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A search for resonant and non-resonant Higgs boson pair production in the $b\bar{b}\tau^+\tau^-$ decay channel in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

The ATLAS Collaboration

A search for resonant and non-resonant pair production of Higgs bosons in the $b\bar{b}\tau^+\tau^-$ final state is presented. The search uses 36.1 fb^{-1} of pp collision data with $\sqrt{s} = 13$ TeV recorded by the ATLAS experiment at the LHC in 2015 and 2016. The semileptonic and fully hadronic decays of the τ-lepton pair are considered. No significant excess above the expected background is observed in the data. The cross-section times branching ratio for non-resonant Higgs boson pair production is constrained to be less than 30.9 fb, 12.7 times the Standard Model expectation, at 95% confidence level. The data are also analyzed to probe resonant Higgs boson pair production, constraining a model with an extended Higgs sector based on two doublets and a Randall–Sundrum bulk graviton model. Upper limits are placed on the resonant Higgs boson pair production cross-section times branching ratio, excluding resonances X in the mass range 305 GeV $< m_X <$ 402 GeV in the simplified hMSSM minimal supersymmetric model for $\tan\beta = 2$ and excluding bulk Randall–Sundrum gravitons G_{KK} in the mass range 325 GeV $< m_{G_{\mathrm{KK}}} <$ 885 GeV for $k/\overline{M}_{\mathrm{Pl}} = 1$.

In 2012, the ATLAS and CMS Collaborations at the LHC discovered a new particle with a mass of approximately 125 GeV [1–3]. According to all current measurements it is compatible with the Standard Model (SM) Higgs boson (H) [4–8]. An important pending test of the Brout–Englert–Higgs mechanism is the measurement of Higgs boson pair production. At the LHC, pairs of SM Higgs bosons can be produced via the Higgs self-interaction ('triangle-diagram') and the destructively interfering top-quark loop ('box-diagram') [9, 10]. Non-resonant Higgs boson pair production (NR HH) can be significantly enhanced relative to the SM prediction by modifications to the top-quark Yukawa coupling, the trilinear Higgs boson coupling λ_{HHH} or by introducing production mechanisms with new intermediate particles. Many theories beyond the SM predict heavy resonances that could decay into a pair of SM Higgs bosons, such as a heavy CP-even scalar X in two-Higgs-doublet models [11], or spin-2 Kaluza–Klein (KK) excitations of the graviton, G_{KK}, in the bulk Randall–Sundrum (RS) model [12–14].

This Letter describes a search for resonant and non-resonant Higgs boson pair production in a final state with two b-quarks and two τ-leptons using 36.1 fb^{-1} of pp collision data recorded with the ATLAS detector [15, 16] in 2015 and 2016. The $\tau_{\text{lep}}\tau_{\text{had}}$ and $\tau_{\text{had}}\tau_{\text{had}}$ decay channels are considered, where the subscripts (lep = electron or muon, had = hadrons) indicate the decay mode of the τ-lepton. Previous searches for Higgs boson pair production were performed at center-of-mass energies $\sqrt{s}$ = 8 TeV [17–19] and $\sqrt{s}$ = 13 TeV [20–22] by the ATLAS and CMS Collaborations. The ATLAS search in the 4b channel constitutes the most sensitive result to date and the observed (expected) limit excludes a cross-section greater than 13.0 (20.7) times the SM prediction at 95% confidence level (CL).

The SM non-resonant HH process was simulated with MadGraph5_aMC@NLO at next-to-leading order (NLO) [23–27] using the CT10 parton distribution function (PDF) set [28]. Parton showers and hadronization were simulated with Herwig++ [29] using the UEEE5 set of tuned parameters (tune) [30]. The events were reweighted to reproduce the m_{HH} spectrum obtained in Refs. [9, 31], which fully accounts for the finite mass of the top quark. The cross-section times branching ratio to the $bb\tau\tau$ final state, evaluated at next-to-next-to-leading order (NNLO) and including next-to-next-to-leading logarithm (NNLL) corrections and NLO top-quark mass effects, is $2.44^{+0.18}_{-0.22}$ fb [32]. Events with a generic narrow-width scalar X or G_{KK} decaying into HH were produced in MadGraph5_aMC@NLO at leading order (LO) and interfaced to the Pythia 8 [33] parton shower model using the A14 tune [34] together with the NNPDF23LO PDF set [35]. The cross-section and width of the G_{KK} were taken from Ref. [36] and depend on $k/\overline{M}_{\text{Pl}}$, where k corresponds to the curvature of the warped extra dimension and $\overline{M}_{\text{Pl}} = 2.4 \times 10^{18}$ GeV is the effective four-dimensional Planck scale. Events with $k/\overline{M}_{\text{Pl}} = 1$ and $k/\overline{M}_{\text{Pl}} = 2$ were simulated.

The dominant SM background processes are $t\bar{t}$, QCD multi-jet and Z bosons produced in association with jets originating from heavy-flavor quarks (bb, bc, cc), subsequently referred to as Z+heavy-flavor[1]. SM Higgs boson production in association with a Z boson, subsequently decaying into a $bb\tau\tau$ [2] final state, is an irreducible background in this analysis. The $t\bar{t}$ and single-top-quark background events were simulated using Powheg-Box [37], with the CT10 PDF set, and MadSpin [38]. The parton showers were simulated using Pythia 6 [39] and the Perugia 2012 tune [40]. The $t\bar{t}$ background was scaled to match the NNLO+NNLL cross-sections [41], while the single-top samples were corrected to NLO [42, 43] (approximate NNLO [44]) predictions for the t- and s-channel (Wt final state). Events with W or Z bosons and associated jets were simulated with the Sherpa 2.2.1 generator [45–49], using the NNPDF30NNLO

[1] Equivalently, Z bosons produced in association with at least one light-flavor quark (u, d or s) are referred to as Z+light-flavor.

[2] The notations $\tau\tau$ and bb are used throughout this Letter, in place of $\tau^+\tau^-$ and $b\bar{b}$, as charge conjugation is implied.

PDF set [50] and normalized to the NNLO cross-sections [51]. Diboson and Drell–Yan backgrounds were produced with Sherpa 2.1.1 [45] using the CT10NLO PDF set and the generator cross-section predictions. Quark-induced ZH processes were generated with Pythia 8, using the A14 tune and the NNPDF23LO PDF set. The samples were normalized to NNLO cross-sections for QCD and NLO for electroweak processes [52–58]. The gluon-induced ZH process [59] was generated with Powheg using the CT10 PDF set and using Pythia 8 with the AZNLO tune [60] to simulate parton showers. Cross-sections [61–65] were scaled to NLO+NLL in QCD. SM Higgs boson production in association with a top-quark pair was simulated with MadGraph5_aMC@NLO; Pythia 8 was used to simulate the parton shower, while the cross-section was taken from Ref. [10]. In all signal and background samples, the mass of the H bosons was set to 125 GeV. The contributions from other SM Higgs boson processes are negligible. EvtGen v1.2.0 [66] was used to model the properties of bottom and charm hadron decays for all processes except those simulated in Sherpa. The detector response to the generated events was simulated with Geant4 [67, 68]. Simulated events are reweighted to match the distribution of the number of inelastic collisions per event (pileup) in data.

Events are required to have at least one collision vertex reconstructed from at least two charged-particle tracks with transverse momentum[3] $p_{\mathrm{T}}^{\mathrm{track}} > 0.4$ GeV. The primary vertex for each event is selected as the vertex with the highest $\sum(p_{\mathrm{T}}^{\mathrm{track}})^2$. Jets are formed using the anti-k_t algorithm [69] with a radius parameter $R = 0.4$ and calorimeter energy clusters as inputs [70–72]. These jets are taken as seeds for the reconstruction of the visible products of hadronically decaying τ-leptons ($\tau_{\text{had-vis}}$) [73–75], which are subsequently required to have one or three associated tracks. In order to distinguish $\tau_{\text{had-vis}}$ from quark- and gluon-initiated jets, a boosted decision tree (BDT) [76], trained separately for $\tau_{\text{had-vis}}$ with one and three charged particles, is employed. Selected $\tau_{\text{had-vis}}$ candidates must satisfy the 'medium' BDT working point. Electron candidates are identified using a likelihood technique in combination with additional track-hit requirements [77]; the transition region between the barrel and endcap calorimeters is excluded. Information from the tracking and muon systems is used to reconstruct muon candidates [78]. Only isolated electrons and muons are considered, where no nearby tracks or calorimeter energy deposits within a p_{T}-dependent variable-size ΔR cone around the lepton are allowed. Jets arising from pileup are suppressed using dedicated track and vertex requirements [79]. The missing transverse momentum, with magnitude $E_{\mathrm{T}}^{\mathrm{miss}}$, is defined as the negative vectorial sum of all reconstructed and fully calibrated objects in the event, along with an additional track-based soft term [80]. Jets containing b-hadrons are identified using the MV2c10 multivariate discriminant [81, 82] trained against a light-quark-flavor sample also containing 10% of c-hadrons. A working point with 70% efficiency on simulated $t\bar{t}$ events is used. The default ATLAS overlap-removal procedure is applied to the reconstructed electrons, muons, $\tau_{\text{had-vis}}$ and jets to prevent double-counting of energy deposits in the detector.

The selected final state is characterized by one electron or muon and one $\tau_{\text{had-vis}}$ of opposite charge, or two $\tau_{\text{had-vis}}$ of opposite charge, plus two b-tagged jets and $E_{\mathrm{T}}^{\mathrm{miss}}$. In all cases, events with additional electrons, muons or $\tau_{\text{had-vis}}$ are rejected. The offline selection criteria for the electron, muon, and $\tau_{\text{had-vis}}$ depend on the triggers used. In the $\tau_{\text{lep}}\tau_{\text{had}}$ channel events are selected with a single-lepton trigger (SLT) and a lepton

[3] ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the center of the detector and the z-axis along the beam pipe. The x-axis points to the center of the LHC ring, and the y-axis points upward. 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 $\eta = -\ln\tan(\theta/2)$. The distance between two objects in η–ϕ space is $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$. Transverse momentum is defined by $p_{\mathrm{T}} = p\sin\theta$.

plus τ_{had} trigger (LTT), which are analyzed separately and combined with the $\tau_{\text{had}}\tau_{\text{had}}$ channel in the final fit. Depending on the data period, the electron or muon that passes the SLT trigger is required to have $p_{\text{T}} > 25$–27 GeV. Events which fail this requirement are considered for the LTT category if the electron (muon) has $p_{\text{T}} > 18$ GeV (15 GeV). In all cases, these p_{T} requirements are 1 GeV higher than the trigger thresholds to ensure a nearly constant trigger efficiency relative to the offline selection. The $\tau_{\text{lep}}\tau_{\text{had}}$ events are required to have one $\tau_{\text{had-vis}}$ candidate with $|\eta| < 2.3$ and $p_{\text{T}} > 20$ GeV for SLT events, raised to 30 GeV for LTT events due to $\tau_{\text{had-vis}}$ p_{T} requirements applied in this category of triggers. In the $\tau_{\text{had}}\tau_{\text{had}}$ channel a logical OR of single τ_{had} triggers (STT) and di-τ_{had} triggers (DTT) is used. The leading $\tau_{\text{had-vis}}$ candidate is required to have a minimum p_{T} between 40 and 180 GeV, depending on the data-taking period and the trigger used. The sub-leading $\tau_{\text{had-vis}}$ is required to have a minimum p_{T} of 20 (30) GeV for STT (DTT) events. The leading jet is required to have $p_{\text{T}} > 45$ GeV, except in the LTT and DTT channels where this is raised to 80 GeV due to a requirement on the presence of a jet at the Level-1 trigger to reduce the rate (during 2016 data-taking only for the DTT). In all cases the sub-leading jet must have $p_{\text{T}} > 20$ GeV. The invariant mass of the di-τ system, $m_{\tau\tau}^{\text{MMC}}$, is calculated using the Missing Mass Calculator [83] and is required to be greater than 60 GeV. Signal region (SR) events are defined as those meeting the criteria above, and in addition containing two b-tagged jets; they are further separated into $\tau_{\text{lep}}\tau_{\text{had}}$ SLT, $\tau_{\text{lep}}\tau_{\text{had}}$ LTT and $\tau_{\text{had}}\tau_{\text{had}}$ categories.

BDTs are used in the analysis to improve the separation of signal from background. Their distributions in the three signal regions, along with control region yields to constrain the normalizations of the dominant backgrounds, form the inputs to the final fit. The BDTs for the $\tau_{\text{had}}\tau_{\text{had}}$ channel are trained against the main backgrounds, $t\bar{t}$, $Z \to \tau\tau$ and multi-jet events; in the $\tau_{\text{lep}}\tau_{\text{had}}$ channel they are trained solely against the dominant $t\bar{t}$ background. For the BDT trainings, the $t\bar{t}$ and $Z \to \tau\tau$ backgrounds are taken purely from simulation, while the multi-jet events are estimated using the data-driven approach described below. Variables which provide good discrimination and are minimally correlated are used as inputs to the BDTs, as summarized in Table 1. The variables selected in each channel differ, reflecting the different background compositions. In the resonant search, BDTs are trained separately for each signal mass considered, from 260 GeV to 1000 GeV (800 GeV for LTT), where the signal model combines the target resonance mass and its two neighboring mass points, to be sensitive to masses between the simulated points. For NR HH production, the BDTs are trained on a signal sample with the SM admixture of the contributions from the box-diagram and triangle-diagram. The BDTs are more sensitive to the box-diagram where the two Higgs bosons are produced at higher p_{T} and the selection efficiency is greater.

In both channels, simulated events are used to model background processes containing reconstructed $\tau_{\text{had-vis}}$ that are matched to generated τ_{had} within $\Delta R = 0.2$ (subsequently referred to as true-τ_{had}) and other minor background contributions. The rate of events with at least one true-τ_{had} and a jet reconstructed as an electron or muon is found to be negligible. For $t\bar{t}$ background events containing one or more true-τ_{had} the normalization is obtained in the final fit, constrained mainly by the low $\tau_{\text{lep}}\tau_{\text{had}}$ BDT score regions, resulting in a normalization factor of 1.06 ± 0.13. The normalization of the $Z \to ee/\tau\tau$+heavy-flavor background is determined using $Z \to \mu\mu$+heavy-flavor events. Their selection closely follows the event selection used for signal events. Instead of two τ-lepton candidates, two muons with $p_{\text{T}} > 27$ GeV and dimuon invariant mass between 81 and 101 GeV are selected. To remove the contribution from SM $ZH(H \to bb)$ production, m_{bb} is required to be lower than 80 GeV or greater than 140 GeV. The normalization is determined by including the $Z \to \mu\mu$+heavy-flavor control region yield in the final fit, resulting in a normalization factor of 1.34 ± 0.16. Normalization factors are not applied to the Z+light-flavor contributions. The modeling

Table 1: Variables used as inputs to the BDTs for the different channels and signal models. Here, m_{HH} is reconstructed from the $\tau\tau$ and bb systems using a 125 GeV Higgs mass constraint; m_{bb} is the invariant bb-mass; $\Delta R(\tau,\tau)$ is evaluated between the electron or muon and $\tau_{\text{had-vis}}$ (two $\tau_{\text{had-vis}}$) in the case of the $\tau_{\text{lep}}\tau_{\text{had}}$ ($\tau_{\text{had}}\tau_{\text{had}}$) channel; $E_{\text{T}}^{\text{miss}}\phi$ centrality quantifies the relative angular position of the $E_{\text{T}}^{\text{miss}}$ relative to the visible τ decay products in the transverse plane [84] and is defined as $(A+B)/(\sqrt{A^2+B^2})$, where $A = \sin(\phi_{E_{\text{T}}^{\text{miss}}} - \phi_{\tau_2})/\sin(\phi_{\tau_1} - \phi_{\tau_2})$, $B = \sin(\phi_{\tau_1} - \phi_{E_{\text{T}}^{\text{miss}}})/\sin(\phi_{\tau_1} - \phi_{\tau_2})$, and τ_1 and τ_2 stand for electron or muon and $\tau_{\text{had-vis}}$ (two $\tau_{\text{had-vis}}$) in the case of the $\tau_{\text{lep}}\tau_{\text{had}}$ ($\tau_{\text{had}}\tau_{\text{had}}$) channel; m_{T}^{W} is the transverse mass of the lepton and the $E_{\text{T}}^{\text{miss}}$; $\Delta\phi(H,H)$ is the azimuthal angle between the two Higgs boson candidates; $\Delta p_{\text{T}}(\text{lep}, \tau_{\text{had-vis}})$ is the difference in p_{T} between the electron or muon and $\tau_{\text{had-vis}}$.

Variable	$\tau_{\text{lep}}\tau_{\text{had}}$ channel (SLT resonant)	$\tau_{\text{lep}}\tau_{\text{had}}$ channel (SLT non-resonant & LTT)	$\tau_{\text{had}}\tau_{\text{had}}$ channel
m_{HH}	✓	✓	✓
$m_{\tau\tau}^{\text{MMC}}$	✓	✓	✓
m_{bb}	✓	✓	✓
$\Delta R(\tau,\tau)$	✓	✓	✓
$\Delta R(b,b)$	✓	✓	✓
$E_{\text{T}}^{\text{miss}}$	✓		
$E_{\text{T}}^{\text{miss}}\phi$ centrality	✓		✓
m_{T}^{W}	✓	✓	
$\Delta\phi(H,H)$	✓		
$\Delta p_{\text{T}}(\text{lep}, \tau_{\text{had-vis}})$	✓		
Sub-leading b-jet p_{T}	✓		

of the BDT score distributions is validated in the 0-b-tag and 1-b-tag regions as well as in dedicated $t\bar{t}$ and Z+heavy-flavor validation regions.

Contributions from processes in which a quark- or gluon-initiated jet is misidentified as a $\tau_{\text{had-vis}}$ candidate (fake-τ_{had}) are estimated using data-driven methods for major backgrounds. A fake-τ_{had} enriched sample is defined by requiring that a $\tau_{\text{had-vis}}$ fails the 'medium' BDT identification but satisfies a very loose requirement on the BDT score. This selection maintains a composition of quark- and gluon-initiated jets similar to those mimicking $\tau_{\text{had-vis}}$ in the SR. In the case where the event contains more than one such fake-τ_{had}, one is chosen randomly. The SR selection, except for the $\tau_{\text{had-vis}}$ identification, is applied to the fake-τ_{had} enriched sample to extract template distributions for the fake-τ_{had} background after the true-τ_{had} contamination is subtracted using simulation. The templates are scaled with fake-factors (FF) defined as the ratio of the number of fake-τ_{had} that pass the $\tau_{\text{had-vis}}$ identification to the number that fail, calculated in dedicated control regions (CR) and parametrized in p_{T} ($\tau_{\text{had-vis}}$) and the number of associated tracks.

For the $\tau_{\text{lep}}\tau_{\text{had}}$ final state, fake-τ_{had} background contributions from $t\bar{t}$, W+jets and multi-jet processes are estimated using a combined fake-factor method similar to that described in Ref. [85] [4]. In order to account for the different sources of fake-τ_{had}, the FFs are derived separately for each background contribution. The CR for multi-jet events is defined by inverting the isolation requirement applied to

[4] The fake-τ_{had} contribution of the $t\bar{t}$ background is estimated using simulated events when training the BDTs and using the fake-factor method elsewhere.

the electron or muon for events with 0 or 1 b-tagged jet. The $t\bar{t}$ (W+jets) control region is defined by requiring two (zero) b-tagged jets and $m_{\mathrm{T}}^{W} > 40$ GeV, where $m_{\mathrm{T}}^{W} = \sqrt{2p_{\mathrm{T}}^{\mathrm{lep}}E_{\mathrm{T}}^{\mathrm{miss}}(1-\cos\Delta\phi_{\mathrm{lep},E_{\mathrm{T}}^{\mathrm{miss}}})}$, and $\Delta\phi_{\mathrm{lep},E_{\mathrm{T}}^{\mathrm{miss}}}$ is the azimuthal angle between the electron or muon and the $E_{\mathrm{T}}^{\mathrm{miss}}$. Fake-factors for $t\bar{t}$ and W+jets are found to be consistent for both processes. The individual fake-factors are then combined as $\mathrm{FF(comb)} = \mathrm{FF(QCD)} \times r_{\mathrm{QCD}} + \mathrm{FF}(t\bar{t}/W + \mathrm{jets}) \times (1 - r_{\mathrm{QCD}})$, where r_{QCD} is defined as the fraction of fake-τ_{had} from (predominantly multi-jet) processes contributing to the data in the fake-τ_{had} enriched template region that are not accounted for by simulated background processes, and is less than 5% in the 2-b-tag region. Due to the different origin of fake-τ_{had}, the FFs for $t\bar{t}/W$+jets can be up to 30% larger than those for multi-jet processes. Events with two b-tagged jets but a same-sign charge (SS) electron or muon and $\tau_{\mathrm{had\text{-}vis}}$ are used for validating the fake-τ_{had} background, showing all distributions are well modeled. Given this, and the small size of the contribution, no transfer factor is applied to correct the multi-jet estimation from the 1-b-tag region to the 2-b-tag region.

In the $\tau_{\mathrm{had}}\tau_{\mathrm{had}}$ final state, only the multi-jet background is estimated from data using the FF method. The differential FFs are derived in a 1-b-tag SS control region, while the overall normalization is taken from the 2-b-tag SS control region. The $t\bar{t}$ background is estimated from simulation, where the fake-τ_{had} $t\bar{t}$ contribution is corrected in bins of $\eta(\tau_{\mathrm{had\text{-}vis}})$ using the probability for a jet from a hadronic W-boson decay to mimic a $\tau_{\mathrm{had\text{-}vis}}$ candidate (fake-rate), as measured with data in the $\tau_{\mathrm{lep}}\tau_{\mathrm{had}}$ $t\bar{t}$ control region [85]. Contributions from true-τ_{had} are subtracted using simulation.

The uncertainty in the integrated luminosity of the combined 2015+2016 dataset is 2.1% [86] and is applied to the signal and background components whose normalizations are derived from simulation. An uncertainty related to the pileup reweighting procedure is also applied [87]. Experimental uncertainties in the identification and reconstruction of the electron [88], muon [89], $\tau_{\mathrm{had\text{-}vis}}$ [73], and jets [71, 90] are accounted for and propagated through the analysis to determine their effect on the final results. These affect the trigger requirements, the identification and reconstruction efficiencies, the isolation, and the reconstructed energies and their resolutions. The uncertainties are propagated to the calculation of the $E_{\mathrm{T}}^{\mathrm{miss}}$ [80], which has an additional uncertainty from the soft term. The uncertainties with the largest impact on the result are those related to the $\tau_{\mathrm{had\text{-}vis}}$ identification efficiency, which correspond to an uncertainty of 16% on the NR signal strength, i.e. the simulated NR HH yield assuming a cross-section times branching fraction equal to the expected limit and normalized to the SM expectation ($\sigma^{\mathrm{exp}}/\sigma^{\mathrm{SM}}$). Uncertainties in flavor-tagging [91, 92] also have a significant impact, inducing an uncertainty in the NR signal strength of 8.3%, dominated by those associated with the b-tagging efficiency.

Theory uncertainties in the modeling of the $t\bar{t}$ background containing one or more true-τ_{had} are assessed by varying the matrix element generator (using aMC@NLO instead of Powheg-Box) and the parton shower model (using Herwig++ instead of Pythia 6), and by adjusting the factorization and renormalization scales along with the amount of additional radiation. The resulting variations in the BDT distributions are included as shape uncertainties in the final fit. In order to account for potential acceptance differences between CRs and SRs, the normalization of the $t\bar{t}$ background containing true-τ_{had}, determined predominantly from the $\tau_{\mathrm{lep}}\tau_{\mathrm{had}}$ SR in the final fit, is allowed to vary within a range determined by the acceptance variations associated with the $t\bar{t}$ modeling uncertainties. This amounts to +30/−32% for the $\tau_{\mathrm{had}}\tau_{\mathrm{had}}$ SR and and +8.1%/−9.3% for the $Z \to \mu\mu$+heavy-flavor control region. This is the dominant uncertainty in the $t\bar{t}$ modeling.

For the Z+jets background, the theory uncertainties in the modeling of the BDT shapes are derived by comparing the nominal Sherpa sample with an alternative MadGraph5_aMC@NLO + Pythia 8 sample and by varying the choice of renormalization and factorization scales, along with the PDF prescription [93]. The normalization of the $Z \rightarrow \tau\tau$+heavy-flavor background in the $\tau_{\text{lep}}\tau_{\text{had}}$ ($\tau_{\text{had}}\tau_{\text{had}}$) SR is allowed to vary by 29% (35%) relative to the normalization derived in the $Z \rightarrow \mu\mu$+heavy-flavor control region in order to account for acceptance differences between the two. An additional 20% normalization uncertainty in the $Z \rightarrow ee$+light-flavor background, related to the misidentification of electrons as taus, is derived by comparing data and simulation in a $Z \rightarrow ee$ control region with 0 or 1 b-tagged jets. The ZH (ttH) background normalization is varied by 28% (30%) based on ATLAS measurements [94, 95]. The normalizations of the remaining minor backgrounds taken from simulation are allowed to vary within their respective cross-section uncertainties.

The uncertainty in the modeling of backgrounds due to jets being misidentified as $\tau_{\text{had-vis}}$ is estimated by varying the fake-factors and fake-rates within their statistical uncertainties and varying the amount of true-τ_{had} background subtracted. Based on studies with simulated $t\bar{t}$ and W+jets events, a systematic uncertainty is assigned to cover the difference in the gluon and quark flavor composition of jets misidentified as a $\tau_{\text{had-vis}}$ between the signal region and the fake-τ_{had} enriched sample, parametrized as a function of the $\tau_{\text{had-vis}}$ identification BDT score. The uncertainty in the extrapolation of FF(QCD) to the signal region is estimated from the difference between the nominal FFs and alternative ones, calculated either in the SS region for the $\tau_{\text{lep}}\tau_{\text{had}}$ channel or a multi-jet enriched region, where $\Delta\phi(\tau_{\text{had-vis}}, \tau_{\text{had-vis}}) > 2.0$, in the $\tau_{\text{had}}\tau_{\text{had}}$ case. Similarly, changes in the fake-τ_{had} determination when varying the $t\bar{t}$ control region m_{T}^{W} requirement in simulation and data are used to estimate a systematic uncertainty in both the fake-factors and fake-rates. The overall effect of these uncertainties on the fake-τ_{had} background estimate leads to an 8.4% variation of the NR signal strength, predominantly due to the true-τ_{had} subtraction in the $t\bar{t}$ control region and the composition of the fake-τ_{had}.

Theory uncertainties in the signal acceptance are calculated by independently varying the renormalization and factorization scales, the choice of PDF and each PDF set by its uncertainties. The uncertainty in the parton shower is taken into account by comparing the default Herwig++ with Pythia 8. Uncertainties in the underlying event, initial-state radiation and final-state radiation are accounted for by changing the Pythia tune, but are small. The effects of various categories of uncertainty on the measured non-resonant signal strength corresponding to the expected upper limit at 95% CL are summarized in Table 2. The individual sources of uncertainty making up the categories listed in the table are grouped together in the final fit to determine their correlated combined effect on the signal strength. For all signal hypotheses, the statistical uncertainties dominate.

For each signal model considered, a profile-likelihood fit [96] is applied to the BDT score distributions simultaneously in the three SRs to extract the signal cross-section, along with the $t\bar{t}$ and Z+heavy-flavor normalizations. The lattermost is constrained by including the dedicated control region in the fit. All sources of systematic and statistical uncertainty in the signal and background model are implemented as deviations from the nominal model, scaled by nuisance parameters that are profiled in the fit. None of the dominant nuisance parameters are significantly constrained or pulled relative to their input value by the fit. The BDT score distributions for the non-resonant search and the G_{KK} signal are shown in Figure 1 after performing the fit and assuming a background-only hypothesis. The acceptance times efficiency for the NR HH signal is 4.2% (2.9%) in the combined SLT and LTT $\tau_{\text{lep}}\tau_{\text{had}}$ ($\tau_{\text{had}}\tau_{\text{had}}$) channel over the full BDT

Source	Uncertainty (%)
Total	± 54
Data statistics	± 44
Simulation statistics	± 16
Experimental Uncertainties	
Luminosity	± 2.4
Pileup reweighting	± 1.7
τ_{had}	± 16
Fake-τ estimation	± 8.4
b-tagging	± 8.3
Jets and $E_{\mathrm{T}}^{\mathrm{miss}}$	± 3.3
Electron and muon	± 0.5
Theoretical and Modeling Uncertainties	
Top	± 17
Signal	± 9.3
$Z \to \tau\tau$	± 6.8
SM Higgs	± 2.9
Other backgrounds	± 0.3

Table 2: The percentage uncertainties on the simulated non-resonant signal strength, i.e. the simulated NR HH yield assuming a cross-section times branching fraction equal to the 95% CL expected limit of 14.8 times the SM expectation.

Table 3: Observed and expected upper limits on the production cross-section times the $HH \to bb\tau\tau$ branching ratio for NR HH at 95% CL, and their ratios to the SM prediction. The $\pm 1\sigma$ variations about the expected limit are also shown.

		Observed	-1σ	Expected	$+1\sigma$
$\tau_{\mathrm{lep}}\tau_{\mathrm{had}}$	$\sigma(HH \to bb\tau\tau)$ [fb]	57	49.9	69	96
	$\sigma/\sigma_{\mathrm{SM}}$	23.5	20.5	28.4	39.5
$\tau_{\mathrm{had}}\tau_{\mathrm{had}}$	$\sigma(HH \to bb\tau\tau)$ [fb]	40.0	30.6	42.4	59
	$\sigma/\sigma_{\mathrm{SM}}$	16.4	12.5	17.4	24.2
Combination	$\sigma(HH \to bb\tau\tau)$ [fb]	30.9	26.0	36.1	50
	$\sigma/\sigma_{\mathrm{SM}}$	12.7	10.7	14.8	20.6

distribution, decreasing to 3.3% (2.4%) for the two most sensitive BDT bins. As no significant excess over the expected background is observed, upper limits are set on non-resonant and resonant Higgs boson pair production at 95% CL using the CL_{s} method [97].

Table 3 presents the upper limits on the cross-section for non-resonant HH production times the $HH \to bb\tau\tau$ branching ratio, and comparisons with the SM prediction. The observed (expected) limit is 30.9 fb (36.0 fb), 12.7 (14.8) times the SM prediction. In order to compare with previous results, the BDTs are trained and applied to the signal sample without reweighting the m_{HH} spectrum to Refs. [9, 31], giving an observed (expected) limit of 37.4 fb (33.5 fb), 15.4 (13.8) times the SM prediction.

The results of searches for resonant HH production are presented as exclusion limits on the cross-section times the $HH \to bb\tau\tau$ branching ratio as a function of the resonance mass. The expected and observed

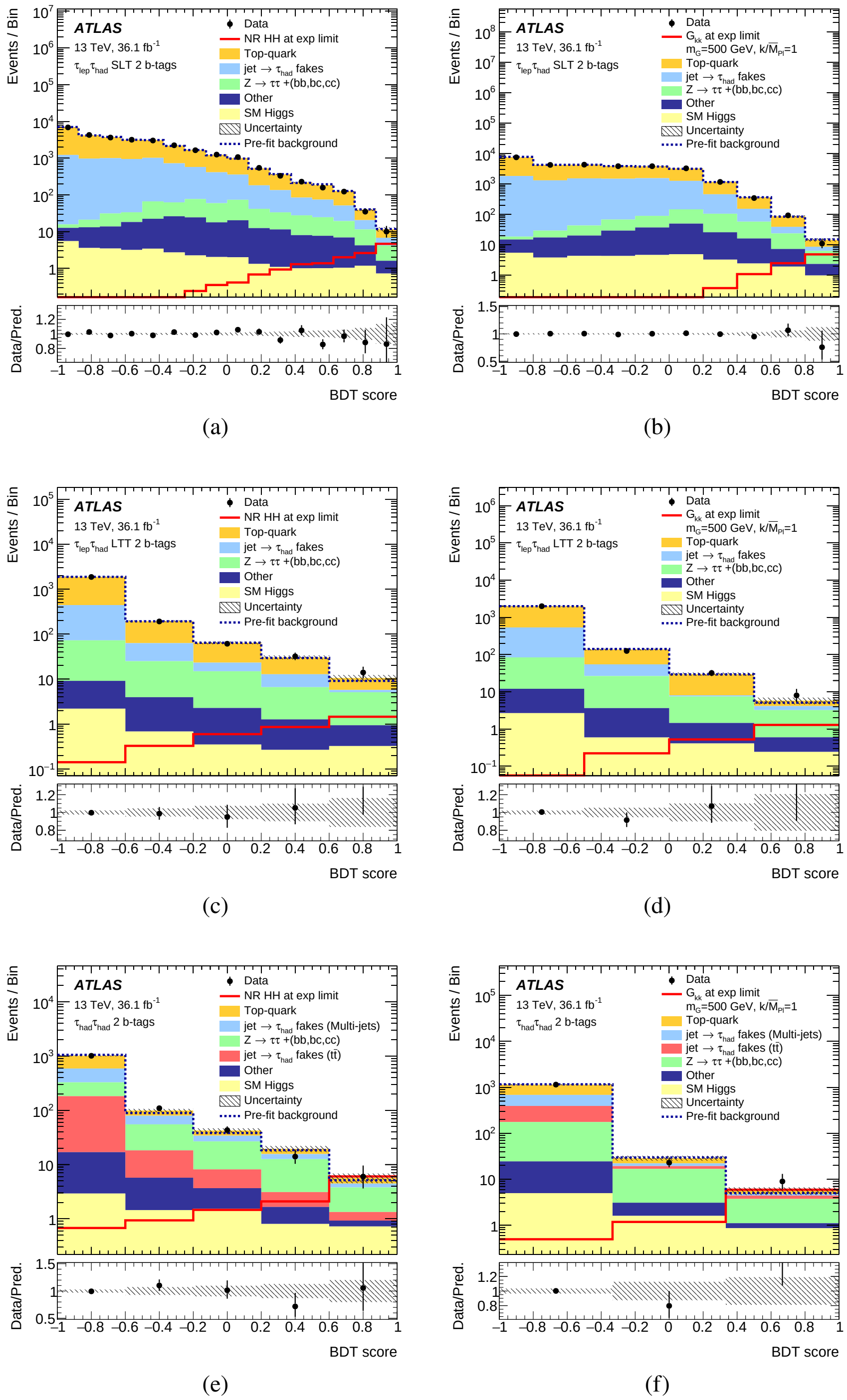

Figure 1: Distributions of the BDT score for NR HH signal (left) and bulk RS signal with $m_{G_{\mathrm{KK}}} = 500$ GeV and $k/\overline{M}_{\mathrm{Pl}} = 1$ (right) in the (a, b) $\tau_{\mathrm{lep}}\tau_{\mathrm{had}}$ single-lepton trigger (SLT), (c, d) lepton + τ_{had} trigger (LTT) and (e, f) $\tau_{\mathrm{had}}\tau_{\mathrm{had}}$ channels. Distributions are shown after the fit to the background-only hypothesis and the signal is scaled to approximately the expected limit. The hatched band indicates the combined statistical and systematic uncertainty in the background. The ratio of the data to the sum of the backgrounds is shown in the lower panel.

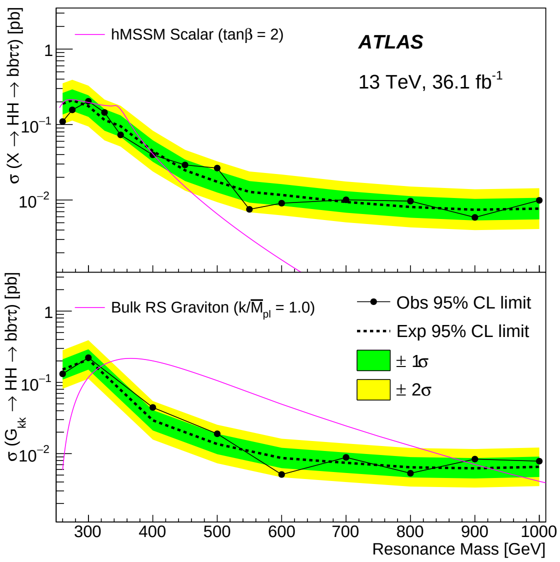

Figure 2: Observed and expected limits at 95% CL on the cross-sections of a generic narrow-width scalar X (top) and RS G_{KK} (bottom) times the branching fraction to two CP-even Higgs bosons H, when combining the $\tau_{\mathrm{lep}}\tau_{\mathrm{had}}$ and $\tau_{\mathrm{had}}\tau_{\mathrm{had}}$ channels. The expected cross-section for the hMSSM scalar X production and the bulk RS graviton production with $k/\overline{M}_{\mathrm{Pl}} = 1.0$ are also shown in the respective plots. In the hMSSM case, the bump in the theory prediction around 350 GeV corresponds to the threshold for X decaying into $t\bar{t}$ pairs.

limits for narrow-width scalar resonances X and G_{KK} signal models are shown in Figure 2. For scalar resonances, the results are interpreted in a simplified minimal supersymmetric model, the hMSSM [98, 99], where the mass of the light CP-even Higgs boson is fixed to 125 GeV. The mass range 305 GeV < m_X < 402 GeV is excluded at 95% CL for $\tan\beta = 2$, where $\tan\beta$ is the ratio of the vacuum expectation values of the scalar doublets. Gravitons are excluded at 95% CL in the mass range 325 GeV < $m_{G_{\mathrm{KK}}}$ < 885 GeV assuming $k/\overline{M}_{\mathrm{Pl}} = 1$. Above $\sim$ 600 GeV, the limits are largely insensitive to the value of $k/\overline{M}_{\mathrm{Pl}}$, while at low m_{HH} they improve significantly with increasing k due to the larger natural width. The limits on resonant HH are significantly more stringent than previous results in the $bb\tau\tau$ channel and competitive with limits obtained in other channels.

In summary, a search for resonant and non-resonant Higgs boson pair production in the $bb\tau\tau$ final state is conducted with 36.1 fb^{-1} of pp collision data delivered by the LHC at $\sqrt{s}$ = 13 TeV and recorded by the ATLAS detector. The analysis of non-resonant Higgs pair production excludes an enhancement of the SM expectation by more than a factor of 12.7 at 95% CL. This is the most stringent limit on HH production to date. Upper limits are set on resonant Higgs boson pair production for a narrow-width scalar X and a spin-2 Kaluza–Klein graviton G_{KK} in the bulk RS model.

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References

[1] ATLAS Collaboration, *Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC*, Phys. Lett. B **716** (2012) 1, arXiv: 1207.7214 [hep-ex].

[2] CMS Collaboration, *Observation of a new boson with mass near* 125 *GeV in pp collisions at* $\sqrt{s} = 7$ *and* 8 *TeV*, JHEP **06** (2013) 081, arXiv: 1303.4571 [hep-ex].

[3] ATLAS and CMS Collaborations, *Combined Measurement of the Higgs Boson Mass in pp Collisions at* $\sqrt{s}$*=7 and 8 TeV with the ATLAS and CMS Experiments*, Phys. Rev. Lett. **114** (2015) 191803, arXiv: 1503.07589 [hep-ex].

[4] F. Englert and R. Brout, *Broken Symmetry and the Mass of Gauge Vector Mesons*, Phys. Rev. Lett. **13** (1964) 321.

[5] P. W. Higgs, *Broken Symmetries and the Masses of Gauge Bosons*, Phys. Rev. Lett. **13** (1964) 508.

[6] G. S. Guralnik, C. R. Hagen, and T. W. B. Kibble, *Global Conservation Laws and Massless Particles*, Phys. Rev. Lett. **13** (1964) 585.

[7] P. W. Higgs, *Spontaneous Symmetry Breakdown without Massless Bosons*, Phys. Rev. **145** (1966) 1156.

[8] T. W. B. Kibble, *Symmetry Breaking in Non-Abelian Gauge Theories*, Phys. Rev. **155** (1967) 1554.

[9] S. Borowka et al., *Higgs Boson Pair Production in Gluon Fusion at Next-to-Leading Order with Full Top-Quark Mass Dependence*, Phys. Rev. Lett. **117** (2016) 012001, [Erratum: Phys. Rev. Lett. 117 (2016) 079901], arXiv: 1604.06447 [hep-ph].

[10] 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].

[11] G. Branco et al., *Theory and phenomenology of two-Higgs-doublet models*, Phys. Rept. **516** (2012) 1, arXiv: 1106.0034 [hep-ph].

[12] L. Randall and R. Sundrum, *A Large Mass hierarchy from a Small Extra Dimension*, Phys. Rev. Lett. **83** (1999) 3370, arXiv: hep-ph/9905221.

[13] K. Agashe, H. Davoudiasl, G. Perez, and A. Soni, *Warped gravitons at the CERN LHC and beyond*, Phys. Rev. D **76** (2007) 036006, arXiv: hep-ph/0701186.

[14] A. L. Fitzpatrick, J. Kaplan, L. Randall, and L.-T. Wang, *Searching for the Kaluza-Klein graviton in bulk RS Models*, JHEP **09** (2007) 013, arXiv: hep-ph/0701150.

[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*, CERN-LHCC-2010-013, ATLAS-TDR-19, 2010, URL: https://cds.cern.ch/record/1291633.

[17] ATLAS Collaboration, *Searches for Higgs boson pair production in the $hh \to bb\tau\tau$, $\gamma\gamma WW^*$, $\gamma\gamma bb$, $bbbb$ channels with the ATLAS detector*, Phys. Rev. D **92** (2015) 092004, arXiv: 1509.04670 [hep-ex].

[18] ATLAS Collaboration, *Search for Higgs boson pair production in the $b\bar{b}b\bar{b}$ final state from pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector*, Eur. Phys. J. C **75** (2015) 412, arXiv: 1506.00285 [hep-ex].

[19] ATLAS Collaboration, *Search For Higgs Boson Pair Production in the $\gamma\gamma b\bar{b}$ Final State using pp Collision Data at $\sqrt{s} = 8$ TeV from the ATLAS Detector*, Phys. Rev. Lett. **114** (2015) 081802, arXiv: 1406.5053 [hep-ex].

[20] ATLAS Collaboration, *Search for pair production of Higgs bosons in the $b\bar{b}b\bar{b}$ final state using proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, (2018), arXiv: 1804.06174 [hep-ex].

[21] CMS Collaboration, *Search for Higgs boson pair production in events with two bottom quarks and two tau leptons in proton–proton collisions at $\sqrt{s}$ =13TeV*, Phys. Lett. B **778** (2018) 101, arXiv: 1707.02909 [hep-ex].

[22] CMS Collaboration, *Search for a massive resonance decaying to a pair of Higgs bosons in the four b quark final state in proton-proton collisions at $\sqrt{s}$ = 13 TeV*, Phys. Lett. B **781** (2018) 244, arXiv: 1710.04960 [hep-ex].

[23] 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].

[24] R. Frederix et al., *Higgs pair production at the LHC with NLO and parton-shower effects*, Phys. Lett. B **732** (2014) 142, arXiv: 1401.7340 [hep-ph].

[25] S. Dawson, S. Dittmaier, and M. Spira, *Neutral Higgs-boson pair production at hadron colliders: QCD corrections*, Phys. Rev. D **58** (1998) 115012, arXiv: hep-ph/9805244 [hep-ph].

[26] T. Plehn, M. Spira, and P. M. Zerwas, *Pair production of neutral Higgs particles in gluon-gluon collisions*, Nucl. Phys. B **479** (1996) 46, [Erratum: Nucl. Phys.B 531 (1998) 655], arXiv: hep-ph/9603205.

[27] R. Grober, M. Muhlleitner, M. Spira, and J. Streicher, *NLO QCD corrections to Higgs pair production including dimension-6 operators*, JHEP **09** (2015) 092, arXiv: 1504.06577 [hep-ph].

[28] H.-L. Lai et al., *New parton distributions for collider physics*, Phys. Rev. D **82** (2010) 074024, arXiv: 1007.2241 [hep-ph].

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

[30] S. Gieseke, C. Rohr, and A. Siodmok, *Colour reconnections in Herwig++*, Eur. Phys. J. C **72** (2012) 2225, arXiv: 1206.0041 [hep-ph].

[31] S. Borowka et al., *Full top quark mass dependence in Higgs boson pair production at NLO*, JHEP **10** (2016) 107, arXiv: 1608.04798 [hep-ph].

[32] S. Borowka et al., *Higgs Boson Pair Production in Gluon Fusion at Next-to-Leading Order with Full Top-Quark Mass Dependence*, Phys. Rev. Lett. **117** (2016) 012001, [Erratum: Phys. Rev. Lett.117,no.7,079901(2016)], arXiv: 1604.06447 [hep-ph].

[33] T. Sjöstrand, S. Mrenna and P. Skands, *A brief introduction to PYTHIA 8.1*, Comput. Phys. Commun. **178** (2008) 852, arXiv: 0710.3820 [hep-ph].

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

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

[36] A. Oliveira, *Gravity particles from Warped Extra Dimensions, predictions for LHC*, (2014), arXiv: 1404.0102 [hep-ph].

[37] 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].

[38] P. Artoisenet, R. Frederix, O. Mattelaer, and R. Rietkerk, *Automatic spin-entangled decays of heavy resonances in Monte Carlo simulations*, JHEP **03** (2013) 015, arXiv: 1212.3460 [hep-ph].

[39] T. Sjöstrand, S. Mrenna and P. Skands, *PYTHIA 6.4 physics and manual*, JHEP **05** (2006) 026, arXiv: hep-ph/0603175.

[40] P. Skands, *Tuning Monte Carlo generators: The Perugia tunes*, Phys. Rev. D **82** (2010) 074018, arXiv: 1005.3457 [hep-ph].

[41] M. Czakon, M. L. Mangano, A. Mitov, and J. Rojo, *Constraints on the gluon PDF from top quark pair production at hadron colliders*, JHEP **07** (2013) 167, arXiv: 1303.7215 [hep-ph].

[42] M. Aliev, H. Lacker, U. Langenfeld, S. Moch, P. Uwer, et al., *HATHOR: HAdronic Top and Heavy quarks crOss section calculatoR*, Comput. Phys. Commun. **182** (2011) 1034, arXiv: 1007.1327 [hep-ph].

[43] P. Kant et al., *HatHor for single top-quark production: Updated predictions and uncertainty estimates for single top-quark production in hadronic collisions*, Comput. Phys. Commun. **191** (2015) 74, arXiv: 1406.4403 [hep-ph].

[44] N. Kidonakis, *Two-loop soft anomalous dimensions for single top quark associated production with a W^- or H^-*, Phys. Rev. D **82** (2010) 054018, arXiv: 1005.4451 [hep-ph].

[45] T. Gleisberg et al., *Event generation with SHERPA 1.1*, JHEP **02** (2009) 007, arXiv: 0811.4622 [hep-ph].

[46] T. Gleisberg and S. Höche, *Comix, a new matrix element generator*, JHEP **12** (2008) 039, arXiv: 0808.3674 [hep-ph].

[47] F. Cascioli, P. Maierhofer, and S. Pozzorini, *Scattering Amplitudes with Open Loops*, Phys. Rev. Lett. **108** (2012) 111601, arXiv: 1111.5206 [hep-ph].

[48] S. Schumann and F. Krauss, *A Parton shower algorithm based on Catani-Seymour dipole factorisation*, JHEP **03** (2008) 038, arXiv: 0709.1027 [hep-ph].

[49] S. Höche, F. Krauss, M. Schönherr, and F. Siegert, *QCD matrix elements + parton showers: The NLO case*, JHEP **04** (2013) 027, arXiv: 1207.5030 [hep-ph].

[50] NNPDF Collaboration, *Parton distributions for the LHC Run II*, (2014), arXiv: 1410.8849 [hep-ph].

[51] C. Anastasiou, L. J. Dixon, K. Melnikov, and F. Petriello, *High precision QCD at hadron colliders: Electroweak gauge boson rapidity distributions at NNLO*, Phys. Rev. D **69** (2004) 094008, arXiv: hep-ph/0312266.

[52] M. L. Ciccolini, S. Dittmaier, and M. Krämer, *Electroweak radiative corrections to associated WH and ZH production at hadron colliders*, Phys. Rev. D **68** (2003) 073003, arXiv: hep-ph/0306234.

[53] O. Brein, A. Djouadi, and R. V. Harlander, *NNLO QCD corrections to the Higgs-strahlung processes at hadron colliders*, Phys. Lett. B **579** (2004) 149, arXiv: hep-ph/0307206.

[54] G. Ferrera, M. Grazzini, and F. Tramontano, *Associated Higgs-W-Bosons production at hadron colliders: A Fully Exclusive QCD Calculation at NNLO*, Phys. Rev. Lett. **107** (2011) 152003, arXiv: 1107.1164 [hep-ph].

[55] O. Brein, R. V. Harlander, M. Wiesemann, and T. Zirke, *Top-quark mediated effects in hadronic Higgs-Strahlung*, Eur. Phys. J. C **72** (2012) 1868, arXiv: 1111.0761 [hep-ph].

[56] G. Ferrera, M. Grazzini, and F. Tramontano, *Higher-order QCD effects for associated WH production and decay at the LHC*, JHEP **04** (2014) 039, arXiv: 1312.1669 [hep-ph].

[57] G. Ferrera, M. Grazzini, and F. Tramontano, *Associated ZH production at hadron colliders: the fully differential NNLO QCD calculation*, Phys. Lett. B **740** (2015) 51, arXiv: 1407.4747 [hep-ph].

[58] J. M. Campbell, R. K. Ellis, and C. Williams, *Associated production of a Higgs boson at NNLO*, JHEP **06** (2016) 179, arXiv: 1601.00658 [hep-ph].

[59] S. Alioli, P. Nason, C. Oleari, and E. Re, *NLO Higgs boson production via gluon fusion matched with shower in POWHEG*, JHEP **04** (2009) 002, arXiv: 0812.0578 [hep-ph].

[60] ATLAS Collaboration, *Measurement of the Z/γ^* boson transverse momentum distribution in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector*, JHEP **09** (2014) 145, arXiv: 1406.3660 [hep-ex].

[61] L. Altenkamp, S. Dittmaier, R. V. Harlander, H. Rzehak, and T. Zirke, *Gluon-induced Higgs-strahlung at next-to-leading order QCD*, JHEP **02** (2013) 078, arXiv: 1211.5015 [hep-ph].

[62] B. Hespel, F. Maltoni, and E. Vryonidou, *Higgs and Z boson associated production via gluon fusion in the SM and the 2HDM*, JHEP **06** (2015) 065, arXiv: 1503.01656 [hep-ph].

[63] R. V. Harlander, A. Kulesza, V. Theeuwes, and T. Zirke, *Soft gluon resummation for gluon-induced Higgs Strahlung*, JHEP **11** (2014) 082, arXiv: 1410.0217 [hep-ph].

[64] R. V. Harlander, S. Liebler, and T. Zirke, *Higgs Strahlung at the Large Hadron Collider in the 2-Higgs-doublet model*, JHEP **02** (2014) 023, arXiv: 1307.8122 [hep-ph].

[65] O. Brein, R. V. Harlander, and T. J. E. Zirke, *vh@nnlo - Higgs Strahlung at hadron colliders*, Comput. Phys. Commun. **184** (2013) 998, arXiv: 1210.5347 [hep-ph].

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

[67] S. Agostinelli et al., *GEANT4 - a simulation toolkit*, Nucl. Instrum. Meth. A **506** (2003) 250.

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

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

[70] ATLAS Collaboraion, *Topological cell clustering in the ATLAS calorimeters and its performance in LHC Run 1*, Eur. Phys. J. C **77** (2017) 490, arXiv: 1603.02934 [hep-ex].

[71] 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].

[72] ATLAS Collaboration, *Tagging and suppression of pileup jets with the ATLAS detector*, ATLAS-CONF-2014-018, 2014, URL: https://cds.cern.ch/record/1700870.

[73] ATLAS Collaboration, *Measurement of the tau lepton reconstruction and identification performance in the ATLAS experiment using pp collisions at $\sqrt{s} = 13$ TeV*, ATLAS-CONF-2017-029, 2017, URL: https://cds.cern.ch/record/2261772.

[74] ATLAS Collaboration, *Reconstruction, Energy Calibration, and Identification of Hadronically Decaying Tau Leptons in the ATLAS Experiment for Run-2 of the LHC*, ATL-PHYS-PUB-2015-045, 2015, URL: https://cds.cern.ch/record/2064383.

[75] ATLAS Collaboration, *Identification and energy calibration of hadronically decaying tau leptons with the ATLAS experiment in pp collisions at $\sqrt{s}$=8 TeV*, Eur. Phys. J. C **75** (2015) 303, arXiv: 1412.7086 [hep-ex].

[76] A. Hoecker et al., *TMVA: Toolkit for Multivariate Data Analysis*, PoS **ACAT** (2007) 040, arXiv: physics/0703039 [physics.data-an].

[77] 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.

[78] 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].

[79] 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].

[80] ATLAS Collaboration, *Performance of missing transverse momentum reconstruction with the ATLAS detector using proton-proton collisions at $\sqrt{s} = 13$ TeV*, (2018), arXiv: 1802.08168 [hep-ex].

[81] ATLAS Collaboration, *Performance of b-Jet Identification in the ATLAS Experiment*, JINST **11** (2016) P04008, arXiv: 1512.01094 [hep-ex].

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

[83] A. Elagin, P. Murat, A. Pranko, and A. Safonov, *A new mass reconstruction technique for resonances decaying to $\tau\tau$*, Nucl. Instrum. Meth. A **654** (2011) 481, arXiv: 1012.4686 [hep-ex].

[84] ATLAS Collaboration, *Evidence for the Higgs-boson Yukawa coupling to tau leptons with the ATLAS detector*, JHEP **04** (2015) 117, arXiv: 1501.04943 [hep-ex].

[85] A. Collaboration, *Search for additional heavy neutral Higgs and gauge bosons in the ditau final state produced in 36 fb^{-1} of pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, JHEP **01** (2018) 055, arXiv: 1709.07242 [hep-ex].

[86] ATLAS Collaboration, *Luminosity determination in pp collisions at $\sqrt{s} = 8$ TeV using the ATLAS detector at the LHC*, Eur. Phys. J. C **76** (2016) 653, arXiv: 1608.03953 [hep-ex].

[87] ATLAS Collaboration, *Measurement of the Inelastic Proton-Proton Cross Section at $\sqrt{s} = 13$ TeV with the ATLAS Detector at the LHC*, Phys. Rev. Lett. **117** (2016) 182002, arXiv: 1606.02625 [hep-ex].

[88] ATLAS Collaboration, *Electron identification measurements in ATLAS using $\sqrt{s} = 13$ TeV data with 50 ns bunch spacing*, ATLAS-PHYS-PUB-2015-041, 2015, URL: https://cds.cern.ch/record/2048202.

[89] ATLAS Collaboration, *Muon reconstruction performance in early 13 TeV data*, ATLAS-PHYS-PUB-2015-037, 2015, URL: https://cds.cern.ch/record/2047831.

[90] ATLAS Collaboration, *Jet Calibration and Systematic Uncertainties for Jets Reconstructed in the ATLAS Detector at $\sqrt{s} = 13$ TeV*, ATLAS-PHYS-PUB-2015-015, 2015, URL: https://cds.cern.ch/record/2037613.

[91] ATLAS Collaboration, *Expected performance of the ATLAS b-tagging algorithms in Run-2*, ATLAS-PHYS-PUB-2015-022, 2015, URL: https://cds.cern.ch/record/2037697.

[92] ATLAS Collaboration, *Commissioning of the ATLAS b-tagging algorithms using $t\bar{t}$ events in early Run-2 data*, ATLAS-PHYS-PUB-2015-039, 2015, URL: https://cds.cern.ch/record/2047871.

[93] J. Butterworth et al., *PDF4LHC recommendations for LHC Run II*, J. Phys. G **43** (2016) 023001, arXiv: 1510.03865 [hep-ph].

[94] ATLAS Collaboration, *Evidence for the $H \to b\bar{b}$ decay with the ATLAS detector*, JHEP **12** (2017) 024, arXiv: 1708.03299 [hep-ex].

[95] ATLAS Collaboration, *Evidence for the associated production of the Higgs boson and a top quark pair with the ATLAS detector*, Phys. Rev. D **97** (2018) 072003, arXiv: 1712.08891 [hep-ex].

[96] G. Cowan, K. Cranmer, E. Gross, and O. Vitells, *Asymptotic formulae for likelihood-based tests of new physics*, Eur. Phys. J. C **71** (2011) 1554, [Erratum: Eur. Phys. J. C 73 (2013) 2501], arXiv: 1007.1727 [physics.data-an].

[97] A. L. Read, *Presentation of search results: the CL_s technique*, J. Phys. G **28** (2002) 2693.

[98] A. Djouadi and J. Quevillon, *The MSSM Higgs sector at a high M_{SUSY}: reopening the low $\tan\beta$ regime and heavy Higgs searches*, JHEP **10** (2013) 028, arXiv: 1304.1787 [hep-ph].

[99] A. Djouadi et al., *The post-Higgs MSSM scenario: Habemus MSSM?* Eur. Phys. J. C **73** (2013) 2650, arXiv: 1307.5205 [hep-ph].

[100] ATLAS Collaboration, *ATLAS Computing Acknowledgements*, ATL-GEN-PUB-2016-002, URL: https://cds.cern.ch/record/2202407.

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