PROCEEDINGS OF SCIENCE

Search for electroweak production of supersymmetric sleptons and charginos with the ATLAS detector

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A new search for the electroweak production of supersymmetric particles decaying into two leptons with missing transverse momentum is presented. Assuming R-parity conservation, two simplified models are considered: direct pair production of sleptons decaying into the lightest neutralinos through leptons of the Standard Model and direct pair production of the lightest charginos decaying into the lightest neutralinos through W bosons of the SM. The analysis targets phase space regions where the difference in mass between the slepton or the lightest chargino and the lightest neutralino is close to or below the mass of the W boson. Such regions with compressed mass spectra have not been covered by any searches conducted so far due to the low cross section of the supersymmetric signal. Therefore, improved analysis strategies are crucial to separate the supersymmetric signal from the SM backgrounds. A search for an excess of same-flavour lepton pairs in opposite-sign lepton events is made in the direct slepton pair production analysis while a multivariate approach using gradient boosted decision trees is exploited in the chargino pair production analysis and considering both the same-flavour and different-flavour channels. 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 data excesses over the expected background are observed and exclusion limits at 95% confidence level are set for each considered model. Exclusion limits are also set for selectrons and smuons separately and portions of the region excluded by the search of smuons pair production are expected to be compatible with the muon $g-2$ anomaly for small $\tan\beta$ values.

The Tenth Annual Conference on Large Hadron Collider Physics - LHCP2022
16-20 May 2022
online

https://pos.sissa.it/

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1. Introduction

Supersymmetry (SUSY) [1–6] is a theoretical extension of the Standard Model (SM) that introduces a new fermionic/bosonic 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 valid candidate for dark matter [8, 9]. In the electroweak sector, sleptons are the superpartners of the SM leptons and electroweakinos are the superpartners of the SM Higgs and the electroweak gauge bosons. The electroweakinos mix to form chargino ($\tilde{\chi}^{\pm}_{i}, i = 1, 2$) and neutralino ($\tilde{\chi}^{0}_{j}, j = 1, 2, 3, 4$) mass eigenstates. Electroweak scale SUSY with light smuons (superpartners of the SM muons) can explain the $g - 2$ anomaly [10, 11] through additional loop corrections. In particular, for small $\tan\beta$ values, regions with low mass splittings $m(\tilde{\mu}) - m(\tilde{\chi}^{0}_{1})$ are favoured to explain the anomaly [12].

The search targets the direct production of sleptons $\tilde{\ell}\tilde{\ell}$ decaying into the LSP via the emission of a charged lepton as shown in Figure 1 (left), 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 as shown in Figure 1 (right). 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.

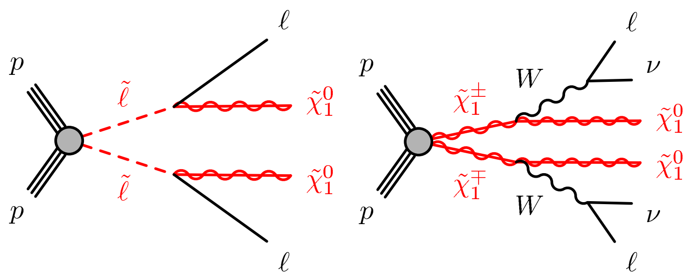

Figure 1: Diagrams of the supersymmetric simplified models considered, with two leptons and weakly interacting particles in the final state: (left) slepton pair production and (right) $\tilde{\chi}^{+}_{1}\tilde{\chi}^{-}_{1}$ production with W-boson-mediated decays. Only $\tilde{e}$ and $\tilde{\mu}$ are included in the direct slepton model. In the final state, ℓ stands for an electron or muon.

The search uses proton-proton (pp) collisions recorded by the ATLAS detector [13] at the Large Hadron Collider (LHC) during Run 2 at $\sqrt{s} = 13$ TeV. A previous search [14] considering the same models and signature was performed. The search also exploited the 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. This new search [15] targets mass splittings close to the mass of the W boson, with a gain in sensitivity reached through dedicated analysis strategies used for each of the two signal scenarios considered.

2. Analysis strategy

Since the slepton signal exhibits only a Same-Flavour (SF) leptons signature ($ee/\mu\mu$), a data-driven technique is performed to estimate the background in the slepton search, looking at Different-Flavour (DF) lepton pairs ($e\mu$) in opposite-sign lepton events. This technique is based on the observation that background processes as $t\bar{t}$, single top, WW and $Z(\to \tau\tau)$+jets decay into SF or DF leptons with the same probability and are referred to as ‘Flavour Symmetric Backgrounds’ (FSB). Therefore, 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). An event selection based on the most discriminating kinematic variables is used in the slepton search to define the Signal Region (SR) and a shape fit technique in the SR, exploiting several bins of the m_{T2} [16, 17] distribution, is performed in channels with both 0 or 1 jets.

In the chargino search, the signal produces both SF and DF lepton pairs and the signal topology is close to the SM WW process. In this case, a machine learning technique based on gradient Boosted Decision Trees (BDTs) [18] is adopted to separate the signal from the backgrounds. BDTs are trained on signal samples with $m(\tilde{\chi}_1^{\pm}) - m(\tilde{\chi}_1^0)$ of the order of the W boson mass and a multiclass classification provides four output score corresponding to four different classes (BDT-signal, BDT-VV, BDT-Top and BDT-others). The background normalisation strategy relies on the definition of Control Regions (CRs) where the main backgrounds are normalised to data. Two CRs are used, CR-VV to target the diboson background $VV(V = Z\,\mathrm{or}\,W)$ and CR-top to target the top-quark backgrounds ($t\bar{t}$ and Wt). A selection on the BDT-signal score is used to define the SR, requiring BDT-signal > 0.81 for SR-DF and BDT-signal > 0.77 for SR-SF. Finally, a shape fit technique in the SR, exploiting several bins of the BDT-signal score, is performed in the channel with 0 jets.

3. Results

The results of the two searches are interpreted in the context of the sleptons and charginos simplified models shown in Figure 1. The statistical interpretation of the results is performed using the HistFitter [19] framework. The CL$_s$ method [20] is used to set exclusion limits at 95% Confidence Level (CL) on the masses of the supersymmetric particles. The predicted number of background events together with the observed data in the binned SRs are shown in Figure 2 (left) for the slepton search and Figure 2 (right) for the chargino search.

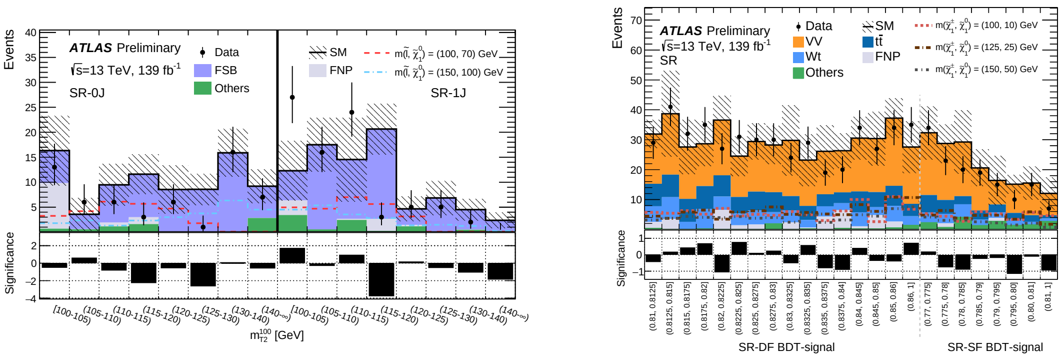

Figure 2: The upper panel shows the observed number of events, together with the expected SM backgrounds, (left) in the slepton SRs and (right) in the chargino SRs [15]. Fake and Non-Prompt leptons (FNP) are estimated through the matrix method and ‘Others’ include non-dominant background sources, e.g. $t\bar{t}$+V, Higgs boson and Drell–Yan events. The lower panel shows the significance as defined in Ref. [21].

No significant deviations from the SM expectations are observed in any of the SRs considered. Exclusion limits at 95% CL on the masses of the sleptons and the neutralinos are shown in Figure 3 (left) for both $\tilde{e}_{\mathrm{L,R}}/\tilde{\mu}_{\mathrm{L,R}}$ combined and Figure 3 (right) for smuons separately. Exclusion limits at

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95% CL are also set on the masses of the charginos and the neutralinos, as shown in Figure 4 (left) in the $m(\tilde{\chi}_1^\pm) - \Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0)$ plane and in Figure 4 (right) in the $m(\tilde{\chi}_1^\pm) - m(\tilde{\chi}_1^0)$ plane.

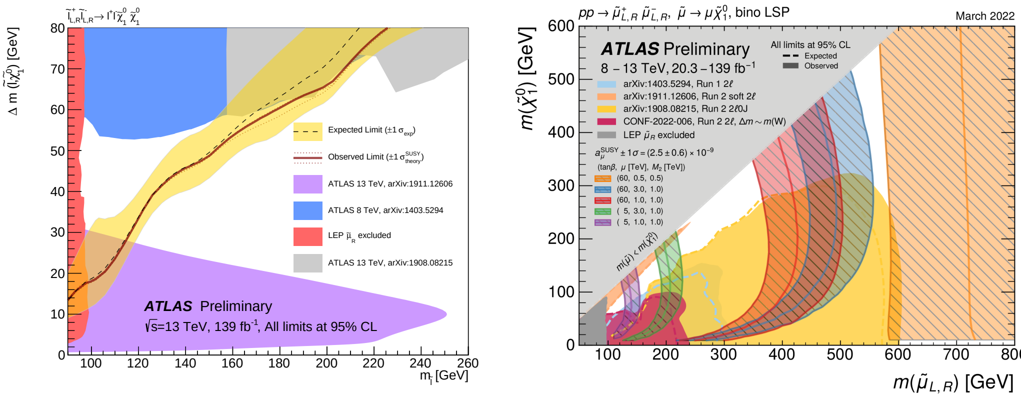

Figure 3: Observed and expected exclusion limits on SUSY simplified models for slepton-pair production in the (left) $m(\tilde{\ell}) - \Delta m(\tilde{\ell}, \tilde{\chi}_1^0)$ and (right) $m(\tilde{\ell}) - m(\tilde{\chi}_1^0)$ planes [15]. Only $\tilde{e}$ and $\tilde{\mu}$ are considered.

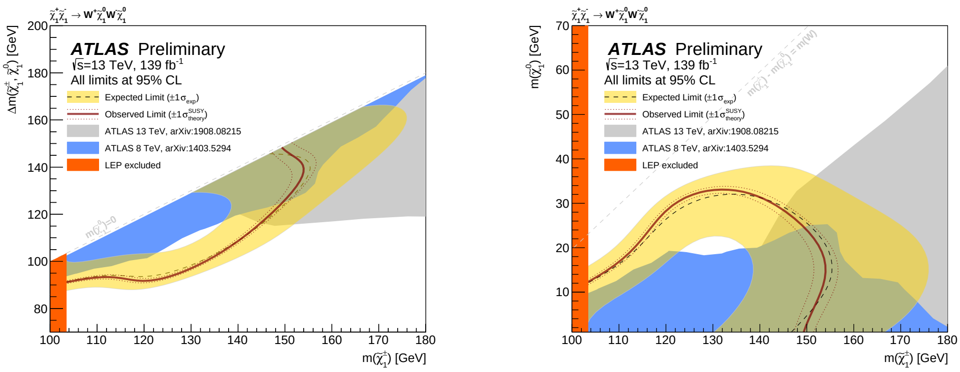

Figure 4: Observed and expected exclusion limits on SUSY simplified models for chargino-pair production with W-boson-mediated decays in the (left) $m(\tilde{\chi}_1^\pm) - \Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0)$ and (right) $m(\tilde{\chi}_1^\pm) - m(\tilde{\chi}_1^0)$ planes [15].

4. Conclusion

The results of a search for the electroweak production of charginos and sleptons decaying into final states containing two leptons are presented. The search uses pp collisions recorded by the ATLAS detector at the LHC during Run 2. Data are found to be consistent with the SM predictions and exclusion 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 down to about 100 GeV. Slepton exclusion limits bridge the gap between previous ATLAS searches [14, 23, 24] and surpass the limits set by LEP [25]. Exclusion limits set for the smuon pair production separately exclude portions of the regions in the $m(\tilde{\mu}) - m(\tilde{\chi}_1^0)$ plane that are expected to be compatible with the $g-2$ anomaly for small $\tan\beta$ values [22]. Chargino exclusion limits supersede the ATLAS 8 TeV results [23] and extend the previous ATLAS 13 TeV results [14] in particularly interesting regions where the charginos could have hidden behind the looking-alike WW background.

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