

# Search for Single and Pair-Production of Dijet Resonances with the CMS Detector

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## Abstract.

Searches for new physics in the single and paired dijet mass spectrum are performed using data collected by the CMS experiment at the LHC at a collision energy of  $\sqrt{s}=7$  or  $\sqrt{s}=8$  TeV. No evidence for new physics is found and upper limits are set for various models. At 95% confidence level, a string resonance in the single dijet spectrum is excluded for masses between 1 and 4.7 TeV and, for the first time, a coloron in the paired dijet spectrum is excluded for masses between 250 and 740 GeV.

## 1. Introduction

Many beyond-the-standard-model models predict the existence of new massive strongly produced objects that decay into quarks ( $q$ ) and gluons ( $g$ ). These states may show up as narrow resonances in the leading (highest  $p_T$ ) jet spectrum. We consider the following models: string resonance ( $qg$ ,  $q\bar{q}$  and  $gg$ ) [1, 2];  $E_6$  diquark ( $\bar{q}\bar{q}$  and  $qq$ ) predicted from grand unified theory based on the  $E_6$  gauge group [3]; excited quarks  $q^*$  ( $qg$ ) expected from composite quark model [4, 5]; axial vector particles called axigluons  $A$  ( $q\bar{q}$ ) [6, 7]; color-octet vector  $C$  ( $q\bar{q}$ ) [8]; color-octet scalar  $S_8$  ( $gg$ ) [9]; new gauge bosons  $W'$  and  $Z'$  from new gauge symmetries ( $q\bar{q}$ ) [10]; massive gravitons  $G$  ( $q\bar{q}$  and  $gg$ ) from the Randall-Sundrum (RS) model of extra dimensions [11]. The color-octet vector is predicted by the flavor-universal coloron model, which embeds the SU(3) symmetry of QCD in a larger gauge group; the color-octet scalar is included in many dynamical electroweak symmetry breaking models, such as technicolor.

In addition to singly produced particles, many models predict the pair production of massive colored particles [12]. The searches of new narrow resonance in the leading dijet mass spectrum is not optimized for pair-produced particles for the following reason: the probability that one of the particles decays into the two leading dijet is only about 10%. A dedicated search is needed for pair-produced particle. We use coloron production as our benchmark model ( $gg \rightarrow CC \rightarrow q\bar{q}q\bar{q}$ ). We also consider the possibility that colorons decay into color-octet scalars ( $S_8$ ). Furthermore, we consider an R-Parity violating SUSY model [13] in which pair-produced top squark (stops) each decay to  $q\bar{q}$  as a third possibility.



## 2. Jets Reconstruction at CMS

Jets are reconstructed using a particle flow technique [14] at CMS [15]. The CMS particle-flow algorithm combines calorimeter information with reconstructed tracks to identify photons, leptons, and both neutral and charged hadrons within jets. The particle-flow objects serve as input for jet reconstruction, performed using the anti- $k_T$  algorithm [16] with a cone radius  $R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$  of 0.5 or 0.7. Jet energy scale corrections are derived from Monte Carlo (MC) simulation [17] as well as data.

## 3. Dijet Resonances Searches

We search for narrow resonances in the dijet mass spectrum using the two leading jets in the data. The data sample is collected with multijet high-level triggers based on  $H_T$ , the scalar sum of the transverse momenta of all jets in the event with  $p_T > 40$  GeV and  $|\eta| < 2.5$ . The  $H_T$  threshold are 650 GeV and 750 GeV, depending on the running period. The trigger efficiency is measured from the data to be larger than 99.9% for dijet masses reconstructed offline above 890 GeV. Jets that pass the standard jet quality requirements are combined into “wide jets” [18] if their separation  $R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} \leq 1.1$ . The combining is done before determining the leading dijet mass spectrum.

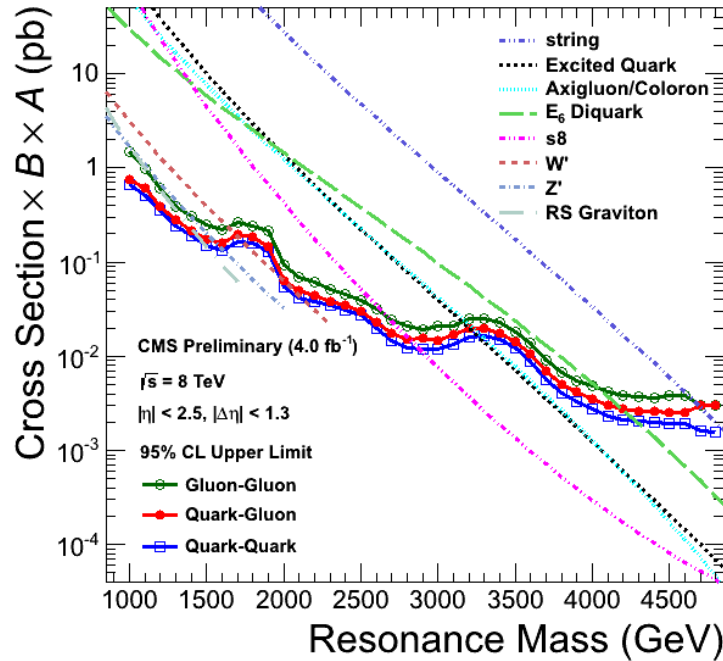
The data used in this study correspond to an integrated luminosity of  $4.0 \text{ fb}^{-1}$  at a collision energy of  $\sqrt{s}=8$  TeV [19]. The dijet mass background shape is modeled by a smooth parameterization. The dijet resonance shapes for  $qq$ ,  $qg$  and  $gg$  partons are dominated by experimental resolution and are obtained from full simulation. No significant excess is observed. The upper limits at 95% CL set on the cross section times branching ratio times acceptance of centrally ( $|\Delta\eta| < 1.3$  and  $|\eta| < 2.5$ ) produced dijet mass resonances for ( $qq$ ,  $qg$ ,  $gg$ ) are shown in Fig. 1. We set lower limits on the mass of string resonances, excited quarks, axigluons, colorons,  $S_8$  resonances,  $E_6$  diquarks,  $W'$  and  $Z'$  bosons, and RS gravitons in the 1–4.7 TeV range as listed in Table 1. Many of the values in the table represent significant improvements on exclusion limits from previous dijet mass searches.

Model	Final State	Obs. Mass Excl. [TeV]	Exp. Mass Excl. [TeV]
String Resonance (S)	qg	[1.0, 4.69]	[1.0,4.64]
Excited Quark ( $Q^*$ )	qg	[1.0, 3.19]	[1.0,3.43]
$E_6$ Diquark (D)	qq	[1.0, 4.28]	[1.0,4.12]
Axigluon (A)/Coloron (C)	$q\bar{q}$	[1.0, 3.28]	[1.0,3.55]
$S_8$ Resonance ( $S_8$ )	gg	[1.0, 2.66]	[1.0,2.53]
$W'$ Boson ( $W'$ )	$q\bar{q}$	[1.0, 1.74]	[1.0,1.92]
		[1.97, 2.12]	
$Z'$ Boson ( $Z'$ )	$q\bar{q}$	[1.0, 1.60]	[1.0,1.50]
RS Graviton (RSG)	$q\bar{q}+gg$	[1.0, 1.36]	[1.0,1.20]

**Table 1.** Observed and expected 95% CL exclusions on the mass of various resonances. Systematic uncertainties are included.

## 4. Searches for Pair-produced Dijet Resonances in a Four Jet Final State

We search for new narrow resonances in the paired dijet mass spectrum. The data sample is collected with triggers that require the presence of at least four jets, based on information from the calorimeters. Each jet must have  $|\eta| < 3.0$  and  $p_T > 70$  or 80 GeV, depending on the run period. The trigger is 99.5% efficient for events with our selection—four leading jets, each with a  $p_T$  exceeding 110 GeV with  $|\eta| < 2.5$ . The two jets in every possible pairs is required to have



**Figure 1.** The observed 95% CL upper limits from the high-mass analysis on  $\sigma \times B \times A$  for dijet resonances decaying through gluon-gluon (open circles), quark-gluon (solid circles), and quark-quark (open boxes) channels compared with theoretical predictions for string resonances [1, 2],  $E_6$  diquarks [3], excited quarks [4, 5], axigluons [6, 7], colorons [8],  $S_8$  resonances [9], new gauge bosons  $W'$  and  $Z'$  [10], and Randall-Sundrum gravitons [11].

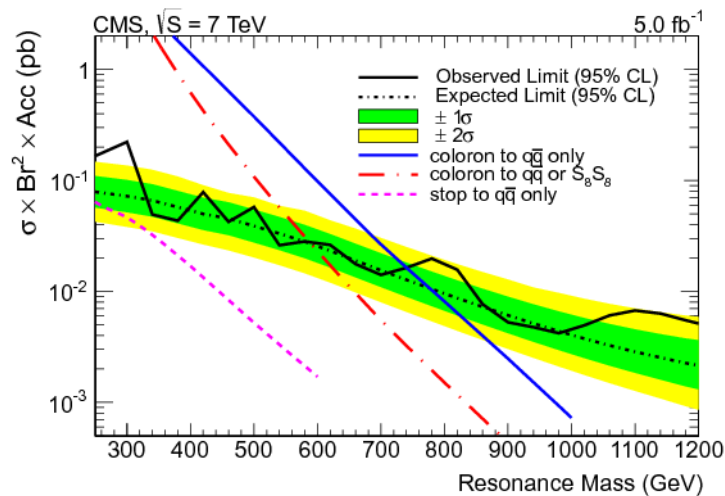
a separation on  $\Delta R_{jj} = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} \geq 0.7$  to ensure a negligible overlap among the jets. There are three possible dijet pairs from the leading four jets, and each dijet pair is required to have  $\Delta m < 0.15m_{avg}$ , where  $\Delta m$  is the mass difference between the two dijets and  $m_{avg}$  is their average mass. Thus the difference is required to be less than three times the dijet mass resolution (4.5%).

We require  $\Delta > 25$  GeV for each dijet, where  $\Delta = \Sigma_{i=1,2}(p_T)_i - m_{avg}$  is the scalar sum of the transverse momenta of the two jets in the dijet and the average pair mass in the event. The  $\Delta$  requirement removes a broad structure around 300 GeV from QCD events and ensures a smoothly falling dijet mass background shape. It also reduces the QCD background by more than an order of magnitude while retaining approximately 25% of the signal.

The data used in this study correspond to an integrated luminosity of  $5.0 \text{ fb}^{-1}$  at a collision energy of  $\sqrt{s}=7$  TeV [20]. No evidence of new physics is found in the data. The expected and observed 95% CL upper limits as a function of mass are presented in Fig. 2. For the first time, at 95% CL, the pair production of colorons is excluded for coloron masses between 250 and 740 GeV assuming that a coloron decays 100% into  $q\bar{q}$ , or between 250 and 580 GeV assuming that coloron decays into  $q\bar{q}$  compete with decays into  $S_8 S_8$ . With the current integrated luminosity there is some sensitivity to a SUSY model for pair-produced stops.

## 5. Conclusion

We performed searches for new physics in the singly-produced and pair-produced dijet mass spectrum. No sign for new physics is found. Upper limits are set for various models and



**Figure 2.** The observed and expected 95% CL limits on the product of the resonance pair production cross section, the square of the branching fraction to dijets, and the detector acceptance, given by the solid and dot-dashed black curves, respectively. The shaded regions indicate the  $1\sigma$  and  $2\sigma$  bands around the expected limits. Predictions of a coloron model and a SUSY model are also shown.

significant parameters space are excluded. We exclude the string resonance between 1 TeV and 4.7 TeV in the searches from the single dijet mass spectrum, and exclude the coloron with a mass between 250 GeV and 740 GeV for the first time in the searches from the paired dijet mass spectrum.

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