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Searches for new resonances in dijet and dilepton final states with the ATLAS and CMS detectors

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Abstract

Searches for new massive resonances in final states with a pair of leptons or jets have always been a powerful tool for discovery in high energy physics.We review here the latest results from the ATLAS and CMS experiments, based on proton-proton collision data collected at the centre-of-mass energy of 8 and 13 TeV at the LHC.The LHC dijet searches explore both the low-mass range and the high mass end of the spectrum by employing several novel search strategies. The results are interpreted in a range of theories beyond the standard model of particle physics.

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Searches for new resonances in dijet and dilepton final states with the ATLAS and CMS detectors

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Searches for new massive resonances in final states with a pair of leptons or jets have always been a powerful tool for discovery in high energy physics. We review here the latest results from the ATLAS and CMS experiments, based on proton-proton collision data collected at the centre-of-mass energy of 8 and 13 TeV at the LHC. The LHC dijet searches explore both the low-mass range and the high mass end of the spectrum by employing several novel search strategies. The results are interpreted in a range of theories beyond the standard model of particle physics.

1 Introduction

One of the most striking signatures of physics beyond the standard model (SM) would be the observation of a narrow resonance in the invariant mass spectrum of lepton or jet pairs. Such resonances are predicted by many models designed to address the shortcomings of the SM, as for example models with dark matter (DM), the Z' spin-1 boson from Grand Unified Theory (GUT) or the spin-2 Kaluza-Klein graviton (Randall-Sundrum model) [1,2].

At the CERN LHC, the searches for new resonances performed by the ATLAS and CMS Collaborations [3,4] have mostly focused on the production of high mass particles at the end of the spectrum. Searches at the low mass range are challenging because of the very large backgrounds. In the dijet final state, overwhelming event rates from QCD multijet events at low masses are beyond the trigger bandwidth of the CMS and ATLAS experiments, which limit the statistical power of the dijet resonance searches below 1 TeV. These difficulties are avoided by applying various new techniques like reducing event size, looking at boosted dijet events or selecting dijet events originated from the fragmentation of a b-quark. In this report we review the results of recent searches for high mass resonances in dijet and dilepton final states performed by the ATLAS and CMS Collaborations.

2 Dijet resonance searches

2.1 High mass dijet resonance searches

Searches for high mass resonances decaying to dijet final states in proton-proton collisions at $\sqrt{s} = 13$ TeV are performed by both ATLAS and CMS Collaborations [5,6]. Collision events are recorded by a single-jet trigger with a p_{T} greater than 380 (500) GeV by the ATLAS (CMS) experiment. In addition, events are triggered if the scalar sum of jet p_{T} for all reconstructed jets with $p_{\mathrm{T}} > 30$ GeV and $|\eta| < 3.0$ is greater than 800 GeV by the CMS experiment. Events

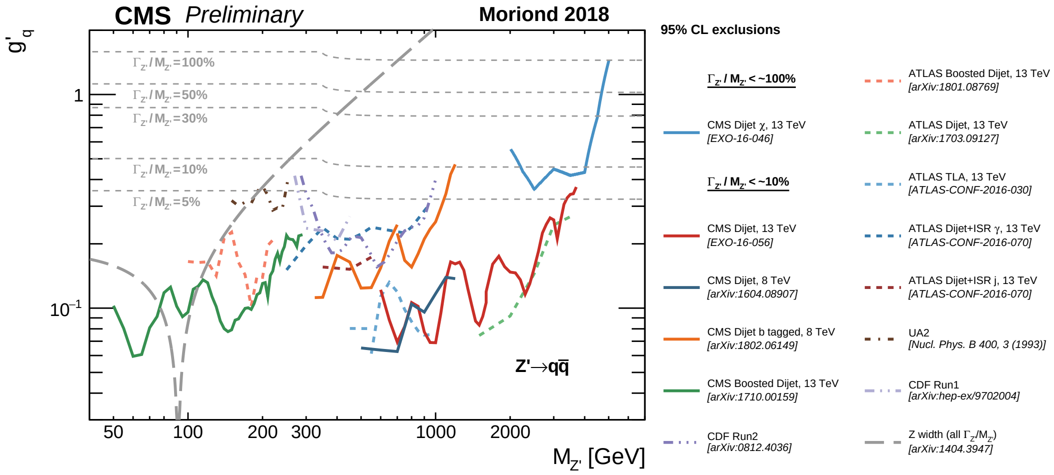

Figure 1 – Limits on the universal coupling g'_q between a leptophobic Z' boson and quarks from various dijet analyses from CMS, ATLAS, CDF, and UA2 [7].

are selected offline if there is at least two jets with $m_{jj} > 1.1$ TeV and $m_{jj} > 1.25$ TeV in the ATLAS and CMS analyses, respectively, for which the trigger is fully efficient.

The dominant background for this analysis is the QCD production of two or more jets which is simulated by PYTHIA8 Monte Carlo generator. The QCD background, mostly from t-channel dijet events, peaks at the large value of the rapidity/pseudorapidity separation of the two jets. On the other hand, new physics processes, mostly in the s-channel mode, have isotropic distribution for the mentioned variable. Therefore, the rapidity/pseudorapidity separation of the two jets are used in the ATLAS and CMS analyses to suppress the QCD background. After the selection, the observed number of dijet events falls smoothly as a function of the dijet mass. Due to the challenging uncertainties on the prediction of the QCD background, the observed dijet mass spectra is fitted to estimate the SM background.

The dijet mass spectra obtained in the ATLAS and CMS analyses are well described by the smooth falling data-driven distribution predicted by SM and no significance evidence for a high mass resonance is observed. Upper limits at 95% confidence level are set on the production cross section times the branching ratio for a narrow or wide heavy resonance. These results are interpreted to constrain a range of new physics scenarios as new heavy vector bosons (Z',W'), excited quarks ($q^\star$), excited chiral bosons ($W^\star$), quantum black holes (QBH), Randall-Sundrum, etc. In figure 1, limits obtained by the ATLAS (dashed green line) and CMS (red line) Collaborations on the universal quark coupling g'_q as a function of the resonance mass for a leptophobic Z' resonance are shown.

2.2 Low mass dijet resonance searches

Due to the high p_T threshold of the single jet trigger (∼400 GeV), a large fraction of dijet events with an invariant mass below 1 TeV are not recorded by the trigger system. Recently, the ATLAS and CMS Collaborations employed an innovative data-taking approach, in which only a reduced set of trigger level information is recorded and analyzed [6,8]. Thus, by reducing the event size, the trigger acceptance rate is increased and the invariant mass region below 1 TeV becomes accessible. This approach is called "data scouting" and "trigger-object-level analysis" in CMS and ATLAS, respectively. The low mass resonance searches are performed by the ATLAS and CMS Collaborations at $\sqrt{s} = 13$ TeV using 29.9 and 27 fb^{-1} of data, respectively [6,8]. No significant local excess is observed compared to the SM prediction and upper limits are set at 95% CL on the signal cross section as a function of the resonance mass. The sensitivity to the coupling to quarks, g'_q is comparable between the ATLAS and CMS results, as shown in figure

1 with dashed blue line and red line, respectively.

2.3 Boosted dijet resonance searches

Another approach for lowering the dijet mass range search is to trigger events where at least one high p_T jet or photon from initial state radiation (ISR) is produced in association with a light dijet resonance. The high p_T requirement on the ISR jet or photon leads to a boosted light resonance and its decay products become collimated. Therefore, the resonance mass is calculated from the mass of a large radius jet. The ATLAS and CMS Collaborations reported results of applying this technique to search for low mass resonances [9,10]. For the first time the mass range below 100 GeV is probed. In figure 1, excluded regions for a light Z' mass versus coupling values are shown from the ATLAS and CMS analyses.

2.4 Di-bjet resonance searches

Another way for probing low dijet mass range is based on identifying b-jets at the trigger level. The background rate for $b\bar{b}$ final state is much lower compared to the inclusive dijet final states. The ATLAS and CMS Collaborations, using this technique, could reach down to 570 and 325 GeV in dijet mass respectively [11,12]. No significant deviations from the SM expectation have been observed and limits at the 95% CL are set on the signal cross section.

3 Dilepton resonance searches

Both ATLAS and CMS Collaborations have searched for a heavy neutral particle decaying into an electron or muon pair at 13 TeV [13,14]. The CMS Collaboration has updated the search for high mass resonance in dielectron final state using 41.6 fb^{-1} of data recorded in 2017 [15]. Dilepton channels benefit from a simple final state with low backgrounds from Drell-Yan, $t\bar{t}$, WW and multijets processes. No significant excess is observed in the measured dilepton mass spectra. The limits obtained by the ATLAS and CMS Collaborations are shown in figure 2. A Z'_{SSM} boson with mass less than 4.7 TeV is excluded.

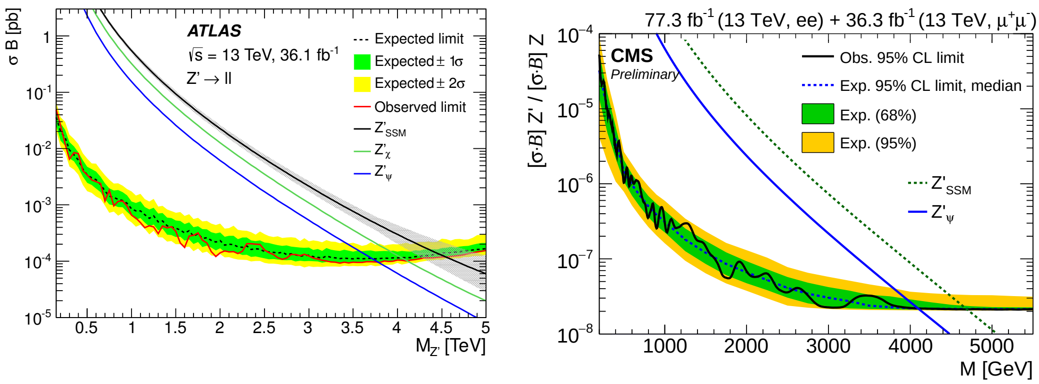

Figure 2 – The 95% CL upper limits on the production cross section times branching fraction for a spin-1 resonance using the ATLAS [11] (left) and CMS [15] (right) dilepton mass spectra. The CMS limits are relative to the production cross section times branching fraction for a Z boson.

4 Dark matter interpretation

Searches for dijet and dilepton resonances exploit the fact that any mediator produced from quarks in the initial state can decay into quarks or leptons, which would lead to an excess over the distribution of the invariant mass. Therefore, limits obtained from these searches can be

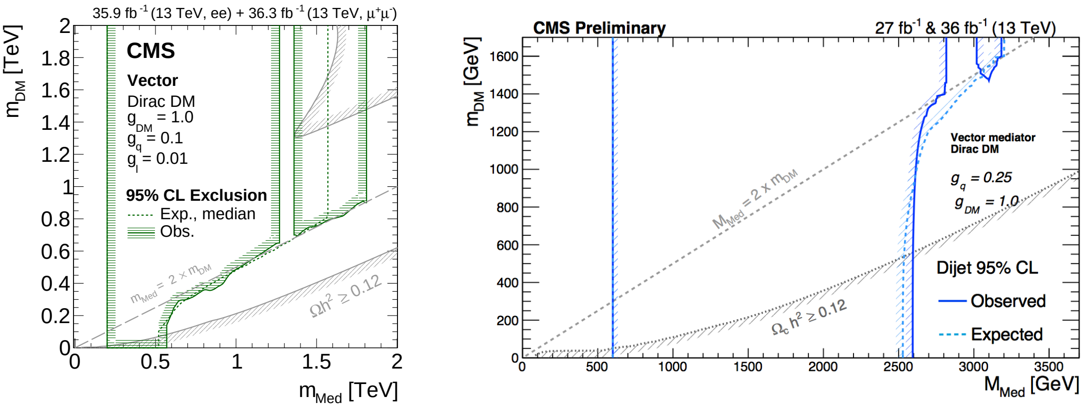

Figure 3 – The 95% CL observed (solid) and expected (dashed) excluded regions in the plane of dark matter mass versus mediator mass, for a vector mediator obtained from dilepton (left) and dijet (right) analyses. The constraint obtained from the cosmological relic density of DM is shown with light gray color.

reinterpreted to constrain simplified models of DM, with vector or axial vector mediators that couple to quarks and leptons. In figure 3, excluded regions in the plane of dark matter mass versus mediator mass obtained from the CMS high mass dilepton and dijet resonance searches are shown [6,14] and are compared to the constraint from the cosmological relic density of DM.

5 Summary

The ATLAS and CMS Collaborations at the LHC have searched for several types of new heavy resonances using dilepton and dijet final states in a wide range of mass. No significant excess has been observed and limits at 95% confidence level have been set on a variety of models. Searches for new heavy resonances with the full run II dataset are underway and legacy results are expected to be released in the coming years.

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