have to be present in the event. The two selected muons are required to carry opposite electric charge, originate from the same vertex and have an opening angle smaller than $\pi - 0.02$ radians, where the latter requirement rejects background from cosmic muons. The invariant mass distribution of selected muon pairs in data is compared to the expectation from SM backgrounds in Fig. 1. Over the entire mass range, the background is dominated by the irreducible $Z/\gamma^* \to \ell\ell$ process. In the search region above $M_{\mu\mu} = 200$ GeV, the Drell-Yan contribution amounts to 80% of the expected background with $t\bar{t}$ and diboson production dominating the remaining 20%.
Dielectron events are selected based on a double-electron trigger asking for two clusters in the electromagnetic calorimeter (ECAL) with $E_T > 33$ GeV. Events containing two isolated electrons with $E_T > 35$ GeV are split into two categories for further analysis: a dielectron sample with both electrons in the central part of the ECAL with $|\eta| < 1.44$ and one with a central electron and the second electron in the ECAL endcap with $1.56 < |\eta| < 2.5$. These subsets of the dielectron candidates differ in background composition and invariant mass resolution.

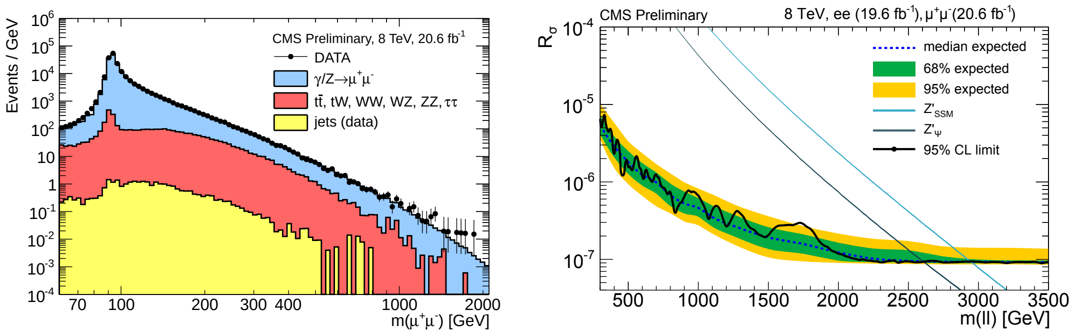

Figure 1: Left: Invariant mass distribution of selected muon pairs. Right: 95% confidence level limits on the cross section ratio R_σ as a function of signal mass.

No significant excess is observed in either dilepton channel and limits on two Z' models are set: a sequential SM Z'_{SSM} and a Z'_ψ expected in certain grand unified theories. In order to reduce the impact of systematic uncertainties on the results, limits are determined on the cross section ratio R_σ between the spin-1 Z' signal and the SM Drell-Yan cross section (including the branching ratios), rather than on the signal cross section. The cross sections in the ratio are evaluated in the mass range $0.6\ M_{Z'} - 1.4\ M_{Z'}$ and $60 - 120$ GeV for the signal and SM Drell-Yan processes, respectively. A Bayesian limit setting procedure using an unbinned likelihood with a uniform prior for the signal cross section is used to derive lower limits on the signal mass at 95% confidence level (CL). Combination of the dimuon channel and the two dielectron channels yields lower limits on the Z' mass of 2960 GeV and 2600 GeV for the Z'_{SSM} and Z'_ψ signals, respectively. The limits on R_σ are shown in Fig. 1.

3 Dijet resonances

At a hadron collider such as the LHC, searches for resonance production in the dijet final state [3] probe a variety of BSM models. At a signal mass of 1 TeV, the signal cross sections for the different resonance models considered (Table 1) cover a wide range from the pb regime in case of weakly coupling models such as the Z'_{SSM} up to several nb for string resonances. The models further differ in the type of jets in the final state (qq, qg, gg or a combination).

This leads to different resonance shapes depending on the signal under study, with larger low-mass tails in final states containing gluon jets. The statistical interpretation is therefore carried out with different signal shapes, depending on the final state.
The jet reconstruction starts from the particle-flow (PF) CMS event reconstruction and builds jets using the anti-k$_T$ algorithm with jet parameter $R = 0.5$ (AK5 jets). Among the jets with $p_T > 30$ GeV and $|\eta| < 2.5$, the two leading jets are selected and two "wide jets" are formed around them by adding the Lorentz vectors of all other jets within $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 1.1$. The two wide jets then form the dijet system used in the analysis with invariant mass M_{jj}. This approach reduces the sensitivity to gluon radiation off the two partons from the resonance decay. The event selection is performed on a dataset obtained from a combination of two triggers selecting events with the scalar sum of the jet transverse momenta above $H_T = 650$ GeV or with $M_{jj} > 750$ GeV, respectively. The selection of two wide jets is performed as described above and they both have to fall within $|\eta| < 2.5$. Requiring a small pseudorapidity gap of $|\Delta\eta_{jj}| < 1.3$ reduces the SM dijet background. Events with $M_{jj} < 890$ GeV are rejected. The resulting dijet mass spectrum is depicted in Fig. 2 and compared to the expectation.

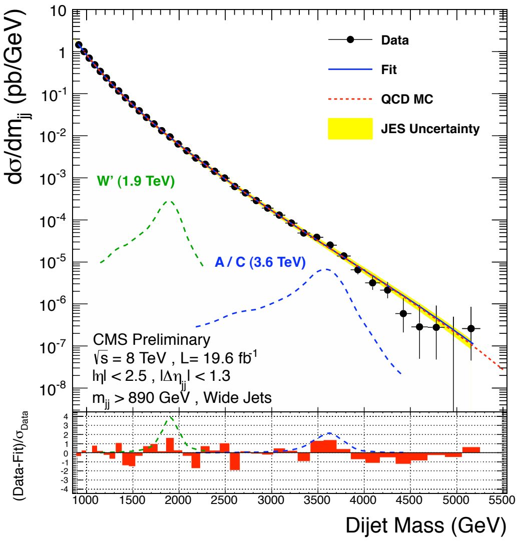

Figure 2: Invariant mass distribution of selected wide jet pairs. Signal distributions are shown for W' and axigluon/coloron signals.

In the absence of a significant excess, upper limits are set on the product of signal cross section, branching ratio, and acceptance for the various resonance models. The 95% CL upper limits are obtained from a Bayesian approach with uniform prior for the signal cross section and derived for the three different combination of jet types, qq, qg, and gg, all of which come with different resonance shapes. The observed limits on the cross section for signals with qq final state are stronger than for those with gg final state by a factor 2 to 3. The corresponding excluded ranges of the resonance mass for different signal models are given in Table 1 and reach up to 5 TeV in case of string resonances. Searches for dijet resonances have also been performed by the CMS collaboration with b-tagged jets [4] and W/Z-tagged jets [5].

Model	Final State	Obs. Mass Excl. [TeV]
String Resonance	qg	[1.20 , 5.08]
Excited Quark	qg	[1.20 , 3.50]
E_6 Diquark	qq	[1.20 , 4.75]
Axigluon/Coloron	q$\bar{q}$	[1.20 , 3.60]+ [3.90 , 4.08]
Color Octet Scalar	gg	[1.20 , 2.79]
W' Boson	q$\bar{q}$	[1.20 , 2.29]
Z' Boson	q$\bar{q}$	[1.20 , 1.68]
RS Graviton	q$\bar{q}$+gg	[1.20 , 1.58]

Table 1: Excluded resonance mass ranges at 95% CL for the different signal models.

4 Photon+jet resonances

The search for resonances in the photon+jet invariant mass spectrum [6] is motivated by theories of quark compositeness at an energy scale Λ involving excited quark states q^*. The production of the excited quark via quark-gluon fusion and the decay into the photon+quark final state involve strong and electromagnetic gauge couplings with a coupling modifier f as a free parameter. A combination of spin-1/2, mass degenerate excitations of the first generation quarks $q^* = (u^*, d^*)$ is used as the signal model.

Photon+jet pairs are selected from a dataset that has been collected with a single-photon trigger with $E_T > 150$ GeV. The presence of at least one isolated photon with $p_T > 170$ GeV in the central part of the ECAL with $|\eta| < 1.44$ is requested. Selected AK5 jet candidates have to be separated in $\eta - \phi$ space by $\Delta R > 0.5$ from the selected photon. The leading jet with $p_T > 170$ GeV and $|\eta| < 3$ is chosen. The dominant backgrounds in this search, QCD photon+jet production and dijet events with a jet misidentified as a photon, are produced predominantly via t-channel diagrams. These contributions are reduced by requiring $|\Delta\eta_{\gamma j}| < 2.0$ and a back-to-back topology $|\Delta\phi_{\gamma j}| > 1.5$. The invariant mass $M_{\gamma j}$ has to exceed 560 GeV. After selection, the expected background composition is dominated by SM photon+jet production, which contributes 80.5%, followed by dijet events with 18.5% and electroweak backgrounds with 1%. The invariant mass resolution ranges from 4.5% at $M_{\gamma j} = 1$ TeV to 3% at $M_{\gamma j} = 3$ TeV. The observed invariant mass distribution exhibits no significant deviation from the background expectation, and bounds in the two-parameter space of coupling modifier f and the excited quark mass M_{q^*} at 95% CL are obtained, as shown in Fig. 3. For the choice $f = 1$ and $\Lambda = M_{q^*}$, excited quarks are excluded at 95% CL in the mass range 0.7 TeV $< M_{q^*} <$ 3.5 TeV.

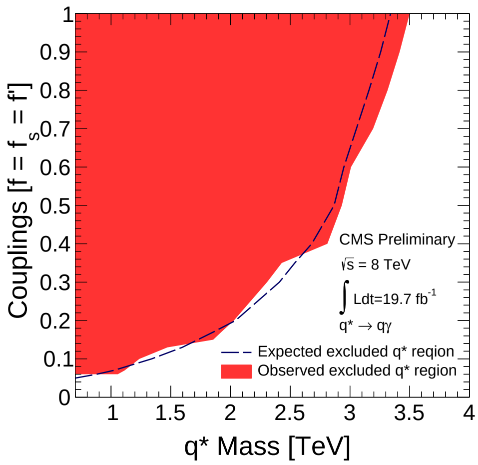

Figure 3: 95% CL bounds in the two-parameter space of coupling modifier f and M_{q^*}, assuming $\Lambda = M_{q^*}$.

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