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Search for supersymmetry in the multijet and missing transverse momentum final state in pp collisions at 13 TeV

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ABSTRACT

A search for new physics is performed based on all-hadronic events with large missing transverse momentum produced in proton–proton collisions at $\sqrt{s} = 13$ TeV. The data sample, corresponding to an integrated luminosity of 2.3 fb^{-1}, was collected with the CMS detector at the CERN LHC in 2015. The data are examined in search regions of jet multiplicity, tagged bottom quark jet multiplicity, missing transverse momentum, and the scalar sum of jet transverse momenta. The observed numbers of events in all search regions are found to be consistent with the expectations from standard model processes. Exclusion limits are presented for simplified supersymmetric models of gluino pair production. Depending on the assumed gluino decay mechanism, and for a massless, weakly interacting, lightest neutralino, lower limits on the gluino mass from 1440 to 1600 GeV are obtained, significantly extending previous limits.

1. Introduction

The standard model (SM) of particle physics successfully describes a wide range of phenomena. However, in the SM, the Higgs boson mass is unstable to higher-order corrections, suggesting that the SM is incomplete. Many extensions to the SM have been proposed to provide a more fundamental theory. Supersymmetry (SUSY) [1–8], one such extension, postulates that each SM particle is paired with a SUSY partner from which it differs in spin by one-half unit. As examples, squarks and gluinos are the SUSY partners of quarks and gluons, respectively, while neutralinos $\widetilde{\chi}^0$ (charginos $\widetilde{\chi}^{\pm}$) arise from a mixture of the SUSY partners of neutral (charged) Higgs and electroweak gauge bosons. Radiative corrections involving SUSY particles can compensate the contributions from SM particles and thereby stabilize the Higgs boson mass. For this cancellation to be "natural" [9–12], the top squark, bottom squark, and gluino must have masses on the order of a few TeV or less, possibly allowing them to be produced at the CERN LHC.

Amongst SUSY processes, gluino pair production, typically yielding four or more hadronic jets in the final state, has the largest potential cross section, making it an apt channel for early SUSY searches in the recently started LHC Run 2. Furthermore, in R-parity [13] conserving SUSY models, as are considered here, the lightest SUSY particle (LSP) is stable and assumed to be weakly interacting, leading to potentially large undetected, or "missing", transverse momentum. Supersymmetry events at the LHC might thus be characterized by significant missing transverse momentum, numerous jets, and — in the context of natural SUSY — jets initiated by top and bottom quarks.

This Letter describes a search for gluino pair production in the all-hadronic final state. The data, corresponding to an integrated luminosity of 2.3 fb^{-1} of proton–proton collisions at a center-of-mass energy of $\sqrt{s} = 13$ TeV, were collected with the CMS detector in 2015, the initial year of the LHC Run 2. Recent searches for gluino pair production at $\sqrt{s} = 8$ TeV, based on data collected in LHC Run 1, are presented in Refs. [14–16]. Because of the large mass scales and their all-hadronic nature, the targeted SUSY events are expected to exhibit large values of H_{T}, where H_{T} is the scalar sum of the transverse momenta (p_{T}) of the jets. As a measure of missing transverse momentum, we use the variable $H_{\mathrm{T}}^{\mathrm{miss}}$, which is the magnitude of the vector sum of the jet p_{T}. We present a general search for gluino pair production leading to final states with large H_{T}, large $H_{\mathrm{T}}^{\mathrm{miss}}$, and large jet multiplicity. The data are examined in bins of N_{jet}, $N_{\mathrm{b\text{-}jet}}$, H_{T}, and $H_{\mathrm{T}}^{\mathrm{miss}}$, where N_{jet} is the

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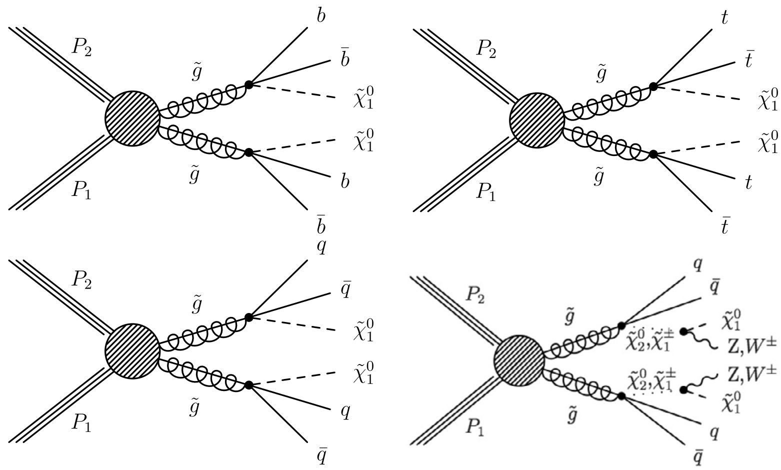

Fig. 1. Event diagrams for the new-physics scenarios considered in this study: the (upper left) T1bbbb, (upper right) T1tttt, (lower left) T1qqqq, and (lower right) T5qqqqVV simplified models. For the T5qqqqVV model, the quark q and antiquark $\bar{q}$ do not have the same flavor if the gluino $\tilde{g}$ decays as $\tilde{g} \to q\bar{q}\tilde{\chi}_1^\pm$, with $\tilde{\chi}_1^\pm$ a chargino.

number of jets and $N_{\text{b-jet}}$ the number of tagged bottom quark jets (b jets). The search is performed in exclusive bins of these four observables.

We consider SUSY scenarios in the context of four simplified models [17–20] of new particle production. Diagrams for the four models are shown in Fig. 1. Simplified models contain the minimal particle content to represent a topological configuration. As SUSY production scenarios, the four simplified models can be interpreted as follows. In the first scenario, shown in Fig. 1 (upper left), gluino pair production is followed by the decay of each gluino to a bottom quark and an off-shell bottom squark. The off-shell bottom squark decays to a bottom quark and the LSP, where the LSP is assumed to be the lightest neutralino $\tilde{\chi}_1^0$ and to escape detection, leading to significant H_T^{miss}. The second scenario, shown in Fig. 1 (upper right), is the same as the first scenario except with top quarks and off-shell top squarks in place of the bottom quarks and squarks. The third scenario, shown in Fig. 1 (lower left), is the corresponding situation with gluino decay to a light-flavored quark and off-shell-squark: up, down, strange, and charm with equal probability, for each gluino separately. In the fourth scenario, shown in Fig. 1 (lower right), also based on gluino pair production, each gluino similarly decays to a light-flavored quark and corresponding off-shell squark. The off-shell squark decays to a quark and to either the next-to-lightest neutralino $\tilde{\chi}_2^0$ or the lightest chargino $\tilde{\chi}_1^\pm$. The probability for the decay to proceed via the $\tilde{\chi}_2^0$, $\tilde{\chi}_1^+$, or $\tilde{\chi}_1^-$, integrated over the event sample, is 1/3 for each possibility. The $\tilde{\chi}_2^0$ ($\tilde{\chi}_1^\pm$) subsequently decays to the $\tilde{\chi}_1^0$ LSP and to a on- or off-shell Z ($W^\pm$) boson. We refer to the four simplified models as the T1bbbb, T1tttt, T1qqqq, and T5qqqqVV scenarios, respectively [21]. Thus the first two scenarios explicitly presume either bottom or top squark production. The latter two scenarios represent more inclusive situations and provide complementary sensitivity to top squark production for large values of N_{jet}. We assume all SUSY particles other than the gluino, the LSP, and — for the T5qqqqVV models — the $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^\pm$, to be too heavy to be directly produced, and the gluino to be short-lived.

The principal sources of background arise from the SM production of top quarks, a W or Z boson in association with jets (W + jets or Z + jets events), and multiple jets through the strong interaction. We refer to the latter class of background as quantum chromodynamics (QCD) multijet events. The events with top quarks mostly arise from top quark–antiquark ($t\bar{t}$) production, but also from single top quark processes. The W and Z bosons in W + jets and Z + jets events can be either on- or off-shell. For top quark and W + jets events, significant H_T^{miss} can arise if a W boson decays leptonically, producing a neutrino and an undetected charged lepton, while Z + jets events can exhibit significant H_T^{miss} if the Z boson decays to two neutrinos. For QCD multijet events, significant H_T^{miss} can arise if the event contains a charm or bottom quark that undergoes a semileptonic decay, but the principal source of H_T^{miss} is the mismeasurement of jet p_T.

This study combines and extends search strategies developed for the analysis of CMS data collected at $\sqrt{s} = 8$ TeV, specifically the study of Ref. [22], which examined data in bins of $N_{\text{b-jet}}$ but not N_{jet} and proved to be sensitive to the T1bbbb scenario, and the study of Ref. [23], which examined data in bins of N_{jet} but not $N_{\text{b-jet}}$ and proved to be sensitive to the T1tttt, T1qqqq, and T5qqqqVV scenarios. Here, the two approaches are combined in a unified framework to yield a more comprehensive and inclusive study with improved sensitivity.

2. Detector, trigger, and event reconstruction

The CMS detector is built around 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). The ECAL and HCAL, each composed of a barrel and two endcap sections, extend over a pseudorapidity range $|\eta| < 3.0$. Forward calorimeters on each side of the interaction point encompass $3.0 < |\eta| < 5.0$. The tracking detectors cover $|\eta| < 2.5$. Muons are measured within $|\eta| < 2.4$ by gas-ionization detectors embedded in the steel flux-return yoke outside the solenoid. The detector is nearly hermetic, permitting accurate measurements of H_T^{miss}. A more detailed description of the CMS detector, together with a definition of the coordinate system and relevant kinematic variables, is given in Ref. [24].

Signal event candidates are recorded using trigger conditions based on thresholds on H_T and missing transverse momentum. The trigger efficiency, which exceeds 98% following application of the event selection criteria described below, is measured in data and is accounted for in the analysis. Separate data samples requiring the presence of either charged leptons or photons are used for the determination of backgrounds from SM processes, as discussed below.

Physics objects are defined using the particle-flow (PF) algorithm [25,26], which reconstructs and identifies individual particles through an optimized combination of information from different detector components. The PF candidates are classified as photons,