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Search for supersymmetry in events with photons at CMS

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We report on searches for new physics in events with at least one photon, jets, and missing transverse energy. The searches use proton-proton collision data recorded in 2016 by the CMS experiment at the LHC. The results are interpreted in terms of several simplified models of supersymmetry.

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Final states with photons are a central feature of many models of new physics. The following analyses focus on photon signatures arising either from the presence of a Higgs boson or from supersymmetry (SUSY) models with gauge mediated SUSY breaking (GMSB).

1. Razor H $\rightarrow \gamma\gamma$ [1]

Many models of physics beyond the standard model (BSM) feature significant production of Higgs bosons from the cascade decays of new postulated massive particles, and SUSY models in particular can result in Higgs bosons via a variety of channels. Higgs boson production in these models is often seen in conjunction with large hadronic energy due to the presence of strongly produced SUSY particles, as well as missing transverse momentum $p_{\mathrm{T}}^{\mathrm{miss}}$ from a stable lightest SUSY particle (LSP). One particular decay mode, resulting in Higgs bosons in conjunction with b jets and significant $p_{\mathrm{T}}^{\mathrm{miss}}$, is highlighted in the simplified model diagram shown in Fig. 1. The existence of many possible scenarios motivates the use of an inclusive search for anomalous Higgs boson production, and a broad class of signal regions are defined at high values of $p_{\mathrm{T}}^{\mathrm{miss}}$ and transverse hadronic energy H_{T}. The analysis specifically considers diphoton decays of the Higgs boson, as this is found to be one of the most experimentally accessible search channels due to the large suppression of standard model backgrounds.

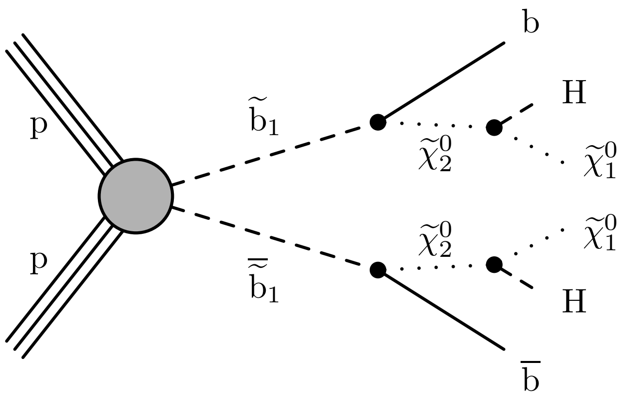

Figure 1: Simplified model of bottom squark pair production resulting in b jets plus Higgs bosons.

A candidate Higgs boson is selected by requiring two photons with $p_{\mathrm{T}} > 40$ GeV and $p_{\mathrm{T}} > 20$ GeV with $|\eta| < 1.44$ and diphoton invariant mass between 103 GeV and 160 GeV, a range selected to include a sufficiently large sideband region to estimate the background. The Higgs boson candidate can then be combined with any additional jets in the event to construct two "megajet" hemispheres according to the Razor algorithm [4]. From these the Razor variables M_R and R^2 can be computed:

$$M_R \equiv \sqrt{(|\vec{p}^{j_1}| + |\vec{p}^{j_2}|)^2 - \left(p_z^{j_1} + p_z^{j_2}\right)^2} \quad (1.1)$$

$$R^2 \equiv \left(\frac{M_T^R}{M_R}\right)^2 \quad (1.2)$$

where j_1 and j_2 are the two megajets, and M_T^R is defined as

$$M_T^R \equiv \sqrt{\frac{E_T^{miss}\left(p_T^{j_1} + p_T^{j_2}\right) - \vec{p}_T^{miss} \cdot \left(\vec{p}_T^{j_1} + \vec{p}_T^{j_2}\right)}{2}} \quad (1.3)$$

Events are then separated into four exclusive categories as shown in Fig. 2. If the Higgs boson candidate has transverse momentum above 110 GeV the event is classified as "HighPt". Otherwise the event is categorized as "H($\gamma\gamma$)–HZ(bb)" if it contains two b-tagged jets whose invariant mass falls between 76 and 106 GeV or between 110 and 140 GeV. This provides greater sensitivity to the case where the candidate is accompanied by an additional Higgs or Z boson, as is common in many SUSY models. The remaining events are grouped into high- and low-resolution classes depending on whether the fractional mass resolution of the diphoton pair is less than 0.85% or not. This separation into resolution categories yields an overall enhancement in the signal over non-resonant backgrounds.

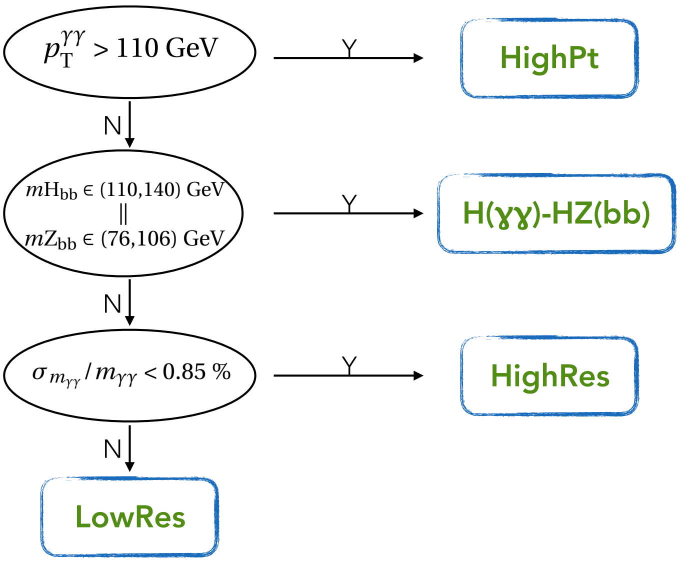

Figure 2: Flowchart showing the procedure for categorizing signal events.

The observed cross section upper limits are shown in Fig. 3 as a function of the bottom squark and LSP masses. The analysis excludes bottom squarks of mass less than about 450 GeV for LSP masses below 250 GeV. The analysis shows a strong sensitivity to the SUSY models considered even at very low LSP masses.

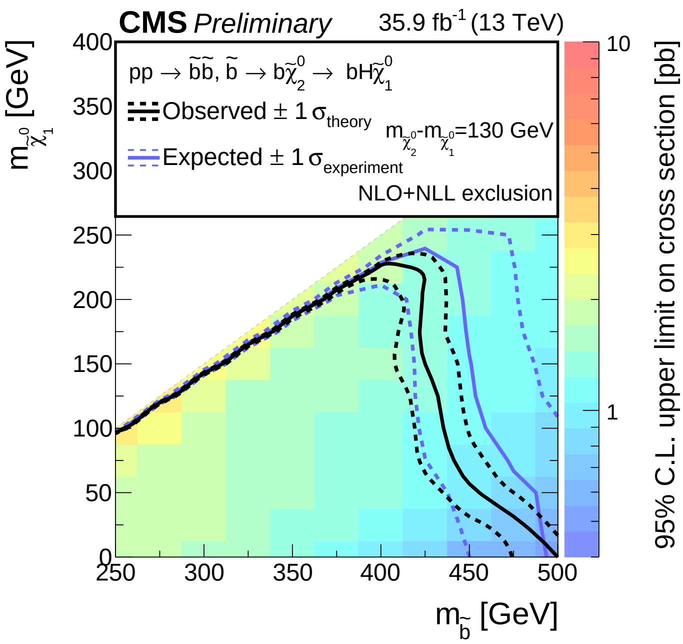

Figure 3: The observed 95% CL upper limits on the cross section for bottom squark pair production. The black (blue) contours represent the observed (expected) boundary of the exclusion region along with 1σ theoretical (experimental) uncertainties.

2. $\gamma + p_{\mathrm{T}}^{\mathrm{miss}}$ [2]

This search focuses on SUSY signatures with gauge-mediated SUSY breaking (GMSB). Typically in GMSB scenarios the LSP is stable and taken to be the gravitino $\widetilde{G}$ and the next-to-lightest SUSY particle (NLSP) is the lightest neutralino $\widetilde{\chi}_1^0$ and undergoes a prompt decay to the gravitino via $\widetilde{\chi}_1^0 \to N\widetilde{G}$, where N is a photon, a Z boson, or a SM Higgs boson.

This analysis has optimal sensitivity to cases with bino-like neutralinos, where the decay to a photon occurs with high probability. The final state is required to include at least one photon with $p_{\mathrm{T}}^{\gamma} > 180$ GeV and $p_{\mathrm{T}}^{\mathrm{miss}} > 300$ GeV due to the stable LSP. No requirement is placed on the number of leptons, jets, or total hadronic energy in order to maintain sensitivity to different SUSY production mechanisms.

The signal region is divided into four exclusive channels defined by $S_{\mathrm{T}} \equiv p_{\mathrm{T}}^{\mathrm{miss}} + \Sigma_i p_{\mathrm{T}}^{\gamma_i}$, where i is an index that runs over all photons in an event. The region $S_{\mathrm{T}} < 600$ GeV has negligible signal contribution, and is taken as a background validation region. The distribution of S_{T} for the backgrounds are shown in Fig. 4 along with specific signal mass points for two different models, shown stacked with the background contributions in each S_{T} region. Good agreement is observed between the data and the total predicted background contribution. Here TChiWg (T5Wg) represents a simplified SUSY model with electroweak SUSY production (di-gluino production) and mass-degenerate neutralino/chargino co-NLSPs leading to a W and a photon in the final state. In the first case the neutralino/chargino mass is taken to be 700 GeV, while it is set to 1700 GeV in the second case, with a gluino mass of 1750 GeV.

Diagrams of two of the specific simplified models considered in this analysis are shown in

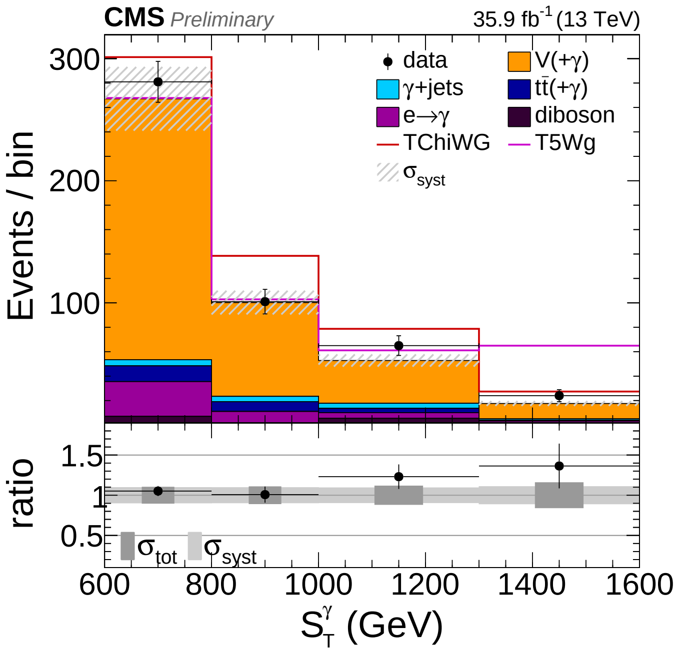

Figure 4: Comparison of data with the predicted background contribution in the four exclusive S_T bins of the signal region. Two benchmark SUSY models are also shown stacked on the background for comparison. The TChiWg model has a NLSP mass of 700 GeV, while the T5Wg model uses a NLSP mass of 1700 GeV and a gluino mass of 1750 GeV.

Fig. 5 (top) paired with their corresponding observed cross section upper limits as a function of the gluino and NLSP masses (bottom). The model on the left assumes diphoton decays, while the model on the right assumes an equal likelihood for a photon or W boson decay. The analysis is able to exclude gluino masses up to 2.1 and 2.0 TeV respectively, with the limit weakening significantly at lower neutralino masses. This is due to the loss of acceptance of the final state particles, arising from the lower energy of the photons and gravitinos.

3. $\gamma + \mathrm{EM}H_T + p_T^{miss}$ [3]

This search is also motivated by GMSB models of SUSY with a light, stable gravitino LSP and a promptly decaying neutralino/chargino co-NLSP. Additionally, the analysis assumes strong production of SUSY particles resulting in gluino or squark decays that produce large hadronic activity in the final state. Events are required to include at least one photon in the barrel region with $p_T^\gamma > 100$ GeV and $p_T^{miss} > 350$ GeV due to the stable LSP, as well as significant transverse energy from jets and photons $\mathrm{EM}H_T$, defined as $\mathrm{EM}H_T \equiv p_T^\gamma + \Sigma_i p_T^{j_i}$, where $p_T^{j_i}$ is the p_T of the ith jet in the event.

The signal selection is divided into exclusive regions based on two $\mathrm{EM}H_T$ ranges (700–2000 and ≥ 2000 GeV) and three p_T^{miss} ranges (350–450, 450–600, and ≥ 600 GeV). The distribution of p_T^{miss} and the background event yields in the three p_T^{miss} signal bins are shown in Fig. 6 for $\mathrm{EM}H_T < 2000$ GeV (left) and $\mathrm{EM}H_T > 2000$ GeV (right). Specific signal mass points for two different models are shown stacked with the background contributions in each region. The model

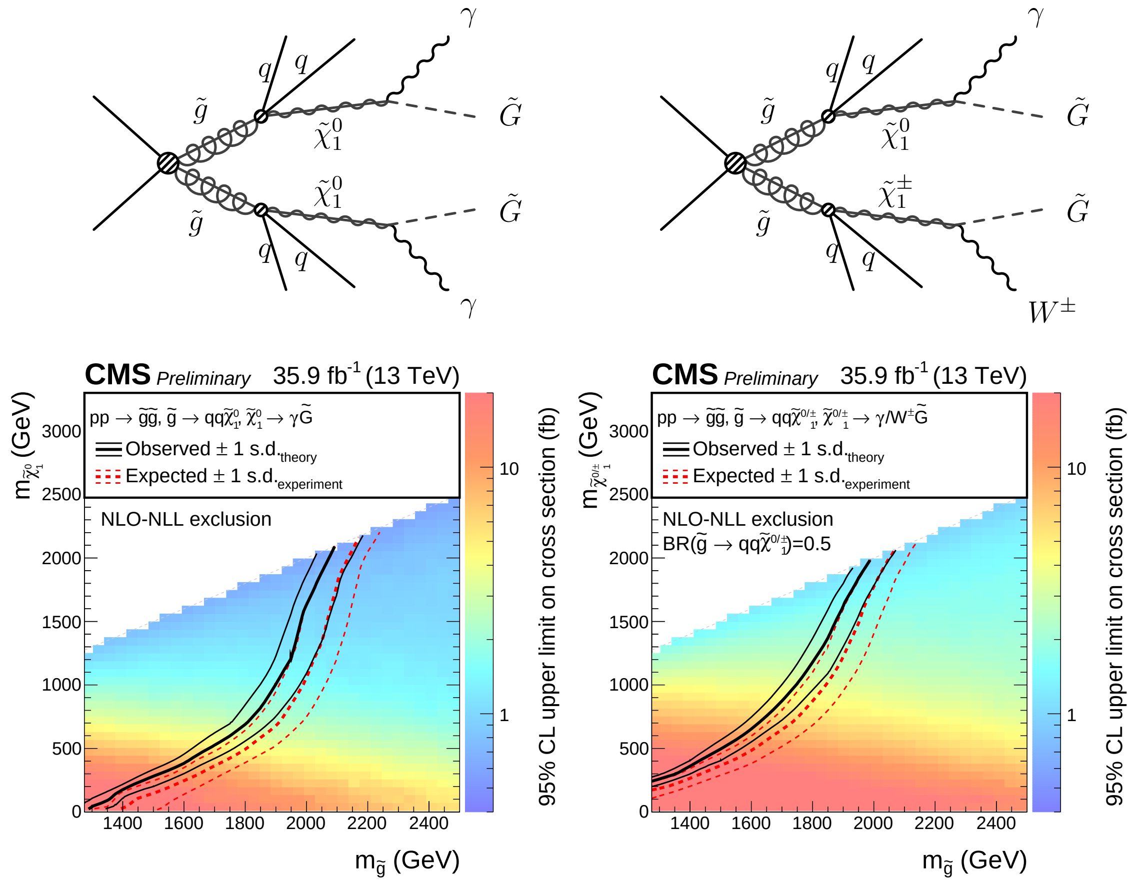

Figure 5: Diagrams showing two of the simplified SUSY models considered in this analysis (top) along with the observed 95% CL upper limits on the cross section for gluino pair production (bottom). The black (red) contours represent the observed (expected) boundary of the exclusion region along with 1σ theoretical (experimental) uncertainties.

label T5Wg (T6gg) represents the simplified SUSY model with di-gluino (di-squark) production leading to a W and a photon (two photons) in the final state. For the signal yields shown in the figure, the gluino (squark) mass is taken to be 1600 GeV (1750 GeV) while the NLSP is taken to be 100 GeV (1650 GeV). The overall number of observed events is in agreement with the background prediction; the second $p_{\mathrm{T}}^{\mathrm{miss}}$ region of both the low- and high-EMH_{T} categories shows an excess with a local significance of 1.9 and 2.7 standard deviations, respectively.

Diagrams of two of the specific simplified models considered in this analysis are shown in Fig. 7 (top) paired with their corresponding observed cross section upper limits as a function of the gluino and NLSP masses (bottom). The model on the left assumes diphoton decays, while the model on the right assumes an equal likelihood for a photon or W boson decay. The analysis has higher sensitivity to models with two photons in the final state due to the higher probability of successfully reconstructing at least one of the photons. Expected and observed limits similar to the γ + $p_{\mathrm{T}}^{\mathrm{miss}}$ analysis are seen at high values of the chargino/neutralino mass, where the sensitivity of the analysis is dominated by the agreement seen in the highest-$p_{\mathrm{T}}^{\mathrm{miss}}$ signal region. At lower neutralino

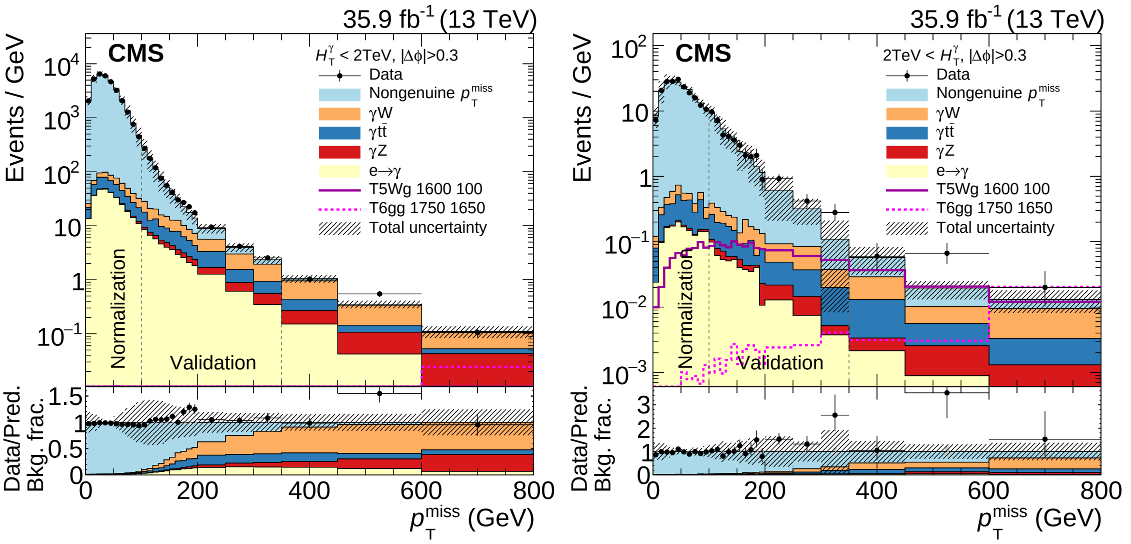

Figure 6: Comparison of data with the predicted background contribution in the three exclusive p_T^{miss} bins of the signal region for the EMH_T $<$ 2000 GeV (left) and EMH_T $>$ 2000 GeV (right) categories. Two benchmark SUSY models are also shown stacked on the background for comparison. The T5Wg model has a NLSP mass of 100 GeV and gluino mass of 1600 GeV, while the T6gg model uses a NLSP mass of 1650 GeV and a squark mass of 1750 GeV.

masses the signal acceptance is reduced because the decay products of the strongly produced SUSY particle have higher energy, leaving less energy available for the photon and gravitino.

References

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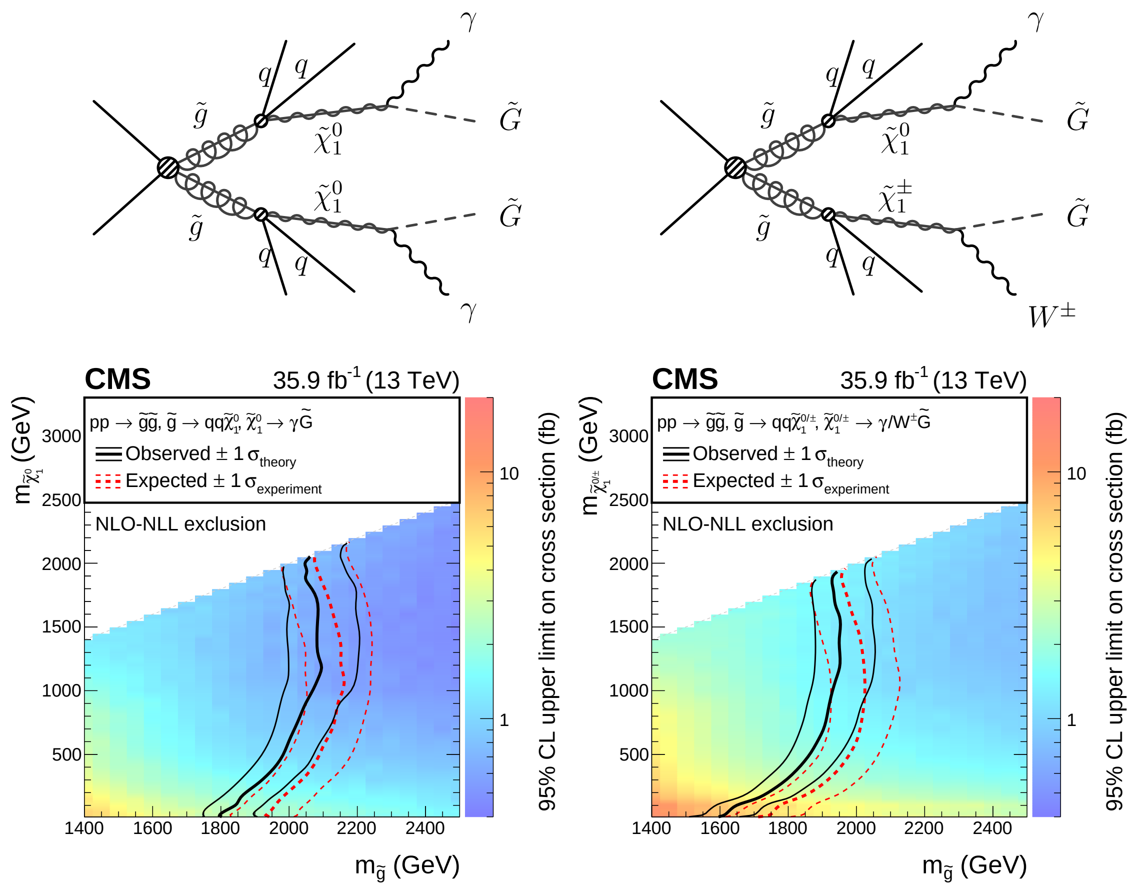

Figure 7: Diagrams showing two of the simplified SUSY models considered in this analysis (top) along with the observed 95% CL upper limits on the cross section for gluino pair production (bottom). The black (red) contours represent the observed (expected) boundary of the exclusion region along with 1σ theoretical (experimental) uncertainties.