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Search for production of SUSY particles produced via electroweak interactions

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Supersymmetry is one of the most popular extensions to the Standard Model of particle physics, as it can provide solutions to several limitations of the Standard Model. Many supersymmetric model feature new partices with masses less than a few hundred GeV, well within the reach of the Large Hadron Collider (LHC) at CERN. If strongly produced particles - squarks and gluinos - are much heavier, then the electroweak production of charginos and neutralinos may be the dominant supersymmetry production mechanism at the LHC. These proceedings present results from new searches for the production of charginos and neutralinos with particular focus on the recent paper by the ATLAS collaboration that summarises and extends the searchs for the electroweak production of sparticles using data from Run-1 of the LHC.

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1. Introduction

Supersymmetry (SUSY) [1] is one of the most popular extensions to the Standard Model (SM) of particle physics, as it can provide solutions to several limitations of the SM. It is a proposed space-time symmetry between fermions and bosons. This results in a near doubling of the elementary particles contained in the model. These proceedings discuss the search for electroweak production of sparticles with the ATLAS detector [2], one of the two large general-purpose detector at the Large Hadron Collider (LHC) [3] at CERN. The sparticles discussed are comprised of the supersymmetric charginos $\tilde{\chi}_i^{\pm}$ ($i = 1,2$) and neutralinos $\tilde{\chi}_j^0$ ($j = 1,...,4$), which are mixtures of the bino, the wino triplet and the higgsinos, which in turn are the superpartners of the $U(1)_\gamma$ and $\mathrm{SU}(2)_L$ gauge bosons and Higgs doublets of SUSY.

Electroweak SUSY production is motivated by naturalness [4] [5] and it is complementary to search focusing on strongly produced sparticles. Natural models of SUSY favour light chargino and neutralino masses, in a range well accessible at the LHC. In the event that the strong production is sufficiently heavy, electroweak SUSY production may be the dominant SUSY production mechanism at the LHC.

All searches for SUSY have produced null results to date, with no significant excess above the Standard Model expected event yields observed. These null results can be translated into limits on the masses of supersymmetric particles. For the electroweak production searches prior to the analyses discussed in these proceedings [6] the limits were set to the order of several hundreds of GeV. However, the region of the parameter space that corresponds to near mass degeneracy between the mass degenerate lightest chargino ($\tilde{\chi}_1^{\pm}$)) or second lightest neutralino ($\tilde{\chi}_2^0$) and the lightest neutralino ($\tilde{\chi}_1^0$) - referred to as compressed scenarios - was not probed by these searches. Several analyses were defined to probe compressed scenarios and models with low production cross-sections and are summarised in Ref. [7], which also summarises the overall ATLAS sensitivity to electroweak production of sparticles.

2. Electroweak SUSY Searches with Simplified Models

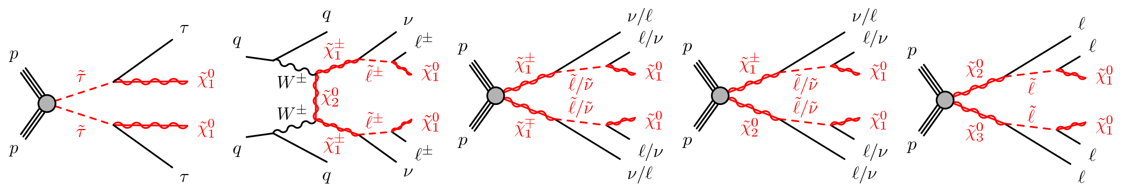


Figure 1: Diagrams illustrating the production of electroweak SUSY particles and their decay modes in the five simplified models that are employed in the interpretation of the results in the electroweak summary paper.

Ref. [7] was designed to summarise and to extend the searches for electroweak SUSY with the ATLAS detector using the data taken during the first run (Run-1) of the LHC, corresponding to 20.3 fb^{-1} of pp collisions at a centre-of-mass energy $\sqrt{s} = 8$ TeV. Five new analyses were included in the paper that were not published before. These analyses target two- and/or three-lepton final states and strive to extend the reach of earlier analyses by lowering the thresholds on the transverse momenta (p_T) of the leptons, by exploting initial-state radiation (ISR) or vector-boson fusion event topologies, or through the application of multi-variate analysis (MVA) techniques [8]. The new analyses were statistically combined with the existing searches to extend the excluded mass ranges, adding also new combinations and reinterpretations of existing searches. The new analysis are focused on improving the sensitivity to the searches for compressed SUSY scenarios which have decay chains which lead to decay products produced with low transverse momentum. These decay products may fail trigger offline threshold p_T requirements. This deteriorates the signal acceptances and reduces the sensitivity of the analyses.

The results of the searches described in the electroweak summary paper are interpreted in simplified models. Simplified models that specify only one production mode and decay chain for the SUSY particles considered, with the branching ratios for the decays assumed to be 100%. The five simplified models employed in the interpretation of the results are shown in Figure 1. From left to right they are as follows: direct stau pair production, vector-boson fusion same-sign $\tilde{\chi}_1^{\pm}$ pair production, direct $\tilde{\chi}_1^{\pm}$ pair production, direct production $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ and direct $\tilde{\chi}_2^0\tilde{\chi}_3^0$ production. In all cases, the decays of the electroweak gauginos may occur via all three slepton or sneutrino generations.

3. 2τ (MVA) Analysis

The *two-tau* (MVA) analysis is an update of an earlier analysis [9], which targets the direct production of charginos, neutralinos and staus in final states with at least two hadronically decaying tau leptons and missing transverse momentum. This analysis uses a boosted-decision tree (BDT) to improve upon the sensitivity of the earlier cut-based analysis. The results are interpreted in a simplified model with direct-stau production, where the cut-based analysis had no sensitivity. Events with exactly two taus with opposite charge are selected. Events that contain a b-tagged jet or where the two taus have an invariant mass that is compatible with the mass of the on-shell Z-boson are rejected. The BDT is trained on twelve input variables, which are based on kinematic properties of the two taus and E_T^{miss} and have good discriminatory power. A signal region is defined using a cut on the output value of the BDT. Good agreement is observed between data and SM background expectations in the distribution of the BDT output variable, however no exceess is observed in the signal region. The results are interpreted in terms of 95% CL exclusion limits on the production cross section for stau pairs as a function of the mass of the stau and the LSP. The best limit is observed at a stau mass of around 110 GeV with a massless LSP.

4. 2 SS ℓ (VBF) Analysis

The 2 SSℓ analysis targets the production of charginos via vector-boson fusion (VBF) with two light leptons with the same charge in the final state. VBF production has a significantly lower production cross section than direct production, however the requirement of two additional VBF jets increases the discriminatory power against the SM background. The jets also provide a boost to the charginos, resulting in energetic decay products even in compressed scenarios. In addition to two light leptons with the same charge, events are selected which have two jets and missing transverse momentum above 120 GeV in order to be in the plateau of the E_T^{miss} trigger that is used in this analysis. One signal region is defined, exploiting the VBF topology by requiring that the two jets be well-separated and in opposite hemispheres of the ATLAS detector. Additional selection criteria are applied in order to suppress the remaining SM backgrounds, mainly diboson and top quark production. No excess is observed in the SR above SM, with limits set on the VBF $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ production cross section. The limits obtained from the 2012 dataset remain above the theoretical predictions by at least a factor of three. This implies that the analysis is not yet sensitive to this production channel.

5. Compressed Spectra with 2ℓ and 3ℓ Final States

The remaining three analyses target direct chargino pair production or chargino-neutralino production with two or three light leptons in the final state and aim to extend the reach of earlier searches [6] for compressed scenarios.

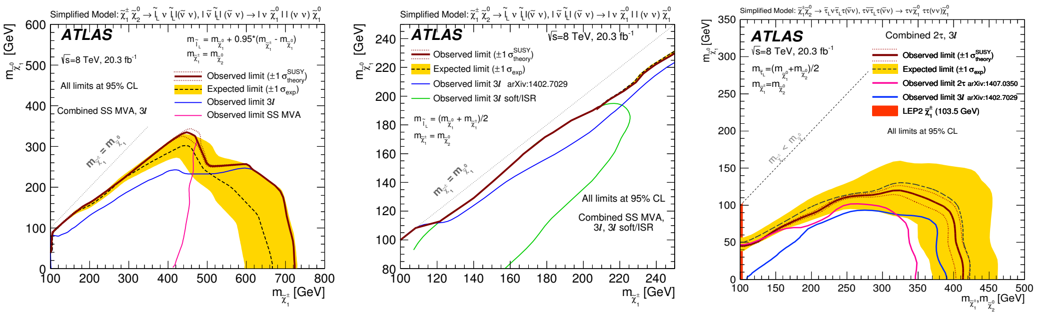
The 2 OS ℓ (ISR) analysis extends the earlier search for SUSY in final states with two leptons to small mass splittings $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$ by exploiting the presence of an ISR jet. The ISR jet boosts the leptons from the SUSY decay chain, which otherwise may have too low momentum to pass the trigger or reconstruction thresholds. Events are selected which have exactly two light leptons with opposite charge (OS leptons) and an ISR jet with high transverse momentum. Events are excluded which have b-tagged or forward jets, or in which the invariant mass of the two light leptons is compatible with the on-shell Z boson mass. Two signal regions are defined based on “super-razor variables” [10], which provide good discriminatory power in compressed spectra.

The 3ℓ (ISR) analysis extends the earlier search for SUSY in final states with three leptons to small smass splittings $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$. An ISR jet request was also utilised, furthermore, three-lepton triggers with lower lepton p_T thresholds were included to increase the acceptance of events from compressed spectra. Events are selected with exactly three light leptons, including one pair with same flavour but opposite charge (SFOS). Events with b-tagged jets or where a SFOS lepton pair comes from an Υ meson decay are rejected. Four signal regions are defined which either veto or require a jet with large p_T and are defined in distinct windows for the value of the minimum mass of the SFOS pair.

The 2 SS ℓ (MVA) analysis complements the search for three-lepton final states, in the case where one of the three leptons has too low p_T to be reconstructed. Events are selected with exactly two light leptons with the same charge sign. This analysis utilises eight BDT, which are trained independently to defined the eight signal regions, optimised for four different mass splitting scenarios $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$, with each either requesting or vetoing ISR jets. All three analysis observe good agreement between the event counts in data and their SM predictions, with no significant excess observed in any of the signal regions.

6. Interpretations

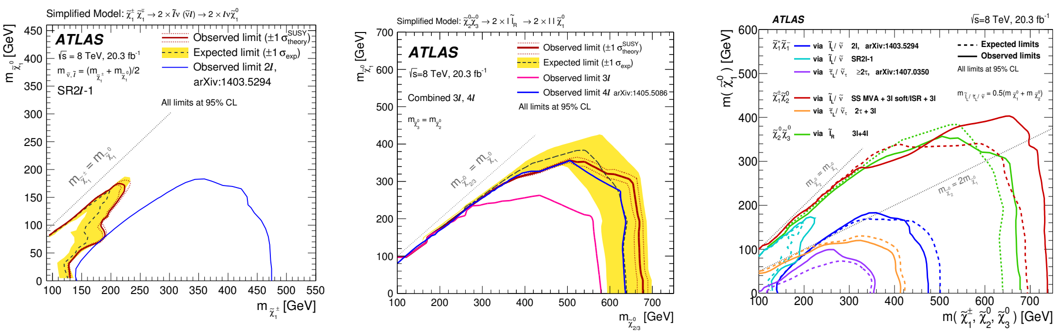
The exclusion limits on the mass parameters $m(\tilde{\chi}_1^0$ and $m(\tilde{\chi}_1^{\pm}) = m(\tilde{\chi}_2^0)$ for the simplified model $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ production are shown in Figure 2. Both $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ are assumed to be pure wino, whereas the $\tilde{\chi}_1^0$ is pure bino. The resulting observed limits from combinations of both the new analyses and the earlier published analyses are given by the thick red lines and are compared



(a) (b) (c)

Figure 2: 95% CL exclusion limits on $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ production from the combinations of several analyses. (a) $\tilde{\ell}_{\mathrm{L}}$-mediated decays with slepton mass set to 95% between $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$, (b) $\tilde{\ell}_{\mathrm{L}}$-mediated decays with slepton mass set to 50% between $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$, (c) $\tilde{\tau}_{\mathrm{L}}$-mediated decays with stau mass set 50% between $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^0$

against the earlier exclusion limits, drawn as thinner lines. Figure 2(a) corresponds to the scenario where the intermediate slepton mass is set to 95% between the $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$ this is a very compressed scenario and, the limits highlights that the 2ℓ SS MVA analysis performs well in the near mass-degenerate region (pink contour), where one of the three leptons may be too low in p_T to be reconstructed, whereas the 3ℓ (blue contour) performs well in the larger mass splitting regions. This highlights the complentarity of the two analyses. Figure 2(b) corresponds to the scenario where the intermediate slepton mass is set to 50% between the $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$. The figure shows a zoom-in of the compressed region close to the diagonal, which highlights the improvement of the limit in this difficult region that is obtained from the 3ℓ (ISR/soft-leptons) analysis. The 2 SS ℓ (MVA) abalysis is also included in the combination but has no sensitivity in this region by itself and thus no exclusion contour is shown. Figure 2(c) shows a new combination of the existing 2τ and 3ℓ analyses in a scenario where the gaugino decays are mediated via staus only.



(a) (b) (c)

Figure 3: The 95% CL exclusion limits on $\tilde{\chi}_1^\pm\tilde{\chi}_1^\pm$ production (a) and $\tilde{\chi}_2^0\tilde{\chi}_3^0$ production with $\tilde{\ell}_{\mathrm{L}}$-mediated decays. (c) shows the summary of the 95% CL exclusion limits for $\tilde{\ell}_{\mathrm{L}}$-mediated decays.

Figure 3(a) demonstrates the complementarity of the new 2 OS ℓ (ISR) analysis and the earlier 2ℓ analysis in the exclusion limits for the $\tilde{\chi}_1^\pm\tilde{\chi}_1^\pm$ simplified model with $\tilde{\ell}_{\mathrm{L}}$-mediated decays, with the slepton mass set 50% between $m(\tilde{\chi}_1^\pm)$ and $m(\tilde{\chi}_1^0)$, where the new analysis provides new sensitivity to compressed scenarios for $\tilde{\chi}_1^{\pm}$ masses below 220 GeV. The previous 2ℓ analysis continues to dominate the sensitivity to scenarios with large mass splittings, excluding $\tilde{\chi}_1^{\pm}$ masses up to 465 GeV. Figure 3 shows a new combination of the existing 3ℓ and 4ℓ analyses in the simplified model with $\tilde{\chi}_2^0\tilde{\chi}_3^0$ production and decays mediated via $\tilde{\ell}_{\mathrm{R}}$. Here, the $\tilde{\chi}_2^0$ and $\tilde{\chi}_3^0$ are assumed to be pure higgsino and mass-degenerate. This combination improves the earlier limits on the mass of the initial SUSY particles from the 4ℓ analysis by about 30 GeV.

The ATLAS results for electroweak SUSY searches at 8 TeV in the framework of simplified models are summarised in Figures 3(c) for $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ and $\tilde{\chi}_2^0\tilde{\chi}_3^0$ production with $\tilde{\ell}$-mediated decays). Improvements seen in the large mass splitting region with respect to the previously published summary plot with $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ masses excluded up to 740 GeV for massless $\tilde{\chi}_1^0$. The inclusion of the new analyses provide sensitivity to the compressed region up to $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ masses of 250 GeV.

7. Conclusion

The electroweak SUSY summary paper, presents the final statement on searches for supersymmetry in the data from the first run of the LHC. There have been no significant signs of physics beyond the SM from the Run-1 data. New analyses have been developed to target previously unexplored regions of the SUSY parameter space, which implement new analysis techniques and offer powerful combinations with existing analyses.

With Run-2 underway and a dataset of around 4 fb^{-1} of integrated luminosity from pp-collisions at the increased centre-of-mass energy of $\sqrt{s}$ = 13 TeV has been collected in 2015. The strongly produced sparticles benefit directly from the increased centre-of-mass energy due to the large cross sections, which allow them to go higher masses than the electroweak produced sparticles. However, electroweak SUSY will benefit from the higher integrated luminosity to be collected in the three years of Run-2, which is expected to exceed the integrated luminosity from Run-1 by a factor of around four. This illustrates that the searches for electroweak SUSY production, remains a highly motivated and robust channel for beyond the SM physics.

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