PROCEEDINGS OF SCIENCE

Searches for supersymmetry in final states with photons at CMS

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Final states with isolated photons are expected from the decay chains of supersymmetric particles, either directly or as a result of decays of Higgs bosons produced in the decay chain. Results of three searches for strong and electroweak production of supersymmetric particles in events with one or two isolated photons are presented, based on pp collisions recorded with the CMS experiment at $\sqrt{s} = 13$ TeV. In the case of strong production, the most stringent mass limits on gluinos obtained by these searches reach 2 TeV.

XXVI International Workshop on Deep-Inelastic Scattering and Related Subjects (DIS2018)
16-20 April 2018
Kobe, Japan

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PoS(DIS2018)071

1. Introduction

Supersymmetry (SUSY) is one of the possible extensions of the standard model (SM) since it provides explanations for unsolved problems in particle physics. For the following searches R-parity is assumed to be conserved, thus SUSY particles are always pair-produced, and undergo a series of decays until the lightest supersymmetric particle (LSP), which is stable. In this report mostly searches for SUSY with gauge-mediated SUSY breaking (GMSB) are presented. In GMSB the gravitino ($\widetilde{\mathrm{G}}$) is the LSP with negligible mass, it escapes undetected leading to missing transverse momentum ($p_{\mathrm{T}}^{\mathrm{miss}}$) in the detector. The next-to-LSP (NLSP) is assumed to be the lightest neutralino ($\widetilde{\chi}_1^0$). The results are interpreted in simplified model scenarios (SMS). Complete SUSY models depend on many parameters, in SMS only a small number of new particles are introduced with few parameters. The exclusion limits of SMS models can be applied to general SUSY models with the same topologies. This report presents results based on proton-proton collision data collected at $\sqrt{s} = 13$ TeV in 2016 by the CMS detector [1], corresponding to 35.9 fb^{-1} of integrated luminosity.

2. Electroweak SUSY production with one or two photons and $p_{\mathrm{T}}^{\mathrm{miss}}$

This search [2] focuses on electroweak production of SUSY particles in three different signal scenarios. In general gauge mediation (GGM) scenarios, such as those considered in this section, the $\widetilde{\chi}_1^0$ is assumed to be purely bino-like, the $\widetilde{\chi}_1^{\pm}$ and the $\widetilde{\chi}_2^0$ are assumed to be purely wino-like. The wino and bino masses are varied in the interpretation. The SMS called TChiWg probes associated production of mass-degenerate $\widetilde{\chi}_1^{\pm}$ and $\widetilde{\chi}_1^0$, with decay modes $\widetilde{\chi}_1^0 \to \gamma\widetilde{\mathrm{G}}$ and $\widetilde{\chi}_1^{\pm} \to \mathrm{W}^{\pm}\widetilde{\mathrm{G}}$. TChiNg scenario assumes nearly mass-degenerate $\widetilde{\chi}_1^{\pm}$ and $\widetilde{\chi}_1^0$. The $\widetilde{\chi}_1^{\pm}$ is assumed to decay to $\widetilde{\chi}_1^0$ and low-momentum particles. The $\widetilde{\chi}_1^0$ is assumed to decay to $\widetilde{\mathrm{G}}$ and $\gamma/\mathrm{Z}/\mathrm{H}$ with 50%/25%/25% branching fraction.

Events with at least one photon with $p_{\mathrm{T}} > 180$ GeV in the barrel region ($|\eta| < 1.44$) and $p_{\mathrm{T}}^{\mathrm{miss}} > 300$ GeV are selected. The transverse mass of the $p_{\mathrm{T}}^{\mathrm{miss}}$ and the leading photon is required to be $M_{\mathrm{T}}(\gamma, \vec{p}_{\mathrm{T}}^{\mathrm{miss}}) > 300$ GeV. The scalar sum of $p_{\mathrm{T}}^{\mathrm{miss}}$ and the p_{T} of the photons is required to be $S_T^{\gamma} \equiv p_{\mathrm{T}}^{\mathrm{miss}} + \sum_{\gamma_i} p_{\mathrm{T}}(\gamma_i) > 600$ GeV. The main SM backgrounds are Vγ (V = W$^{\pm}$,Z) and γ+jets. The Vγ and γ+jets backgrounds are estimated from Monte Carlo (MC) simulated events that are normalized to data in a control region (CR). The CR differs from the signal region in $M_{\mathrm{T}}(\gamma, \vec{p}_{\mathrm{T}}^{\mathrm{miss}}) > 100$ GeV, $p_{\mathrm{T}}^{\mathrm{miss}} > 100$ GeV (signal region excluded) and without a requirement in S_{T}^{γ}. The normalization is assessed by a simultaneous fit of Vγ and γ+jets MC distributions to data in bins of $\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}$,nearest jet$/\gamma)$, which is the angular distance in the transverse plane of $p_{\mathrm{T}}^{\mathrm{miss}}$ and the nearest jet or photon. The post-fit distribution can be seen in Fig. 1 (left). A sub-dominant background arises from electrons that are misidentified as photons (e$\to \gamma$). The misidentification rate is measured in $\mathrm{Z} \to \mathrm{e}^+\mathrm{e}^-$ decays with a tag-and-probe method and applied to a CR where, instead of a γ, an electron is required. Other minor backgrounds from $\mathrm{t\bar{t}}\gamma$ and diboson productions are modeled with MC simulation.

Distributions of S_{T}^{γ} in the four search bins are shown in Fig. 1 (right). No indication of new physics can be seen. Upper limits on the signal cross sections are computed. In the GGM scenario, wino and bino masses are excluded below 950 GeV, when $m_{\widetilde{\mathrm{B}}} \approx m_{\widetilde{\mathrm{W}}}$. In TChiWg and TChiNg

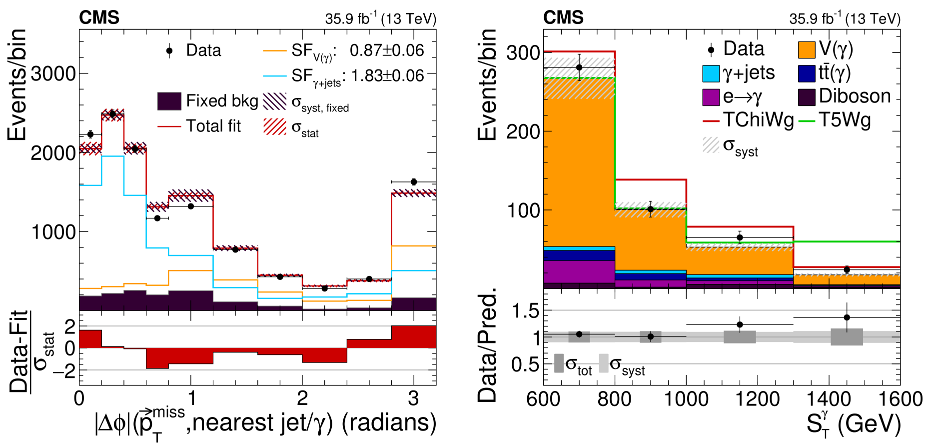

Figure 1: Post-fit distribution of γ+jets (blue) and $V\gamma$ (orange) MC (left). Signal region with predicted backgrounds, observed data, and signal MC (right) [2].

scenarios NLSP masses are excluded up to 780 GeV and 950 GeV, respectively. The exclusion contours are shown in Fig. 2.

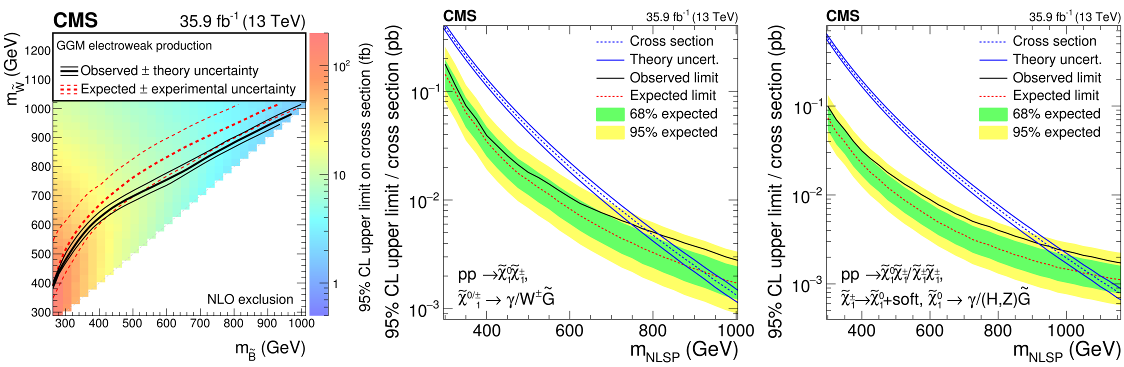

Figure 2: Exclusion contours for the GGM (left), the TChiWg (middle), and the TChiNg (right) scenarios [2].

3. Strong SUSY production with one or two photons and $p_{\mathrm{T}}^{\mathrm{miss}}$

This search [3] focuses on strong production of SUSY particles in four different SMS models. Squark-antisquark pair production are considered in the T6gg and the T6Wg scenarios. For T6gg the (anti)squark decays to an (anti)quark and a $\widetilde{\chi}_1^0$, and the $\widetilde{\chi}_1^0$ decays promptly to a γ and a $\widetilde{\mathrm{G}}$. For T6Wg the squark decays to a quark and a $\widetilde{\chi}_1^0$ or a $\widetilde{\chi}_1^{\pm}$ with 50% branching fraction, respectively. The $\widetilde{\chi}_1^0$ decays to a γ and a $\widetilde{\mathrm{G}}$ and the $\widetilde{\chi}_1^{\pm}$ decays to a $\mathrm{W}^{\pm}$ and a $\widetilde{\mathrm{G}}$. In the T5gg and the T5Wg scenarios gluino pair production is considered. The squarks are assumed to be heavy and decoupled, leading to a three-body decay of the gluino to two quarks and a gaugino. In T5gg the NLSP is always the $\widetilde{\chi}_1^0$, while in T5Wg either $\widetilde{\chi}_1^0$ or $\widetilde{\chi}_1^{\pm}$ with 50% probability, respectively. $\widetilde{\chi}_1^0$ and $\widetilde{\chi}_1^{\pm}$ follows the same decay as in T6gg and T6Wg. All these scenarios lead to final states with one or two photons, two to six jets and $p_{\mathrm{T}}^{\mathrm{miss}}$ coming from $\widetilde{\mathrm{G}}$.

Events are required to have at least one photon with $p_T > 100$ GeV in the barrel region. The scalar sum of all jet p_T and photon p_T is required to be $H_T^\gamma > 700$ GeV. Three p_T^{miss} bins ($350-450$, $450-600$, and ≥ 600 GeV) and two H_T^γ selections ($700-2000$ and ≥ 2000 GeV) give rise to in total six regions. The main background γ+jets is estimated from data. The e $\rightarrow \gamma$ background is estimated in a similar manner as in Section 2. The remaining backgrounds (γW, γZ, $\gamma t\bar{t}$) are estimated from MC. The γ+jets background is estimated using two CRs. The photon CR has the same definition as the search region except $p_T^{miss} < 100$ GeV. The jet CR is the same as the search region but vetoing events containing a photon. For the background estimation in the signal region, the p_T^{miss} distribution in the jet CR is scaled to the p_T^{miss} distribution in the photon CR in the $p_T^{miss} < 100$ GeV range. The method is validated by comparing the prediction to the shape obtained from simulation, as shown in Fig. 3 (left).

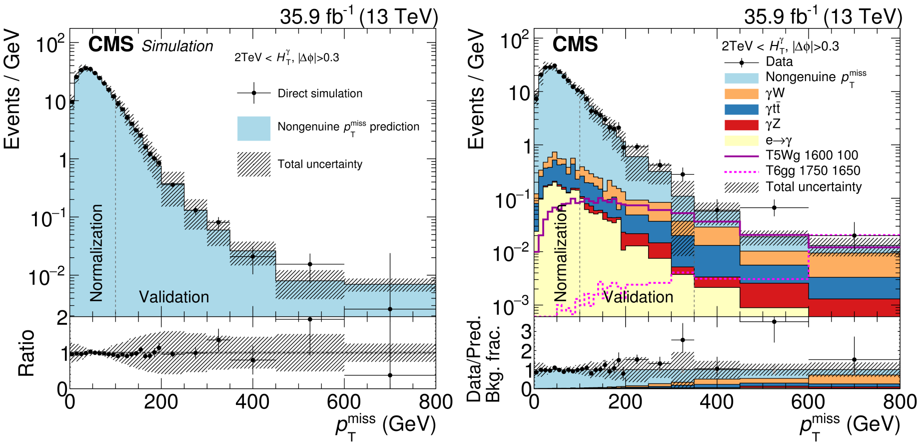

Figure 3: Validation of the γ+jets background prediction (left) and the results in the high-H_T^γ signal regions; backgrounds, data and the expected signal (right) [3].

The distributions of p_T^{miss} in the high-H_T^γ region are shown in Fig. 3 (right). No sign of new physics is visible in any of the search bins. Upper limits on the signal cross sections are computed and the exclusion contours are shown in Fig. 4. In the T6gg model squarks are excluded for masses below 1650 GeV, while for T6Wg $m_{\tilde{q}} > 1550$ GeV. Gluino masses are excluded below 2000 GeV for T5gg and below 1900 GeV for T5Wg.

4. SUSY with Higgs boson(s) to diphoton decays

This search [4] focuses on identifying $H \rightarrow \gamma\gamma$ decays in SUSY models with at least one SM-like Higgs boson that appears in the decay of the SUSY particle. The results are interpreted in four SMS scenarios. Bottom squark pair production is considered in model the T2bH where the squark decays to a b quark and the $\tilde{\chi}_2^0$ which is the NLSP. The $\tilde{\chi}_2^0$ further decays to a Higgs boson and the LSP ($\tilde{\chi}_1^0$). The mass splitting between $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$ is assumed to be 130 GeV to produce on-shell Higgs boson. In the electroweak TChiWH scenario, the $\tilde{\chi}_1^\pm$ and the $\tilde{\chi}_2^0$ are mass-degenerate and produced together, the $\tilde{\chi}_1^\pm$ decays to a $W^\pm$ and the LSP and the $\tilde{\chi}_2^0$ decays to Higgs boson and LSP. The analysis is sensitive to two more scenarios, both are embedded in the scope of GMSB. In these models, mass-degenerate $\tilde{\chi}_2^0$, $\tilde{\chi}_1^0$, and $\tilde{\chi}_1^\pm$ are assumed, resulting in effective pair production of a

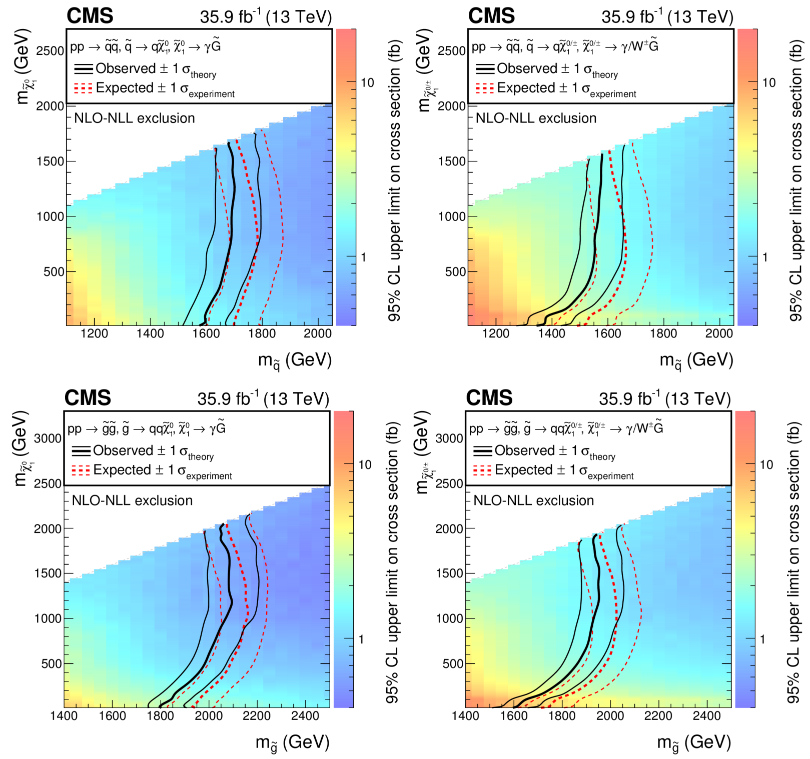

Figure 4: Exclusion contours of the T6gg (top left), the T6Wg (top right), the T5gg (bottom left), and the T5Wg (bottom right) scenarios [3].

$\widetilde{\chi}_1^0$ pair. The first scenario is called TChiHH where the $\widetilde{\chi}_1^0$ always decays to $\widetilde{\mathrm{G}}$ and a Higgs boson, while in the TChiHZ model the $\widetilde{\chi}_1^0$ has a branching fraction of 50% to either a Higgs or a Z boson and the $\widetilde{\mathrm{G}}$.

At least two photons are required in the barrel region with $p_\mathrm{T}^{\gamma_1} > 40$ GeV and $p_\mathrm{T}^{\gamma_2} > 20$ GeV. The pair with the largest sum of p_T is chosen as the Higgs candidate, and it is required to have an invariant mass within $103 < m_{\gamma\gamma} < 160$ GeV. The main background is $\gamma\gamma$+jets either with prompt photons or jets misidentified as photons. The SM Higgs boson production is estimated from MC. The non-resonant background is estimated with a fit of the $m_{\gamma\gamma}$ spectrum.

The expected signal contribution is extracted from a fit over the $m_{\gamma\gamma}$ spectrum in the signal-plus-background hypothesis. No significant deviation from SM is visible, upper limits on the signal cross section are computed. In the T2bH scenario, bottom squarks are excluded for masses below 450 GeV. In the TChiWH model, the NLSP masses below 150 GeV are excluded. For the TChiHH scenario, neutralino masses below 205 GeV are excluded, while in TChiHZ masses below 130 GeV are excluded. The exclusion contours are shown in Fig. 5.

5. Summary

Three recent searches for SUSY with one or two photons in the final state are presented. These searches significantly improve the exclusion limits obtained at 8 TeV or earlier, especially

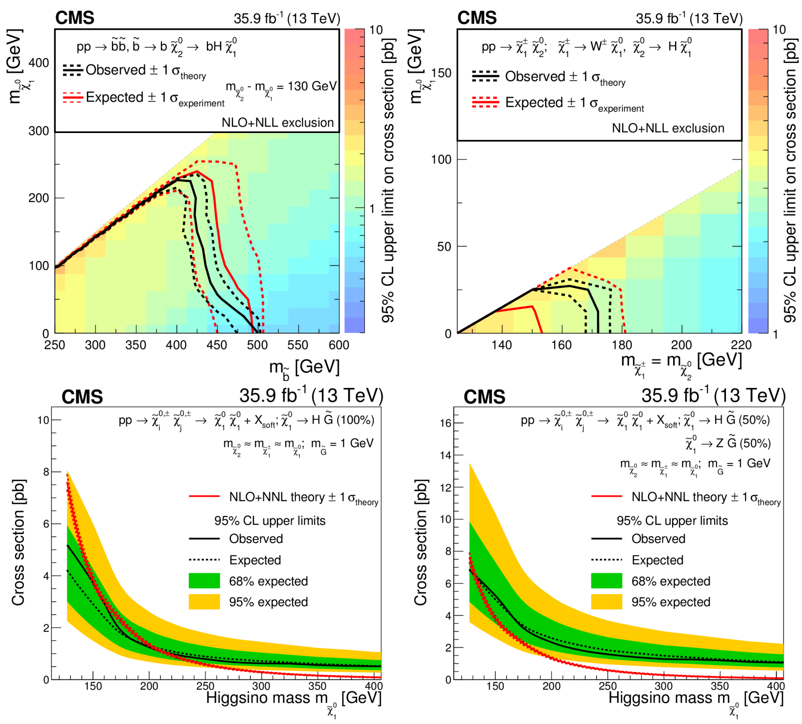

Figure 5: Exclusion contours of the T2bH (top left), the TChiWH (top right), the TChiHH (bottom left) and the TChiHZ (bottom right) scenarios [4].

for the GMSB models. The most stringent limits reach 1.6 TeV for squarks, 2 TeV for gluinos, and 0.8 TeV for electroweakly produced NLSPs.

Acknowledgements

The author wishes to thank for their support the National Research, Development and Innovation Fund, NKFIA of Hungary (research grant no. 124845) and the Lendület (Momentum) Programme of the Hungarian Academy of Sciences (contract no. LP 2015-7/2015).

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