Search for four-top-quark production in final states with one charged lepton and multiple jets using 3.2 fb^{-1} of pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector at the LHC

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A search for four-top-quark production is presented based on the proton-proton collision data taken at $\sqrt{s}$ = 13 TeV at the Large Hadron Collider and collected with the ATLAS detector during 2015, corresponding to an integrated luminosity of 3.2 fb^{-1}. Data are analysed in the single-lepton channel, characterised by an isolated high transverse momentum electron or muon and multiple jets. No significant excess of events above the background expectation is found and an observed (expected) upper limit of 21 (16) times the four-top quark Standard Model cross-section is obtained at 95% CL. Additionally, upper bounds on four-top-quark production are set in different scenarios of physics beyond the Standard Model.

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1. Introduction

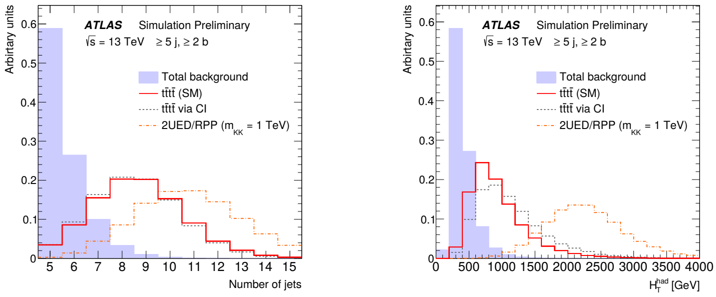
In the following, we review a search [1] for four-top-quark production, $t\bar{t}t\bar{t}$, in proton-proton collisions at $\sqrt{s}$ = 13 TeV using data corresponding to an integrated luminosity of 3.2 fb^{-1} collected by the ATLAS experiment [2]. Data are analysed in the single-lepton channel, characterised by an isolated high transverse momentum electron or muon. The search targets resolved topologies and exploits the high jet multiplicity (up to ten resolved jets), high b-tagged jet multiplicity (up to four b-tagged jets) and large total sum of jet transverse momenta which characterise signal events. These include four-top-quark production with the Standard Model (SM) kinematics, as well as several beyond the SM (BSM) models considered as benchmarks: $t\bar{t}t\bar{t}$ production via four-top-quarks contact interaction (CI) and in universal extra dimensions (UED) scenarios [3]. Although this analysis technique results in a relatively high signal-to-background ratio (S/B), a statistically significant observation of the rare SM four-top-quark process is not expected using the dataset recorded so far by the ATLAS experiment. Hence, any deviation from the SM prediction will provide supporting evidence for BSM physics, while setting upper limits on BSM production cross-sections will constrain such theories.

2. Analysis overview

Signal events from SM four-top-quark production with single-lepton decay topology, where each parton coming from a top quark or a W-boson decay can give rise to a separate jet, are characterised by the presence of ten non-overlapping high-p_{T} jets, out of which six are light- and four are b-quark jets, one charged lepton and missing transverse momentum from the escaping neutrino. However, the limited detector acceptance and the b-tagging efficiency need to be taken into account. In order to maximise the sensitivity of the search, preselected events are classified according to their event topology, defined by the number of jets with $p_{\mathrm{T}} > 25$ GeV and the number of b-jets.

A total of 18 independent topologies is considered: three topologies with exactly nine jets out of which at least four jets are b-tagged, or with at least ten jets out of which three or at least four jets are b-tagged, are referred to as "signal regions". These three regions have the largest S/B ($1.1\% - 4.5\%$) and dominate the fit to extract the four-top-quark signals or set limits on their production cross-sections. To estimate the SM backgrounds, six topologies consisting of five or six jets of which two, three or at least four are b-tagged are referred to as "control regions", providing a sample depleted of expected signal and dominated by top-quark pairs produced in association with additional jets, which is the main background in this search. Nine "validation regions" that do not overlap with the control region and signal region selections and that feature a low expected signal contamination are designed primarily to validate the assumption that the $t\bar{t}$+jets modelling extracted from the control regions can be extrapolated to the signal regions.

The scalar sum of the jet transverse momenta ($H_{\mathrm{T}}^{\mathrm{had}}$), considering all selected jets, is used as discriminating variable in each of the signal and control regions. Fig. 1a compares the expected shape of the jet multiplicity distribution after preselection between the total predicted background and several signal scenarios. Fig. 1b compares the expected shape of the $H_{\mathrm{T}}^{\mathrm{had}}$ distributions between the SM four-top-quark signal and the total predicted background and also includes two of the considered BSM signal samples. Thus, the $H_{\mathrm{T}}^{\mathrm{had}}$ variable provides good discrimination between signal and background events in the signal regions and allows constraints to be set on the combined effect of several sources of systematic uncertainty given the large number of events in the control regions.



(a) (b)

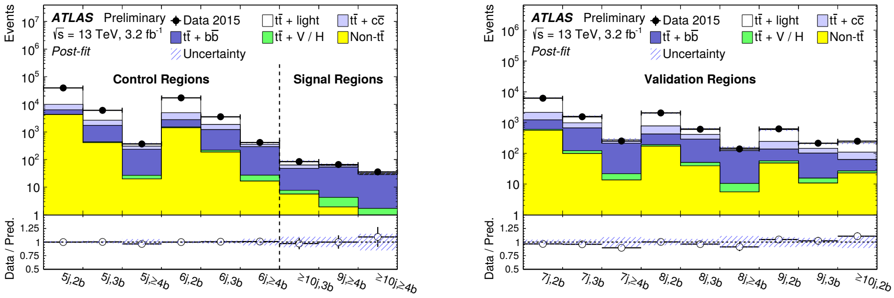
Figure 1: Comparison of (a) jet multiplicity and (b) $H_{\mathrm{T}}^{\mathrm{had}}$ distributions between some of the considered four-top-quark signals (solid, dashed and dotted lines) and total background (shaded histogram) after the preselection. The distributions are normalised to unit area [1].

Monte Carlo simulation samples are used to model the expected signal and background distributions. The main source of background comes from $t\bar{t}$+jets, which are generated inclusively, but events are categorised depending on the flavour content of additional particle jets in the event. The modelling of the $t\bar{t}+b\bar{b}$ background, particularly important for this search, is improved by reweighting the default prediction to a dedicated prediction at next-to-leading order accuracy in QCD for $t\bar{t}+b\bar{b}$ including parton showering [4]. Small contributions arise from weak boson production in association with jets, from the associated production of a vector boson or a Higgs boson and a $t\bar{t}$-pair and from diboson production.

Several sources of systematic uncertainty on reconstructed objects and background modelling are considered that can affect the normalisation of signal and background and/or the shape of their corresponding final discriminant distributions. Individual sources of systematic uncertainty are considered uncorrelated. Correlations of a given systematic uncertainty are maintained across processes and channels. Dominating uncertainties are related to $t\bar{t}+b\bar{b}$ normalisation and modelling.

3. Results and conclusions

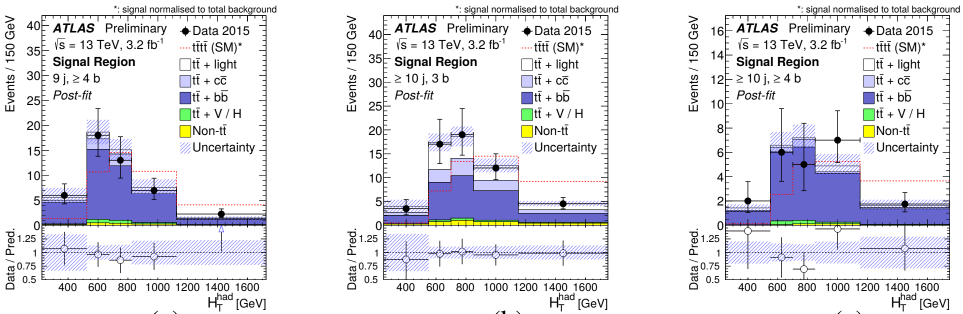
Four-top-quark production signals are searched for by performing a binned profile likelihood fit to the $H_{\mathrm{T}}^{\mathrm{had}}$ distribution simultaneously in the six control regions and the three signal regions, excluding the nine validation regions. As a result of the fit, the large uncertainty in the pre-fit background prediction decreases significantly in all regions due to constraints provided by data and correlations between different sources of uncertainty introduced by the fit to the data regions, which results in a sizable increase in the search sensitivity. A comparison of observed and expected yields after the fit can be found in Fig. 2a in the case of the control and signal regions and in Fig. 2b in the case of the validation regions. The agreement between data and prediction in normalisation and shape is generally improved after the fit and shows no evidence of significant background mismodelling in the control and validation regions. Comparisons between data and prediction of



(a) (b)

Figure 2: Comparison of prediction to data in (a) six control and three signal regions and (b) nine validation regions prior to the fit (top) and after the background-only fit to data (bottom). The bottom panel displays the ratio of data to the SM prediction. The hashed area represents the total uncertainty on the background [1].

the $H_{\mathrm{T}}^{\mathrm{had}}$ distribution after the background-only fit are shown in Fig. 3 in the case of the signal regions. Given the absence of a statistically significant excess of events above the background



(a) (b) (c)

Figure 3: Comparison between data and prediction of the $H_{\mathrm{T}}^{\mathrm{had}}$ distribution in the signal regions after the background-only fit to data: (a) 9j, $\geq$ 4b region, (b) $\geq$ 10j, 3b region and (c) $\geq$ 10j, $\geq$ 4b region. The bottom panel displays the ratio of data to the total prediction. The hashed area represents the total systematic uncertainty on the background. The last bin in all figures contains the overflow [1].

expectation, upper limits are set. In the case of $t\bar{t}t\bar{t}$ production with SM kinematics, the observed (expected) 95% CL upper limit on the production cross-section is 190 fb (143 fb), or 21 (16) times the SM prediction (assumed to be 9.2 fb). In case of $t\bar{t}t\bar{t}$ production via an effective field theory model with a four-top-quark CI, the observed (expected) 95% CL upper limit on the production cross-section is 148 fb (115 fb). The upper limits on the production cross-section times branching ratio for the specific UED model yields an observed (expected) 95% CL limit on the characteristic mass scale m_{KK} of 1.28 TeV (1.30 TeV).

References

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