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Search for phenomena beyond the Standard Model in events with large b-jet multiplicity using the ATLAS detector at the LHC

The ATLAS Collaboration

A search is presented for new phenomena in events characterised by high jet multiplicity, no leptons (electrons or muons), and four or more jets originating from the fragmentation of b-quarks (b-jets). The search uses 139 fb^{-1} of $\sqrt{s}$ = 13 TeV proton–proton collision data collected by the ATLAS experiment at the Large Hadron Collider during Run 2. The dominant Standard Model background originates from multijet production and is estimated using a data-driven technique based on an extrapolation from events with low b-jet multiplicity to the high b-jet multiplicities used in the search. No significant excess over the Standard Model expectation is observed and 95% confidence-level limits that constrain simplified models of R-parity-violating supersymmetry are determined. The exclusion limits reach 950 GeV in top-squark mass in the models considered.

1 Introduction

Events with a large number of high-transverse momentum (p_{T}) jets originating from the fragmentation of b-quarks (b-jets) are rarely produced by Standard Model (SM) processes in proton–proton (pp) collisions at the LHC. As a result, this signature can provide sensitivity to certain phenomena beyond the SM (BSM) [1–3]. Event signatures with five or more b-jets, no leptons (electrons or muons) and without any requirements on missing transverse momentum are not covered by existing searches at the LHC.

Supersymmetry (SUSY) provides an extension to the SM by introducing partners of the known bosons and fermions. It predicts the existence of superpartner states (with different statistics) associated to each of the SM particles and fields. The lightest among such superpartners (LSP) may or may not be stable, depending on the conservation of R-parity [4–6]. Final states with high leptonic or hadronic multiplicity are commonly predicted by R-parity-violating (RPV) SUSY. Models of RPV SUSY do not provide stable superpartners, and they give rise to a wide variety of experimental signatures whose nature depends on which of the many RPV couplings are non-zero.

In the analysis presented here, a particular benchmark model is considered in order to interpret the measurements in the different jet and b-jet multiplicity regions. The process under consideration is the pair production of the top squark as the lightest of the coloured SUSY partners. The existence of light SUSY partners of third-generation quarks, bottom squarks ($\tilde{b}$) and top squarks ($\tilde{t}$), is favoured by naturalness considerations [7, 8]. The scenario assumes the LSP to be a triplet of two neutralino ($\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$) and one chargino ($\tilde{\chi}_1^{\pm}$) states that are mass-degenerate and carry dominantly higgsino components (in the following collectively referred to as "higgsinos"). The top squark decays either into a chargino, $\tilde{\chi}_1^{\pm}$, and a bottom quark or into a neutralino, $\tilde{\chi}_{1,2}^0$, and a top quark. The chargino and neutralino decay, respectively, to bbs and tbs quark triplets, as shown in Figure 1; this decay is mediated through their higgsino components via the non-zero baryon-number-violating RPV coupling λ''_{323} [9, 10].

When $m_{\tilde{t}} - m_{\tilde{\chi}_{1,2}^0, \tilde{\chi}_1^{\pm}} \leq m_{\mathrm{top}}$ (Figure 1(a)), the $\tilde{t} \to t\tilde{\chi}_{1,2}^0$ decay is kinematically forbidden and the top-squark branching ratio (B) to $b\tilde{\chi}_1^{\pm}$ is equal to unity; when $m_{\tilde{t}} - m_{\tilde{\chi}_{1,2}^0, \tilde{\chi}_1^{\pm}} \geq m_{\mathrm{top}}$ the value of B is taken to be 0.5. In the latter case, the rest of the decay rate is evenly divided between the two neutralino states: $\tilde{t} \to t\tilde{\chi}_{1,2}^0 (\tilde{\chi}_{1,2}^0 \to tbs)$ (Figure 1(b)). For the supersymmetric particle masses under consideration, the analysis considers only values of $\lambda''_{323} \approx O(10^{-2}\text{–}10^{-1})$ [11] which ensure prompt neutralino and chargino decays and omit more complex RPV decay patterns such as $\tilde{\chi}_1^{\pm} \to W^{\pm *}\tilde{\chi}_1^0 (\tilde{\chi}_1^0 \to tbs)$ or $\tilde{\chi}_2^0 \to Z^* \tilde{\chi}_1^0 (\tilde{\chi}_1^0 \to tbs)$ that could be substantial for very small values of λ''_{323} [3].

Previous searches targeting RPV SUSY models of pair-produced top squarks decaying through the coupling λ''_{323} have been carried out by the ATLAS and CMS collaborations. Those searches already exclude top-squark masses in the ranges 100 GeV $\leq m_{\tilde{t}} \leq$ 470 GeV and 480 GeV $\leq m_{\tilde{t}} \leq$ 610 GeV (ATLAS [12]), and 80 GeV $\leq m_{\tilde{t}} \leq$ 270 GeV, 285 GeV $\leq m_{\tilde{t}} \leq$ 340 GeV and 400 GeV $\leq m_{\tilde{t}} \leq$ 505 GeV (CMS [13]) in scenarios where the top squark is the LSP and decays directly via $\tilde{t} \to bs$. For the direct top-squark production and λ''_{323}-mediated decays of higgsino LSP scenarios, ATLAS has excluded top-squark masses up to 1.10 TeV, depending on the higgsino mass considered, in the region where $m_{\tilde{t}} - m_{\tilde{\chi}_{1,2}^0, \tilde{\chi}_1^{\pm}} \geq m_{\mathrm{top}}$, by analysing lepton plus jets events [11]. CMS has excluded top-squark masses between 100 and 720 GeV for top-squark decays into four quarks in boosted topologies and with the mass of the higgsinos set to 75% of the squark mass [14].

This analysis considers events with six or more jets, of which at least four are identified as b-jets (b-tagged). There must be no identified electron or muon, and no requirement is made on the missing transverse

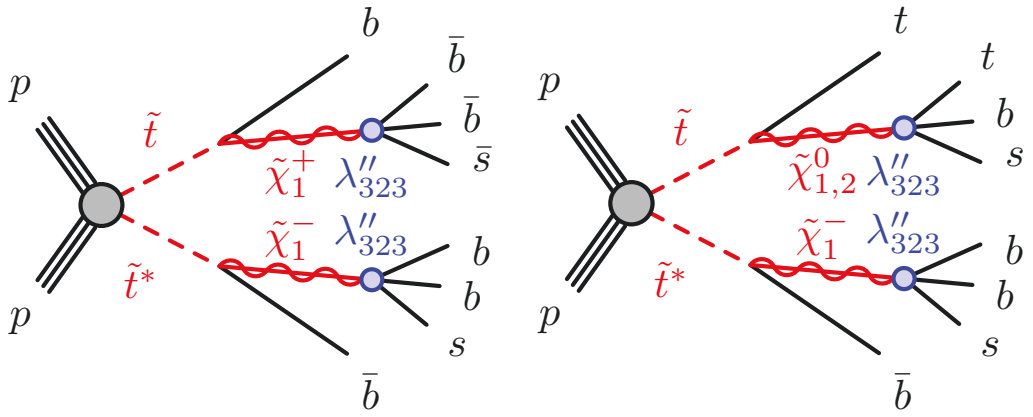


Figure 1: Diagrams of the signal processes involving pair production of top squarks $\tilde{t}$: (a) with the decay into a b-quark and the lightest chargino $\tilde{\chi}_1^+$ ($\tilde{t} \to b\tilde{\chi}_1^+$) with the subsequent decay of the chargino $\tilde{\chi}_1^+ \to \bar{b}\bar{b}\bar{s}$ and charge conjugate (c.c.), and (b) the decay into a top quark and the two lightest neutralinos $\tilde{\chi}_{1,2}^0$ with the subsequent decay $\tilde{\chi}_{1,2}^0 \to tbs$.

momentum. In this channel, the dominant background is the non-resonant production of multijet events, referred to as 'multijet' in the following, and a data-driven method is applied to estimate its yield. Other backgrounds arise from top-quark pair production accompanied by extra b-jets or by a Z or Higgs boson decaying into a b-quark pair. Results are reported as 95% confidence level (CL) exclusion limits on the top-squark mass in the benchmark models described above. Model-independent limits on the possible contribution of BSM physics are also evaluated at large jet and b-tagged jet multiplicities.

2 ATLAS detector

The ATLAS experiment [15] at the LHC is a multipurpose particle detector with a forward–backward symmetric cylindrical geometry and a near 4π coverage in solid angle.[1] It consists of an inner tracking detector (ID) surrounded by a thin superconducting solenoid providing a 2 T axial magnetic field, electromagnetic and hadron calorimeters, and a muon spectrometer (MS). The inner tracking detector covers the pseudorapidity range $|\eta| < 2.5$. It consists of silicon pixel, silicon microstrip, and transition radiation tracking detectors. An additional innermost layer of the silicon pixel tracker, the insertable B-layer [16, 17], was installed in 2014 at an average radial distance of 3.3 cm from the beam-line to improve track reconstruction and flavour identification of quark-initiated jets. Lead/liquid-argon (LAr) sampling calorimeters provide electromagnetic energy measurements with high granularity. A steel/scintillator-tile calorimeter provides hadronic energy measurements and covers the central pseudorapidity range ($|\eta| < 1.7$). The endcap and forward regions are instrumented with LAr calorimeters for both the electromagnetic and

[1] ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z-axis along the beam pipe. The x-axis points from the IP to the centre of the LHC ring, and the y-axis points upwards. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the z-axis. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln\tan(\theta/2)$. Angular distance is measured in units of $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$.

hadronic energy measurements up to $|\eta| = 4.9$. The muon spectrometer surrounds the calorimeters and is based on three large air-core toroidal superconducting magnets with eight coils each. The field integral of the toroids ranges between 2.0 and 6.0 T m across most of the detector. The muon spectrometer includes a system of precision tracking chambers and fast detectors for triggering. A two-level trigger system is used to select events to be recorded. The first-level trigger is implemented in hardware and uses a subset of the detector information to accept events at a rate of at most 100 kHz. This is followed by a software-based high-level trigger (HLT) that reduces the accepted event rate to ~1.2 kHz, on average.

3 Data collection and simulated event samples

This search is based on 139 fb^{-1} of centre-of-mass energy $\sqrt{s} = 13$ TeV pp collision data, collected between 2015 and 2018, that satisfy beam, detector and data-quality criteria. The uncertainty in the combined 2015–2018 integrated luminosity is 1.7% [18], obtained using the LUCID-2 detector [19] for the primary luminosity measurements. The average number of interactions ($\langle\mu\rangle$) in the same and nearby bunch crossings (pile-up) varies from $\langle\mu\rangle = 13.4$ (2015 dataset) to $\langle\mu\rangle = 36.1$ (2018 dataset), with a highest $\langle\mu\rangle = 37.8$ (2017 dataset) and an average $\langle\mu\rangle = 33.7$. Data were collected using a four-jet trigger which, in the HLT, requires four jets each having $|\eta| < 2.5$, with $p_{\mathrm{T}} > 100$ GeV for the 2015–2016 data period and $p_{\mathrm{T}} > 120$ GeV for the 2017–2018 data period. Data events used for the validation of the data-driven multijet background were collected using the lowest unprescaled single-lepton triggers; the lowest trigger p_{T} threshold used for muons is 20 (26) GeV in 2015 (2016–2018), while for electrons the trigger p_{T} threshold is 24 (26) GeV in 2015–2017 (2018).

Monte Carlo (MC) simulations are used to model the SUSY signals, as well as to aid in the description of the background processes. In the remainder of this section, the simulation of the signal and of the main background processes contributing to the selected events in data is described. For all the simulated physics processes, the top-quark mass is assumed to be $m_{\mathrm{top}} = 172.5$ GeV and the Higgs boson mass is taken to be $m_H = 125$ GeV. The generation of the simulated event samples includes the effect of multiple pp interactions in the same and neighbouring bunch crossings, as well as the effect of pile-up on the detector response. These interactions were produced using Pythia 8.230 [20] with a set of tuned parameters called the A3 tune [21] and the NNPDF2.3 leading-order (LO) [22] parton distribution function (PDF) set.

All generated MC samples were processed through a simulation [23] of the detector geometry and response using either Geant4 [24] or a fast simulation [25] of the calorimeter response and were then processed by the same reconstruction software used on data. To model the parton shower, hadronisation, and underlying event, the Pythia 8 generator was used with the NNPDF2.3 LO PDF set and the A14 [26] set of tunable parameters. The decays of bottom and charm hadrons were modelled using EvtGen [27]. Simulated MC events are weighted such that the object identification efficiencies, energy scales and energy resolutions match those determined from data control samples [28, 29].

MC samples for multijet production were generated using Pythia 8.230 with leading-order matrix elements for dijet production and a p_{T}-ordered parton shower. EvtGen v1.6.0 was used for bottom and charm hadron decays. The renormalisation and factorisation scales were set to the geometric mean of the squared transverse masses of the two outgoing partons, $\sqrt{(p_{\mathrm{T},1}^2 + m_1^2)(p_{\mathrm{T},2}^2 + m_2^2)}$.

The production of $t\bar{t}$ events (referred to as $t\bar{t}$+jets) was modelled using the Powheg-Box v2 [30–33] generator at next-to-leading order (NLO) with the NNPDF3.0 NLO [34] PDF set and with the h_{damp}

parameter[2] set to 1.5 m_{top} [35]. Pythia 8.230 was used for the parton shower and EvtGen v1.6.0 for bottom and charm hadron decays. The $t\bar{t}$+jets sample was generated inclusively in the number of jets using fast simulation. The MC sample cross-section is corrected to the theory prediction at next-to-next-to leading order (NNLO) in QCD including resummation of next-to-next-to-leading logarithmic (NNLL) soft gluon terms by means of the Top++ (v2.0) program [36–42]. The generated events may have jets which do not originate from the decay of the $t\bar{t}$ system. These additional jets are used to categorise the events depending on the flavour of the matching parton. Particle jets are reconstructed from all stable particles generated in the event (excluding muons and neutrinos) using the anti-k_t algorithm [43] with a radius parameter $R = 0.4$ and are required to have $p_{\text{T}} > 15$ GeV and $|\eta| < 2.5$. Events having at least one such particle jet, matched within $\Delta R < 0.3$ to a generated b-hadron having $p_{\text{T}} > 5$ GeV and not originating from a top-quark decay, are labelled as $t\bar{t}$+$\geq 1b$ events. Similarly, events which are not already categorised as $t\bar{t}$+$\geq 1b$, and where at least one particle jet is matched to a c-hadron not originating from a W boson decay, are labelled as $t\bar{t}$+$\geq 1c$ events. Events labelled as either $t\bar{t}$+$\geq 1b$ or $t\bar{t}$+$\geq 1c$ are referred to as $t\bar{t}$ +HF events (HF for 'heavy flavour'). The remaining events, including those with no additional jets, are labelled as $t\bar{t}$+light events (light for 'light flavour').

The Wt single-top-quark background was generated at NLO in QCD by Powheg-Box v2 with the NNPDF3.0 NLO PDF set. Overlaps between the $t\bar{t}$ and Wt final states were removed using the 'diagram removal' scheme [44]. Pythia 8.230 was used for the parton shower and EvtGen v1.6.0 for bottom and charm hadron decays. Samples of single-top events are normalised to the cross-section calculated at NLO in QCD with NNLL soft gluon corrections [45, 46].

The production of $t\bar{t}V$ events was modelled using the MadGraph5_aMC@NLO v2.3.3 [47] generator at NLO with the NNPDF3.0 NLO PDF set. Pythia 8.210 was used for the parton shower and EvtGen v1.2.0 for bottom and charm hadron decays.

The production of $t\bar{t}H$ events was modelled using the Powheg-Box v2 generator to NLO with the NNPDF3.0 NLO PDF set. Pythia 8.230 was used for the parton shower and EvtGen v1.6.0 for bottom and charm hadron decays. The cross-sections are calculated at NLO QCD and NLO electroweak accuracy using MadGraph5_aMC@NLO [48].

Signal events were produced using the MadGraph5_aMC@NLO v2.3.3 generator at NLO with the NNPDF2.3 LO PDF, and the fast simulation of the detector response. Pythia 8.230 was used for the parton shower and EvtGen v1.6.0 for bottom and charm hadron decays. Signal cross-section calculations include approximate next-to-next-to-leading-order ($\text{NNLO}_{\text{Approx}}$) supersymmetric QCD corrections and the resummation of soft gluon emission at NNLL accuracy [49]. The nominal cross-section and its uncertainty are taken from an envelope of predictions using different PDF sets as well as different factorisation and renormalisation scales. Top-squark masses between 600 GeV and 1 TeV and higgsino masses between 100 GeV and 950 GeV are considered.

4 Event reconstruction

Events are required to have a primary vertex reconstructed from at least two tracks with transverse momentum $p_{\text{T}} > 500$ MeV. When several vertices are found in a given bunch crossing, the vertex with the largest summed p_{T}^2 of the associated tracks is selected as the primary vertex.

[2] The h_{damp} parameter is a resummation damping factor and one of the parameters that controls the matching of Powheg matrix elements to the parton shower and thus effectively regulates the high-p_{T} radiation against which the $t\bar{t}$ system recoils.

Electrons are reconstructed from energy deposits (clusters) in the electromagnetic calorimeter matched to tracks reconstructed in the ID [50, 51] and are required to have $p_{\mathrm{T}} > 10$ GeV and $|\eta| < 2.47$. Candidates in the calorimeter barrel–endcap transition region ($1.37 < |\eta| < 1.52$) are excluded. Electron tracks must match the primary vertex of the event: the longitudinal impact parameter[3] is required to satisfy $|z_0| < 0.5$ mm, while the transverse impact parameter is required to satisfy $|d_0|/\sigma_{d_0} < 5$, where σ_{d_0} represents the uncertainty in the measured $|d_0|$ values. *Loose* electrons are identified using the 'Medium' identification criterion provided by a likelihood-based discriminant [52]. *Tight* electrons are required to pass the 'TightLH' selection [52] and the 'Gradient' isolation criteria [52] and $p_{\mathrm{T}} > 27$ GeV.

Muons are reconstructed by matching either track segments or full tracks in the MS to tracks in the ID [53]. Combined tracks are then re-fitted using information from both detector systems. Muon tracks must match the primary vertex of the event: the longitudinal impact parameter is required to satisfy $|z_0| < 0.5$ mm, while the transverse impact parameter is required to satisfy $|d_0|/\sigma_{d_0} < 3$. *Loose* muons are those that pass the 'Loose' muon selection [53] and have $p_{\mathrm{T}} > 10$ GeV and $|\eta| < 2.5$, and *Tight* muons are those that pass the 'Medium' muon selection [53], satisfy the 'FixedCutTightTrackOnly' isolation criterion [53], and have $p_{\mathrm{T}} > 27$ GeV.

Jets are reconstructed from three-dimensional topological energy clusters [54] in the calorimeter using the anti-k_t jet algorithm [43] with a radius parameter of 0.4. Reconstructed jets are then corrected to the particle level by the application of a jet energy scale calibration that is derived from simulation and by *in situ* corrections obtained from 13 TeV data [55]. Jets used in this analysis are required to have $p_{\mathrm{T}} > 25$ GeV and $|\eta| < 2.5$ after calibration.

To avoid selecting jets from pile-up, low-p_{T} ($p_{\mathrm{T}} < 120$ GeV) jets in the central ($|\eta| < 2.5$) region of the detector are required to satisfy the jet-vertex tagger [56] configured such that it has an efficiency of approximately 92% to identify jets from a primary vertex. This requirement is applied to both data and simulation. Quality criteria are imposed to identify jets arising from non-collision sources or detector noise (using the `BadLoose` operating point [57]), and any event containing at least one such jet is removed. This removal produces a negligible loss of efficiency for signal events.

The b-jets are identified via a b-tagging algorithm that uses multivariate techniques to combine information from the impact parameters of displaced tracks as well as topological properties of secondary and tertiary decay vertices reconstructed within the jet. This analysis uses the MV2c10 tagger [58], trained on a hybrid sample of simulated $t\bar{t}$ and Z' events statistically enriched at high-p_{T} in order to discriminate b-jets from a background consisting of light- (93%) and c-labelled (7%) jets [29]. A weight is calculated corresponding to the probable presence of a b-quark or a c-quark, and jets are confirmed b-tagged if they satisfy a minimum requirement on the MV2c10 b-tagging weight corresponding to an average efficiency in $t\bar{t}$ events of 60% for b-jets, 4% for c-jets and a rejection factor of approximately 1200 for light-flavour jets across the jet p_{T} range.

An overlap removal procedure is carried out to resolve ambiguities between jets and lepton candidates. To prevent treating electron energy deposits as jets, the closest jet within $\Delta R_y = \sqrt{(\Delta y)^2 + (\Delta\phi)^2} = 0.2$ of a selected electron is removed.[4] If the nearest jet surviving that selection is within $\Delta R_y = 0.4$ of the electron, the electron is discarded. To reduce the background from heavy-flavour decays inside jets, muons

[3] The transverse impact parameter (d_0) is defined as the distance of closest approach in the transverse plane between a track and the beam-line. The longitudinal impact parameter (z_0) corresponds to the z-coordinate difference between the point along the track at which the transverse impact parameter is defined and the primary vertex.

[4] The rapidity is defined as $y = \frac{1}{2}\ln\frac{E+p_z}{E-p_z}$ where E is the energy and p_z is the longitudinal component of the momentum along the beam-line.

Table 1: The strategy of the analysis. For the model-dependent fit, the signal regions ($SR_{\tilde{t}}$) consist of events with N_j = 6, 7, 8 and ≥ 9 jets and N_b = 4 and ≥ 5. These are used independently in the final fit. For the model-independent fit, two dedicated signal regions ($SR_{discovery}$), with ($N_j \geq 9$, $N_b \geq 5$) and ($N_j \geq 8$, $N_b \geq 5$), are used. The validation regions (VR-MJ), which are based on a maximum value of the centrality mass, C_{mass}^{max}, introduced for the description of the VRs in Section 5, are also indicated.

Analysis Regions		N_b = 3	N_b = 4	N_b ≥ 5
N_j	6	VR-MJ $C_{mass}^{max} = 1.2$	$SR_{\tilde{t}}$ VR-MJ $C_{mass}^{max} = 0.9$	$SR_{\tilde{t}}$
	7	VR-MJ $C_{mass}^{max} = 1.2$	$SR_{\tilde{t}}$ VR-MJ $C_{mass}^{max} = 0.7$	$SR_{\tilde{t}}$
	8	VR-MJ $C_{mass}^{max} = 0.9$	$SR_{\tilde{t}}$ VR-MJ $C_{mass}^{max} = 0.5$	$SR_{\tilde{t}}$, $SR_{discovery}$
	≥9	VR-MJ $C_{mass}^{max} = 0.7$	$SR_{\tilde{t}}$ VR-MJ $C_{mass}^{max} = 0.4$	$SR_{\tilde{t}}$, $SR_{discovery}$

are removed if they are separated from the nearest jet by $\Delta R_y < 0.4$. However, if that jet has fewer than three associated tracks, the muon is kept and the jet is removed instead.

5 Analysis strategy

Events selected for further analysis are required to have at least five jets, of which at least two must be b-tagged. The four highest-p_T jets are required to be on the trigger efficiency plateau, namely to have $p_T > 120$ GeV or $p_T > 140$ GeV, depending on the jet-p_T trigger requirement in 2015–2016 or 2017–2018, and have $|\eta| < 2.5$. All other jets present in the event are required to have $p_T > 25$ GeV and $|\eta| < 2.5$. A lepton veto is applied: events that contain *loose* muons or electrons with $p_T > 10$ GeV, whether isolated or non-isolated, are discarded.

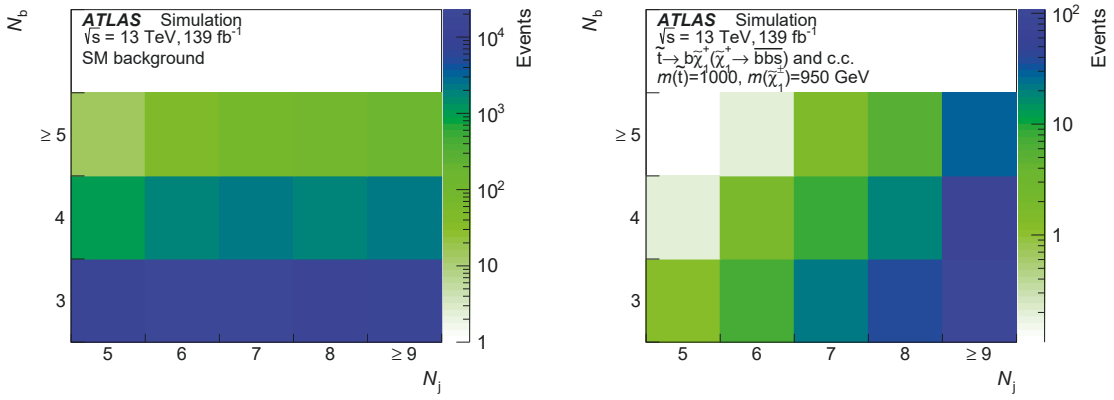
After the selections described above, the largest background contribution to the measurement is from non-resonant multijet production from light-quark and gluonic final states. The next largest is from $t\bar{t}$+jets production. Other small background contributions originate from the production of a single top quark and from the production of a $t\bar{t}$ pair in association with either a vector boson or a Higgs boson. The estimation of the multijet background using a data-driven method and the validation of this estimate without significant bias from potential signal contamination are the main challenges for this analysis.

To probe top-squark pair production and estimate the contribution of signal top squarks in data, a model-dependent fit of the yield of events with jet multiplicity N_j = 6, 7, 8 and ≥ 9 and b-tagged jet multiplicity N_b = 4 and ≥ 5 is performed. These (N_j, N_b) regions are indicated as $SR_{\tilde{t}}$ in Table 1. The signal contribution predicted for different values of $m_{\tilde{t}}$ and $m_{\tilde{\chi}_{1,2}^0, \tilde{\chi}_1^\pm}$ is considered in all bins and is scaled by one common signal-strength parameter ($\mu_{\tilde{t}\tilde{t}^*}$). For the model considered here, the product of acceptance

and reconstruction efficiency ($A \times \epsilon$) is of order $\sim 5 \times 10^{-2}$ for $N_j \geq 9$ and $N_b \geq 5$. Figure 2 shows the number of signal events obtained from the model as a function of N_j and N_b compared to the estimated backgrounds. Their evaluation is described in Section 6. The signal yields are concentrated at high jet and b-tagged jet multiplicity, while the backgrounds are concentrated at low b-tagged jet multiplicity. To validate the background estimates, intervals with $N_j = 6$, 7, 8 and ≥ 9, and $N_b = 3$ and 4, subsequently referred to as VR-MJ, are used. In these, a region-dependent selection is applied, based on a maximum accepted value of the centrality mass (C_{mass}), defined as:

$$C_{\text{mass}} = \frac{H_T}{\sqrt{(\sum_{i=1}^{N_j} E_i)^2 - (\sum_{i=1}^{N_j} \mathbf{p}_i)^2}},$$

i.e. the ratio of the scalar sum of all jet p_T in the event (H_T) to the invariant mass of the set of observed jets. The signal-to-background ratio decreases monotonically with decreasing C_{mass} for all N_j and N_b values. The value of the maximum value of C_{mass} ($C_{\text{mass}}^{\text{max}}$) is chosen such that the signal-to-background ratio is less than 5%. Values of the $C_{\text{mass}}^{\text{max}}$ limits used are listed in Table 1.



(a) (b)

Figure 2: Predicted numbers of events as a function of jet multiplicity, N_j, and b-tagged jet multiplicity, N_b, for (a) SM background (multijet and top-quark production) and (b) top-squark pair production in the $\tilde{t} \to b\tilde{\chi}_1^+$ ($\tilde{\chi}_1^+ \to \bar{b}b\bar{s}$) (and c.c.) channel, for $m_{\tilde{t}} = 1000$ GeV and $m_{\tilde{\chi}_1^\pm} = 950$ GeV.

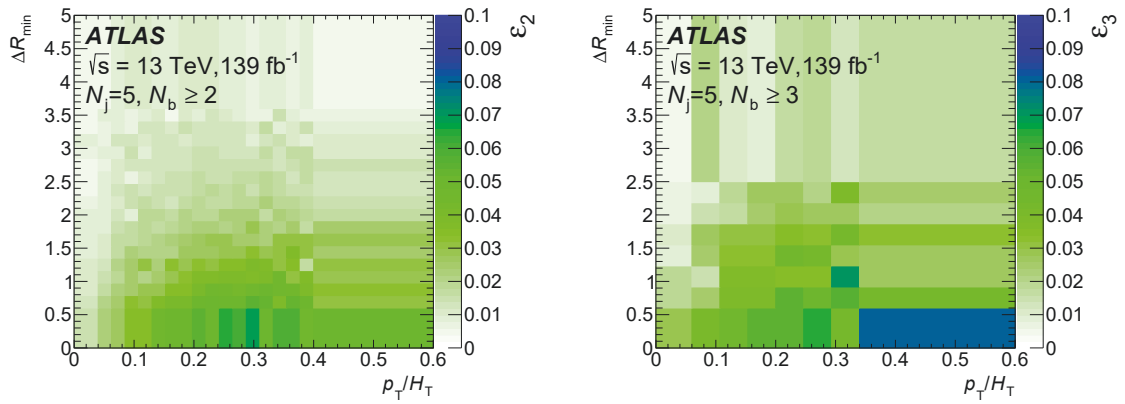
A separate, model-independent test is used to search for, and to set generic exclusion limits on, potential contributions from a hypothetical BSM signal by comparing the observed number of events with background predictions in two dedicated signal regions, one with $N_j \geq 9$ and $N_b \geq 5$ and the other with $N_j \geq 8$ and $N_b \geq 5$ (labelled $\text{SR}_{\text{discovery}}$ in Table 1), that were not explored in previous searches at the LHC.

6 Multijet background estimation

The predominant multijet background is estimated via a data-driven method, subsequently referred to as the tag-rate function method for multijet events (TRF_{MJ}) [59, 60]. The aim is to extrapolate the b-tag multiplicity distributions from $N_j = 5$, where the signal contamination for models not already excluded by other LHC searches is negligible, to larger N_j values. The TRF_{MJ} method uses a tag-rate function to

quantify the experimental probability of b-tagging an additional jet in samples of events with at least two, or at least three, b-tagged jets. This per-jet probability is then used to estimate the shape of the multijet b-tag multiplicity distribution for each N_j value.

Events that satisfy the selection criteria described in Section 5 and that have exactly five jets, of which at least two are b-tagged, are used to determine the b-tagging probability. The data are first corrected by subtracting the expected non-multijet background found in simulation, approximately 5% of the total. After excluding the two jets in each event with the highest b-tagging weight, the probability that each remaining jet is b-tagged, denoted ε_2, is calculated for this jet. A similar procedure is used to calculate the probability ε_3 of additional b-tagged jets in events with at least three b-tagged jets. These ε probabilities are parameterised as a function of both the p_T of the remaining jet divided by H_T, and the minimum ΔR between that jet and the two (for ε_2) or three (for ε_3) jets with the largest b-tagging weight in the event (ΔR_{min}). This choice of variables for the parameterisation is made to minimise the residual differences (non-closure) between the TRF_{MJ} prediction and the number of events obtained when selecting b-jets directly in the most sensitive signal regions in the multijet events simulated by MC. The dependence of ε_2 and ε_3 on both p_T/H_T and ΔR_{min} is shown in Figure 3. The rapid variation with ΔR_{min} is consistent with the dependence expected from multi-b-jet production due to gluon-splitting. The p_T/H_T dependence, more visible at small ΔR_{min}, reflects the variation of the b-tagging efficiency with jet p_T.



(a) (b)

Figure 3: Two-dimensional distributions of the probability (a) ε_2 or (b) ε_3 of b-tagging an additional jet in a sample of events with (a) at least two or (b) at least three b-tagged jets as a function of the ratio of jet transverse momentum to H_T, p_T/H_T, and the minimum ΔR between the jet and the (a) two or (b) three b-tagged jets with the highest b-tagging weight in the event, ΔR_{min}. The choice of binning is made so as to avoid empty bins.

Following the methods of Ref. [61], in the second step of the TRF_{MJ} method the expected number of events with each different number of b-tagged jets is estimated for each N_j value by weighting all events with $N_b \geq 2$ by the *event probability* of having $N_b = 2$, 3, 4 and ≥5, respectively. Upon subtracting the non-multijet background contribution [59], the event probabilities are estimated using both ε_2 and ε_3, after first excluding the two jets with the highest b-tagging weight. For $N_b = 2$ the event probabilities are estimated directly from ε_2, treating the tagging probability for each jet as independent. For $N_b = 3$, 4 and ≥5, a two-step procedure is employed. First, a 'pseudodata sample' with $N_b \geq 3$ is emulated, using ε_2 in events with $N_b \geq 2$. The additional emulated b-tagged jet is chosen randomly from the remaining $N_j - 2$ jets by using their probability-dependent b-tagging weights [60]. This emulated sample is then

used to estimate the event probabilities, this time relying on ε_3. The probability of finding $N_b = 4$ and $N_b \geq 5$ is estimated using the emulated $N_b \geq 3$ sample via ε_3. Due to too few events in the control sample from which the ε_2 and ε_3 values are extracted, it is not possible to estimate the probability of b-tagging an additional jet in a sample of events with at least four b-tagged jets.

6.1 Validation of $\mathrm{TRF_{MJ}}$ method

The $\mathrm{TRF_{MJ}}$ method is validated using two different comparisons with data: in the VR-MJ regions defined in Section 5, and in a separate set of Z + jets-enriched events. Figure 4 shows a comparison between measured and estimated event rates in VR-MJ. The data and predictions are in agreement within systematic uncertainties (described in Section 7).

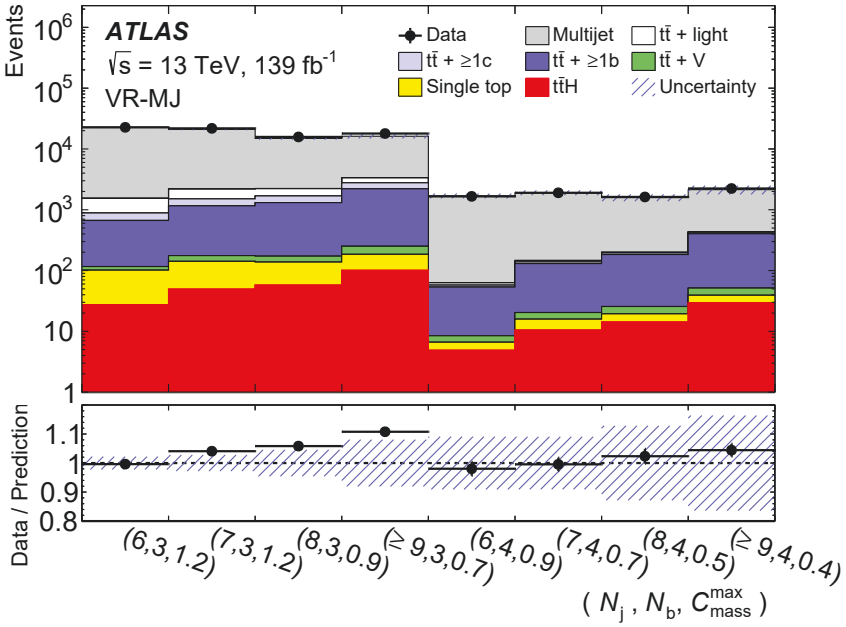


Figure 4: Comparison between data and the predicted number of events with $N_j = 6$, 7, 8 and ≥ 9 and $N_b = 3$ and 4 in the VR-MJ validation regions, which are based on a maximum value of the centrality mass, $C^{\mathrm{max}}_{\mathrm{mass}}$. The bottom panel displays the ratios of data to the total prediction, uncertainty bars are statistical only. The systematic uncertainties listed in Section 7 are represented by the blue hatched area.

An independent test of the method is performed in Z + jets-enriched events, referred as 'VR-ZJ', where additional jets are produced by radiation and where $b\bar{b}$ pairs arise from gluon splitting. In order to select events where a Z boson decays into pairs of electrons or muons, events are required to pass a single-lepton trigger. Two opposite-sign, same-flavour, *tight* electrons or muons are required to each have $p_T > 27$ GeV and a pair mass larger than 60 GeV. Events are required to have at least five jets with $p_T > 25$ GeV and $|\eta| < 2.5$, of which at least two must be b-tagged. The tagging probabilities ε_2 and ε_3 are derived from five-jet VR-ZJ events and used to predict the number of events with $N_j = 6$, 7, 8, ≥ 9 and $N_b = 4$, ≥ 5. As shown in Figure 5, this statistically limited test further validates the $\mathrm{TRF_{MJ}}$ method.

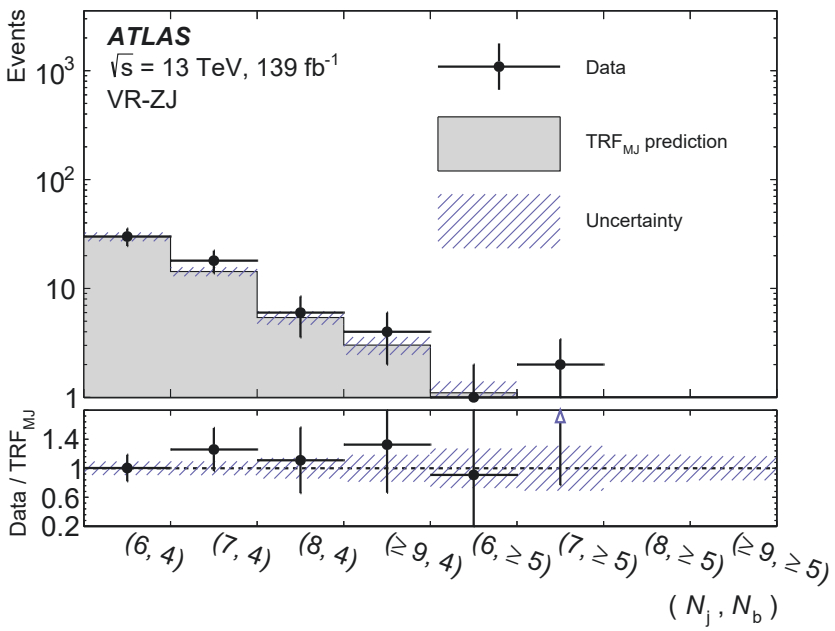


Figure 5: Comparison between data and the number of events with N_j = 6, 7, 8 and ≥ 9 and N_b =4 and ≥5 predicted by the TRF_{MJ} method (grey histogram) in the VR-ZJ region, defined by the requirement of two isolated leptons with invariant mass larger than 60 GeV. The bottom panel displays the ratios of data to the TRF_{MJ} prediction, uncertainty bars are statistical only. Systematic uncertainties in the TRF_{MJ} prediction are represented by the blue hatched area.

7 Systematic uncertainties

Several sources of systematic uncertainty are considered that can affect the overall normalisation of signal and background samples and their relative contribution for different values of N_j and N_b. In estimating the dominant multijet background from the data, systematic uncertainties arise from the assumptions made in obtaining the TRF_{MJ} background estimates. Uncertainties related to the theoretical modelling and due to the description of the detector response in simulated events are relevant only for the signal and background MC samples.

The main assumption of the TRF_{MJ} method is that it is possible to define per-jet b-tagging probabilities (ε_2 and ε_3) in events with at least two or at least three b-tagged jets and, in particular, that the variables used for the parameterisation are sensitive to the heavy-flavour composition of the jet sample. A second assumption is that the per-jet probabilities are independent of the jet multiplicity and, therefore, may be derived in a specific region, namely that with exactly five jets, and applied to regions with N_j = 6, 7, 8 and ≥ 9 jets. The validity of these assumptions is verified using MC simulations. The TRF_{MJ} method is applied to Pythia 8 MC dijet events, and the larger of a) the residual non-closure and b) the statistical uncertainty in the number of events with a given b-tagged jet multiplicity, is symmetrised and taken to be the systematic uncertainty associated with the method. Table 2 shows the final TRF_{MJ} systematic uncertainty in the multijet background estimation in each (N_j, N_b) region. For N_b = 4 the TRF_{MJ} uncertainties are dominated by the non-closure component, while for $N_b \geq 5$, the statistical component dominates. The TRF_{MJ} uncertainties are the source of the largest systematic uncertainty for the analysis.

Table 2: Systematic uncertainties in the data-driven estimation of the multijet background using the $\mathrm{TRF_{MJ}}$ method. The uncertainties are assessed using Pythia 8 MC dijet events for each value of jet multiplicity (N_j) and b-tagged jet multiplicity (N_b) used in the final fit.

$\mathrm{TRF_{MJ}}$ uncertainty		N_b = 4	N_b ≥5
N_j	6	9%	27%
	7	9%	30%
	8	13%	18%
	≥9	16%	14%

The second largest contribution to the total systematic uncertainty arises from the modelling of the $t\bar{t}$+jets background. The diagrams that contribute to $t\bar{t}$+≥1b, $t\bar{t}$+≥1c, and $t\bar{t}$ +light production are different, and the associated uncertainties may affect these processes differently in different regions. As a result, all uncertainties in $t\bar{t}$+jets background modelling, except the uncertainty in the inclusive cross-section, are considered to be uncorrelated among $t\bar{t}$+≥1b, $t\bar{t}$+≥1c, and $t\bar{t}$+light.

The uncertainty in the inclusive $t\bar{t}$ NNLO+NNLL production cross-section is taken to be ±6% [42]. This uncertainty includes effects from varying the factorisation and renormalisation scales, the PDF, α_S, and the top-quark mass. The normalisations of the $t\bar{t}$+≥1c and $t\bar{t}$+≥1b yields are taken from their fractional contribution to the nominal $t\bar{t}$+jets sample as generated using the Powheg-Box program. In addition to the uncertainty in the inclusive $t\bar{t}$ cross-section, an additional uncertainty of 50%, based on the measurement of the $t\bar{t}$+≥1b and $t\bar{t}$+≥1c normalisation factors reported in Ref. [62], is assigned to the $t\bar{t}$+≥1c and $t\bar{t}$+≥1b production cross-sections.

The impact of the parton shower and hadronisation model uncertainties on the $t\bar{t}$+jets, $t\bar{t}H$ and Wt single-top-quark yields is evaluated by comparing the sample from the nominal generator set-up with a sample produced with the NLO Powheg-Box v2 generator using the NNPDF3.0 NLO PDF set. The latter events are interfaced with Herwig 7.04 [63, 64], using the H7UE set of tuned parameters [64] and the MMHT2014LO PDF set [65], and processed using fast simulation of the detector response. The difference between the two predictions of the $t\bar{t}$+≥1b event yield ranges from 20% (33%) for N_j = 6 and N_b = 4 (≥ 5) to 46% (60%) in the region with $N_j \geq 9$ and N_b = 4 (≥ 5).

To assess the uncertainty due to the choice of matching scheme, the Powheg-Box sample is compared with a sample produced by MadGraph5_aMC@NLO and Pythia 8. For the calculation of the hard scattering, MadGraph5_aMC@NLO v2.6.0 with the NNPDF3.0 NLO PDF set is used. The events are processed with Pythia 8.230, using the A14 set of tuned parameters and the NNPDF2.3 LO PDF set, and the fast simulation of the detector response. The uncertainty, which is obtained from the difference in yield between the two models and is symmetrised, affects both the normalisation and the N_j- and N_b-dependence of background rates. It is largest for large values of the jet and b-tagged jet multiplicities. For $t\bar{t}$+≥1b, it reaches 25% for N_j = 8, ≥ 9 and N_b = 4, and 41% (32%) for N_j = 8 (≥ 9) and N_b ≥ 5.

The effect of renormalisation and factorisation scale uncertainties and PDF uncertainties is evaluated for $t\bar{t}H$ and $t\bar{t}V$ events. For the former, the scales are varied simultaneously by common factors of 2.0 and 0.5. For the latter, the envelope of the 100 variations for NNPDF3.0 NLO [34] are taken into account. An uncertainty of ±5% is assigned to the total cross-section for single-top production [45, 66, 67]. For

both the $t\bar{t}H$ and single-top events, additional uncertainties due to initial- and final-state radiation and the choice of generator are evaluated in a manner similar to that used for $t\bar{t}$ + jets. The uncertainty in the amount of interference between Wt and $t\bar{t}$ production at NLO is assessed by comparing samples using the default 'diagram removal' scheme with those using an alternative 'diagram subtraction' scheme [44]. All modelling uncertainties from non-$t\bar{t}$+jets simulated backgrounds are, after investigation, found to be negligible.

The uncertainties assigned to the expected signal yield for the SUSY benchmark processes considered include the experimental uncertainties related to the luminosity and to the detector modelling, which are dominated by the modelling of the jet energy scale and the b-tagging efficiencies. For example, for the $\tilde{t} \to b\tilde{\chi}_1^+(\tilde{\chi}_1^+ \to \bar{b}\bar{b}\bar{s}$ and c.c.) signal model, the b-tagging uncertainties in the region $N_j \geq 9$ and $N_\mathrm{b} = 4$ are approximatively 10%, and the jet-related uncertainties of the signal yields are in the range of 3–5%. The uncertainties in the signal yields related to the modelling of additional jet radiation are studied by varying the factorisation, renormalisation, and jet-matching scales as well as the parton-shower tune in the simulation. The corresponding uncertainties are small for most of the signal parameter space and are largest for small top-squark masses, where they reach 7%. The uncertainty in the signal cross-section ranges between 8% and 11% for a top-squark mass in the range 600–1000 GeV.

8 Results

The events are allocated to $(N_\mathrm{j}, N_\mathrm{b})$ regions with different signal-to-background ratios in order to constrain systematic uncertainties and to improve the separation of signal and background. Then, in each region, the total signal and background yields, shown in Tables 3 and 4, are used in combination as the input for the statistical analysis to extract the final results.

Table 3: Event yields from background predictions and data in the regions with $N_\mathrm{j} = 6$, 7, 8 or ≥ 9 and $N_\mathrm{b} = 4$. The quoted uncertainties are the sum in quadrature of the statistical and systematic uncertainties in the yields for all samples. The individual background uncertainties can be larger than the total uncertainty due to correlations between parameters.

	$(N_\mathrm{j}, N_\mathrm{b})$			
Process	(6, 4)	(7, 4)	(8, 4)	(≥9, 4)
Multijet	1760 ± 170	1920 ± 180	1510 ± 210	1870 ± 350
$t\bar{t}$ + light	6 ± 4	8.0 ± 3.4	6 ± 4	8 ± 7
$t\bar{t}$ + ≥1c	4.1 ± 2.9	8 ± 5	11 ± 6	22 ± 17
$t\bar{t}$ + ≥1b	45 ± 26	110 ± 70	160 ± 100	350 ± 260
$t\bar{t} + W$	0.055 ± 0.032	0.26 ± 0.07	0.30 ± 0.10	1.34 ± 0.28
$t\bar{t} + Z$	1.8 ± 0.4	4.3 ± 1.0	6.0 ± 1.5	10.9 ± 2.3
Wt	1.7 ± 2.0	5 ± 5	5.1 ± 3.1	10 ± 11
$t\bar{t}H$	4.9 ± 0.9	10.5 ± 1.7	14.2 ± 2.4	29 ± 8
Total background	1820 ± 170	2060 ± 190	1710 ± 220	2300 ± 400
Data	1660	1901	1624	2237

Hypothesis testing is performed using a modified frequentist method as implemented in RooStats [68] and is based on a profile likelihood which takes into account the systematic uncertainties as nuisance

Table 4: Event yields from background predictions and data in the regions with N_j = 6, 7, 8 or ≥ 9 and $N_b \geq 5$. The quoted uncertainties are the sum in quadrature of the statistical and systematic uncertainties in the yields for all samples. The individual background uncertainties can be larger than the total uncertainty due to correlations between parameters.

	(N_j, N_b)			
Process	(6, ≥5)	(7, ≥5)	(8, ≥5)	(≥9, ≥5)
Multijet	49 ± 13	75 ± 23	74 ± 14	123 ± 20
$t\bar{t}$ + light	<0.01	0.3 ± 0.6	<0.01	0.00 ± 0.04
$t\bar{t}$ + ≥1c	<0.01	0.016 ± 0.029	0.3 ± 0.4	0.26 ± 0.31
$t\bar{t}$ + ≥1b	1.2 ± 0.9	3.9 ± 2.7	7 ± 6	28 ± 25
$t\bar{t} + W$	<0.01	0.005 ± 0.007	0.021 ± 0.025	0.090 ± 0.035
$t\bar{t} + Z$	0.05 ± 0.05	0.22 ± 0.12	0.7 ± 0.4	0.7 ± 0.7
Wt	<0.01	<0.01	0.00 ± 0.13	0.9 ± 1.2
$t\bar{t}H$	0.12 ± 0.05	0.49 ± 0.13	0.82 ± 0.21	2.9 ± 1.5
Total background	50 ± 13	80 ± 23	84 ± 15	156 ± 27
Data	35	75	80	179

parameters. This procedure minimises the impact of systematic uncertainties on the search sensitivity by taking advantage of the highly populated, background-dominated (N_j, N_b) regions included in the likelihood fit. The signal-strength parameter, $\mu_{\tilde{t}\tilde{t}^*}$, defined for positive values and corresponding to the signal normalisation, is unconstrained in the profile-likelihood fit. The normalisation of each component of the background and $\mu_{\tilde{t}\tilde{t}^*}$ are determined simultaneously from the fit to the data.

Individual sources of systematic uncertainty are taken as uncorrelated. Contributions from $t\bar{t}$ + ≥ 1b, $t\bar{t}$ + ≥ 1c, $t\bar{t}$ + light, $t\bar{t} + V$, $t\bar{t}H$ and single-top-quark backgrounds are constrained by the uncertainties of the respective theoretical calculations, the uncertainty in the luminosity (described in Section 3), and experimental data. The $\mathrm{TRF_{MJ}}$ uncertainty is taken as uncorrelated across regions because of its large statistical component. In all cases, the profile-likelihood-ratio test is used to establish 95% confidence intervals using the $\mathrm{CL_s}$ [69] prescription. The likelihood is configured differently for the model-independent and model-dependent hypothesis tests.

For the model-independent test, a profile-likelihood fit is performed independently in the two $\mathrm{SR_{discovery}}$ regions with ($N_j \geq 8$, $N_b \geq 5$) and ($N_j \geq 9$, $N_b \geq 5$). This test is used to search for, and to compute generic exclusion limits on, the potential contribution from a hypothetical BSM signal in the given $\mathrm{SR_{discovery}}$ regions.

For the model-dependent test, assuming a specific top-squark model with variable mass values, tests of the signal-plus-background hypothesis, i.e. $\mu_{\tilde{t}\tilde{t}^*} = 1$, are formed for a series of values of $m_{\tilde{t}}$ and $m_{\tilde{\chi}^0_{1,2},\tilde{\chi}^\pm_1}$. These are used to derive exclusion limits for the specific top-squark model. The full set of regions, N_j = 6, 7, 8 and ≥ 9 and N_b = 4 and ≥ 5, is employed in the likelihood. The expected signal contribution, as predicted by the given model, is considered in all regions and is scaled by $\mu_{\tilde{t}\tilde{t}^*}$.

Figure 6 shows the observed numbers of data events compared with the fitted background model. The likelihood fit is configured using the model-dependent set-up where all bins are input to the fit, and $\mu_{\tilde{t}\tilde{t}^*}$ is set to zero. This configuration is also referred to as the *background-only* fit and includes no free-floating

parameters, only nuisance parameters with Gaussian constraints. An example signal model is also shown in the figure to illustrate the separation between the signal and the background.

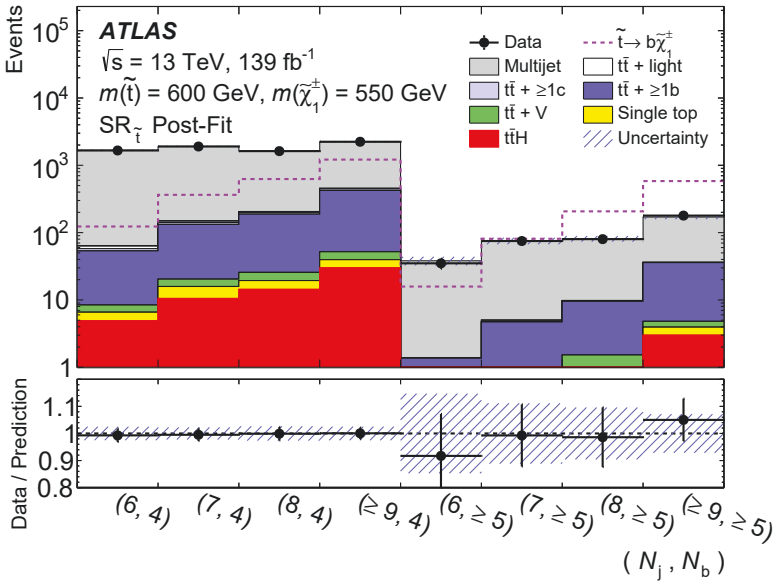


Figure 6: Expected background and observed number of events in different jet and b-tag multiplicity bins. The background is estimated by including all bins in a background-only fit and is plotted separately for each contribution. An example signal yield for $\tilde{t} \to \bar{b}\tilde{\chi}_1^+$ ($\tilde{\chi}_1^+ \to \bar{b}\bar{b}s$ and c.c.) production with $m_{\tilde{t}}$ = 600 GeV and $m_{\tilde{\chi}_1^\pm}$ = 550 GeV is overlaid. The bottom panel displays the ratios of data to the total prediction, uncertainty bars are statistical only. All uncertainties, which can be correlated across bins, are included in the error bands (hatched regions).

8.1 Model-independent interpretation

The model-independent results are calculated from the observed number of events and the background predictions in the two $\mathrm{SR}_{\mathrm{discovery}}$ regions. The observed number of events and the backgrounds obtained from the fits are shown for both $\mathrm{SR}_{\mathrm{discovery}}$ regions in Table 5.

Model-independent 95% CL upper limits on the expected and observed number of BSM events, N_{exp}^{95} and $\sigma_{\mathrm{obs}}^{95}$, that may contribute to the signal regions are computed from the observed number of events and the fitted background. Normalising these results by the integrated luminosity, L, of the data sample, allows them to be interpreted as upper limits on the visible BSM cross-section $\sigma_{\mathrm{obs}}^{95}$, defined as:

$$\sigma_{\mathrm{obs}}^{95} = \sigma_{\mathrm{prod}} \times \mathrm{A} \times \epsilon = \frac{N_{\mathrm{obs}}^{95}}{L},$$

where σ_{prod} is the production cross-section. The resulting limits are presented in Table 6. In addition, the p_0 values, which quantify the probability that a background-only hypothesis results in a fluctuation giving an event yield equal to or larger than the one observed in the data, are calculated, as are the corresponding Gaussian significance values Z.

Table 5: Fitted background yields in ($N_j \geq 8$, $N_b \geq 5$) and ($N_j \geq 9$, $N_b \geq 5$) signal regions. The individual background uncertainties can be larger than the total uncertainty due to correlations between parameters.

Process	$N_j \geq 8$, $N_b \geq 5$	$N_j \geq 9$, $N_b \geq 5$
Multijet	200 ± 40	123 ± 20
$t\bar{t} + \geq 1c$	0.6 ± 0.6	0.29 ± 0.33
$t\bar{t} + \geq 1b$	26 ± 20	20 ± 15
$t\bar{t} + W$	0.11 ± 0.05	0.09 ± 0.04
$t\bar{t} + Z$	1.4 ± 0.7	0.8 ± 0.7
Wt	0.9 ± 0.8	0.9 ± 1.2
$t\bar{t}H$	3.7 ± 1.6	2.9 ± 1.4
Total background	230 ± 40	147 ± 20
Data	259	179

Table 6: Observed 95% CL model-independent upper limits on the visible BSM cross-section, σ^{95}_{obs}, expressed in fb, along with the observed (expected) limits, N^{95}_{obs} (N^{95}_{exp}), on the number of excess events. The limits are determined for two signal regions, ($N_j \geq 8$, $N_b \geq 5$) and ($N_j \geq 9$, $N_b \geq 5$). The p_0 value quantifies the probability that the background-only hypothesis would result in a fluctuation that gives an event yield equal to or larger than the one observed in the data, and Z is the corresponding Gaussian significance.

Signal region	σ^{95}_{obs} [fb]	N^{95}_{obs}	N^{95}_{exp}	p_0 (Z)
$N_j \geq 8$, $N_b \geq 5$	0.76	105	85^{+30}_{-24}	0.24 (0.7)
$N_j \geq 9$, $N_b \geq 5$	0.54	75	52^{+20}_{-15}	0.11 (1.2)

8.2 Model-dependent interpretation

For each signal model probed, the fit is configured using the model-dependent set-up, as detailed in the first part of Section 8. Figure 7 shows exclusion limits at the 95% confidence level in the top-squark production model when $B(\tilde{t} \rightarrow b\tilde{\chi}^+_1)$ is assumed to be unity. For this model, top-squark masses are excluded up to 950 GeV for chargino masses close to the kinematic threshold for producing this final state. For lower values of the chargino mass, the limit weakens such that for chargino masses of around 200 GeV, the top-squark mass is constrained to be more than 800 GeV. In this phase space region, the signal is concentrated at lower N_j and N_b values where the background is larger.

The limits for higgsino LSPs are shown in Figure 8. In the region $m_{\tilde{t}} - m_{\tilde{\chi}^0_{1,2},\tilde{\chi}^\pm_1} \geq m_{top}$ the sensitivity of the analysis is lower than in the pure $\tilde{t} \rightarrow b\tilde{\chi}^\pm_1$ case because contributions to the signal that have one leptonically decaying top quark fail the lepton-veto requirement. The large contribution of the multijet background reduces the present sensitivity relative to a previous ATLAS search that analysed events characterised by the presence of a lepton plus jets [11].

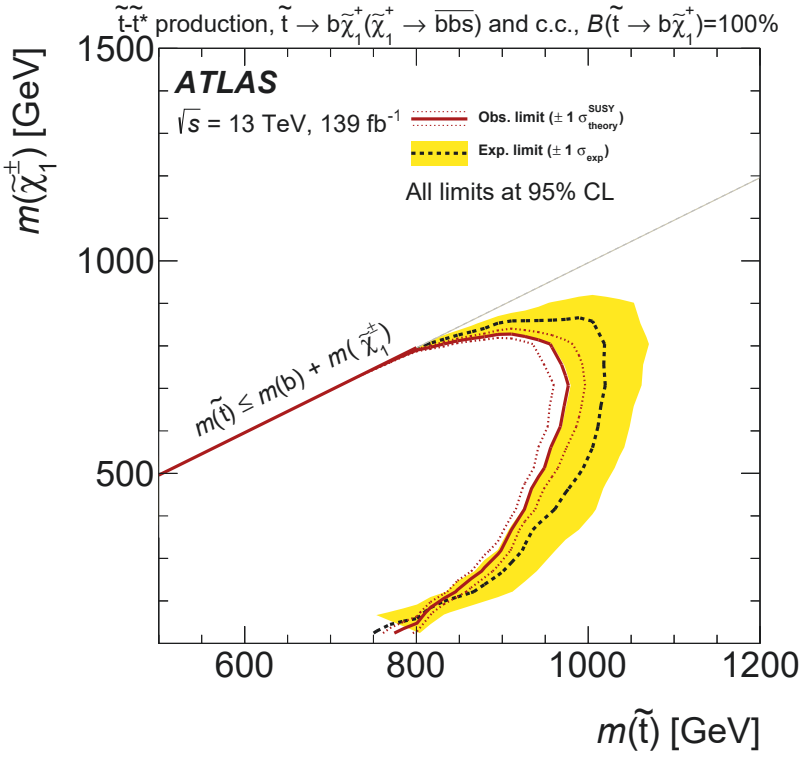


Figure 7: Observed and expected exclusion contours for the $\tilde{t}$ and $\chi_1^\pm$ masses in a top-squark production model with RPV decays of the $\chi_1^\pm$. Limits are shown for $B(\tilde{t} \rightarrow b\chi_1^+)$ equal to unity. The contours of the band around the expected limit are the $\pm 1\sigma$ variations, including all uncertainties except theoretical uncertainties in the signal cross-section. The dotted lines around the observed limit illustrate the change in the observed limit as the nominal signal cross-section is scaled up and down by the theoretical uncertainty. All limits are computed at 95% CL. The results are constrained by the kinematic limits of the top-squark decay into a chargino and a bottom quark (diagonal line).

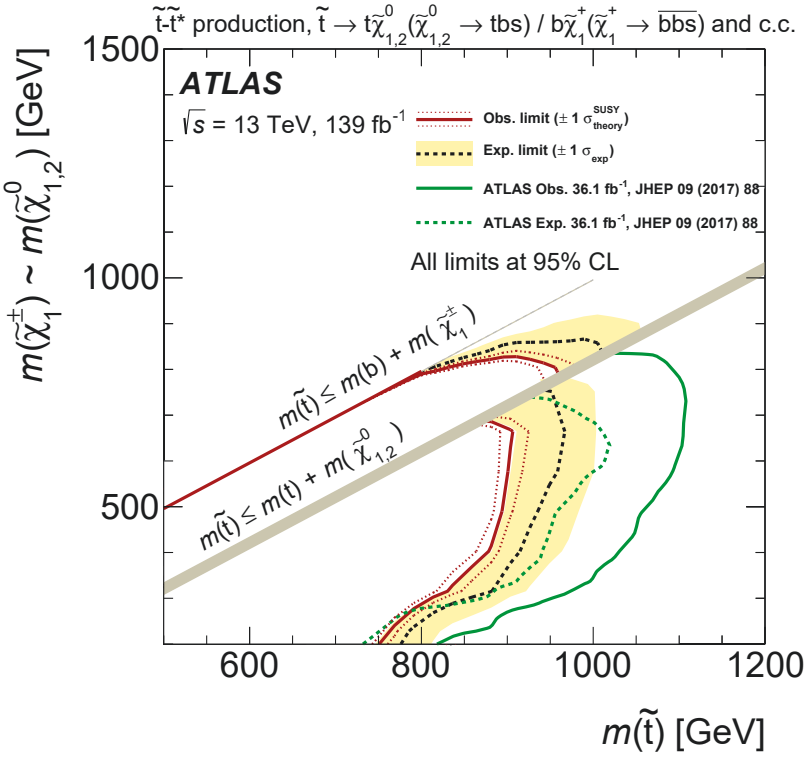


Figure 8: Observed and expected exclusion contours for the $\tilde{t}$ and $\chi_1^{\pm}$ masses in a top-squark production model with RPV decays of the $\chi_1^{\pm}$ and of the $\tilde{\chi}^0_{1,2}$. Limits are shown in the case of a higgsino LSP. The contours of the band around the expected limit are the $\pm 1\sigma$ variations, including all uncertainties except theoretical uncertainties in the signal cross-section. The dotted lines around the observed limit illustrate the change in the observed limit as the nominal signal cross-section is scaled up and down by the theoretical uncertainty. All limits are computed at 95% CL. The results are constrained by the kinematic limits of the top-squark decay into a chargino and a bottom quark (upper diagonal line) and into a neutralino and a top quark (lower diagonal line), respectively. Also shown are the limits from Ref. [11].

9 Conclusion

A search for physics beyond the Standard Model in events with high jet multiplicity and a large number of b-tagged jets is described in this paper. The search uses 139 fb^{-1} of $\sqrt{s}$ = 13 TeV proton–proton collision data collected by the ATLAS experiment at the LHC. In contrast to many previous searches in similar final states, leptons are vetoed and no requirement is placed on the missing transverse momentum in the event. The multijet background dominates the observed yields and is estimated using a data-driven technique based on an extrapolation from events with low b-jet multiplicity to the high b-jet multiplicities. No significant excess over the SM expectation is observed, and model-independent limits on the contribution of new phenomena to the signal-region yields are computed. In the context of a model with direct top-squark production and RPV decays of the higgsinos, the data exclude top squarks with masses up to 950 GeV in the region $m_{\tilde{t}} - m_{\tilde{\chi}^0_{1,2},\tilde{\chi}^\pm_1} \leq m_{\text{top}}$, where this analysis has exclusive sensitivity. The results represent the first limits from ATLAS on the production of top squarks that decay exclusively into a chargino and a b-quark.

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References

[1] J. A. Evans, *A swarm of Bs*, JHEP **1408** (2014) 073, arXiv: 1402.4481 [hep-ph].

[2] M. R. Buckley, D. Feld, S. Macaluso, A. Monteux and D. Shih, *Cornering natural SUSY at LHC Run II and beyond*, JHEP **08** (2017) 115, arXiv: 1610.08059 [hep-ph].

[3] S. Diglio, L. Feligioni and G. Moultaka, *Stashing the stops in multijet events at the LHC*, Phys. Rev. **D96** (2017) 055032, arXiv: 1611.05850 [hep-ph].

[4] P. Fayet, *Supergauge invariant extension of the Higgs mechanism and a model for the electron and its neutrino*, Nucl. Phys. B **90** (1975) 104.

[5] A. Salam and J. A. Strathdee, *Supersymmetry and fermion number conservation*, Nucl. Phys. **B 87** (1975) 85.

[6] R. Barbieri et al., *R-parity violating supersymmetry*, Phys. Rept. **420** (2005) 1, arXiv: hep-ph/0406039.

[7] R. Barbieri and G. Giudice, *Upper bounds on supersymmetric particle masses*, Nucl. Phys. B **306** (1988) 63.

[8] B. de Carlos and J. Casas, *One-loop analysis of the electroweak breaking in supersymmetric models and the fine-tuning problem*, Phys. Lett. B **309** (1993) 320, arXiv: hep-ph/9303291.

[9] G. D'Ambrosio, G. Giudice, G. Isidori and A. Strumia, *Minimal flavour violation: an effective field theory approach*, Nuclear Physics B **645** (2002) 155, ISSN: 0550-3213, URL: http://dx.doi.org/10.1016/S0550-3213(02)00836-2.

[10] C. Csáki, Y. Grossman and B. Heidenreich, *Minimal flavor violation supersymmetry: A natural theory forR-parity violation*, Physical Review D **85** (2012), ISSN: 1550-2368, URL: http://dx.doi.org/10.1103/PhysRevD.85.095009.

[11] ATLAS Collaboration, *Search for new phenomena in a lepton plus high jet multiplicity final state with the ATLAS experiment using $\sqrt{s}$ = 13 TeV proton-proton collision data*, JHEP **09** (2017) 088, arXiv: 1704.08493 [hep-ex].

[12] ATLAS Collaboration, *A search for pair-produced resonances in four-jet final states at $\sqrt{s}$ = 13 TeV with the ATLAS detector*, Eur. Phys. J. C **78** (2018) 250, arXiv: 1710.07171 [hep-ex].

[13] CMS Collaboration, *Search for pair-produced resonances decaying to quark pairs in proton-proton collisions at $\sqrt{s}$ = 13 TeV*, Phys. Rev. D **98** (2018) 112014, arXiv: 1808.03124 [hep-ex].

[14] CMS Collaboration, *Search for pair-produced resonances each decaying into at least four quarks in proton-proton collisions at $\sqrt{s}$ = 13 TeV*, Phys. Rev. Lett. **121** (2018) 141802, arXiv: 1806.01058 [hep-ex].

[15] ATLAS Collaboration, *The ATLAS experiment at the CERN Large Hadron Collider*, JINST **3** (2008) S08003.

[16] ATLAS Collaboration, *ATLAS insertable B-layer technical design report*, ATLAS-TDR-19, 2010, URL: https://cds.cern.ch/record/1291633.

[17] B. Abbott et al., *Production and integration of the ATLAS Insertable B-Layer*, JINST **13** (2018) T05008, arXiv: 1803.00844 [physics.ins-det].

[18] ATLAS Collaboration, *Luminosity determination in pp collisions at $\sqrt{s}$ = 13 TeV using the ATLAS detector at the LHC*, ATLAS-CONF-2019-021, 2019, URL: https://cds.cern.ch/record/2677054.

[19] G. Avoni et al., *The new LUCID-2 detector for luminosity measurement and monitoring in ATLAS*, Journal of Instrumentation **13** (2018) P07017.

[20] T. Sjöstrand et al., *An introduction to PYTHIA 8.2*, Comput. Phys. Commun. **191** (2015) 159, arXiv: 1410.3012 [hep-ph].

[21] *The Pythia 8 A3 tune description of ATLAS minimum bias and inelastic measurements incorporating the Donnachie-Landshoff diffractive model*, tech. rep. ATL-PHYS-PUB-2016-017, CERN, 2016, URL: https://cds.cern.ch/record/2206965.

[22] R. D. Ball et al., *Parton distributions with LHC data*, Nucl. Phys. B **867** (2013) 244, arXiv: 1207.1303 [hep-ph].

[23] ATLAS Collaboration, *The ATLAS Simulation Infrastructure*, Eur. Phys. J. C **70** (2010) 823, arXiv: 1005.4568 [physics.ins-det].

[24] GEANT4 Collaboration, S. Agostinelli et al., *GEANT4: A Simulation toolkit*, Nucl. Instrum. Meth. A **506** (2003) 250.

[25] W. Lukas, *Fast Simulation for ATLAS: Atlfast-II and ISF*, tech. rep. ATL-SOFT-PROC-2012-065, CERN, 2012, URL: https://cds.cern.ch/record/1458503.

[26] ATLAS Collaboration, *ATLAS Pythia 8 tunes to 7 TeV data*, ATL-PHYS-PUB-2014-021, 2014, URL: https://cds.cern.ch/record/1966419.

[27] D. J. Lange, *The EvtGen particle decay simulation package*, Nucl. Instrum. Meth. A **462** (2001) 152.

[28] ATLAS Collaboration, *Jet energy scale measurements and their systematic uncertainties in proton-proton collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector*, Phys. Rev. D **96** (2017) 072002, arXiv: 1703.09665 [hep-ex].

[29] ATLAS Collaboration, *ATLAS b-jet identification performance and efficiency measurement with $t\bar{t}$ events in pp collisions at $\sqrt{s}$ = 13 TeV*, Eur. Phys. J. C **79** (2019) 970, arXiv: 1907.05120 [hep-ex].

[30] S. Frixione, P. Nason and G. Ridolfi, *A positive-weight next-to-leading-order Monte Carlo for heavy flavour hadroproduction*, JHEP **09** (2007) 126, arXiv: 0707.3088 [hep-ph].

[31] P. Nason, *A new method for combining NLO QCD with shower Monte Carlo algorithms*, JHEP **11** (2004) 040, arXiv: hep-ph/0409146.

[32] S. Frixione, P. Nason and C. Oleari, *Matching NLO QCD computations with Parton Shower simulations: the POWHEG method*, JHEP **11** (2007) 070, arXiv: 0709.2092 [hep-ph].

[33] S. Alioli, P. Nason, C. Oleari and E. Re, *A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX*, JHEP **06** (2010) 043, arXiv: 1002.2581 [hep-ph].

[34] NNPDF Collaboration, R.D. Ball et al., *Parton distributions for the LHC Run II*, JHEP **04** (2015) 040, arXiv: 1410.8849 [hep-ph].

[35] ATLAS Collaboration, *Studies on top-quark Monte Carlo modelling for Top2016*, ATL-PHYS-PUB-2016-020, 2016, URL: https://cds.cern.ch/record/2216168.

[36] M. Beneke, P. Falgari, S. Klein and C. Schwinn, *Hadronic top-quark pair production with NNLL threshold resummation*, Nucl. Phys. B **855** (2012) 695, arXiv: 1109.1536 [hep-ph].

[37] M. Cacciari, M. Czakon, M. Mangano, A. Mitov and P. Nason, *Top-pair production at hadron colliders with next-to-next-to-leading logarithmic soft-gluon resummation*, Phys. Lett. B **710** (2012) 612, arXiv: 1111.5869 [hep-ph].

[38] P. Bärnreuther, M. Czakon and A. Mitov, *Percent-Level-Precision Physics at the Tevatron: Next-to-Next-to-Leading Order QCD Corrections to $q\bar{q} \to t\bar{t} + X$*, Phys. Rev. Lett. **109** (2012) 132001, arXiv: 1204.5201 [hep-ph].

[39] M. Czakon and A. Mitov, *NNLO corrections to top-pair production at hadron colliders: the all-fermionic scattering channels*, JHEP **12** (2012) 054, arXiv: 1207.0236 [hep-ph].

[40] M. Czakon and A. Mitov, *NNLO corrections to top pair production at hadron colliders: the quark-gluon reaction*, JHEP **01** (2013) 080, arXiv: 1210.6832 [hep-ph].

[41] M. Czakon, P. Fiedler and A. Mitov, *Total Top-Quark Pair-Production Cross Section at Hadron Colliders Through $O(\alpha_S^4)$*, Phys. Rev. Lett. **110** (2013) 252004, arXiv: 1303.6254 [hep-ph].

[42] M. Czakon and A. Mitov, *Top++: A program for the calculation of the top-pair cross-section at hadron colliders*, Comput. Phys. Commun. **185** (2014) 2930, arXiv: 1112.5675 [hep-ph].

[43] M. Cacciari, G. P. Salam and G. Soyez, *The anti-k_t jet clustering algorithm*, JHEP **04** (2008) 063, arXiv: 0802.1189 [hep-ph].

[44] S. Frixione, E. Laenen, P. Motylinski, B. R. Webber and C. D. White, *Single-top hadroproduction in association with a W boson*, JHEP **07** (2008) 029, arXiv: 0805.3067 [hep-ph].

[45] N. Kidonakis, *Two-loop soft anomalous dimensions for single top quark associated production with a W- or H-*, Phys. Rev. **D82** (2010) 054018, arXiv: 1005.4451 [hep-ph].

[46] N. Kidonakis, 'Top Quark Production', *Proceedings, Helmholtz International Summer School on Physics of Heavy Quarks and Hadrons (HQ 2013): JINR, Dubna, Russia, July 15-28, 2013*, 2014 139, arXiv: 1311.0283 [hep-ph].

[47] J. Alwall et al., *The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations*, JHEP **07** (2014) 079, arXiv: 1405.0301 [hep-ph].

[48] D. de Florian et al., *Handbook of LHC Higgs Cross Sections: 4. Deciphering the Nature of the Higgs Sector*, (2016), arXiv: 1610.07922 [hep-ph].

[49] W. Beenakker, C. Borschensky, M. Krämer, A. Kulesza and E. Laenen, *NNLL-fast: predictions for coloured supersymmetric particle production at the LHC with threshold and Coulomb resummation*, JHEP **12** (2016) 133, arXiv: 1607.07741 [hep-ph].

[50] ATLAS Collaboration, *Electron and photon energy calibration with the ATLAS detector using LHC Run 1 data*, Eur. Phys. J. C **74** (2014), arXiv: 1407.5063 [hep-ex].

[51] ATLAS Collaboration, *Electron efficiency measurements with the ATLAS detector using the 2015 LHC proton–proton collision data*, ATLAS-CONF-2016-024, 2016, URL: https://cds.cern.ch/record/2157687.

[52] ATLAS Collaboration, *Electron and photon performance measurements with the ATLAS detector using the 2015–2017 LHC proton-proton collision data*, JINST **14** (2019) P12006, arXiv: 1908.00005 [hep-ex].

[53] ATLAS Collaboration, *Muon reconstruction performance of the ATLAS detector in proton–proton collision data at $\sqrt{s} = 13$ TeV*, Eur. Phys. J. C **76** (2016) 292, arXiv: 1603.05598 [hep-ex].

[54] W. Lampl et al., *Calorimeter Clustering Algorithms: Description and Performance*, tech. rep. ATL-LARG-PUB-2008-002. ATL-COM-LARG-2008-003, CERN, 2008, URL: https://cds.cern.ch/record/1099735.

[55] ATLAS Collaboration, *Jet energy scale and resolution measured in proton-proton collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector*, (2020), arXiv: 2007.02645 [hep-ex].

[56] ATLAS Collaboration, *Performance of pile-up mitigation techniques for jets in pp collisions at $\sqrt{s}$ = 8 TeV using the ATLAS detector*, Eur. Phys. J. C **76** (2016) 581, arXiv: 1510.03823 [hep-ex].

[57] ATLAS Collaboration, *Selection of jets produced in 13 TeV proton-proton collisions with the ATLAS detector*, ATLAS-CONF-2015-029 (2015), URL: http://cdsweb.cern.ch/record/2037702.

[58] ATLAS Collaboration, *Optimisation of the ATLAS b-tagging performance for the 2016 LHC Run*, tech. rep. ATL-PHYS-PUB-2016-012, CERN, 2016, URL: https://cds.cern.ch/record/2160731.

[59] ATLAS Collaboration, *Search for the Standard Model Higgs boson decaying into $b\bar{b}$ produced in association with top quarks decaying hadronically in pp collisions at $\sqrt{s}$ = 8 TeV with the ATLAS detector*, JHEP **05** (2016) 160, arXiv: 1604.03812 [hep-ex].

[60] ATLAS Collaboration, *Search for four-top-quark production in the single-lepton and opposite-sign dilepton final states in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector*, Phys. Rev. **D99** (2019) 052009, arXiv: 1811.02305 [hep-ex].

[61] D0 Collaboration, *Measurement of the t anti-t production cross section in p anti-p collisions at $\sqrt{s}$ = 1.96 TeV using secondary vertex b tagging*, Phys. Rev. D **74** (2006) 112004, arXiv: hep-ex/0611002.

[62] ATLAS Collaboration, *Search for the standard model Higgs boson produced in association with top quarks and decaying into a $b\bar{b}$ pair in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector*, Phys. Rev. **D97** (2018) 072016, arXiv: 1712.08895 [hep-ex].

[63] M. Bahr et al., *Herwig++ physics and manual*, Eur. Phys. J. C **58** (2008) 639, arXiv: 0803.0883 [hep-ph].

[64] J. Bellm et al., *Herwig 7.0/Herwig++ 3.0 release note*, Eur. Phys. J. C **76** (2016) 196, arXiv: 1512.01178 [hep-ph].

[65] L. Harland-Lang, A. Martin, P. Motylinski and R. Thorne, *Parton distributions in the LHC era: MMHT 2014 PDFs*, Eur. Phys. J. C **75** (2015) 204, arXiv: 1412.3989 [hep-ph].

[66] N. Kidonakis, *Next-to-next-to-leading-order collinear and soft gluon corrections for t-channel single top quark production*, Phys. Rev. D **83** (2011) 091503, arXiv: 1103.2792 [hep-ph].

[67] N. Kidonakis, *NNLL resummation for s-channel single top quark production*, Phys. Rev. D **81** (2010) 054028, arXiv: 1001.5034 [hep-ph].

[68] W. Verkerke and D. Kirkby, *The RooFit toolkit for data modeling*, 2003, arXiv: physics/0306116 [physics.data-an].

[69] A. L. Read, *Presentation of search results: The CL(s) technique*, J. Phys. **G28** (2002) 2693.

[70] ATLAS Collaboration, *ATLAS Computing Acknowledgements*, ATL-SOFT-PUB-2020-001, URL: https://cds.cern.ch/record/2717821.

The ATLAS Collaboration

G. Aad[102], B. Abbott[128], D.C. Abbott[103], A. Abed Abud[36], K. Abeling[53], D.K. Abhayasinghe[94], S.H. Abidi[166], O.S. AbouZeid[40], N.L. Abraham[155], H. Abramowicz[160], H. Abreu[159], Y. Abulaiti[6], B.S. Acharya[67a,67b,n], B. Achkar[53], L. Adam[100], C. Adam Bourdarios[5], L. Adamczyk[84a], L. Adamek[166], J. Adelman[121], M. Adersberger[114], A. Adiguzel[12c], S. Adorni[54], T. Adye[143], A.A. Affolder[145], Y. Afik[159], C. Agapopoulou[65], M.N. Agaras[38], A. Aggarwal[119], C. Agheorghiesei[27c], J.A. Aguilar-Saavedra[139f,139a,ad], A. Ahmad[36], F. Ahmadov[80], W.S. Ahmed[104], X. Ai[18], G. Aielli[74a,74b], S. Akatsuka[86], M. Akbiyik[100], T.P.A. Åkesson[97], E. Akilli[54], A.V. Akimov[111], K. Al Khoury[65], G.L. Alberghi[23b,23a], J. Albert[175], M.J. Alconada Verzini[160], S. Alderweireldt[36], M. Aleksa[36], I.N. Aleksandrov[80], C. Alexa[27b], T. Alexopoulos[10], A. Alfonsi[120], F. Alfonsi[23b,23a], M. Alhroob[128], B. Ali[141], S. Ali[157], M. Aliev[165], G. Alimonti[69a], C. Allaire[36], B.M.M. Allbrooke[155], B.W. Allen[131], P.P. Allport[21], A. Aloisio[70a,70b], F. Alonso[89], C. Alpigiani[147], E. Alunno Camelia[74a,74b], M. Alvarez Estevez[99], M.G. Alviggi[70a,70b], Y. Amaral Coutinho[81b], A. Ambler[104], L. Ambroz[134], C. Amelung[26], D. Amidei[106], S.P. Amor Dos Santos[139a], S. Amoroso[46], C.S. Amrouche[54], F. An[79], C. Anastopoulos[148], N. Andari[144], T. Andeen[11], J.K. Anders[20], S.Y. Andrean[45a,45b], A. Andreazza[69a,69b], V. Andrei[61a], C.R. Anelli[175], S. Angelidakis[9], A. Angerami[39], A.V. Anisenkov[122b,122a], A. Annovi[72a], C. Antel[54], M.T. Anthony[148], E. Antipov[129], M. Antonelli[51], D.J.A. Antrim[170], F. Anulli[73a], M. Aoki[82], J.A. Aparisi Pozo[173], M.A. Aparo[155], L. Aperio Bella[46], N. Aranzabal[36], V. Araujo Ferraz[81a], R. Araujo Pereira[81b], C. Arcangeletti[51], A.T.H. Arce[49], F.A. Arduh[89], J-F. Arguin[110], S. Argyropoulos[52], J.-H. Arling[46], A.J. Armbruster[36], A. Armstrong[170], O. Arnaez[166], H. Arnold[120], Z.P. Arrubarrena Tame[114], G. Artoni[134], H. Asada[117], K. Asai[126], S. Asai[162], T. Asawatavonvanich[164], N. Asbah[59], E.M. Asimakopoulou[171], L. Asquith[155], J. Assahsah[35d], K. Assamagan[29], R. Astalos[28a], R.J. Atkin[33a], M. Atkinson[172], N.B. Atlay[19], H. Atmani[65], K. Augsten[141], V.A. Austrup[181], G. Avolio[36], M.K. Ayoub[15a], G. Azuelos[110,al], H. Bachacou[144], K. Bachas[161], F. Backman[45a,45b], P. Bagnaia[73a,73b], M. Bahmani[85], H. Bahrasemani[151], A.J. Bailey[173], V.R. Bailey[172], J.T. Baines[143], C. Bakalis[10], O.K. Baker[182], P.J. Bakker[120], E. Bakos[16], D. Bakshi Gupta[8], S. Balaji[156], R. Balasubramanian[120], E.M. Baldin[122b,122a], P. Balek[179], F. Balli[144], W.K. Balunas[134], J. Balz[100], E. Banas[85], M. Bandieramonte[138], A. Bandyopadhyay[24], Sw. Banerjee[180,i], L. Barak[160], W.M. Barbe[38], E.L. Barberio[105], D. Barberis[55b,55a], M. Barbero[102], G. Barbour[95], T. Barillari[115], M-S. Barisits[36], J. Barkeloo[131], T. Barklow[152], R. Barnea[159], B.M. Barnett[143], R.M. Barnett[18], Z. Barnovska-Blenessy[60a], A. Baroncelli[60a], G. Barone[29], A.J. Barr[134], L. Barranco Navarro[45a,45b], F. Barreiro[99], J. Barreiro Guimarães da Costa[15a], U. Barron[160], S. Barsov[137], F. Bartels[61a], R. Bartoldus[152], G. Bartolini[102], A.E. Barton[90], P. Bartos[28a], A. Basalaev[46], A. Basan[100], A. Bassalat[65,ai], M.J. Basso[166], R.L. Bates[57], S. Batlamous[35e], J.R. Batley[32], B. Batool[150], M. Battaglia[145], M. Bauce[73a,73b], F. Bauer[144], P. Bauer[24], H.S. Bawa[31], A. Bayirli[12c], J.B. Beacham[49], T. Beau[135], P.H. Beauchemin[169], F. Becherer[52], P. Bechtle[24], H.C. Beck[53], H.P. Beck[20,p], K. Becker[177], C. Becot[46], A. Beddall[12d], A.J. Beddall[12a], V.A. Bednyakov[80], M. Bedognetti[120], C.P. Bee[154], T.A. Beermann[181], M. Begalli[81b], M. Begel[29], A. Behera[154], J.K. Behr[46], F. Beisiegel[24], M. Belfkir[5], A.S. Bell[95], G. Bella[160], L. Bellagamba[23b], A. Bellerive[34], P. Bellos[9], K. Beloborodov[122b,122a], K. Belotskiy[112], N.L. Belyaev[112], D. Benchekroun[35a], N. Benekos[10], Y. Benhammou[160], D.P. Benjamin[6], M. Benoit[29], J.R. Bensinger[26], S. Bentvelsen[120], L. Beresford[134], M. Beretta[51], D. Berge[19], E. Bergeaas Kuutmann[171], N. Berger[5], B. Bergmann[141], L.J. Bergsten[26], J. Beringer[18], S. Berlendis[7], G. Bernardi[135], C. Bernius[152], F.U. Bernlochner[24], T. Berry[94], P. Berta[100], A. Berthold[48], I.A. Bertram[90], O. Bessidskaia Bylund[181], N. Besson[144], A. Bethani[101], S. Bethke[115], A. Betti[42], A.J. Bevan[93], J. Beyer[115], D.S. Bhattacharya[176], P. Bhattarai[26], V.S. Bhopatkar[6], R. Bi[138], R.M. Bianchi[138], O. Biebel[114], D. Biedermann[19], R. Bielski[36], K. Bierwagen[100], N.V. Biesuz[72a,72b], M. Biglietti[75a], T.R.V. Billoud[141], M. Bindi[53], A. Bingul[12d],

C. Bini[73a,73b], S. Biondi[23b,23a], C.J. Birch-sykes[101], M. Birman[179], T. Bisanz[36], J.P. Biswal[3], D. Biswas[180,i], A. Bitadze[101], C. Bittrich[48], K. Bjørke[133], T. Blazek[28a], I. Bloch[46], C. Blocker[26], A. Blue[57], U. Blumenschein[93], G.J. Bobbink[120], V.S. Bobrovnikov[122b,122a], S.S. Bocchetta[97], D. Bogavac[14], A.G. Bogdanchikov[122b,122a], C. Bohm[45a], V. Boisvert[94], P. Bokan[171,171,53], T. Bold[84a], A.E. Bolz[61b], M. Bomben[135], M. Bona[93], J.S. Bonilla[131], M. Boonekamp[144], C.D. Booth[94], A.G. Borbély[57], H.M. Borecka-Bielska[91], L.S. Borgna[95], A. Borisov[123], G. Borissov[90], D. Bortoletto[134], D. Boscherini[23b], M. Bosman[14], J.D. Bossio Sola[104], K. Bouaouda[35a], J. Boudreau[138], E.V. Bouhova-Thacker[90], D. Boumediene[38], A. Boveia[127], J. Boyd[36], D. Boye[33c], I.R. Boyko[80], A.J. Bozson[94], J. Bracinik[21], N. Brahimi[60d], G. Brandt[181], O. Brandt[32], F. Braren[46], B. Brau[103], J.E. Brau[131], W.D. Breaden Madden[57], K. Brendlinger[46], R. Brener[159], L. Brenner[36], R. Brenner[171], S. Bressler[179], B. Brickwedde[100], D.L. Briglin[21], D. Britton[57], D. Britzger[115], I. Brock[24], R. Brock[107], G. Brooijmans[39], W.K. Brooks[146d], E. Brost[29], P.A. Bruckman de Renstrom[85], B. Brüers[46], D. Bruncko[28b], A. Bruni[23b], G. Bruni[23b], M. Bruschi[23b], N. Bruscino[73a,73b], L. Bryngemark[152], T. Buanes[17], Q. Buat[154], P. Buchholz[150], A.G. Buckley[57], I.A. Budagov[80], M.K. Bugge[133], F. Bührer[52], O. Bulekov[112], B.A. Bullard[59], T.J. Burch[121], S. Burdin[91], C.D. Burgard[120], A.M. Burger[129], B. Burghgrave[8], J.T.P. Burr[46], C.D. Burton[11], J.C. Burzynski[103], V. Büscher[100], E. Buschmann[53], P.J. Bussey[57], J.M. Butler[25], C.M. Buttar[57], J.M. Butterworth[95], P. Butti[36], W. Buttinger[36], C.J. Buxo Vazquez[107], A. Buzatu[157], A.R. Buzykaev[122b,122a], G. Cabras[23b,23a], S. Cabrera Urbán[173], D. Caforio[56], H. Cai[138], V.M.M. Cairo[152], O. Cakir[4a], N. Calace[36], P. Calafiura[18], G. Calderini[135], P. Calfayan[66], G. Callea[57], L.P. Caloba[81b], A. Caltabiano[74a,74b], S. Calvente Lopez[99], D. Calvet[38], S. Calvet[38], T.P. Calvet[102], M. Calvetti[72a,72b], R. Camacho Toro[135], S. Camarda[36], D. Camarero Munoz[99], P. Camarri[74a,74b], M.T. Camerlingo[75a,75b], D. Cameron[133], C. Camincher[36], S. Campana[36], M. Campanelli[95], A. Camplani[40], V. Canale[70a,70b], A. Canesse[104], M. Cano Bret[78], J. Cantero[129], T. Cao[160], Y. Cao[172], M.D.M. Capeans Garrido[36], M. Capua[41b,41a], R. Cardarelli[74a], F. Cardillo[173], G. Carducci[41b,41a], I. Carli[142], T. Carli[36], G. Carlino[70a], B.T. Carlson[138], E.M. Carlson[175,167a], L. Carminati[69a,69b], R.M.D. Carney[152], S. Caron[119], E. Carquin[146d], S. Carrá[46], G. Carratta[23b,23a], J.W.S. Carter[166], T.M. Carter[50], M.P. Casado[14,f], A.F. Casha[166], E.G. Castiglia[182], F.L. Castillo[173], L. Castillo Garcia[14], V. 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