Search for supersymmetry in events with four or more leptons in $\sqrt{s}=13$ TeV pp collisions with ATLAS

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Results from a search for supersymmetry in events with four or more charged leptons (electrons, muons and taus) are presented. The analysis uses a data sample corresponding to 36.1 fb^{-1} of proton–proton collisions delivered by the Large Hadron Collider at $\sqrt{s}=13$ TeV and recorded by the ATLAS detector. Four-lepton signal regions with up to two hadronically decaying taus are designed to target a range of supersymmetric scenarios that can be either enriched in or depleted of events involving the production and decay of a Z boson. Data yields are consistent with Standard Model expectations and results are used to set upper limits on the event yields from processes beyond the Standard Model. Exclusion limits are set at the 95% confidence level in simplified models of general gauge mediated supersymmetry, where Higgsino masses are excluded up to 295 GeV. In R-parity-violating simplified models with decays of the lightest supersymmetric particle to charged leptons, lower limits of 1.46, 1.06, and 2.25 TeV are placed on wino, slepton and gluino masses, respectively.

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I. INTRODUCTION

Supersymmetry (SUSY) [1–6] is a space-time symmetry that postulates the existence of new particles with spin differing by one half-unit from their Standard Model (SM) partners. In supersymmetric extensions of the SM, each SM fermion (boson) is associated with a SUSY boson (fermion), having the same quantum numbers as its partner except for spin. The introduction of these new SUSY particles provides a potential solution to the hierarchy problem [7–10].

The scalar superpartners of the SM fermions are called sfermions (comprising the charged sleptons, $\tilde{\ell}$, the sneutrinos, $\tilde{\nu}$, and the squarks, $\tilde{q}$), while the gluons have fermionic superpartners called gluinos ($\tilde{g}$). The bino, wino and Higgsino fields are fermionic superpartners of the $\mathrm{SU}(2)\times\mathrm{U}(1)$ gauge fields of the SM, and the two complex scalar doublets of a minimally extended Higgs sector, respectively. Their mass eigenstates are referred to as charginos $\tilde{\chi}_i^{\pm}$ ($i=1$, 2) and neutralinos $\tilde{\chi}_j^0$ ($j=1$, 2, 3, 4), numbered in order of increasing mass.

In the absence of a protective symmetry, SUSY processes not conserving lepton number (L) and baryon number (B) could result in proton decay at a rate that is in conflict with the tight experimental constraints on the proton lifetime [11]. This conflict can be avoided by imposing the conservation of R-parity [12], defined as $(-1)^{3(B-L)+2S}$, where S is spin, or by explicitly conserving either B or L in the Lagrangian in R-parity-violating (RPV) scenarios. In RPV models, the lightest SUSY particle (LSP) is unstable and decays to SM particles, including charged leptons and neutrinos when violating L but not B. In R-parity-conserving (RPC) models, the LSP is stable and leptons can originate from unstable weakly interacting sparticles decaying into the LSP. Both the RPV and RPC SUSY scenarios can therefore result in signatures with high lepton multiplicities and substantial missing transverse momentum, selections on which can be used to suppress SM background processes effectively.

This paper presents a search for new physics in final states with at least four isolated, charged leptons (electrons, muons or taus) where up to two hadronically decaying taus are considered. The analysis exploits the full proton–proton data set collected by the ATLAS experiment during the 2015 and 2016 data-taking periods, corresponding to an integrated luminosity of 36.1 fb^{-1} at a center-of-mass energy of 13 TeV. The search itself is optimized using several signal models but is generally model independent, using selections on the presence or absence of Z bosons in the event and loose requirements on effective mass or missing transverse momentum. Results are presented in terms of the number of events from new physics processes with a four charged lepton signature, and also in terms of RPV and RPC SUSY models.

Previous searches for SUSY particles using signatures with three or more leptons were carried out at the Tevatron

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collider [13–18], and at the LHC by the ATLAS experiment [19–22] and the CMS experiment [23–27]. This analysis closely follows the 7 TeV [19] and 8 TeV [22] ATLAS analyses.

II. SUSY SCENARIOS

SUSY models are used for signal region optimization and to interpret the results of this analysis. Models of both RPV SUSY and RPC SUSY are considered here, as they each require a different approach for signal selection, as discussed in Sec. V.

In all scenarios, the light CP-even Higgs boson, h, of the minimal supersymmetric extension of the SM [28,29] Higgs sector is assumed to be practically identical to the SM Higgs boson [30], with the same mass and couplings as measured at the LHC [31–33]. In addition, the decoupling limit is used, which is defined by $m_A \gg m_Z$, while the CP-odd (A), the neutral CP-even (H), and the two charged ($H^{\pm}$) Higgs bosons are considered to be very heavy and thus considerably beyond the kinematic reach of the LHC.

A. RPV SUSY scenarios

In generic SUSY models with minimal particle content, the superpotential includes terms that violate conservation of L and B [34,35]:

$$\frac{1}{2}\lambda_{ijk}L_iL_j\bar{E}_k + \lambda'_{ijk}L_iQ_j\bar{D}_k + \frac{1}{2}\lambda''_{ijk}\bar{U}_i\bar{D}_j\bar{D}_k + \kappa_iL_iH_2,$$

where L_i and Q_i indicate the lepton and quark SU(2)-doublet superfields, respectively, and $\bar{E}_i$, $\bar{U}_i$ and $\bar{D}_i$ are the corresponding singlet superfields. Quark and lepton generations are referred to by the indices i, j and k, while the Higgs field that couples to up-type quarks is represented by the Higgs SU(2)-doublet superfield H_2. The λ_{ijk}, λ'_{ijk} and λ''_{ijk} parameters are three sets of new Yukawa couplings, while the κ_i parameters have dimensions of mass.

Simplified models of RPV scenarios are considered, where the LSP is a bino-like neutralino ($\tilde{\chi}_1^0$) and decays via an RPV interaction. The LSP decay is mediated by the following lepton-number-violating superpotential term:

$$W_{LL\bar{E}} = \frac{1}{2}\lambda_{ijk}L_iL_j\bar{E}_k.$$

This RPV interaction allows the following decay of the neutralino LSP:

$$\tilde{\chi}_1^0 \to \ell_k^{\pm}\ell_{i/j}^{\mp}\nu_{j/i}, \quad (1)$$

through a virtual slepton or sneutrino, with the allowed lepton flavors depending on the indices of the associated λ_{ijk} couplings [36]. The complex conjugate of the decay in Eq. (1) is also allowed. Thus, in the case of pair production, every signal event contains a minimum of four charged leptons and two neutrinos.

TABLE I. Decay modes and branching ratios for the $\tilde{\chi}_1^0$ LSP in the RPV models, where ν denotes neutrinos or antineutrinos of any lepton generation.

Scenario	$\tilde{\chi}_1^0$ branching ratios		
$LL\bar{E}12k$	$e^+e^-\nu$ (1/4)	$e^{\pm}\mu^{\mp}\nu$ (1/2)	$\mu^+\mu^-\nu$ (1/4)
$LL\bar{E}i33$	$e^{\pm}\tau^{\mp}\nu$ (1/4)	$\tau^+\tau^-\nu$ (1/2)	$\mu^{\pm}\tau^{\mp}\nu$ (1/4)

In principle, the nine[1] λ_{ijk} RPV couplings allow the $\tilde{\chi}_1^0$ to decay to every possible combination of charged lepton pairs, where the branching ratio for each combination differs for each λ_{ijk}. For example, for $\lambda_{121} \neq 0$ the branching ratios for $\tilde{\chi}_1^0 \to e\mu\nu$, $\tilde{\chi}_1^0 \to ee\nu$ and $\tilde{\chi}_1^0 \to \mu\mu\nu$ are 50%, 50% and 0% respectively, whereas for $\lambda_{122} \neq 0$ the corresponding branching ratios are 50%, 0% and 50%. In Ref. [22], it was found that the four-charged-lepton search sensitivity is comparable in the cases of $\lambda_{121} \neq 0$ or $\lambda_{122} \neq 0$, and for $\lambda_{133} \neq 0$ or $\lambda_{233} \neq 0$. Since the analysis reported here uses similar techniques, the number of L-violating RPV scenarios studied is reduced by making no distinction between the electron and muon decay modes of the $\tilde{\chi}_1^0$. Two extremes of the λ_{ijk} RPV couplings are considered:

(i) $LL\bar{E}12k$ ($k \in 1,\ 2$) scenarios, where $\lambda_{12k} \neq 0$ and only decays to electrons and muons are included,

(ii) $LL\bar{E}i33$ ($i \in 1,\ 2$) scenarios, where $\lambda_{i33} \neq 0$ and only decays to taus and either electrons or muons are included.

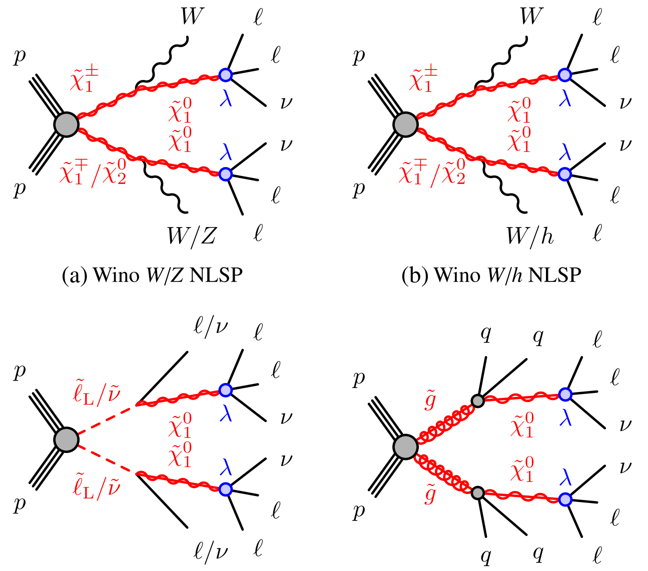
In both cases, all other RPV couplings are assumed to be zero. The branching ratios for the $\tilde{\chi}_1^0$ decay in the $LL\bar{E}12k$ and $LL\bar{E}i33$ are shown in Table I. The sensitivity to λ couplings not considered here (e.g., λ_{123}) is expected to be between that achieved in the $LL\bar{E}12k$ and $LL\bar{E}i33$ scenarios.

For the pure-bino $\tilde{\chi}_1^0$ considered here, the $\tilde{\chi}_1^0\tilde{\chi}_1^0$ production cross section is found to be vanishingly small, thus models that include one or more next-to-lightest SUSY particles (NLSP) are considered in order to obtain a reasonably large cross section. The choice of NLSP in the $LL\bar{E}12k$ and $LL\bar{E}i33$ scenarios determines the cross section of the SUSY scenario, and can impact the signal acceptance to a lesser extent. In all cases, the NLSP is pair produced in an RPC interaction, and decays to the LSP (which itself undergoes an RPV decay). Three different possibilities are considered for the NLSP in the $LL\bar{E}12k$ and $LL\bar{E}i33$ scenarios:

(i) *Wino NLSP*: Mass-degenerate wino-like charginos and neutralinos are produced in association ($\tilde{\chi}_1^+\tilde{\chi}_1^-$ or $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$). The $\tilde{\chi}_1^{\pm}$ ($\tilde{\chi}_2^0$) decays to the LSP while emitting a W (Z or h) boson, as shown in Figs. 1(a) and 1(b).

(ii) $\tilde{\ell}_{\mathrm{L}}/\tilde{\nu}$ *NLSP*: Mass-degenerate left-handed sleptons and sneutrinos of all three generations are produced

[1]The 27 λ_{ijk} RPV couplings are reduced to 9 by the antisymmetry requirement $\lambda_{ijk} = -\lambda_{jik}$.



(a) Wino W/Z NLSP (b) Wino W/h NLSP

(c) $\tilde{\ell}_L/\tilde{\nu}$ NLSP (d) $\tilde{g}$ NLSP

FIG. 1. Diagrams of the benchmark SUSY models of RPC NLSP pair production of (a) and (b) a wino, (c) slepton/sneutrino and (d) gluino, followed by the RPV decay of the $\tilde{\chi}_1^0$ LSP. The LSP is assumed to decay as $\tilde{\chi}_1^0 \to \ell\ell\nu$ with 100% branching ratio.

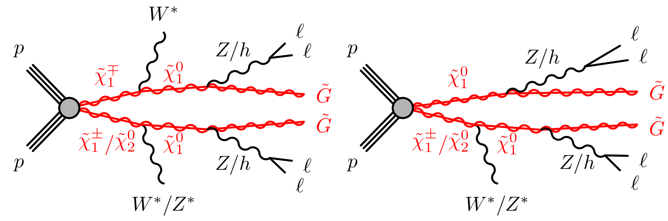
in association ($\tilde{\ell}_L\tilde{\ell}_L$, $\tilde{\nu}\tilde{\nu}$, $\tilde{\ell}_L\tilde{\nu}$). The $\tilde{\ell}_L$ ($\tilde{\nu}$) decays to the LSP while emitting a charged lepton (neutrino) as seen in Fig. 1(c).

(iii) $\tilde{g}$ *NLSP*: Gluino pair production, where the gluino decays to the LSP while emitting a quark-antiquark pair (u, d, s, c, b only, with equal branching ratios), as seen in Fig. 1(d).

For the RPV models, the LSP mass is restricted to the range $10\ \text{GeV} \leq m(\text{LSP}) \leq m(\text{NLSP}) - 10\ \text{GeV}$ to ensure that both the RPC cascade decay and the RPV LSP decay are prompt. Nonprompt decays of the $\tilde{\chi}_1^0$ in similar models were previously studied in Ref. [37].

B. RPC SUSY scenarios

RPC scenarios with light $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^\pm$ Higgsino states are well motivated by naturalness [38,39]. However, they can be experimentally challenging, as members of the Higgsino triplet are close in mass and decays of the $\tilde{\chi}_2^0/\tilde{\chi}_1^\pm$ to a $\tilde{\chi}_1^0$ LSP result in low-momentum decay products that are difficult to reconstruct efficiently. Searches for Higgsino-like $\tilde{\chi}_1^\pm$ in approximately mass-degenerate scenarios were performed by the LEP experiments, where chargino masses below 103.5 GeV were excluded [40] (reduced to 92 GeV for chargino-LSP mass differences between 0.1 and 3 GeV). Recently, the ATLAS experiment has excluded Higgsino-like $\tilde{\chi}_2^0$ up to masses ∼145 GeV and down to $\tilde{\chi}_2^0$-LSP mass differences of 2.5 GeV [41] for scenarios where the $\tilde{\chi}_1^\pm$ mass is assumed to be halfway between the two lightest neutralino masses. In the



(a) (b)

FIG. 2. Diagrams of the processes in the SUSY RPC GGM Higgsino models. The W^*/Z^* produced in the $\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$ decays are off-shell ($m \sim 1$ GeV) and their decay products are usually not reconstructed.

Planck-scale-mediated SUSY breaking scenario the gravitino $\tilde{G}$ is the fermionic superpartner of the graviton, and its mass is comparable to the masses of the other SUSY particles, $m \sim 100$ GeV [42,43]. General gauge mediated (GGM) SUSY models [44] predict the $\tilde{G}$ is nearly massless and offer an opportunity to study light Higgsinos. The decays of the Higgsinos to the LSP $\tilde{G}$ would lead to on-shell Z/h, and the decay products can be reconstructed.

Simplified RPC models inspired by GGM are considered here, where the only SUSY particles within reach of the LHC are an almost mass-degenerate Higgsino triplet $\tilde{\chi}_1^\pm$, $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$ and a massless $\tilde{G}$. To ensure the SUSY decays are prompt, the $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ masses are set to 1 GeV above the $\tilde{\chi}_1^0$ mass, and due to their weak coupling with the gravitino always decay to the $\tilde{\chi}_1^0$ via virtual Z/W bosons (which in turn decay to very soft final states that are not reconstructed). The $\tilde{\chi}_1^0$ decays promptly to a gravitino plus a Z or h boson, $\tilde{\chi}_1^0 \to Z/h + \tilde{G}$, where the leptonic decays of the Z/h are targeted in this analysis. Four production processes are included in this Higgsino GGM model: $\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^\pm\tilde{\chi}_1^0$, $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0\tilde{\chi}_2^0$, as shown in Fig. 2, and the total SUSY cross section is dominated by $\tilde{\chi}_1^\pm\tilde{\chi}_1^0$ and $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ production. The $\tilde{\chi}_1^0 \to Z\tilde{G}$ branching ratio is a free parameter of the GGM Higgsino scenarios, and so offers an opportunity to study 4ℓ signatures with one or more Z candidates.

III. THE ATLAS DETECTOR

The ATLAS detector [45] is a multipurpose particle physics detector with forward-backward symmetric cylindrical geometry.[2] The inner tracking detector (ID) covers

[2]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 from the IP 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 $\eta = -\ln\tan(\theta/2)$. Rapidity is defined as $y = 0.5\ln[(E + p_z)/(E - p_z)]$, where E denotes the energy and p_z is the component of the momentum along the beam direction.

$|\eta| < 2.5$ and consists of a silicon pixel detector, a semiconductor microstrip detector, and a transition radiation tracker. The innermost pixel layer, the insertable B-layer [46], was added for the $\sqrt{s} = 13$ TeV running period of the LHC. The ID is surrounded by a thin superconducting solenoid providing a 2 T axial magnetic field. A high-granularity lead/liquid-argon sampling calorimeter measures the energy and the position of electromagnetic showers within $|\eta| < 3.2$. Sampling calorimeters with liquid argon as the active medium are also used to measure hadronic showers in the end cap ($1.5 < |\eta| < 3.2$) and forward ($3.1 < |\eta| < 4.9$) regions, while a steel/scintillator tile calorimeter measures hadronic showers in the central region ($|\eta| < 1.7$). The muon spectrometer (MS) surrounds the calorimeters and consists of three large superconducting air-core toroid magnets, each with eight coils, a system of precision tracking chambers ($|\eta| < 2.7$), and fast trigger chambers ($|\eta| < 2.4$). A two-level trigger system [47] selects events to be recorded for off-line analysis.

IV. MONTE CARLO SIMULATION

Monte Carlo (MC) generators were used to simulate SM processes and new physics signals. The SM processes considered are those that can lead to signatures with at least four reconstructed charged leptons. Details of the signal and background MC simulation samples used in this analysis, as well as the order of cross section calculations in perturbative QCD used for yield normalization, are shown in Table II. Signal cross sections were calculated to next-to-leading order in the strong coupling constant, adding the resummation of soft gluon emission at next-to-leading-logarithmic accuracy (NLO + NLL) [48–55]. The nominal signal cross section and its uncertainty were taken from an envelope of cross section predictions using different parton distribution function (PDF) sets and factorization and renormalization scales, as described in Ref. [56].

The dominant irreducible background processes that can produce four prompt and isolated charged leptons are ZZ, $t\bar{t}Z$, VVV and Higgs production (where $V = W$, Z, and includes off-shell contributions). For the simulated ZZ production, the matrix elements contain all diagrams with four electroweak vertices, and they were calculated for up to one extra parton at NLO, and up to three extra partons at LO. The production of top quark pairs with an additional Z boson was simulated with the cross section normalized to NLO. Simulated triboson (VVV) production includes the processes ZZZ, WZZ and WWZ with four to six charged leptons, and was generated at NLO with additional LO matrix elements for up to two extra partons. The simulation of Higgs processes includes Higgs production via gluon-gluon fusion (ggH) and vector-boson fusion (VBF), and associated production with a boson (WH, ZH) or a top-antitop pair ($t\bar{t}H$). Other irreducible background processes with small cross sections are grouped into a category labeled "Other," which contains the tWZ, $t\bar{t}WW$, $tttW$ and $t\bar{t}t\bar{t}$ processes.

TABLE II. Summary of the simulated SM background samples used in this analysis, where $V = W$, Z, and includes off-shell contributions. "Tune" refers to the set of tuned parameters used by the generator. The sample marked with a † is used for a cross-check of yields and for studies of systematic uncertainties.

Process	Generator(s)	Simulation	Cross-section calculation	Tune	PDF set
WZ, WW	SHERPA 2.2.1 [57]	Full	NLO [58]	SHERPA default	NNPDF30NNLO [59]
ZZ	SHERPA 2.2.2 [57]	Full	NLO [58]	SHERPA default	NNPDF30NNLO [59]
VVV	SHERPA 2.2.1	Full	NLO [58]	SHERPA default	NNPDF30NNLO
ggH, VBF, $ggZH$	POWHEG v2 [60] + PYTHIA 8.186 [61]	Full	NNLO + NNLL [62]	AZNLO [63]	CT10 [64]
ZH, WH	PYTHIA 8.186	Full	NNLO + NNLL	A14 [65]	NNPDF23LO
$t\bar{t}H$	MadGraph5_aMC@NLO 2.3.2 [66] + PYTHIA 8.186	Full	NLO [67]	A14	NNPDF23LO [68]
$t\bar{t}Z$, $t\bar{t}W$, $t\bar{t}WW$	MadGraph_5_aMC@NLO 2.2.2 [69] + PYTHIA 8.186	Full	NLO [67]	A14	NNPDF23LO
$t\bar{t}Z^{\dagger}$	SHERPA 2.2.1	Fast	NLO [67]	SHERPA default	NNPDF30NNLO
tWZ	aMC@NLO 2.3.2 + PYTHIA 8.186	Full	NLO [67]	A14	NNPDF23LO
$tttW$, $t\bar{t}t\bar{t}$	MadGraph5_aMC@NLO 2.2.2 + PYTHIA 8.186	Full	NLO [69]	A14	NNPDF23LO
$t\bar{t}$	POWHEG v2 + PYTHIA 6.428 [70]	Full	NNLO + NNLL [71]	Perugia2012 [72]	CT10
Z + jets, W + jets	MadGraph5_aMC@NLO 2.2.2 + PYTHIA 8.186	Full	NNLO [73]	A14	NNPDF23LO
SUSY signal	MadGraph5_aMC@NLO 2.2.2 + PYTHIA 8.186	Fast	NLO + NLL [48–55]	A14	NNPDF23LO

For all MC simulation samples, the propagation of particles through the ATLAS detector was modeled with GEANT4 [74] using the full ATLAS detector simulation [75], or a fast simulation using a parametrization of the response of the electromagnetic and hadronic calorimeters [75] and GEANT4 elsewhere. The effect of multiple proton-proton collisions in the same or nearby bunch crossings, in-time and out-of-time pileup, is incorporated into the simulation by overlaying additional minimum-bias events generated with PYTHIA8 [61] onto hard-scatter events. Simulated events are reconstructed in the same manner as data, and are weighted to match the distribution of the expected mean number of interactions per bunch crossing in data. The simulated MC samples are corrected to account for differences from the data in the triggering efficiencies, lepton reconstruction efficiencies, and the energy and momentum measurements of leptons and jets.

V. EVENT SELECTION

After the application of beam, detector and data-quality requirements, the total integrated luminosity considered in this analysis corresponds to $36.1 \pm 1.2\ \mathrm{fb}^{-1}$. Events recorded during stable data-taking conditions are used in the analysis if the reconstructed primary vertex has at least two tracks with transverse momentum $p_{\mathrm{T}} > 400$ MeV associated with it. The primary vertex of an event is identified as the vertex with the highest Σp_{T}^2 of associated tracks.

Preselected electrons are required to have $|\eta| < 2.47$ and $p_{\mathrm{T}} > 7$ GeV, where the p_{T} and η are determined from the calibrated clustered energy deposits in the electromagnetic calorimeter and the matched ID track, respectively. Electrons must satisfy "loose" criteria of the likelihood-based identification algorithm [76], with additional track requirements based on the innermost pixel layer. Preselected muons are reconstructed by combining tracks in the ID with tracks in the MS [77], and are required to have $|\eta| < 2.7$ and $p_{\mathrm{T}} > 5$ GeV. Muons must satisfy "medium" identification requirements based on the number of hits in the different ID and MS subsystems, and the significance of the charge-to-momentum ratio, defined in Ref. [77]. Events containing one or more muons that have a transverse impact parameter relative to the primary vertex $|d_0| > 0.2$ mm or a longitudinal impact parameter relative to the primary vertex $|z_0| > 1$ mm are rejected to suppress the cosmic-ray muon background.

Jets are reconstructed with the anti-k_t algorithm [78] with a radius parameter of $R = 0.4$. Three-dimensional calorimeter energy clusters are used as input to the jet reconstruction, and jets are calibrated following Ref. [79]. Jets must have $|\eta| < 2.8$ and $p_{\mathrm{T}} > 20$ GeV. To reduce pileup effects, jets with $p_{\mathrm{T}} < 60$ GeV and $|\eta| < 2.4$ must satisfy additional criteria using the jet vertex tagging algorithm described in Ref. [80]. Events containing jets failing to satisfy the quality criteria described in Ref. [81] are rejected to suppress events with large calorimeter noise or noncollision backgrounds.

The visible part of hadronically decaying tau leptons, denoted as $\tau_{\text{had-vis}}$ and conventionally referred to as *taus* throughout this paper, is reconstructed [82] using jets as described above with $|\eta| < 2.47$ and $p_{\mathrm{T}} > 10$ GeV. The $\tau_{\text{had-vis}}$ reconstruction algorithm uses information about the tracks within $\Delta R \equiv \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} = 0.2$ of the jet direction, in addition to the electromagnetic and hadronic shower shapes in the calorimeters. Preselected $\tau_{\text{had-vis}}$ candidates are required to have one or three associated tracks (prongs), because taus predominantly decay to either one or three charged hadrons together with a neutrino and often additional neutral hadrons. The preselected $\tau_{\text{had-vis}}$ are required to have $p_{\mathrm{T}} > 20$ GeV and unit total charge of their constituent tracks. In order to suppress electrons misidentified as preselected $\tau_{\text{had-vis}}$, taus are vetoed using transition radiation and calorimeter information. The preselected $\tau_{\text{had-vis}}$ candidates are corrected to the $\tau_{\text{had-vis}}$ energy scale using an η- and p_{T}-dependent calibration. A boosted decision tree algorithm (BDT) uses discriminating track and cluster variables to optimize $\tau_{\text{had-vis}}$ identification, where "loose," "medium" and "tight" working points are defined [83], but not used to preselect tau leptons. In this analysis, kinematic variables built with hadronically decaying taus use only their visible decay products.

The missing transverse momentum, $E_{\mathrm{T}}^{\mathrm{miss}}$, is the magnitude of the negative vector sum of the transverse momenta of all identified physics objects (electrons, photons, muons and jets) and an additional soft term [84]. Taus are included as jets in the $E_{\mathrm{T}}^{\mathrm{miss}}$. The soft term is constructed from the tracks matched to the primary vertex, but not associated with identified physics objects, which allows the soft term to be nearly independent of pileup.

To avoid potential ambiguities among identified physics objects, preselected charged leptons and jets must survive "overlap removal," applied in the following order:

(1) Any tau within $\Delta R = 0.2$ of an electron or muon is removed.
(2) Any electron sharing an ID track with a muon is removed.
(3) Jets within $\Delta R = 0.2$ of a preselected electron are discarded.
(4) Electrons within $\Delta R = 0.4$ of a preselected jet are discarded, to suppress electrons from semileptonic decays of c- and b-hadrons.
(5) Jets with fewer than three associated tracks are discarded either if a preselected muon is within $\Delta R = 0.2$ or if the muon can be matched to a track associated with the jet.
(6) Muons within $\Delta R = 0.4$ of a preselected jet are discarded to suppress muons from semileptonic decays of c- and b-hadrons.
(7) Jets within $\Delta R = 0.4$ of a preselected tau passing medium identification requirements are discarded.

TABLE III. The triggers used in the analysis of 2015 and 2016 data. The off-line p_{T} thresholds are required only for reconstructed charged leptons which match to the trigger signatures. Trigger thresholds for data recorded in 2016 are higher than in 2015 due to the increase in beam luminosity, and "or" denotes a move to a higher-threshold trigger during data taking.

	Off-line p_{T} threshold [GeV]	
Trigger	2015	2016
Single isolated e	25	27
Single nonisolated e	61	61
Single isolated μ	21	25 or 27
Single nonisolated μ	41	41 or 51
Double e	13, 13	18, 18
Double μ (symmetric)	...	11, 11 or 15, 15
(asymmetric)	19, 9	21, 9 or 23, 9
Combined $e\mu$	$8(e)$, $25(\mu)$	$8(e)$, $25(\mu)$

Finally, to suppress low-mass particle decays, if surviving electrons and muons form an opposite-sign (OS) pair with $m_{\mathrm{OS}} < 4$ GeV, or form a same-flavor, opposite-sign (SFOS) pair in the $\Upsilon(1S) - \Upsilon(3S)$ mass range $8.4 < m_{\mathrm{SFOS}} < 10.4$ GeV, both leptons are discarded.

"Signal" light charged leptons, abbreviated as *signal leptons*, are preselected leptons surviving overlap removal and satisfying additional identification criteria. Signal electrons and muons must pass p_{T}-dependent isolation requirements, to reduce the contributions from semileptonic decays of hadrons and jets misidentified as prompt leptons. The isolation requirements use calorimeter- and track-based information to obtain 95% efficiency for charged leptons with $p_{\mathrm{T}} = 25$ GeV in $Z \to e^+e^-$, $\mu^+\mu^-$ events, rising to 99% efficiency at $p_{\mathrm{T}} = 60$ GeV. To improve the identification of closely spaced charged leptons (e.g., from boosted decays), contributions to the isolation from nearby electrons and muons passing all other signal lepton requirements are removed. To further suppress electrons and muons originating from secondary vertices, $|z_0 \sin\theta|$ is required to be less than 0.5 mm, and the d_0 normalized to its uncertainty is required to be small, with $|d_0|/\sigma_{d_0} < 5(3)$ for electrons (muons). Signal electrons must also satisfy medium likelihood-based identification criteria [76], while signal taus must satisfy the medium BDT-based identification criteria against jets [83].

Events are selected using single-lepton or dilepton triggers, where the trigger efficiencies are in the plateau region above the off-line p_{T} thresholds indicated in Table III. Dilepton triggers are used only when the leptons in the event fail p_{T}-threshold requirements for the single-lepton triggers. The triggering efficiency for events with four, three and two electrons/muons in signal SUSY scenarios is typically >99%, 96% and 90%, respectively.

VI. SIGNAL REGIONS

Events with four or more signal leptons (e, μ, $\tau_{\mathrm{had\text{-}vis}}$) are selected and are classified according to the number of light signal leptons ($L = e, \mu$) and signal taus (T) required: at least four light leptons and exactly zero taus $4L0T$, exactly three light leptons and at least one tau $3L1T$, or exactly two light leptons and at least two taus $2L2T$.

Events are further classified according to whether they are consistent with a leptonic Z boson decay or not. The Z requirement selects events where any SFOS LL pair combination has an invariant mass close to the Z boson mass, in the range 81.2–101.2 GeV. A second Z candidate may be identified if a second SFOS LL pair is present and satisfies $61.2 < m(LL) < 101.2$ GeV. Widening the low-mass side of the $m(LL)$ window used for the selection of a second Z candidate increases GGM signal acceptance. The Z veto rejects events where any SFOS lepton pair combination has an invariant mass close to the Z boson mass, in the range 81.2–101.2 GeV. To suppress radiative Z boson decays into four leptons (where a photon radiated from a $Z \to \ell\ell$ decay converts to a second SFOS lepton pair) the Z veto also considers combinations of any SFOS LL pair with an additional lepton (SFOS + L), or with a second SFOS LL pair (SFOS + SFOS), and rejects events where either the SFOS + L or SFOS + SFOS invariant mass lies in the range 81.2–101.2 GeV.

In order to separate the SM background from SUSY signal, the $E_{\mathrm{T}}^{\mathrm{miss}}$ and the effective mass of the event, m_{eff}, are both used. The m_{eff} is defined as the scalar sum of the $E_{\mathrm{T}}^{\mathrm{miss}}$, the p_{T} of signal leptons and the p_{T} of all jets with $p_{\mathrm{T}} > 40$ GeV. The $p_{\mathrm{T}} > 40$ GeV requirement for jets aims to suppress contributions from pileup and the underlying event. A selection using the m_{eff} rather than the $E_{\mathrm{T}}^{\mathrm{miss}}$ is particularly effective for the RPV SUSY scenarios, which produce multiple high-energy leptons (and in some cases jets), but only low to moderate $E_{\mathrm{T}}^{\mathrm{miss}}$ from neutrinos in the final state. The chosen m_{eff} thresholds are found to be close to optimal for the RPV scenarios with different NLSPs considered in this paper.

Two signal regions (SR) are defined with $4L0T$ and a Z veto: a general, model-independent signal region (SR0A) with $m_{\mathrm{eff}} > 600$ GeV, and a tighter signal region (SR0B) with $m_{\mathrm{eff}} > 1100$ GeV, optimized for the RPV $LL\bar{E}12k$ scenarios. Two further SRs are defined with $4L0T$, a first and second Z requirement as described above, and different selections on $E_{\mathrm{T}}^{\mathrm{miss}}$: a loose signal region (SR0C) with $E_{\mathrm{T}}^{\mathrm{miss}} > 50$ GeV, and a tighter signal region (SR0D) with $E_{\mathrm{T}}^{\mathrm{miss}} > 100$ GeV, optimized for the low-mass and high-mass Higgsino GGM scenarios, respectively. Finally, two SRs are optimized for the tau-rich RPV $LL\bar{E}i33$ scenarios: one with $3L1T$ where the tau has $p_{\mathrm{T}} > 30$ GeV, a Z veto and $m_{\mathrm{eff}} > 700$ GeV (SR1), and a second with $2L2T$ where the taus have $p_{\mathrm{T}} > 30$ GeV, a Z veto and $m_{\mathrm{eff}} > 650$ GeV (SR2). The signal region definitions are summarized in Table IV.

TABLE IV. Signal region definitions. The $p_T(\tau_{had\text{-}vis})$ column denotes the p_T threshold used for the tau selection or veto. SR0B and SR0D are subsets of SR0A and SR0C, respectively, while SR1 and SR2 are completely disjoint.

Region	$N(e,\mu)$	$N(\tau_{had\text{-}vis})$	$p_T(\tau_{had\text{-}vis})$	Z boson	Selection	Target
SR0A	≥4	= 0	>20 GeV	Veto	$m_{eff} > 600$ GeV	General
SR0B	≥4	= 0	>20 GeV	Veto	$m_{eff} > 1100$ GeV	RPV $LL\bar{E}12k$
SR0C	≥4	= 0	>20 GeV	Require first and second	$E_T^{miss} > 50$ GeV	Higgsino GGM
SR0D	≥4	= 0	>20 GeV	Require first and second	$E_T^{miss} > 100$ GeV	Higgsino GGM
SR1	= 3	≥1	>30 GeV	Veto	$m_{eff} > 700$ GeV	RPV $LL\bar{E}i33$
SR2	= 2	≥2	>30 GeV	Veto	$m_{eff} > 650$ GeV	RPV $LL\bar{E}i33$

VII. BACKGROUND DETERMINATION

Several SM processes can result in signatures resembling SUSY signals with four reconstructed charged leptons, including both the "real" and "fake" lepton contributions. Here, a real charged lepton is defined to be a prompt and genuinely isolated lepton, while a fake charged lepton is defined to be a nonprompt or nonisolated lepton that could originate from semileptonic decays of b- and c-hadrons, or from in-flight decays of light mesons, or from misidentification of particles within light-flavor or gluon-initiated jets, or from photon conversions. The SM processes are classified into two categories:

Irreducible background: Hard-scattering processes giving rise to events with four or more real leptons, ZZ, $t\bar{t}Z$, $t\bar{t}WW$, tWZ, VVZ (ZZZ, WZZ, WWZ), Higgs (ggH, WH, ZH, $t\bar{t}H$), $t\bar{t}t\bar{t}$, $t\bar{t}tW$.

Reducible background: Processes leading to events with at least one fake lepton, $t\bar{t}$, $Z+$jets, WZ, WW, WWW, $t\bar{t}W$, $t\bar{t}t$. Processes listed under irreducible that do not undergo a decay to four real leptons (e.g., $ZZ \to q\bar{q}\ell\ell$) are also included in the reducible background.

Backgrounds with three or more fake leptons (e.g., $W+$jets) are found to be very small for this analysis, and the systematic uncertainty on the reducible background is increased to cover any effect from them (discussed in Sec. VII A).

In the signal regions, the irreducible background is dominated by $t\bar{t}Z$, VVZ ($V = W$, Z), and ZZ, while the reducible background is dominated by the two-fake-lepton backgrounds $t\bar{t}$ and $Z+$jets. The irreducible backgrounds are estimated from MC simulation, while the reducible backgrounds are derived from data with the fake-factor method. Signal regions with $4L0T$ are dominated by irreducible background processes, whereas the reducible background processes dominate the $3L1T$ and $2L2T$ signal regions. The predictions for irreducible and reducible backgrounds are tested in validation regions (Sec. VII B). In the fake-factor method, the number of reducible background events in a given region is estimated from data using probabilities for a fake preselected lepton to pass or fail the signal lepton selection. The ratio $F = f/\bar{f}$ for fake leptons is the "fake factor," where f ($\bar{f}$) is the probability that a fake lepton is misidentified as a signal (loose) lepton. The probabilities used in the fake-factor calculations are based on simulation and corrected to data where possible. Loose leptons are preselected leptons surviving overlap removal that do not satisfy signal lepton criteria. For this fake-factor

TABLE V. Control region definitions where "L" and "T" denote signal light leptons and taus, while "l" and "t" denote loose light leptons and taus. Loose leptons are preselected leptons surviving overlap removal that do not pass signal lepton criteria. Additional selection for $p_T(\tau_{had\text{-}vis})$, Z veto/requirement, E_T^{miss}, m_{eff} are applied to match a given signal or validation region.

		$N(e,\mu)$	$N(e,\mu)$	$N(\tau_{had\text{-}vis})$	$N(\tau_{had\text{-}vis})$
Reducible estimation for	Control region	Signal	Loose	Signal	Loose
$4L0T$	CR1_LLLl	= 3	≥1	= 0	≥0
	CR2_LLll	= 2	≥2	= 0	≥0
$3L1T$	CR1_LLLt	= 3	= 0	= 0	≥1
	CR1_LLTl	= 2	= 1	≥1	≥0
	CR2_LLlt	= 2	= 1	= 0	≥1
$2L2T$	CR1_LLTt	= 2	= 0	= 1	≥1
	CR2_LLtt	= 2	= 0	= 0	≥2

evaluation, a very loose selection on the identification BDT is also applied to the preselected taus, since candidates with very low BDT scores are typically gluon-induced jets and jets arising from pileup, which is not the case for the signal tau candidates.

The reducible background prediction is extracted by applying fake factors to control regions (CR) in data. The CR definition only differs from that of the associated SR in the quality of the required leptons; here exactly one (CR1) or two (CR2) of the four leptons must be identified as a loose lepton, as shown in Table V. In $3L1T$ events, the contribution from events with two fake light leptons is negligible, as is the contribution from one and two fake light leptons in $2L2T$ events.

Fake factors are calculated separately for fake electrons, muons and taus, from light-flavor jets, heavy-flavor jets, gluon-initiated jets (taus only) and photon conversions (electrons and taus only). These categories are referred to as fake-lepton "types." The fake factor for each fake-lepton type is computed for each background process due to a dependence on the hard process (e.g., $t\bar{t}$, $Z+\text{jets}$). The fake factor per fake-lepton type and per process is binned in lepton p_{T}, η and number of prongs for taus.

To account correctly for the relative abundances of fake-lepton types and production processes, a weighted average F_w of fake factors is computed in each CR, as

$$F_w = \sum_{i,j} (R^{ij} \times s^i \times F^{ij}).$$

The factors R^{ij} are "process fractions" that depend on the fraction of fake leptons of type i from process j, determined from MC simulation in the corresponding CR2, and are similar to the process fractions obtained in the signal regions from MC simulation, which suffer from having few events. The term F^{ij} is the corresponding fake factor calculated using MC simulation. The "scale factors" s^i are corrections that depend on the fake-lepton type, and are applied to the fake factors to account for possible differences between data and MC simulation. These are assumed to be independent of the physical process, and are determined from data in dedicated regions enriched in objects of a given fake-lepton type.

For fake light leptons from heavy-flavor jets, the scale factor is measured in a $t\bar{t}$-dominated control sample. The heavy-flavor scale factors are seen to have a modest p_{T}-dependence, decreasing for muons from 1.00 ± 0.07 to 0.73 ± 0.18 as the muon p_{T} increases from 5 to 20 GeV. For electrons, the heavy-flavor scale factor is seen to increase from 1.16 ± 0.11 to 1.35 ± 0.29 across the same p_{T} range. For taus, the heavy-flavor, gluon-initiated and conversion scale factors cannot be reliably measured using data. Instead, they are assumed to be the same as the light-flavor jet scale factor described below.

The scale factor for fake taus originating from light-flavor jets is measured separately for one- and three-prong taus in a control sample dominated by $Z+\text{jets}$ events. The scale factors are seen to be p_{T}-dependent, decreasing from 1.30 ± 0.05 to 0.96 ± 0.06 (1.42 ± 0.11 to 1.23 ± 0.13) as the one-prong (three-prong) tau p_{T} increases from 20 to 60 GeV. The contribution to the signal regions from fake light leptons originating from light-flavor jets is very small (less than 1.8% of all e, μ) and the scale factor cannot be reliably measured using data. Therefore, values of 1.00 ± 0.25 are used instead, motivated by similar uncertainties in the other scale factor measurements.

For fake electrons from conversions, the scale factor is determined in a sample of photons from final-state radiation of Z boson decays to muon pairs. The electron conversion scale factor is seen to have a small p_{T}-dependence, increasing from 1.38 ± 0.17 to 1.53 ± 0.20 as the electron p_{T} increases from 7 to 25 GeV.

The number $N^{\text{SR}}_{\text{red}}$ of background events with one or two fake leptons from reducible sources in each SR is determined from the number of events in data in the corresponding CRs, $N^{\text{CR1}}_{\text{data}}$ and $N^{\text{CR2}}_{\text{data}}$, according to

$$N^{\text{SR}}_{\text{red}} = [N^{\text{CR1}}_{\text{data}} - N^{\text{CR1}}_{\text{irr}}] \times F_{w,1} - [N^{\text{CR2}}_{\text{data}} - N^{\text{CR2}}_{\text{irr}}] \times F_{w,1} \times F_{w,2}, \tag{2}$$

where $F_{w,1}$ and $F_{w,2}$ are the two weighted fake factors that are constructed using the leading and subleading in p_{T} loose leptons in the CRs, respectively. The small contributions from irreducible background processes in the CRs, $N^{\text{CR1,CR2}}_{\text{irr}}$, are evaluated using MC simulation and subtracted from the corresponding number of events seen in data. The second term removes the double counting of events with two fake leptons in the first term. Both CR1 and CR2 are dominated by the two-fake-lepton processes $t\bar{t}$ and $Z+\text{jets}$, thus the first term is roughly double the second term. Higher-order terms in F_w describing three- and four-fake-lepton backgrounds are neglected, as are some terms with a very small contribution; e.g., in $3L1T$ events, the contribution from events with two fake light leptons is negligible. A systematic uncertainty is applied to account for these neglected terms, as described in the following section.

A. Systematic uncertainties

Several sources of systematic uncertainty are considered for the SM background estimates and signal yield predictions. The systematic uncertainties affecting the simulation-based estimate can be divided into three components: MC statistical uncertainty, sources of experimental uncertainty (from identified physics objects e, μ, τ and jets, and also $E^{\text{miss}}_{\text{T}}$), and sources of theoretical uncertainty. The reducible background is affected by different sources of uncertainty associated with data counts in control regions and uncertainties in the weighted fake factors. The primary

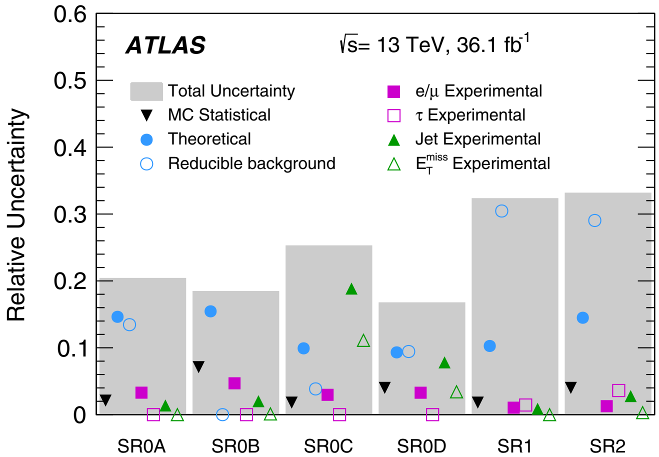


FIG. 3. Breakdown of the dominant systematic uncertainties in the background estimates for the signal regions. The individual uncertainties can be correlated, and do not necessarily sum in quadrature to the total background uncertainty. The text provides category details.

sources of systematic uncertainty, described below, are summarized in Fig. 3.

The MC statistical uncertainty for the simulation-based background estimate is small and less than 7% of the total background estimate in all signal regions. Systematic uncertainties in the SUSY signal yields from experimental and theoretical sources are typically of the order of 10% each. The experimental uncertainties include the uncertainties associated with electrons, muons, taus, jets, and $E_{\mathrm{T}}^{\mathrm{miss}}$, as well as the uncertainty associated with the simulation of pileup, and uncertainty in the luminosity (2.1%, following a methodology similar to that detailed in Ref. [85]). The uncertainties associated with pileup and luminosity are included in the total uncertainty in Fig. 3. The experimental uncertainties pertaining to electrons, muons and taus include the uncertainties due to the lepton identification efficiencies, lepton energy scale and energy resolution, isolation and trigger efficiencies. Systematic uncertainties from electron, muon, and tau sources are generally low in all signal regions, at about 5% relative to the total expected background. The uncertainties associated with jets are due to the jet energy scale, jet energy resolution and jet vertex tagging. Uncertainties in the object momenta are propagated to the $E_{\mathrm{T}}^{\mathrm{miss}}$ measurement, and additional uncertainties in $E_{\mathrm{T}}^{\mathrm{miss}}$ arising from energy deposits not associated with any reconstructed objects are also considered. The jet and $E_{\mathrm{T}}^{\mathrm{miss}}$ uncertainties are generally of the order of a few percent in the signal regions, but this rises to 21% (7%) in SR0C (SR0D), where a selection on $E_{\mathrm{T}}^{\mathrm{miss}}$ is made.

Theoretical uncertainties in the simulation-based estimates include the theoretical cross section uncertainties due to the choice of renormalization and factorization scales and PDFs, the acceptance uncertainty due to PDF and scale variations, and the choice of MC generator. The theoretical cross section uncertainties for the irreducible backgrounds used in this analysis are 12% for $t\bar{t}Z$ [67], 6% for ZZ [58], and 20% for the triboson samples [58], where the order of the cross section calculations is shown in Table II. For the Higgs boson samples, an uncertainty of 20% is used for WH, ZH and VBF [62], while uncertainties of 100% are assigned to $t\bar{t}H$ and ggH [86]. The uncertainties in the $t\bar{t}H$ and ggH estimates are assumed to be large to account for uncertainties in the acceptance, while the inclusive cross sections are known to better precision. Uncertainties arising from the choice of generator are determined by comparing the MadGraph5_aMC@NLO and SHERPA generators for $t\bar{t}Z$. Finally, the uncertainty in the ZZ and $t\bar{t}Z$ acceptance due to PDF variations, and due to varying the renormalization and factorization scales by factors of $1/2$ and 2, is also taken into account. In SR0A and SR0B, the theoretical uncertainties dominate the total uncertainty, mainly due to the 20% uncertainty from the $t\bar{t}Z$ MC generator choice, and the 10% uncertainty from the $t\bar{t}Z$ PDF/scale variations (25% for ZZ).

The uncertainty in the reducible background is dominated by the statistical uncertainty of the data events in the corresponding CR1 and CR2. The uncertainty in the weighted fake factors includes the MC statistical uncertainty in the process fractions, the uncertainty in the fake lepton scale factors, and the statistical uncertainty from the fake factors measured in simulation. The uncertainties for the fake factors from each fake-lepton type are treated as correlated across processes. Thus, since both CR1 and CR2 are dominated by two-fake-lepton processes with the same type of fake lepton, correlations in the fake factors applied to CR1 and CR2 result in a close cancellation of the uncertainties from the weighted fake factors between the first and second terms in Eq. (2). Finally, a conservative uncertainty is applied to account for the neglected terms in Eq. (2). For example, in $4L0T$ events the three- and

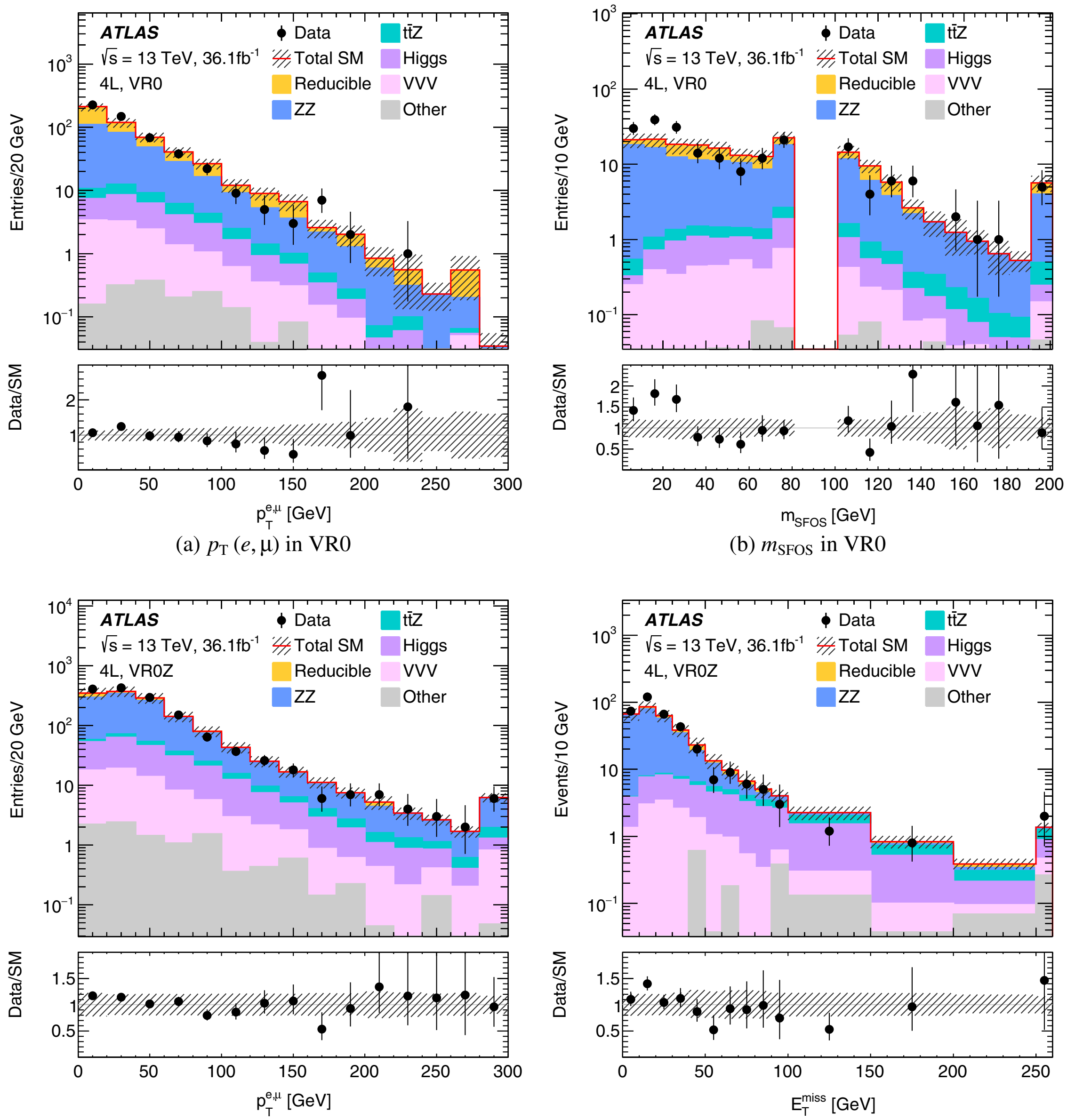
TABLE VI. Validation region definitions. The $p_{\mathrm{T}}(\tau_{\text{had-vis}})$ column denotes the p_{T} threshold used for the tau selection or veto.

Validation region	$N(e,\mu)$	$N(\tau_{\text{had-vis}})$	$p_{\mathrm{T}}(\tau_{\text{had-vis}})$	Z boson	Selection	Target
VR0	≥ 4	$= 0$	> 20 GeV	Veto	$m_{\text{eff}} < 600$ GeV	$t\bar{t}$, $Z+$jets, ZZ
VR0Z	≥ 4	$= 0$	> 20 GeV	Require first and veto second	$\cdots$	ZZ
VR1	$= 3$	≥ 1	> 30 GeV	Veto	$m_{\text{eff}} < 700$ GeV	$t\bar{t}$, $Z+$jets
VR2	$= 2$	≥ 2	> 30 GeV	Veto	$m_{\text{eff}} < 650$ GeV	$t\bar{t}$, $Z+$jets

TABLE VII. Expected and observed yields for 36.1 fb^{-1} in the validation regions. "Other" is the sum of the tWZ, $t\bar{t}WW$, and $t\bar{t}t\bar{t}$ backgrounds. Both the statistical and systematic uncertainties in the SM background are included in the uncertainties shown.

Sample	VR0	VR0Z	VR1	VR2
Observed	132	365	116	32
SM total	123 ± 11	334 ± 52	91 ± 19	28 ± 6
ZZ	65 ± 7	234 ± 23	8.8 ± 1.0	3.4 ± 0.5
$t\bar{t}Z$	3.9 ± 0.6	10.5 ± 1.5	1.76 ± 0.25	0.60 ± 0.10
Higgs	5 ± 4	43 ± 37	3.2 ± 2.9	1.3 ± 1.2
VVV	2.9 ± 0.6	16.1 ± 3.4	1.23 ± 0.27	0.29 ± 0.07
Reducible	46 ± 7	28 ± 26	76 ± 19	22 ± 6
Other	0.40 ± 0.07	2.7 ± 0.5	0.34 ± 0.06	0.16 ± 0.04

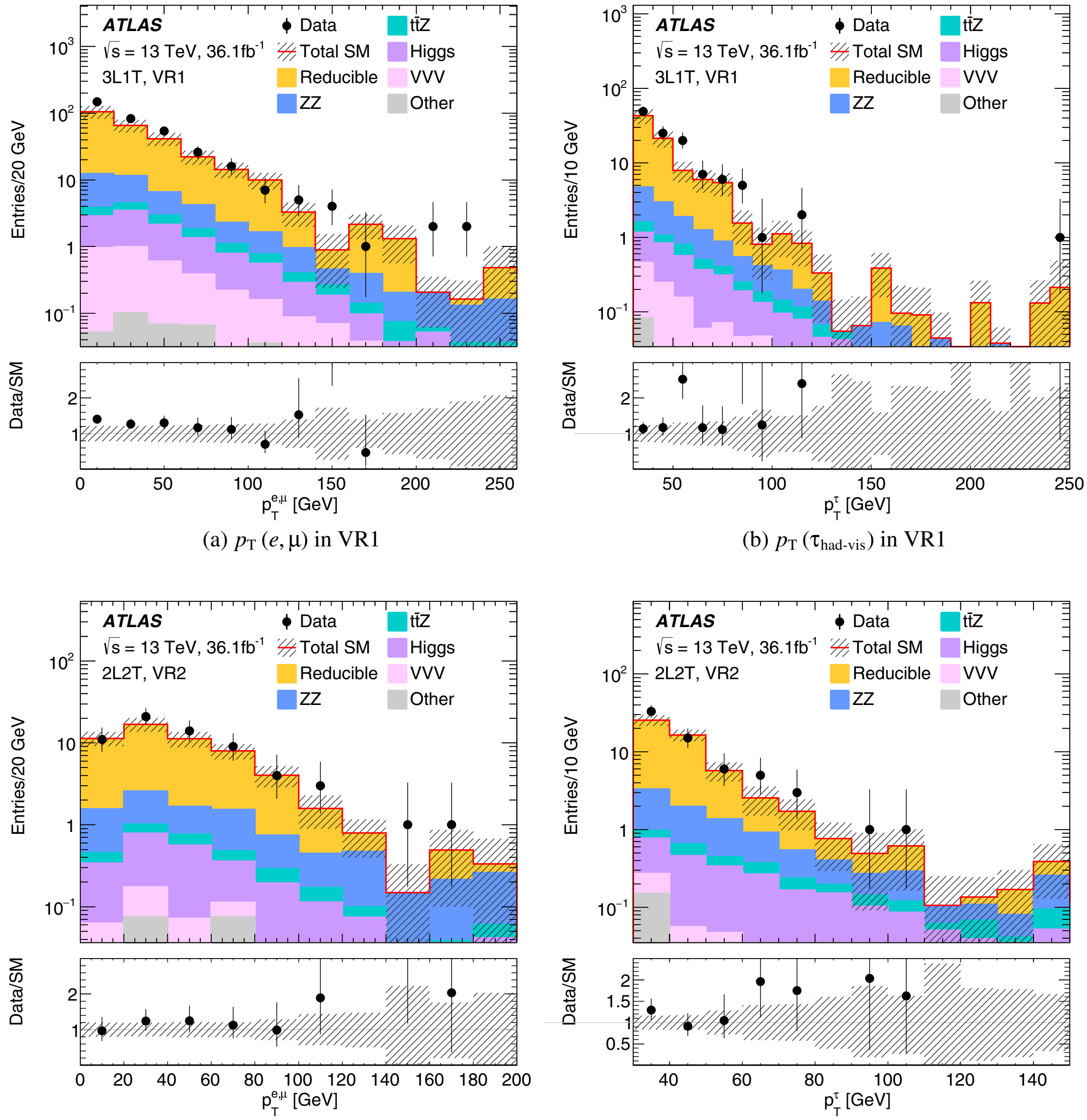
four-fake-lepton terms are neglected. Weighted fake factors are applied to data events with one signal and three loose light leptons to estimate an upper limit on this neglected contribution for each $4L0T$ validation region (VR) and SR. The calculated upper limit plus 1σ statistical uncertainty is added to the reducible background uncertainty, adding an absolute uncertainty of 0.14 events in SR0A. This is repeated for the $3L1T$ and $2L2T$ regions, accounting for the neglected terms with one or two fake light leptons as necessary, adding an absolute uncertainty of 0.07 events in SR1, and 0.20 events in SR2.



(a) $p_T\,(e,\mu)$ in VR0 (b) m_{SFOS} in VR0

(c) $p_T\,(e,\mu)$ in VR0Z (d) E_T^{miss} in VR0Z

FIG. 4. The distributions for data and the estimated SM backgrounds in VR0 and VR0Z for (a) and (c) the electron and muon p_T, (b) the SFOS invariant mass, and (d) the E_T^{miss}. "Other" is the sum of the tWZ, $t\bar{t}WW$, and $t\bar{t}t\bar{t}$ backgrounds. The last bin includes the overflow. Both the statistical and systematic uncertainties in the SM background are included in the shaded band.



(a) $p_{\mathrm{T}}\,(e,\mu)$ in VR1 (b) $p_{\mathrm{T}}\,(\tau_{\text{had-vis}})$ in VR1

(c) $p_{\mathrm{T}}\,(e,\mu)$ in VR2 (d) $p_{\mathrm{T}}\,(\tau_{\text{had-vis}})$ in VR2

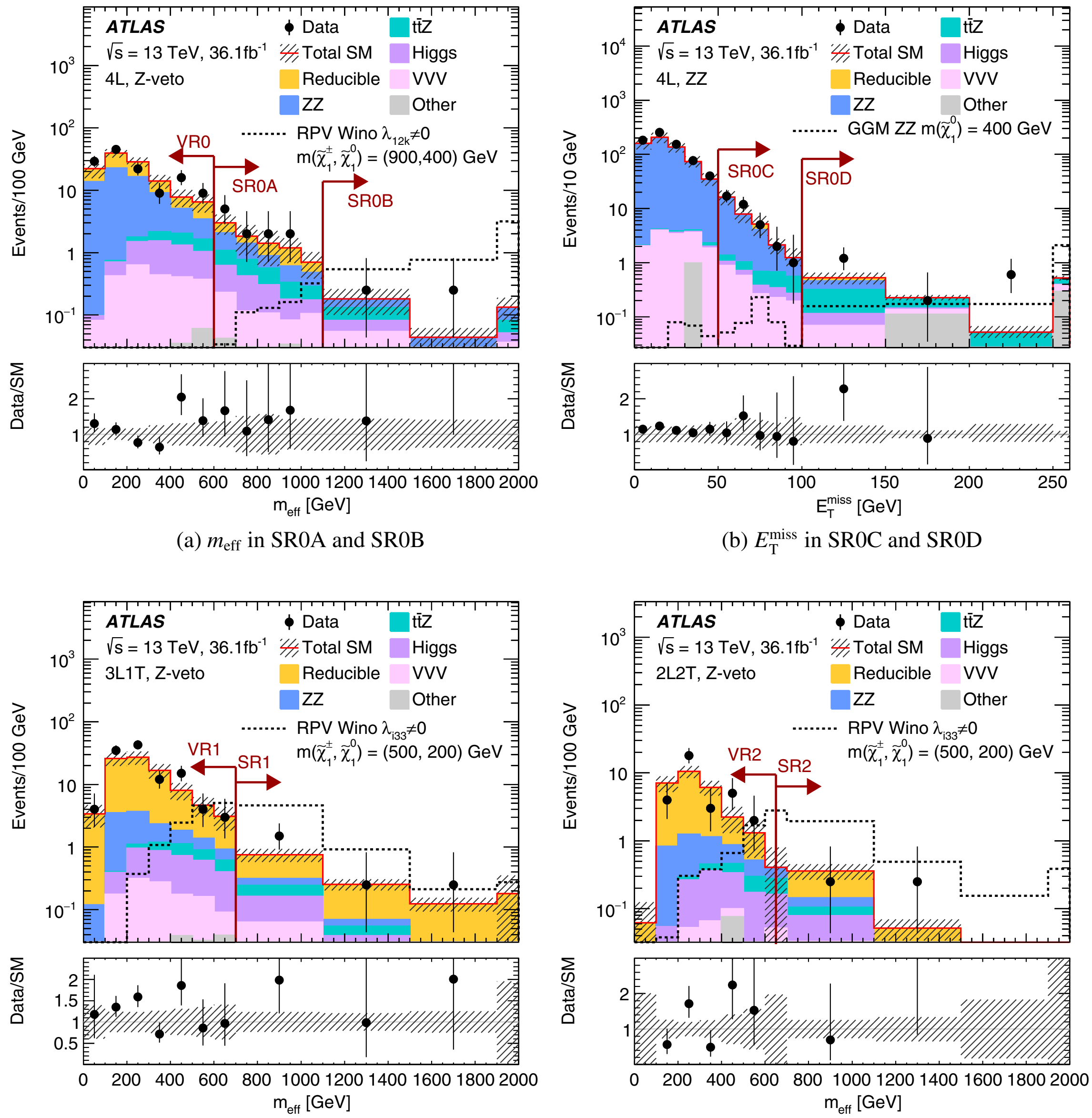
FIG. 5. The distributions for data and the estimated SM backgrounds in VR1 and VR2 for (a) and (c) the light lepton p_{T}, and (b) and (d) the tau p_{T}. "Other" is the sum of the tWZ, $t\bar{t}WW$, and $t\bar{t}t\bar{t}$ backgrounds. The last bin includes the overflow. Both the statistical and systematic uncertainties in the SM background are included in the shaded band.

B. Background modeling validation

The general modeling of both the irreducible and reducible backgrounds is tested in VRs that are defined to be adjacent to, yet disjoint from, the signal regions, as shown in Table VI. For signal regions that veto Z boson candidates, three VRs are defined by reversing the m_{eff} requirement, while for signal regions requiring two Z boson candidates, one VR is defined by vetoing the presence of a second Z boson candidate. The background model adopted in the VRs is the same as in the SRs, with the irreducible backgrounds obtained from MC simulation and the reducible background estimated from data using the fake-factor method with process fractions and loose lepton control regions corresponding to the VRs. The systematic uncertainties on the SM backgrounds in the VRs are evaluated as in Sec. VII A. The SM background in the VRs is dominated by ZZ, $t\bar{t}$ and $Z+$jets.

Observed and expected event yields in the VRs are shown in Table VII, where good agreement is seen in general within statistical and systematic uncertainties. No significant excesses above the SM expectations are observed in any VR.

The lepton p_{T}, m_{SFOS} and $E_{\mathrm{T}}^{\mathrm{miss}}$ distributions in the VRs are shown in Figs. 4 and 5. Figure 4(a) shows that VR0 has a slight downward trend in the ratio of the



(a) m_{eff} in SR0A and SR0B
(b) $E_{\mathrm{T}}^{\mathrm{miss}}$ in SR0C and SR0D
(c) m_{eff} in SR1
(d) m_{eff} in SR2

FIG. 6. The (a), (c) and (d) m_{eff} distribution for events passing the signal region requirements except the m_{eff} requirement in SR0A, SR0B, SR1 and SR2. The (b)$E_{\mathrm{T}}^{\mathrm{miss}}$ distribution is shown for events passing the signal region requirements except the $E_{\mathrm{T}}^{\mathrm{miss}}$ requirement in SR0C and SR0D. Distributions for data, the estimated SM backgrounds, and an example SUSY scenario are shown. "Other" is the sum of the tWZ, $t\bar{t}WW$, and $t\bar{t}t\bar{t}$ backgrounds. The last bin captures the overflow events. Both the statistical and systematic uncertainties in the SM background are included in the shaded band. The red arrows indicate the m_{eff} or $E_{\mathrm{T}}^{\mathrm{miss}}$ selections in the signal regions.

data to estimated SM background as the p_{T} of the leptons increases, which was found to be most noticeable in the p_{T} of the leading electron in the event. However, since the corresponding signal regions (SR0A and SR0B) require high m_{eff}, the potential impact of a small mismodeling of one electron in the event was found to be insignificant.

The m_{eff} distributions in VR0, VR1 and VR2 can be seen in the lower m_{eff} bins in Fig. 6.

VIII. RESULTS

The expected and observed yields in each signal region are reported in Table VIII, together with the statistical and systematic uncertainties in the background predictions. The observations are consistent with the SM expectations within a local significance of at most 2.3σ. The m_{eff} and $E_{\mathrm{T}}^{\mathrm{miss}}$ distributions for all events passing signal region requirements, except the m_{eff} or $E_{\mathrm{T}}^{\mathrm{miss}}$ requirement itself, are shown in Fig. 6.

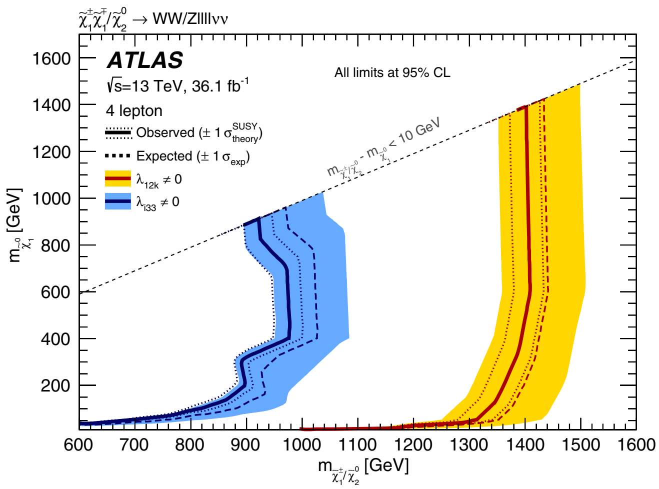
TABLE VIII. Expected and observed yields for 36.1 fb^{-1} in the signal regions. "Other" is the sum of the tWZ, $t\bar{t}WW$, and $t\bar{t}t\bar{t}$ backgrounds. Both the statistical and systematic uncertainties in the SM background are included in the uncertainties shown. Also shown are the model-independent limits calculated from the signal region observations; the 95% C.L. upper limit on the visible cross section times efficiency ($\langle\epsilon\sigma\rangle^{95}_{\text{obs}}$), the observed number of signal events (S^{95}_{obs}), and the signal events given the expected number of background events (S^{95}_{exp}, $\pm1\sigma$ variations of the expected number) calculated by performing pseudoexperiments for each signal region. The last three rows report the CL_b value for the background-only hypothesis, and finally the one-sided p_0-value and the local significance Z (the number of equivalent Gaussian standard deviations).

Sample	SR0A	SR0B	SR0C	SR0D	SR1	SR2
Observed	13	2	47	10	8	2
SM total	10.2 ± 2.1	1.31 ± 0.24	37 ± 9	4.1 ± 0.7	4.9 ± 1.6	2.3 ± 0.8
ZZ	2.7 ± 0.7	0.33 ± 0.10	28 ± 9	0.84 ± 0.34	0.35 ± 0.09	0.33 ± 0.08
$t\bar{t}Z$	2.5 ± 0.6	0.47 ± 0.13	3.2 ± 0.4	1.62 ± 0.23	0.54 ± 0.11	0.31 ± 0.08
Higgs	1.2 ± 1.2	0.13 ± 0.13	0.9 ± 0.8	0.28 ± 0.25	0.5 ± 0.5	0.32 ± 0.32
VVV	0.79 ± 0.17	0.22 ± 0.05	2.7 ± 0.6	0.64 ± 0.14	0.18 ± 0.04	0.20 ± 0.06
Reducible	2.4 ± 1.4	$0.000^{+0.005}_{-0.000}$	$0.9^{+1.4}_{-0.9}$	$0.23^{+0.38}_{-0.23}$	3.1 ± 1.5	1.1 ± 0.7
Other	0.53 ± 0.06	0.165 ± 0.018	0.85 ± 0.19	0.45 ± 0.10	0.181 ± 0.022	0.055 ± 0.012
$\langle\epsilon\sigma\rangle^{95}_{\text{obs}}$ fb	0.32	0.14	0.87	0.36	0.28	0.13
S^{95}_{obs}	12	4.9	31	13	10	4.6
S^{95}_{exp}	$9.3^{+3.6}_{-2.3}$	$3.9^{+1.6}_{-0.8}$	23^{+8}_{-5}	$6.1^{+2.1}_{-1.3}$	$6.5^{+3.5}_{-1.3}$	$4.7^{+2.0}_{-1.3}$
CL_b	0.76	0.74	0.83	0.99	0.86	0.47
p_0	0.23	0.25	0.15	0.011	0.13	0.61
Z	0.75	0.69	1.0	2.3	1.2	0

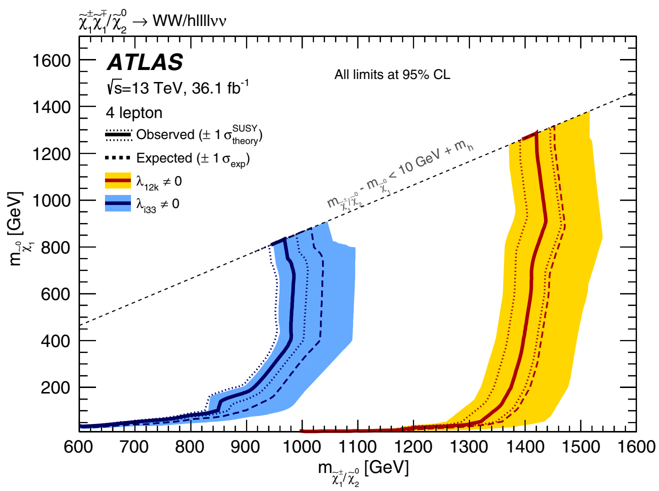
The HistFitter [87] software framework is used for the statistical interpretation of the results. In order to quantify the probability for the background-only hypothesis to fluctuate to the observed number of events or higher, a one-sided p_0-value is calculated using pseudoexperiments, where the profile likelihood ratio is used as a test statistic [88] to exclude the signal-plus-background hypothesis. A signal model can be excluded at 95% confidence level (C.L.) if the CL_s [89] of the signal-plus-background hypothesis is below 0.05. For each signal region, the expected and observed upper limits at 95% C.L. on the number of beyond-the-SM events (S^{95}_{exp} and S^{95}_{obs}) are calculated using the model-independent signal fit. The 95% C.L. upper limits on the signal cross section times efficiency ($\langle\epsilon\sigma\rangle^{95}_{\text{obs}}$) and the CL_b value for the background-only hypothesis are also calculated for each signal region.

The number of observed events in each signal region is used to set exclusion limits in the SUSY models, where the statistical combination of all disjoint signal regions is used. For overlapping signal regions, specifically SR0A and SR0B, and also SR0C and SR0D, the signal region with the better expected exclusion is used in the combination. Experimental uncertainties affecting irreducible backgrounds, as well as the simulation-based estimate of the weighted fake factors, are treated as correlated between regions and processes. Uncertainties associated to the data-driven estimate of the reducible background are correlated between regions only. Theoretical uncertainties in the irreducible background and signal are treated as correlated between regions, while statistical uncertainties from MC simulation and data in the CR are treated as uncorrelated between regions and processes. For the exclusion limits, the observed and expected 95% C.L. limits are calculated by performing pseudoexperiments for each SUSY model point, taking into account the theoretical and experimental uncertainties in the SM background and the experimental uncertainties in the signal. For all expected and observed exclusion limit contours, the $\pm1\sigma_{\text{exp}}$ uncertainty band indicates the impact on the expected limit of the systematic and statistical uncertainties included in the fit. The $\pm1\sigma^{\text{SUSY}}_{\text{theory}}$ uncertainty lines around the observed limit illustrate the change in the observed limit as the nominal signal cross section is scaled up and down by the theoretical cross section uncertainty.

Figures 7 and 8 show the exclusion contours for the RPV models considered here, where SR0B dominates the exclusion for $LL\bar{E}12k$ models, and the combination of SR1 and SR2 is important for the $LL\bar{E}i33$ models. The exclusion limits in the RPV models extend to high masses, due to the high lepton multiplicity in these scenarios ($\tilde{\chi}^0_1 \to \ell\ell\nu$ with 100% branching ratio) and the high efficiency of the m_{eff} selections. In the RPV wino NLSP $LL\bar{E}12k$ models shown in Figs. 7(a) and 7(b), $\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ masses up to $\sim$1.46 TeV are excluded for $m(\tilde{\chi}^0_1) > 500$ GeV. The sensitivity is reduced for large mass splittings between the $\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ and the $\tilde{\chi}^0_1$, where the decay products are strongly boosted, and $\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ masses

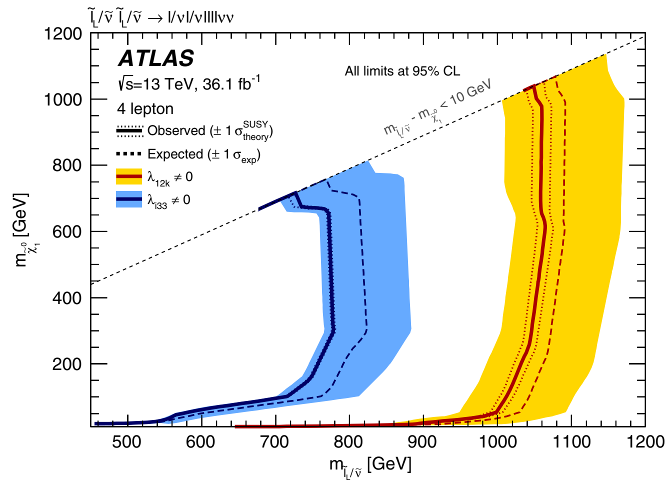


(a) RPV wino W/Z NLSP

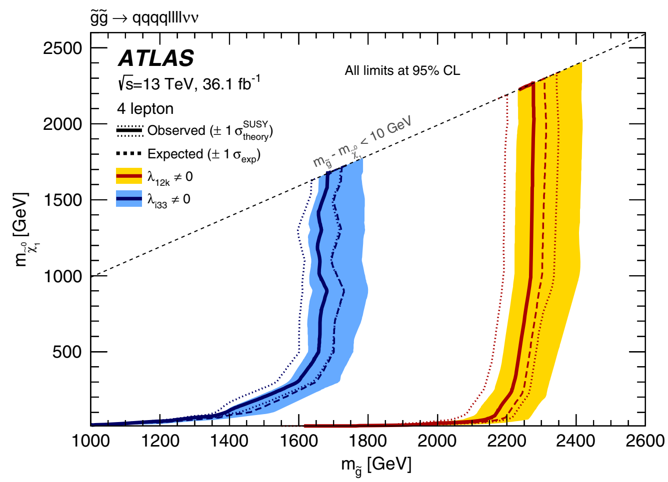


(b) RPV wino W/h NLSP

FIG. 7. Expected (dashed) and observed (solid) 95% C.L. exclusion limits on (a) wino W/Z NLSP, and (b) wino W/h NLSP pair production with RPV $\tilde{\chi}_1^0$ decays via λ_{12k}, or λ_{i33} where $i, k \in 1, 2$. The limits are set using the statistical combination of disjoint signal regions. Where the signal regions are not mutually exclusive, the observed $\mathrm{CL_s}$ value is taken from the signal region with the better expected $\mathrm{CL_s}$ value.



(a) RPV $\tilde{\ell}_\mathrm{L}/\tilde{\nu}$ NLSP



(b) RPV $\tilde{g}$ NLSP

FIG. 8. Expected (dashed) and observed (solid) 95% C.L. exclusion limits on (a) $\tilde{\ell}_\mathrm{L}/\tilde{\nu}$ NLSP, and (b) gluino NLSP pair production with RPV $\tilde{\chi}_1^0$ decays via λ_{12k}, or λ_{i33} where $i, k \in 1, 2$. The limits are set using the statistical combination of disjoint signal regions. Where the signal regions are not mutually exclusive, the observed $\mathrm{CL_s}$ value is taken from the signal region with the better expected $\mathrm{CL_s}$ value.

up to ∼1.32 TeV are excluded for $m(\tilde{\chi}_1^0) > 50$ GeV. Figures 7(a) and 7(b) also show exclusion contours for the RPV wino NLSP $LL\bar{E}i33$ models, where $\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$ masses up to ∼980 GeV are excluded for 400 GeV < $m(\tilde{\chi}_1^0) <$ 700 GeV. The sensitivity is also reduced for large mass differences between the $\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$ and the $\tilde{\chi}_1^0$, where the tau leptons, in particular, are collimated. These results extend the limits set in a similar model considering only $\tilde{\chi}_1^+\tilde{\chi}_1^-$ production in Ref. [22] by around 400–750 GeV.

Figure 8(a) shows exclusion contours for the RPV $\tilde{\ell}_\mathrm{L}/\tilde{\nu}$ NLSP model, where left-handed slepton/sneutrino masses are excluded up to ∼1.06 TeV for $m(\tilde{\chi}_1^0) \simeq 600$ GeV for $LL\bar{E}12k$ models, and up to 780 GeV for $m(\tilde{\chi}_1^0) \simeq 300$ GeV for $LL\bar{E}i33$ models. These results extend the limits set in a similar model considering only $\tilde{\ell}_\mathrm{L}\tilde{\ell}_\mathrm{L}$ production in Ref. [22] by around 200–400 GeV.

The exclusion contours for the RPV $\tilde{g}$ NLSP model are shown in Fig. 8(b), where gluino masses are excluded up to ∼2.25 TeV for $m(\tilde{\chi}_1^0) > 1$ TeV for $LL\bar{E}12k$ models, and up to ∼1.65 TeV for $m(\tilde{\chi}_1^0) > 500$ GeV for $LL\bar{E}i33$ models. These results significantly improve upon limits set in a similar model in Ref. [22] by around 500–700 GeV.

Figure 9 shows the exclusion contours for the Higgsino GGM models considered here. The exclusion is dominated by SR0C and SR0D for low and high Higgsino masses,

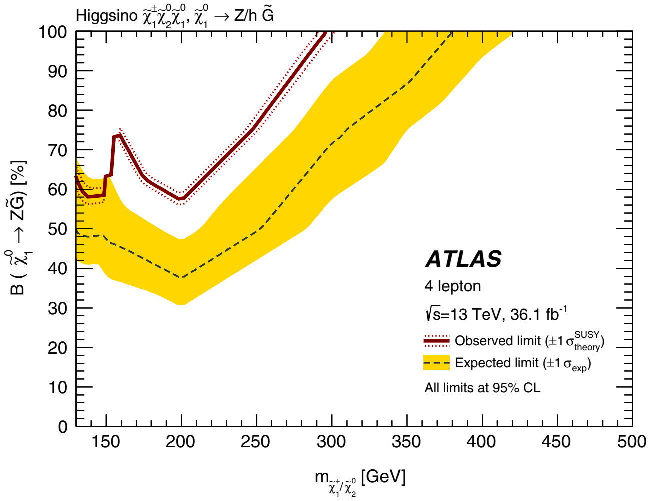


FIG. 9. Expected (dashed) and observed (solid) 95% C.L. exclusion limits on the Higgsino GGM models. The limits are set using the statistical combination of disjoint signal regions. Where the signal regions are not mutually exclusive, the observed $\mathrm{CL_s}$ value is taken from the signal region with the better expected $\mathrm{CL_s}$ value.

respectively. Higgsino-like $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0/\tilde{\chi}_1^0$ with masses up to 295 GeV are excluded in scenarios with a branching ratio $\mathcal{B}(\tilde{\chi}_1^0 \rightarrow Z + \tilde{G}) = 100\%$, while the exclusion is weakened for scenarios with $\mathcal{B}(\tilde{\chi}_1^0 \rightarrow Z + \tilde{G}) < 100\%$. This analysis is not sensitive to scenarios with $\mathcal{B}(\tilde{\chi}_1^0 \rightarrow h + \tilde{G}) = 100\%$, where final states with lower lepton multiplicity may be more successful. The expected limit is comparable to those set using the combination of multiple analysis channels in Ref. [90], but the observed limit is not as strong.

IX. CONCLUSION

Results are reported from a search for new physics in the final state with four or more leptons (electrons, muons or taus), using 36.1 fb^{-1} of $\sqrt{s} = 13$ TeV proton-proton collision data collected by the ATLAS detector at the LHC in 2015 and 2016. Six signal regions are defined with up to two hadronically decaying taus, and target lepton-rich RPV and RPC SUSY signals with selections requiring large effective mass or missing transverse momentum, and the presence or absence of reconstructed Z boson candidates. Data yields in the signal regions are consistent with Standard Model expectations. The results are interpreted in simplified models of NLSP pair production with RPV LSP decays, where wino-like $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$, $\tilde{\ell}_L/\tilde{\nu}$, and $\tilde{g}$ masses up to 1.46 TeV, 1.06 GeV, and 2.25 TeV are excluded, respectively. The results are also interpreted in simplified Higgsino GGM models, where Higgsino-like $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0/\tilde{\chi}_1^0$ masses up to 295 GeV are excluded in scenarios with a 100% branching ratio for $\tilde{\chi}_1^0$ decay to a Z boson and a gravitino.

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[1] Yu. A. Golfand and E. P. Likhtman, Pis'ma Zh. Eksp. Teor. Fiz. **13**, 452 (1971) [Extension of the algebra of Poincare group generators and violation of P invariance, JETP Lett. **13**, 323 (1971)].
[2] D. V. Volkov and V. P. Akulov, Is the neutrino a Goldstone particle?, Phys. Lett. B **46**, 109 (1973).
[3] J. Wess and B. Zumino, Supergauge transformations in four dimensions, Nucl. Phys. **B70**, 39 (1974).
[4] J. Wess and B. Zumino, Supergauge invariant extension of quantum electrodynamics, Nucl. Phys. **B78**, 1 (1974).
[5] S. Ferrara and B. Zumino, Supergauge invariant Yang-Mills theories, Nucl. Phys. **B79**, 413 (1974).
[6] A. Salam and J. A. Strathdee, Supersymmetry and Non-Abelian gauges, Phys. Lett. B **51**, 353 (1974).
[7] N. Sakai, Naturalness in supersymmetric GUTs, Z. Phys. C **11**, 153 (1981).
[8] S. Dimopoulos, S. Raby, and F. Wilczek, Supersymmetry and the scale of unification, Phys. Rev. D **24**, 1681 (1981).
[9] L. E. Ibanez and G. G. Ross, Low-energy predictions in supersymmetric grand unified theories, Phys. Lett. B **105**, 439 (1981).
[10] S. Dimopoulos and H. Georgi, Softly broken supersymmetry and SU(5), Nucl. Phys. **B193**, 150 (1981).
[11] S. Ahmed *et al.*, Constraints on Nucleon Decay via "Invisible" Modes from the Sudbury Neutrino Observatory, Phys. Rev. Lett. **92**, 102004 (2004).
[12] G. R. Farrar and P. Fayet, Phenomenology of the production, decay, and detection of new hadronic states associated with supersymmetry, Phys. Lett. B **76**, 575 (1978).
[13] D0 Collaboration, Search for Supersymmetry via Associated Production of Charginos and Neutralinos in Final States with Three Leptons, Phys. Rev. Lett. **95**, 151805 (2005).
[14] D0 Collaboration, Search for associated production of charginos and neutralinos in the trilepton final state using 2.3 fb^{-1} of data, Phys. Lett. B **680**, 34 (2009).
[15] D0 Collaboration, Search for R-parity violating supersymmetry via the LL anti-E couplings λ_{121}, λ_{122} or λ_{133} in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$-TeV, Phys. Lett. B **638**, 441 (2006).
[16] D0 Collaboration, Search for Chargino-Neutralino Production in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$-TeV, Phys. Rev. Lett. **99**, 191806 (2007).
[17] CDF Collaboration, Search for Supersymmetry in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$-TeV Using the Trilepton Signature of Chargino-Neutralino Production, Phys. Rev. Lett. **101**, 251801 (2008).
[18] CDF Collaboration, Search for Anomalous Production of Multilepton Events in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$-TeV, Phys. Rev. Lett. **98**, 131804 (2007).
[19] ATLAS Collaboration, Search for R-parity-violating supersymmetry in events with four or more leptons in $\sqrt{s} =$ 7 TeV pp collisions with the ATLAS detector, J. High Energy Phys. 12 (2012) 124.
[20] ATLAS Collaboration, Search for Supersymmetry in Events with Three Leptons and Missing Transverse Momentum in $\sqrt{s} = 7$ TeV pp Collisions with the ATLAS Detector, Phys. Rev. Lett. **108**, 261804 (2012).
[21] ATLAS Collaboration, Search for direct production of charginos and neutralinos in events with three leptons and missing transverse momentum in $\sqrt{s} = 8$ TeV pp collisions with the ATLAS detector, J. High Energy Phys. 04 (2014) 169.
[22] ATLAS Collaboration, Search for supersymmetry in events with four or more leptons in $\sqrt{s} = 8$ TeV pp collisions with the ATLAS detector, Phys. Rev. D **90**, 052001 (2014).
[23] CMS Collaboration, Search for physics beyond the Standard Model using multilepton signatures in pp collisions at $\sqrt{s} = 7$ TeV, Phys. Lett. B **704**, 411 (2011).
[24] CMS Collaboration, Search for anomalous production of multilepton events in pp collisions at $\sqrt{s} = 7$ TeV, J. High Energy Phys. 06 (2012) 169.
[25] CMS Collaboration, Search for electroweak production of charginos and neutralinos using leptonic final states in pp collisions at $\sqrt{s}$=7 TeV, J. High Energy Phys. 11 (2012) 147.
[26] CMS Collaboration, Search for Top Squarks in R-Parity-Violating Supersymmetry Using Three or More Leptons and b-Tagged Jets, Phys. Rev. Lett. **111**, 221801 (2013).
[27] CMS Collaboration, Search for anomalous production of events with three or more leptons in pp collisions at $\sqrt{s} = 8$ TeV, Phys. Rev. D **90**, 032006 (2014).
[28] P. Fayet, Supersymmetry and weak, electromagnetic and strong interactions, Phys. Lett. B **64**, 159 (1976).
[29] P. Fayet, Spontaneously broken supersymmetric theories of weak, electromagnetic and strong interactions, Phys. Lett. B **69**, 489 (1977).
[30] M. Carena, S. Heinemeyer, O. Stål, C. E. M. Wagner, and G. Weiglein, MSSM Higgs boson searches at the LHC: Benchmark scenarios after the discovery of a Higgs-like particle, Eur. Phys. J. C **73**, 2552 (2013).
[31] 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**, 1 (2012).
[32] CMS Collaboration, Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC, Phys. Lett. B **716**, 30 (2012).
[33] ATLAS and CMS Collaborations, Measurements of the Higgs boson production and decay rates and constraints on its couplings from a combined ATLAS and CMS analysis of the LHC pp collision data at $\sqrt{s} = 7$ and 8 TeV, Report No. ATLAS-CONF-2015-044 [https://cds.cern.ch/record/2052552].
[34] S. Weinberg, Supersymmetry at ordinary energies. 1. Masses and conservation laws, Phys. Rev. D **26**, 287 (1982).
[35] N. Sakai and T. Yanagida, Proton decay in a class of supersymmetric grand unified models, Nucl. Phys. **B197**, 533 (1982).
[36] R. Barbier *et al.*, R-parity violating supersymmetry, Phys. Rep. **420**, 1 (2005).
[37] ATLAS Collaboration, Search for massive, long-lived particles using multitrack displaced vertices or displaced lepton pairs in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector, Phys. Rev. D **92**, 072004 (2015).
[38] R. Barbieri and G. F. Giudice, Upper bounds on supersymmetric particle masses, Nucl. Phys. **B306**, 63 (1988).
[39] B. de Carlos and J. A. Casas, One loop analysis of the electroweak breaking in supersymmetric models and the fine-tuning problem, Phys. Lett. B **309**, 320 (1993).

[40] The LEP SUSY Working Group and the ALEPH, DELPHI, L3 and OPAL experiments, Notes No. LEPSUSYWG/01-03.1 and No. 04-01.1 [http://lepsusy.web.cern.ch/lepsusy/Welcome.html].
[41] ATLAS Collaboration, Search for electroweak production of supersymmetric states in scenarios with compressed mass spectra at $\sqrt{s} = 13$ TeV with the ATLAS detector, Phys. Rev. D **97**, 052010 (2018).
[42] A. B. Lahanas and D. V. Nanopoulos, The road to no scale supergravity, Phys. Rep. **145**, 1 (1987).
[43] H. P. Nilles, Supersymmetry, supergravity and particle physics, Phys. Rep. **110**, 1 (1984).
[44] P. Meade, N. Seiberg, and D. Shih, General gauge mediation, Prog. Theor. Phys. Suppl. **177**, 143 (2009).
[45] ATLAS Collaboration, The ATLAS experiment at the CERN Large Hadron Collider, J. Instrum. **3**, S08003 (2008).
[46] ATLAS Collaboration, ATLAS insertable B-layer technical design report, Report No. CERN-LHCC-2010-013, 2010 [http://cds.cern.ch/record/1291633].
[47] ATLAS Collaboration, 2015 start-up trigger menu and initial performance assessment of the ATLAS trigger using run-2 data, Report No. ATL-DAQ-PUB-2016-001, 2016 [http://cds.cern.ch/record/2136007].
[48] W. Beenakker, R. Höpker, M. Spira, and P. M. Zerwas, Squark and gluino production at hadron colliders, Nucl. Phys. **B492**, 51 (1997).
[49] A. Kulesza and L. Motyka, Threshold Resummation for Squark-Antisquark and Gluino-Pair production at the LHC, Phys. Rev. Lett. **102**, 111802 (2009).
[50] A. Kulesza and L. Motyka, Soft gluon resummation for the production of gluino-gluino and squark-antisquark pairs at the LHC, Phys. Rev. D **80**, 095004 (2009).
[51] W. Beenakker, S. Brensing, M. Krämer, A. Kulesza, E. Laenen, and I. Niessen, Soft-gluon resummation for squark and gluino hadroproduction, J. High Energy Phys. 12 (2009) 041.
[52] W. Beenakker, S. Brensing, M. Krämer, A. Kulesza, E. Laenen, L. Motyka, and I. Niessen, Squark and gluino hadroproduction, Int. J. Mod. Phys. A **26**, 2637 (2011).
[53] B. Fuks, M. Klasen, D. R. Lamprea, and M. Rothering, Gaugino production in proton-proton collisions at a center-of-mass energy of 8 TeV, J. High Energy Phys. 10 (2012) 081.
[54] B. Fuks, M. Klasen, D. R. Lamprea, and M. Rothering, Precision predictions for electroweak superpartner production at hadron colliders with Resummino, Eur. Phys. J. C **73**, 2480 (2013).
[55] B. Fuks, M. Klasen, D. R. Lamprea, and M. Rothering, Revisiting slepton pair production at the Large Hadron Collider, J. High Energy Phys. 01 (2014) 168.
[56] C. Borschensky, M. Krämer, A. Kulesza, M. Mangano, S. Padhi, T. Plehn, and X. Portell, Squark and gluino production cross sections in pp collisions at $\sqrt{s} = 13$, 14, 33 and 100 TeV, Eur. Phys. J. C **74**, 3174 (2014).
[57] T. Gleisberg, S. Höche, F. Krauss, M. Schönherr, S. Schumann, F. Siegert, and J. Winter, Event generation with SHERPA 1.1, J. High Energy Phys. 02 (2009) 007.
[58] ATLAS Collaboration, Multiboson simulation for 13 TeV ATLAS analyses, Report No. ATL-PHYS-PUB-2016-002, 2016 [https://cds.cern.ch/record/2119986].
[59] R. D. Ball *et al.*, Parton distributions for the LHC run II, J. High Energy Phys. 04 (2015) 040.
[60] S. Alioli, P. Nason, C. Oleari, and E. Re, A general framework for implementing NLO calculations in shower Monte Carlo programs: The POWHEG BOX, J. High Energy Phys. 06 (2010) 043.
[61] T. Sjöstrand, S. Ask, J. R. Christiansen, R. Corke, N. Desai, P. Ilten, S. Mrenna, S. Prestel, C. O. Rasmussen, and P. Z. Skands, An introduction to PYTHIA 8.2, Comput. Phys. Commun. **191**, 159 (2015).
[62] D. de Florian *et al.*, Handbook of LHC Higgs cross sections: 4. Deciphering the nature of the Higgs sector, arXiv:1610.07922.
[63] ATLAS Collaboration, Measurement of the Z/γ^* boson transverse momentum distribution in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector, J. High Energy Phys. 09 (2014) 145.
[64] H.-L. Lai, M. Guzzi, J. Huston, Z. Li, P. M. Nadolsky, J. Pumplin, and C.-P. Yuan, New parton distributions for collider physics, Phys. Rev. D **82**, 074024 (2010).
[65] ATLAS Collaboration, ATLAS PYTHIA 8 tunes to 7 TeV data, Report No. ATL-PHYS-PUB-2014-021, 2014 [https://cds.cern.ch/record/1966419].
[66] S. Frixione and B. R. Webber, Matching NLO QCD computations and parton shower simulations, J. High Energy Phys. 06 (2002) 029.
[67] ATLAS Collaboration, Modeling of the $t\bar{t}H$ and $t\bar{t}V (V = W, Z)$ processes for $\sqrt{s} = 13$ TeV ATLAS analyses, Report No. ATL-PHYS-PUB-2016-005, 2016 [https://cds.cern.ch/record/2120826].
[68] R. D. Ball *et al.*, Parton distributions with LHC data, Nucl. Phys. **B867**, 244 (2013).
[69] J. Alwall, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, O. Mattelaer, H.-S. Shao, T. Stelzer, P. Torrielli, and M. Zaro, The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations, J. High Energy Phys. 07 (2014) 079.
[70] T. Sjöstrand, S. Mrenna, and P. Z. Skands, PYTHIA 6.4 physics and manual, J. High Energy Phys. 05 (2006) 026.
[71] ATLAS Collaboration, Simulation of top-quark production for the ATLAS experiment at $\sqrt{s} = 13$ TeV, Report No. ATL-PHYS-PUB-2016-004, 2016 [https://cds.cern.ch/record/2120417].
[72] P. Z. Skands, Tuning Monte Carlo generators: The Perugia tunes, Phys. Rev. D **82**, 074018 (2010).
[73] ATLAS Collaboration, Monte Carlo generators for the production of a W or Z/γ^* boson in association with jets at ATLAS in run 2, Report No. ATL-PHYS-PUB-2016-003, 2016 [https://cds.cern.ch/record/2120133].
[74] S. Agostinelli *et al.*, GEANT4: A simulation toolkit, Nucl. Instrum. Methods Phys. Res., Sect. A **506**, 250 (2003).
[75] ATLAS Collaboration, The ATLAS simulation infrastructure, Eur. Phys. J. C **70**, 823 (2010).
[76] ATLAS Collaboration, Electron efficiency measurements with the ATLAS detector using the 2015 LHC proton-proton collision data, Report No. ATLAS-CONF-2016-024, 2016 [https://cds.cern.ch/record/2157687].
[77] ATLAS Collaboration, Muon reconstruction performance of the ATLAS detector in proton-proton collision data at $\sqrt{s} = 13$ TeV, Eur. Phys. J. C **76**, 292 (2016).

[78] M. Cacciari, G. P. Salam, and G. Soyez, The anti-k_t jet clustering algorithm, J. High Energy Phys. 04 (2008) 063.
[79] ATLAS Collaboration, Jet calibration and systematic uncertainties for jets reconstructed in the ATLAS detector at $\sqrt{s} = 13$ TeV, Report No. ATL-PHYS-PUB-2015-015, 2015 [https://cds.cern.ch/record/2037613].
[80] ATLAS Collaboration, Performance of pileup mitigation techniques for jets in pp collisions with the ATLAS detector, Eur. Phys. J. C **76**, 581 (2016).
[81] ATLAS Collaboration, Jet calibration and systematic uncertainties for jets reconstructed in the ATLAS detector at $\sqrt{s} = 13$ TeV, Report No. ATL-PHYS-PUB-2015-015, 2015 [http://cds.cern.ch/record/2037613].
[82] ATLAS Collaboration, Measurement of the tau lepton reconstruction and identification performance in the ATLAS experiment using pp collisions at $\sqrt{s} = 13$ TeV, Report No. ATLAS-CONF-2017-029, 2017 [https://cds.cern.ch/record/2261772].
[83] ATLAS Collaboration, Reconstruction, energy calibration, and identification of hadronically decaying tau leptons in the ATLAS experiment for run-2 of the LHC, Report No. ATL-PHYS-PUB-2015-045, 2015 [https://cds.cern.ch/record/2064383].
[84] ATLAS Collaboration, Performance of missing transverse momentum reconstruction for the ATLAS detector in the first proton-proton collisions at $\sqrt{s} = 13$ TeV, Report No. ATL-PHYS-PUB-2015-027, 2015 [http://cds.cern.ch/record/2037904].
[85] ATLAS Collaboration, Improved luminosity determination in pp collisions at $\sqrt{s} = 7$ TeV using the ATLAS detector at the LHC, Eur. Phys. J. C **73**, 2518 (2013).
[86] S. Dittmaier *et al.*, Handbook of LHC Higgs cross sections: 2. Differential distributions, arXiv:1201.3084.
[87] M. Baak, G. J. Besjes, D. Côté, A. Koutsman, J. Lorenz, and D. Short, HistFitter software framework for statistical data analysis, Eur. Phys. J. C **75**, 153 (2015).
[88] G. Cowan, K. Cranmer, E. Gross, and O. Vitells, Asymptotic formulas for likelihood-based tests of new physics, Eur. Phys. J. C **71**, 1554 (2011).
[89] A. L. Read, Presentation of search results: The CL(s) technique, J. Phys. G **28**, 2693 (2002).
[90] CMS Collaboration, Searches for electroweak neutralino and chargino production in channels with Higgs, Z, and W bosons in pp collisions at 8 TeV, Phys. Rev. D **90**, 092007 (2014).
[91] ATLAS Collaboration, ATLAS computing acknowledgements 2016–2017, Report No. ATL-GEN-PUB-2016-002, 2016 [https://cds.cern.ch/record/2202407].

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