PROCEEDINGS OF SCIENCE

Searches for supersymmetry in hadronic final states with the CMS experiment

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The latest results of searches for supersymmetry in hadronic and photonic final states with the CMS experiment will be presented. 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 standard model (SM) of particle physics is successful in describing a wide range of high energy particle physics phenomena; however, it leaves some questions unanswered such as those related to the matter/antimatter symmetry, existence of dark matter, and the hierarchy problem where there is huge gap between the Higgs mass and the Plank mass. To answer some of these questions, an extension to the SM with new particles is developed. Supersymmetry [1] (SUSY) proposes the addition of a new symmetry to the standard model of particle physics and proposes for each boson (fermion) in the SM that there is also a fermionic (bosonic) superpartner (sparticle). The searches described in the following are carried out within the simplified model spectra (SMS) framework [2].

2. Searches for strong SUSY production

2.1 Analysis using M_{T2} variable

This search [3] targets the direct production of gluinos and squarks, superpartners of gluons and quarks, which have the highest production cross sections among SUSY particles for a given mass. These SUSY particles when produced, typically decay via a sequence of processes that produces jets, leptons, and large missing transverse momentum (p_T^{miss}) as shown in Fig. 1.

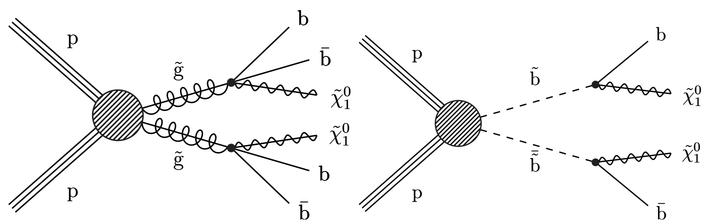

Figure 1: The SMS diagrams for the search that has been performed in the analysis described in Sec. 2.1

Prominent event selections include: triggers with requirement on p_T^{miss}, H_T and jet p_T; Jet selection with radius = 0.4, p_T > 30 GeV in the barrel region; H_T > 250 GeV; M_{T2} > 200 GeV for H_T < 1500 GeV, else M_{T2} > 400 GeV; Veto leptons and lepton tracks.

The lost lepton background (events with $W \rightarrow l\nu$ decays, where the lepton fails certain reconstruction criteria) is estimated from control regions with exactly one lepton triggers and other selections similar to the signal regions. Invisible background (SM background where the Z boson decays into pair of neutrinos which escape the detector) is estimated from a Drell-Yan sample with the help of di-lepton triggers. Multijet background is estimate form control regions with 180 < H_T < 1050 GeV in data samples. This analysis was the first to set stringent limits on the strong productions of gluinos and squarks as shown in Fig. 2. A similar analysis [4] was performed with constraints on H_T, N_{jets} and lepton veto and searches in a four-dimensional search region defined in terms of the number of jets, the number of tagged bottom quark jets, the scalar sum of jet transverse momenta, and the magnitude of the vector sum of jet transverse momenta. No significant excess in data was found in both the analyses and the latter analysis set limits on the gluino mass as large as 2000 to 2310 GeV at 95% confidence level (CL), while lower limits on the squark mass as large as 1190 to 1630 GeV.

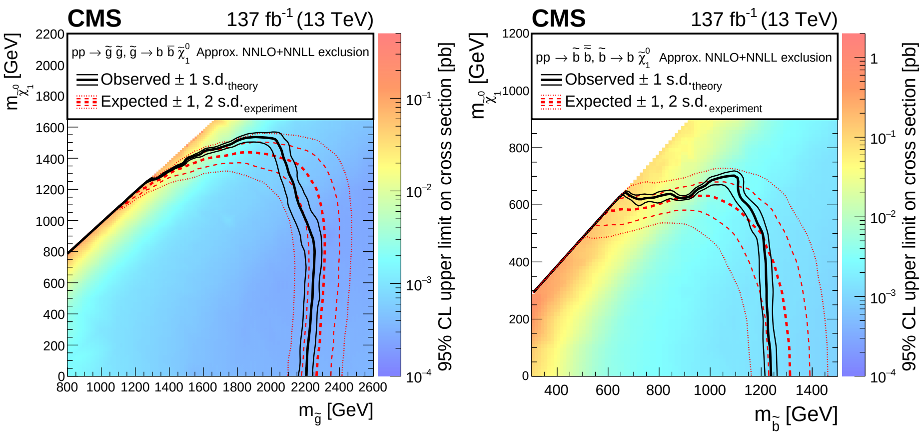

Figure 2: Exclusion limits in the m(gluino) or m(bottom squark) and m(LSP) plane for the decay of gluinos and bottom squarks as described in the Sec. 2.1

2.2 Analysis using single lepton and delta phi variables

This relatively new search [5] in the strong SUSY sector in final states events with a single charged lepton (electron or muon) and multiple hadronic jets targets gluino pair production, where the gluinos decay into the lightest supersymmetric particle (LSP) and either a top quark-antiquark pair, or a light-flavor quark-antiquark pair and a W boson as shown in Fig. 3. Based on the b-jet requirement, the analysis is classified into multi b-tags and 0 b-tags analysis.

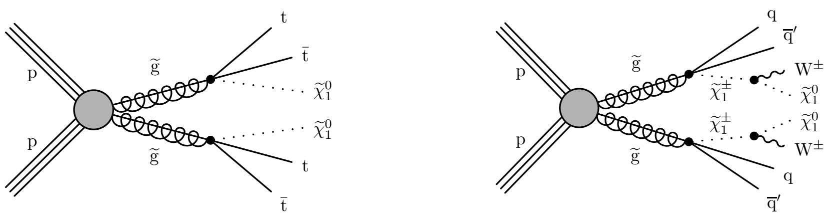

Figure 3: The SMS diagrams for the search that has been performed in the analysis described in Sec. 2.2

Some of the main event selections include: one good lepton with $p_T > 25$ GeV; no additional veto lepton or isolated tracks; $H_T > 500$ GeV and $L_T > 250$ GeV; $N_{jets} \geq 3$ with constraint on leading and subleading jet p_T; $\Delta\phi(p_T^{lepton}, p_T^{W}) > 0.75$ for multi-b analysis.

The quantity $\Delta\phi(p_T^{lepton}, p_T^{W})$ the angular separation between the lepton and the W boson is small for standard model events but large for SUSY events due to the large missing transverse momentum from the LSPs. Along with high N_{jets} requirement, builds a good signal sensitive region. When the mass splitting between the gluino and the LSP is small, the top quark has low p_T and hence a resolved top tagger (deep neural network tagger trained to classify the 3-prong decays of top quark) is used to identify the top quark, while the mass splitting is high, deepAK8 top tagger based on large radius jet [5] is used for the merged top identification. Good agreement is observed between the data and the predictions in all search bins. The multi-b (0-b) analysis excluded the mass of the gluino up to 2120 (2280) GeV and the mass of the LSP up to 1270 (1220) GeV which has an improvement over the analyses discussed in the previous section.

3. Searches for electroweak SUSY production

3.1 Electroweak SUSY search with di-bosons and large $p_{\mathrm{T}}^{\mathrm{miss}}$ in the final state

This search [6] targets production of chargino pair or chargino-neutralino production which decay to hadronically decaying W, Z or H bosons along with large $p_{\mathrm{T}}^{\mathrm{miss}}$ in the final state as shown in Fig. 4. Some of the baseline selections include high H_{T} and $p_{\mathrm{T}}^{\mathrm{miss}}$, lepton veto and use of deep AK8 boson taggers. The signal region is classified into b-veto (0 b-jets) and b-tag (at least 1 b-jet) signal regions depending on the number of b-tagged jets. Signal regions are optimized based on the mass of the AK8 jet to be between 65–105 GeV for b-veto analysis along with the use of dedicated W/Z neural network taggers. While the b-tag analysis is optimized to tag $Z/H \to \mathrm{b\overline{b}}$ and the mass of the AK8 jet between 75–140 GeV along with the use of Z/H neural network taggers.

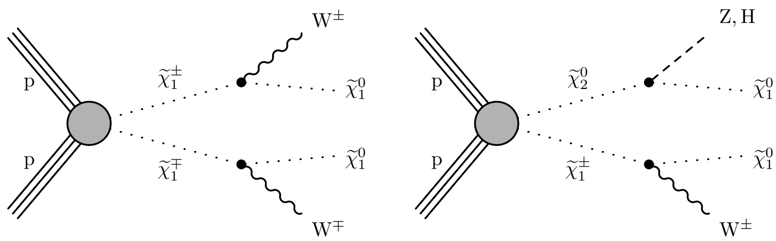

Figure 4: The SMS diagrams for the search that has been performed in the analysis described in Sec. 3.1

The major background for the b-veto analysis comes from the 0 and 1-resonant backgrounds (contains 0 and 1 $W/Z \to qq$ decays respectively). The estimation is done using control regions obtained by inverting the tagger requirement. Transfer factor is obtained from the control regions and applied on the data control regions to get the background predictions. For the b-tag analysis, the top background is estimated using a transfer factor method from 1 lepton control regions. For the remaining major 0-resonant background, anti-tag control regions are used and using another pass/fail transfer factor, the non-resonant background is estimated. The rare background (for example, tri-boson background that has two resonances) is negligible in both analysis and is directly taken from the simulation. This search is sensitive to large class of electroweakino models with wino-like NLSP as in Fig. 5 and also sensitive to higgsino-like NLSP as shown in Fig. 6.

3.2 Search for higgsinos decaying to two Higgs bosons and large $p_{\mathrm{T}}^{\mathrm{miss}}$ in the final state

This search [7] targets the production of two Higgs bosons in the final state that decay to a pair of b quarks. For the electroweak production of nearly mass-degenerate higgsinos, each higgsino decay yields a neutralino ($\widetilde{\chi}_1^0$) that in turn decays to a massless goldstino and a Higgs boson. For the strong production, gluino pairs decay via a slightly lighter $\widetilde{\chi}_2^0$ to H and a light $\widetilde{\chi}_1^0$.

The search regions are based on the boost of the jet reconstructed as Higgs boson. If the jet is highly boosted, then the b-jets from H are reconstructed by a fat jet (referred as boosted analysis) whereas if the two b-jets from H are separated more than ΔR of 2.2, then the AK4 jets are identified with a b-tagger and referred as resolved analysis. The resolved analysis is binned in H candidate mass and no. of b-jets. Backgrounds are predicted using the control side regions ($N_{\mathrm{b-jets}} = 2$) and mass side band regions. The ratio from the signal region and the sidebands is used to get the

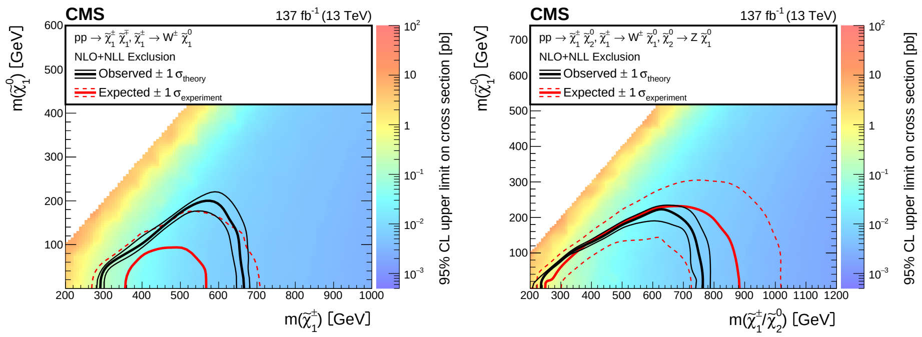

Figure 5: The 95% CL upper limits on the production cross sections for $\widetilde{\chi}_1^\pm\widetilde{\chi}_1^\mp$ assuming that each $\widetilde{\chi}_1^\pm$ decays to a W boson and $\widetilde{\chi}_1^0$ (left) and $\widetilde{\chi}_1^\pm\widetilde{\chi}_2^0$ production assuming that the $\widetilde{\chi}_1^\pm$ decays to a W boson and $\widetilde{\chi}_1^0$ and that the $\widetilde{\chi}_2^0$ decays to a Z boson and $\widetilde{\chi}_1^0$ (right) with wino cross-sections

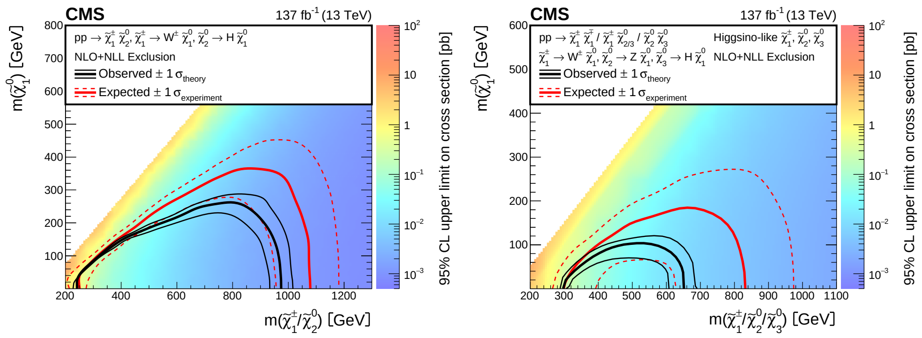

Figure 6: The 95% CL upper limits on the production cross sections for the $\widetilde{\chi}_2^0$ decays to a H and $\widetilde{\chi}_1^0$ (left). Exclusion and observed limits for mass-degenerate higgsino-like $\widetilde{\chi}_1^\pm\widetilde{\chi}_1^\mp$, $\widetilde{\chi}_1^\pm\widetilde{\chi}_2^0$, $\widetilde{\chi}_1^\pm\widetilde{\chi}_3^0$, and $\widetilde{\chi}_2^0\widetilde{\chi}_3^0$ production as functions of the NLSP and LSP masses(right).

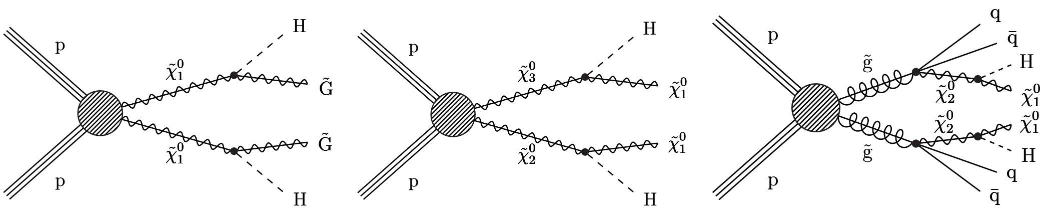

Figure 7: The SMS diagrams for the search that has been performed in the analysis described in Sec. 3.2

predictions in the signal region. The boosted analysis is binned in $p_{\mathrm{T}}^{\mathrm{miss}}$ and no. of Higgs (1–2). Here the background predictions are performed using the ABCD method. Control signal regions and side bands are obtained by looking in a region with $N_{\mathrm{H}} = 0$. The ratios in the control signal regions to control side bands are mutliplied with side bands to obtain the predictions. No significant deviations from the standard model are observed. The masses of $\widetilde{\chi}_1^0$ in the range of 175–1025 GeV are excluded ar 95% CL and for the strong production, the masses of gluino below 2330 GeV are excluded as shown in Fig. 8 respectively.

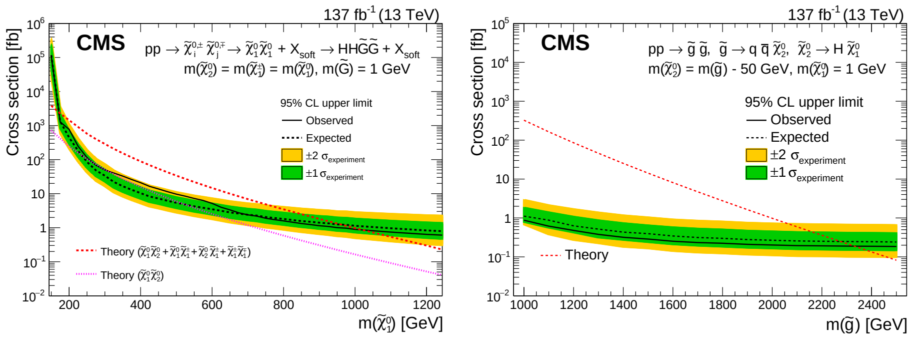

Figure 8: Observed and expected upper limits at 95% CL on the cross section for the GMSB-motivated simplified model TChiHH-G (left). Observed and expected upper limits at 95% CL on the cross section for the simplified model T5HH, for the SMS diagram shown in right Fig. 7 (right)

4. Summary

This report presents the wide variety of recent SUSY searches performed mostly in the hadronic final states. These results place strong exclusion limits on new physics models, however no signs of new physics was observed. Dedicated searches with the help of deep neural network taggers helped us to even achieve sensitivity for the higgsino masses. With the recent start of LHC Run 3, we are optimistic to shed more light and potentially discover the existence of new physics.

References

[1] J.L. Feng Ann. Rev. Nucl. Part. Sci. **63**, 351 (2013)

[2] J. Alwall, P. Schuster and N. Toro, *Simplified models for a first characterization of new physics at the LHC*, Phys. Rev. D **79**, 075020 (2009)

[3] CMS Collaboration, *Searches for physics beyond the standard model with the MT2 variable in hadronic final states with and without disappearing tracks in proton–proton collisions at* $\sqrt{s}$ = 13 *TeV*, Eur. Phys. J. C **80**, 3 (2020)

[4] CMS Collaboration, *Search for supersymmetry in proton-proton collisions at 13 TeV in final states with jets and missing transverse momentum*, JHEP **10**, 244 (2019)

[5] CMS Collaboration, *Search for supersymmetry in final states with a single electron or muon using angular correlations and heavy object tagging in proton-proton collisions at* $\sqrt{s}$ = 13 *TeV*,CMS-PAS-SUS-21-007

[6] CMS Collaboration, *Search for electroweak production of charginos and neutralinos at* $\sqrt{s}$ = 13 *TeV in final states containing hadronic decays of WW, WZ, or WH and missing transverse momentum*, Submitted to Physics Letters B, arXiv:2205.09597 (2022)

[7] CMS Collaboration, *Search for higgsinos decaying to two Higgs bosons and missing transverse momentum in proton-proton collisions at* $\sqrt{s}$ = 13 *TeV*, JHEP **05**, 14 (2022)