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Search for new phenomena in ttbar + heavy-flavour jets at $\sqrt{s} = 13$ TeV with the ATLAS detector

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A search for new phenomena in $t\bar{t}$ final states with additional heavy-flavour jets has been carried out using 13.2 fb^{-1} of data in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector at the LHC. The search targets a variety of signals, including the pair production of vector-like top quarks; four-top-quark production in several new physics scenarios. Data are analysed in the lepton-plus-jets final state as well as the jets-plus-$E_{\mathrm{T}}^{\mathrm{miss}}$ final state. The search exploits the events with the high multiplicity of b-jets, the high scalar sum of transverse momenta of all final state objects, and the presence of boosted hadronically-decaying resonances reconstructed as large-radius jets.

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1. Introduction

The Standard Model (SM) in particle physics can precisely explain most of the experimental results, while it cannot explain several fundamental issues such as the hierarchy problem, the dark matter of the universe, and so on. Physics models beyond the Standard Model (BSM) has been proposed, and searched for by the ATLAS experiment [1] at the Large Hadron Collider (LHC). Some models like Little Higgs [2] predict the existence of new particle called vector-like quark (VLQ). It is defined as color-triplet fermion whose left- and right-handed chiral components have the same color and electroweak charges [3, 4]. This analysis searches for the events where two vector-like top quarks (VLT) are produced in pair via strong interaction, and one of VLTs decays to SM Higgs boson and top quark and the other decays to any of the following decay modes: Ht, Zt, and Wb (Figure 1 (a)). Several BSM scenarios such as top quark compositeness [5] predict a new vector particle coupled to top quark and can be described via an effective field theory (EFT) with a four-fermion contact interaction [6] (Figure 1 (b)). Also the addition of another SU(2) doublet fields to the Higgs sector, referred to as two-Higgs-doublet models (2HDMs) [7] predicts new heavy Higgs bosons. The charged Higgs boson $H^{\pm}$ is produced via associated production with third-generation quarks and decay dominantly into them (Figure 1 (c)). The $t\bar{t}$ final states with additional heavy-flavour jets have good sensitivities for the BSM scenarios described above. The detail of this analysis is written in Ref. [8].

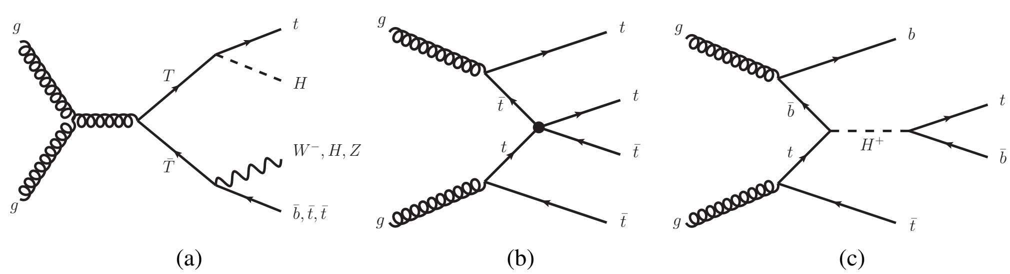


Figure 1: Feynman diagrams for (a) the pair production of vector-like top quarks, (b) four-top-quark production with a four-fermion contact interaction, and (c) the charged Higgs boson associated with third-generation quarks in 2HDM models probed in this analysis.

2. Data sample, Monte Carlo simulation, and event reconstruction

Data used in this analysis are collected in pp collisions at $\sqrt{s} = 13$ TeV from 2015 to July 2016. Events recorded with a single-lepton (electron or muon) trigger or a missing transverse momentum $E_{\mathrm{T}}^{\mathrm{miss}}$ trigger under stable beam conditions and after application of data quality requirements, corresponding to an integrated luminosity of 13.2 fb^{-1}. The Monte Carlo (MC) simulation for both signal and background processes is described in Ref. [8]. MC samples are processed by the same reconstruction procedure as data.

The events are reconstructed by identifying the physics objects, as electrons, muons, jets, b-jets, $E_{\mathrm{T}}^{\mathrm{miss}}$, Mass-tagged jets which is the tagger with large radius jets designed to identify boosted Higgs boson and top quark inclusively as described in Ref. [8].

3. Analysis strategy

In this analysis, the strategy is optimized for the pair production of VLT shown in Figure 1 (a). The two orthogonal channels are designed: 1-lepton and 0-lepton channels. The two channels require the preselection defined in Ref. [8] in events, which basically requires high jet and b-jet multiplicities and either one lepton in 1lepton channel or zero lepton and high $E_{\mathrm{T}}^{\mathrm{miss}}$ in 0-lepton channel. Then, events passing the preselection are categorized by the number of jets, b-jets, Mass-tagged jets. The signal (background) events are expected to have high (low) jet, b-jet, and Mass-tagged jet multiplicities. The detail of categorization is shown in Ref. [8]. After the background predictions are fitted to data on the $m_{\mathrm{eff}}(= \sum p_{\mathrm{T}}^{\mathrm{jet}} + p_{\mathrm{T}}^{\mathrm{lepton}} + E_{\mathrm{T}}^{\mathrm{miss}})$ distributions, the post-fit background prediction is compared with data to search for significant excesses of data.

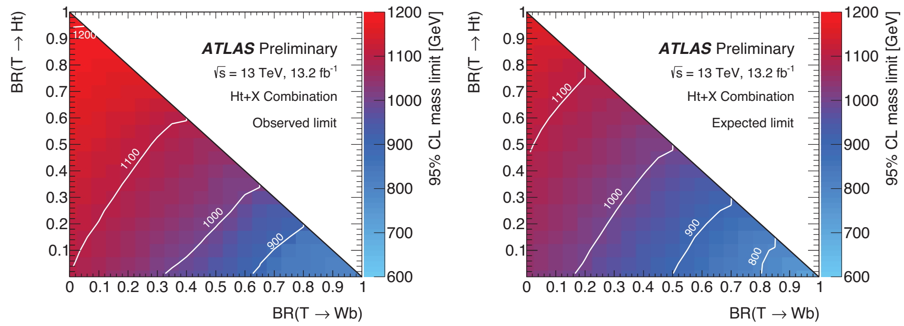
4. Background estimation

The backgrounds of $t\bar{t}$, W/Z+jets, singletop, diboson, $t\bar{t} + W/Z$ are estimated by the MC simulation. The dominant $t\bar{t}$ backgrounds are classified by the flavor content of the additional jets such as $t\bar{t}$+lights, $t\bar{t}$+$\geq$1c, and $t\bar{t}$+$\geq$1b which is dominant in the most sensitive regions. The dedicated MC models are described in Ref. [8].

5. Results and interpretations

The 1-lepton and 0-lepton channels are combined to gain more sensitivity in search for VLT production. Only the 1-lepton channel is used to probe the different four-top-quark production and heavy Higgs production signals. The binned likelihood fit under the background-only hypothesis is performed on the m_{eff} distribution in all search regions. All the systematic and statistical uncertainties are taken into account as the nuisance parameters in the fit. After the fit, the event yields in data for both search regions and validation regions are found to be consistent with those in the post-fit background predictions. Consequently, no significant excess of data for all the search regions in both 1-lepton and 0-lepton channels are observed.

Upper limits at 95% confidence level (CL) on the VLT-pair-production cross section are computed. Then the observed and expected VLT mass limits in the branch ratio plane are shown in Figure 2. In the SU(2) doublet case, the observed (expected) lower limit on VLT mass at 95% CL is set to 1160 (1110) GeV, which are significantly extended comparing to the mass limits of 800 (900) GeV in the previous search using 3.2 fb^{-1} of data at $\sqrt{s} = 13$ TeV [9] due to the improvement of sensitivity by combination of 0-lepton channel and increment of an integrated luminosity. For all the other signal models, the upper limits are shown in Ref. [8].



(a) (b)

Figure 2: (a) Observed and (b) expected 95% CL limit on the VLT mass in the plane of BR($T \to Ht$) versus BR($T \to Wb$) for the combination of the 1-lepton and 0-lepton searches [8].

6. Conclusion

A search for new phenomena in $t\bar{t}$ final states with additional heavy-flavor jets has been carried out using pp collision data at $\sqrt{s} = 13$ TeV recorded by the ATLAS detector at the LHC, corresponding to an integrated luminosity of 13.2 fb^{-1}. The orthogonal 1-lepton and 0-lepton analyses are optimized for the pair production of VLTs signal. After applying the preselection, categorizing events and fitting, excesses in data are not observed. The upper limits at 95% CL for the various signal models are derived, in most cases significantly extending the reach of previous searches. Especially, combination of 0-lepton channel and increment of an integrated luminosity largely improves sensitivity to the signals.

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