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Search for gauge-mediated supersymmetry in events with at least one photon and missing transverse momentum in pp collisions at $\sqrt{s} = 13$ TeV

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ABSTRACT

A search for gauge-mediated supersymmetry (SUSY) in final states with photons and large missing transverse momentum is presented. The data sample of pp collisions at $\sqrt{s} = 13$ TeV was collected with the CMS detector at the CERN LHC and corresponds to an integrated luminosity of 35.9 fb^{-1}. Data are compared with models in which the lightest neutralino has bino- or wino-like components, resulting in decays to photons and gravitinos, where the gravitinos escape detection. The event selection is optimized for both electroweak (EWK) and strong production SUSY scenarios. The observed data are consistent with standard model predictions, and limits are set in the context of a general gauge mediation model in which gaugino masses up to 980 GeV are excluded at 95% confidence level. Gaugino masses below 780 and 950 GeV are excluded in two simplified models with EWK production of mass-degenerate charginos and neutralinos. Stringent limits are set on simplified models based on gluino and squark pair production, excluding gluino (squark) masses up to 2100 (1750) GeV depending on the assumptions made for the decay modes and intermediate particle masses. This analysis sets the highest mass limits to date in the studied EWK models, and in the considered strong production models when the mass difference between the gauginos and the squarks or gluinos is small.

1. Introduction

The search for physics beyond the standard model (SM) is one of the key research topics of the CMS experiment at the CERN LHC. Especially after the discovery of a Higgs boson with a mass of around 125 GeV in 2012 [1–3], supersymmetry (SUSY) [4–17] is one of the theoretically favored possible extensions of the SM. Among several explanations for unsolved problems in particle physics, SUSY provides a mechanism for stabilizing the SM-like Higgs boson mass at the electroweak (EWK) scale. Since current searches are pushing the limits on strongly produced SUSY particles (sparticles) beyond the one-TeV threshold, the interest in probing gaugino masses via EWK production is growing. While searches for heavy sparticles especially profit from the increase in the center-of-mass energy due to the large increase of the production cross section, searches for EWK production benefit from a larger data set, as collected by the CMS experiment in 2016.

In this Letter, a search for SUSY focusing on gauge-mediated SUSY breaking (GMSB) [18–24] scenarios is presented. The R-parity [25] is assumed to be conserved, so that SUSY particles are always produced in pairs. The gravitino ($\widetilde{\mathrm{G}}$) is the lightest SUSY particle (LSP) and 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 ($\widetilde{\chi}_1^0$). Depending on its composition, the $\widetilde{\chi}_1^0$ can decay according to $\widetilde{\chi}_1^0 \to N\widetilde{\mathrm{G}}$, where N is either a photon (γ), an SM-like Higgs boson (H), or a Z boson. If the gauginos are nearly mass-degenerate, the chargino ($\widetilde{\chi}_1^{\pm}$) decays $\widetilde{\chi}_1^{\pm} \to \mathrm{W}^{\pm}\widetilde{\mathrm{G}}$ are also possible. The $\widetilde{\mathrm{G}}$ is assumed to have negligible mass and the NLSP is assumed to decay promptly.

The analyzed data set was collected at the CERN LHC in proton-proton collisions at a center-of-mass energy of 13 TeV and corresponds to an integrated luminosity of 35.9 fb^{-1}. Events are required to contain at least one high-energy photon and large $p_{\mathrm{T}}^{\mathrm{miss}}$. In order to maintain sensitivity to EWK SUSY production, there is no explicit event selection criterion requiring hadronic energy, i.e., the presence of jets in the event. In GMSB SUSY, $p_{\mathrm{T}}^{\mathrm{miss}}$ arises from the stable and noninteracting $\widetilde{\mathrm{G}}$, while photons originate from $\widetilde{\chi}_1^0 \to \gamma\widetilde{\mathrm{G}}$ decays. The energy of the photon as well as of the gravitino and thus the $p_{\mathrm{T}}^{\mathrm{miss}}$ is governed by the $\widetilde{\chi}_1^0$ mass, and the $\widetilde{\chi}_1^0 \to \gamma\widetilde{\mathrm{G}}$ branching fraction is determined by the neutralino's

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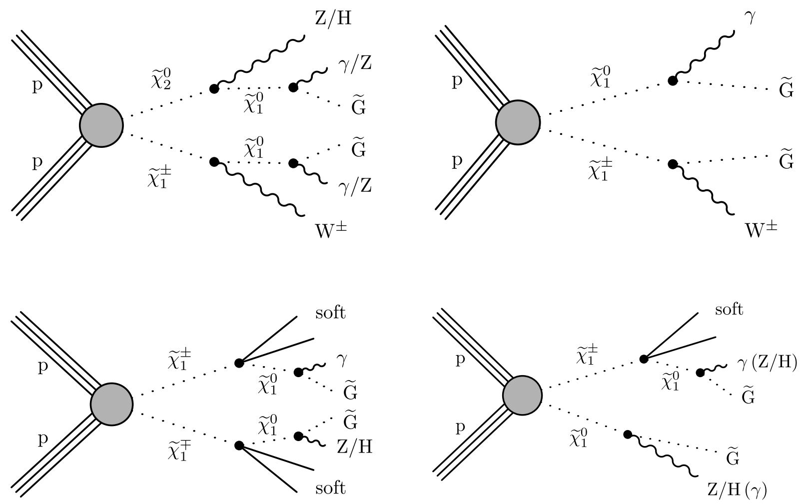

Fig. 1. In the context of GGM, several production and decay channels are possible. The diagram of the dominant process $\widetilde{\chi}^0_2$–$\widetilde{\chi}^\pm_1$ production is shown (upper left), where the gaugino decays depend on the mass configuration under study. In the TChiWg model (upper right), the gauginos are mass degenerate. The TChiNg model comprises $\widetilde{\chi}^\pm_1$ pair production (lower left) and $\widetilde{\chi}^\pm_1\widetilde{\chi}^0_1$ production (lower right), where the $\widetilde{\chi}^\pm_1$ is only slightly heavier than the $\widetilde{\chi}^0_1$, so only low-momentum (soft) particles appear in the decay of $\widetilde{\chi}^\pm_1$ to $\widetilde{\chi}^0_1$.

bino and wino components and its mass. Compared to analyses requiring photons and large hadronic activity, this analysis has superior sensitivity to GMSB SUSY in EWK production, and also in strong production if the squark, gluino, and the lightest gaugino masses are similar (compressed-spectrum scenarios).

An earlier version of this analysis [26] was carried out by CMS on a special 8 TeV data set recorded as part of the "parked-data" program [27] corresponding to an integrated luminosity of 7.4 fb^{-1} using a dedicated trigger and a lower photon transverse momentum (p_T) threshold of 30 GeV. The ATLAS and CMS collaborations have also searched for direct EWK production of gauginos in final states with at least one photon and one electron or muon [28, 29], and in the two-photon channel [29–31]. Single-photon and H_T-based analyses [31], where H_T is the scalar sum of hadronic jet transverse momenta, have good sensitivity for strong production in GMSB models but lack sensitivity for EWK production and compressed-spectrum scenarios.

2. Signal models

To interpret the results, a general gauge mediation (GGM) [32–37] scenario dominated by EWK production is used. Furthermore, two EWK production and four strong production simplified model scenarios (SMS) [38] are considered for interpretation. For the GGM scenario, the squark and gluino masses are set to a high scale rendering them inaccessible and strong production negligible. The bino and wino masses therefore fully determine the model point under study and are varied in the interpretation. The $\widetilde{\chi}^0_1$ is assumed to be purely bino-like, while the $\widetilde{\chi}^\pm_1$ and $\widetilde{\chi}^0_2$ are assumed to be purely wino-like. The dominant process for EWK GGM production is shown in Fig. 1 (upper left). In the GGM framework, where the gauginos are not mass-degenerate by construction, a larger $\widetilde{\chi}^\pm$–$\widetilde{\chi}^0_1$ mass difference increases the hadronic energy in the final state if the Z, H, or W bosons decay hadronically.

The EWK simplified scenario TChiWg probes associated production of mass-degenerate charginos and neutralinos ($\widetilde{\chi}^\pm_1\widetilde{\chi}^0_1$), assuming the decay modes $\widetilde{\chi}^0_1 \to \gamma\widetilde{G}$ and $\widetilde{\chi}^\pm_1 \to W^\pm\widetilde{G}$, as shown in Fig. 1 (upper right). The TChiNg scenario assumes nearly mass-degenerate $\widetilde{\chi}^\pm_1$ and $\widetilde{\chi}^0_1$, but considers $\widetilde{\chi}^\pm_1\widetilde{\chi}^\mp_1$ and $\widetilde{\chi}^\pm_1\widetilde{\chi}^0_1$ production as shown in Fig. 1 (lower left and right). In this scenario, the $\widetilde{\chi}^\pm_1$ is assumed to have a slightly higher mass than $\widetilde{\chi}^0_1$, and it decays to $\widetilde{\chi}^0_1$ and low-momentum particles outside the acceptance of this analysis. The neutralinos are assumed to decay as $\widetilde{\chi}^0_1 \to \gamma\widetilde{G}$, $\widetilde{\chi}^0_1 \to Z\widetilde{G}$, and $\widetilde{\chi}^0_1 \to H\widetilde{G}$ with 50, 25, and 25% probability, respectively.

The strong production SMS models T5gg, T5Wg, T6gg, and T6Wg are shown in Fig. 2, where T5gg and T5Wg represent gluino pair production, and T6gg and T6Wg squark pair production. The neutralino decays as $\widetilde{\chi}^0_1 \to \gamma\widetilde{G}$, while the chargino decays as $\widetilde{\chi}^\pm_1 \to W^\pm\widetilde{G}$. In the T5Wg and T6Wg scenario, a branching fraction of 50% is assumed for the charged and neutral decays of the gluino or squark. The T5gg (T6gg) scenario assumes a branching fraction of 100% for $\widetilde{g} \to q\bar{q}\widetilde{\chi}^0_1$ ($\widetilde{q} \to q\widetilde{\chi}^0_1$).

3. The CMS detector

The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Within the solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter (ECAL), and a brass and scintillator hadron calorimeter (HCAL), each composed of a barrel and two endcap sections. Extensive forward calorimetry complements the coverage provided by the barrel and endcap detectors. Muons are measured in gas-ionization detectors embedded in the steel flux-return yoke outside the solenoid.

In the barrel section of the ECAL, an energy resolution of approximately 1% is achieved for unconverted or late-converting photons arising from the $H \to \gamma\gamma$ decay for photons with $p_T >$ 25 GeV. The remaining barrel photons have an energy resolution of about 1.3% up to a pseudorapidity of $|\eta| = 1$, rising to about 2.5% at $|\eta| = 1.4$. In the endcaps, the energy resolution of unconverted or late-converting photons is about 2.5%, while the remaining endcap photons have a resolution between 3 and 4% [39].

A more detailed description of the CMS detector, together with a definition of the coordinate system used and the relevant kinematic variables, can be found in Ref. [40].

4. Object reconstruction and simulation

The particle-flow (PF) event algorithm [41] reconstructs and identifies each individual particle with an optimized combination