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# Resonant and non-resonant searches at ATLAS and CMS

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Recent results from the ATLAS and CMS Experiments are presented on searches for new physics beyond the standard model of particle physics probing resonant and non-resonant signatures.

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## 1. Introduction

The Compact Muon Solenoid (CMS) [1] and A Toroidal LHC Apparatus (ATLAS) [2] Experiments at the CERN Large Hadron Collider (LHC) have a wide ranging physics program covering searches for physics beyond the standard model (BSM). This document presents a subset of recent results, at the time of the the Tenth Annual Conference on Large Hadron Collider Physics (LHCP 2022) conference, on BSM searches from the CMS and ATLAS Experiments targeting resonant and non-resonant signatures. A comprehensive list of publications of the CMS Experiment can be found in Ref. [3] and that from the ATLAS Experiment can be found in Ref. [4].

## 2. Recent physics results on resonant and non-resonant searches

Selected recent physics results regarding resonant and non-resonant searches from the ATLAS and CMS Experiments are described in the following sections.

### 2.1 Search for vector-like quarks in leptonic final states

A search for pair production of vector-like quarks (VLQ), top ($T$) and bottom ($B$), has been conducted by the CMS Experiment targeting leptonic final states containing electons or muons using proton-proton ($pp$) collisions data at $\sqrt{s}$ = 13 TeV corresponding to an integrated luminosity of 137 fb$^{-1}$ collected between 2016 and 2018 [5]. Single-lepton, di-lepton, and multileptons channels nave been probed. The search is motivated by several BSM models such as the Little Higgs and Composite Higgs models that introduce new heavy fermions to the standard model (SM) such as "vector-like quarks". In minimal models, VLQs are limited to exist as electroweak singlets $T$ and $B$, in a doublet ($T$, $B$), or in doublets and triplets with further VLQs with exotic charge with each scenario resulting in different $T$ and $B$ branching fractions.Feynman diagrams of $T\bar{T}$ and $B\bar{B}$ production with representative decays to to third generation SM quarks and SM bosons are shown in Fig. 1. The observed data in the final states probed is compared with the estimation of the expected SM background. No significant deviation has been observed compared to the estimated SM background. Exclusion limits have been placed at 95% confidence level (CL) on $T$ with masses quarks up to 1.54 TeV and on $B$ quarks with masses up to 1.56 TeV, depending on the branching scenario considered with exclusion limits plots shown in Fig. 2 for the doublet combinations. The search results set the strongest limits to date for $T\bar{T}$ production with decays to $tH$ and $bW$ and for $B\bar{B}$ production with decays to $tW$, where $H$ and $W$ refer to the Higgs boson and the W bson respectively.

### 2.2 Search for low mass boosted resonances decaying into two photons

A search for diphoton resonances in the mass range between 10 to 70 GeV has been conducted by ATLAS Experiment using $pp$ collision data at $\sqrt{s}$ = 13 TeV corresponding to an integrated luminosity of 138 fb$^{-1}$ recorded from 2015 to 2018 [6]. The search is interpreted in terms of axion-like particles(ALPs). Events with at least 2 photons with transverse momentum ($p_T$) above 22 GeV are selected and for the diphoton system a $p_T > 50$ GeV requirement is set. The search for a narrow resonant signal over the SM continuum background in the distribution of the diphoton invariant mass variable is performed. No significant excess is observed, with the largest deviation from the

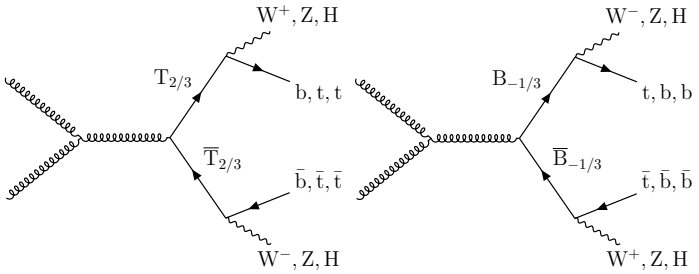


**Figure 1:** Leading order Feynman diagrams showing pair production of $T\bar{T}$ (left) or $B\bar{B}$ (right) shown along with decays to third generation SM quarks and SM bosons [5].

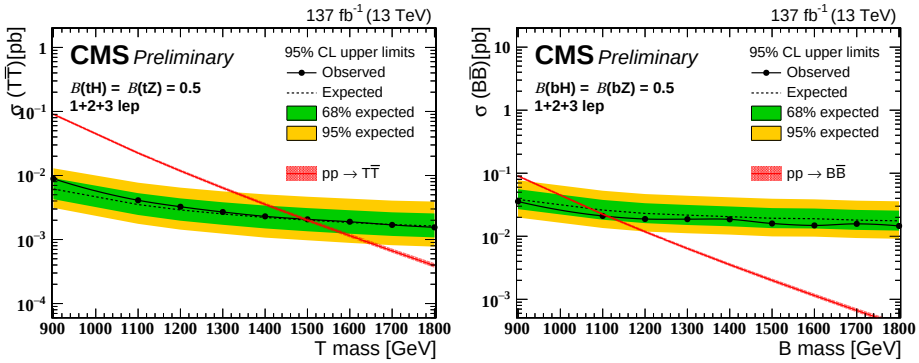


**Figure 2:** Expected 95% CL upper limits on $T\bar{T}$ (left) and $B\bar{B}$ (right) production cross sections for the doublet combinations [5].

SM background observed corresponding to a global significance of 1.48 standard deviations (local significance of 3.05 standard deviations) and limits are placed on the production cross-section times branching ratio as a function of the resonance mass along with an interpretation in terms of ALPs with mass $m_a$ and decay constant $f_a$. The distribution of the diphoton invariant mass for all events passing the analysis selections along with the limits set on ALP decay constant as a function of mass are shown in Fig. 3. The results set the strongest limits on promptly-decaying ALPs coupling to gluons and photons for masses between 10 and 70 GeV.

## 3. Search for a heavy composite Majorana neutrino

The CMS Experiment has performed the search for a heavy composite Majorana neutrino $N_\ell$ in the final state with two same-flavor leptons (electrons or muons) and two quarks using $pp$ collisions dataset at $\sqrt{s}$ = 13 TeV corresponding to an integrated luminosity of 138 fb$^{-1}$ [7]. The observed data are in agreement with the expectation from the SM process and upper limit at 95% CL on the cross section times branching fraction is obtained as a function of the $N_\ell$ mass for models in which $N_\ell$ is produced in association with a lepton, followed by the decay of $N_\ell$ to a same-flavor lepton and a quark pair. $N_e(N_\mu)$ are excluded for mass of the Majorana neutrino $m_{N_\ell}$ below 5.50 (5.70) TeV in the limit where the compositeness scale $\Lambda$ is equal to $m_{N_\ell}$, and below 5.10 (5.50) TeV with the more restrictive requirement that the unitarity bound is satisfied over the full phase space of parton motion within the proton.

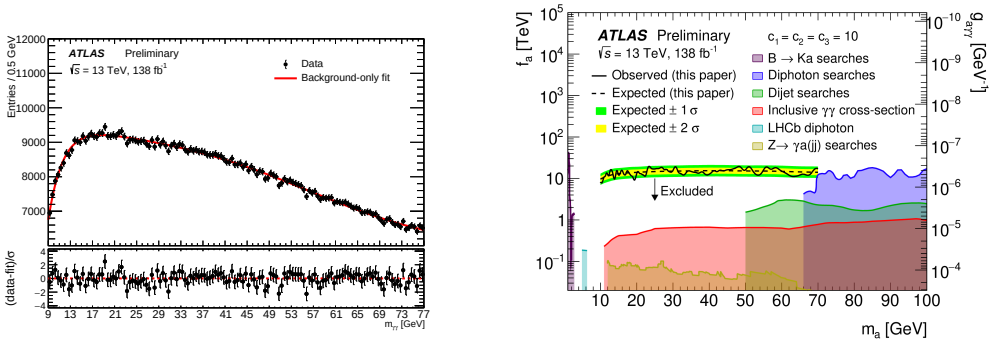


**Figure 3:** Distribution of the diphoton invariant mass for all events passing the analysis selection (left) and the observed and expected lower bounds on the ALP decay constant as a function of mass derived from this analysis compared with other experimental limits (left) [6].

## 4. Other searches with resonant and non-resonant signatures

Other search results with resonant and non-resonant signatures by the ATLAS and CMS Experiments presented at the LHCP 2022 conference were:

- Probe of Majorana neutrinos & Weinberg operator through VBF processes by the CMS Experiment [8].
- Search for $Z^{'}$ bosons decaying to pairs of heavy Majorana neutrinos performed by the CMS Experiment [9].
- Search for $t\bar{t}H/A \rightarrow t\bar{t}t\bar{t}$ production in multilepton final state by the ATLAS Experiment [10].
- Search for doubly charged Higgs boson production by the ATLAS Experiment [11].
- Search for new physics in central exclusive production using the missing mass technique with the CMS-TOTEM precision proton spectrometer [12].
- Search for vector-like leptons in $\geq 3b + N\tau$ final states by the CMS Experiment [13].
- Search for pair-produced scalar and vector leptoquarks by the ATLAS Experiment [14].

## 5. Summary

Selected recent results on searches for new physics beyond the standard model conducted by the ATLAS and CMS Experiments targeting resonant and non-resonant signatures have been presented. These searches cover a wide range of potential signal signatures, however no signs of new physics have been found yet. These results represent only a small subset of the large BSM physics search program of the ATLAS and the CMS Experiments. One can look forward to several more important searches for new physics and follow up analyses using larger statistics for the searches presented using the large datasets to be collected by the ATLAS and the CMS Experiments during the ongoing Run-3 of the LHC.

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