

Searches for pair production of charginos and top squarks in final states with two oppositely charged leptons at CMS experiment

Barbara Chazin on behalf of the CMS Collaboration

Instituto de Física de Cantabria (CSIC-Universidad de Cantabria, Spain)

E-mail: bchazing@cern.ch

Abstract. A search for pair production of supersymmetric particles in events with two oppositely charged leptons and missing transverse momentum is reported. The data sample corresponds to an integrated luminosity of 35.9 fb^{-1} of proton-proton collisions at 13 TeV collected with the CMS detector during the 2016 data taking period at the LHC. No significant deviation is observed from the predicted standard model background. The results are interpreted in terms of several simplified models for chargino and top squark pair production, assuming R-parity conservation and with the neutralino as the lightest supersymmetric particle.

1. Introduction

This document presents the search for two supersymmetric particle production in final states with two opposite charge (OC) leptons (l) and missing transverse momentum (p_T^{miss}) stemming from the LSP. The searches target two specific signal scenarios for top squark (\tilde{t}_1) and one for chargino ($\tilde{\chi}_1^\pm$) pair production using data from proton-proton collisions at $\sqrt{s} = 13 \text{ TeV}$ collected by the CMS experiment [1] at CERN LHC in 2016, and corresponding to an integrated luminosity of 35.9 fb^{-1} .

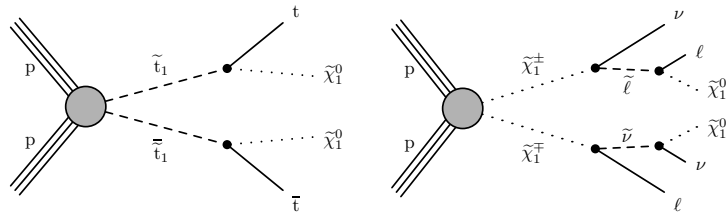


Figure 1. Simplified-models diagrams for top squark (left) and chargino (right) pair production.

The results are interpreted in terms of the two simplified supersymmetric model spectra (SMS) shown in Figure 1. On the left, each top squark \tilde{t}_1 decays into a top quark and the lightest neutralino ($\tilde{\chi}_1^0$). Only further top quark decays into a bottom quark and a W boson are considered. The analysis strategy is optimized for a compressed spectrum scenario dealing

with two degrees of degeneration between top squark and top masses. A first analysis, hereafter referred to as “three-body decay” [2], studies the region at intermediate neutralino masses where the mass difference between the top squark and the LSP (Δm) lies between the mass of the top quark and W bosons masses $m_W < m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} \lesssim m_t$. And a second analysis, hereafter referred to as “degenerate top squark”, focused on the highly compressed spectra where $\Delta m \approx m_t$ and low neutralino masses [3].

Realized in the context of “three-body decay” analysis, the search for chargino pair production [2] considers, as a reference, the model shown on Fig. 1 right, where the charginos decay into a lepton, a neutrino (ν), and the lightest neutralino via an intermediate charged slepton ($\tilde{\chi}_1^\pm \rightarrow \nu \tilde{l} \rightarrow \nu l \tilde{\chi}_1^0$) or sneutrino ($\tilde{\chi}_1^\pm \rightarrow \tilde{l} \nu \rightarrow \nu l \tilde{\chi}_1^0$). The three generations of sleptons are assumed to be degenerate, with a mass equal to the average of the chargino and neutralino masses. The branching fractions (\mathcal{B}' s) of the chargino decays into charged sleptons or sneutrinos are assumed to be equal.

2. General analysis strategy

The signal models are characterized by a common final state with two OC leptons and two lightest neutralinos contributing to large p_T^{miss} . Based on this, a general high-acceptance baseline selection is defined, requiring two OC isolated leptons with transverse momenta $p_T \geq 25$ (20) GeV for the leading (trailing) lepton and pseudorapidity up to $|\eta| < 2.4$. Events with τ leptons decaying into electrons or muons that satisfy the selection requirements are also taken into account. To reduce the contributions from low-mass resonances, $Z \rightarrow \tau\tau$ production and non-prompt leptons from jets originating from hadron decays, the invariant mass m_{ll} of the lepton pair is required to be greater than 20 GeV, and if both leptons have the same flavour (SF), m_{ll} is required to satisfy $|m_{ll} - m_Z| < 15$ GeV, where m_Z is the mass of the Z boson.

After this selection, the SM processes that contribute most are top quark-antiquark pair ($t\bar{t}$) production, the events with a single top quark produced in association with a W boson (tW) and the WW diboson production. For all these backgrounds, the lepton pair and p_T^{miss} come from a W boson pair. Consequently, we can construct the variable m_{T2} [4] that generalizes the transverse mass (m_T) for a system with two invisible particles, by using the two leptons as the two visible systems,

$$m_{T2}(ll) = \min_{\vec{P}_T^{miss1} + \vec{P}_T^{miss2} = \vec{P}_T^{miss}} (\max[m_T(\vec{P}_T^{lep1}, \vec{P}_T^{miss}), (\vec{P}_T^{lep2}, \vec{P}_T^{miss2})]). \quad (1)$$

This observable reaches a kinematic endpoint at the m_W for the considered backgrounds. Signal events, instead, present a $m_{T2}(ll)$ spectra without such an endpoint because of the additional contribution to the p_T^{miss} given by the neutralinos. The sensitivity of each analysis is further enhanced making use of this variable as main discriminant.

3. Three-Body decay analysis

This analysis is developed for two signal hypothesis, top squark pair and the chargino pair productions. The searches involve the same techniques for the background estimation and the signal extraction, while they differ slightly in the signal region (SR) selection in order to improve their respective sensitivity.

After the baseline selection the signal discrimination of $m_{T2}(ll)$ variable is enhanced by dividing the general SR in three bins of p_T^{miss} ([140, 200), [200,300), and ≥ 300 GeV). This allows the analysis not only to exploit the larger tails in the p_T^{miss} distribution of the signal events with respect to the main backgrounds, but also to optimize the sensitivity to signals with different mass separation between the produced supersymmetric particle and the LSP. Each p_T^{miss} bin is in turn divided into events with SF and different flavour (DF) leptons to exploit the smaller contamination from WZ , ZZ diboson and DrellYan production of the latter.

The background rejection is further enhanced by subdividing the signal regions (SRs) in function of the jet and b jet multiplicity. For top squark signals satisfying $\Delta m \gtrsim m_W$, the sensitivity is enlarged requiring a veto on b-tagged jets which allow to reduce the contamination from $t\bar{t}$, tW , and $t\bar{t}Z$ backgrounds. For signal scenarios with larger Δm , instead, requiring a b-tagged jet reduces the background from diboson and DrellYan events increasing thus the sensitivity to top squark production. In addition, the presence of high- p_T jets from ISR in the events with $p_T^{miss} > 300$ GeV is a useful means to discriminate top squark production from SM processes.

In the chargino search, the signal is characterized by the presence of natural p_T^{miss} arising from the neutrinos and the absence of jets in the event those additionally exploited for signal discrimination. Requiring a veto on b-tagged jets is effective rejecting $t\bar{t}$, tW , and $t\bar{t}Z$ events, but due to top quark background still present in the SRs, the p_T^{miss} bins below 300 GeV are split into two subregions depending on the presence of a jet with $p_T > 20$ GeV and $|\eta| < 2.4$. Events with b-tagged jets are kept as a control region (CR) for the normalization of the background from $t\bar{t}$ and tW production.

The $m_{T2}(ll)$ distribution is divided into seven equal bins. Since the first bins of the distribution have low signal contribution, we exploit them to constrain the contributions of the dominant backgrounds in the SRs with one b-tagged jet (dominated by $t\bar{t}$ and tW production) and without b-tagged jets (where WW production becomes relevant). The modelling of these backgrounds is studied in data control regions (CRs), and their normalization is determined via a maximum likelihood (ML) fit to data (as briefly described later).

The normalization of the yields of events from $t\bar{t}Z$, WZ , ZZ , and DrellYan production is taken from simulation and corrected by the event rates measured in dedicated CRs. Remaining minor backgrounds from $t\bar{t}W$, $H \rightarrow WW$, and triboson production are normalized to their theoretical cross section and integrated luminosity.

Several sources of systematic uncertainties affecting both the normalization and the $m_{T2}(ll)$ shape of the backgrounds and signal events are taken into account in this analysis. Specific uncertainties in the modelling of the different SM processes and the signal events are included. The latter uncertainties are mostly related with the performance of the event reconstruction.

Finally, a simultaneous binned ML fit to the $m_{T2}(ll)$ distribution in all the SRs for all dilepton flavour pairs is performed to extract the signal. Uncertainties are included through nuisance parameters with log-normal or Gaussian prior distribution. In Figure 2 the results of the fitting in one of the signal regions are shown for top squark (left) and for chargino (right) searches.

No excess over SM prediction is observed in data. The exclusion regions in the mass plane are obtained by comparing these upper limits with the theoretical production cross section of the process. The 95 % CL upper limits on top squark and chargino pair production cross sections are shown in Figure 3. In the compressed mass region, top quark and a neutralino masses are excluded up to about 420 GeV and 360 GeV respectively (Fig.3 left), extending previous results obtained by the CMS Collaboration with two leptons in the final state [5]. In the second signal hypothesis, masses are excluded up to values of about 800 GeV for the chargino and 320 GeV for the neutralino (Fig.3 right). These are the most stringent limits on this model to date.

4. Degenerate top squark search

This analysis targets a degenerate and nearly degenerated top squark region at low neutralino masses where the signal reproduces the top quark-antiquark pair production kinematics leading to a similar phase space. Therefore, after the baseline selection a common SR is defined by selecting events containing one OC electron-muon pair and at least two jets and one b jet.

The strategy depends strongly on the $\Delta m \gtrsim m_t$ mass difference. When $m_{\tilde{\chi}_0}$ is small, the signal behaviour is very similar to the $t\bar{t}$ process and it is expected as an excess in the

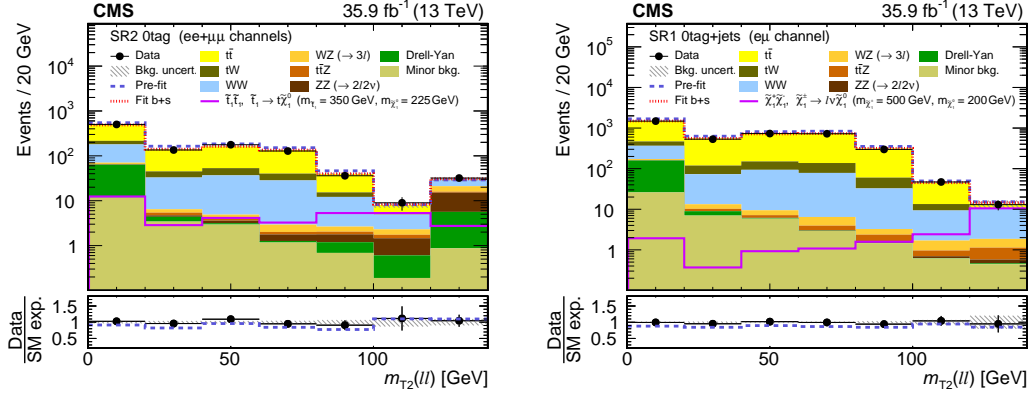


Figure 2. Observed and expected $m_{T2}(ll)$ distributions in the top squark SR with $200 \leq p_T^{miss} < 300$ GeV, veto on b-tagged jets and DF channel (right) and the chargino SR with $140 \leq p_T^{miss} < 200$ GeV, veto on b-tagged jets, no jets present in the event and DF channel (left). The expected total SM contributions after the background+signal fit (dark red dotted line) and before the fit (dark blue dashed line). The last bin includes the overflow entries. In the bottom panel is shown the ratio of data and total SM contribution after the fit using the background-only hypothesis (black dots) and before any fit (dark blue dashed line). The hatched band represents the total uncertainty after the fit [2].

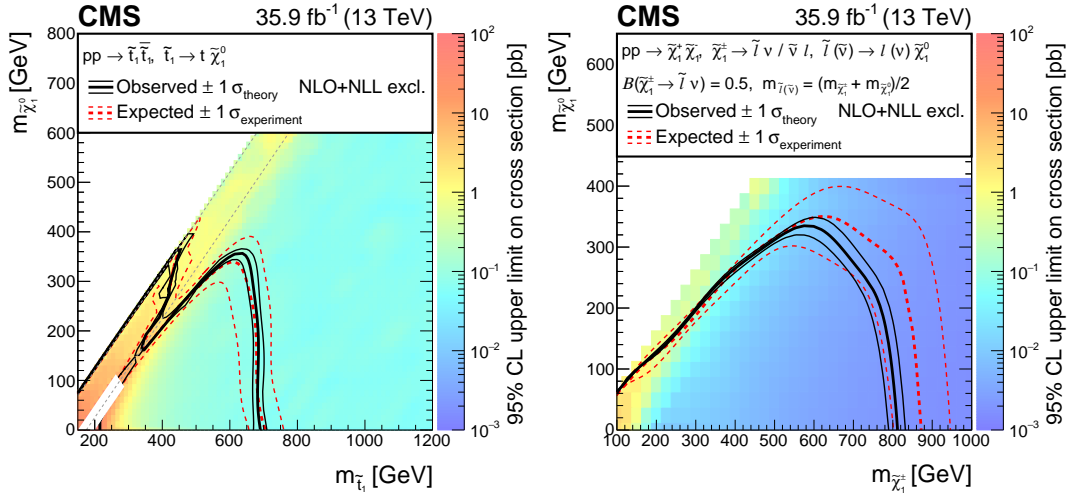


Figure 3. The plot on the left shows the upper limits at 95% CL on top squark production cross section as a function of the top squark and neutralino masses. The grey dashed lines enclose the compressed mass region where $m_W < m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} < m_t$. The plot on the right shows the upper limits at 95% CL on chargino pair production cross section as a function of the chargino and neutralino masses ($m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}$). The dashed red line shows the expected exclusion region under the experimental uncertainties, while the black line shows the observed exclusion region under the theoretical uncertainties in the production cross section [2].

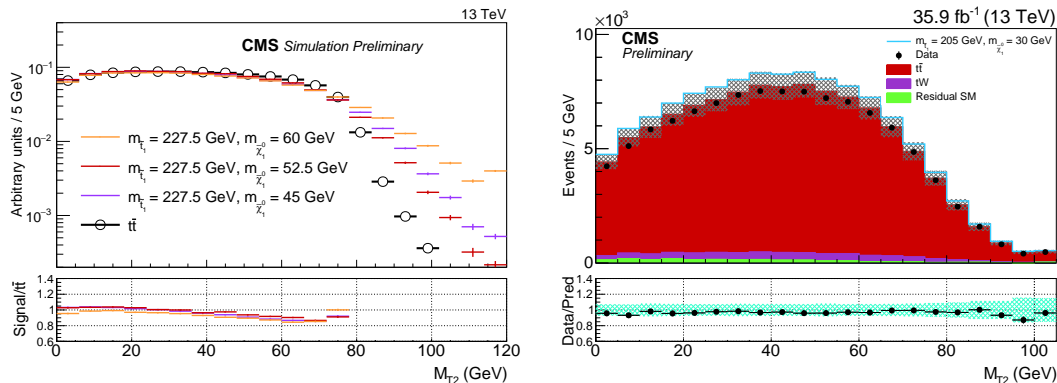


Figure 4. Normalized $m_{T2}(ll)$ distribution at generator level for three signal mass hypothesis with $\Delta m \geq m_t$ (left), and the observed and SM expected $m_{T2}(ll)$ distribution (pre-fit) after SR selection (right). In the latter only one signal point stacked on top of the background estimate is shown. The hatched bands correspond to the combined systematic and statistical uncertainties on background rates. The lower panel shows the ratio between the observed data and the predicted SM background. In both plots, the last bin includes the overflow [3].

$t\bar{t}$ predictions. The SM contribution with respect to a degenerate signal point after the baseline selection are shown in the right of Figure 4 ($m_t = 172.5$ GeV is assumed). The precise measurements of the $t\bar{t}$ cross section [6], [7] and the accurate modelling of the kinematic variables are exploited to distinguish signal to background. On the other hand, for higher $m_{\tilde{\chi}_0}$, the small contribution of p_T^{miss} to signal events works out well for the discriminatory potential at high $m_{T2}(ll)$ values as is shown in Figure 4 left for simulated events at generator level.

The total background contribution to the SR is dominated by the 94% of $t\bar{t}$ production. The second-largest contribution, approximately 4%, is given the tW process. Minor background such as non-prompt leptons, Drell-Yan, dibosons, $t\bar{t}Z$, and $t\bar{t}W$ production represent the remaining 2% of the SM contribution. The number of events with non-prompt leptons are estimated from data in a dedicated CR. The rest of the background yields are estimated from MC simulation in the signal region after normalizing to the theoretical cross section and integrated luminosity.

Several systematic uncertainties in the acceptance, efficiency, and normalization which affect the background and signal estimates are taken into account in this analysis. In addition to the normalization uncertainty, due to the large impact of the $t\bar{t}$ process, several sources of modelling uncertainties are considered. These uncertainties account for the main parameters used in the simulation and are propagated to the $m_{T2}(ll)$ distribution as shape uncertainties.

The statistical interpretation is performed by testing the SM hypothesis against the SUSY hypothesis using a binned profile likelihood fit of the $m_{T2}(ll)$ distribution, where the nuisance parameters are modelled using log-normal prior distributions. The results are studied for three signal models with top squark masses from 170 to 250 GeV and a neutralino mass constrained by three different mass differences $\Delta m = 175, 167.5, \text{ and } 182.5$ GeV. The expected and observed upper limits on the signal strength, defined as the ratio between the excluded and the predicted cross sections, are shown in Figure 5.

For signal points with low neutralino masses and $\Delta m = m_t$, the sensitivity come mostly from the signal normalization, and the top squark masses is excluded up to 208 GeV. Likewise, for higher neutralino masses and $\Delta m = 167.5$ or 182.5 GeV the sensitivity of the analysis is driven by the differences between signal and $t\bar{t}$ distribution for high $m_{T2}(ll)$ values ($m_{T2}(ll) \geq 80$ GeV). Top squark masses up to 235 and 242 GeV are excluded in each case.

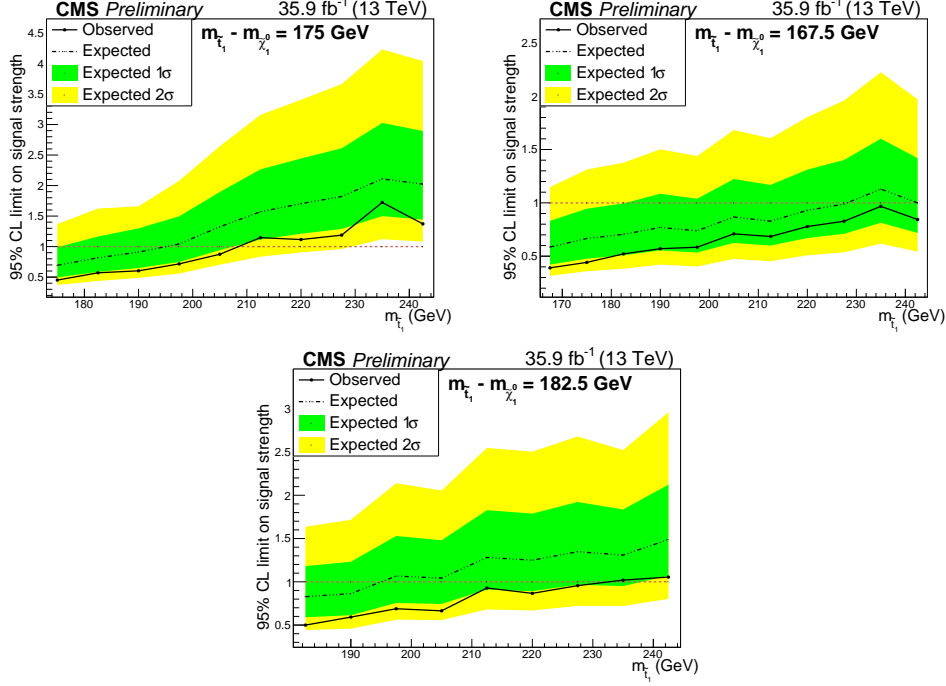


Figure 5. Observed and expected upper limits at 95% CL on the signal strength as function of top squark mass for $m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} = 175$ GeV (upper left), $m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} = 167.5$ GeV (upper right), $m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} = 182.5$ GeV (bottom). The range of variation of the expected values at 68 and 95 % CL correspond to the yellow and green band respectively [3].

5. Summary

Searches for top squark and chargino pair production in final states with two leptons using 2016 LHC data at $\sqrt{s} = 13$ TeV have been presented. Phase space corners have been investigated with no observation of new physics over the SM backgrounds.

Regarding the top squark search in the $m_W < \Delta m \leq m_t$ compressed scenario, the observed limits have been extended up to 420 (360) GeV for top squark (neutralino) masses. First exclusion limits have been set on the top squark mass in the very compressed scenario: up to 210 GeV in models with $\Delta m = m_t$ and 240 GeV in models with $\Delta m = m_t \pm 7.5$ GeV. In the case of chargino search, the exclusion limits on the chargino (neutralino) mass have been extended up to 800 (320) GeV, representing the most stringent limits to date.

Overall, the CMS experiment has excluded top squark and chargino masses below 1.2 TeV and LSP neutralino mass below 0.8 TeV. New and upgraded searches are expected with the full LHC data.

References

- [1] CMS Collaboration *The CMS experiment at the CERN LHC 2008 JINST* **3** S08004
- [2] CMS Collaboration *Searches for pair production of charginos and top squarks in final states with two oppositely charged leptons in proton-proton collisions at $\sqrt{s} = 13$ TeV 2018 JHEP* **11** 79
- [3] CMS Collaboration 2019 Search for the pair production of light top squarks in the $e\mu$ final state in proton-proton collisions at $\sqrt{s} = 13$ TeV *Preprint JHEP035 (P0119)* v1
- [4] Lester C and Summers D *Measuring masses of semiinvisibly decaying particles pair produced at hadron colliders 1999 Phys. Lett. B* **463** 99-103

- [5] CMS Collaboration *Search for top squarks and dark matter particles in opposite-charge dilepton final states at $\sqrt{s} = 13$ TeV* 2018 *Phys. Rev.* **97** 032009
- [6] Czakon M and Mitov A *Top++: A program for the calculation of the top-pair cross-section at hadron colliders* 2014 *Comput. Phys. Commun.* **185** 2930
- [7] CMS Collaboration *Measurement of the $t\bar{t}$ production cross section in the $e\mu$ channel in proton-proton collisions at $\sqrt{s} = 13$ and 8TeV* 2016 *JHEP* **08** 029