

Search for third generation squarks in pp collisions at 13 TeV with CMS

Nadja Strobbe* on behalf of the CMS Collaboration

Fermi National Accelerator Lab. (US)

E-mail: nadja.strobbe@cern.ch

Three searches for third generation squarks using proton-proton collision data at a center-of-mass energy of 13 TeV recorded by the CMS experiment at the LHC are presented. The data correspond to an integrated luminosity of 12.9fb^{-1} . The analyses define exclusive search regions and estimate contributions from standard model processes to these regions by using control samples in the data. No significant deviation from the standard model expectation is observed in the data. The results are interpreted in simplified SUSY models of direct and gluino-mediated top squark production. Depending on the model, top squark masses up to 910 GeV and gluino masses up to 1780 GeV are excluded.

*38th International Conference on High Energy Physics
3-10 August 2016
Chicago, USA*

*Speaker.

1. Introduction

Third generation SUSY searches are motivated by natural SUSY, which requires the presence of a light higgsino, relatively light top and bottom squarks, and a not too heavy gluino. The CMS experiment [1] has a broad search program for third generation SUSY, containing both dedicated and inclusive searches with varying lepton multiplicities. The 12.9 fb^{-1} of certified 13 TeV data obtained in the first half of the 2016 LHC running period provides a great opportunity to search for these signal models. The focus of this paper is on top squarks, with a discussion of the experimental signatures of top squark production in Section 2. Then, three searches for top squark production are briefly outlined, with their results interpreted using Simplified Model Spectra. Sections 3, 4 and 5 cover a search for direct top squark pair production in the all-hadronic final state [2], a search for both direct and gluino-mediated top squark production in the all-hadronic final state using top quark tagging [3], and a search for direct top squark pair production in the single lepton final state [4], respectively. Finally, a conclusion is provided in Section 6.

2. Experimental signatures of top squark production

The two main production modes for top squarks are direct and gluino-mediated production. The latter has a higher cross section and usually results in more particles in the final state, but relies on the mass of the gluino being sufficiently low so that it can be produced at the LHC.

For direct top squark production, the preferred decay mode of the top squark depends on the mass difference between the top squark and the lightest neutralino, $\Delta M(\tilde{t}, \tilde{\chi}_1^0)$, and whether or not the chargino ($\tilde{\chi}_1^\pm$) mass is lower than the \tilde{t} mass. For mass differences larger than the top quark mass, the top squark can decay to $t\tilde{\chi}_1^0$. For smaller mass differences the top quark in the decay will be off-shell, resulting in a 3- or 4-body decay. If the $\tilde{\chi}_1^\pm$ mass is less than the \tilde{t} mass, the top squark can decay to $b\tilde{\chi}_1^\pm$, where the chargino then decays to $W\tilde{\chi}_1^0$. These different decay options are illustrated in Fig. 1. For gluino-mediated top squark production one can distinguish between two sets of models, as shown in Fig. 2. The first set contains models with off-shell top squarks, resulting in a gluino decay to $\tilde{t}\tilde{\chi}_1^0$. In the other case, the top squark is lighter than the gluino and can be produced on-shell so that the gluino decays to $\tilde{t}\tilde{t}$. The top squark can then decay as in the models discussed above, or, in case $\Delta M(\tilde{t}, \tilde{\chi}_1^0)$ is very small, there can be a sizeable branching fraction for the top squark to decay to $c\tilde{\chi}_1^0$. This latter option is used to interpret the results in Section 4.

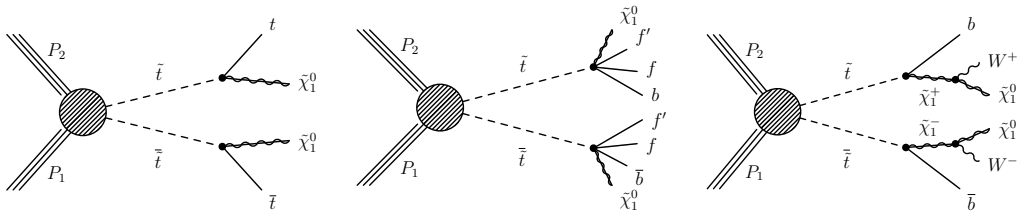


Figure 1: Diagrams for various simplified models of direct top squark production.

The typical signal topology for top squark production consists of a large amount of missing transverse momentum (E_T^{miss}) from the neutralinos in the decay chain, multiple jets including b-tagged jets, and potentially leptons from W boson decay. Signal models become more challenging

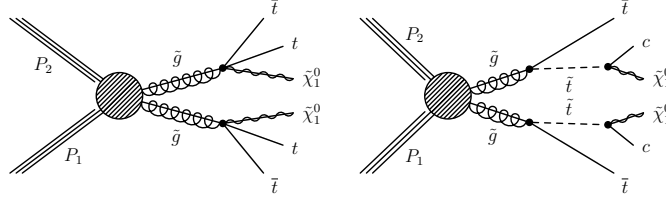


Figure 2: Diagrams for simplified models of gluino-mediated top squark production, with either off-shell (left) or on-shell (right) top squarks.

to detect as the mass splitting between top squark or gluino and the neutralino becomes smaller. In those compressed scenarios there are fewer high- p_T jets, less E_T^{miss} , and softer leptons.

The largest background contribution for all-hadronic 3rd generation SUSY searches originates from one-lepton $t\bar{t}$ and W +jets events, where the lepton is “lost”, i.e., out of the detector acceptance, not reconstructed, or not isolated, since these events have more E_T^{miss} than is expected from all-hadronic events. Smaller contributions to the background include Z +jets events where the Z boson decays to neutrinos ($Z \rightarrow \nu\bar{\nu}$) and thus provides a source of genuine E_T^{miss} , and QCD multijet events where E_T^{miss} arises from mismeasured jets and b-tagged jets from gluon splitting or mistag.

The main background for one-lepton SUSY searches for 3rd generation squarks is not one-lepton $t\bar{t}$ as one would naively expect, but rather dilepton $t\bar{t}$ (or single top quark) production with one lost lepton. One-lepton $t\bar{t}$ can be suppressed by placing a minimum requirement on the transverse mass m_T of the identified lepton and E_T^{miss} , since it will be less than the W boson mass. For dilepton $t\bar{t}$ where one lepton is lost, the two neutrinos and the lost lepton contribute to the E_T^{miss} , resulting in larger values of m_T . Subleading backgrounds originate from W +jets processes with off-shell W boson decays and from $t\bar{t}Z$ with $Z \rightarrow \nu\bar{\nu}$ decays.

3. Search for direct top squark pair production in the all-hadronic final state

This search for direct top squark pair production in the all-hadronic final state uses two approaches. The first is targeted towards scenarios with large $\Delta M(\tilde{t}, \tilde{\chi}_1^0)$ and features the use of W boson and top quark tagging to access the boosted regime. The second approach is geared towards small $\Delta M(\tilde{t}, \tilde{\chi}_1^0)$ scenarios where the top squark decay products are soft and the analysis relies on initial-state radiation (ISR) to extract potential signal events. In both cases, the presence of a significant amount of $E_T^{\text{miss}} > 250$ GeV is required.

The other baseline selection requirements for the large $\Delta M(\tilde{t}, \tilde{\chi}_1^0)$ scenario are the following. There need to be at least 5 jets and at least 2 b-tagged jets. In order to reject QCD multijet background, the minimum $\Delta\phi$ between the leading four jets and E_T^{miss} has to be larger than 0.5. After imposing this baseline selection, 60 signal regions are defined, binned in $m_T(b)$, E_T^{miss} , the number of jets, b-tagged jets, tagged W boson candidates, and tagged top quark candidates. The top quark and W boson tagging uses jets clustered with the anti- k_T algorithm with distance parameter $\Delta R = 0.8$, and places requirements on the soft-drop mass and N-subjettiness variables. Top quark (W boson) candidates are required to have $p_T > 400(200)$ GeV, soft drop mass in the range 110–210 GeV (60–110 GeV), and N-subjettiness $\tau_{32} < 0.69$ ($\tau_{21} < 0.6$).

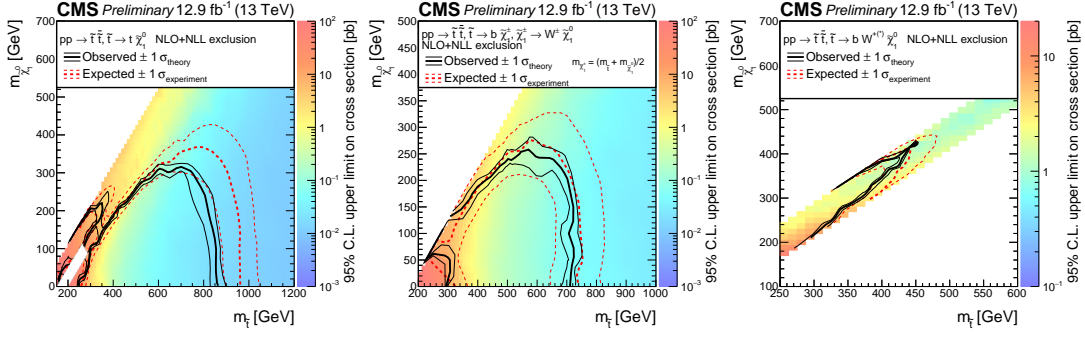


Figure 3: Exclusion limits at 95% CL on the cross section of direct top squark production, as obtained from the all-hadronic search [2]. Three models are considered: top squark decay to $t\tilde{\chi}_1^0$ (left), $b\tilde{\chi}_1^\pm$ with $\tilde{\chi}_1^\pm \rightarrow W\tilde{\chi}_1^0$ (middle), and $bW^{(*)}\tilde{\chi}_1^0$ (right).

The small $\Delta M(\tilde{t}, \tilde{\chi}_1^0)$ scenario requires the presence of two or more jets. There should also be at least one ISR-tagged jet, which is a jet with $p_T > 250$ GeV that is not b-tagged and is pointing away from the E_T^{miss} in the event ($|\Delta\phi(j_{\text{ISR}}, E_T^{\text{miss}})| > 2$). QCD multijet rejection is achieved by requiring that $|\Delta\phi(j_1, E_T^{\text{miss}})| > 0.5$, $|\Delta\phi(j_{2,3}, E_T^{\text{miss}})| > 0.15$, and E_T^{miss} significance $E_T^{\text{miss}}/H_T > 10$. The 40 signal regions for this scenario are binned in the number of jets, the number of b-tagged jets, the p_T of the ISR jet, and the p_T of the b-tagged jet if present.

The main backgrounds are estimated using data control samples: a one-lepton sample for the lost-lepton background, a $Z \rightarrow \ell\ell$ and γ +jets sample for the $Z \rightarrow \nu\bar{\nu}$ background, and an inverted- $\Delta\phi$ control sample for the QCD multijet background. Good agreement was found between the observation in data and the background prediction, and the results are interpreted in simplified models of direct top squark production, see Fig. 3. Top squark masses up to 860 GeV and neutralino masses up to 320 GeV are excluded for top squarks decaying to $t\tilde{\chi}_1^0$. Slightly weaker limits are obtained for models with an intermediate chargino. For very compressed models where the top squark undergoes a 4-body decay, top squark masses up to 450 GeV are excluded.

4. Search for supersymmetry in the all-hadronic final state using top quark tagging

Third generation SUSY models often have top quarks in the final state, up to 2 (4) for direct (gluino-mediated) top squark production. This hadronic analysis uses top quark tagging to identify the number of top quarks in an event, and uses their kinematics to distinguish signal from background. The top quark tagging algorithm achieves a good efficiency across a wide p_T range by considering three categories: *trijet* candidates consisting of three jets within a cone of $\Delta R = 1.5$, with one of the dijet to trijet mass ratios compatible with the W boson to top quark mass ratio; *dijet* candidates which are a combination of two jets, one of which satisfies $70 < m_{\text{jet}} < 110$ GeV; and *monojet* candidates consisting of one jet with $110 < m_{\text{jet}} < 220$ GeV. The final candidates are selected by requiring the candidate mass to be within the range 100–250 GeV, and by removing overlaps between candidates by favoring the candidate with mass closest to the top quark mass.

The baseline selection employed by this analysis consists of the following requirements: at least 4 jets, no leptons, $\Delta\phi(j_{1,2,3}, E_T^{\text{miss}}) > 0.5, 0.5, 0.3$ to suppress QCD multijet background, $E_T^{\text{miss}} > 200$ GeV, $H_T > 500$ GeV, at least one b-tagged jet and at least one top quark candidate.

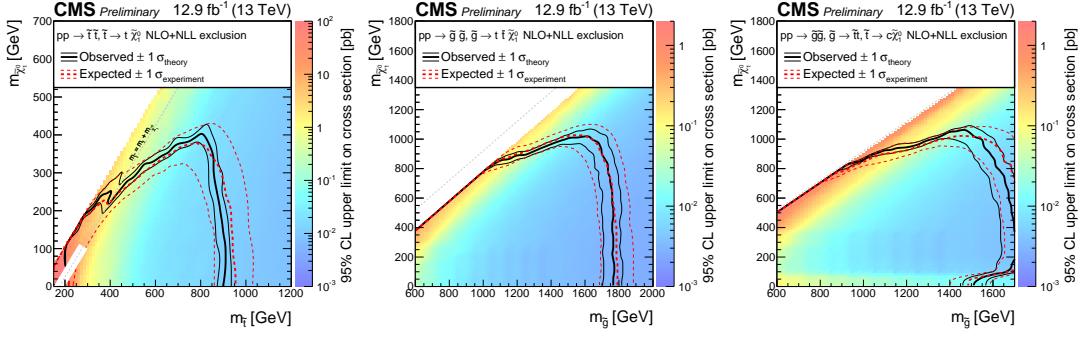


Figure 4: Exclusion limits at 95% CL on the cross section of top squark and gluino production, as obtained from the all-hadronic search using top quark tagging [3]. Three models are considered: top squark decay to $t\tilde{\chi}_1^0$ (left), gluino decay to $t\tilde{t}\tilde{\chi}_1^0$ (middle), and gluino decay to $t\tilde{t}$ with the top squark decaying to $c\tilde{\chi}_1^0$ (right).

The final requirement is that $M_{T2} > 200$ GeV, where the transverse mass M_{T2} is computed using the top quark candidates as input. The analysis uses 59 signal regions binned in E_T^{miss} , M_{T2} , the number of b-tagged jets, and the number of top quark candidates.

The different backgrounds are estimated using a set of independent control samples. The lost-lepton and hadronically decaying tau backgrounds are estimated using a single muon control sample, the $Z \rightarrow \nu\bar{\nu}$ background using a $Z \rightarrow \mu^+\mu^-$ control sample, and the QCD multijet background using an inverted- $\Delta\phi$ control sample. Good agreement between observed data and predicted background is found. This analysis excludes top squark masses up to 910 GeV for neutralino masses up to 400 GeV for models of direct top squark production where the top squark decays to $t\tilde{\chi}_1^0$. Gluino masses up to 1780 GeV can be excluded for neutralino masses up to 1020 GeV for models where the gluino decays to $t\tilde{t}\tilde{\chi}_1^0$. For models with on-shell top squarks decaying to $c\tilde{\chi}_1^0$ in the decay chain, gluino masses up to 1700 GeV are excluded for neutralino masses up to 1060 GeV. For these models $\Delta M(\tilde{t}, \tilde{\chi}_1^0)$ is assumed to be 20 GeV. These results are displayed in Fig. 4.

5. Search for direct top squark pair production in the single lepton final state

Similar to the search presented in Section 3, this search targets direct top squark production explicitly, but in the single lepton final state rather than the all-hadronic final state. The applied preselection consists of requiring the presence of exactly one lepton, at least two jets of which one should be b-tagged, $E_T^{\text{miss}} > 250$ GeV, $m_T > 150$ GeV to reduce W +jets and one-lepton $t\bar{t}$ processes, and $\Delta\phi(j_{1,2}, E_T^{\text{miss}}) > 0.8$. Two additional kinematic variables are used to help discriminate signal from dilepton $t\bar{t}$. The M_{T2}^W variable is the minimal mother mass compatible with the W boson mass and E_T^{miss} constraints for a dilepton $t\bar{t}$ event topology. The modified topness variable is the χ^2 of the compatibility of an event with the dilepton $t\bar{t}$ event hypothesis, ignoring constraints from the second b-tagged jet. This variable is especially useful for asymmetric decay chains, such as when one top squark decays to $t\tilde{\chi}_1^0$ and the other top squark decays via an intermediate chargino. This search uses 15 exclusive signal regions that target different classes of models and that are defined by placing requirements on the number of jets and the value of E_T^{miss} , M_{T2}^W , and modified topness.

The main background arises from dilepton $t\bar{t}$ and single top quark events in which one lepton is lost and it is estimated using a dilepton control sample. Events in which off-shell W bosons de-

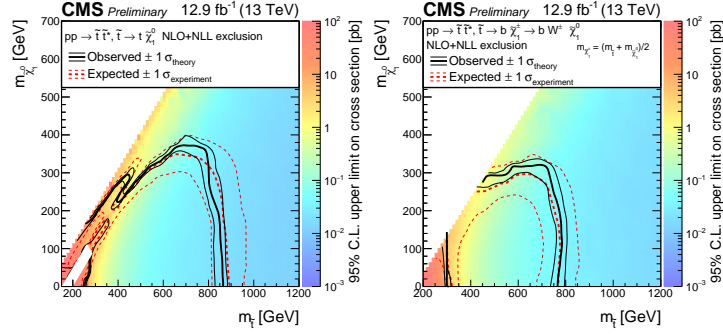


Figure 5: Exclusion limits at 95% CL on the cross section of direct top squark production, as obtained from the one-lepton search [4]. Two models are considered: top squark decay to $t\tilde{\chi}_1^0$ (left), and top squark decay to $b\tilde{\chi}_1^\pm$ with $\tilde{\chi}_1^\pm \rightarrow W\tilde{\chi}_1^0$ (right).

cay leptonically also contribute to the background and are estimated using an event sample without b-tagged jets. Processes such as WZ or $t\bar{t}Z$ production result in a subdominant background contribution and are estimated using simulation. Good agreement between the background prediction and the observed data is found. This analysis excludes top squark masses up to 860 GeV for neutralino masses up to 380 GeV for models with $\tilde{t} \rightarrow t\tilde{\chi}_1^0$ decays. Slightly weaker limits are obtained for models with an intermediate chargino in the decay chain. The limits in the top squark–neutralino mass plane for these two models are shown in Fig. 5.

6. Conclusion

Three searches for third generation squarks using 12.9fb^{-1} of 13 TeV data recorded by the CMS experiment have been presented. No significant deviation from the standard model expectation is observed. The results are interpreted in simplified SUSY models of direct and gluino-mediated top squark production. The limits on the top squark mass are extended up to 910 GeV from 760 GeV in 2015, and on the gluino mass up to 1780 GeV from 1580 GeV. Given the good performance of the LHC during the 2016 running period, with an expected integrated luminosity of up to $30\text{--}40\text{fb}^{-1}$ by the end of the year, we can expect these analyses to further increase their sensitivity to SUSY models involving third generation squarks.

References

- [1] CMS Collaboration, *The CMS experiment at the CERN LHC*, JINST 3 (2008) S08004.
- [2] CMS Collaboration, *Search for direct top squark pair production in the fully hadronic final state in proton-proton collisions at $\sqrt{s} = 13\text{ TeV}$ corresponding to an integrated luminosity of 12.9fb^{-1}* , CMS Physics Analysis Summary CMS-PAS-SUS-16-029, cds.cern.ch/record/2205176.
- [3] CMS Collaboration, *Search for supersymmetry in the all-hadronic final state using top quark tagging in pp collisions at $\sqrt{s} = 13\text{ TeV}$* , CMS Physics Analysis Summary CMS-PAS-SUS-16-030, cds.cern.ch/record/2204930.
- [4] CMS Collaboration, *Search for direct top squark pair production in the single lepton final state at $\sqrt{s} = 13\text{ TeV}$* , CMS Physics Analysis Summary CMS-PAS-SUS-16-028, cds.cern.ch/record/2205271.