PROCEEDINGS OF SCIENCE

Recent highlights of supersymmetry searches from CMS

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This paper presents recent selected supersymmetry (SUSY) searches conducted by the CMS collaboration. Various analyses targeting different SUSY scenarios are summarised, including R-parity violating (RPV) SUSY, Stealth SUSY, SUSY with disappearing tracks, and a combination of several electroweakino searches. No significant deviations from the Standard Model expectations were found in any of the analyses, but the searches significantly constrain the parameter space of SUSY models.

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This document presents a summary of several Supersymmetry (SUSY) searches, including, one analysis that probes R-Parity violating scenarios [1], one analysis that looks for SUSY models with a hidden (stealth) sector [2], and analysis looking for SUSY signal models in events with disappearing tracks [3], or a combination of several different analyses that were targeting the production of electroweakinos [4]. For a more comprehensive, up-to-date list, please refer to [5].

1. R-Parity violating SUSY

The analysis targeted the production of electroweakinos, expected to be in the electroweak scale, in final states involving W and Z bosons and an R-parity violating neutralino, which is assumed to be the LSP [1]. Two different types of RPV scenarios are considered: One model (RPVq) expects the lightest supersymmetric particle (LSP) to decay into three quarks: *uds*, resulting in final states with a W boson, a Z boson, and 6 light quark jets, while the other (RPVb) assumes that the LSP decays to *udb*, thus resulting in a final state with a W boson, a Z boson, and 4 light quark jets and 2 b-quark jets. A schematic representation of both signatures probed is represented in Fig 1.

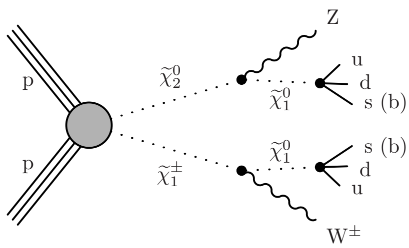
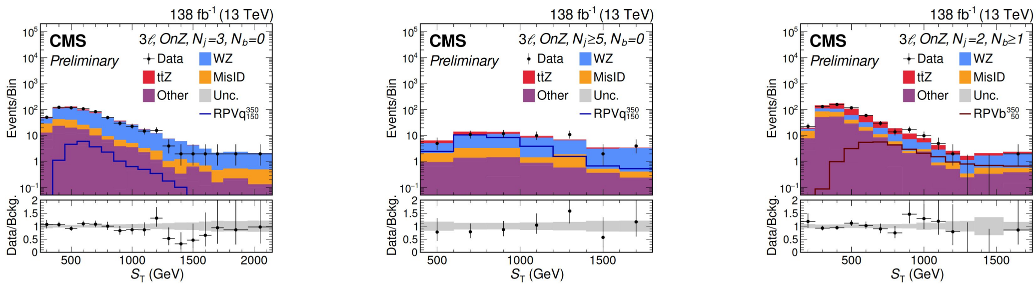


Figure 1: Production of a chargino and the second lightest neutralino, decaying via a SM weak boson as well as the lightest neutralino. The neutralino, taken to be the LSP, subsequently decays through a hadronic RPV interaction into three quarks, either *uds* (RPVq) or *udb* (RPVb).

Signal is probed by selecting events with three isolated leptons, each with $p_T > 10\,\text{GeV}$, as well as up to 6 jets with $p_T > 30\,\text{GeV}$. Two of the leptons are required to have an invariant mass consistent with the mass of the Z boson ($76 < m_{\ell\ell} < 106\,\text{GeV}$). The search regions are defined in terms of the number of jets (N_{jets}) and the number of b-jets ($N_{\text{b-jets}}$), while the distributions are represented in terms of the sum of all objects' p_T (S_T). Example distributions are shown in Fig. 2.

Figure 2: Example search regions utilised in the analysis probing RPV decays.



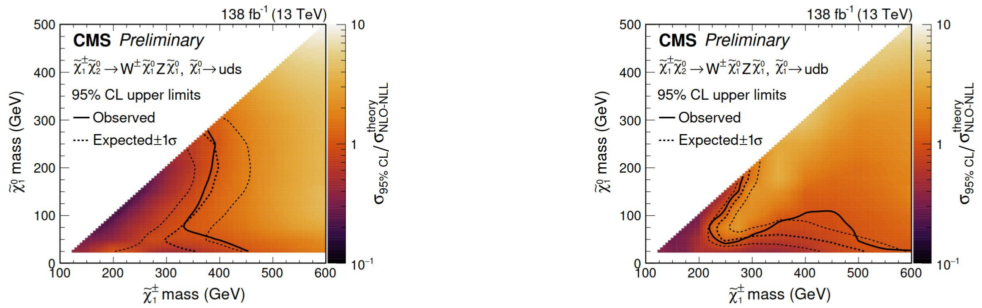
(a) Region with three leptons, $N_{\text{jets}} = 3$ and $N_{\text{b-jets}} = 0$.

(b) Region with three leptons, $N_{\text{jets}} \geq 5$ and $N_{\text{b-jets}} = 0$.

(c) Region with three leptons, $N_{\text{jets}} = 2$ and $N_{\text{b-jets}} \geq 1$.

The main backgrounds in this analysis are the production of WZ bosons for low N_{jets}, and $t\bar{t}Z$ at higher N_{jets}, and their behaviour is constrained via the use of control regions (CRs) with equivalent jet multiplicity checking either events with 2 leptons, or three leptons with none of the leptons with invariant mass consistent with the Z bosons mass. No statistically significant deviations were found, setting instead constrains on the production of these models, represented in terms if 95% confidence level (CL) exclusion limits on the signal cross section, as depicted in Fig 3. Chargino masses are excluded up to around 350 GeV (275) GeV in the compressed scenario and up to 450 GeV (600 GeV) for the RPVq (RPVb) models.

Figure 3: Observed 95% CL upper limits on the signal cross section for the production of electroweakinos in RPV decays, as a function of the chargino and neutralino mass. Results are shown for:



(a) The RPVq model. **(b)** The RPVb model.

2. Stealth SUSY

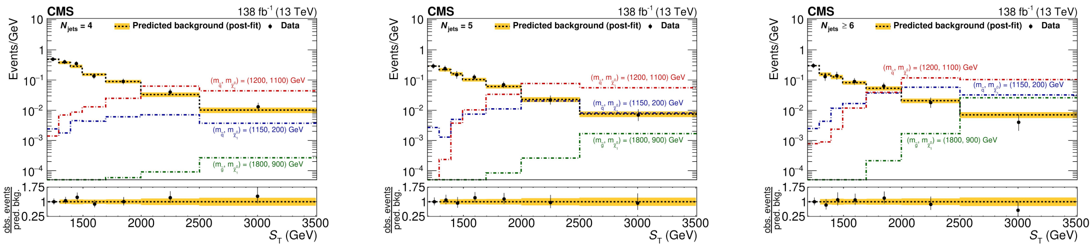
This analysis studies the existence of stealth SUSY models, in particular, a simplified model, denoted as $\tilde{S}$, which decays via its nearly mass-degenerate hidden partner S and a gravitino, which is assumed to be the LSP [2]. Two production modes are considered, their production via gluinos, portrayed in Fig. 4a, and via squarks, shown in Fig. 4b. Both models assume R-Parity, and do not require any special fine tuning.

Figure 4: Diagrams for the simplified models considered in the stealth analysis:

(a) Gluino production. **(b)** Squark production.

In both simplified models, the final state includes two photons as well as multiple jets. Thus, two isolated photons are required, where the p_T of the first photon needs to be at least 35 GeV, and the p_T of the second one of 25 GeV, with their diphoton mass, $m_{\gamma\gamma} > 90$ GeV. In addition to that, at least four jets and $S_T > 1200$ GeV are required. Search regions are divided in terms of N_{jets}, splitting them into the $N_{\text{jets}} = 4$, $N_{\text{jets}} = 5$ and $N_{\text{jets}} \geq 6$ categories, represented in Fig. 5a, Fig. 5b and Fig. 5c, respectively. Likewise, the background is estimated using a data driven approach [2].

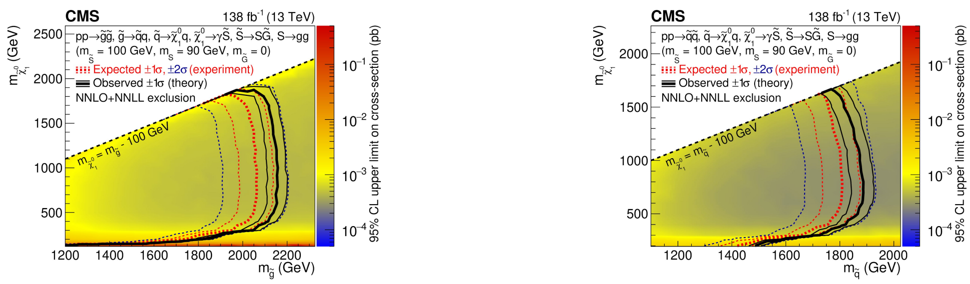
Figure 5: Search regions utilised in the analysis probing for Stealth SUSY.



(a) Region with $N_{\text{jets}} = 4$. **(b)** Region with $N_{\text{jets}} = 5$. **(c)** Region with $N_{\text{jets}} \geq 6$.

No significant deviations from the standard model prediction are found, instead obtaining 95% CL limits, which for the gluino production reach up to 2.1 TeV for neutralino masses between 300 and 1800 GeV, and of 1.85 TeV on the squark mass for neutralino masses between 500 and 1600 GeV. These limits are presented in Figs 6a and 6b, for the gluino and squark production, respectively.

Figure 6: 95% CL upper limits on the production cross section of a pair of supersymmetric particles. Results are shown in terms of the mother SUSY particle's mass and neutralino mass. Two models are considered:



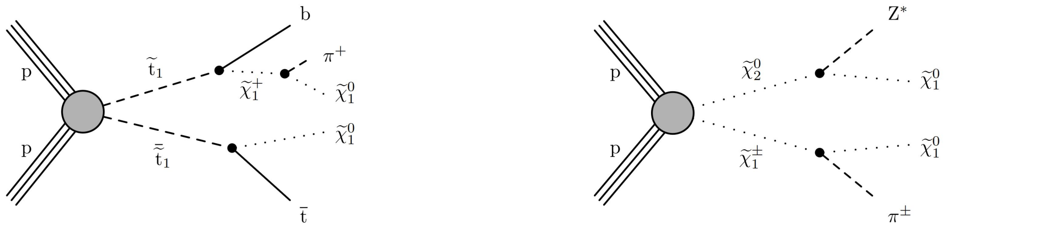
(a) Gluino production. **(b)** Squark production.

3. SUSY with Disappearing Tracks

This analysis looks for long-lived particles predicted by SUSY models, which would leave disappearing tracks in the detector. Both short and long missing tracks are considered. Several simplified models are tested, including the production of gluinos or top/bottom squarks, and the production of electroweakinos with a nearly pure higgsino/wino LSP and a weak boson (Z or W), a model that provides with a good dark matter candidate. Two example distributions are depicted in Fig. 7.

Two different particle lifetimes are considered: $c\tau = 10$ cm, which considers pure higgsino wino states, and a more long lived particle model ($c\tau = 200$ cm). Signal regions are divided into different channels, including a hadronic, a muon, an electron and a multiple missing track channels, further subdividing each channels in terms of p_T^{miss}, N_{jets}, $N_{\text{b-jets}}$, the number of short/long tracks,

Figure 7: Selected diagrams for the analysis probing SUSY with disappearing tracks (Full set in [3])

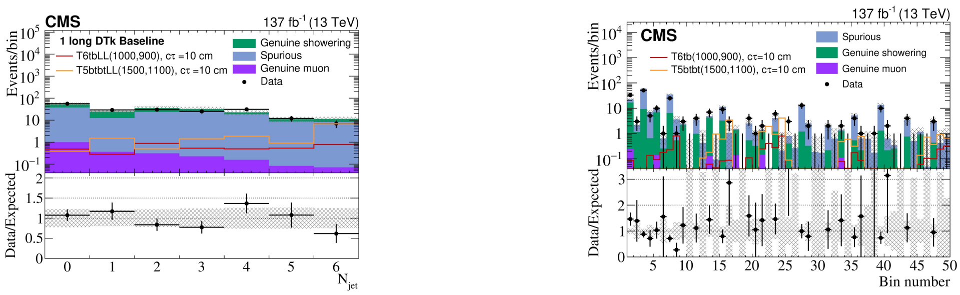


(a) Top squark production.

(b) Electroweakino production with a nearly pure higgsino wino LSP and a Z boson.

and the ionisation energy loss of the candidate tracks. An example distribution is shown in Fig. 8a. The main backgrounds arise from detector effects, and are evaluated in dedicated control regions. In order to improve the signal purity in the search regions, a boosted decision tree is used, using several baseline impact and isolation parameters as inputs. The number of events of data and simulated signal and backgrounds for each of the search and control regions is summarised in Fig. 8b

Figure 8: Selected distributions for the analysis probing SUSY with disappearing tracks (Full set in [3])

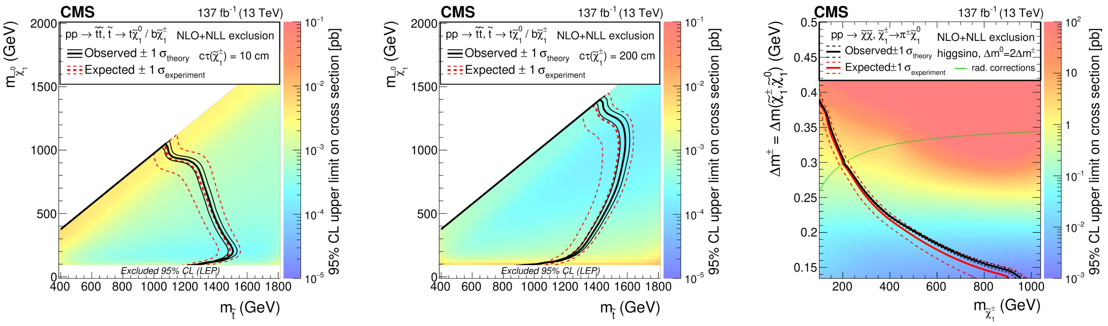


(a) N_{jets} distribution for the baseline region with one long disappearing track.

(b) Simulated and number of events observed for each of the search and control regions

No significant deviations from the standard model are found, setting instead 95% CL upper limits on the production of each of the signal hypotheses previously described. For the top squark production, masses are excluded up to 1500 GeV for neutralino masses up to 850(1150) GeV for $c\tau$ = 10 cm ($c\tau$ = 200 cm), as depicted in Figs. 9a and 9b, respectively. Similarly, bottom squark masses are excluded up to 1600 GeV, and their LSP companion up to 1050 (1450) GeV for the $c\tau$ = 10 cm ($c\tau$ = 200 cm) hypotheses. Gluino masses are excluded up to 2300 GeV, and their accompanying LSP up to 1500 GeV (2000 GeV) for the $c\tau$ = 10 cm ($c\tau$ = 200 cm) hypotheses, respectively. Lastly, for the electroweakino production, LSP masses are excluded up to 650 GeV for the model in which the LSP is in a pure wino state, and up to 210 GeV when the LSP is in a purely wino state, as shown in Fig. 9c.

Figure 9: Observed 95% CL upper limits on the signal cross section for the models discussed in Fig 7. For Figs. 9a and 9b, limits are shown terms of the top squark and the LSP mass, while for Fig. 9c, limits are shown in terms of the chargino mass and the mass splitting between the chargino and the LSP.



(a) Top squark production ($c\tau$ = 10 cm).

(b) Top squark production ($c\tau$ = 200 cm).

(c) Electroweakino production with a nearly pure higssino wino LSP and a Z boson.

4. Electroweakino Combination

The last analysis covered in this document involves the combination of several searches that probed different complementary electroweakino signal hypothesis, in order to improve the sensitivity by merging the various analyses [4]. It is built as an improvement from a previous analysis with a similar intent but including only 2016 data [6]. Two interpretations considered in the 2016 combination were reinterpreted. One first model involves the production of a wino like chargino and neutralino decaying via a bino like neutralino (assumed to be the LSP), as well as a neutral SM boson, portrayed in Fig. 10a. The other signal hypothesis considers the production of a neutralino pair production in gauge-mediated supersymmetry breaking (GMSB), with quasi degenerate higgsinos. Two new interpretations were also included, the production of a slepton pair, shown in Fig. 10b, and the production of an electroweakino in higgsino-bino interpretations, where the neutralino decays via a W boson and the LSP and the (second or third lightest) neutralino to a H boson and the LSP.

Figure 10: Signal hypotheses already studied the previous electroweakino combination combination [6].

(a) Production of a wino-like chargino and a neutralino, decaying via a bino like LSP neutralino.

(b) Slepton pair production.

Six different previously published analyses are included into combination, three of them focusing on final states with more leptonic, namely an analysis targeting final states with either 2 or 3 soft leptons (labelled as 2/3ℓ soft) [7], one looking for 2 leptons either within the Z mass window or non resonant (2ℓ on-Z/2ℓ non-res) [8]; and one focused on events with at least three leptons ($\geq 3\ell$)

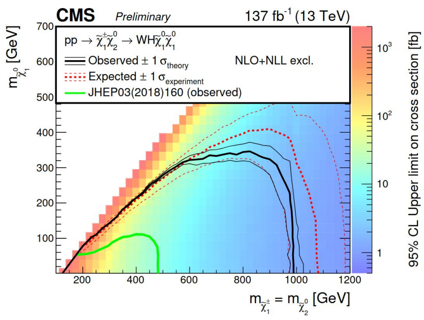
[9]. Likewise, three analyses focused on more hadronic signatures are considered, one focused on events with one lepton and two b jets (1ℓ 2b) [10], one centered around events with four b quarks (4b) [11], and one last pursuing final states including WW/WZ or WH pairs (Hadr. WX) [12]. Table 1 depicts how each of the signal hypotheses are considered by each of the searches.

Search	Gaugino		GMSB			Higgsino-bino			Sleptons
	WZ	WH	ZZ	ZH	HH	WW	HH	WH	$\ell^+\ell^-$
$2/3\ell$ soft	✓								✓
2ℓ on-Z	✓		✓	✓					
2ℓ non-res.									✓
$\geq 3\ell$	✓	✓	✓	✓	✓			✓	
$1\ell 2$b		✓						✓	
4b					✓		✓		
Hadr. WX	✓	✓				✓		✓	

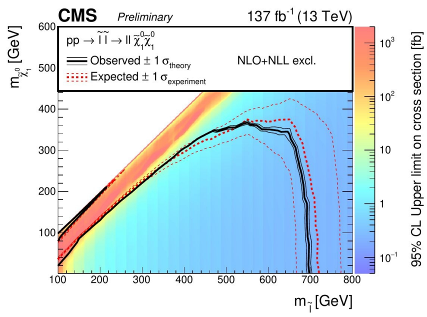
Table 1: Summary table depicting the signal models considered for each of the input analyses.

No significant deviations are found with respect to the standard model, while sensitivity was much improved with respect to each of the separate analyses, as well as with respect to the previous combination. 95% CL limits are set, reaching up to 1 TeV for the chargino production (Fig. 11a, and 990 GeV for the higgsino case, while slepton masses are excluded up to 215 GeV for a mass splitting between the LSP and the neutralino of 5 GeV, and between 110 and 720 GeV for a mass splitting of 50 GeV, as portrayed in Fig. 11b. The whole set of limits for the multiple models are presented in the dedicated reviewed manuscript [4].

Figure 11: Observed 95% CL upper limits on the signal cross section for some selected models presented in [6].



(a) Production of a wino-like chargino and a neutralino, decaying via a bino like LSP neutralino.



(b) Slepton pair production.

5. Summary and Outlook

None of the recent SUSY searches from CMS presented in the document has found any significant deviations from the SM expectations but instead have placed ever more stringent limits on various SUSY parameters. However, the CMS collaboration is in the midst of the Run-3 data taking period, which when finished should triple the current luminosity, enabling future analyses to probe even more phase spaces, either more probing for more energetic decays, or rarer decays, setting the ground for a very prolific future in the quest for either finding or refuting multiple supersymmetric models.

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