Suche nach Elektroweakinos mit dem ATLAS Detektor

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Dissertation

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March 2021

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Part I

Fundamental concepts

Part II

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Chapter 4

Analysis overview

This chapter aims to give an introduction to the search for electroweakinos presented in this work. First, the targeted final state is introduced and motivated, followed by the Standard Model of Particle Physics (SM) background processes that need to be considered when performing searches for Supersymmetry (SUSY) in this final state. Next, the reconstruction and identification of physics objects as well as the event selection requirements are described.

4.1 Search for electroweakinos in the 1-lepton final state

In the search for electroweakinos presented herein, the simplified model introduced in section 1.3.2 is interpreted in a final state with one lepton, two b-jets and high missing transverse momentum. This final state can occur when the W boson decays through $W^{\pm} \to \ell^{\pm}\nu_{\ell}$, while the Higgs boson decays into $h \to b\bar{b}$. Although a final state without leptons would benefit from the higher branching fraction of the $W^{\pm} \to q'\bar{q}$ decay, due to the large quantum chromodynamics (QCD) couplings these final states are largely dominated by QCD multi-jet background processes that are omnipresent at hadron colliders like the Large Hadron Collider (LHC). Final states with exactly one lepton have lower cross sections but allow to reject a majority of the QCD background, as pure QCD multi-jet events can only enter the 1-lepton final state through false reconstruction of a jet as a lepton (so-called *fake* leptons).

Targeting the decay of the Higgs boson into a pair of b quarks benefits from the high branching ratio of 58.3% of this decay mode and allows a full reconstruction of Higgs candidates, a procedure that will be used in the following to achieve a high signal-to-background ratio. Figure 4.1 shows the full signal model targeted in this search, including the considered decays of the W and Higgs bosons.

Previous searches for electroweakinos in this final state have been performed by the ATLAS [167, 168] and CMS [169] collaborations, and have excluded $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ masses up to 540 GeV and 490 GeV, respectively, for massless $\tilde{\chi}_1^0$. The two previous ATLAS searches used $20.3\,\mathrm{fb}^{-1}$ of $\sqrt{s} = 8$ TeV and $36.1\,\mathrm{fb}^{-1}$ of $\sqrt{s} = 13$ TeV pp collision data, respectively. As opposed to this, the search presented in the following uses the full dataset available from the Run 2 data taking period, amounting to an unprecedented $139\,\mathrm{fb}^{-1}$ of pp collision data at $\sqrt{s} = 13$ TeV [170]. As

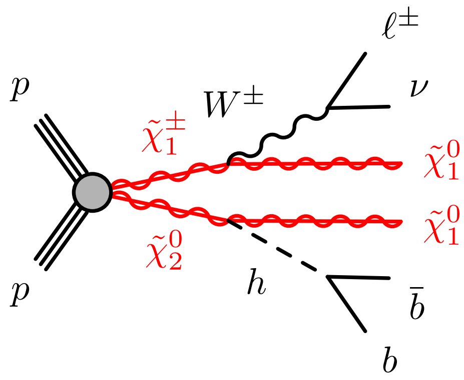


Figure 4.1: Diagram for the simplified model used in this work including the decays $W^\pm \to \ell^\pm \nu_\ell$ and $h \to b\bar{b}$.

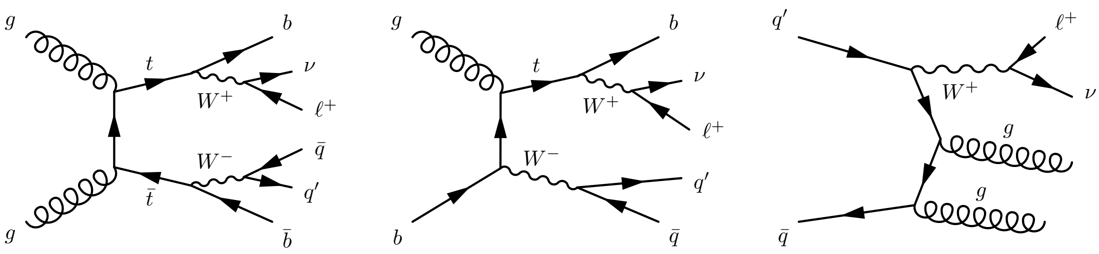
this search analysis events in final states with exactly one lepton, it will often be referred to as the *1-lepton analysis* in the following.

4.2 Standard Model backgrounds

Although the requirement of exactly one lepton isolated from surrounding hadronic activity significantly reduces the contribution from QCD multi-jet background, numerous other SM processes can result in final states with exactly one isolated lepton, multiple jets and missing transverse momentum. Background sources are generally classified into *reducible* and *irreducible* backgrounds. Irreducible backgrounds are processes that have a physical phase space that is indistinguishable from the final state of the signal process considered. Reducible backgrounds, on the other hand, result from partially misreconstructed processes as well as mismeasurements. Examples of reducible processes are events where a lepton originates from a heavy flavour (HF) decay, photon conversions or misreconstructed jets. SM processes that result in final states with an isolated lepton, multiple jets and missing transverse momentum typically involve a W boson decaying into a lepton–neutrino pair (a so-called *leptonic decay*). The neutrino will contribute to the total missing transverse momentum in the event, while additional jets can appear in the final state through QCD radiation or other branches of the decay chain.

By far the largest SM background contribution stems from the production of top quarks, predominantly through top quark pair $t\bar{t}$ production, where both top quarks decay into a W boson and a b quark. Final states with one isolated lepton can occur through leptonic decay of one of the W bosons. Figure 4.2(a) shows a diagram of an exemplary decay of a $t\bar{t}$ system into a final state with one lepton, multiple jets (two of which originate from b quarks) and missing transverse momentum. In addition to $t\bar{t}$, single top production (s-channel, t-channel or tW-channel) can also result in similar final states as the SUSY signal and thus constitutes a significant SM background process. An exemplary decay into a final state relevant for this search is shown in fig. 4.2(b).

Apart from processes involving top quarks, the production of a W boson in association with multiple jets (W + jets) is the third major background considered in the analysis. If the W boson undergoes a leptonic decay and two of the produced jets are tagged as originating from



(a) **(b)** **(c)**

Figure 4.2: Exemplary Feynman diagrams showing the dominant processes (a) $t\bar{t}$, (b) single top and (c) W + jets production with subsequent decays.

b quarks, the signature of this process can be similar to that of signal events. An exemplary diagram for a W + jets event is shown in fig. 4.2(c).

Production of multiple vector bosons V $(= W, Z)$—although not a dominant background due to low cross sections—can still result in the same final state as the signal process. In the following, diboson VV and multiboson VVV processes are considered.

Other SM backgrounds with small contributions in the phases spaces targeted by the analysis include Z + jets production, $t\bar{t} + V$ production, as well as various processes involving Higgs bosons. Z + jets plays only a minor role, as the only irreducible component is $Z(\rightarrow \tau\tau)$ + jets, where one τ-lepton undergoes a leptonic decay and the other one a hadronic decay. Production of $t\bar{t} + V$ has a similar topology as ordinary $t\bar{t}$ processes but with lower cross section and additional objects in the final state. Higgs processes considered in the following include single Higgs production through vector boson fusion (VBF) or gluon–gluon fusion (ggF) as well as $h + V$ and $h + t\bar{t}$ processes. In the following, these backgrounds are grouped together and labelled as *other* backgrounds.

Pure QCD multi-jet events can only appear in the 1-lepton final state through false reconstruction of a jet as a lepton (so-called *fake* leptons) and mismeasurement of $E_{\mathrm{T}}^{\mathrm{miss}}$. It has been shown that this background is negligible in all selections relevant to this search, hence no estimation for QCD contribution is considered in the following [170].

4.3 Monte Carlo samples

Table 4.1 summarises all Monte Carlo (MC) generators and software versions run during generation of the simulated events used in the following. Further details are given in the relevant ATLAS simulation notes [171–174].

4.3.1 Signal samples

The $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ pair production signal samples were generated at leading order (LO) using MadGraph5_aMC@NLO 2.6.2 [175, 176] with up to two additional partons in the matrix element (ME). MadGraph5_aMC@NLO is interfaced with Pythia8 [177] for the parton shower (PS), hadronisation and underlying event, using the CKKW-L [178] scheme for matching the

PS to the MEs. The NNPDF 2.3 LO [179] parton distribution function (PDF) set and the A14 set of tuned parameters [180] are used. For modelling the decay of HF quarks, EvtGen v1.6 [181] is used.

As the $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$ masses are free parameters of the signal model, they are systematically scanned, resulting in a set of 164 distinct signal models evenly distributed in the two-dimensional grid spanned by the two mass parameters. In the following, this two-dimensional grid will be referred to as *signal grid*, while the distinct signal scenarios (each with a unique set of mass parameter values) will be referred to as *signal points*. The generated signal grid covers $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ masses from 150 GeV to 1.1 TeV and $\tilde{\chi}_1^0$ masses from 0 GeV to 550 GeV, avoiding the kinematically forbidden region with $m(\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0) < m(\tilde{\chi}_1^0) + m(h)$ that does not allow for production of on-shell Higgs bosons.

Signal samples well within the expected sensitivity range of the analysis, i.e. with relatively low $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$ masses or already excluded at 95% CL by previous analyses, are generated using the ATLFAST-II detector simulation. The full detector simulation using Geant4 is used for the remaining model points for maximum accuracy in the parameter space relevant to the expected sensitivity. In order to account for pileup effects, all signal samples are overlaid with simulated minimum bias events generated using Pythia8 and the A3 tune [182], and reweighted to match the pileup distribution measured in data.

The cross sections for electroweakino pair production have been calculated using Resummino [183] at next-to-leading order (NLO) in the strong coupling constant and including next-to-leading logarithm (NLL) terms in the soft gluon resummation [184, 185].

4.3.2 Background samples

Top pair production and single top processes were generated using Powheg-Box v2 [186], implementing the Powheg method [187, 188] for merging NLO MEs with the PSs. The PS, hadronisation and underlying event were simulated using Pythia8 with the A14 tune. Production of $t\bar{t}$ in association with a vector boson ($t\bar{t}+V$) is generated using MadGraph5_aMC@NLO 2.3.3, interfaced with Pythia8 for the PS. The set of PDFs used for simulation of $t\bar{t}$, single top, and $t\bar{t}+V$ is the NNPDF2.3LO set.

Production of a vector boson V with additional jets ($W/Z+$jets) is simulated using Sherpa 2.2.1 [130, 189], allowing up to two (four) additional parton emissions at NLO (LO) accuracy. The CKKW ME+PS matching and merging scheme [190, 136] is used, extended to NLO accuracy [191]. Diboson (VV) and multiboson (VVV) processes are simulated using Sherpa 2.2.1 and 2.2.2 with the default Sherpa generator tune. The PDFs used are provided by the NNPDF3.0NNLO set [192].

All Higgs processes are simulated using Powheg-Box v2 for the ME calculations and Pythia8 for the PS, underlying event and hadronisation. While the generation of $h+t\bar{t}$ uses the A14 tune and the NNPDF2.3LO set, $h+V$ and single Higgs production are simulated using the NNPDF 3.0 NNLO set and the AZNLO [193] set of tuned generator parameters.

The detector simulation for all MC background samples was performed using the full detector simulation based on Geant4, introduced in section 2.2.8. Except for the MC samples generated using Sherpa, all background samples use EvtGen v1.2 or v1.6 to model the decay of HF

Table 4.1: Overview of configuration of MC generators used for simulating the various signal and SM background processes.

Process	Matrix element	Parton shower	PDF set	Cross section	Tune
Signal	MadGraph5_aMC@NLO 2.6.2	Pythia 8.230	NNPDF 2.3 LO	NLO+NLL [183–185]	A14
$t\bar{t}$	Powheg-Box	Pythia 8.230	NNPDF2.3LO	NNLO+NNLL [194, 195]	A14
t (s-channel)	Powheg-Box	Pythia 8.230	NNPDF2.3LO	NLO [196]	A14
t (t-channel)	Powheg-Box	Pythia 8.230	NNPDF2.3LO	NLO [196]	A14
$t+W$	Powheg-Box	Pythia 8.230	NNPDF2.3LO	NNLO [196, 197]	A14
$t\bar{t}+V$	MadGraph5_aMC@NLO 2.3.3	Pythia 8.210	NNPDF2.3LO	NLO [198, 199]	A14
$V+$jets	Sherpa 2.2.1		NNPDF3.0NNLO	NNLO [200]	Sherpa default
VV	Sherpa 2.2.1/2.2.2		NNPDF3.0NNLO	NLO [174]	Sherpa default
VVV	Sherpa 2.2.1/2.2.2		NNPDF3.0NNLO	NLO [174]	Sherpa default
$h+t\bar{t}$	Powheg-Box	Pythia 8.230	NNPDF2.3LO	NLO [201]	A14
$h+V$	Powheg-Box	Pythia 8.212	NNPDF3.0NNLO	NNLO [201]	AZNLO
h (ggF)	Powheg-Box	Pythia 8.212	NNPDF3.0NNLO	N^{3}LO+N^{3}LL [201]	AZNLO
h (VBF)	Powheg-Box	Pythia 8.212	NNPDF3.0NNLO	NNLO [201]	AZNLO

quarks. Similar to the signal models, all background samples are overlaid with simulated minimum bias events generated with Pythia8 and the A3 tune.

4.4 Object definitions

The reconstruction of physics objects requires the combination of data from multiple detector components. Due to finite detector resolutions, and the sheer amount of particles produced in each collision, this process does not always work without flaws. Sometimes, objects are falsely reconstructed or not reconstructed at all. In order to minimise reconstruction errors, different identification and reconstruction criteria are introduced for each physics object category. Electrons and muons are categorised into *baseline* and *signal* objects. Baseline objects have a smaller purity but a higher acceptance which is e.g. useful for the reconstruction of the missing transverse momentum. Stricter identification and isolation criteria are required for signal objects, resulting in lower acceptances but also lower probability of reconstruction errors. In the following, signal-type objects are used as the physical objects. Table 4.2 gives a comprehensive summary of the object definitions introduced in the ensuing sections.

4.4.1 Tracks and vertices

The reconstruction of tracks of charged particles starts with the formation of clusters from raw data recorded in the Pixel and silicon microstip tracker (SCT) detectors. Clusters are formed by grouping together adjacent pixels and strips with energy deposits above a certain threshold and are subsequently used to create three-dimensional space-points, representing the points where charged particles traversed the active inner detector (ID) material [202]. Sets of three space-points form track seeds that serve as inputs for a combinatorial Kalman filtering technique [203] that includes additional space-points from the remaining pixel and SCT layers to extend the preliminary trajectory. A χ^2 track fit is performed at each step of the extension. Where seeds can be extended by more than one compatible space-point in a given layer, multiple track candidates are formed. Ambiguities between candidates are resolved by assigning them a score taking into account basic track properties like the χ^2 of the track fit, or its associated p_{T} [202]. The ambiguity solver requires track candidates to contain a minimum of 7 pixel and SCT clusters, have a maximum of one shared pixel cluster and two shared SCT clusters on the same layer and have no more than two holes[†] of which only one is allowed to be in the pixel detector. Track candidates also need to have $p_{\mathrm{T}} > 400\,\mathrm{MeV}$, $|\eta| < 2.5$ and have longitudinal (z_0) and transversal (d_0) impact parameters with respect to their associated vertex satisfying $|z_0 \sin\theta| < 3.0\,\mathrm{mm}$ and $|d_0| < 2.0\,\mathrm{mm}$, where θ is the polar angle of the track [202]. Track candidates surviving the ambiguity solver are extended by compatible hits in the transition radiation tracker (TRT) [204] and subject to a global high-resolution track fit before being added to the final track collection [202].

Vertex reconstruction uses a selection of tracks satisfying a set of quality requirements [205] to fit the best vertex position in a procedure iteratively downweighting less compatible tracks [206]. Once the vertex position has been determined, incompatible tracks with small weights are removed and can be reused for the reconstruction of additional vertices [206]. All reconstructed vertices with at least two associated tracks are kept as valid primary vertex candidates. In events with multiple candidates, the primary vertex is defined to be the one with the highest $\sum p_{\mathrm{T}}^2$ of its associated tracks.

4.4.2 Electrons and Photons

Electron and photon candidates are reconstructed from energy deposits in topologically connected cells in the electromagnetic and hadronic calorimeters. The reconstruction algorithm starts with the preparation of the energy deposits into so-called *topo-clusters* [207]. These are formed by calorimeter cells containing energy deposits above a certain noise threshold, so-called *seed* cells, including their neighbouring cells which, in turn, can also act as seed cells. All cell signals are measured at the electromagnetic scale, assuming that energy deposits stem only from electromagnetic interactions. Although the topo-clustering algorithm starts with cells from both calorimeters, only energies from cells in the Electromagnetic (EM) calorimeter are used in the subsequent electron and photon reconstruction steps [208]. Using only EM topo-clusters with a certain threshold ratio of the EM energy to the total cluster energy significantly reduces contamination from pileup clusters [208]. The EM topo-clusters are then loosely matched to ID tracks that are re-fitted in order to account for energy losses through bremsstrahlung [208]. Vertices from photon conversions are reconstructed from tracks matched to fixed-size clusters [209] and also matched to the EM topo-clusters. In the final step of the reconstruction algorithm, EM topo-clusters are sorted according to descending E_{T} and tested as seed clusters for dynamic, variable-size *superclusters*, with different seed requirements for electrons and photons [208]. Clusters near seed candidates can be added as satellite cluster candidates, originating e.g. from bremsstrahlung. Electrons and photons are then finally built from the reconstructed superclusters and their energies are calibrated using $Z \to ee$ decays [208].

The identification of prompt electrons relies on a likelihood discriminant built from quantities measured in the ID and calorimeters. The quantities are chosen according to their ability to discriminate prompt isolated electrons from non-prompt leptons originating in e.g. HF decays, from photon conversions or from jets. They include the properties of the electron track, the shape of the EM shower and the quality of the match between the electron track and

[†] Holes are intersections of the track trajectory with sensitive detector material not containing a cluster.

the calorimeter clusters [210]. Photon identification, on the other hand, relies on a cut-based selection exploiting the shape of the EM shower [208].

In this analysis, electrons are required to satisfy $p_{\mathrm{T}} > 7\,\mathrm{GeV}$ and $|\eta| < 2.47$. Baseline electrons are identified using the *LooseAndBLayer* requirement on the identification likelihood, requiring a hit in the innermost layer of the pixel detector, at least two additional hits in the remaining layers of the pixel detector and seven hits in the pixel and SCT detectors combined [210]. In addition, the longitudinal impact parameter z_0 of baseline electrons needs to satisfy $\Delta z_0 \sin\theta < 0.5\,\mathrm{mm}$ with respect to the primary vertex. The *LooseAndBLayer* identification yields an average efficiency of about 93%, increasing from low to high electron E_{T} [210]. Signal electrons are a subset of baseline electrons and need to satisfy the *Tight* likelihood identification, yielding an efficiency of 80% for prompt electrons with $E_{\mathrm{T}} = 40\,\mathrm{GeV}$ [210]. In addition to the longitudinal impact parameter, signal leptons also need to satisfy $d_0/\sigma_{d_0} < 5$, where the transverse impact parameter d_0 and its uncertainty σ_{d_0} are measured with respect to the beam line.

Finally, electrons need to be *isolated*, meaning that their vicinity must be clear of additional significant detector activity. Requiring electrons to be isolated prevents the selection of non-prompt electrons originating e.g. from HF decays or misidentifications of light hadrons. Isolation is quantified using two observables, one using tracking information and the other one using calorimeter data. The tracking based isolation variable $p_{\mathrm{T}}^{\mathrm{varcone20}}$ is the sum of all track momenta above 1 GeV (excluding the electrons track itself) in a cone around the electron. The size of the cone is chosen to be $\Delta R = \min(10\,\mathrm{GeV}/p_{\mathrm{T}}, 0.2)$, i.e. is shrinking with increasing transverse momentum of the electron. The calorimeter based variable $E_{\mathrm{T}}^{\mathrm{cone20}}$ corresponds to the sum of the transverse energies in topo-clusters (excluding the electrons itself and after correcting for pileup effects) in a cone with $\Delta R = 0.2$ around the electrons. In this analysis, both baseline and signal electrons are required to satisfy the *Loose* working point [208], corresponding to the requirements $p_{\mathrm{T}}^{\mathrm{varcone20}}/p_{\mathrm{T}} < 0.2$ and $E_{\mathrm{T}}^{\mathrm{cone20}} < 0.15$. In order to improve the rejection of non-prompt electrons at high transverse momenta, electrons with $p_{\mathrm{T}} > 200\,\mathrm{GeV}$ need to satisfy the *HighPtCaloOnly* working point, applying the tighter requirement $E_{\mathrm{T}}^{\mathrm{cone20}} < \max(0.015 \cdot p_{\mathrm{T}}, 3.5\,\mathrm{GeV})$.

Photons are required to have $p_{\mathrm{T}} > 13\,\mathrm{GeV}$ and $|\eta| < 2.37$ and need to satisfy the *Tight* identification and *FixedCutTight* isolation requirements introduced in Ref. [208]. In this analysis, photons are only used in the calculation of the missing transverse momentum.

4.4.3 Muons

The reconstruction of muons uses primarily data from the ID and muon spectrometer (MS) and is based on the fact that muons are minimum ionising particles. Muon candidates are independently reconstructed in the ID and the MS as muon tracks and only then combined to a muon candidate that can be used by physics analysis [211, 212]. The track reconstruction in the ID follows the same procedure used for other charged-particle tracks, described in section 4.4.1. In the MS, the muon track reconstruction starts with the identification of short straight-line track segments. Segments from different MS layers are combined into preliminary muon track candidates if they are loosely compatible with the interaction point (IP) and match a first-order approximation of the parabolic trajectory describing the muon track in the magnetic field. Track candidates are then fitted in a global χ^2 fit, taking into account possible MS chamber misalignments as well as interactions with the detector material [212]. In order to increase the reconstruction performance, MS muon tracks are subsequently combined with the ID tracks using five different reconstruction strategies, described in detail in Ref. [212]. Only two of these strategies are relevant for this analysis:

- *combined muons*, formed by combining the ID and MS tracks through a global fit, taking into account the energy loss in the calorimeters,
- *MS extrapolated muons*, built using MS muon tracks only, but extrapolating the tracks back to the IP and requiring them to be loosely compatible with the IP. Extrapolated muons are mainly used for providing acceptance in the region $2.5 < |\eta| < 2.7$, which is beyond the coverage provided by the ID.

After resolving the overlaps between the different muon types, the muon objects used for physics analysis are subject to a momentum calibration using data from $J/\Psi \to \mu\mu$ and $Z \to \mu\mu$ decays [211, 212].

Identification of muons is performed using quality requirements designed to suppress non-prompt muons originating from pion and kaon decays and allow a robust momentum measurement. Muons in this analysis are built using combined and extrapolated muons that satisfy the *Medium* identification requirements [211]. Combined muons need to have at least three hits in at least two Monitored Drift Tube (MDT) layers, except for the region with $|\eta| < 0.1$, where a single MDT layer is enough, as long as there is no more than one MDT hole layer [212]. Extrapolated muons need to have at least three hits in at least three MDT and Cathode Strip Chamber (CSC) layers [212]. In addition, all muons need to have a significance of the ratio of the measured charge and momentum satisfying $\sigma(q/p) < 7$. Identification of muons with the *Loose* identification working point is evaluated in a $t\bar{t}$ MC sample and yields an efficiency of more than 98% for muons with $p_{\mathrm{T}} > 5\,\mathrm{GeV}$ [212]. The light-hadron rejection rate is roughly 98 for low-p_{T} muons with $p_{\mathrm{T}} < 20\,\mathrm{GeV}$, and decreases with increasing muon p_{T}, reaching 830 for muons with $p_{\mathrm{T}} > 100\,\mathrm{GeV}$ [212].

Baseline muons in this analysis also need to satisfy $p_{\mathrm{T}} > 6\,\mathrm{GeV}$ and $|\eta| < 2.7$. The longitudinal impact parameter of baseline muons with respect to the primary vertex is required to be $\Delta z_0 \sin\theta < 0.5\,\mathrm{mm}$. Signal muons additionally need to be within $|\eta| < 2.5$ and have a transverse impact parameter satisfying $d_0/\sigma_{d_0} < 3$. Similar to electrons, muons also need to be isolated, using the same variables used for electron isolation. Both signal and baseline muons need to conform to the *Loose* working point, requiring $p_{\mathrm{T}}^{\mathrm{varcone20}}/p_{\mathrm{T}} < 0.3$ and $E_{\mathrm{T}}^{\mathrm{cone20}} < 0.15$ [212]. The *Loose* isolation working point yields an efficiency rapidly increasing from 86% for muons with $5\,\mathrm{GeV} < p_{\mathrm{T}} < 20\,\mathrm{GeV}$ to 97% for muons with $20\,\mathrm{GeV} < p_{\mathrm{T}} < 100\,\mathrm{GeV}$. Muons with $p_{\mathrm{T}} > 100\,\mathrm{GeV}$ have an isolation efficiency of more than 99% [212]. The rejection rate for muons from HF decays ranges from 14 to 8 with increasing p_{T} in the range relevant for this search [212].

4.4.4 Jets

Jets are reconstructed at the EM scale using the anti-k_t algorithm [213] with a radius parameter $R = 0.4$, implemented in the FastJet [214, 215] package. The inputs to the anti-k_t algorithm are topo-clusters [216], built using the procedure introduced in section 4.4.2. Tracks with $p_{\mathrm{T}} > 500\,\mathrm{MeV}$ and an association to the primary vertex are assigned to jets using *ghost association* [217], a method treating them as particles with infinitesimal momentum such that the properties of the calorimeter-based jets are not changed.

Reconstructed jets undergo a jet energy scale (JES) calibration, correcting the four-momentum and scaling the energy and mass [216]. In a first step, energy contributions from in-time and out-of-time pileup are removed using a data-driven jet-by-jet approach based on jet areas and pileup p_{T} density. Additionally, a residual correction derived from MC simulation and parameterised by the number of mean interactions per bunch crossing and the number of reconstructed primary vertices is applied [216, 217]. The reconstructed jet four-momentum is corrected to the particle-level energy scale through an absolute JES and η calibration. In order to reduce the dependence of the jet response (i.e. the ratio between the measured jet energy and the true jet energy) on the flavour and energy distribution of its constituents, a series of multiplicative corrections, called global sequential calibration (GSC) [218], is applied. The GSC improves the jet energy resolution (JER) and is based on data from the calorimeters, jet-related tracking information as well as MS information. Differences between the jet response in data and MC simulation, caused by imperfect detector and physics simulations, are corrected using so-called *in situ* calibrations [216]. The jet response in data and MC simulations is measured separately, allowing to derive a correction factor that is applied on data. Similar to the JES, the JER is also calibrated. Its calibration is performed using p_{T} asymmetry measurements in dijet events [219].

Even after the subtraction of pileup effects, some pileup jets still remain. The jet vertex tagger (JVT) [220], a multivariate discriminant, can be used to suppress pileup jets. It is based on variables that describe the fraction of the total jet momentum corresponding to tracks associated to the primary vertex. In this analysis, jets with $p_{\mathrm{T}} < 120\,\mathrm{GeV}$ and $|\eta| < 2.5$ need to be associated to the primary vertex using the *medium* working point, achieving an average 92% efficiency for jets originating from the hard scatter interaction [216].

Baseline jets in this analysis are required to have $p_{\mathrm{T}} > 20\,\mathrm{GeV}$ and $|\eta| < 4.5$. Analysis variables built using jets use signal-level jets with $p_{\mathrm{T}} > 30\,\mathrm{GeV}$ and $|\eta| < 2.8$.

4.4.5 Flavour tagging

As can be seen through the Cabibbo–Kobayashi–Maskawa (CKM) matrix, b-quarks primarily decay through $b \to Wc$. However, due to the small coupling constant proportional to the corresponding CKM matrix element V_{cb} (corresponding to the $b \leftrightarrow c$ transition), b-hadrons have relatively long lifetimes of the order of 1.5 ps ($\langle c\tau \rangle \approx 450\,\mu\mathrm{m}$) [7]. In the typical momentum ranges, b-hadrons can have a measurable flight length before decaying, leading to secondary vertices that are displaced from the hard-scatter interaction point. In order to exploit this, ATLAS uses a collection of algorithms designed to discern HF jets containing b-hadrons from light-flavour jets by exploiting either the impact parameters or reconstructing the displaced vertices. A multivariate classifier, called `MV2` [221] combines the outputs of the different taggers using a boosted decision tree (BDT) algorithm that is trained on $t\bar{t} + Z'$ MC samples.

Due to the Higgs decay $h \to b\bar{b}$ in the signal model targeted, b-jets play a crucial role in the analysis. Baseline jets with $|\eta| < 2.5$ are used as input to the `MV2c10` b-tagging algorithm, an implementation of the `MV2` discriminant using a c-jet fraction of 7% during the BDT training [222, 223]. The working point chosen for the `MV2c10` tagger achieves a b-tagging efficiency of 77% with a rejection rates of 4.9, 15, and 110 for c-jets, τ-jets and light-flavour jets, respectively, measured in simulated $t\bar{t}$ events [222].

4.4.6 Missing transverse momentum

Momentum conservation in the transverse plane implies that the sum of the transverse momenta of all objects in a pp collision should vanish. Particles escaping the detector without being measured thus lead to a momentum imbalance, in the following referred to as missing transverse momentum $\boldsymbol{p}_{\mathrm{T}}^{\mathrm{miss}}$ with magnitude $E_{\mathrm{T}}^{\mathrm{miss}}$. The missing transverse momentum in each event is computed using all reconstructed objects and takes into account tracks associated to the primary vertex but not used for any reconstructed objects [224], yielding

$$\boldsymbol{p}_{\mathrm{T}}^{\mathrm{miss}} = -\sum \boldsymbol{p}_{\mathrm{T}}^{e} - \sum \boldsymbol{p}_{\mathrm{T}}^{\gamma} - \sum \boldsymbol{p}_{\mathrm{T}}^{\mu} - \sum \boldsymbol{p}_{\mathrm{T}}^{\mathrm{jet}} - \sum \boldsymbol{p}_{\mathrm{T}}^{\mathrm{track}}. \tag{4.1}$$

While terms originating from the reconstructed, calibrated objects are collectively referred to as the *hard term*, the remaining track term is referred to as *soft term*. As τ-leptons are not explicitly reconstructed in this analysis, no corresponding term is included in eq. (4.1). Hadronic decays of τ-leptons are, however, included in the jet term as they are, in general, reconstructed as jets. The computation of $E_{\mathrm{T}}^{\mathrm{miss}}$ uses all baseline objects introduced in the previous sections. Ambiguities between objects are resolved using an overlap removal procedure [224] that is separate and independent from the procedure described in section 4.5. In order to reduce effects from pileup, the $E_{\mathrm{T}}^{\mathrm{miss}}$ is computed using the *Tight* working point described in Ref. [225], excluding forward jets with $|\eta| > 2.4$ and $p_{\mathrm{T}} < 30\,\mathrm{GeV}$.

Events without any true $E_{\mathrm{T}}^{\mathrm{miss}}$ can have non-zero reconstructed $E_{\mathrm{T}}^{\mathrm{miss}}$ due to residual pileup effects, object mismeasurements or particles escaping through uninstrumentalised regions of the detector. Such *fake* $E_{\mathrm{T}}^{\mathrm{miss}}$ allows events without any real $E_{\mathrm{T}}^{\mathrm{miss}}$ (e.g. $Z(\to ee) + \text{jets}$) to pass the event selection criteria and end up in the kinematic regions of interest even after requiring a certain threshold value of $E_{\mathrm{T}}^{\mathrm{miss}}$.

4.5 Overlap removal

As the reconstruction procedure runs independently for each object type, it may happen that the same tracks or energy deposits in the calorimeters are used for the reconstruction of two different objects. For example, electrons tend to cluster as well as jets and are therefore often also reconstructed as electron-seeded jets [226]. In order to resolve ambiguities and prevent double-counting, an overlap removal procedure using the distance parameter $\Delta R_y = \sqrt{(\Delta y)^2 + (\Delta\phi)^2}$ is performed. The procedure sequentially runs the following steps on baseline objects, with only surviving objects participating in subsequent steps:

1. Electrons sharing an ID track with a muon are removed, preventing duplication of muons as electrons via bremsstrahlung with subsequent photon conversion [226].

2. Jets within $\Delta R_y < 0.2$ of an electron are rejected, preventing the pure duplication of electrons as electron-seeded jets [226].

3. Electrons overlapping with remaining jets within $\Delta R_y = \min(0.4, 0.04 + 10\,\mathrm{GeV}/p_{\mathrm{T}})$ are removed, resolving the regime where hadronic jets lose a fraction of their energy to electron-seeded jets [226]. The shrinking cone size avoids unnecessary rejection of electrons originating from decays of boosted particles together with jets.

Table 4.2: Overview of the object definitions used in the analysis.

Property	Baseline type	Signal type
	Electrons	
Kinematic	$p_{\mathrm{T}} > 7\,\mathrm{GeV}$, $\lvert\eta\rvert < 2.47$	$p_{\mathrm{T}} > 7\,\mathrm{GeV}$, $\lvert\eta\rvert < 2.47$
Identification	*LooseAndBLayer* [210]	*Tight* [210]
Impact parameters	$\Delta z_0 \sin\theta < 0.5\,\mathrm{mm}$	$\Delta z_0 \sin\theta < 0.5\,\mathrm{mm}$, $d_0/\sigma_{d_0} < 5$
Isolation	–	*Loose* [208] ($p_{\mathrm{T}} \leq 200\,\mathrm{GeV}$) *HighPtCaloOnly* [208] ($p_{\mathrm{T}} > 200\,\mathrm{GeV}$)
	Muons	
Kinematic	$p_{\mathrm{T}} > 6\,\mathrm{GeV}$, $\lvert\eta\rvert < 2.7$	$p_{\mathrm{T}} > 6\,\mathrm{GeV}$, $\lvert\eta\rvert < 2.5$
Identification	*Medium* [211]	*Medium* [211]
Impact parameters	$\Delta z_0 \sin\theta < 0.5\,\mathrm{mm}$	$\Delta z_0 \sin\theta < 0.5\,\mathrm{mm}$, $d_0/\sigma_{d_0} < 3$
Isolation	–	*Loose* [212]
	Jets	
Kinematic	$p_{\mathrm{T}} > 20\,\mathrm{GeV}$, $\lvert\eta\rvert < 4.5$	$p_{\mathrm{T}} > 30\,\mathrm{GeV}$, $\lvert\eta\rvert < 2.8$
JVT	–	*Medium* [216], $p_{\mathrm{T}} < 120\,\mathrm{GeV}$, $\lvert\eta\rvert < 2.5$
	b-jets	
Kinematic	$p_{\mathrm{T}} > 20\,\mathrm{GeV}$, $\lvert\eta\rvert < 4.5$	$p_{\mathrm{T}} > 30\,\mathrm{GeV}$, $\lvert\eta\rvert < 2.5$
JVT	–	*Medium* [216], $p_{\mathrm{T}} < 120\,\mathrm{GeV}$, $\lvert\eta\rvert < 2.5$
b-tagging	–	`MV2c10` [222] with 77% efficiency

4. Jets with less than three associated tracks, within $\Delta R_y < 0.2$ of a muon or where the muon has been matched to the jet through ghost association [227] are removed. This resolves for example scenarios where a muon is reconstructed as a jet due to bremsstrahlung or final state radiation (FSR) with subsequent photon conversion reconstructed both as electron and jet [226].

5. Muons overlapping with a remaining jet are removed. The same shrinking cone size as for electrons is used. This predominantly removes non-prompt muons produced in light meson or HF decays together with jets [226].

4.6 Analysis variables

In order to separate supersymmetric signal events from SM processes, it is necessary to apply requirements on different discriminating observables, creating so-called *signal regions* enriched in signal events. In addition, these variables are also used to construct regions enriched in SM background events, in the following used for the background estimation in the signal regions. The distributions of all discriminating variables are illustrated in fig. 4.3, showing signal and SM background distributions, each normalised to unity. Most observables depend on the absolute mass scale of the supersymmetric particles, as well as the mass difference between $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$.

Number of jets

The simplified model depicted in fig. 4.1 features two b-jets in the final state, originating from the decay of the Higgs boson. In the following, all events are thus required to have exactly two b-jets in the final state, significantly reducing contributions from e.g. W + jets processes that have a relatively low probability of producing two b-jets. In order to avoid rejecting signal events with initial state radiation (ISR) or FSR, a third, light-flavour jet is allowed in the final state.

Invariant mass of the *b*-tagged jets

The invariant mass of the two b-jets $m_{b\bar{b}}$ is defined as

$$m_{b\bar{b}} = \sqrt{(\mathbf{p}_{b_1} + \mathbf{p}_{b_2})^2}, \tag{4.2}$$

where $\mathbf{p}_{b_1}$ and $\mathbf{p}_{b_2}$ are the four-vector momenta of the leading and subleading b-jets, respectively. The term *leading* henceforth refers to the object with the largest p_{T} in its object category. In the high-relativistic limit $E \gg m$, the invariant mass of the two b-jets can be written as

$$m_{b\bar{b}} = \sqrt{2 p_{\mathrm{T}}^{b_1} p_{\mathrm{T}}^{b_2} (\cosh \Delta\eta - \cos \Delta\phi)}. \tag{4.3}$$

As the two b-jets originate from the Higgs decay $h \to b\bar{b}$, their measured invariant mass will in general be close to the measured Higgs mass of around 125 GeV [7], leading to a peak in the $m_{b\bar{b}}$ distribution, as can clearly be seen in fig. 4.3(d). In most SM background processes relevant to the search, the b-jets do not originate from a Higgs decay, and thus their $m_{b\bar{b}}$ distribution does not exhibit the same peak-like structure. In order to enrich signal events in a selection, a $m_{b\bar{b}}$ will be required to be close to the Higgs mass in the following.

Missing transverse energy

The missing transverse energy $E_{\mathrm{T}}^{\mathrm{miss}}$ is an observable finding widespread usage in searches for SUSY at the LHC. In SM processes, $E_{\mathrm{T}}^{\mathrm{miss}}$ only stems from neutrinos and fake $E_{\mathrm{T}}^{\mathrm{miss}}$ arising e.g. from mismeasurements or imperfect detector hermeticity. In the case of the SUSY scenario considered in the following, two lightest supersymmetric particles (LSPs) escape the detector, leaving a considerable amount of missing transverse momentum, such that a lower requirement on $E_{\mathrm{T}}^{\mathrm{miss}}$ allows to separate signal and background processes. Figure 4.3(c) shows the $E_{\mathrm{T}}^{\mathrm{miss}}$ distribution, illustrating the fact that signal models with high absolute sparticle masses as well as high mass differences tend to have the largest $E_{\mathrm{T}}^{\mathrm{miss}}$.

Transverse mass

The transverse masse m_{T} [228, 229] is one of the most important observables considered in this analysis. It aims to reconstruct the mass of a heavy particle decaying into two daughter particles subject to a co-linear boost in the laboratory transverse plane. In SUSY searches targeting the 1-lepton final state, m_{T} is commonly used to reconstruct the transverse mass of the W boson decaying into a lepton–neutrino pair, and is therefore defined as

$$m_{\mathrm{T}} = \sqrt{2p_{\mathrm{T}}^{\ell} E_{\mathrm{T}}^{\mathrm{miss}}(1 - \cos[\Delta\phi(\boldsymbol{p}_{\mathrm{T}}^{\ell}, \boldsymbol{p}_{\mathrm{T}}^{\mathrm{miss}})])}, \tag{4.4}$$

where $\boldsymbol{p}_{\mathrm{T}}^{\ell}$ is the momentum three-vector of the lepton in the event. As additional leptons are vetoed, the vast majority of the leptons in background processes stem from leptonic decays of W bosons. In background events where the neutrino from $W \to \ell\nu$ is the only source of $E_{\mathrm{T}}^{\mathrm{miss}}$, the transverse mass has a theoretical kinematic endpoint at the W boson mass,

$$m_{\mathrm{T}}^{\mathrm{max}} = m_W \approx 80\,\mathrm{GeV}. \tag{4.5}$$

Due to finite detector resolution, mismeasurements or additional $E_{\mathrm{T}}^{\mathrm{miss}}$ in the event, background events can sometimes have $m_{\mathrm{T}} > m_W$, leading to a kinematic endpoint at m_W that is not infinitely sharp.

In the signal scenarios considered in the analysis, the LSPs constitute a majority of the $E_{\mathrm{T}}^{\mathrm{miss}}$ in an event, which typically leads to a m_{T} distribution that is significantly broader than that of background processes and does not present the same kinematic endpoint. A lower requirement on the transverse mass slightly above the W boson mass thus allows to reject a majority of the SM background events while keeping most of the signal events. As can be seen in fig. 4.3(c),the broadness of the m_{T} distribution depends on the scale of the mass parameters, with increasing mass differences leading to increasingly broad distributions. For this reason, different signal regions with varying requirements on m_{T} can be constructed, targeting different kinematic regimes in the signal grid.

Contransverse mass

The contransverse mass m_{CT} [230] is designed to have a kinematic endpoint for pair produced heavy particles decaying into invisible and visible particles subject to a contra-linear boost. In the following, m_{CT} is defined as

$$m_{\mathrm{CT}} = \sqrt{2p_{\mathrm{T}}^{b_1} p_{\mathrm{T}}^{b_2}(1 + \cos\Delta\phi_{bb})}, \tag{4.6}$$

where $p_{\mathrm{T}}^{b_1}$ and $p_{\mathrm{T}}^{b_2}$ are the transverse momenta of the two b-jets in the final state. Although m_{CT} is invariant under co-linear boosts in the beam direction†, it is not invariant under transverse boosts, e.g. due to ISR jets, such that m_{CT} as well as its kinematic endpoint depend on the size and direction of the transverse boost. For this reason, a boost-corrected version of the contransverse mass is used in the following, using a procedure described in detail in Ref. [231].

For $t\bar{t}$ events where each top quark decays via $t \to bW$, the two b-jets used for calculating m_{CT} stem from each of the two decay branches of the $t\bar{t}$ system. It can be shown [231] that, in this case, the boost-corrected contransverse mass has a kinematic endpoint at

$$m_{\mathrm{CT}}^{\mathrm{max}} = \frac{m^2(t) - m^2(W)}{m(t)} \approx 135\,\mathrm{GeV}. \tag{4.7}$$

† This is by construction the case, as only transverse quantities are used.

In signal events, the two input b-jets originate from the same Higgs boson, and thus m_{CT} does not present a kinematic endpoint but rather tends to take much higher values. Figure 4.3(b) clearly illustrates the kinematic endpoint for $t\bar{t}$ backgrounds and further shows that signal distributions take on much higher values depending on their mass parameter scales. Similar as for the transverse mass, varying lower bounds on m_{CT} will be used to define signal regions optimised to different kinematic regimes.

Invariant mass of the lepton and leading b-jet

The invariant mass of the lepton and the leading b-jet $m_{\ell b_1}$ is designed to offer high rejection power towards $t\bar{t}$ and single top processes. In events where the lepton and leading b-jet originate from the same top quark decay $t \to bW \to b\ell\nu$, the $m_{\ell b_1}$ distribution has a kinematic endpoint at

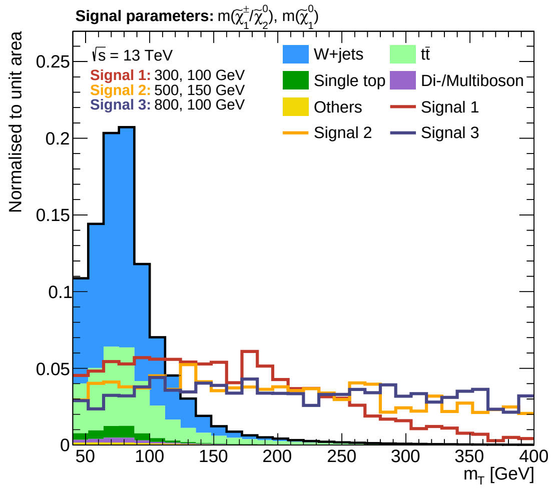
$$m_{\ell b_1}^{\max} = \sqrt{m^2(t) - m^2(W)} \approx 153\,\mathrm{GeV} \tag{4.8}$$

In signal events, the lepton and leading b-jet originate from the decay chains of the $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$, respectively and thus the $m_{\ell b_1}$ distribution depends on the mass scale of the SUSY particles, yielding good discriminative power especially for signal scenarios with high $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ masses.

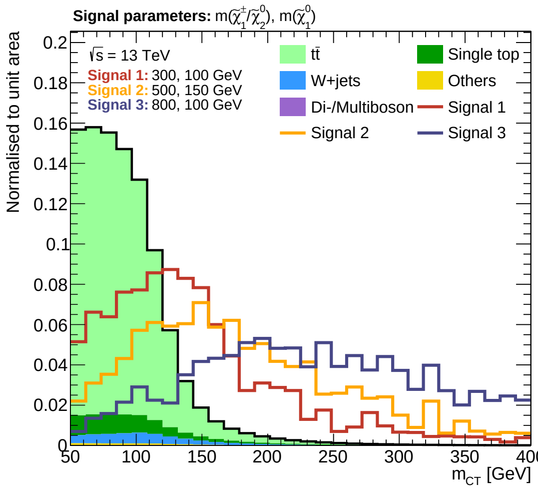
4.7 Trigger strategy

The trigger strategy of an analysis is crucial to select pp events worth investigating, and typically relies on triggers sensitive to physics objects that are important to the considered signal scenarios. The data used in this analysis have been recorded with $E_{\mathrm{T}}^{\mathrm{miss}}$ triggers. Selecting events with invisible particles is inherently difficult precisely because these particles do not leave a trace in the detector. As described in section 2.2.7, the Level 1 (L1) trigger uses only parts of the instrumented regions, a technique that is not well suited for momentum imbalance triggers that rely on a sum of momenta over the full solid angle [232]. In addition, the significant increase in luminosity in Run 2 of the LHC degrades the $E_{\mathrm{T}}^{\mathrm{miss}}$ resolution in the calorimeters, the only detector component used for the $E_{\mathrm{T}}^{\mathrm{miss}}$ triggers [232]. The L1 triggers used in this analysis employed a threshold of $E_{\mathrm{T}}^{\mathrm{miss}} > 50\,\mathrm{GeV}$, before feeding passing events to the High Level Trigger (HLT) for further analysis.

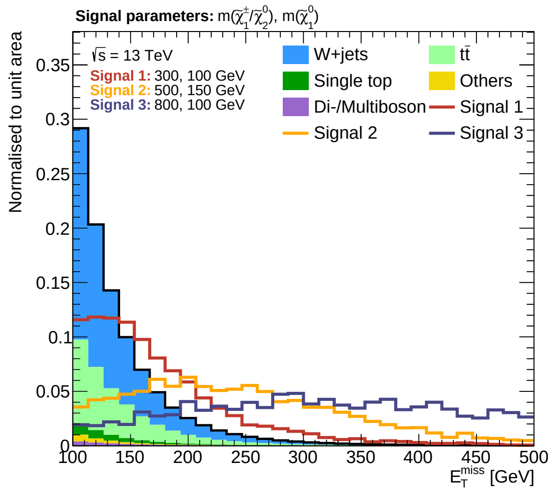
Two different types of $E_{\mathrm{T}}^{\mathrm{miss}}$ triggers are used by the HLT, one based on jets (`mht` algorithm), and one implementing local pile-up suppression (`pufit` algorithm). As hadronic jets dominate the visible momentum in most interesting events, using them for $E_{\mathrm{T}}^{\mathrm{miss}}$ computation and triggering is well-motivated. The `mht` algorithm was used during the 2015–2016 data taking period and computes the $E_{\mathrm{T}}^{\mathrm{miss}}$ from the negative vectorial sum of the transverse momenta of all jets with a transverse momentum $p_{\mathrm{T}} > 7\,\mathrm{GeV}$ before calibration [232]. The HLT jets are reconstructed and calibrated using a similar procedure as for offline analysis, and are thus corrected for pile-up effects [233]. The `pufit` algorithm was used during the 2017–2018 data taking period and takes as input topo clusters formed using the method described in section 4.4.2. The clusters are subsequently combined into η–ϕ patches of approximately jet size and corrected for pile-up effects based on the distribution of the energy deposits in the calorimeter. The `pufit` algorithm assumes that high E_{T} deposits stem from the hard-scatter events, while low E_{T} deposits originate mostly from pile-up effects [232]. The online $E_{\mathrm{T}}^{\mathrm{miss}}$ threshold used increased



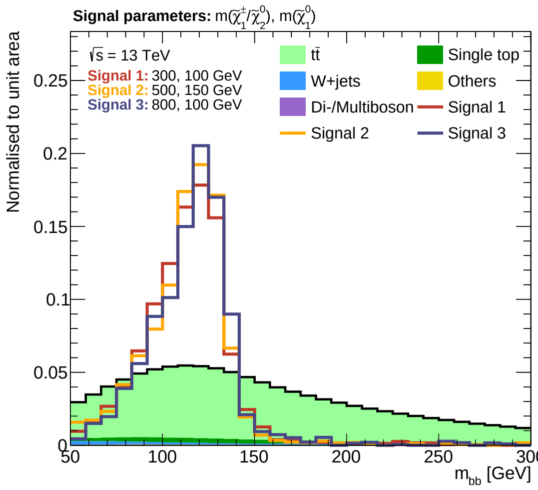
(a)



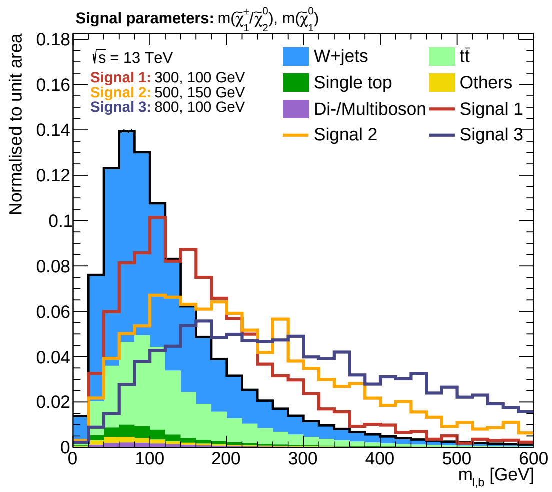
(b)



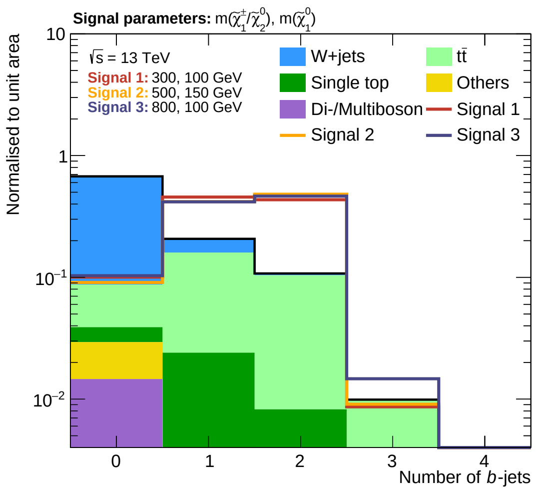
(c)



(d)

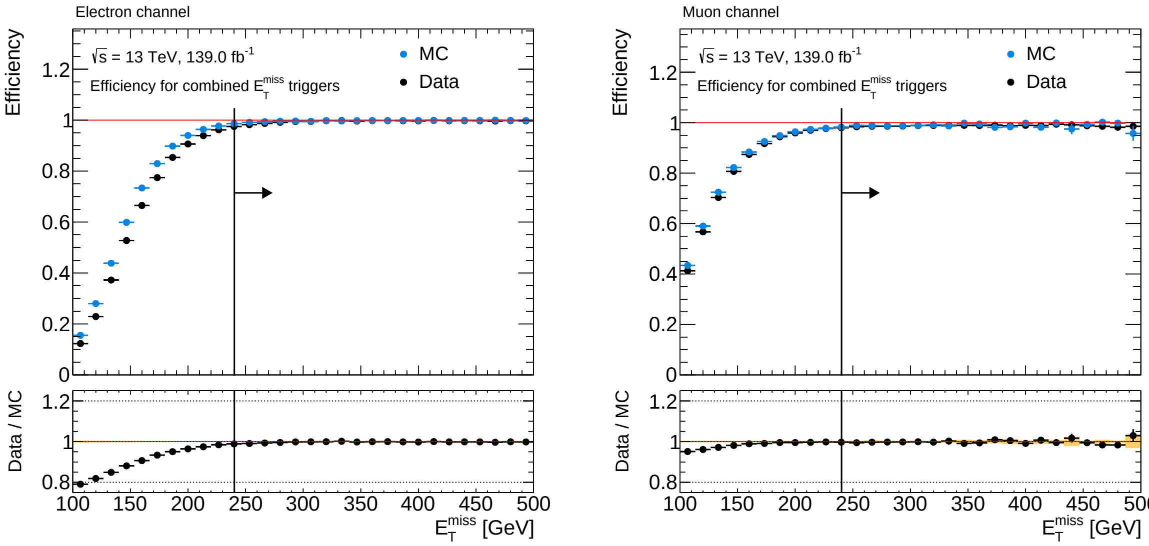


(e)



(f)

Figure 4.3: Distributions of the most important observables used in the analysis. The simulated SM backgrounds are stacked on top of each other, and distributions from exemplary signal models with the quoted mass parameters are overlaid. In order to emphasise the shape differences, both background and signal distributions are normalised to unity. A preselection of exactly one lepton (signal and baseline), at least two light jets and $E_T^{miss} > 100\,\text{GeV}$ is applied.



(a) Electron channel

(b) Muon channel

Figure 4.4: Efficiencies of the combined $E_{\mathrm{T}}^{\mathrm{miss}}$ triggers in data and MC events, triggered by single lepton triggers in the (a) electron and (b) muon channels. A preselection requiring exactly one lepton (baseline and signal), at least two jets, and $E_{\mathrm{T}}^{\mathrm{miss}} > 100\,\mathrm{GeV}$ is applied. The arrow indicates the offline $E_{\mathrm{T}}^{\mathrm{miss}}$ requirement applied on all selections in the analysis.

from 70 GeV to 110 GeV in order to keep the trigger rate more or less stable under rising instant luminosities during the different data-taking periods.

Since the online reconstruction techniques used by the triggers are slightly different† than those used in offline analysis, the performance of triggers is in general not a simple step function but a so-called *turn-on curve* with rising efficiency, followed by a *plateau region* with constant efficiency. In order to achieve the same trigger selection in MC as in data, the MC events are each assigned a random run number that are distributed according to the respective integrated luminosities of each data taking period. Using the run numbers, the same triggers used for data taking during each run can be applied for MC events.

Figure 4.4 shows the combined $E_{\mathrm{T}}^{\mathrm{miss}}$ trigger efficiencies for the electron and muon channel separately. In the following, an offline requirement of $E_{\mathrm{T}}^{\mathrm{miss}} > 240\,\mathrm{GeV}$ is applied for all analysis regions, selecting events where the $E_{\mathrm{T}}^{\mathrm{miss}}$ triggers are fully efficient and no significant difference between MC and data is observed. Thus, no trigger efficiency correction is considered in the following. A statistical uncertainty of 2% is used to account for the difference between data and MC in the trigger plateaus.

4.8 Event cleaning

Before being considered for analysis, events need to pass a series of quality requirements. Data events need to be certified to be good for physics analysis by the data quality system [234],

† This is necessary to be able to handle the data streams caused by the *pp* collisions.

requiring that no transient detector issues have compromised the quality of the data events recorded. This could happen due to e.g. sudden noise bursts in detector electronics, or high-voltage trips in detector components. Only data events are considered where all detector components were flagged as being operational, a process that is performed at the granularity of a *luminosity block*—a time period of roughly 60 s of data-taking where the instantaneous luminosity, detector and trigger configuration are considered to be constant.

A second series of quality requirements is applied on both data and MC events. To be considered in any subsequent analysis step, events need to have at least one reconstructed primary vertex with a minimum of two tracks with $p_{\mathrm{T}} > 500\,\mathrm{MeV}$ associated to it. Events are discarded where a jet is tagged as originating from a non-collision background process. The `Loose` working point described in Ref. [235] is used to tag such jets, yielding an efficiency of 99.5% for jets from pp collision events with $p_{\mathrm{T}} > 20\,\mathrm{GeV}$. Similarly, events are rejected if they contain a *bad* muon with a significantly worse than usual momentum resolution that can affect many variables in the entire event and therefore may have non-negligible effects on the analysis. In the following, muons are flagged as *bad* if the relative error on the combined q/p measurement is either larger than 0.2 or worse than the one from the individual ID and MS track fits. Events are also rejected if a reconstructed muon is flagged to originate from cosmic radiation, using thresholds on the transverse and longitudinal impact parameters of $d_0 > 0.2\,\mathrm{mm}$ and $z_0 > 1\,\mathrm{mm}$ with respect to the primary vertex.

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Abbreviations

BDT boosted decision tree. 75

CKM Cabibbo–Kobayashi–Maskawa. 75

CSC Cathode Strip Chamber. 74

EM Electromagnetic. 72–74

FSR final state radiation. 77, 78

ggF gluon–gluon fusion. 69

GSC global sequential calibration. 75

HF heavy flavour. 68, 70, 72–75, 77

HLT High Level Trigger. 80

ID inner detector. 71–74, 76, 83

IP interaction point. 73, 74

ISR initial state radiation. 78, 79

JER jet energy resolution. 75

JES jet energy scale. 75

JVT jet vertex tagger. 75, 77

L1 Level 1. 80

LHC Large Hadron Collider. 67, 78

LO leading order. 69

LSP lightest supersymmetric particle. 78, 79

MC Monte Carlo. 69–71, 74, 75, 82, 83

MDT Monitored Drift Tube. 74

ME matrix element. 69, 70

MS muon spectrometer. 73–75, 83

NLL next-to-leading logarithm. 70

NLO next-to-leading order. 70

PDF parton distribution function. 70

PS parton shower. 69, 70

QCD quantum chromodynamics. 67–69

SCT silicon microstip tracker. 71–73

SM Standard Model of Particle Physics. 67–69, 71, 77–79, 81

SUSY Supersymmetry. 67, 68, 78, 80

TRT transition radiation tracker. 72

VBF vector boson fusion. 69

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