PROCEEDINGS OF SCIENCE

Recent Searches for Supersymmetry in CMS

Sezen Sekmen
for the CMS Collaboration[a,*]

[a] *Kyungpook National University, Department of Physics*
Daegu, Republic of Korea

E-mail: ssekmen@cern.ch

This report summarizes four of the recently published supersymmetry (SUSY) searches performed on 139 fb^{-1} of 13 TeV pp collision data collected by the CMS experiment between years 2016-2018. These are the combined search for electroweak production of winos, binos, higgsinos, and sleptons; search for stealth SUSY in final states with two photons, jets, and low missing transverse momentum; search for new physics in multijet events with at least one photon and large missing transverse momentum; and search for SUSY in final states with disappearing tracks. The latter is presented first time at the LHCP2023 conference. These searches, all targeting challenging signatures, feature innovative analysis methodologies and have resulted in enhanced sensitivity in various regions of the SUSY parameter space.

The Eleventh Annual Conference on Large Hadron Collider Physics (LHCP2023)
22-26 May 2023
Belgrade, Serbia

*Speaker

https://pos.sissa.it/

PoS(LHCP2023)159

The Compact Muon Solenoid (CMS) detector at the Large Hadron Collider (LHC) has collected 139 fb^{-1} of 14 TeV of proton proton collision data during the so-called Run 2 period, between years 2016-2018. CMS has been conducting a rich and diverse supersymmetry search program. As of May 2023, there were 28 public results with multi-year CMS Run 2 data exploring a large spectrum of SUSY signatures. These wide variety of studies range from inclusive, multi-bin searches simultaneously covering multiple final states, to dedicated searches targeting specific final states. Recently, focus has shifted towards challenging final states such as those with compressed mass spectra, low cross sections (e.g. direct slepton production), long-lived particles, or low missing transverse momentum (p_T^{miss}) (e.g. R-parity violating or stealth scenarios). New methodologies are progressively being developed to address these difficult final states, such as refined object identification, increased use of machine learning and combination of multiple analyses.

This report summarizes 4 among the most recent CMS SUSY results. The first features a combination of 6 searches targeting direct electroweak production of winos, binos, higgsinos and sleptons [1]: i) 2 or 3 soft e/μ, opposite-sign same flavor lepton pair [2]; ii) $> 3\ell +$ p_T^{miss} or same sign dilepton + p_T^{miss} [3]; iiii) $e^+e^-/\mu^+\mu^-$ for on-shell or off-shell Z [4]; iv) e/μ + H(bb) + p_T^{miss} [5]; v) H(bb)H(bb) + p_T^{miss} [6] both for resolved and boosted Higgs; and vi) hadronic boosted W,Z,H [7]. Direct production of electroweakinos (EWKinos) or sleptons have (very) low cross sections, which makes combination of searches crucial to enhance sensitivity and obtain reach complementarity. The searches involved cover leptonic, semi-leptonic and hadronic final states, and are designed to explore spectra with different levels of mass compression. Figure 1, left panel shows the individual and combined limits for the $\tilde{\chi}_0^{\pm}\tilde{\chi}_2^0 \to WZ\tilde{\chi}_1^0\tilde{\chi}_1^0$ channel. The compressed mass region is covered by the soft lepton analysis, while the boosted region is covered by the boosted W/Z/H-tagged hadronic analysis, confirming the complementarity aspect of the combination. The right panel shows mass-plane cross section upper limit for direct slepton pair production, with observed and expected exclusion limits in the compressed region, obtained by the "2/3ℓ soft" search.

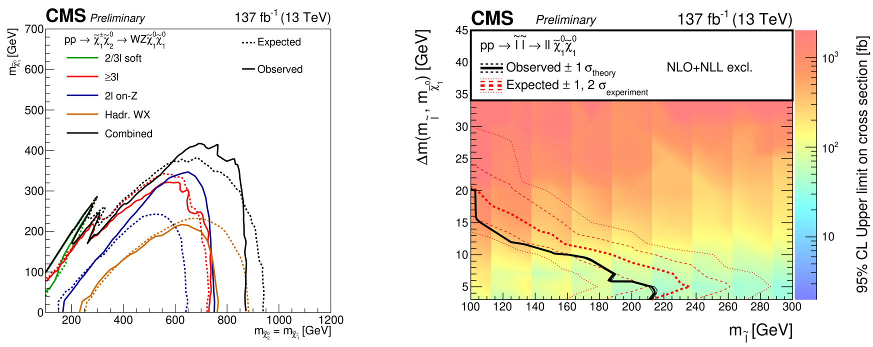

Figure 1: EWK combination – Left: Exclusion contours for the individual analyses targeting the WZ topology for the full parameter space. Right: The 95% CL direct slepton pair production cross section upper limits, with observed and expected exclusion contours in the compressed region, from the $2/3\ell$ soft search.

The second search explores stealth SUSY, where MSSM is enhanced by a weak scale light hidden sector weakly coupling to SUSY. This results in a mass-degenerate singlet S and singlino $\tilde{S}$, allowing the process $\tilde{\chi}_1^0 \to \gamma\tilde{S}$, $\tilde{S} \to \tilde{G}S$ where gravitino $\tilde{G}$ is the lightest SUSY particle (LSP). Lower $\Delta m(\tilde{S}, S)$ leads to softer gravitinos and a lower p_T^{miss}. The search looks for strong production of stealth SUSY in final states with two moderate p_T photons, $\geq$ 4 jets and low p_T^{miss}, where S_T, the scalar sum of all object p_Ts is required to be greater than 1200 GeV. Signal is extracted in S_T distribution in bins of 4, 5 and $\geq$ 6 jets, where the background S_T shape is estimated from a control region with low jet multiplicity. Data are found to be consistent with the SM, and limits are obtained for gluino and squark pair production cases for fixed singlino, singlet and gravitino masses. The analysis excludes gluinos up to 2.15 TeV and squarks up to 1.85 TeV, which provide the most stringent limits for these models. Figure 2 shows the S_T distribution for the $n_{jets} \geq 6$ search region and limits on the gluino production cross section.

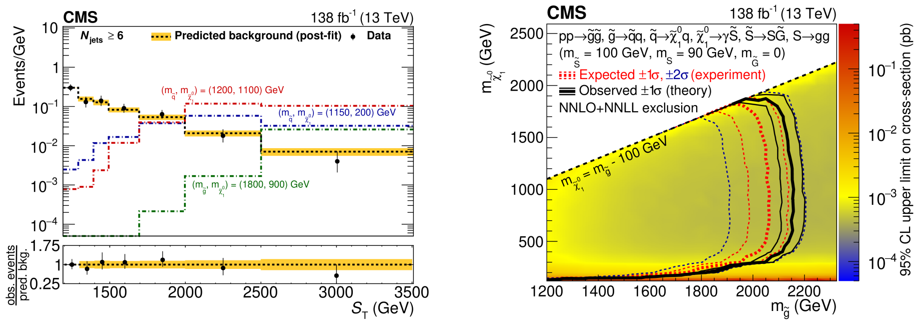

Figure 2: Stealth SUSY analysis – Left: Comparison of the measured S_T distribution with the post-fit background prediction for $n_{jets} \geq 6$. Right: The 95% CL upper limits and exclusion contours on the gluino pair production cross section as functions of $\tilde{g}$ and $\tilde{\chi}_1^0$ masses.

The third search, also featuring photons, targets gauge mediated SUSY models (GMSB), where the LSP is a light gravitino. For mass spectra with heavy sleptons, the decays $\tilde{\chi}_1^0 \to Z/H\tilde{G}$ and $\tilde{\chi}_1^\pm \to W\tilde{G}$ become prominent. The search explores a variety of final states with $\geq$ 1 high-p_T photon, multiple jets and large p_T^{miss}. The analysis has search regions optimized for strong production as well as those dedicated to direct EWKino production with boosted W/Z/H bosons, which are tagged by a simple requirement on mass of large radius jets. Orthogonal search regions are formed in bins of number of jets, b-tagged jets, W/Z bosons, H bosons and of p_T^{miss}. Data are found to be consistent with SM backgrounds that were estimated by transfer factors applied to data control regions. The analysis excludes gluinos up to 2.36 TeV, top squarks up to 1.43 TeV, wino-like $\tilde{\chi}^0\tilde{\chi}^\pm$ up to 1.3 TeV and higgsino-like $\tilde{\chi}^0\tilde{\chi}^\pm$ up to 1.05 TeV. Figure 3 shows cross section limits for $\tilde{g} \to t\bar{t}\tilde{\chi}_1^0$ followed by $\tilde{\chi}_1^0 \to Z/\gamma\tilde{G}$ and Higgsino-like degenerate chargino/neutralino production processes.

The fourth search explores compressed SUSY mass spectra with $\Delta m(\tilde{\chi}_1^\pm - \tilde{\chi}_1^0) \sim O(100)$ MeV, where the charginos are long-lived. They typically decay within the CMS tracker into a soft, undetectable pion and a $\tilde{\chi}_1^0$, which leads to a so-called "disappearing track" (DTk) signature accompanied by p_T^{miss}. The search is performed in the 1/$\geq$ 2 DTk + p_T^{miss}+ $\geq$ 1 jet + 0/1 lepton final state, targeting both strong and EWK production of long-lived charginos. DTks are defined by requiring negligible energy deposits in the calorimeters. Short and long DTks are reconstructed from hits in the pixel-only and pixel+strip tracking detectors, respectively, in order to be sensitive to a large range of $\tilde{\chi}_1^\pm$ lifetimes. Boosted decision tree classifiers are trained to improve DTk purity. Events are categorized into hadronic+DTk, e+DTk and μ+DTk channels. 49 orthogonal search bins are formed based on p_T^{miss}, number of jets, b-jets, short DTks, long DTks and energy loss by ionization (i.e dE/dx) in the pixel detectors. Main backgrounds consist of hadrons and leptons

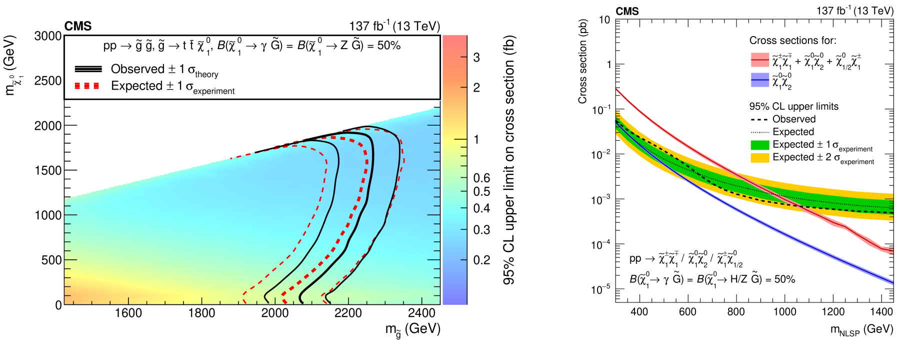

Figure 3: Photon + jets + p_T^{miss} plots – Left: The 95% CL upper limits on the production cross sections for $\tilde{g} \to t\tilde{t}\tilde{\chi}_1^0$ followed by $\tilde{\chi}_1^0 \to Z/\gamma\tilde{G}$ (left). Right: The 95% CL upper limits on Higgsino-like EWKino production cross sections versus $\tilde{\chi}_1^0$ mass.

poorly reconstructed in tracker and tracks built out of chance alignment of hits from different particles. Backgrounds are estimated in a data-driven way where transfer factors calculated in sideband regions are applied to DTk candidates in control regions. Figure 4 shows the comparison of data and SM background predictions in the search regions along with limits for direct stop and direct EWK production. This is the first LHC search that studied a lepton+disappearing track channel, a BDT for DTk identification and pixel dE/dx for event categorization. Hundreds of GeV sensitivity improvement is seen in the compressed mass regions.

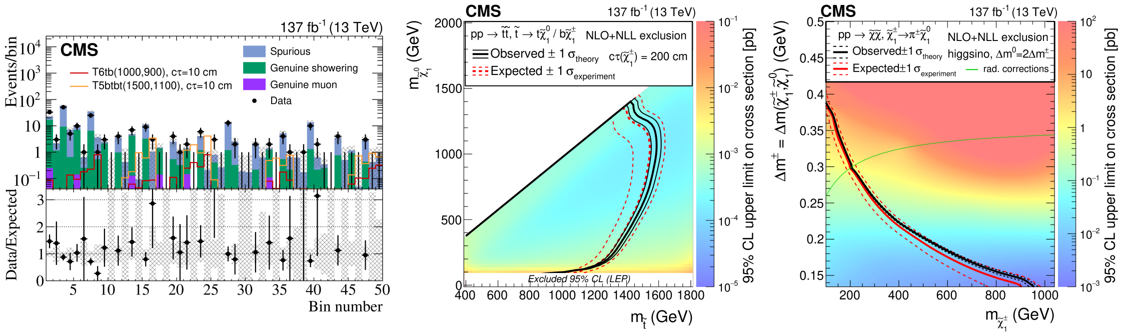

Figure 4: Disappearing track analysis – Left: Data and SM background predictions comparison for the 49 signal regions. Center: Observed 95% CL upper limits on the top squark production cross sections for $\tilde{t} \to t\tilde{\chi}_1^0/b\tilde{\chi}_1^{\pm}$ for a chargino proper decay length $c\tau = 200$ cm. Right: Observed 95% CL upper limits on the signal cross sections for a higgsino DM model. The green line represents the set of model points corresponding to the pure higgsino model where only radiative corrections to the mass splitting are assumed. Chargino lifetimes are based on two-loop calculations

CMS continues to explore every corner of the SUSY parameter space, particularly targeting challenging signatures. Numerous searches are in progress towards publication in the near future.

Acknowledgements: SS is supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education under contracts NRF-2018R1A6A1A06024970 and NRF-2008-00460.

References

[1] [CMS], "Combined search for electroweak production of winos, binos, higgsinos, and sleptons in proton-proton collisions at $sqrts$ = 13 TeV", CMS-PAS-SUS-21-008.

[2] A. Tumasyan *et al.* [CMS], "Search for supersymmetry in final states with two or three soft leptons and missing transverse momentum in proton-proton collisions at $\sqrt{s}$ = 13 TeV," JHEP **04** (2022), 091 doi:10.1007/JHEP04(2022)091 [arXiv:2111.06296 [hep-ex]].

[3] A. Tumasyan *et al.* [CMS], "Search for electroweak production of charginos and neutralinos in proton-proton collisions at $\sqrt{s}$ = 13 TeV," JHEP **04** (2022), 147 doi:10.1007/JHEP04(2022)147 [arXiv:2106.14246 [hep-ex]].

[4] A. M. Sirunyan *et al.* [CMS], "Search for supersymmetry in final states with two oppositely charged same-flavor leptons and missing transverse momentum in proton-proton collisions at $\sqrt{s}$ = 13 TeV," JHEP **04** (2021), 123 doi:10.1007/JHEP04(2021)123 [arXiv:2012.08600 [hep-ex]].

[5] A. Tumasyan *et al.* [CMS], "Search for chargino-neutralino production in events with Higgs and W bosons using 137 fb$^{?1}$ of proton-proton collisions at $\sqrt{s}$ = 13 TeV," JHEP **10** (2021), 045 doi:10.1007/JHEP10(2021)045 [arXiv:2107.12553 [hep-ex]].

[6] A. Tumasyan *et al.* [CMS], "Search for higgsinos decaying to two Higgs bosons and missing transverse momentum in proton-proton collisions at $\sqrt{s}$ = 13 TeV," JHEP **05** (2022), 014 doi:10.1007/JHEP05(2022)014 [arXiv:2201.04206 [hep-ex]].

[7] A. Tumasyan *et al.* [CMS], "Search for electroweak production of charginos and neutralinos at s=13TeV in final states containing hadronic decays of WW, WZ, or WH and missing transverse momentum," Phys. Lett. B **842** (2023), 137460 doi:10.1016/j.physletb.2022.137460 [arXiv:2205.09597 [hep-ex]].

[8] A. Hayrapetyan *et al.* [CMS], "Search for stealth supersymmetry in final states with two photons, jets, and low missing transverse momentum in proton-proton collisions at $\sqrt{s}$ = 13 TeV", [arXiv:2310.03154 [hep-ex]], CMS-SUS-19-001.

[9] A. Hayrapetyan *et al.* [CMS], "Search for new physics in multijet events with at least one photon and large missing transverse momentum in proton-proton collisions at 13 TeV", JHEP **10** (2023), 046 doi:10.1007/JHEP10(2023)046 [arXiv:2307.16216 [hep-ex]], CMS-SUS-21-009.

[10] A. Hayrapetyan *et al.* [CMS], "Search for supersymmetry in final states with disappearing tracks in proton-proton collisions at $\sqrt{s}$ = 13 TeV", [arXiv:2309.16823 [hep-ex]], CMS-SUS-21-006.

PoS(LHCP2023)159