Search for supersymmetry in proton-proton collisions at 13 TeV using identified top quarks

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A search for supersymmetry is presented based on proton-proton collision events containing identified hadronically decaying top quarks, no leptons, and an imbalance $p_{\mathrm{T}}^{\mathrm{miss}}$ in transverse momentum. The data were collected with the CMS detector at the CERN LHC at a center-of-mass energy of 13 TeV, and correspond to an integrated luminosity of 35.9 fb^{-1}. Search regions are defined in terms of the multiplicity of bottom quark jet and top quark candidates, the $p_{\mathrm{T}}^{\mathrm{miss}}$, the scalar sum of jet transverse momenta, and the m_{T2} mass variable. No statistically significant excess of events is observed relative to the expectation from the standard model. Lower limits on the masses of supersymmetric particles are determined at 95% confidence level in the context of simplified models with top quark production. For a model with direct top squark pair production followed by the decay of each top squark to a top quark and a neutralino, top squark masses up to 1020 GeV and neutralino masses up to 430 GeV are excluded. For a model with pair production of gluinos followed by the decay of each gluino to a top quark-antiquark pair and a neutralino, gluino masses up to 2040 GeV and neutralino masses up to 1150 GeV are excluded. These limits extend previous results.

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I. INTRODUCTION

The observation [1–3] of a Higgs boson (H) has been the most significant discovery to date at the CERN LHC. However, its relatively small mass of about 125 GeV [4] can be understood in the context of the standard model (SM) only through fine tuning of the associated quantum loop corrections [5]. A compelling model that can account for the observed Higgs boson mass without this fine tuning is the extension to the SM called supersymmetry (SUSY) [6–14]. The main assertion of SUSY is the existence of one or more particles, called superpartners, for every SM particle, where the spin of a superpartner differs from that of its SM counterpart by a half integer. The superpartners of quarks, gluons, and Higgs bosons are squarks $\tilde{q}$, gluinos $\tilde{g}$, and Higgsinos, respectively, while neutralinos $\tilde{\chi}^0$ and charginos $\tilde{\chi}^{\pm}$ are mixtures of the superpartners of electroweak and Higgs bosons. In so-called natural models of SUSY [15], the top squark, bottom squark, gluino, and Higgsinos are required to have masses no larger, and often much smaller, than a few TeV, motivating searches for these particles at the LHC.

In this paper we present a search for top squarks and gluinos. The data were collected in 2016 by the CMS experiment at the LHC and correspond to an integrated luminosity of 35.9 fb^{-1} of proton-proton (pp) collisions at a center-of-mass energy of 13 TeV. The search is performed in all-hadronic events with a large imbalance $p_{\mathrm{T}}^{\mathrm{miss}}$ in transverse momentum, where by "all-hadronic" we mean that the final states are composed solely of hadronic jets. Recent searches for SUSY in a similar final state are presented in Refs. [16–20]. The current analysis is distinguished by the requirement that identified ("tagged") hadronically decaying top quarks be present. It represents an extension, using improved analysis techniques and a data sample 16 times larger, of the study in Ref. [20].

In the search, top squarks are assumed to be produced either through the direct production of a top squark-antisquark pair or in the decay of pair-produced gluinos. They are assumed to decay to the lightest neutralino $\tilde{\chi}_1^0$—taken to be a stable, weakly interacting, lightest SUSY particle (LSP)—and a quark. Since the LSP interacts only weakly, it does not produce a signal in the detector, thus generating $p_{\mathrm{T}}^{\mathrm{miss}}$. A novel top quark tagging algorithm is employed to identify hadronically decaying top quarks produced in the decay chains. The algorithm makes use of the facts that a top quark essentially always decays to a bottom quark and a W boson, and that—in hadronic decays—the W boson decays to a quark-antiquark ($q\bar{q}'$) pair. The algorithm recognizes three different types of decay topology for the top quark. In order of increasing Lorentz boost for the top quark, these are: (i) three distinct jets with no more than one of them identified as a bottom quark jet ("b jet"), where two non-b jets arise from the q

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TABLE IV. *(Continued)*

Search region	N_t	N_b	m_{T2} [GeV]	p_T^{miss} [GeV]	Data	Predicted background
60	2	2	200–300	350–450	11	$8.7^{+2.7}_{-1.9}{}^{+1.4}_{-1.3}$
61	2	2	200–300	450–600	1	$0.6^{+1.6}_{-0.4}{}^{+0.3}_{-0.2}$
62	2	2	200–400	≥ 600	1	$0.6^{+1.7}_{-0.5} \pm 0.2$
63	2	2	300–400	250–350	28	$27^{+5}_{-4} \pm 3$
64	2	2	300–400	350–450	6	$4.9^{+2.9}_{-1.6} \pm 0.9$
65	2	2	300–400	450–600	3	$1.7^{+2.4}_{-1.0}{}^{+0.6}_{-0.5}$
66	2	2	400–500	250–450	4	$4.7^{+2.3}_{-1.2}{}^{+0.7}_{-0.8}$
67	2	2	400–500	450–600	1	$1.4^{+2.7}_{-0.7}{}^{+0.4}_{-0.6}$
68	2	2	≥ 400	≥ 600	1	$0.5^{+2.7}_{-0.1} \pm 0.2$
69	2	2	≥ 500	250–450	0	$0.1^{+1.4}_{-0.1} \pm 0.1$
70	2	2	≥ 500	450–600	2	$0.5^{+2.2}_{-0.1} \pm 0.1$
71	2	≥ 3	300–900	250–350	3	$9.6^{+3.0}_{-2.1} \pm 1.7$
72	2	≥ 3	300–900	350–500	2	$0.7^{+2.0}_{-0.4} \pm 0.2$
73	2	≥ 3	300–1300	≥ 500	0	$0.3^{+0.5}_{-0.3}{}^{+0.3}_{-0.2}$
74	2	≥ 3	900–1300	250–350	6	$4.7^{+2.9}_{-1.7}{}^{+0.7}_{-0.9}$
75	2	≥ 3	900–1300	350–500	3	$1.2^{+1.6}_{-0.7} \pm 0.4$
76	2	≥ 3	≥ 1300	250–350	3	$3.5^{+2.1}_{-1.2} \pm 1.4$
77	2	≥ 3	≥ 1300	350–500	2	$2.1^{+2.1}_{-1.0}{}^{+0.4}_{-0.5}$
78	2	≥ 3	≥ 1300	≥ 500	0	$0.2^{+1.7}_{-0.3} \pm 0.2$
79	≥ 3	1	≥ 300	250–350	0	$0.3^{+2.0}_{-0.3} \pm 0.2$
80	≥ 3	1	≥ 300	≥ 350	1	$0.6^{+1.6}_{-0.5} \pm 0.2$
81	≥ 3	2	≥ 300	250–400	1	$1.7^{+1.5}_{-0.7}{}^{+0.6}_{-0.5}$
82	≥ 3	2	≥ 300	≥ 400	0	$0.1^{+2.2}_{-0.1} \pm 0.1$
83	≥ 3	≥ 3	≥ 300	250–350	0	$0.5^{+1.5}_{-0.4} \pm 0.5$
84	≥ 3	≥ 3	≥ 300	≥ 350	0	$0.0^{+1.6}_{-0.0}{}^{+0.1}_{-0.0}$

TABLE V. The observed number of events and the total background prediction for the aggregate search regions. The first uncertainty in the background prediction is statistical and the second is systematic.

Search region	N_t	N_b	m_{T2} [GeV]	p_T^{miss} [GeV]	Data	Predicted background
1	≥ 1	≥ 1	≥ 200	≥ 250	4424	$4100 \pm 50^{+390}_{-340}$
2	≥ 2	≥ 2	≥ 200	≥ 250	124	$116 \pm 8^{+15}_{-12}$
3	≥ 3	≥ 1	≥ 200	≥ 250	2	$3.3^{+2.0}_{-1.1}{}^{+1.2}_{-1.1}$
4	≥ 3	≥ 3	≥ 200	≥ 250	0	$0.5^{+1.4}_{-0.4} \pm 0.5$
5	≥ 2	≥ 1	≥ 200	≥ 400	41	$30^{+4}_{-3}{}^{+5}_{-4}$
6	≥ 1	≥ 2	≥ 600	≥ 400	4	$7.5^{+2.1}_{-1.2}{}^{+2.0}_{-1.9}$

Search region	N_t	N_b	H_T [GeV]	p_T^{miss} [GeV]	Data	Predicted background
7	≥ 1	≥ 2	≥ 1400	≥ 500	6	$6.0^{+2.7}_{-1.5} \pm 1.5$
8	≥ 2	≥ 3	≥ 600	≥ 350	7	$3.9^{+2.1}_{-1.2} \pm 0.9$
9	≥ 2	≥ 3	≥ 300	≥ 500	0	$0.6^{+1.0}_{-0.4} \pm 0.4$
10	≥ 2	≥ 3	≥ 1300	≥ 500	0	$0.2^{+1.8}_{-0.3} \pm 0.2$

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