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Recent results from supersymmetry search combinations with the ATLAS and CMS experiments

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The latest results from combinations of multiple searches targeting the production of top squarks as well as electroweak production of supersymmetric particles are presented. Additionally some recent searches for charginos, neutralinos, and sleptons under various simplified models are described. The analyses are based on the full dataset of proton-proton collisions collected during the Run 2 of the LHC at a center-of-mass energy of 13 TeV.

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1. Introduction

The record-breaking data set provided by the Large Hadron Collider (LHC) during Run 2 (2016–2018) allows exploration of various supersymmetric (SUSY) scenarios. Among production of different SUSY particles, top squarks, neutralinos and charginos (electroweakinos: mass eigenstates formed by the mixing of winos, bino, and higgsinos), and sleptons are produced with low cross sections. Thus, the full data set of Run 2 is particularly crucial for such searches.

In addition to targeting processes with low cross sections, the full Run 2 data set encourages the development of novel analysis techniques that can be utilised to target previously uncovered corners of the phase space. For example, compressed scenarios lead to signatures with small amounts of visible energy due to a small mass-splitting between the lightest supersymmetric particle (LSP, stable and neutral) and the next-to-LSP (NLSP). Thus, these cases cannot be explored by the standard search strategies that tend to rely on final states with multiple standard model objects, and large missing energy (MET) from undetected SUSY states. A compressed scenario under a model with a bino-like LSP and a slepton NLSP is particularly interesting as it could explain [1] the recent results on the muon g-2 anomaly, measured by the Muon g-2 Collaboration [2].

To fully benefit from the existing data set, individual searches can be statistically combined to place even further constraints on SUSY phase-space. Combinations of Run 2 searches will make a strong statement on the existence of new physics, and provide useful information to steer the searches of Run 3. Both ATLAS and CMS Collaborations have performed combinations of searches for top squarks, and electroweakinos. The following sections highlight latest results on these combinations, as well as describe recent results on supersymmetric searches that could be used for a combination in future. In particular the focus is on the compressed scenarios. While the compressed spectra can be considered under many models, in the following two cases are discussed: with a bino-like LSP, and wino-like or slepton NLSP. All searches presented here were performed with data collected with either the ATLAS [3] or CMS [4] experiment during the Run 2 of LHC.

2. Combinations of searches for top squarks and electroweakinos

Both ATLAS [5] and CMS [6] Collaborations have conducted searches for the top squark pair production. The latest combination of searches for top squark pair production was performed by the CMS Collaboration [6], and targets final states with two neutralinos (LSPs), two W bosons and two bottom quarks. The combination excludes top squark masses up to 1325 GeV for a massless neutralino for one of the considered models, where both top squarks decay directly into a top quark and a neutralino.

Searches for top squark pairs can additionally be used to place constraints on (pseudo)scalars that mediate dark matter production. Both ATLAS [5] and CMS [6] Collaborations have provided combination of searches while targeting a dark matter candidate production in association with a top pair, for which the Feynman Diagram is shown in Fig. 1. The most recent combination results are those from the ATLAS Collaboration, and include an extension of the previous published 0-lepton final state by adding a category where the missing energy is decreased from 250 to 160 GeV [5]. This is achieved by combining missing energy and b-tagged jet triggers, while ensuring orthogonality with the previously existing 0-lepton category by requiring missing energy significance $S < 14$ and the absence of large radius jets. The results displaying the improvement from the new 0-lepton category, as well as the results of the combination of the searches for the scalar mediator are shown in Fig. 1.

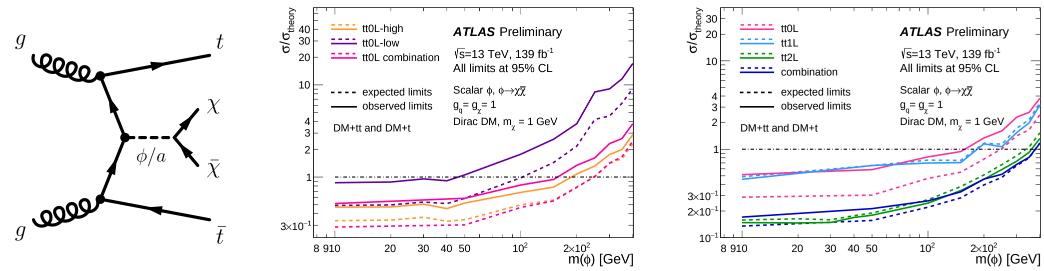

Figure 1: Feynman diagram for a dark matter candidate production in association with a top pair (left). Exclusion limits for a colour-neutral scalar mediator dark matter model as a function of the mediator mass for a dark matter candidate mass of 1 GeV for the 0-lepton categories (middle) and all the individual categories as well as their combination (right). [5]

The most recent combination of searches targeting the production of chargino and neutralino is performed by the ATLAS Collaboration [7], utilising final states with a W and Z boson as well as two LSP neutralinos. The considered models describe either a wino-like NLSP with bino-like LSP, or a higgsino-triplet. For the former model two cases are considered, either with a positive or negative product of the two signed neutralino eigenmass parameters. A 3-lepton search (targeting off- and on-shell Z boson) is combined with a previously published 2-lepton search (targeting compressed spectra). The two analyses complement each other in the compressed region and thus increase the coverage as is shown in Fig. 2. A similar combination of searches is underway by the CMS Collaboration.

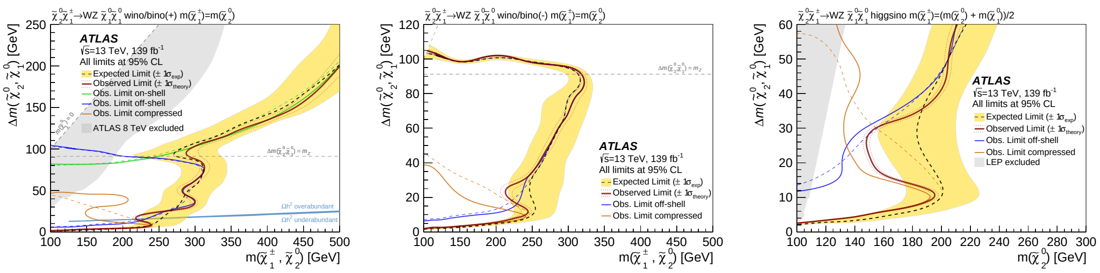

Figure 2: Exclusion limits obtained for the combination of searches targeting the production of chargino and neutralino in the wino/bino (+) scenario (left), the wino/bino (-) scenario (middle), and the higgsino scenario (right). In the two former cases, the sign indicates either a positive or negative product of the two signed neutralino eigenmass parameters. [7]

3. Recent searches beyond the existing combinations of SUSY searches

The ATLAS Collaboration has recently performed two searches [8, 9], both using final states with two leptons and MET, but requiring different amounts of hadronic activity. The searches, together with the various models covered, are described more in detail below.

The first search [8] targets production of mass-degenerate chargino and neutralino, with a final state with a W and Z boson, and two neutralino LSPs. The search also considers pair production of higgsinos, based on the gauge-mediated SUSY breaking (GMSB) model[1] with quasi-degenerate higgsinos, resulting in a final state either with two Z bosons, or a Z and H boson, as well as two gravitino LSPs. Maximal coverage for the considered models is obtained by using 13 orthogonal search regions, most of them including final states with multiple jets (including b-tagged jets). Selection is applied on the invariant mass of the two leptons (the on-/off-shell Z boson) and the mass of the jet system (W, Z, H bosons). The signal extraction relies on the MET significance or invariant mass of the dilepton. As demonstrated in Fig. 3, the search excludes neutralino (chargino) masses up to 800 GeV under the first model, whereas in the GMSB interpretation neutralino masses are excluded up to 900 GeV (ZZ decay).

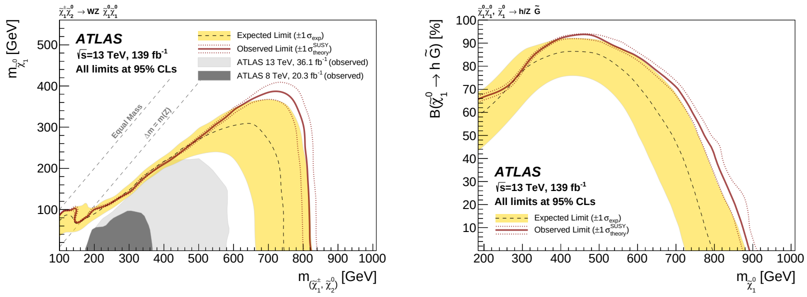

Figure 3: Expected and observed exclusion contours from the search for production of mass-degenerate chargino and neutralino with the WZ final state (left) as well as for the pair production of higgsinos under the GMSB model with the ZZ (ZH) final state (right). [8]

The second search [9] targets pair production of charginos with a final state with two W bosons, as well as the slepton pair production, considering only events with low hadronic activity. In the former case, the search provides coverage for the semi-compressed spectra near the W boson mass, whereas in the case of sleptons the compressed spectra are explored. Two signal categories are constructed: same- and different-flavour lepton pairs. Signal is discriminated from the background processes by utilising four boosted decision trees. One of the boosted decision trees targets the signal and is also utilised for the signal extraction, while the rest is for the main background processes (VV, top, and other processes). The direct slepton pair production is targeted with a slightly different strategy, namely permitting up to one jet from the initial state radiation to give an access to the compressed spectra with low visible energy. Events with a same-flavour lepton pair are divided into two signal categories, either with 0 or 1 jet. The different-flavour lepton pairs are used for background estimation. As the invariant mass of the lepton pair is not a meaningful variable for a slepton pair production, the signal extraction relies on the $M_{T,2}$ variable. The results of the search for both considered models are shown in Fig. 4.

[1]Gauge-mediated SUSY breaking model with quasi-degenerate higgsinos: all other higgsinos decay immediately to the lightest of the higgsino triplet (NLSP).

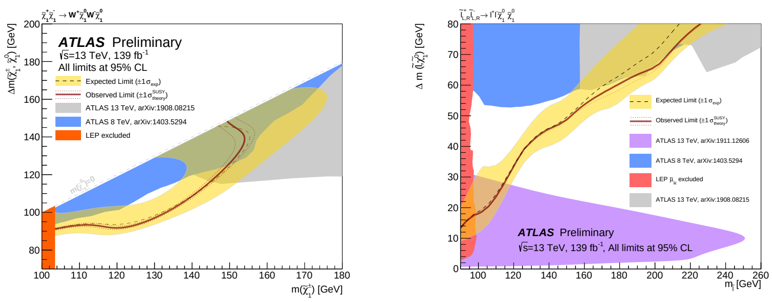

Figure 4: Observed and expected exclusion limits on SUSY simplified models for chargino-pair production with final states of two W bosons (left) and for slepton-pair production (right). [9]

4. Conclusions

Production of top squarks, electroweakinos (neutralinos and charginos), and sleptons can be fully explored only with the full Run 2 data set to account for the low cross sections and experimentally challenging final states that require development of new analysis techniques. Furthermore, combining individual searches provides numerous opportunities to consider various signal scenarios that could appear in multiple parts of the phase space. Both ATLAS and CMS have searched for the pair production of top squarks, and the CMS Collaboration has performed the latest combination. Both collaborations utilised combination to place constraints on (pseudo)scalars that mediate DM production. The ATLAS Collaboration has provided the latest combinations of searches for electroweakinos, and a similar combination of searches is underway by the CMS Collaboration. The recent searches by the ATLAS Collaboration target for example the pair production of sleptons in the compressed spectra, a particularly interesting scenario given the recent results on the muon g-2 anomaly. In such cases combinations of Run 2 searches are crucial to increase the coverage, and to steer the searches planned for Run 3.

References

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