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Searches for electroweak production of supersymmetric gauginos and sleptons with the ATLAS detector

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Searches for electro-weak production of sleptons, charginos and neutralinos with final states with three and four leptons, and two tau-leptons are presented. The searches are performed on 20.7 fb^{-1} of $\sqrt{s} = 8$ TeV proton-proton collision 2012 data recorded with the ATLAS detector at the Large Hadron Collider. No significant excess has been found in any of the searches. These results are interpreted in the framework of simplified Supersymmetry models.

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1. Introduction

Supersymmetry (SUSY) introduces a set of particles beyond the Standard Model (SM). It infers the existence of a partner to each SM particle differing from the latter by one half unit of spin. The SUSY partners of the SM charged leptons (sleptons), neutrinos (sneutrinos) and quarks (squarks) are scalar bosons, whereas the SUSY partners of SM gauge bosons (gauginos), Higgs bosons (higgsinos) and gluons (gluinos) are spin 1/2 fermions. In the Minimal Supersymmetric Standard Model (MSSM) [1], gauginos and higgsinos build the mass eigenstates charginos ($\tilde{\chi}_i^\pm,\ i = 1,2$) and neutralinos ($\tilde{\chi}_j^0,\ j = 1,2,3,4$).
In models, where the masses of squarks and gluinos are heavier than a few TeV, the direct production of slepton and chargino/neutralino pairs via electro-weak (EW) interaction can be dominant at the Large Hadron Collider (LHC). The decay of these particles can lead to high lepton multiplicities. The searches presented here target final states with exactly three leptons (not considering taus), at least four leptons (considering taus) and exactly two tau-leptons.
Three different EW production channels are targeted by three different analyses. The $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ production channel is searched for in the 3 leptons analysis, the $\tilde{\chi}_2^0\tilde{\chi}_3^0$ production in the 4 leptons analysis and the $\tilde{\chi}_1^\pm\tilde{\chi}_1^\mp$ (as well as the $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$) production in the 2 tau leptons final state analysis.
The Analyses presented use the full 2012, $\sqrt{s} = 8$ TeV, proton-proton collision dataset recorded with the ATLAS detector at the LHC. The dataset corresponds to an integrated luminosity of 20.7 fb^{-1}. Detailed information can be found in dedicated public analysis notes for the: three lepton analysis [2], four lepton analysis [3] and two tau leptons analysis [4]. The ATLAS experiment is described in [5].

2. Three Lepton Analysis

In this analysis the direct production of $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ decaying to a final state with three leptons (electrons or muons) and missing transverse momentum originating from the two undetected Lightest Supersymmetric Particles (LSP) and neutrinos is considered. The masses and the decay modes of the relevant sparticles ($\tilde{\chi}_1^\pm, \tilde{\chi}_2^0, \tilde{\chi}_1^0, \tilde{\nu}, \tilde{l}_L$) are the only free parameters in the considered simplified models. It is assumed that the $\tilde{\chi}_1^\pm$ and the $\tilde{\chi}_2^0$ consist predominantly of the wino component and are mass degenerate, whereas the $\tilde{\chi}_1^0$ consists predominantly of the bino component. Two different decay scenarios of the $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ are considered, where in both cases the decays are prompt. In the first scenario the $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ decay with equal branching fraction to $\tilde{e}_L$, $\tilde{\mu}_L$ and $\tilde{\nu}$ with masses $m_{\tilde{\nu}} = m_{\tilde{l}_L} = (m_{\tilde{\chi}_1^0} + m_{\tilde{\chi}_1^\pm})/2$, in the following modes:

- $\tilde{\chi}_1^\pm \to \tilde{\nu} l^\pm \to \tilde{\chi}_1^0 \nu l^\pm$ or $\tilde{\chi}_1^\pm \to \tilde{l}^\pm \nu \to \tilde{\chi}_1^0 l^\pm \nu$
- $\tilde{\chi}_2^0 \to l^\pm \tilde{l}^\mp \to l^\pm l^\mp \tilde{\chi}_1^0$

In the second scenario, all sleptons are assumed to be heavy, so that the $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ decay via W and Z bosons (which may be on or off mass-shell) dominates:

- $\tilde{\chi}_1^\pm \to W^{\pm(*)} \tilde{\chi}_1^0 \to l^\pm \nu \tilde{\chi}_1^0$
- $\tilde{\chi}_2^0 \to Z^{(*)} \tilde{\chi}_1^0 \to l^\pm l^\mp \tilde{\chi}_1^0$

Two kinds of signal regions (SR) are defined for this analysis to cover the above modes: the Z-depleted and the Z-enriched regions. Selected events inside these regions must contain exactly three leptons with at least one same-flavor opposite-sign (SFOS) pair and no b-jets with $p_{\mathrm{T}} > 20$ GeV to suppress top-quark contributions. The Z-depleted regions is required not to have any SFOS pair with invariant mass inside 10 GeV of the Z boson mass-window. The Z-enriched regions instead is required to have at least one of those pairs inside that interval. By applying different cuts to four discriminate variables, it is possible to divide the two regions described before in three orthogonal subregions each (SRNoZa, SRNoZb, SRNoZc and SRZa, SRZb, SRZc), whereby the background is rejected as well as possible allowing to cover with significant statistics all regions of interest. These variables are: the SFOS invariant mass of leptons (m_{SFOS}), the missing transverse energy ($E_{\mathrm{T}}^{\mathrm{miss}}$), the transverse mass between the worst Z-candidate lepton and $E_{\mathrm{T}}^{\mathrm{miss}}$ (m_{T}) and the p_{T} of the 3$^{\mathrm{rd}}$ leading lepton.
The main SM background (BG) contribution is carried by the di-boson (WZ, ZZ) production if all three leptons are real (irreducible BG). This BG is estimated directly with Monte Carlo (MC) simulations. The reducible BG, which is required to have at least one fake lepton coming from mis-indentified jet or photon conversion, is dominated by top-quark and Z+jets contributions. The estimation of this BG is obtained by a data-driven loose-to-tight matrix method.

3. Four Lepton Analysis

This analysis is sensitive to the R-parity conserving (RPC) as well as to R-parity violating (RPV) [6] scenarios. A possible Proton decay is not taken into account, since only the lepton number is violated (whereas the baryon number is still conserved) [7]. Selected events requires four (or more) isolated leptons, where only the combination with at least three light-flavor lepton is considered.
The RPC scenario is here described by two different models. The first one assumes the $\tilde{\chi}_2^0\tilde{\chi}_3^0$ production with decay through right-handed sleptons (supposed to be lighter than $\tilde{\chi}_{2,3}^0$), which leads to a final state of four light-flavor leptons (with BR equally shared by electrons and muons) and missing transverse energy carried by neutralinos: $\tilde{\chi}_{2,3}^0 \rightarrow \tilde{l}_R^{\pm} l^{\mp} \rightarrow \tilde{\chi}_1^0 l^{\mp} l^{\pm}$. The second one is a General Gauge Mediated (GGM) model, which is a SUSY breaking model, where the NLSP $\tilde{\chi}_1^0$ decay via Z- or Higgs bosons to a four-lepton final state with missing transverse energy carried by gravitinos (LSP), which are almost massless: $\tilde{\chi}_1^0 \rightarrow \tilde{G}Z/H \rightarrow l^{\pm}l^{\mp}$. If the $\tilde{\chi}_1^0$ is higgsino-like, the decay via Z-boson dominates for large values of tanβ, the ratio of the vacuum expectation values of the Higgs doublets, and also dominates for small higgsino mass term μ at small tanβ. For this reason the $\tilde{\chi}_1^0$ decays via Z-boson with a BR of 97% for small tanβ, but its decay can also occur via Higgs-boson with a BR of $20\% - 50\%$ for large tanβ.
In the RPV models considered here single coupling dominance is assumed, in particular only λ_{121} or λ_{133} are different from zero. In RPV scenarios with $\lambda_{121} \neq 0$ the LSP decay leads to events with light-letpon flavors in the final states, whereas $\lambda_{133} \neq 0$ will produce predominantly tau-leptons. In both cases the decay of interest is: $\tilde{\chi}_1^0 \rightarrow \nu_{i/j} l_{j/i}^{\pm} l_k^{\mp}$, where the indices i, j and k refer to lepton generations. That leads to final states with large lepton multiplicities (4-6 leptons) and missing transverse energy due to the presence of neutrinos.
Two signal regions are defined for each allowed tau multiplicity: one vetoing Z-candidates and one

requiring Z-candidates. Z-boson candidates are vetoed (selected) by identifying pairs, triplet or quadruplet of light-flavor leptons with an invariant mass outside (inside) a 10 GeV window around the Z boson mass. Different cuts applied on $E_{\mathrm{T}}^{\mathrm{miss}}$ and effective mass defined as:

$$m_{eff} = E_{\mathrm{T}}^{\mathrm{miss}} + \sum_{e} p_{\mathrm{T}}^{e} + \sum_{\mu} p_{\mathrm{T}}^{\mu} + \sum_{\tau} p_{\mathrm{T}}^{\tau} + \sum_{j} p_{\mathrm{T}}^{j}$$

where p_{T}^{e} $(p_{\mathrm{T}}^{\mu}, p_{\mathrm{T}}^{\mu})$ is the transverse momentum of signal electrons (muons, taus) and p_{T}^{j} is the transverse momentum of jets with $p_{\mathrm{T}} > 40$ GeV, allows to further divide the two signal regions in subregions (three for Z-vetoing regions: SR0noZa, SR0noZb, SR1noZ and two for Z-requiring regions: SR0Z, SR1Z). Signal is discriminated from background using these subregions, which target different 4-lepton analyses models.
The irreducible BG is dominated by at least four real lepton, which come mainly from *ZZ*, *Higgs*, ZWW and $t\bar{t}Z$ processes. They are estimated using the corresponding MC samples, for which lepton efficiencies are corrected to account for differences with respect to the data. For the reducible BG only processes with three real plus at least one fake lepton (coming from $t\bar{t}W$, *WZ* and WWW) and two real plus at least two fake leptons (coming from $t\bar{t}$, *Z+jets* and WW) are taken into account. Other processes are considered negligible. The reducible BG is estimated using a MC-assisted weighting method [3].

4. Two Taus Analysis

In this analysis the production of $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$ and of $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ are considered, where charginos and neutralinos decay with 100% branching fraction to final states with taus:

- $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0} \rightarrow \tilde{\tau}_{\mathrm{L}}\nu(\tau\tilde{\nu})\tilde{\tau}_{\mathrm{L}}\tau \rightarrow \tau\nu\tilde{\chi}_1^{0}\tau\tau\tilde{\chi}_1^{0}$
- $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp} \rightarrow 2\times\tilde{\tau}\nu(\tilde{\nu}\tau) \rightarrow 2\times\tau\nu\tilde{\chi}_1^{0}$

Only hadronically decaying taus are considered in this search. At least one pair taus is required, with opposite sign (OS). Events with additional light leptons are vetoed to allow for a statistical combination with similar searches using light leptons. Staus and tau neutrinos are assumed to be mass degenerate, furthermore $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^{0}$ are supposed to be degenerated as well.
The analysis exploits, among other variables, the expected large magnitude of the $E_{\mathrm{T}}^{\mathrm{miss}}$ generated by undetected LSPs to discriminate SM processes from signal events. A further variable here used is the "stransverse mass" m_{T_2} [8] reconstructed using the two hadronic taus and $E_{\mathrm{T}}^{\mathrm{miss}}$, which could be very discriminant since in signal events the kinematic endpoint depends on the mass difference between the decaying SUSY particle (stau) and the LSP (neutralino). In order to reject the SM BG, two signal regions, which apply different cuts to the variables previous described and veto in one case on jets and in the other on b-jets, are built (SR OS m_{T2} and SR OS m_{T2}-nobjet).
The irreducible BG (real taus from prompt boson decays) arise mainly from $t\bar{t}$, single top, $t\bar{t}+V$, $Z+jets$ and di-boson processes, and is estimated from MC simulation. The reducible BG (fake taus from mis-identified jets) is dominated by W+jets and by multi-jets production. These contributions are estimated from data.

5. Results

Table 1 shows the results for data observations and the total SM BG expectations including the systematic uncertainties for the six SRs of the three lepton analysis, for the five SRs of the four-lepton analysis and for the two SRs of the two tau analysis. No significant excess of data over the expected SM BG is observed in any of the regions and therefore limits are set on $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$, $\tilde{\chi}_2^0\tilde{\chi}_3^0$ or $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ production in the simplified model.
The expected and observed exclusion limits for the three searches at 95% confidence level based on $\mathrm{CL_s}$ method [9] are presented in Figures 1 to 3. The yellow band around the median expected limit (black-dashed line) shows the $\pm 1\sigma$ variations on the median expected limit, including all uncertainties except theoretical uncertainties on the signal cross-section. The red-dotted lines around the observed limit indicate the sensitivity to $\pm 1\sigma$ variations on these theoretical uncertainties (red-solid line). All systematic uncertainties are taken into account via nuisance parameters. Figure 1 shows limits set for the three lepton analysis, using grids with $\tilde{\chi}_1^0$ mass on the y-axis and degenerated $\tilde{\chi}_2^0, \tilde{\chi}_1^{\pm}$ mass on the x-axis, for decay scenario via sleptons (where $m_{\tilde{l}} = (m_{\tilde{\chi}_1^0} + m_{\tilde{\chi}_2^0})/2$) (a) and for decay scenario via gauge bosons (b). It can be noticed how the limits have been extended in comparison with the previous analysis based on 13 fb^{-1} [10] (blue-solid line). Limits are calculated using a combined likelihood fit of all SRs.
In the RPC model limits are shown, see Figure 2(a), using a grid with the difference between the $\tilde{\chi}_3^0$ and $\tilde{\chi}_1^0$ masses on the y-axis and the $\tilde{\chi}_1^0$ mass on the x-axis. Masses of $\tilde{\chi}_2^0$ and $\tilde{\chi}_3^0$ are degenerated and the right-handed slepton mass is always put in between the $\tilde{\chi}_3^0$ and the $\tilde{\chi}_1^0$ masses: $m_{\tilde{l}_R} = (m_{\tilde{\chi}_3^0} + m_{\tilde{\chi}_3^0})/2$. In the GGM model limits are shown, see Figure 2(b), using a grid with the gluino mass on the y-axis and both the higgsino mass (μ) and the $\tilde{\chi}_1^0$ mass on the x-axis. In GGM analysis limits have been extended in the region dominated by weak production (with high $m_{\tilde{g}}$) in comparison with the previous analysis performed with gluino-pair production at 5.8 fb^{-1} [11] (blue-solid line), which is more sensitive for exclusion in regions with low $m_{\tilde{g}}$.
Figure 3 shows limits set for the two-tau analysis, using a grid with $\tilde{\chi}_1^0$ mass on the y-axis and degenerated $\tilde{\chi}_2^0, \tilde{\chi}_1^{\pm}$ mass on the x-axis for the chargino-neutralino (a), and using a grid with $\tilde{\chi}_1^0$ mass on the y-axis and $\tilde{\chi}_1^{\pm}$ mass on the x-axis the chargino-pair production (b). The decay via staus or sneutrinos is supposed to occur with this mass requirement $m_{\tilde{\tau},\tilde{\nu}} = (m_{\tilde{\chi}_1^0} + m_{\tilde{\chi}_1^{\pm}})/2$. The SR with the best expected limit at each point is used to calculate the limits.

6. Conclusions

Searches for direct electro-weak production of gauginos and sleptons with the ATLAS detector have been presented. Three different kinds of analyses: three lepton, four lepton (with RPC and RPV) and two lepton (with taus only) final state with missing transverse energy, have been considered. No significant excess above the SM background has been observed. First ATLAS limits on electro-weak production with two hadronically decaying taus final states have been presented and limits of exclusion have been extended, with respect to the previous analyses, in all other grids presented [10], [11].

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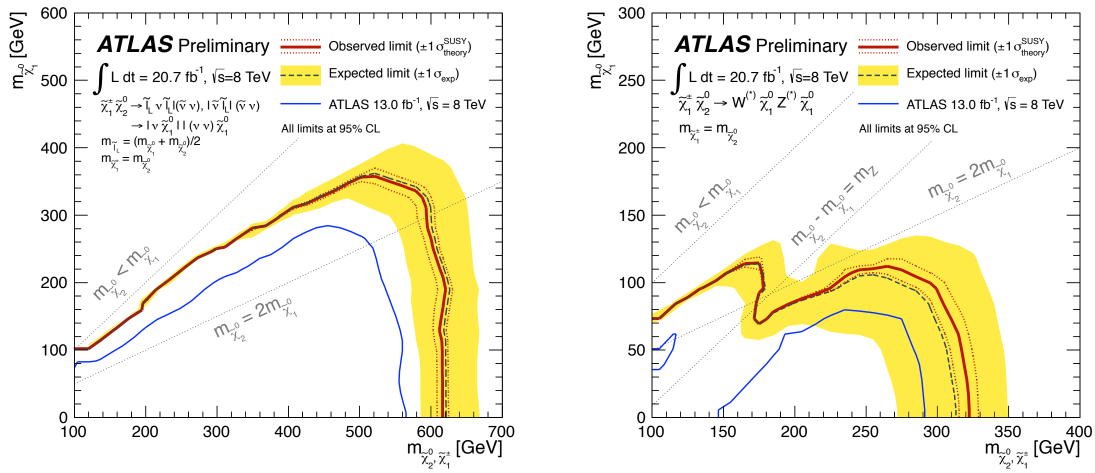
3 Lepton	SRnoZa	SRnoZb	SRnoZc	SRZa	SRZb	SRZc
BG Data	96 ± 19 101	29 ± 6 32	4.4 ± 1.8 5	249 ± 35 273	22 ± 5 23	6.3 ± 1.5 6
4 Lepton	SR0noZa	SR0noZb	SR1noZ	SR0Z	SR1Z	
BG Data	1.7 ± 0.8 2	1.6 ± 0.6 1	2.0 ± 1.3 4	4.8 ± 1.8 8	$1.3^{+1.0}_{-0.5}$ 3	
2 Tau	SR OS m_{T2}	SR OS m_{T2}-nobjet				
BG Data	$11.0 \pm 2.7 \pm 1.5$ 6	$17 \pm 4 \pm 3$ 14				

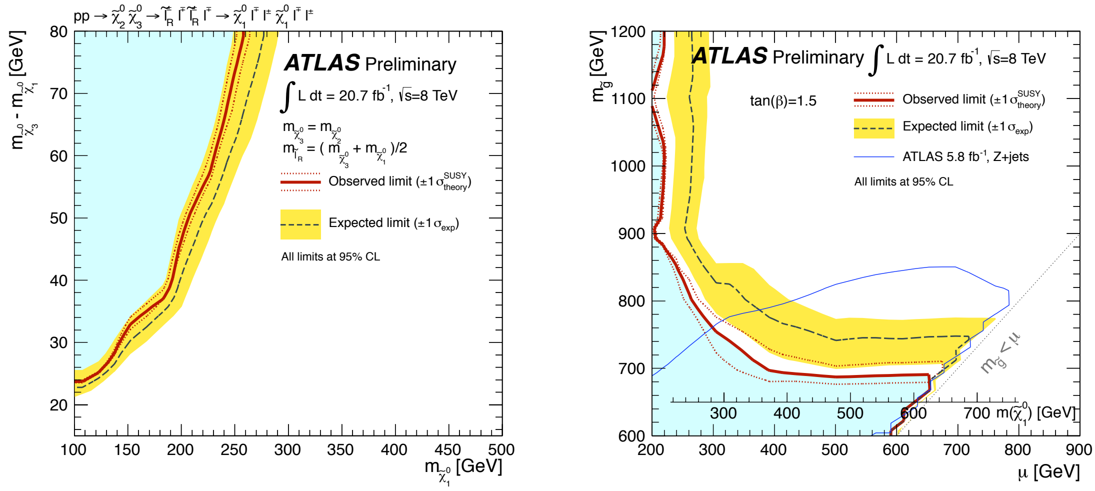
Table 1: BG expectations and data observations in the three lepton analysis signal regions [2] (top), in the four lepton analysis signal regions [3] (middle), in the two tau analysis signal regions [4] (bottom). For the two tau signal regions the uncertainties from MC statistics and the systematic uncertainties are shown separately (in this order).



(a) Decay via sleptons

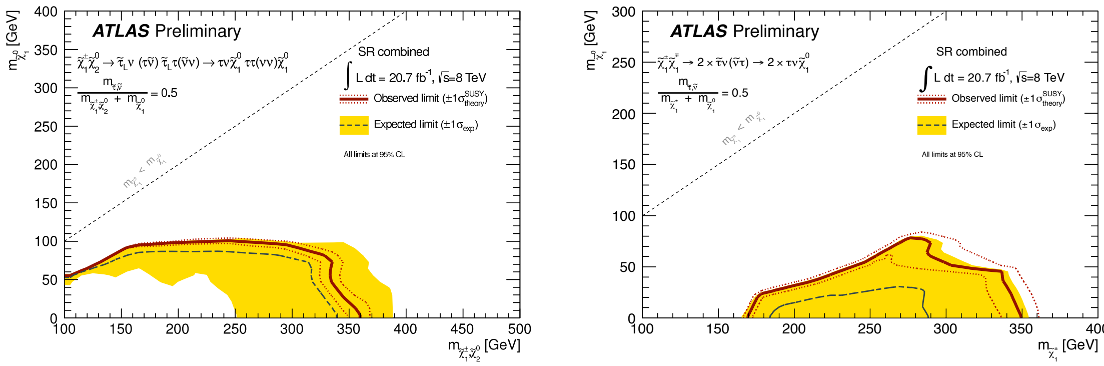
(b) Decay via gauge bosons.

Figure 1: Observed and expected 95% CL limit contours for chargino and neutralino production in the simplified model scenario with (a) decay via sleptons and (b) decay via gauge bosons (sleptons are assumed to be heavy). Limits are calculated using the statistical combination of all signal regions for each of the model points. Linear interpolation is used to account for the discrete nature of signal grids [2].



(a) RPC $\tilde{\chi}_2^0\tilde{\chi}_3^0$ (b) GGM $\tan\beta = 1.5$

Figure 2: Observed and expected 95% CL limit contours for (a) one of the RPC simplified models [3] and (b) one of the GGM simplified models [3]. In (a) the signal region SR0noZa is used to calculate the limits, whereas in (b) SR0Z is used. Linear interpolation is used to account for the discrete nature of signal grids.



(a) $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ production (b) $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ production

Figure 3: Observed and expected 95% CL limit contours for (a) chargino-neutralino and (b) chargino-pair production. The signal region with the best expected limit at each point is used [4].