PROCEEDINGS OF SCIENCE

Search for resonant two-bodies decays

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Two-bodies decays are very common signatures for New Physics. Several results from the ATLAS and CMS experiments at $\sqrt{s} = 13$ TeV are summarized, including results from diboson, dijet and diphoton searches.

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1. Introduction

The 2 of LHC started in 2015 with an increased centre-of-mass-energy $\sqrt{s} = 13$ TeV with respect to $\sqrt{s} = 7$ or 8 TeV of Run1. During 2015 ATLAS has collected a luminosity of 3.2 fb^{-1} of proton-proton collisions, while CMS has collected 2.7 fb^{-1} with the magnet fully operational (3.8 T) and 0.6 with the magnet off (0 T) because of an intermittent problem, subsequently rectified, with the cryogenic system. During Run1 ATLAS and CMS collected 20.3 fb^{-1} and 19.7 fb^{-1} respectively, at $\sqrt{s} = 8$ TeV.

Even if the luminosity collected at $\sqrt{s} = 13$ TeV used in the presented results is a small fraction of the luminosity at 8 TeV, the new results are competitive with the old one for the search of new resonances, thanks to the increased parton luminosity as shown in figure 1.

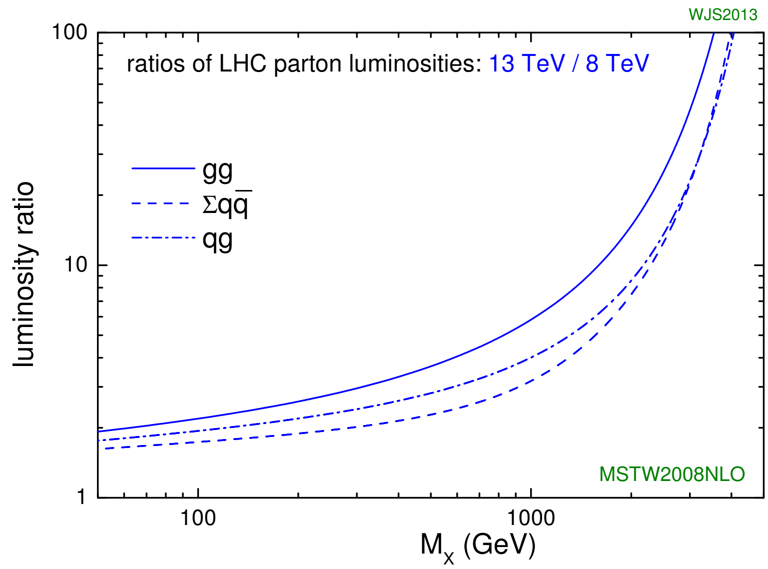


Figure 1: Ratio of parton luminosities at $\sqrt{s} = 13$ TeV compared to $\sqrt{s} = 8$ TeV using the MSTW 2008 NLO PDFs [1].

Many theoretical models predict the existence of new particles that decay into two bodies, including spin-2 particles (graviton), spin-1 (Z', W') and spin-0 (Higgs-like scalar). In the analyses summarized in the note the theoretical framework considered are: extra dimentions (ADD QBH, RS1), new gauge boson (Sequential Standard Model (SSM), leptophobic-Z', Heavy Vector Triplet (HVT)), contact interaction (CI), excited fermions, extended Higgs sector.

Most of the analyses consist of the search for a resonant excess in the invariant mass of two bodies or similar quantities where the decay of the two bodies is not fully reconstructed (e.g. $WZ \to qq\nu\nu$). One of the critical point of the analyses is the model of the background, and different approaches are used: some analyses use data-driven method, fitting the shape of the distribution of the total background directly from data, others use the shape from simulations of the various components normalized to data using control regions.

The considered final states include vector bosons, jets, leptons, and photons.

2. Diboson

Several models can be tested with diboson final states (WW,WZ,ZZ), including heavy CP-even scalar singlet ($X \to WW/ZZ$), heavy vector boson triplet ($W' \to WZ, Z' \to WW$), RS spin-2 graviton ($G \to WW/ZZ$).

Both leptonic and hadronic decays of the vector boson are used. At high-energy the reconstruction of boosted bosons is difficult due to the fact that the products of the decay are very collimated. In the case of the hadronic decay the two jets originating from the two quarks are reconstructed as a single large jet. Several techniques, including the mass of the jets or jet-subtructure, are used to identify jets from boson decays from hadronic jets.

In run1, with 8 TeV data, one of the largest excess was in the $WZ \to jj$ channel with a significance of 3.4σ (2.5 including LEE effect) around 2 TeV observed by ATLAS [5], but not confirmed by CMS [6]. Similarly CMS observed an excess of 2.9σ in the $H(bb)\ell\nu$ electronic channel [7].

ATLAS presented a combination of the WW, WZ and ZZ channels [9] considering the decays: $\nu\nu qq$, $\ell\nu qq$ $\ell\ell qq$, $qqqq$. In the fully hadronic channel the background is fitted directly from data, while in the other channels the backgrounds are studied in control regions enriched of $W+j$, $Z+j$ and tt events. The data exclude at 95% CL a scalar singlet with mass below 2650 GeV, a heavy vector boson triplet with mass below 2600 GeV, and a graviton (bulk Randall-Sundrum) with mass below 1100 GeV.

CMS presented a search for massive resonances decaying into pairs of boosted W and Z bosons [10] with final states $\ell\nu qq$ or $qqqq$. Upper limits at 95% CL are set for resonance masses between 800 and 4000 GeV. The HVT (model B) W' production cross section have been excluded in the range from 755 to 5.7 fb, the bulk graviton $\to WW$ production cross section in the range from 472 to 4.0 fb, and the bulk graviton $\to ZZ$ production cross section in the range from 227 to 6.8 fb. An upper limit of 2 TeV at 95% CL is set on the HVT (model B) W' resonance mass.

Figure 2 shows the results for both experiments.

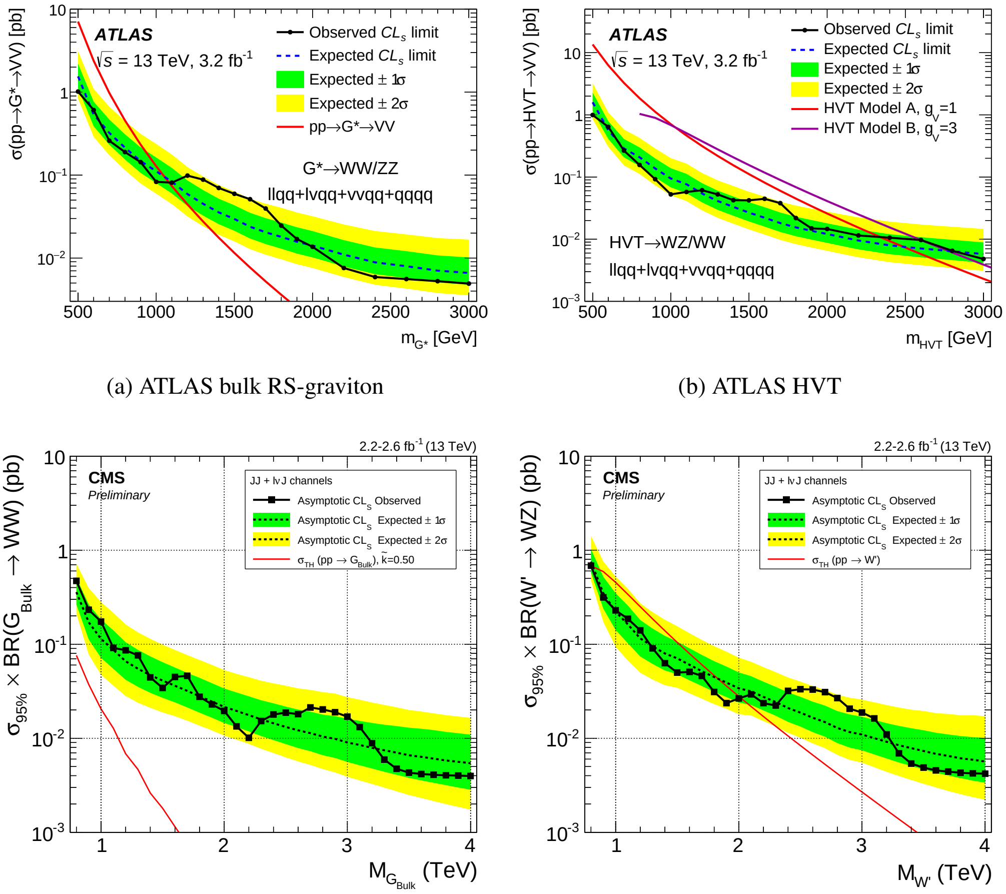
3. Dijet

Events with two jets in the final state are heavily produced at LHC and can be used to search for New Physics in many models, including quantum black holes (QBH), exited quarks (q^*), W', leptophobic-Z', contact interaction.

ATLAS and CMS updated the "mass analysis" where the distribution of the invariant mass of the two leading jets is examined for local excesses above the smoothly falling prediction of the Standard Model. The largest excess in Run1 was observed by CMS, with a local significance of 2σ with a dijet invariant mass around 1.8 TeV [8]. ATLAS and CMS also presented an "angular analysis" where a quantity related to the pseudorapidity gap between the two jets is used as observable.

Figure 3 shows the invariant mass spectrum for both experiments.

ATLAS [2] used data to exclude, at 95% CL, quantum black holes with threshold masses below 8.3 TeV, 8.1 TeV, or 5.1 TeV in three different benchmark scenarios; resonance masses below 5.2 TeV for excited quarks, 2.6 TeV in a W' model, a range of masses starting from $m'_Z = 1.5$ TeV and couplings from $gq = 0.2$ in a Z' model; and contact interactions with a compositeness scale below



(a) ATLAS bulk RS-graviton

(b) ATLAS HVT

(c) CMS bulk RS-graviton

(d) CMS W'

Figure 2: Observed and expected 95% CL upper limits on the production cross sections.

12.0 TeV and 17.5 TeV respectively for destructive and constructive interference between the new interaction and QCD processes.

CMS [3] set upper limits at 95% confidence level on the production cross section for narrow resonances with masses above 1.5 TeV. When interpreted in the context of specific models, the limits exclude string resonances with masses below 7.0 TeV, scalar diquarks below 6.0 TeV, axigluons and colorons below 5.1 TeV, excited quarks below 5.0 TeV, color-octet scalars below 3.1 TeV, and W' bosons below 2.6 TeV. Using the angular analysis [11], in the benchmark scenario, where only left-handed quarks participate and which is evaluated to leading-order in QCD, quark contact interations are excluded to a scale of 12.1 (16.3) TeV for destructive (constructive) interference at 95% confidence level.

ATLAS also presented an analysis [4] requiring 1 or 2 b-jet for the search of $bg \to b^* \to gb$, $q\bar{q} \to Z' \to bb$. The requirement of b-jets increases the production of 2-3 times, with respect to valence quarks, moving from 8 to 13 TeV. No evidence of anomalous phenomena is observed in the data, which are used to exclude, at 95% credibility level, excited b^* quarks with masses from 1.1 TeV to 2.1 TeV and leptophobic Z bosons with masses from 1.1 TeV to 1.5 TeV.

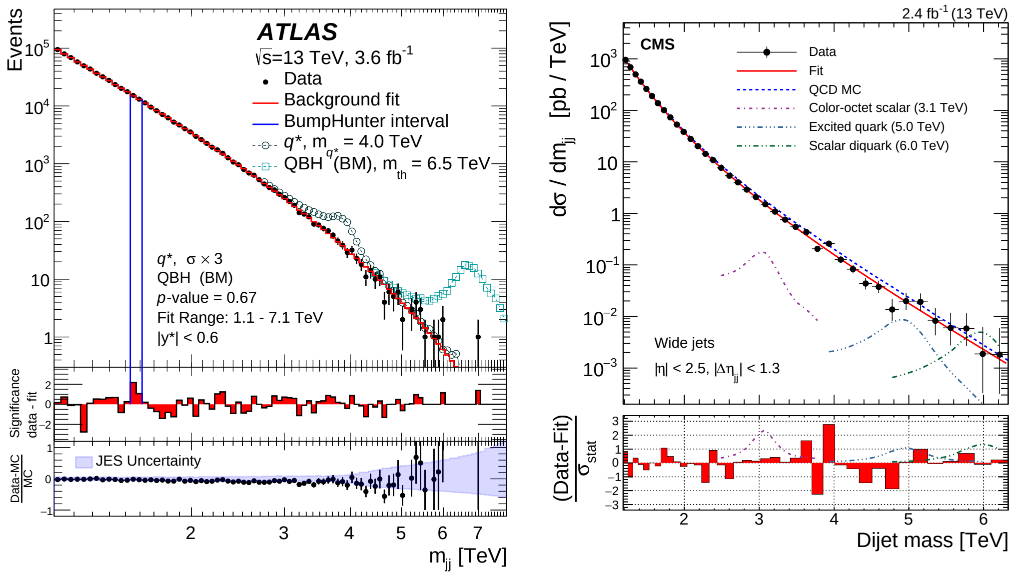


Figure 3: Dijet invariant mass spectrum for ATLAS and CMS.

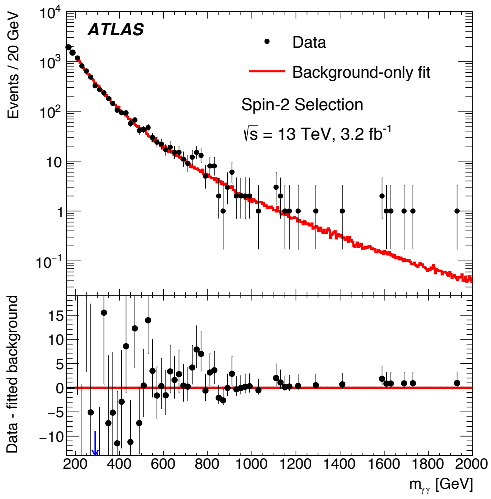
4. Diphoton

The search of New Physics in the diphoton channel is very promising since it is a very clean channel, requiring just two energetic isolated prompt photons in the final state.

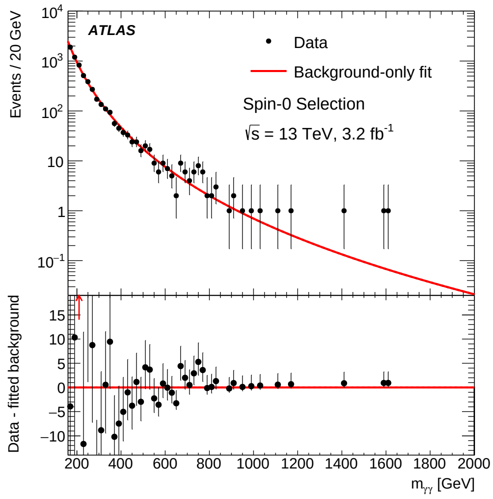
ATLAS [12] optimized two analyses, which differ for the cuts on isolation and the cut on the p_T of the photons, for the search of a scalar Higgs-like boson and for the search of graviton. CMS [13] considered similar signal models and used a single analysis, but combining two separate categories of data depending on the pseudorapidity of the two photons: barrel-barrel and endcap-barrel; endcap-endcap events are not considered by CMS due to the fact that the yield of the considered models in this category is expected to be negligible. For this analysis CMS considered also the data collected without magnetic field (0 T), re-implementing several steps of the analysis without the information from the momenta of the tracks: the selection of the primary vertex has been tuned using only the track multiplicity, the photon-identification is 5-15% less efficient, the calibration has been re-optimized and the resulting resolution at 0 T is better due to the fact that a better collection of the electrons energy is achieved in the detector in the absence of the magnetic field.

The total background, from $\gamma\gamma$, γj and jj, is fitted directly on data with a functional form in all the cases, except for the spin-2 analysis by ATLAS, where a template from the simulation is used. In the first case both ATLAS and CMS considered a systematic error to take into account possible mismodelling that can create an excess evaluated with simulations. In the second case the template has some degree of freedom, connected to the theoretical systematics. Figure 4 shows the diphoton invariant mass spectrum for both experiments.

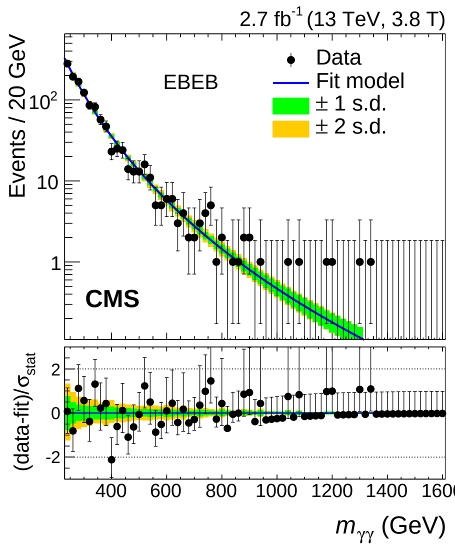
Using 13 TeV data, both the collaborations found a local excess around $m_{\gamma\gamma} \simeq 750$ GeV. The maximum significances among different values of mass and width (local significances) are corrected the the look-elsewhere-effect (global significance). In the spin-0 analysis ATLAS found an excess of 3.9σ local (2.1σ global) with a width of $\Gamma_X/M_X \simeq 6\%$ and of 2.9σ local in the narrow



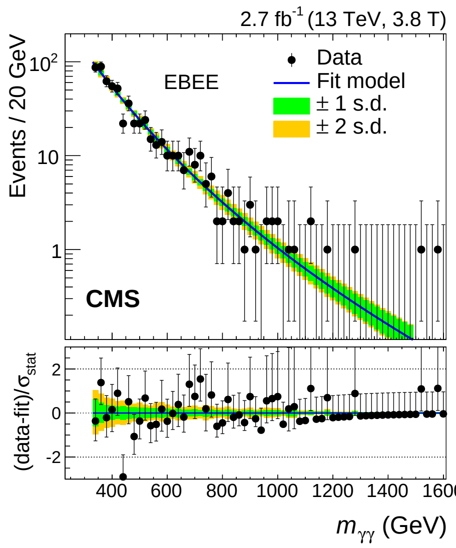
(a) ATLAS spin-2 selection



(b) ATLAS spin-0 selection



(c) CMS EBEB category with 3.8 T



(d) CMS EBEE category with 3.8 T

Figure 4: Diphoton invariant mass spectra.

width approximation. In the spin-2 analysis ATLAS found an excess of 3.8σ (2.1σ global) with a width of $\Gamma_X/M_X \simeq 8\%$ and an excess of 3.3σ in the narrow width hypothesis. CMS observed a modest excess around $m_{\gamma\gamma} \simeq 750$ GeV: under the narrow width hypothesis the local significance is 3.4σ combining the 8 TeV a and 13 TeV dataset which is reduced to 1.6σ global. Lower significances are found for larger signal hypotheses. ATLAS didn't combine the two dataset, but quoted a compatibility of the two datasets between 1.2 and 3.3σ, depending on the analysis and the scaling of the cross sections (gg of qq productions). CMS observed a modest excess around $m_{\gamma\gamma} \simeq 750$ GeV: under the narrow width hypothesis the local significance is 3.4σ combining the 8 TeV a and 13 TeV dataset which is reduced to 1.6σ global. Lower significances are found for larger signal hypotheses.

While this is the largest excess observed by the two experiments in 2015 more data are needed to confirm the observed excess.

5. Dileptons

A common signature of New Physics beyond the standard model is a new massive neutral spin-1 particle, referred to as a Z′, which can decay to same sign and opposite charge lepton pairs. This search channel benefits from high signal selection efficiencies and relatively small, well understood backgrounds.

A search for such a Z′ in events with electron-positron and muon-antimuon final states has been performed at $\sqrt{s} = 13$ TeV by ATLAS [14] using 3.2 fb^{-1} and by CMS [15] using 2.8 fb^{-1} of pp collision data. The electronic and muonic channel are combined.

Same flavor isolated leptons with high-p_T are selected by ATLAS and CMS. For the electronic channel CMS requires to have at least one electron in the barrel. The opposite sign requirement is used only in the muonic channel due to higher chance of charge mis-identification for high-E_T electrons.

The dominant and irreducible background of this search is $Z/\gamma^* \rightarrow \ell^+\ell^-$ with $\ell = \mu, e$. Other backgrounds produce real prompt leptons where the two prompt leptons are from different particles, usually W bosons: $t\bar{t}$, tW and dibosons processes. The contribution from these processes is estimated from simulation by both the experiments. The background arising from non-prompt and misidentified leptons occurs when one or more of the leptons is wrongly identified as a prompt lepton. The dominant processes in this category are dijets and W+jets events, largely rejected by the analyses selection criteria, and estimated from data. Figure 5 shows the distribution of the dilepton invariant mass for the selected events in the two channels by both the experiments.

Limits at 95% confidence level are computed combining the electronic and muonic channel. For the electronic channel CMS considered two categories: barrel-barrel and barrel-endcap due to differing backgrounds and resolutions. CMS set limits on a Z'_{SSM} and Z'_{Ψ} with a mass less than 3.15 TeV and 2.60 TeV respectively. Considering the same width the limits set by ATLAS are 3.08 TeV and 2.85 TeV. ATLAS also set a lower 95% confidence level exclusion limits on the energy scale Λ for various $\ell\ell qq$ contact interaction models between 16.4 TeV and 23.1 TeV.

6. Conclusions

Both ATLAS and CMS have presented several results using data from 2015 at $\sqrt{s} = 13$ TeV showing good performance of the detectors. Thanks to the increased energy of the proton-proton collisions the new results are already competitive with the previous ones at $\sqrt{s} = 8$ TeV even if the luminosity is a small fraction. No deviation from the Standard Model have been found, except for a modest local excess in the diphoton search that needs more data to be confirmed.

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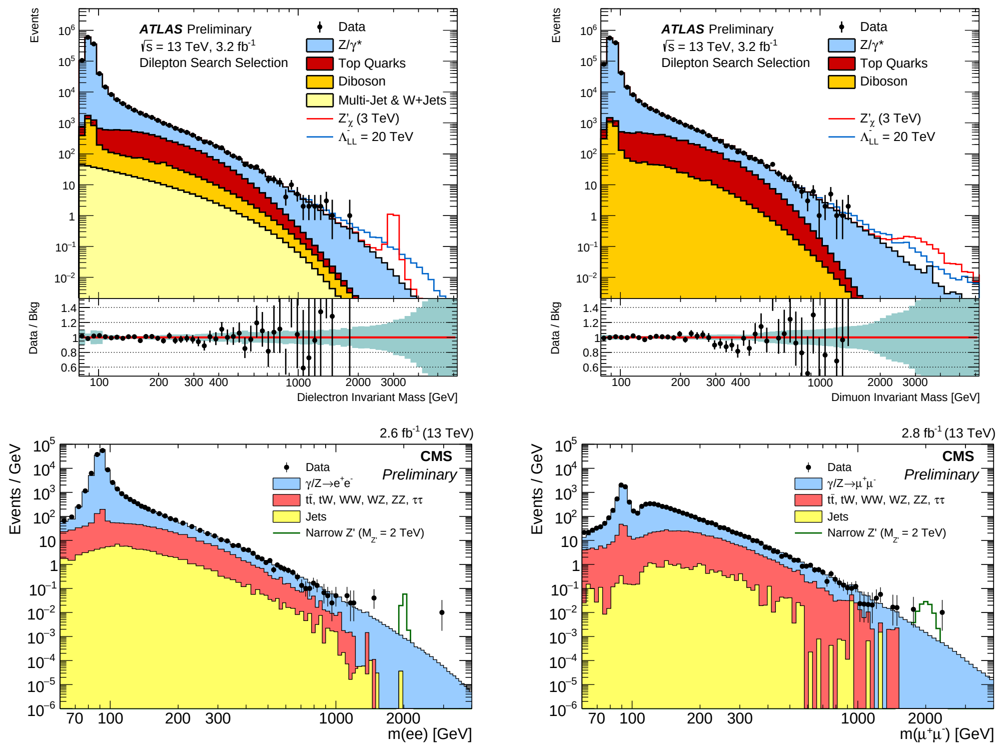

Figure 5: The invariant mass spectrum of ee (left) and $\mu^+\mu^-$ (right) selected events from the ATLAS (top) and CMS (bottom) analysis superimposed with the expected background from the Standard Model.

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