ATLAS CONF Note
ATLAS-CONF-2022-006
25th March 2022

Search for direct pair production of sleptons and charginos decaying to two leptons and neutralinos with mass splittings near the W boson mass in $\sqrt{s} = 13$ TeV pp collisions with the ATLAS detector

The ATLAS Collaboration

A search for the electroweak production of charged slepton or chargino pairs decaying into two-lepton final states with missing transverse momentum is presented. Two simplified models of R-parity-conserving supersymmetry are considered: direct pair-production of sleptons ($\tilde{\ell}\tilde{\ell}$) and direct pair-production of the lightest charginos ($\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$), which decay into W bosons. The lightest neutralino ($\tilde{\chi}_1^0$) is assumed to be the lightest supersymmetric particle (LSP). The analysis targets the mass regions $(m(\tilde{\ell}) - m(\tilde{\chi}_1^0))$ and $(m(\tilde{\chi}_1^{\pm}) - m(\tilde{\chi}_1^0))$ close to the W boson mass (“moderately compressed" regions). The search uses 139 fb^{-1} of proton–proton collisions recorded by the ATLAS detector at the Large Hadron Collider at $\sqrt{s} = 13$ TeV. No significant excesses over the expected background are observed. Exclusion limits on the simplified models under study are reported in the $(\tilde{\ell}, \tilde{\chi}_1^0)$ and $(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0)$ mass planes at 95% confidence level (CL). Sleptons with masses up to 150 GeV are excluded at 95% CL for the case of a mass splitting between sleptons and the LSP of 50 GeV. Chargino masses up to 135 GeV are excluded at 95% CL for the case of a mass splitting between the chargino and the LSP up to 100 GeV.

ATLAS-CONF-2022-006
28 March 2022

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1 Introduction

Weak scale Supersymmetry (SUSY) [1–6] is a theoretical extension of the Standard Model (SM), which can solve the fine-tuning problem through the addition of a new fermion/boson supersymmetric partner to each boson/fermion in the SM. In SUSY models with R-parity conservation [7], SUSY particles must be produced in pairs and the lightest supersymmetric particle (LSP) is stable and weakly interacting, thus a candidate for dark matter [8, 9].

The SUSY particle production cross-sections at Large Hadron Collider (LHC) are highly dependent on their masses. Squarks and gluinos are strongly produced and have significantly larger production cross-sections than non-coloured SUSY particles of equal masses, such as the sleptons (superpartners of the SM leptons) and the electroweakinos (superpartners of the SM Higgs and the electroweak gauge bosons, known as higgsinos, winos and binos, and collectively known as electroweakinos). The electroweakinos mix to form chargino ($\tilde{\chi}_i^{\pm}, i = 1, 2$) and neutralino ($\tilde{\chi}_j^0, j = 1, 2, 3, 4$) mass eigenstates (states are ordered by increasing values of their mass).

Electroweak scale SUSY with light smuons (superpartners of the SM muons) and a light LSP can explain the $(g-2)_\mu$ anomaly [10, 11] through additional loop corrections. In particular, for small $\tan\beta$ [1]values, the “compressed" and “moderately compressed" mass regions in $m(\tilde{\mu}) - m(\tilde{\chi}_1^0)$ plane are favoured to explain the anomaly [12].

The searches presented in this paper target the direct production of sleptons pairs decaying into the LSP via the emission of a charged lepton, and the direct production of $\tilde{\chi}_1^+\tilde{\chi}_1^-$, where each chargino decays to the LSP via the emission of a W boson, which decays leptonically. A signature with two charged leptons (electrons and/or muons), $E_{\mathrm{T}}^{\mathrm{miss}}$ (defined as the magnitude of the missing transverse momentum $\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}$) and low hadronic activity is considered, and a moderately compressed mass spectrum is targeted.

A previous search [13] considering the same models and signature was performed. The search exploited the full ATLAS Run 2 data set, but it was optimized to target the phase space with a large mass difference between chargino or slepton and the LSP. An event selection based on the two lepton invariant mass, $E_{\mathrm{T}}^{\mathrm{miss}}$, $E_{\mathrm{T}}^{\mathrm{miss}}$ significance [14], veto against b-tagged (i.e. originating from b-quarks) jets and the number of light jets (required to be < 2) was performed. Finally, a shape fit technique was applied, exploiting several bins of the m_{T2} [2] distribution.

The results of these new searches complement the previous ones in the mass regions $(m(\tilde{\ell}) - m(\tilde{\chi}_1^0))$ and $(m(\tilde{\chi}_1^{\pm}) - m(\tilde{\chi}_1^0))$ near the W boson mass (“moderately compressed" regions). The areas in the parameter space excluded by these results extend beyond those excluded by previous searches by ATLAS [13, 15, 16] and CMS [17–22] in the same channels. The gain in sensitivity is reached thanks to a dedicated analysis strategy used for each of the two signal scenarios considered. Since the slepton signal presents only a same-flavour leptons signature, a data-driven technique is performed to estimate the background for this search, looking at different-flavour lepton pairs in opposite-sign lepton events. In the chargino search the signal results in both same-flavour and different-flavour lepton pairs and the topology of the signal is close to the SM WW process. In this case a machine learning technique is used, based on a Boosted Decision Tree specifically trained on signal samples with $(m(\tilde{\chi}_1^{\pm}) - m(\tilde{\chi}_1^0))$ of the order of the W boson mass.

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[1] In the Minimal Supersymmetric Standard Model (MSSM) $\tan\beta$ is defined as the ratio of the vacuum expectation values of the two complex Higgs doublets.

[2] The m_{T2} variable is defined in Section 6.2

This paper is structured as follows: Section 2 and Section 3 contain the descriptions of the signal scenarios considered in these searches and of the ATLAS detector, respectively. The data and simulated Monte Carlo (MC) samples used in the analysis, along with the trigger selections, are detailed in Section 4. Section 5 describes the physics object definitions. The search strategies and the SM background estimations are discussed in sections 6 and 7, respectively. The experimental and theoretical systematic uncertainties considered in the two searches are documented in Section 8. Finally, the results and their statistical interpretations are presented in Section 9 and the conclusion in Section 10.

2 SUSY scenarios

The design of the analysis and the interpretation of results are based on simplified models [23–25], where the masses of relevant sparticles (in this case the $\tilde{\ell}$, $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^0$) are the only free parameters and all the other sparticles are assumed to be heavy and decoupled.

In models with direct $\tilde{\ell}\tilde{\ell}$ production (Figure 1(a)), each slepton decays into a lepton and a bino-like $\tilde{\chi}_1^0$ with a 100% branching ratio. Only $\tilde{e}$ and $\tilde{\mu}$ are considered in these models, and different assumptions about the masses of the superpartners of the left-handed and right-handed charged leptons, $\tilde{e}_\mathrm{L}$, $\tilde{e}_\mathrm{R}$, $\tilde{\mu}_\mathrm{L}$ and $\tilde{\mu}_\mathrm{R}$, are considered. Lepton flavour is conserved in all models.

The $\tilde{\chi}_1^\pm$ is assumed to be wino-like and decay into a bino-like $\tilde{\chi}_1^0$ via emission of a W boson, which may decay into an electron or muon plus neutrino(s) either directly or through the emission of a leptonically decaying τ-lepton (Figure 1(b)).

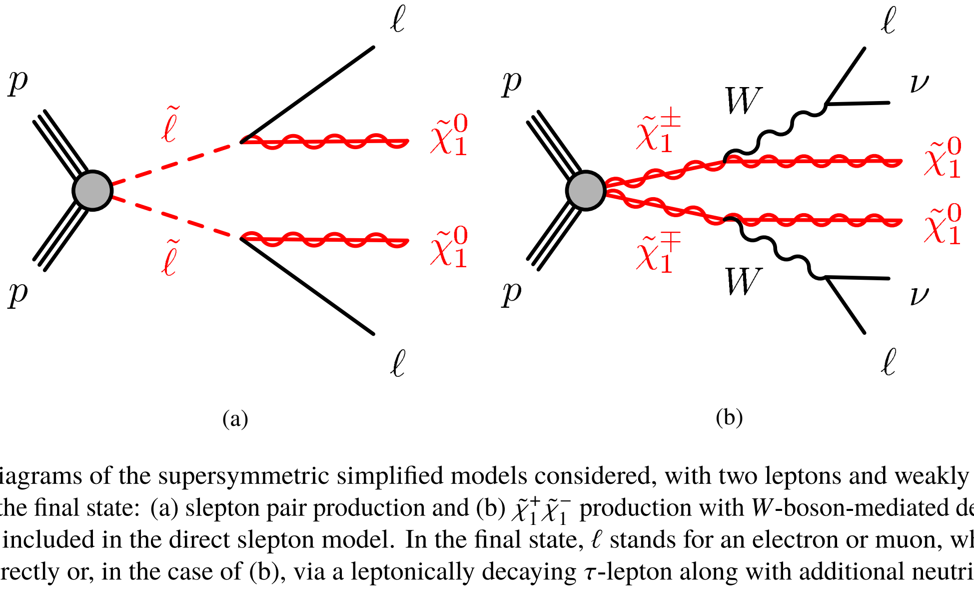

Figure 1: Diagrams of the supersymmetric simplified models considered, with two leptons and weakly interacting particles in the final state: (a) slepton pair production and (b) $\tilde{\chi}_1^+\tilde{\chi}_1^-$ production with W-boson-mediated decays. Only $\tilde{e}$ and $\tilde{\mu}$ are included in the direct slepton model. In the final state, ℓ stands for an electron or muon, which can be produced directly or, in the case of (b), via a leptonically decaying τ-lepton along with additional neutrinos.

3 ATLAS detector

The ATLAS detector [26] at the LHC is a multipurpose particle detector with a forward–backward symmetric cylindrical geometry and an almost complete coverage in solid angle around the collision point.[3] It consists of an inner tracking detector surrounded by a thin superconducting solenoid providing a 2T axial magnetic field, electromagnetic and hadron calorimeters, and a muon spectrometer.

The inner-detector (ID) system covers the pseudorapidity range $|\eta| < 2.5$. It consists of a high-granularity silicon pixel, silicon microstrip, and transition radiation tracking detectors, which enables radially extended track reconstruction up to $|\eta| = 2.0$ and provides electron identification information. The Insertable B-Layer [27, 28], installed before Run 2, typically provides the innermost hit on a track.

The calorimeter system covers the pseudorapidity range $|\eta| < 4.9$. Lead/liquid-argon (LAr) sampling calorimeters provide electromagnetic (EM) energy measurements with high granularity within the region $|\eta| < 3.2$. An iron/scintillator-tile hadron calorimeter covers the central pseudorapidity range $|\eta| < 1.7$. The endcap and forward regions are instrumented with LAr calorimeters for EM and hadronic energy measurements.

The muon spectrometer (MS) surrounds the calorimeters and incorporates three large air-core toroidal superconducting magnets with eight coils each, providing a field integral ranging between 2.0 and 6.0 Tm across most of the detector. It comprises a system of precision tracking chambers measuring the deflection of muons in the magnetic field and fast detectors for triggering. The precision chamber system covers the region $|\eta| < 2.7$, while the muon trigger system covers the range $|\eta| < 2.4$.

A two-level trigger system is used to select events. The first-level (L1) trigger is implemented in hardware and reduces the incoming data rate to a design value of 100 kHz using a subset of detector information. It is followed by a software-based high-level trigger (HLT), that reduces the accepted event rate to 1 kHz on average depending on the data-taking conditions, selecting interesting final-state events with algorithms accessing the full detector information [29, 30]. An extensive software suite [31] is used for real and simulated data reconstruction and analysis, for operation and in the trigger and data acquisition systems of the experiment.

4 Data and simulated event samples

The dataset used in this analysis was collected by the ATLAS detector in pp collisions provided by the LHC during its second run from 2015 to 2018. The beams were colliding at a centre-of-mass energy of $\sqrt{s} = 13$ TeV and with a minimum separation of 25 ns between consecutive crossings of proton bunches. The average number $\langle\mu\rangle$ of additional pp interactions per bunch crossing (pile-up) ranged from 14 in 2015 to about 38 in 2017–2018. After data-quality requirements [32], applied to ensure that all elements of the detectors were operational during data-taking, the data sample amounts to a total integrated luminosity of 139 fb^{-1}. The uncertainty in the combined 2015–2018 integrated luminosity is 1.7% [33], obtained using the LUCID-2 detector [34] for the primary luminosity measurements.

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[3] ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z-axis along the beam pipe. The x-axis points from the IP to the centre of the LHC ring, and the y-axis points upwards. Cylindrical coordinates (r, ϕ) are used in the tran sverse 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 and p_z denote the energy and the component of the particle momentum along the beam direction, respectively.

Candidate events were selected by triggers that required at least one lepton (electron or muon) [35, 36]. The trigger-level thresholds for the transverse momentum, p_{T}, of the lepton involved in the trigger decision were different according to the data-taking periods and looser than those applied in the lepton offline selection to ensure that trigger efficiencies are constant in the relevant phase space. They were in the range 20–120 GeV for data collected in 2015, 24–300 GeV for data collected in 2016, and 26–300 GeV for data collected in 2017 and 2018.

MC simulations were used to generate samples of collision events, which model the expected kinematics of the investigated signal and SM background processes. For background processes, the detector response was simulated using the full modelling of the ATLAS detector [37] in Geant4 [38], while for the signal samples a faster version of the simulation was used that relies on a parameterized response of the calorimeters and Geant4 for the other components of the detector [37]. The effect of pile-up was modelled by overlaying the hard-scatter events with simulated inelastic pp events generated with Pythia 8.186 [39] and EvtGen [40] with the NNPDF2.3LO set of parton distribution functions (PDF) [41] and the A3 set of tuned parameters [42]. The MC samples were reweighted so that the distribution of the average number of interactions per bunch crossing reproduces the observed distribution in the data. All simulated events are processed with the same trigger, reconstruction and identification algorithms as the data. Dedicated correction factors are applied to simulation to account for differences between data and simulation in the jet and lepton reconstruction efficiency, energy scale, energy resolution and modelling of the trigger [43, 44], and in the b-tagging efficiency [45].

Table 1 gives a detailed summary of all SM background samples used in the analysis. It lists the generators, the PDF sets, and the sets of underlying-event and hadronisation parameters (tune) for the parton shower, the order of the cross-section computation in α_{s}. Further information on the ATLAS simulations of $t\bar{t}$, single top (Wt), multiboson and boson plus jet processes can be found in the relevant public notes [46–49].

SUSY signal samples were generated from leading-order (LO) matrix elements with up to two extra partons using MadGraph [50] v2.6.1 for the direct $\tilde{\ell}\tilde{\ell}$ production and MadGraph [50] v2.6.2 for $\tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow W^+\tilde{\chi}_1^0 W^-\tilde{\chi}_1^0$, in both cases interfaced with Pythia 8.2 with the A14 set of tuned parameters [51], for the modelling of the SUSY decay chain, parton showering, hadronisation and the description of the underlying event. In order to include spin correlation effects in off-shell W boson decays, MadSpin [52] was used in generation for mass splittings between the chargino and LSP smaller than 100 GeV. Parton luminosities were provided by the NNPDF2.3LO PDF set [41]. Jet–parton matching was performed following the CKKW-L prescription [53], with a matching scale set to one quarter of the pair-produced superpartner mass for the slepton model and to 15 GeV for the chargino model. Signal cross-sections were calculated to next-to-leading order (NLO) in α_{s} adding the resummation of soft gluon emission at next-to-leading-logarithm accuracy (NLO+NLL) [54–60]. The nominal cross-sections and their uncertainties were taken from an envelope of cross-section predictions using different PDF sets and factorisation and renormalisation scales, as described in Ref. [61]. The cross-section for $\tilde{\chi}_1^+\tilde{\chi}_1^-$ production, each with a mass of 150 GeV, is 2.61 ± 0.14 pb, while the cross-section for $\tilde{\ell}\tilde{\ell}$ production, each with a mass of 150 GeV, is 63.3 ± 3.3 fb for each generation of left-handed sleptons and 23.3 ± 1.4 fb for each generation of right-handed sleptons.

5 Object reconstruction

Candidate events are required to have at least one pp interaction vertex with a minimum of two associated tracks, each with $p_{\mathrm{T}} > 500$ MeV. In events with multiple vertices, the primary vertex is defined as the one

Table 1: Simulated background event samples with the corresponding matrix element and parton shower (PS) generators, cross-section order in α_s used to normalise the event yield, underlying-event tune and the generator PDF sets used. For Diboson, Triboson and $t\bar{t}+V$ samples: $V = W, Z$. Diboson samples also include Higgs boson events.

Physics process	Generator	Parton shower	Normalisation	Tune	PDF (generator)	PDF (PS)
$t\bar{t}$	POWHEG BOX v2 [62–65]	PYTHIA 8.230 [66]	NNLO+NNLL [67]	A14 [51]	NNPDF3.0NLO [68]	NNPDF2.3LO [41]
Single top (Wt)	POWHEG BOX v2 [63–65, 69]	PYTHIA 8.230	NLO+NNLL[70, 71]	A14	NNPDF3.0NLO	NNPDF2.3LO
Diboson VV	SHERPA 2.2.1 or 2.2.2 [72]	SHERPA 2.2.1 or 2.2.2 [73, 74]	NLO [75–78]	SHERPA default [48]	NNPDF3.0NNLO [68]	NNPDF3.0NNLO
Triboson VVV	SHERPA 2.2.2	SHERPA 2.2.2	NLO	SHERPA default	NNPDF3.0NNLO	NNPDF3.0NNLO
$t\bar{t}+V$	MADGRAPH5_aMC@NLO 2.3.3 [79]	PYTHIA 8.210 [66]	NLO [79, 80]	A14	NNPDF3.0NLO	NNPDF2.3LO
$t\bar{t}+H$	POWHEG BOX v2 [62–65, 81]	PYTHIA 8.230	NLO	A14	NNPDF3.0NLO	NNPDF2.3LO
$t\bar{t}+WW$	MADGRAPH5_aMC@NLO 2.2.2	PYTHIA 8.186 [39]	NLO [79]	A14	NNPDF2.3LO	NNPDF2.3LO
$t\bar{t}+WZ$	MADGRAPH5_aMC@NLO 2.3.3	PYTHIA 8.212 [39]	NLO [79]	A14	NNPDF2.3LO	NNPDF2.3LO
$tZ, t\bar{t}t\bar{t}, t\bar{t}t$	MADGRAPH5_aMC@NLO 2.3.3	PYTHIA 8.230	NLO [79]	A14	NNPDF3.0NLO	NNPDF2.3LO
$Z/\gamma^*(\rightarrow ll)$+jets	SHERPA 2.2.1 [72]	SHERPA 2.2.1 [74]	NNLO [82]	SHERPA default	NNPDF3.0NNLO	NNPDF3.0NNLO

with the highest scalar sum of the squared transverse momenta of associated tracks.

The leptons selected for the analysis are classified as baseline or signal leptons using an increasingly stringent set of quality and kinematic selection criteria. The signal leptons are a subset of the baseline leptons. Baseline objects are used in the calculation of missing transverse momentum, to resolve ambiguities between the analysis objects in the event and in the fake/non-prompt (FNP) lepton background estimation described in Section 7. Signal leptons are used for the final event selection.

Baseline electron candidates are reconstructed using three-dimensional clusters of energy deposition in the electromagnetic calorimeter that are matched to an ID track. They are required to pass a *Loose* likelihood-based identification requirement [43] with an additional condition on the number of hits in the B-Layer, and to have $p_T > 9$ GeV and $|\eta| < 2.47$. The tracks associated with baseline electron candidates are required to be within $|z_0 \sin\theta| = 0.5$ mm of the primary vertex, where z_0 is the longitudinal impact parameter relative to the reconstructed primary vertex. Signal electrons are required to satisfy a *Tight* identification requirement [43] and the track associated with the signal electron is required to have $|d_0|/\sigma(d_0) < 5$, where d_0 is the transverse impact parameter relative to the primary vertex and $\sigma(d_0)$ is its uncertainty.

Baseline muon candidates are reconstructed in the pseudorapidity range $|\eta| < 2.6$ by matching MS tracks with ID tracks. They are required to have $p_T > 9$ GeV, to be within $|z_0 \sin\theta| = 0.5$ mm of the primary vertex and to satisfy the *Medium* identification requirements defined in Ref. [44], based on the numbers of hits in the different ID and MS subsystems, and on the significance of the charge-to-momentum ratio q/p. Finally, the track associated with the signal muon must have $|d_0|/\sigma(d_0) < 3$.

Isolation criteria are applied to signal electrons and muons in order to suppress contributions from conversions, semileptonic decays of heavy-flavour hadrons, or hadrons and jets wrongly identified as leptons, collectively referred as fake or non-prompt leptons. The scalar sum of the p_T of tracks inside a variable-size cone around the lepton (excluding its own track), must be less than 15% of the lepton p_T. The track isolation cone size for electrons (muons) $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ is given by the minimum of $\Delta R = 10\ \text{GeV}/p_T$ and $\Delta R = 0.2\ (0.3)$. In addition, for electrons (muons) the sum of the transverse energy of the calorimeter energy clusters in a cone of $\Delta R = 0.2$ around the lepton (excluding the energy from the lepton itself) must be less than 20% (30%) of the lepton p_T.

Jets are reconstructed from particle-flow objects [83] calibrated at the EM scale using the anti-k_t jet clustering algorithm [84] as implemented in the FastJet package [85], with a radius parameter $R = 0.4$. The reconstructed jets are corrected to particle level by the application of a jet energy scale (JES) and resolution (JER) derived using 13 TeV data and simulation [86]. Only jet candidates with $p_T > 20$ GeV and $|\eta| < 2.4$ are considered. To reduce the effects of pile-up, for jets with $p_{\mathrm{T}} < 60$ GeV a significant fraction of the tracks associated with each jet are required to have an origin compatible with the primary vertex, as defined by the jet vertex tagger [87]. This requirement reduces the fraction of jets from pile-up to 1%, with an efficiency for pure hard-scatter jets of about 90%. Finally, in order to remove events impacted by detector noise and non-collision backgrounds, specific jet-quality requirements [88, 89] are applied, designed to provide an efficiency of selecting jets from proton-proton collisions above 99.5% (99.9%) for $p_{\mathrm{T}} > 20\,(100)$GeV.

Jets that are likely to originate from the hadronization of a bottom quark are flagged as 'b-jets' if they lie within $|\eta| < 2.4$ and are tagged by the DL1r algorithm [45], a multivariate discriminant based on various inputs such as track impact parameters and displaced secondary vertices. A selection that provides 85% efficiency for tagging b-jets in simulated $t\bar{t}$ events is used. The corresponding rejection factors against jets originating from c-quarks, from τ-leptons, and from light quarks and gluons in the same sample at this working point are 2, 4 and 31, respectively.

Ambiguities may exist between reconstructed objects. To prevent single detector signatures from being identified as multiple objects, an overlap-removal procedure is applied to baseline leptons and jets in several consecutive steps:

- jet candidates within $\Delta R' = \sqrt{\Delta y^2 + \Delta\phi^2} = 0.2$ of an electron candidate, or jets with fewer than three tracks that lie within $\Delta R' = 0.4$ of a muon candidate are removed, as they mostly originate from calorimeter energy deposits from electron shower or muon bremsstrahlung;
- electrons and muons within $\Delta R' = \min(0.4, 0.04 + 10/p_{\mathrm{T}})$ of the surviving jets are discarded, to reject leptons from the decay of b- or c-hadrons;
- if an electron shares an ID track with a muon, the electron is discarded unless the muon is tagged as a minimum-ionizing particle in the calorimeter, in which case the muon is discarded.

The missing transverse momentum $\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}$ is defined as the negative vector sum of the transverse momenta of all identified baseline physics objects (electrons, photons, muons and jets), and an additional soft term including all tracks that pass basic quality requirements and are associated with the primary vertex but not matched to any reconstructed object [90]. The magnitude of $\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}$ is referred to as $E_{\mathrm{T}}^{\mathrm{miss}}$. Additionally, an 'object-based $E_{\mathrm{T}}^{\mathrm{miss}}$ significance' [14], referred to as $E_{\mathrm{T}}^{\mathrm{miss}}$ significance in this paper, helps to discriminate events where $E_{\mathrm{T}}^{\mathrm{miss}}$ arises from undetected particles in the final state from those where it arises from poorly measured particles, resolution or identification inefficiencies. It is defined as

$$E_{\mathrm{T}}^{\mathrm{miss}}\text{significance} = \frac{|\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}|}{\sqrt{\sigma_L^2(1-\rho_{LT}^2)}}$$

where σ_L is the (longitudinal) component parallel to the $\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}$ of the total transverse momentum resolution for all objects in the event and the quantity ρ_{LT} is the correlation factor between the parallel and perpendicular components of the transverse momentum resolution for each object.

6 Event selection

6.1 Preselection

The strategy for event preselection, where a common approach has been adopted for both the analysis models, is described here. Further selections, specific for each of the two target scenarios, are discussed in Sections 6.3.1 and 6.3.2.

Events are required to have exactly two oppositely charged signal leptons ℓ_1 and ℓ_2, ℓ_1 with $p_{\mathrm{T}} > 27$ GeV (leading lepton) and ℓ_2 with $p_{\mathrm{T}} > 9$ GeV (sub-leading lepton). The invariant mass of the two leptons must be $m_{\ell\ell} > 11$ GeV, in order to remove low mass resonances.

Events are separated into 'same flavour' (SF) events, i.e. $e^{\pm}e^{\mp}$ and $\mu^{\pm}\mu^{\mp}$, and 'different flavour' (DF) events, i.e. $e^{\pm}\mu^{\mp}$, since the two classes of events have different background compositions. SF events are required to have a dilepton invariant mass far from the Z peak, $|m_{\ell\ell} - 91| > 15$ GeV, to reduce VZ and Z+jets backgrounds.

Events are further required to have no more than one jet ($n_{\mathrm{jet}} < 2$). Selected events must also satisfy $E_{\mathrm{T}}^{\mathrm{miss}}$ significance > 3.

6.2 Kinematic variables

Final event selections are obtained by separating signal from SM background using different kinematic variables. For both SUSY models in Figure 1, the stransverse mass m_{T2} [91, 92] and $\cos\theta^*_{\ell\ell}$, defined below, are among the most discriminating variables. The stransverse mass generalizes the transverse mass m_{T} [4] for symmetric event topologies where two identical particles each decay into a visible and an invisible product. In this case the individual transverse momenta of the invisible particles can no longer be directly approximated by the measured missing transverse momentum, as the information about their individual contributions to the missing transverse momentum is lost. The stransverse mass is defined as

$$m_{\mathrm{T2}}(\mathbf{p}_{\mathrm{T},1}, \mathbf{p}_{\mathrm{T},2}, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}) = \min_{\mathbf{q}_{\mathrm{T},1}+\mathbf{q}_{\mathrm{T},2}=\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}} \left\{ \max[\, m_{\mathrm{T}}(\mathbf{p}_{\mathrm{T},1}, \mathbf{q}_{\mathrm{T},1}), m_{\mathrm{T}}(\mathbf{p}_{\mathrm{T},2}, \mathbf{q}_{\mathrm{T},2}) \,] \right\},$$

where $\mathbf{p}_{\mathrm{T},1}$ and $\mathbf{p}_{\mathrm{T},2}$ are the transverse-momentum vectors of the two leptons, and $\mathbf{q}_{\mathrm{T},1}$ and $\mathbf{q}_{\mathrm{T},2}$ are vectors with $\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}} = \mathbf{q}_{\mathrm{T},1} + \mathbf{q}_{\mathrm{T},2}$. The minimisation is performed over all the possible decompositions of $\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}$. The masses of the invisible particles are free parameters and are set to 100 GeV (m_{T2}^{100}) in the slepton search, since this choice improves the sensitivity to several signal models in the slepton mass range targeted by the analysis, and to 0 GeV (m_{T2}) in the chargino search. The variables m_{T2}^{100} and m_{T2}, expected to have different kinematic endpoints for SM processes like $t\bar{t}$ or WW than for SUSY processes, are powerful at discriminating background events from some of the signals considered herein.

The angular variable $\cos\theta^*$, where θ^* is the polar angle between the incoming quark in one of the protons and the produced sparticle, is sensitive to the sparticle spin, and the cross section behaves differently for spin 1 or half spin sparticles. Since θ^* is not directly measurable, $\cos\theta^*_{\ell\ell} = \tanh(\Delta\eta_{\ell\ell}/2)$ is defined in terms of the difference in pseudorapidity between the two leptons, and it is sensitive to the slepton

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[4] The transverse mass is defined as $m_{\mathrm{T}} = \sqrt{2 \cdot p_{\mathrm{T}} \cdot q_{\mathrm{T}} \cdot (1 - \cos(\Delta\phi))}$, where $\Delta\phi$ is the difference in azimuthal angle between the particles with transverse momenta $\mathbf{p}_{\mathrm{T}}$ and $\mathbf{q}_{\mathrm{T}}$.

production angle. The leptons “inherit" some knowledge of the rapidity of their slepton parents, and the two variables $\cos\theta^*$ and $\cos\theta^*_{\ell\ell}$ are well correlated to each other [93]. Other powerful discriminating variables between signal events and backgrounds such as $t\bar{t}$ or VV ($V = W, Z$) are the azimuthal angular separations between the two leptons, $\Delta\phi_{\ell,\ell}$, between $\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}$ and the leading lepton, $\Delta\phi_{p_{\mathrm{T}}^{\mathrm{miss}},\ell_1}$, and between $\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}$ and the sub-leading lepton, $\Delta\phi_{p_{\mathrm{T}}^{\mathrm{miss}},\ell_2}$. The distributions of these variables depend on the presence of jets in the event. Considering the slepton production as an example, in the absence of jets sleptons are expected to be produced back to back, and the leptons coming from their decays to be well separated in the azimuthal plane. The most energetic $\tilde{\chi}_1^0$ and the sub-leading lepton are expected to come from the same slepton, therefore the $\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}$ vector is expected to be well separated from the $\mathbf{p}_{\mathrm{T}}{}^{\ell_1}$ direction.

Another exploited variable is the magnitude of $\mathbf{p}_{\mathrm{T,boost}}^{\ell\ell}$ ($p_{\mathrm{T,boost}}^{\ell\ell}$), the vector sum of the $\mathbf{p}_{\mathrm{T}}$ of the two leptons and $\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}$. It can be interpreted as the magnitude of the vector sum of all the transverse hadronic activity in the event. In both of the analyzed SUSY scenarios, in absence of jets, $p_{\mathrm{T,boost}}^{\ell\ell}$ is expected to have low values due to the p_{T} balance of the system. The azimuthal separation between $\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}$ and $\mathbf{p}_{\mathrm{T,boost}}^{\ell\ell}$ vectors is defined as $\Delta\phi_{\mathrm{boost}}$.

6.3 Signal regions

Dedicated signal-enriched regions (SRs) are defined for each signal scenario, optimized individually for benchmark signal models by maximizing the discovery significance. The selection requirements for the signal regions are explained in the following for the slepton and the chargino scenarios. In both cases, they target signal models with a low to moderate mass difference between slepton/chargino and neutralino (up to ~150 GeV).

6.3.1 Slepton model

Event selection which targets the slepton model requires a SF opposite-charge-sign (SFOS) lepton pair, $E_{\mathrm{T}}^{\mathrm{miss}}$ coming from the LSPs, and low hadronic activity apart from Initial State Radiation (ISR) or pile-up. No dedicated selection for $\tilde{e}_{\mathrm{L}}$, $\tilde{e}_{\mathrm{R}}$, $\tilde{\mu}_{\mathrm{L}}$ or $\tilde{\mu}_{\mathrm{R}}$ is performed. After the preselection, only events with $n_{b\text{-tagged jets}} = 0$, i.e. the number of jets identified as b-jets by the DL1r algorithm, are retained, in order to reduce the $t\bar{t}$ and single top backgrounds. Events are then further classified by the multiplicity of non-b-tagged jets (0J,1J).

Following the classification of the events, a dedicated cut optimisation for each of the two categories is performed. A relevant difference between them is related to the cuts on $p_{\mathrm{T,boost}}^{\ell\ell}$ and $\Delta\phi_{p_{\mathrm{T}}^{\mathrm{miss}},\ell_1}$, which are no longer useful for the 1J event category since the presence of the jet implies that the $E_{\mathrm{T}}^{\mathrm{miss}}$ and the leptons p_{T} are not balanced anymore. Then, two sets of SRs are defined: a set of exclusive SRs, ‘binned’ in m_{T2}^{100}, and a set of ‘inclusive’ SRs, to be used for model-dependent and model-independent results, respectively. The binning in m_{T2}^{100} is chosen to maximise the search sensitivity and to preserve reasonable statistics in each bin, and the ‘inclusive’ SRs have different lower bound on m_{T2}^{100} to enhance sensitivity to new physics with various mass scale. The definitions of these regions are shown in Table 2. Each SR is identified by the number of non-b-tagged jets (0J,1J) and the range of the m_{T2}^{100} interval.

Table 2: The definitions of the binned and inclusive signal regions for the slepton model. Relevant kinematic variables are defined in the text. The ‘0J’ and ‘1J’ labels refer to the multiplicity of non-b-tagged jets.

Signal region (SR)	SR-0J	SR-1J
$n_{b\text{-tagged jets}}$	= 0	
$E_{\mathrm{T}}^{\mathrm{miss}}$ significance	>7	
$n_{\text{non-}b\text{-tagged jets}}$	= 0	= 1
${p_{\mathrm{T}}}^{\ell_1}$ [GeV]	> 140	> 100
${p_{\mathrm{T}}}^{\ell_2}$ [GeV]	> 20	> 50
$m_{\ell\ell}$ [GeV]	> 11	> 60
$p_{\mathrm{T,boost}}^{\ell\ell}$ [GeV]	< 5	-
$\lvert\cos\theta^{*}_{\ell\ell}\rvert$	< 0.2	< 0.1
$\Delta\phi_{\ell,\ell}$	> 2.2	> 2.8
$\Delta\phi_{p_{\mathrm{T}}^{\mathrm{miss}},\ell_1}$	> 2.2	-
Binned SRs		
m_{T2}^{100}[GeV]	∈[100,105)	
	∈[105,110)	
	∈[110,115)	
	∈[115,120)	
	∈[120,125)	
	∈[125,130)	
	∈[130,140)	
	∈[140,∞)	
Inclusive SRs		
m_{T2}^{100} [GeV]	∈[100,∞)	
	∈[110,∞)	
	∈[120,∞)	
	∈[130,∞)	
	∈[140,∞)	

6.3.2 Chargino model

Event selection which targets the chargino model considers both same-flavour and different-flavour opposite-charge-sign lepton pair in the event. After the preselection, only events with $n_{b\text{-tagged jets}} = 0$ and $n_{\text{non-}b\text{-tagged jets}} = 0$ are retained. The first cut reduces the $t\bar{t}$ and single top backgrounds, and the second one has been observed to increase the sensitivity of the analysis. A machine learning (ML) technique based on the Gradient Boosted Decision Tree (BDT) is exploited in the search for charginos [94]. Events passing the preselection cuts and the cuts on the number of jets are separated in two categories, SF and DF, and for each category the signal and SM background Monte Carlo samples are split into two sets: the training and test sets. The BDT classifier is trained on the training set, and tested on the statistically independent test set. The test set is used to measure and to optimize the classifier performance depending on the parameters which are defined in the ML procedure, and to derive the final results. Signal samples with a mass splitting between the chargino and neutralino of 90 and 100 GeV were found to be the best optimization benchmark across the signal grid. They were summed together and part of them was used for the training set. Multiclass classification is performed, i.e. the classifier is trained to separate events into four classes: signal, VV, top ($t\bar{t}$ and single-top) and all other backgrounds (Z/γ+jets, VVV and other minor backgrounds). For each event, the four scores BDT-signal, BDT-VV, BDT-top and BDT-other, corresponding to the four classes, provide the probability for the event to belong to each class, and sum to one. This technique is found to be more effective than a simpler binary classification in discriminating signal from background. The set of variables used in the training was optimized in the analysis through an iterative procedure which started from a larger set of variables, removed the variables one by one and retrained until no gain in performance was observed. The reduced, final set of variables consists of $p_T^{\ell_1}$, $p_T^{\ell_2}$, $E_{\mathrm{T}}^{\mathrm{miss}}$, m_{T2}, $m_{\ell\ell}$, $\Delta\phi_{\mathrm{boost}}$, $\Delta\phi_{p_{\mathrm{T}}^{\mathrm{miss}},\ell_1}$,$\Delta\phi_{p_{\mathrm{T}}^{\mathrm{miss}},\ell_2}$, $\cos\theta^*_{\ell\ell}$ and $E_{\mathrm{T}}^{\mathrm{miss}}$significance.

The BDT score cuts are used to define the SRs. Two additional requirements of $E_{\mathrm{T}}^{\mathrm{miss}}$significance > 8 and $m_{\mathrm{T2}} > 50$ GeV are used, which are used in all relevant regions for the search, in order to enhance the sensitivity. A set of exclusive SRs ‘binned’ in BDT-signal to maximise model-dependent search sensitivity is defined. The definitions of these regions are shown in Table 3.

Table 3: The definitions of the binned signal regions for the chargino model. Relevant variables are defined in the text.

<table>
<tr><th>Signal region (SR)</th><th>SR-DF</th><th>SR-SF</th></tr>
<tr><td>$n_{b\text{-tagged jets}}$</td><td colspan="2">= 0</td></tr>
<tr><td>$n_{\text{non-}b\text{-tagged jets}}$</td><td colspan="2">= 0</td></tr>
<tr><td>$E_{\mathrm{T}}^{\mathrm{miss}}$ significance</td><td colspan="2">>8</td></tr>
<tr><td>m_{T2} [GeV]</td><td colspan="2">>50</td></tr>
<tr><td>BDT-other</td><td></td><td>< 0.01</td></tr>
<tr><td>Binned SRs</td><td></td><td></td></tr>
<tr><td rowspan="16">BDT-signal</td><td>∈(0.81,0.8125]</td><td>∈(0.77,0.775]</td></tr>
<tr><td>∈(0.8125,0.815]</td><td>∈(0.775,0.78]</td></tr>
<tr><td>∈(0.815,0.8175]</td><td>∈(0.78,0.785]</td></tr>
<tr><td>∈(0.8175,0.82]</td><td>∈(0.785,0.79]</td></tr>
<tr><td>∈(0.82,0.8225]</td><td>∈(0.79,0.795]</td></tr>
<tr><td>∈(0.8225,0.825]</td><td>∈(0.795,0.80]</td></tr>
<tr><td>∈(0.825,0.8275]</td><td>∈(0.80,0.81]</td></tr>
<tr><td>∈(0.8275,0.83]</td><td>∈(0.81,1]</td></tr>
<tr><td>∈(0.83,0.8325]</td><td></td></tr>
<tr><td>∈(0.8325,0.835]</td><td></td></tr>
<tr><td>∈(0.835,0.8375]</td><td></td></tr>
<tr><td>∈(0.8375,0.84]</td><td></td></tr>
<tr><td>∈(0.84,0.845]</td><td></td></tr>
<tr><td>∈(0.845,0.85]</td><td></td></tr>
<tr><td>∈(0.85,0.86]</td><td></td></tr>
<tr><td>∈(0.86,1]</td><td></td></tr>
</table>

7 Background estimation

The SM backgrounds can be classified into irreducible backgrounds, from processes with prompt leptons which can yield events with a final state similar to the signal, and reducible backgrounds, which contain one or more FNP leptons. Among the irreducible backgrounds, for both the slepton and chargino searches the dominant sources are processes with top quarks and diboson VV.

The slepton search uses a dedicated data-driven technique to estimate some of the dominant backgrounds. This technique is based on the observation that, while the slepton decays produce events with two SFOS leptons in the final state, background processes as $t\bar{t}$, single top, WW and $Z \rightarrow \tau\tau$+jets decay into opposite sign SF or DF leptons with the same probability ('Flavour Symmetric backgrounds', FSB). The DF channel (populated by the background only) can be used to predict the contribution of FSB to the SF channel (populated by the background and, potentially, by the signal).

The chargino search uses a partially data-driven technique to estimate the dominant backgrounds. Dedicated control regions (CRs), enriched in particular backgrounds, are used to normalize MC simulation yields to data. A simultaneous profile likelihood fit (described in Section 9), is used to constrain the MC yields with the observed data. The CRs are designed to be both orthogonal and similar to the SRs, whilst also having little signal contamination; this is achieved by taking the SR definitions and inverting some of the selection criteria. Dedicated validation regions (VRs) are defined to be kinematically close to CRs and SRs, and are used to assess the quality of the background estimation and its extrapolation to the SRs.

Subdominant irreducible SM background contributions arising from Drell-Yan, $t\bar{t}$ +boson(s), tZ, $t\bar{t}t\bar{t}$, $t\bar{t}t$, Higgs boson, VVV, jointly referred to in this paper as 'Other backgrounds' (or 'Others' in the Figures), are estimated from simulation using the samples described in Section 4.

The reducible background from FNP leptons is estimated from data using the matrix method (MM) [95]. This method uses two types of lepton identification criteria: 'signal' leptons, corresponding to leptons passing the analysis final selection, and 'baseline' leptons, which pass a looser selection as defined in Section 5. Probabilities for prompt leptons satisfying the baseline selection to also satisfy the signal selection are measured as a function of lepton p_{T} and η in MC simulation, using control samples enriched in real leptons. Similar probabilities for FNP leptons to pass the signal selection are measured from data in events dominated by leptons from the decays of heavy-flavour hadrons and from photon conversions, and from MC control samples dominated by leptons from light-flavour quark decays. Final probability is then computed adding the FNP contributions from the different sources with appropriate weights (w_i) which reflect the relative amount of each source, extracted from MC simulations using truth information. These probabilities are used in the MM method when solving a set of equations relating the number of observed baseline and signal leptons to the estimated number of real and FNP leptons in the CRs, VRs, and SRs. To avoid double counting between the simulated samples used for background estimation and the FNP lepton background estimate provided by the MM, all simulated events containing one or more FNP leptons are removed from the background samples.

7.1 Estimation of the backgrounds in the slepton search

Data events with DF leptons surviving the SR cuts (N_{DF}) can be used, after subtracting the FNP lepton contribution, to predict the FSB in the SF channel. Since electrons and muons have different trigger, reconstruction, isolation and identification efficiencies, these differences must be taken into account. The efficiency correction method is applied, which computes the number of expected FSB events in the SF channel as:

$$\begin{aligned} N_{ee}^{\text{expected}} &= 0.5 \times \frac{1}{\kappa} \times \alpha \times N_{DF} \\ N_{\mu\mu}^{\text{expected}} &= 0.5 \times \kappa \times \alpha \times N_{DF} \\ N_{SF}^{\text{expected}} &= 0.5 \times \left(\kappa + \frac{1}{\kappa}\right) \times \alpha \times N_{DF} \end{aligned} \tag{1}$$

where the factor 0.5 assumes that the production rate of the DF events is twice that of the dimuon and dielectron events, and κ and α take into account the difference in reconstruction, identification and trigger efficiencies for muons and electrons, respectively. They are defined as

$$\begin{aligned} \kappa &= \sqrt{\frac{N_{\mu^+\mu^-}}{N_{e^+e^-}}} \\ \alpha &= \frac{\sqrt{\epsilon_{\mu\mu}^{\text{trig}} \epsilon_{ee}^{\text{trig}}}}{\epsilon_{e\mu}^{\text{trig}}} \end{aligned} \tag{2}$$

with $N_{\mu^+\mu^-}$ and $N_{e^+e^-}$ being the number of dielectron and dimuon events respectively, and $\epsilon_{\mu\mu}^{\text{trig}}$, $\epsilon_{ee}^{\text{trig}}$ and $\epsilon_{e\mu}^{\text{trig}}$ the efficiencies of triggering dimuon, dielectron and muon-electron events with the trigger selection described in Section 4.

The factor κ is extracted from data in a control sample obtained relaxing the cuts on ${p_{\text{T}}}_1^{\ell}$ and $E_{\text{T}}^{\text{miss}}$ significance and inverting the cut on $|\cos\theta^*_{\ell\ell}|$ to make it orthogonal to the SRs. A dependence of κ on the leading lepton p_{T} was observed in different η regions of the detector, and it is therefore parameterised as a function of ${p_{\text{T}}}^{\ell_1}$ only, $\kappa = a + \frac{b}{{p_{\text{T}}}^{\ell_1}}$. This parameterisation describes the behaviour of κ both in data and MC simulations well.

The factor α is computed from the global efficiencies of the trigger selection applied in the analysis, evaluated on a control sample of data triggered with an independent selection. In the η and p_T ranges of the two leptons satisfying the selection criteria in the SRs the α dependence on these kinematic variables has been found negligible.

In order to validate the efficiency correction method, two validation regions, VR-0J and VR-1J, are defined, with the same selection of the corresponding SR but inverting the $|\cos\theta^*_{\ell\ell}|$ cut. Although VR-0J and VR-1J are subsets of the control sample used to extract the factor κ, they use different events, since in these VRs the FSB contribution is evaluated from DF events in data using Eq. 1. Figure 2 shows m_{T2}^{100} in VR-0J and VR-1J and a good agreement is observed between the data and the total estimated SM background in these distributions and in all other variables relevant for the analysis.

Finally, the FSB yields in the SR-0J and SR-1J defined in Table 2 are estimated using the DF events surviving in data after requiring the cuts for each SR and applying the factors κ and α on an event-by-event basis. They are reported in Table 4.

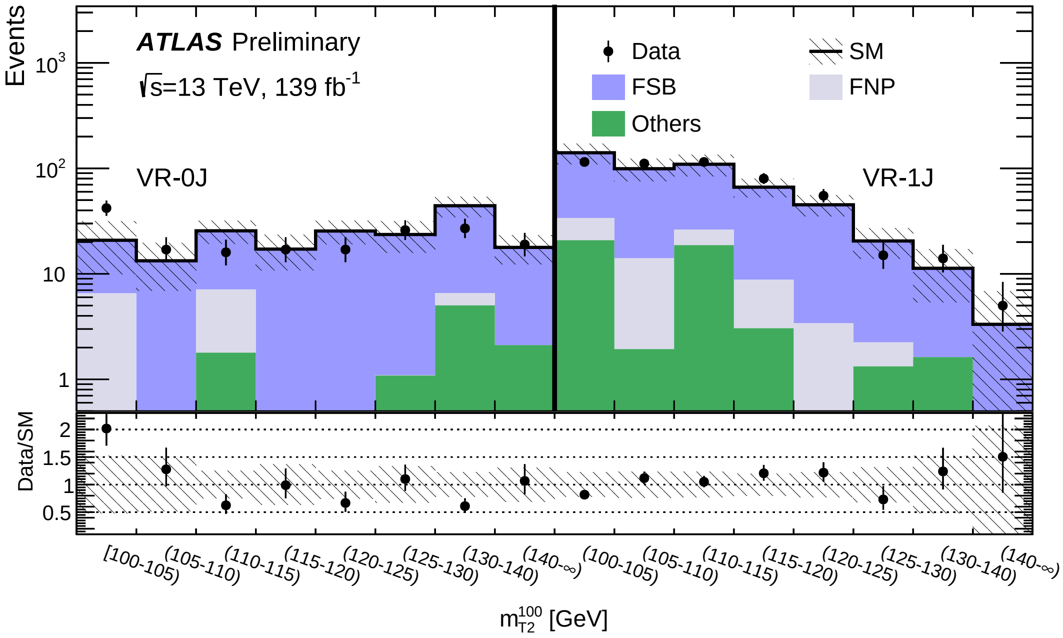


Figure 2: Distributions of m_{T2}^{100} in VR-0J and in VR-1J for data and the estimated SM backgrounds. The FSB contribution is evaluated with the data-driven efficiency correction method. The FNP lepton background is calculated using the data-driven matrix method. 'Others' include the non-dominant background sources, e.g. $t\bar{t}$+V, Higgs boson and Drell–Yan events. The shaded band represents the total uncertainty, coming from all sources, on the expected SM background. The lower panel shows the ratio of data to the SM background estimate.

Table 4: Expected flavour symmetric background yields in the SR-0J and SR-1J estimated using the data DF events surviving in data after requiring the cuts for each SR and applying the factors κ and α on an event-by-event basis. Yields are separated for ee and $\mu\mu$ events. The uncertainties include both statistical and systematic contributions.

SR	ee events	$\mu\mu$ events	Total
SR-0J	34.6 ± 4.9	30.2 ± 4.4	64.8 ± 9.3
SR-1J	37.1 ± 5.0	31.8 ± 4.5	68.9 ± 9.4

The irreducible SM non-flavour symmetric background contribution in the SR-0J and SR-1J is estimated directly from simulation using the samples described in Section 4.

7.2 Estimation of the backgrounds in the chargino search

The general strategy to define CRs and VRs relies on reversing the BDT-signal cut applied to the SRs or selecting events with $n_{b\text{-tagged jets}} = 1$ for the top CR, in order to ensure orthogonality with the SRs and a low signal contamination. A summary of the regions considered is given in Table 5 and the strategy is described in the following.

Table 5: Control region definitions for extracting the normalisation factors for the dominant background processes in the chargino search and validation region definitions used to study the modelling of the SM backgrounds. The cuts are applied on top of the preselection. 'DF' or 'SF' refer to control/validation regions with different lepton flavour or same lepton flavour pair combinations, respectively.

Control region (CR)	CR-VV		CR-top	
$E_{\mathrm{T}}^{\mathrm{miss}}$ significance	> 8			
m_{T2} [GeV]	> 50			
$n_{\text{non-}b\text{-tagged jets}}$	= 0			
Leptons flavour	DF	SF	DF	SF
$n_{b\text{-tagged jets}}$	= 0	= 0	= 1	= 1
BDT-other	-	< 0.01	-	< 0.01
BDT-signal	$\in (0.2, 0.65]$	$\in (0.2, 0.65]$	$\in (0.5, 0.7]$	$\in (0.7, 0.75]$
BDT-VV	> 0.2	> 0.2	-	-
BDT-top	< 0.1	< 0.1	-	-

Validation region (VR)	VR-VV-DF	VR-VV-SF	VR-top-DF	VR-top-SF	VR-top0J-DF	VR-top0J-SF
$E_{\mathrm{T}}^{\mathrm{miss}}$ significance	> 8					
m_{T2} [GeV]	> 50					
$n_{\text{non-}b\text{-tagged jets}}$	= 0					
$n_{b\text{-tagged jets}}$	= 0	= 0	= 1	= 1	= 0	= 0
BDT-other	-	< 0.01	-	< 0.01	-	< 0.01
BDT-signal	$\in (0.65, 0.81]$	$\in (0.65, 0.77]$	$\in (0.7, 1]$	$\in (0.75, 1]$	$\in (0.5, 0.81]$	$\in (0.5, 0.77]$
BDT-VV	> 0.2	> 0.2	-	-	< 0.15	< 0.15
BDT-top	< 0.1	< 0.1	-	-	-	-

Two CRs are used, CR-VV to target the diboson VV and CR-top to target the top-quark backgrounds ($t\bar{t}$ and Wt). The selection $E_{\mathrm{T}}^{\mathrm{miss}}$significance > 8, $m_{\mathrm{T2}} > 50$ GeV and $n_{\text{non-}b\text{-tagged jets}} = 0$ applied in these CRs is the same used in the SRs, in order to ensure that they have a similar kinematic phase-space as the SRs. Upper limits on BDT-signal score are exploited to ensure orthogonality with the SRs and a low signal contamination. Cuts on the background BDT scores are then considered to achieve a good purity of the specific background for which the CR is designed. The $n_{b\text{-tagged jets}} = 1$ selection is used in CR-top to ensure a large top background contribution. A dedicated selection is used for DF and SF events, in order to be consistent with the SR definitions. The CR selections are summarised in the first part of Table 5. The number of expected signal events in the CRs, investigated for all considered signal model and found negligible for most of them, is of $\sim 5\%$ at maximum.

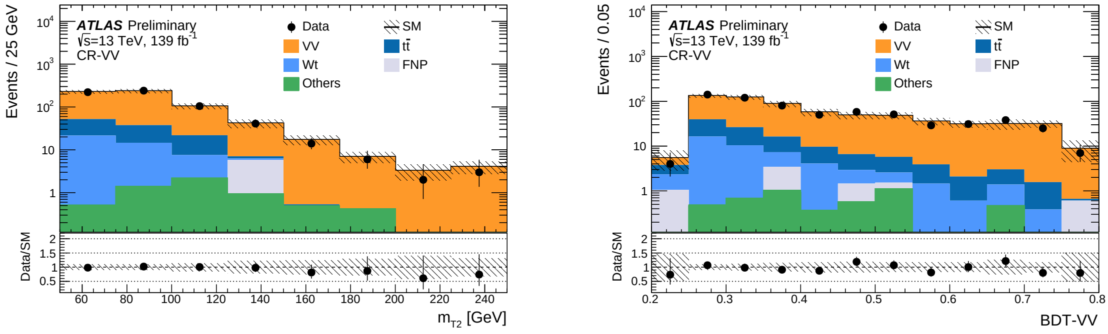
Diboson and top-quark backgrounds are normalised to the data observed in CR-VV and CR-top in a simultaneous likelihood fit, using a normalization factor for each background (μ_{VV} and μ_{top}). The number of observed events in each CR, as well as the predicted yield of each SM process, is shown in Table 6. For backgrounds whose normalisation is extracted from the likelihood fit, the yield expected from the MC simulation is also reported. The normalisation factors applied to the VV and top-quark backgrounds are found to be $\mu_{VV} = 1.38 \pm 0.08$ and $\mu_{top} = 1.09 \pm 0.03$ respectively, where the errors include all uncertainties described in Section 8. These normalisation factors are applied in all of the chargino search VRs and SRs. The shapes of kinematic distributions are well reproduced by the simulation in each CR, as show in Figure 3.

Table 6: Observed event yields and predicted background yields from the likelihood fit in the CRs for the chargino search. For backgrounds with a normalisation extracted from the likelihood fit, the yield expected from the simulation before the likelihood fit is also shown. The FNP lepton background is calculated using the data-driven matrix method. 'Other backgrounds' include the non-dominant background sources, e.g. $t\bar{t}$+V, Higgs boson and Drell–Yan events. The uncertainties include both statistical and systematic contributions.

Region	CR-VV	CR-top
Observed events	634	4468
Fitted backgrounds	634 ± 25	4470 ± 70
Fitted VV	520 ± 27	68 ± 12
Fitted $t\bar{t}$	69 ± 7	3240 ± 100
Fitted single top	40 ± 6	1130 ± 90
Other backgrounds	$4.8^{+5.1}_{-4.8}$	29 ± 5
FNP leptons	$0.02^{+1.4}_{-0.02}$	$0.06^{+12}_{-0.06}$
Simulated VV	376	49
Simulated $t\bar{t}$	63	2974
Simulated single top	37	1040

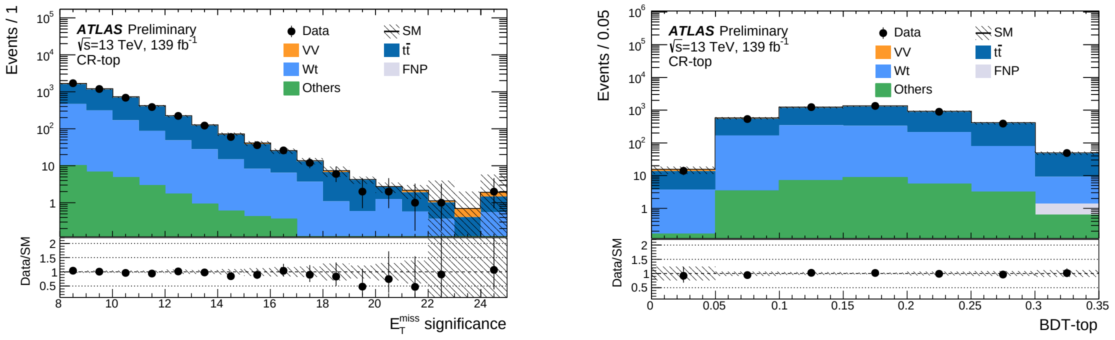
A set of six validation regions is used to verify the agreement of data and SM predictions within uncertainties in regions with a phase space kinematically close to the SRs, after performing the likelihood fit. The definitions are reported in the second part of Table 5. The regions VR-VV-DF, VR-VV-SF, VR-top-DF and VR-top-SF are designed to be in an intermediate BDT-signal selection compared to the corresponding CRs and SRs. Regions VR-top0J-DF and VR-top0J-SF are used to validate the extrapolation of the top normalization factor from the region with $n_{b\text{-tagged jets}} = 1$ (CR-top) to regions with $n_{b\text{-tagged jets}} = 0$ (SRs). Furthermore VR-top0J-DF and VR-top0J-SF are also used to validate the top-quark background estimate in regions with the same relative fraction of $t\bar{t}$ and Wt as the one observed in the SRs.

The numbers of observed events and the predicted background in each VR are shown in Table 7. They agree within one standard deviation except in VR-top0J-DF, where a 1.8σ discrepancy is observed. For backgrounds with a normalisation extracted from the likelihood fit, the expected yield from simulated samples before the likelihood fit is also shown. Figure 4 shows a selection of kinematic distributions for data and the estimated SM background in the validation regions defined in Table 5. Good agreement is observed in all regions.



(a) m_{T2} distribution in CR-VV

(b) BDT-VV distribution in CR-VV



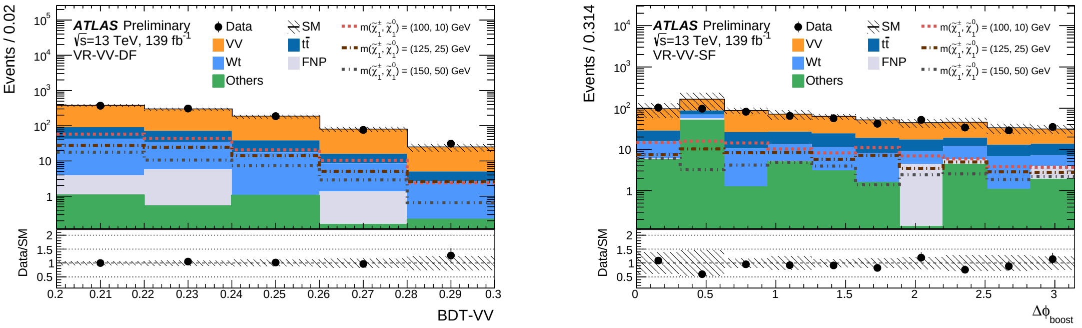
(c) $E_{\mathrm{T}}^{\mathrm{miss}}$significance distribution in CR-top

(d) BDT-top distribution in CR-top

Figure 3: Distributions of (a) m_{T2} , (b) BDT-VV in CR-VV, (c) $E_{\mathrm{T}}^{\mathrm{miss}}$significance and (d) BDT-top in CR-top for data and the estimated SM backgrounds. The normalisation factors extracted from the corresponding CRs are used to rescale the $t\bar{t}$, single-top-quark and VV backgrounds. The FNP lepton background is calculated using the data-driven matrix method. ‘Others’ include the non-dominant background sources, e.g. $t\bar{t}$+V, Higgs boson and Drell–Yan events. The uncertainty band includes systematic and statistical errors from all sources and the final bin in each histogram includes the overflow. The lower panels show the ratio of data to the SM background estimate.

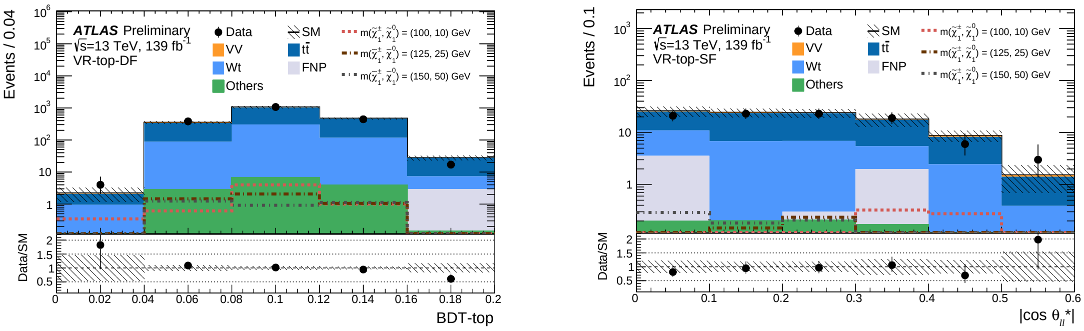
Table 7: Observed event yields and predicted background yields in the VRs for the chargino search. For backgrounds with a normalisation extracted from the likelihood fit in the CRs, the yield expected from the simulation before the likelihood fit is also shown. The FNP lepton background is calculated using the data-driven matrix method. ‘Other backgrounds’ include the non-dominant background sources, e.g. $t\bar{t}$+V, Higgs boson and Drell–Yan events. The uncertainties include both statistical and systematic contributions.

Regions	VR-VV-DF	VR-VV-SF	VR-top-DF	VR-top-SF	VR-top0J-DF	VR-top0J-SF
Observed events	972	596	1910	95	810	17
Fitted backgrounds	940 ± 60	670 ± 90	1900 ± 90	101 ± 10	880 ± 40	18 ± 4
Fitted VV	730 ± 50	400 ± 50	32 ± 13	2.2 ± 2.1	427 ± 30	8.1 ± 2.6
Fitted $t\bar{t}$	116 ± 12	111 ± 11	1350 ± 50	67 ± 7	260 ± 21	5.8 ± 1.8
Fitted single top	94 ± 19	75 ± 11	500 ± 60	27 ± 7	168 ± 18	4 ± 1
Other backgrounds	3.1 ± 1.5	70 ± 70	13.6 ± 2.5	0.8 ± 0.4	5.2 ± 1.9	0.05 ± 0.05
FNP leptons	$0.02^{+2.3}_{-0.02}$	7 ± 4	$0.03^{+5}_{-0.03}$	4.2 ± 1.3	21 ± 8	$0.05^{+0.15}_{-0.05}$
Simulated VV	527	291	23	1.6	309	5.9
Simulated $t\bar{t}$	106	102	1240	61	239	5.3
Simulated single top	87	69	460	25	154	3.2



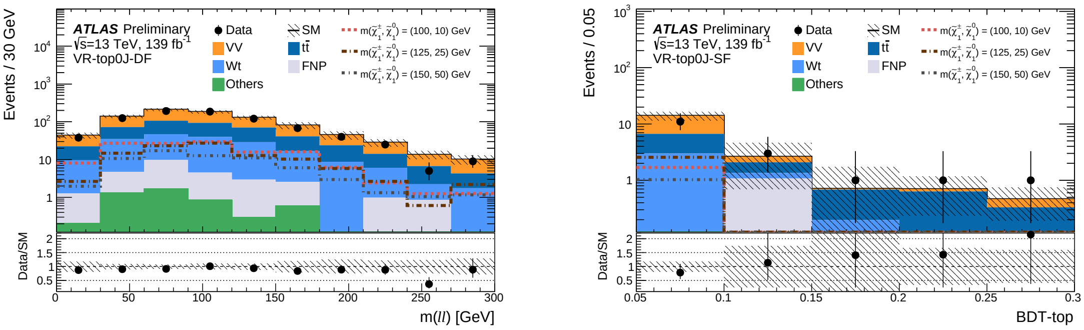
(a) BDT-VV distribution in VR-VV-DF

(b) $\Delta\phi_{\mathrm{boost}}$ distribution in VR-VV-SF



(c) BDT-top distribution in VR-top-DF

(d) $|\cos\theta^{*}_{\ell\ell}|$ distribution in VR-top-SF



(e) $m_{\ell\ell}$ distribution in VR-top0J-DF

(f) BDT-top distribution in VR-top0J-SF

Figure 4: Distributions of (a) BDT-VV in VR-VV-DF, (b) $\Delta\phi_{\mathrm{boost}}$ in VR-VV-SF, (c) BDT-top in VR-top-DF, (d) $|\cos\theta^{*}_{\ell\ell}|$ in VR-top-SF, (e) $m_{\ell\ell}$ in VR-top0J-DF and (f) BDT-top in VR-top0J-SF, for data and the estimated SM backgrounds. The normalisation factors extracted from the corresponding CRs are used to rescale the $t\bar{t}$, single-top-quark and VV backgrounds. The FNP lepton background is calculated using the data-driven matrix method. 'Others' include the non-dominant background sources, e.g. $t\bar{t}$+V, Higgs boson and Drell–Yan events. The uncertainty band includes systematic and statistical errors from all sources and the last bin includes the overflow. Distributions for three benchmark signal points are overlaid for comparison. The lower panels show the ratio of data to the SM background estimate.

8 Systematic uncertainties

The likelihood fits used for calculating the results of the two analyses consider all relevant sources of experimental and theoretical systematic uncertainty affecting the SM background estimates and the signal predictions. The major sources of uncertainty in the slepton search are related to the FSB estimation, while in the chargino search the dominant contributions come from the VV theoretical uncertainty, normalisation of background processes and uncertainty associated to the jet energy scale and resolution and to the $\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}$ soft-term scale and resolution. Statistical uncertainties associated with the simulated MC samples are also accounted for. For the chargino search, in the cases where the normalisation of background processes (VV and top) are calculated using control regions, the systematic uncertainties only affect the extrapolation to the signal regions.

The jet energy scale and resolution uncertainties are calculated as a function of the p_{T} and η of the jet, and the pile-up conditions and flavour composition of the selected jet sample. They are derived using a combination of data and simulated samples, through studies including measurements of the transverse momentum balance between a jet and a reference object in dijet, Z+jets and γ+jets events [86, 96, 97]. An additional uncertainty in the modelling of $\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}$ comes from the soft-term resolution and scale [90]. Experimental uncertainties on the scale factors used to account for differences between the data and simulation in b-jet identification, lepton reconstruction efficiency and trigger efficiency are also included. The remaining experimental uncertainties include lepton energy scale and resolution and are found to be negligible across all analysis regions.

Several sources of theoretical uncertainty in the modelling of the dominant backgrounds are considered. Modelling uncertainties on diboson, $t\bar{t}$, single-top (Wt) and Z+jets backgrounds are considered in the chargino search, whilst the slepton search only considers modelling uncertainties on the WZ/ZZ diboson processes and Z+jets, due to the data-driven background estimation method used for the flavour-symmetric backgrounds.

The diboson modelling uncertainties are calculated by varying the PDF sets [68] as well as the QCD renormalisation and factorisation scales used to generate the samples. Uncertainties from missing higher orders are evaluated [98] using six variations of the QCD factorisation and renormalisation scales in the matrix elements by factors of 0.5 and 2, avoiding variations in opposite directions. Additional uncertainties on the resummation and matching scales between the matrix element generator and parton shower are considered.

The $t\bar{t}$ background is affected by modelling uncertainties associated with the parton shower modelling, the different approaches in the matching between the matrix element and the parton shower and the modelling of the initial and final-state radiation (ISR/FSR). Uncertainties in the parton shower simulation are estimated by comparing samples generated with Powheg Box interfaced to either Pythia8.186 or Herwig 7.04 [99, 100]. The ISR/FSR uncertainties are calculated by comparing the predictions of the nominal sample with alternative scenarios with the relevent generator parameters varied [101]. The uncertainty associated with the choice of event generator is estimated by comparing the nominal samples with samples generated with aMC@NLO interfaced to Pythia8.186 [101]. Finally, for single-top-quark production an uncertainty is assigned to the treatment of the interference between the Wt and $t\bar{t}$ samples. This is done by comparing the nominal sample generated using the diagram removal method with a sample generated using the diagram subtraction method [102, 103].

Table 8: Breakdown of the dominant systematic uncertainties on background estimates in the inclusive SRs requiring $m_{\mathrm{T2}}^{100} \in [100, \infty)$ for the 0J and 1J selections in the slepton search. The individual uncertainties can be correlated, and do not necessarily add up quadratically to the total background uncertainty. The percentages show the size of the uncertainty relative to the total expected background.

Region m_{T2} [GeV]	SR-0J $\in[100,\infty)$	SR-1J $\in[100,\infty)$
Total background expectation	76	78
MC and FSB statistical uncertainties	14%	13%
FSB estimate	9%	9%
FNP leptons	5%	4%
$Z/\gamma^{*}(\rightarrow ll)$+jets theoretical uncertainties	$< 1\%$	3%
$E_{\mathrm{T}}^{\mathrm{miss}}$ modelling	2.3%	$< 1\%$
Jet energy scale	$< 1\%$	$< 1\%$
Jet energy resolution	$< 1\%$	1%
b-tagging	$< 1\%$	$< 1\%$
Lepton modelling	1%	$< 1\%$
Total systematic uncertainty	17%	17%

The Z+jets background is affected by QCD factorisation and renormalisation scales uncertainties. Furthermore, uncertainties on the resummation and matching scales between the matrix element generator and parton shower are also considered.

There are several contributions to the uncertainty in the MM estimate of the FNP background. The real efficiencies and the electron light-flavoured fake rate (which are calculated using MC simulation) are affected by the experimental uncertainties on the scale factors applied to account for differences between data and simulation in the lepton trigger, identification, reconstruction and isolation efficiencies. For the heavy-flavour fake rate an uncertainty is calculated to account for uncertainties in the subtraction of the prompt-lepton contamination in the control region, by varying this contamination and evaluating the effects on the resulting FNP background estimates. Finally, uncertainties in the expected composition of the FNP leptons in the signal regions are included, along with statistical uncertainties on all of the real efficiencies and fake rates used in the calculation.

For the slepton search, additional uncertainties associated with the data-driven background estimate of the flavour-symmetric backgrounds (FSB estimate) discussed in Section 7 are also applied. The statistical uncertainty on the DF sample is included. Uncertainties on the κ and α factors that account for the difference in reconstruction, identification and trigger efficiencies for muons and electrons are obtained by considering the differences between global efficiencies calculated in data and simulation. Finally, additional uncertainties are applied to account for possible differences between the results for reweighting the events as a function of the sub-leading lepton p_{T} instead of the leading lepton p_{T}, and for the choice of the fitting function for the dependence of κ on this variable. A summary of the impact of the systematic uncertainties on the background yields in the inclusive SRs requiring $m_{\mathrm{T2}}^{100} \in [100, \infty)$, after performing the likelihood fit, is shown in Table 8 for the 0J and 1J selections.

Table 9: Breakdown of the dominant systematic uncertainties on background estimates in the inclusive region SR-DF-81-SF-77 for the chargino search. The individual uncertainties can be correlated, and do not necessarily add up quadratically to the total background uncertainty. The percentages show the size of the uncertainty relative to the total expected background.

Region	SRD-DF0J-81-SF0J-77
Total background expectation	622
$E_{\mathrm{T}}^{\mathrm{miss}}$ modelling	6.6%
Diboson theoretical uncertainties	5.2%
Jet energy scale	5.1%
VV normalisation	3.6%
Jet energy resolution	1.8%
MC statistical uncertainties	1.7%
Lepton modelling	1.1%
Top theoretical uncertainties	1%
$t\bar{t}$ normalization	1%
FNP leptons	0.8%
b-tagging	0.7%
$Z/\gamma^{*}(\rightarrow ll)$+jets theoretical uncertainties	0.04%
Total systematic uncertainty	8.7%

For the chargino search, a summary of the impact of the systematic uncertainties on the background yields in the inclusive region SR-DF-81-SF-77, obtained as the integral of all the binned regions in Table 3 (thus requiring BDT-signal $\in (0.81, 1]$ for DF events and $\in (0.77, 1]$ for SF events), is shown in Table 9 after performing the likelihood fit.

9 Results

The results of the two searches are interpreted in the context of the sleptons and charginos simplified models shown in Figure 1, and as general limits on new physics cross-sections.

The statistical interpretation of the results is performed using the HistFitter [104] framework. The likelihood is a product of Poisson probability density functions (PDF), describing the observed number of events in each CR/SR, and Gaussian pdf distributions that describe the nuisance parameters associated with each of the systematic uncertainties. Furthermore Poisson distributions are used for MC statistical uncertainties. Systematic uncertainties that are correlated between different samples are accounted for in the fit configuration by using the same nuisance parameter. In particular, experimental systematic uncertainties are correlated between background and signal samples for all regions. The uncertainties are applied in each of the CRs and SRs and their effect is correlated for events across all regions in the fit.

The background fit strategy is different in the two searches. The chargino search uses data in the CRs and the likelihood fit is performed to constrain the nuisance parameters of the likelihood function, which include the background normalisation factors and parameters associated with the systematic uncertainties. The slepton search uses the FSB prediction in the SRs, and the likelihood fit is used to constrain the nuisance parameters associated with the systematic uncertainties. In both cases, the results of the background fit are used to test the compatibility of the observed data with the background estimates in the inclusive SRs.

The $\mathrm{CL_s}$ method [105] is used, for the slepton search, to set model-independent upper limits at 95% confidence level (CL) on the visible signal cross-section σ^{vis}, defined as the cross-section times acceptance times efficiency, of processes beyond the SM. They are derived in each inclusive SR by performing a fit that includes the CRs, the observed yield in the SR as a constraint, and a signal yield in the SR as a free parameter of interest. The observed ($S^{0.95}_{\mathrm{obs}}$) and expected ($S^{0.95}_{\mathrm{exp}}$) limits at 95% CL on the numbers of events from processes beyond the SM in the inclusive SRs are calculated. The p_0-values, which represent the probability of the SM background alone to fluctuate to the observed number of events or higher, are also included in the results and are capped at $p_0 = 0.50$.

Exclusion limits at 95% CL are provided on the masses of the sleptons, chargino and neutralino. The $\mathrm{CL_s}$ prescription is also used in this case, including the data in the binned SRs in the simultaneous likelihood fit.

9.1 Results of the slepton search

The predicted number of background events, obtained applying the efficiency correction method to compute the number of expected FSB events, together with the observed data in the binned SRs defined in Table 2, are shown in Figure 5 for 0J and 1J selections. In the binned SR-0J, the expected background exceeds the observed data in two m_{T2}^{100} bins, with a local significance of about 2σ. The same behaviour is observed in these bins when using pure MC simulations to estimate the background, thus the disagreement most likely arises from statistical fluctuations in data. In the binned SR-1J, there are excesses of data of about 1.5σ in two m_{T2}^{100} bins, while the expected background exceeds the observed data with a local significance of 3.5σ in one m_{T2}^{100} bin. These discrepancies are found to be strictly correlated with statistical fluctuations in the distribution of DF events in data which are used to estimate the FSB. This is observed when comparing pure MC simulations to DF data in the SRs. Furthermore, when comparing pure MC simulations to SF data in the SRs, fluctuations of the data in the opposite direction are observed. The combination of the two effects enhances the discrepancy.

The observed and predicted numbers of background events in the inclusive SRs are reported in Table 10, together with the model-independent upper limits on visible signal cross-section σ^{vis}, the observed and expected limits at 95% CL on the number of potential beyond the SM events, and the p_0-values. Exclusion limits at 95% CL on the masses of the sleptons and neutralino are shown in Figure 6 for mass-degenerate $\tilde{e}_{\mathrm{L,R}}/\tilde{\mu}_{\mathrm{L,R}}$, bridging the gap between previous ATLAS searches and surpassing limits from LEP: sleptons up to 150 GeV are excluded at 95% CL in the case of a mass splitting between the sleptons and the LSP of 50 GeV.

Exclusion limits are also set for selectrons and smuons separately, considering the same selection (including both dielectron and dimuon events in the likelihood fit) used for the general result. These are shown in Figure 7 for single slepton species $\tilde{e}_{\mathrm{R}}$, $\tilde{e}_{\mathrm{L}}$ and $\tilde{\mu}_{\mathrm{L}}$ along with combined limits for mass-degenerate $\tilde{e}_{\mathrm{L,R}}$ and $\tilde{\mu}_{\mathrm{L,R}}$. Concerning this last case, portions of the region excluded by this search in the $m(\tilde{\mu}) - m(\tilde{\chi}^0_1)$ plane are expected to be compatible with the $(g-2)_{\mu}$ anomaly for small $\tan\beta$ values [106].

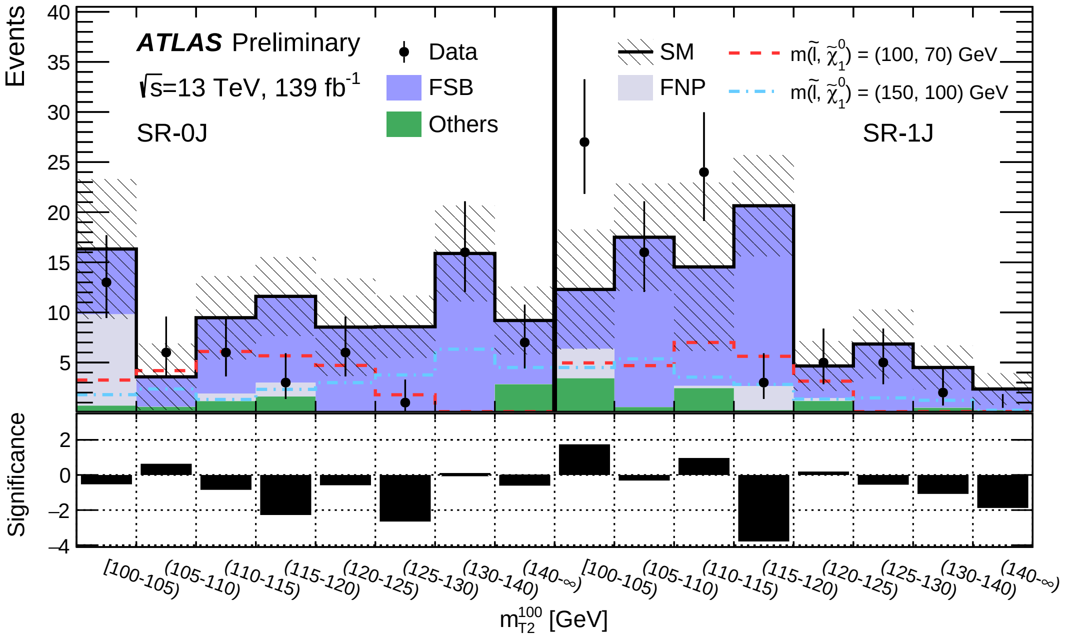
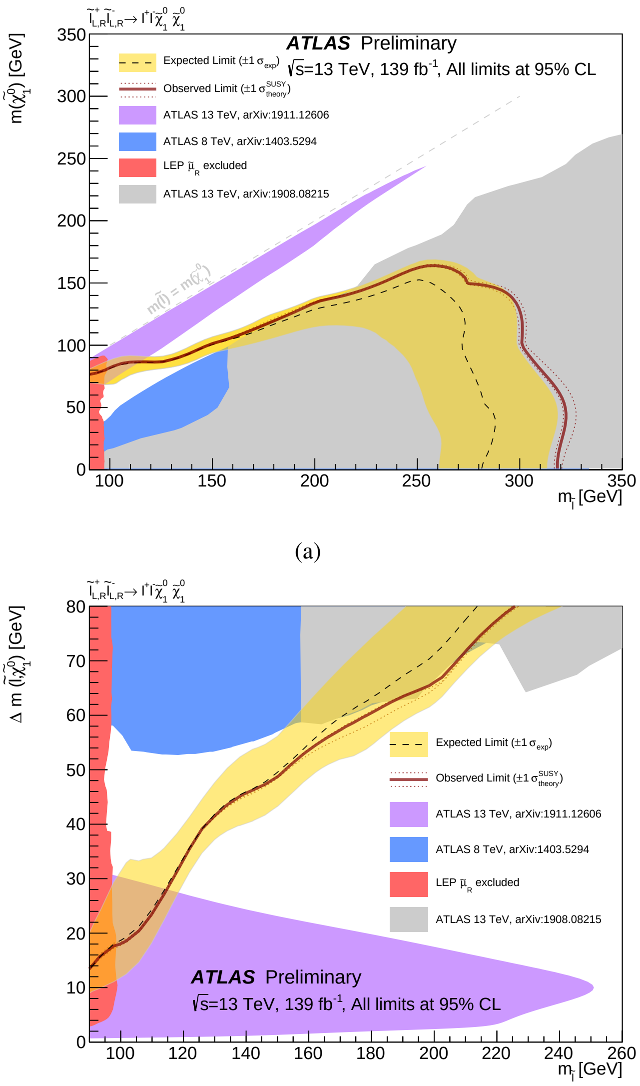


Figure 5: The upper panel shows the observed number of events in each of the binned SRs defined in Table 2, together with the expected SM backgrounds obtained after applying the efficiency correction method to compute the number of expected FSB events. 'Others' include the non-dominant background sources, e.g. $t\bar{t}$+V, Higgs boson and Drell–Yan events. The uncertainty band includes systematic and statistical errors from all sources. The distributions of two signal points with mass splittings $\Delta m(\ell, \tilde{\chi}_1^0) = m(\tilde{\ell}) - m(\tilde{\chi}_1^0) = 30$ GeV and $\Delta m(\ell, \tilde{\chi}_1^0) = m(\tilde{\ell}) - m(\tilde{\chi}_1^0) = 50$ GeV are overlaid. The lower panel shows the significance as defined in Ref. [107].

Table 10: Observed event yields and predicted background yields for the inclusive SRs defined in Table 2. The model-independent upper limits at 95% CL on the observed and expected numbers of beyond-the-SM events $S^{0.95}_{\mathrm{obs/exp}}$ and on the effective beyond-the-SM cross-section σ^{vis} ($\langle A\epsilon\sigma\rangle^{0.95}_{\mathrm{obs}}$) are also shown. The $\pm 1\sigma$ variations on $S^{0.95}_{\mathrm{exp}}$ are provided. The last column shows the p_0-value of the SM-only hypothesis. For SRs where the data yield is smaller than expected, the p_0-value is capped at 0.50.

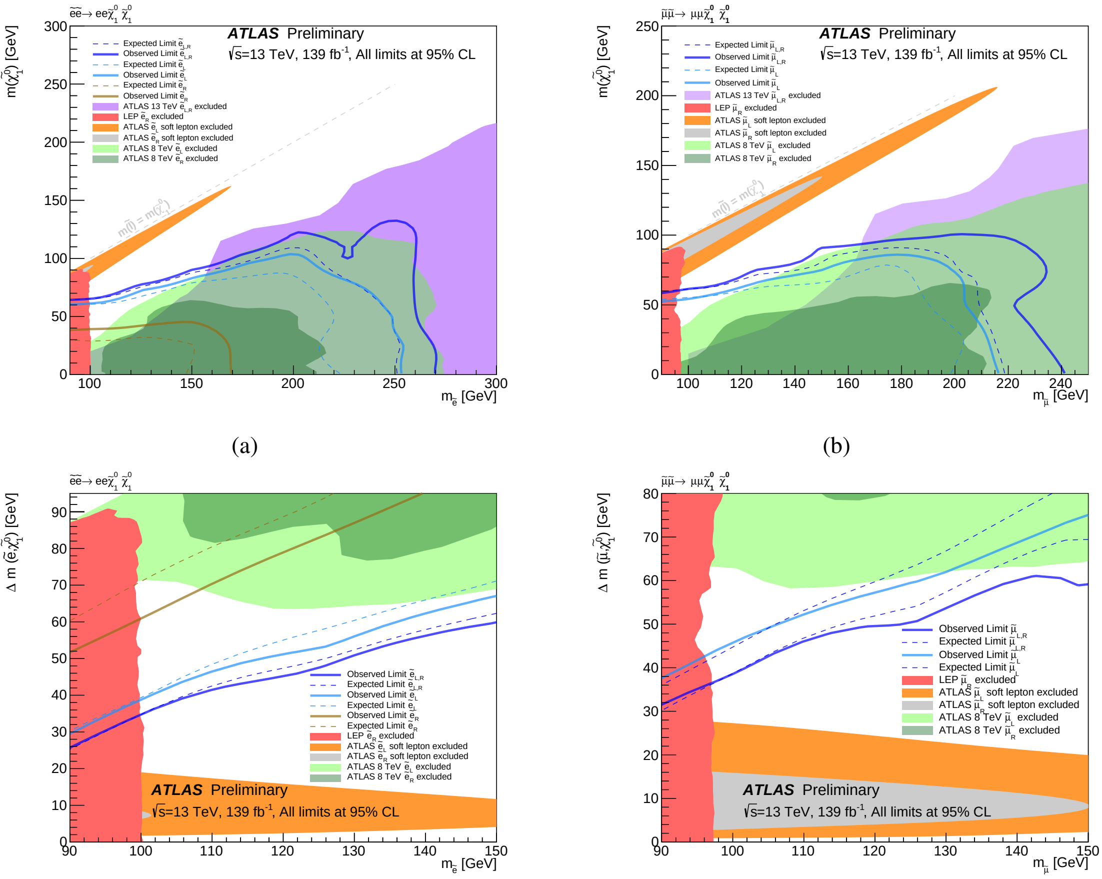
Signal region	Observed	Expected	σ^{vis}[fb]	S^{95}_{obs}	S^{95}_{exp}	p_0
SR-0J $m_{\mathrm{T2}}^{100} \in [100, \infty)$	58	76 ± 13	0.13	18.3	26^{+10}_{-7}	0.50
SR-0J $m_{\mathrm{T2}}^{100} \in [110, \infty)$	39	58 ± 11	0.09	13.2	21^{+8}_{-6}	0.50
SR-0J $m_{\mathrm{T2}}^{100} \in [120, \infty)$	30	40 ± 8	0.10	13.5	18^{+7}_{-5}	0.50
SR-0J $m_{\mathrm{T2}}^{100} \in [130, \infty)$	23	24 ± 6	0.10	14.2	15^{+6}_{-4}	0.50
SR-0J $m_{\mathrm{T2}}^{100} \in [140, \infty)$	7	9.2 ± 3.4	0.05	7.5	$8.6^{+4}_{-2.5}$	0.50
SR-1J $m_{\mathrm{T2}}^{100} \in [100, \infty)$	82	78 ± 13	0.24	33.5	31^{+11}_{-8}	0.41
SR-1J $m_{\mathrm{T2}}^{100} \in [110, \infty)$	39	50 ± 17	0.17	24.0	28^{+9}_{-7}	0.50
SR-1J $m_{\mathrm{T2}}^{100} \in [120, \infty)$	12	16 ± 5	0.07	9.5	12^{+5}_{-3}	0.50
SR-1J $m_{\mathrm{T2}}^{100} \in [130, \infty)$	2	6.9 ± 2.8	0.03	3.9	$6.1^{+3.0}_{-1.9}$	0.50
SR-1J $m_{\mathrm{T2}}^{100} \in [140, \infty)$	0	2.4 ± 1.6	0.02	2.4	$3.4^{+2.2}_{-1.2}$	0.50



(a)

(b)

Figure 6: Observed and expected exclusion limits on SUSY simplified models for slepton-pair production in the (a) $m(\tilde{\ell}) - m(\tilde{\chi}^0_1)$ and (b) $m(\tilde{\ell}) - \Delta m(\tilde{\ell}, \tilde{\chi}^0_1)$ planes. Only $\tilde{e}$ and $\tilde{\mu}$ are considered. The observed (solid thick line) and expected (thin dashed line) exclusion contours are indicated. The shaded band around the dashed line corresponds to the $\pm 1\sigma$ variations in the expected limit, including all uncertainties except theoretical uncertainties in the signal cross-section. The dotted lines around the observed limit illustrate the change in the observed limit as the nominal signal cross-section is scaled up and down by the theoretical uncertainty. All limits are computed at 95% CL. The observed limits obtained at LEP [108] for $\tilde{\mu}_R$ and by the ATLAS experiment in previous searches are also shown [13, 15, 109].



(a)

(b)

(c)

(d)

Figure 7: Observed and expected exclusion limits on SUSY simplified models for direct selectron production in the (a) $m(\tilde{e}) - m(\tilde{\chi}_1^0)$ and (c) $m(\tilde{e}) - \Delta m(\tilde{e}, \tilde{\chi}_1^0)$ planes, and for direct smuon production in the (b) $m(\tilde{\mu}) - m(\tilde{\chi}_1^0)$ and (d) $m(\tilde{\mu}) - \Delta m(\tilde{\mu}, \tilde{\chi}_1^0)$ planes. In Figure (a) and (c) the observed (solid thick lines) and expected (dashed lines) exclusion contours are indicated for combined $\tilde{e}_{\mathrm{L,R}}$ and for $\tilde{e}_{\mathrm{L}}$ and $\tilde{e}_{\mathrm{R}}$. In Figure (b) and (d) the observed (solid thick lines) and expected (dashed lines) exclusion contours are indicated for combined $\tilde{\mu}_{\mathrm{L,R}}$ and for $\tilde{\mu}_{\mathrm{L}}$. No sensitivity is observed to $\tilde{\mu}_{\mathrm{R}}$. All limits are computed at 95% CL. The observed limits obtained at LEP [108] and by the ATLAS experiment in previous searches are also shown in the shaded areas [13, 15, 109].

9.2 Results of the chargino search

The predicted numbers of background events obtained applying the results of the background fit in the binned SRs defined in Table 3 are shown together with the observed data in Figure 8. No significant deviations from the SM expectations are observed in any of the SRs considered, as shown in Figure 8.

Exclusion limits at 95% CL are set, using the $\mathrm{CL_s}$ prescription, on the masses of the chargino and the LSP. These also use the $\mathrm{CL_s}$ prescription and include the exclusive SRs and the CRs in the simultaneous likelihood fit. The SF and DF SRs are included in the likelihood fit. The exclusion limits are shown in in Figure 9: chargino masses up to 135 GeV are excluded at 95% CL in the case of a mass splitting between chargino and neutralino up to 100 GeV.

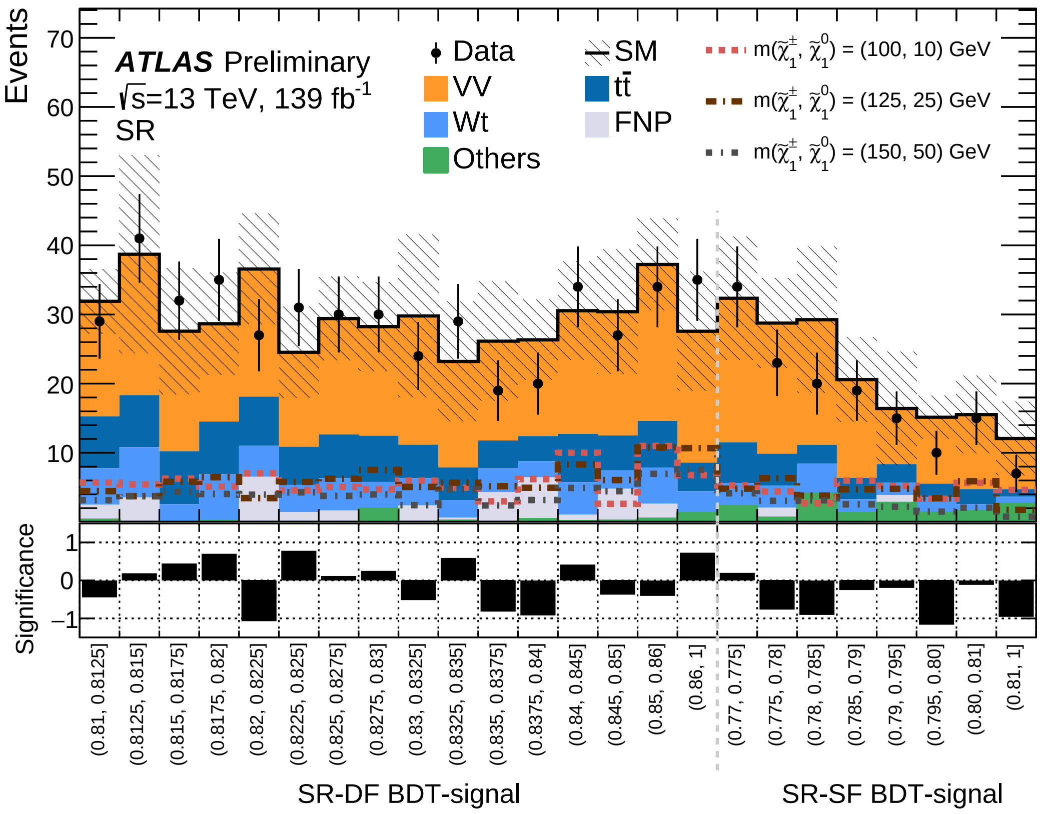
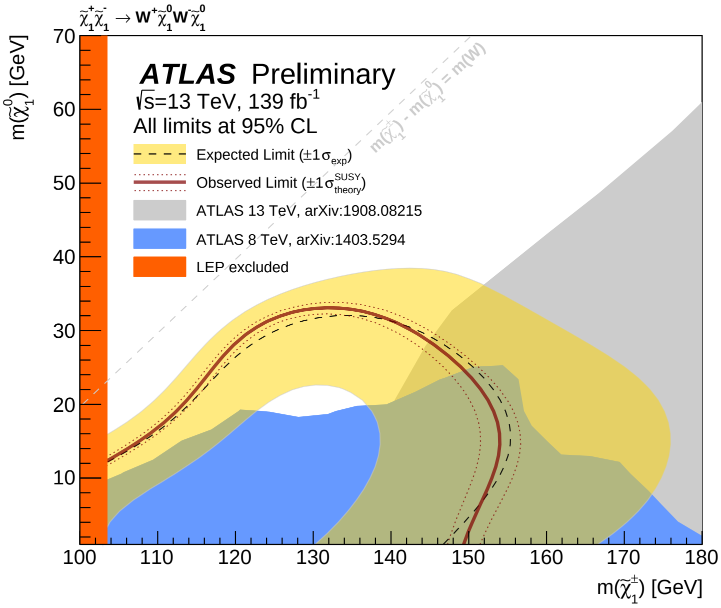
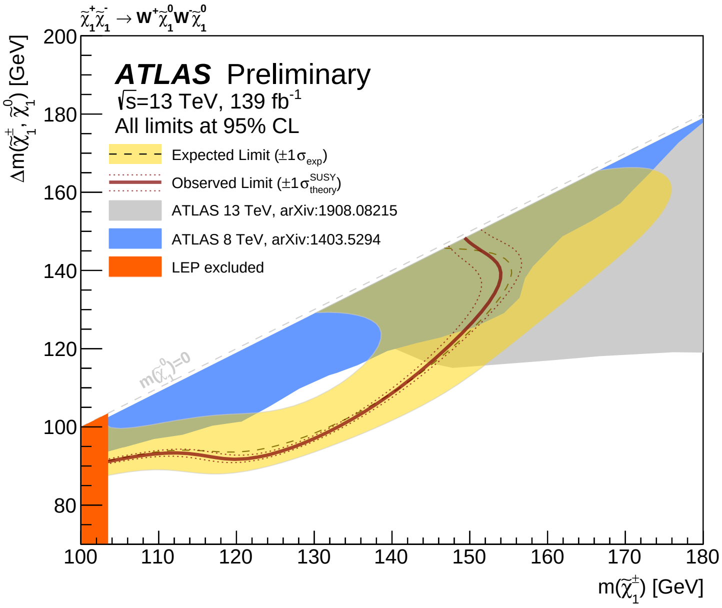


Figure 8: The upper panel shows the observed number of events in the SRs defined in Table 3, together with the expected SM backgrounds obtained after the background fit in the CRs. 'Others' include the non-dominant background sources, e.g. $t\bar{t}$+V, Higgs boson and Drell–Yan events. The uncertainty band includes systematic and statistical errors from all sources. Distributions for three benchmark signal points are overlaid for comparison. The lower panel shows the significance as defined in Ref. [107].



(a)



(b)

Figure 9: Observed and expected exclusion limits on SUSY simplified models for chargino-pair production with W-boson-mediated decays in the (a) $m(\tilde{\chi}_1^{\pm}) - m(\tilde{\chi}_1^0)$ and (b) $m(\tilde{\chi}_1^{\pm}) - \Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0)$ planes. The observed (solid thick line) and expected (thin dashed line) exclusion contours are indicated. The shaded band around the dashed line corresponds to the $\pm 1\sigma$ variations in the expected limit, including all uncertainties except theoretical uncertainties in the signal cross-section. The dotted lines around the observed limit illustrate the change in the observed limit as the nominal signal cross-section is scaled up and down by the theoretical uncertainty. All limits are computed at 95% CL. The observed limits obtained at LEP [110] and by the ATLAS experiment in previous searches are also shown [13, 15]. In case of the search performed on ATLAS Run 1 data at $\sqrt{s} = 8$ TeV [15] no sensitivity was expected for the exclusion in the mass plane.

10 Conclusion

The results of a search for the electroweak production of charginos and sleptons decaying into final states containing two leptons with opposite electric charge and missing transverse momentum are presented. The search uses 139 fb^{-1} of $\sqrt{s} = 13$ TeV proton–proton collisions collected by the ATLAS experiment at the LHC during Run 2 (2015-2018). Two scenarios are considered: the direct production of slepton pairs, where each slepton decays directly into the lightest neutralino and a lepton, and the production of lightest-chargino pairs, followed by their decays into final states with leptons and the lightest neutralino via W bosons. The regions with low to moderate mass difference (up to ∼150 GeV) between sleptons and neutralino and between chargino and neutralino are explored in this analysis. These regions, in case of $m(\tilde{\mu}) - m(\tilde{\chi}_1^0)$ plane, are favoured to explain the $(g-2)_\mu$ anomaly for small $\tan\beta$ values. A data-driven technique is performed to estimate the main backgrounds in the slepton search and a semi-data-driven approach using CRs to normalize the main backgrounds, classified with a Boosted Decision Tree, is used in the chargino search.

Data are found to be consistent with the Standard Model predictions and limits at 95% CL are set on the masses of relevant supersymmetric particles in each of these scenarios. Sleptons up to 150 GeV are excluded at 95% CL in the case of a mass splitting between sleptons and neutralino of 50 GeV, and chargino masses up to 135 GeV are excluded at 95% CL in the case of a mass splitting between chargino and neutralino up to 100 GeV. These results extend the previous exclusion limits [15–20, 22] for the same scenarios in the regions with a low to moderate mass difference (up to ∼150 GeV) between slepton or chargino and neutralino.

Acknowledgements

We thank CERN for the very successful operation of the LHC, as well as the support staff from our institutions without whom ATLAS could not be operated efficiently.

We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWFW and FWF, Austria; ANAS, Azerbaijan; SSTC, Belarus; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; ANID, Chile; CAS, MOST and NSFC, China; Minciencias, Colombia; MEYS CR, Czech Republic; DNRF and DNSRC, Denmark; IN2P3-CNRS and CEA-DRF/IRFU, France; SRNSFG, Georgia; BMBF, HGF and MPG, Germany; GSRI, Greece; RGC and Hong Kong SAR, China; ISF and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; NWO, Netherlands; RCN, Norway; MEiN, Poland; FCT, Portugal; MNE/IFA, Romania; JINR; MES of Russia and NRC KI, Russian Federation; MESTD, Serbia; MSSR, Slovakia; ARRS and MIZŠ, Slovenia; DSI/NRF, South Africa; MICINN, Spain; SRC and Wallenberg Foundation, Sweden; SERI, SNSF and Cantons of Bern and Geneva, Switzerland; MOST, Taiwan; TAEK, Turkey; STFC, United Kingdom; DOE and NSF, United States of America. In addition, individual groups and members have received support from BCKDF, CANARIE, Compute Canada and CRC, Canada; COST, ERC, ERDF, Horizon 2020 and Marie Skłodowska-Curie Actions, European Union; Investissements d'Avenir Labex, Investissements d'Avenir Idex and ANR, France; DFG and AvH Foundation, Germany; Herakleitos, Thales and Aristeia programmes co-financed by EU-ESF and the Greek NSRF, Greece; BSF-NSF and GIF, Israel; Norwegian Financial Mechanism 2014-2021, Norway; NCN and NAWA, Poland; La Caixa Banking Foundation, CERCA Programme Generalitat de Catalunya and PROMETEO and GenT Programmes Generalitat Valenciana, Spain; Göran Gustafssons Stiftelse, Sweden; The Royal Society and Leverhulme Trust, United Kingdom.

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK) and BNL (USA), the Tier-2 facilities worldwide and large non-WLCG resource providers. Major contributors of computing resources are listed in Ref. [111].

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Auxiliary material

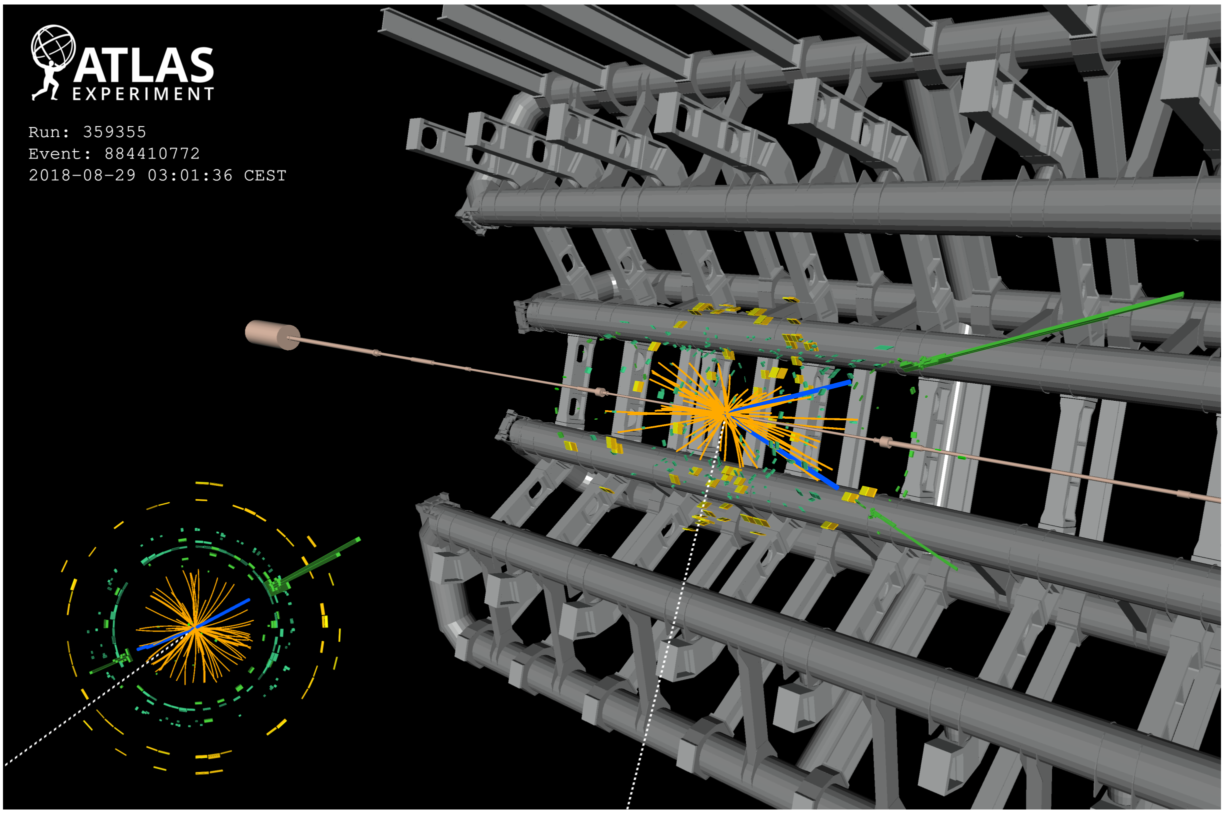

Figure 10: Event display of a candidate $\tilde{e}\tilde{e}$ into electrons and $\tilde{\chi}_1^0\tilde{\chi}_1^0$ event, recorded during $\sqrt{s} = 13$ TeV pp collisions in the year 2018. The event belongs to the SR-0J signal region targeting direct slepton production and contains two identified electrons with opposite electric charge, missing transverse energy, and very little hadronic activity. The event is shown along with a portion of the ATLAS detector on the right, and in the x-y plane on the left. Charged particle tracks are reconstructed using hits in the inner-detector and are shown in orange. Electrons are reconstructed by matching EM calorimeter deposits (green) to these inner detector tracks, with those corresponding to the identified electrons being highlighted in blue. The transverse momenta of the electrons are measured to be 159 GeV and 55 GeV. The missing transverse energy in the event is indicated by the dashed white line and has a magnitude of 101 GeV. Together, the electrons and missing transverse energy are used to calculate the “stransverse mass” (m_{T2}^{100}), which is measured to be 104 GeV.