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Search for supersymmetry in events with a photon, a lepton, and missing transverse momentum in pp collisions at $\sqrt{s} = 8$ TeV

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A search for supersymmetry involving events with at least one photon, one electron or muon, and large missing transverse momentum has been performed by the CMS experiment. The data sample corresponds to an integrated luminosity of 19.7 fb^{-1} of pp collisions at $\sqrt{s} = 8$ TeV, produced at the CERN LHC. No excess of events is observed beyond expectations from standard model processes. The result of the search is interpreted in the context of a general model of gauge-mediated supersymmetry breaking, where the charged and neutral winos are the next-to-lightest supersymmetric particles. Within this model, winos with a mass up to 360 GeV are excluded at the 95% confidence level. Two simplified models inspired by gauge-mediated supersymmetry breaking are also examined, and used to derive upper limits on the production cross sections of specific supersymmetric processes.

1. Introduction

The extension of the standard model (SM) of particle physics through the concept of supersymmetry (SUSY) [1], which imposes a symmetry between fermions and bosons, can offer a solution to some of the issues not accommodated in the SM, such as the existence of dark matter in the universe or the extreme fine tuning required to control radiative corrections to the Higgs boson mass (hierarchy problem) [2–4]. The minimal supersymmetric standard model (MSSM) [5–7] provides a calculable framework with a fully known particle content, introducing a superpartner for each SM particle. For example, squarks, gluinos, and gravitinos are the SUSY partners of quarks, gluons, and gravitons, respectively. The MSSM has guided the search program for physics beyond the SM at facilities such as the Fermilab Tevatron and CERN LHC. Existing searches have not yet found evidence for SUSY, but a large parameter space of the MSSM remains to be explored.

Within the MSSM, scenarios based on gauge-mediated SUSY breaking (GMSB) [8–18] are of particular interest because of their ability to naturally circumvent the so-called SUSY flavour problem [19]. The framework of general gauge mediation (GGM) [20] offers a clear definition of GMSB and establishes its key aspects. For example, GMSB predicts the gravitino ($\widetilde{G}$) to be the lightest supersymmetric particle (LSP). The combination of this feature and the weakness of the coupling of $\widetilde{G}$ to other MSSM particles has specific consequences in collider phenomenology. Under the assumption that R-parity [6] is conserved, SUSY particles are pair-produced at the LHC. Except for direct LSP pair production, each SUSY particle initiates a decay chain that yields the next-to-lightest supersymmetric particle (NLSP). Branching fraction for the SUSY particle decay involving $\widetilde{G}$ is negligible except for the NLSP, leaving the decay of the NLSP to its SM partner and the $\widetilde{G}$ as effectively the only gravitino production mechanism. The gravitino escapes detection, leading to missing momentum in the event. The signature of a GMSB signal is thus strongly dependent on the identity of the NLSP. In most GMSB models, the NLSP is taken to be a bino- or wino-like lightest neutralino, where a bino and wino are the superpartners of the SM U(1) and SU(2) gauge fields, respectively. Previous searches for a GMSB signal typically exploited the diphoton signature [21–29], in which each of the two bino-like neutralinos decays promptly into a photon and a gravitino. Similar scenarios with nonprompt NLSP decays have also been considered [30,31]. Thus far, no evidence for GMSB SUSY has been observed, resulting in upper limits on the production cross sections given as a function of the SUSY particle masses, the NLSP lifetime, or other model parameters.

This paper presents a search for SUSY with the CMS experiment at the LHC, and targets GGM models with wino-like NLSPs. The data sample corresponds to an integrated luminosity of 19.7 fb^{-1} of pp collision data collected in 2012 at $\sqrt{s} = 8$ TeV. In particular, we study the wino co-NLSP model [32], in which nearly mass-degenerate charged and neutral winos are significantly lighter than the other electroweakinos and constitute the lightest SUSY parti-

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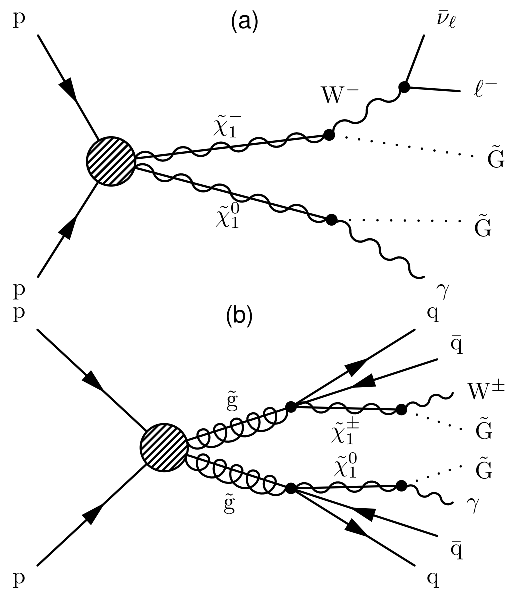

Fig. 1. Diagrams showing the production and decays of wino-like co-NLSPs ($\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^0$) leading to final states with a photon, an electron or muon, and missing momentum from undetected gravitinos $\tilde{G}$ (a) without and (b) with involvement of coloured SUSY particles.

cles aside from the gravitino. Although the lifetime of the NLSP is effectively a free parameter in GGM phenomenology, a prompt decay of winos is assumed in this analysis. A signature of at least one photon (γ), one electron or muon (ℓ), and large missing transverse momentum ($\vec{p}_T^{\rm miss}$) is used in this search. The photon is assumed to be emitted by a neutralino NLSP, and the leptons by either a charged or neutral NLSP decaying to a W or Z boson, respectively. This signature suppresses many SM backgrounds, obviating the need for additional requirements such as associated jet activity. The diagrams in Fig. 1 provide examples of the decay chains studied in this analysis. The present search is sensitive to the direct electroweakino production mode of Fig. 1(a), where the winos are produced without involving coloured SUSY particles, but also to strong production modes such as the gluino ($\tilde{g}$) pair-production process shown in Fig. 1(b). Similar searches were conducted by the ATLAS [33] and CMS [34,35] experiments using LHC pp collision data at $\sqrt{s} = 7$ or 8 TeV, as well as the CDF experiment [36] at the Tevatron using p$\bar{\rm p}$ collision data at $\sqrt{s} = 1.8$ TeV. None of these analyses sees an excess of events over the respective SM predictions. The wino co-NLSP model has also been probed through the signatures of three leptons or two leptons and two jets [37,38], which target the decay of the neutralino NLSP to a gravitino and a Z boson rather than to a gravitino and a photon. None of these analyses observed a significant excess of events over their respective SM predictions.

2. 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 consisting of a barrel and two endcap sections. Muons are measured in gas-ionization detectors embedded in the steel flux-return yoke outside the solenoid. Extensive forward calorimetry complements the coverage provided by the barrel and endcap detectors. A detailed description of the CMS detector, together with a definition of the coordinate system and the relevant kinematic variables, can be found in Ref. [39].

In the barrel section of the ECAL, an energy resolution of about 1% is achieved for unconverted and late-converting photons with transverse energy $E_T \approx 10$ GeV. The remaining barrel photons have a resolution of about 1.3% up to a pseudorapidity $|\eta| < 1.0$, rising to about 2.5% for $|\eta| = 1.4$ [40].

The electron momentum is determined by combining the energy measurement in the ECAL with the momentum measurement in the tracker. The momentum resolution for electrons with transverse momentum $p_T \approx 45$ GeV from $Z \to e^+e^-$ decays ranges from 1.7% for non-showering electrons in the barrel region to 4.5% for showering electrons in the endcaps [41].

Muons are measured in the range $|\eta| < 2.4$, with detector elements based on three technologies: drift tubes, cathode strip chambers, and resistive plate chambers. Through the matching of track segments measured in the muon detectors with tracks measured in the tracker, a transverse momentum resolution of 1.3–2.0% is achieved for barrel muons with $20 < p_T < 100$ GeV. In the endcaps, the resolution increases up to around 6%. The p_T resolution in the barrel is better than 10% for muons with transverse momentum up to 1 TeV [42].

Physics objects are defined using the particle-flow (PF) algorithm [43,44], which reconstructs and identifies individual particles through an optimized combination of information from different elements of the CMS detector. The PF candidates are classified as photons, charged hadrons, neutral hadrons, electrons, or muons. Finally, the CMS detector is nearly hermetic, permitting accurate measurements of $\vec{p}_T^{\rm miss}$.

3. Data collection and event selection

The search is conducted in the electron–photon (eγ) and muon–photon ($\mu\gamma$) channels. The data samples are collected using a dedicated trigger for each channel, as described below. An event is considered to be in the eγ ($\mu\gamma$) channel if it contains at least one high-energy photon and an electron (muon). Events that simultaneously satisfy the criteria for the two search channels, representing about 0.1% of the selected events, are classified as $\mu\gamma$ candidates because muon objects are less often the result of hadron misidentification than are electron objects.

The trigger for the eγ channel requires at least two isolated photon-like objects, with E_T thresholds of 36 and 22 GeV for the highest and second-highest E_T photon, respectively. The trigger does not veto photon objects that can be matched to a track, allowing events with a photon and an electron to also satisfy the trigger. The $\mu\gamma$ channel uses a muon–photon trigger with a p_T threshold of 22 GeV for both the photon and muon objects. To ensure a fully efficient trigger and a similar selection efficiency for the two channels, the subsequent analysis requires $E_T > 40$ GeV for the photon and $p_T > 25$ GeV for the electron or muon. With these requirements, the trigger efficiency for the signal models described in Section 7 is found to be 93–98% for both channels, depending on the model and SUSY mass values.

Photon candidates are reconstructed from clusters of energy in the ECAL [40]. The momentum vector of the photon points from the primary pp interaction vertex to the center of the ECAL energy cluster, under the assumption that the photon originates from the primary vertex, which is defined as the vertex with the highest $\sum p_T^2$ of associated tracks. Only photons from clusters in the pseudorapidity range $|\eta| < 1.44$ are included in this analysis. These clusters were selected as photon candidates by a set of criteria that are designed to achieve a 90% identification efficiency for true photons. For a cluster to be identified as a photon, its shape must be consistent with that expected from a photon, and the en-