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Search for R-parity violating decays of a top squark in proton-proton collisions at $\sqrt{s} = 8$ TeV

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Abstract

The results of a search for a supersymmetric partner of the top quark (top squark), pair-produced in proton-proton collisions at $\sqrt{s} = 8$ TeV, are presented. The search, which focuses on R-parity violating, chargino-mediated decays of the top squark, is performed in final states with low missing transverse momentum, two oppositely charged electrons or muons, and at least five jets. The analysis uses a data sample corresponding to an integrated luminosity of $19.7\,\mathrm{fb}^{-1}$ collected with the CMS detector at the LHC in 2012. The data are found to be in agreement with the standard model expectation, and upper limits are placed on the top squark pair production cross section at 95% confidence level. Assuming a 100% branching fraction for the top squark decay chain, $\widetilde{\mathrm{t}} \to \mathrm{b}\widetilde{\chi}_1^{\pm}, \widetilde{\chi}_1^{\pm} \to \ell^{\pm} + \mathrm{jj}$, top squark masses less than 890 (1000) GeV for the electron (muon) channel are excluded for the first time in models with a single nonzero R-parity violating coupling λ'_{ijk} $(i, j, k \leq 2)$, where i, j, k correspond to the three generations.

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1 Introduction

Supersymmetry (SUSY) [1, 2] is an extension of the standard model (SM) that may provide a solution to the hierarchy problem [3, 4]. In the SUSY framework, quadratically divergent radiative corrections to the Higgs boson mass, dominated by loops involving the top quark, are canceled by loops with a supersymmetric partner of the top quark (top squark). The mass of the top squark is expected to be within a few hundred GeV of the top quark mass, and the supersymmetric Higgs boson partners are also expected to have masses less than 1 TeV [5, 6].

Searches for SUSY are performed in many decay channels and are classified into R-parity conserving (RPC) and R-parity violating (RPV) scenarios. The quantum number, R-parity, $P_{\mathrm{R}} = (-1)^{3B+L+2s}$ has a value $+1$ for SM particles and -1 for superpartners, where B, L, and s are baryon number, lepton number, and spin, respectively [7]. In RPC models the top squark is expected to decay into the lightest SUSY particle, which escapes detection. This results in an event signature with substantial missing transverse momentum. Recent searches performed at the LHC at CERN in events with high missing transverse momentum have reduced the parameter space available for a low mass top squark [8–13]. However, R-parity may not be conserved, in which case searches for SUSY particle decaying to SM particles without substantial missing transverse momentum are important.

The superpotential terms that result in R-parity violation are given by:

$$W_{\mathrm{RPV}} = \frac{1}{2}\,\lambda_{ijk} L_i L_j \overline{E}_k + \lambda'_{ijk} L_i Q_j \overline{D}_k + \frac{1}{2}\,\lambda''_{ijk} \overline{U}_i \overline{D}_j \overline{D}_k + \mu_i L_i H_u; \tag{1}$$

where λ_{ijk}, λ'_{ijk}, and λ''_{ijk} are three trilinear Yukawa couplings; $i, j, k = 1, 2, 3$ are generation indices; L and Q are the $SU(2)_L$ doublet superfields of the lepton and quark; H_{u} is the Higgs field that gives mass to the up-type quarks; μ_i are the bilinear terms that mix lepton and Higgs superfields, and $\overline{E}$, $\overline{D}$, and $\overline{U}$ are the $SU(2)_L$ singlet superfields of the charged lepton, down-type quark, and up-type quark. The third term violates the conservation of baryon number, while the first two violate the conservation of lepton number. If baryon number and lepton number were both violated, proton decay would proceed at a rate excluded by experimental observations [14, 15]. To avoid these experimental constraints and to simplify the interpretation of results, it is commonly assumed that only one of the λ_{ijk}, λ'_{ijk}, or λ''_{ijk} couplings is different from zero. In this analysis only λ'_{ijk} couplings with $(i, j, k) \leq 2$ are considered.

In RPV SUSY models with the chargino $\widetilde{\chi}^{\pm}_1$ lighter than the top squark and nonzero λ'_{ijk}, the top squark $\widetilde{\mathrm{t}}$ can decay via $\widetilde{\mathrm{t}} \to \mathrm{b}\widetilde{\chi}^{\pm}_1$, with subsequent decay of the chargino to a lepton and two jets via an off-shell sneutrino ($\widetilde{\chi}^{\pm}_1 \to \ell^{\pm} + \mathrm{jj}$) [16], as depicted in Fig. 1. The branching fraction of decay $\widetilde{\chi}^{\pm}_1 \to \nu + \mathrm{jj}$ via an off-shell slepton will be negligible unless the slepton and sneutrino masses are comparable. The decay $\widetilde{\chi}^{\pm}_1 \to \mathrm{W}^{\pm}\widetilde{\chi}^0_1$ is suppressed for models with $\widetilde{\chi}^{\pm}_1$ and $\widetilde{\chi}^0_1$ almost degenerate in mass.

We perform a search for top squark decays, as depicted in Fig. 1, using proton-proton (pp) collisions at a center-of-mass energy of 8 TeV, corresponding to an integrated luminosity of 19.7 fb^{-1}, collected with the CMS detector at the LHC in 2012. As top squarks are expected to be dominantly pair-produced at the LHC [17], the search is performed using events with exactly two oppositely charged electrons ($\mathrm{e}^{\pm}\mathrm{e}^{\mp}$) or muons ($\mu^{\pm}\mu^{\mp}$), at least five jets of which one or more jet is identified as arising from hadronization of a bottom quark (b-tagged jet), and high S_{T}, where S_{T} is defined as the scalar sum of the transverse momenta of leptons and jets. As a consequence of the assumption that only one of the λ'_{ijk} couplings is nonzero, the two leptons must have opposite charge and the same flavor. Details of the event selection are described in

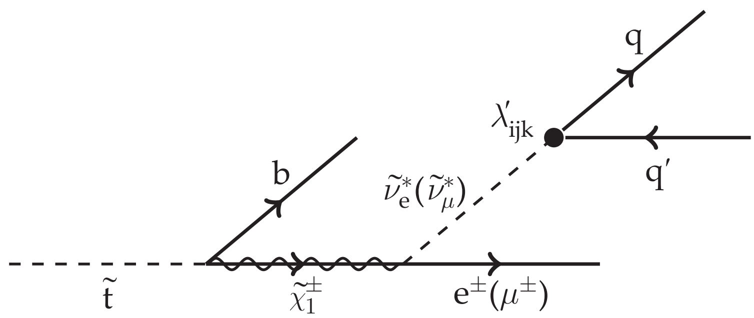

Figure 1: Diagram for the R-parity violating, chargino-mediated decay of a top squark. The chargino decays to a lepton and two jets via an off-shell sneutrino with nonzero λ'_{ijk} coupling.

Section 3.

The sensitivity of the $\mathrm{e}^{\pm}\mathrm{e}^{\mp}(\mu^{\pm}\mu^{\mp})$ search does not depend on which of the four RPV couplings associated with the second operator LQD ($L_i Q_j \overline{D}_k$) in Eq. (1): λ'_{111}, λ'_{112}, λ'_{121}, and λ'_{122} (λ'_{211}, λ'_{212}, λ'_{221}, and λ'_{222}) is non-zero, because the final states and kinematic distributions are the same in each case. We expect that the searches have some sensitivity to models with third-generation couplings λ'_{311}, λ'_{312}, λ'_{321}, and λ'_{322}, via leptonic τ decays; however, we do not include this possible extra contribution in this paper. The difference $\Delta M_{\widetilde{\mathrm{t}},\widetilde{\chi}^{\pm}_1}$ between top squark mass $M_{\widetilde{\mathrm{t}}}$, and chargino mass $M_{\widetilde{\chi}^{\pm}_1}$, is chosen to be 100 GeV, since this value is representative of the bulk of the $M_{\widetilde{\mathrm{t}}}$-$M_{\widetilde{\chi}^{\pm}_1}$ parameter space where the signal reconstruction efficiency is slowly varying. This analysis does not attempt to quantify the decrease in efficiency (and signal sensitivity) in the regions of parameter space where either $\Delta M_{\widetilde{\mathrm{t}},\widetilde{\chi}^{\pm}_1}$ or $M_{\widetilde{\chi}^{\pm}_1}$ is very small (<100 GeV).

Several searches for R-parity violating top squark decays via LQD couplings have been performed by the CMS [18–20] and ATLAS [21] collaborations. These searches have focused on top squark pairs decaying via λ'_{i32} couplings into final states of two leptons ($\mathrm{e}^{\pm}$ or $\mu^{\pm}$) and two jets or two leptons ($\mathrm{e}^{\pm}$ or $\mu^{\pm}$) and six jets, four of which are b-tagged jets [20, 21]; via λ'_{3jk} couplings into a final state including two tau leptons and two b-tagged jets [19]; and via the λ'_{233} coupling into a final state including three leptons and additional jets [18]. The analysis described in this paper is the first search for R-parity violating top squark decays via purely first- or second-generation LQD couplings; in this case, the final states are two leptons ($\mathrm{e}^{\pm}$ or $\mu^{\pm}$) and six jets, two of which are b-tagged jets.

2 The CMS detector

A detailed description of the CMS detector, together with a definition of the coordinate system used, can be found elsewhere [22]. A notable feature of the CMS detector is its 6 m internal diameter superconducting solenoid magnet that provides a field of 3.8 T. Within the field volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter, and a brass and scintillator hadron calorimeter. Muon detectors based on gas ionization chambers are embedded in a steel flux-return yoke located outside the solenoid. Events are collected by a two-layer trigger system based on a hardware level-1 trigger, followed by a software-based high-level trigger.

The pseudorapidity range covered by the tracking system is $|\eta| < 2.5$, the muon detector extends up to $|\eta| < 2.4$, and the calorimeters cover a region with $|\eta| < 3.0$. The region of $3 < |\eta| < 5$ is instrumented with steel and quartz fiber forward calorimeters. The hermeticity of the detector up to large values of $|\eta|$ permits accurate measurement of the momentum balance transverse to the beam direction.

3 Trigger and event selection

Events are selected using a trigger that requires at least one electron (muon) with a transverse momentum (p_T) threshold of 27 (24) GeV, and $|\eta| < 2.5$ (2.1). All objects are reconstructed using a particle-flow (PF) algorithm [23, 24], which uses information from all subsystems to reconstruct photons, electrons, muons, charged hadrons, and neutral hadrons.

To reduce the background from jets containing leptons, we impose isolation constraints on the transverse energy $E_{T,cone}$ from charged-particle tracks or deposits in the calorimeter within a cone $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.3\,(0.4)$ around the trajectory of the electron (muon), where ϕ is the azimuthal angle. The energy from the reconstructed lepton and the average transverse energy density from pileup are subtracted from $E_{T,cone}$, where pileup is defined as additional inelastic pp collisions within the same or the adjacent LHC bunch crossing. Tracking information together with calorimeter information is used to identify and subtract hadronic energy depositions from charged particles originating from pileup. The contributions to the neutral hadron and photon energy components due to pileup are also computed and subtracted. In the electron channel, the contributions to the neutral hadron and photon energy components due to pileup interactions are subtracted from $E_{T,cone}$ using the jet area technique [25], which computes the transverse energy density of neutral particles from the median of the neutral energy distribution in jets with $p_T > 3$ GeV on an event-by-event basis. In the muon channel, the method assumes the pileup energy density from neutral particles to be half of that from charged hadrons, based on measurements performed in jets [24].

Electrons are reconstructed by matching an energy cluster in the ECAL with a track reconstructed using a Gaussian sum filter [26]. Electrons are required to have $p_T > 50$ GeV and $|\eta| < 2.5$. The transition region between the ECAL barrel and endcap is excluded ($1.444 < |\eta| < 1.566$) because the calorimeter is not well modeled in this region. Electrons are identified using a multivariate identification algorithm [26], whose input variables are sensitive to bremsstrahlung along the electron path, matching between tracks and ECAL energy deposits, and shower-shape variables. The algorithm is trained with a sample of simulated Drell–Yan (DY) events that contains true electrons and a data sample enriched in misidentified electrons. In addition, the transverse impact parameter of the electron track is required to be less than 2 mm. To reduce backgrounds that arise from photon conversions in the inner pixel detector, at least one pixel hit in the innermost pixel layer is required and the electron must be inconsistent with the hypothesis that it resulted from photon pair creation. We ensure that the electron is isolated from other activity in the event by requiring that $E_{T,cone}$ be less than 10% of the electron p_T.

Muon tracks are reconstructed using the information from the muon chambers and the silicon tracker and are required to be consistent with the reconstructed primary vertex. The tracks are required to have at least one hit in both the pixel tracker and muon detector, and at least six hits in the silicon strip tracker. Muons are required to have $p_T > 50$ GeV and $|\eta| < 2.1$. Most cosmic ray muons are rejected by requiring that the transverse (longitudinal) impact parameter be less than 2 (5) mm relative to the primary vertex, defined as the vertex with the largest sum of the p_T^2 from all tracks associated with it. Only muons with at least ten hits in the silicon strip tracker and at least one hit in the pixel detector are considered, which ensures a precise momentum measurement. Isolation is imposed by the requirement that $E_{T,cone}$ be less than 12%

of the muon p_{T} [27].

The differences in lepton reconstruction and trigger efficiencies between data and simulation are corrected in simulation in bins of p_{T} and η, using a tag-and-probe method [28].

Jets are reconstructed from PF objects [29] using the anti-k_{T} clustering algorithm [30] with a distance parameter of 0.5. The tracker and ECAL granularity are exploited to precisely measure the charged particles, and hence to determine jet directions at the production vertex. To remove jets arising from instrumental and non-collision backgrounds, additional criteria on charged and neutral hadron energy are applied.

The energy and momentum of each jet are corrected as a function of the jet p_{T} and η to account for the combined response function of the calorimeters. The average energy from pileup is subtracted from the jet [31]. Only jets within $|\eta| < 2.4$ are considered. The corrected jet p_{T} must be at least 100 GeV for the leading jet, 50 GeV for the second-leading jet, and 30 GeV for the remaining jets. At least five jets are required in the event.

Events with at least one b-tagged jet are selected. The combined secondary-vertex algorithm [32] uses information from the track impact parameter and vertex information to discriminate between jets that originate from b quarks and jets from light-flavor quarks and gluons. The algorithm correctly identifies jets produced by the hadronization of a b quark (b jets) with an efficiency of approximately 70% and misidentifies jets from light-flavor quarks or gluons (charm quarks) at a rate of approximately 1% (20%) [32]. The b-tagging efficiency in the simulation is scaled to match the measured efficiency in data as a function of p_{T}, η, and the flavor of the jet.

The missing transverse momentum $\vec{p}_{\mathrm{T}}^{\text{miss}}$ in the event is defined as the projection of the negative vector sum of the momenta of all reconstructed PF candidates on the plane perpendicular to the beams. The magnitude of $\vec{p}_{\mathrm{T}}^{\text{miss}}$ in the event is referred to as $E_{\mathrm{T}}^{\text{miss}}$. To suppress leptonic $\mathrm{t\bar{t}}$ decays that often have significant $E_{\mathrm{T}}^{\text{miss}}$ because of the presence of neutrinos in the final state, $E_{\mathrm{T}}^{\text{miss}}$ is required to be less than 100 GeV. The dilepton mass $M_{\ell\ell}$, computed from the two lepton four-momenta, is required to be greater than 130 GeV, based on an optimization to reduce the contribution from low-mass resonances and Z boson decays.

To enhance the statistical significance, for each lepton flavor the sample is divided into three exclusive categories of jet multiplicity: $N_{\text{jets}} = 5, 6, \text{or} \geq 7$. To improve the sensitivity to signal decays, we compute an S_{T} threshold $S_{\mathrm{T}}^{\text{min}}$ optimized for each top squark mass hypothesis and for each N_{jets} bin. The $S_{\mathrm{T}}^{\text{min}}$ is determined by maximizing the value of $\mathrm{S}/\sqrt{\mathrm{S}+\mathrm{B}}$, where S and B are the number of expected signal and background events above $S_{\mathrm{T}}^{\text{min}}$, respectively.

4 Simulation of background and signal events

Monte Carlo (MC) simulations of background and signal events are used to optimize the selection criteria for maximum signal sensitivity and to estimate backgrounds. The simulation of the hard-scattering event is performed using the leading-order (LO) matrix element event generator MADGRAPH 5 [33], unless noted otherwise. The CTEQ6L1 [34] set of parton distribution functions (PDF) is used to describe the proton structure. The simulation of the hard-scattering event is then passed to PYTHIA 6.426 [35] with the Z2* tune [36] to model the parton shower, hadronization, and the underlying event. A full simulation of the response of the CMS detector is performed using GEANT4 [37]. Additional simulated minimum bias events are overlaid to reproduce the effects of pileup.

The main SM backgrounds for this search are DY and $\mathrm{t\bar{t}}$ pair production. Additional SM backgrounds, which include diboson (WW, WZ, and ZZ) and single top quark production, are small. The $t\bar{t}$ sample is generated with up to three additional partons, the DY events are produced with up to four additional partons, and the diboson samples are generated with up to two additional partons. Single top quark production (t-, s-, and tW-channels) is simulated with POWHEG v1.0 [38–42]. Simulated samples of $t\bar{t}$ and DY are normalized using cross sections computed at next-to-next-to-leading-order (NNLO) [43, 44]. Cross sections computed at next-to-leading-order (NLO) [45, 46] are used to normalize the single top quark and diboson samples.

The signal samples are generated using MADGRAPH 5, PYTHIA 6.426, and the CTEQ6L1 PDF set. The top squark pair production cross section is computed at NLO as a function of $M_{\tilde{t}}$, including soft gluon resummation at next-to-leading logarithm (NLL) [47–50]. The uncertainty in the cross section includes uncertainties associated with the renormalization and factorization scale, and the PDF set [51].

5 Background estimation

Corrections to the normalization of $t\bar{t}$ and DY simulations are estimated by examining background enriched samples in data. A summary of the selection criteria for the signal search region and the control regions, including selections on the dilepton mass, is presented in Table 1. Diboson and single top quark production yield small contributions to the background and are estimated from simulation. In simulated $t\bar{t}$ sample, events are reweighted so that the p_T of the top quark matches the data in a dedicated control sample [52].

Table 1: Summary of the selection criteria for the signal region and the control regions. Data in the control regions described as $t\bar{t}$, DY normalization, and DY shape are used to estimate SM backgrounds in the signal region.

		Lepton selection	N_{jets}	N_{b-tags}
Signal region		$e^{\pm}e^{\mp}(\mu^{\pm}\mu^{\mp})$, $M_{\ell\ell} > 130\,\mathrm{GeV}$	≥ 5	≥ 1
Control regions	$t\bar{t}$ shape	$e^{\pm}\mu^{\mp}$	≥ 5	≥ 1
	DY normalization	$e^{\pm}e^{\mp}(\mu^{\pm}\mu^{\mp})$, $50 < M_{\ell\ell} < 130\,\mathrm{GeV}$	≥ 5	≥ 1
	DY shape	$e^{\pm}e^{\mp}(\mu^{\pm}\mu^{\mp})$, $50 < M_{\ell\ell} < 130\,\mathrm{GeV}$	≥ 5	0

The leptonic $t\bar{t}$ decays contribute to 89% of the total background. Since the signal produces only same-flavor leptons, we estimate the $t\bar{t}$ background from a control sample of $e^{\pm}\mu^{\mp}$ events after correcting it for the small contributions of DY, diboson, and single top events using simulations. We use this control sample to compute correction factors for the $t\bar{t}$ simulation for different jet multiplicities in the signal region. The $e^{\pm}\mu^{\mp}$ control sample is well modeled by the simulation, thus correction factors are statistically consistent with unity.

The Drell–Yan production constitutes approximately 8% of the SM background in the signal region, and is reduced by requiring at least one b-tagged jet. The contribution from this source is estimated using a control sample of two oppositely charged same-flavor leptons, which have an invariant mass $M_{\ell\ell}$ in the range 50–130 GeV. We perform a fit to the $M_{\ell\ell}$ distribution to estimate the number of DY events. The DY shape is obtained from background-subtracted data using a DY-enriched sample with no b-tagged jets. The background from diboson decays including leptonic Z boson decays is estimated from simulation and is constrained in the fit. The $M_{\ell\ell}$ shape for the remaining backgrounds does not exhibit a Z boson mass peak, and is described by a linear function. The fit determines the number N_{DY} of DY events and the number of all other background events. To check that the procedure is insensitive to a potential signal contamination, we performed a fit with signal events included, and observed that the obtained N_{DY} is independent of the presence of the potential signal in the control sample. The ratio of N_{DY} from the fit to the simulated number of DY events is calculated for each value of N_{jets} and is used to correct the simulation. This correction factor ranges from 1.2 ± 0.1 to 2.1 ± 0.6 and increases with jet multiplicity.

We checked that the corrections to the DY normalization are valid in the signal region with $M_{\ell\ell} > 130$ GeV. We compared the numbers of events in different mass ranges using a DY-enriched sample with at least five jets and no b-tagged jets. The ratio of the number of events with $M_{\ell\ell}$ in the Z-peak (normalization region) to the number with $M_{\ell\ell}$ in the high-mass tail (signal region) is predicted from simulation to be 11.8 ± 0.4 and observed to be 14.0 ± 3.5 in data, in reasonable agreement.

6 Systematic uncertainties

We evaluate systematic uncertainties related to each background and to the signal reconstruction efficiency; these are summarized in Table 2.

Table 2: Systematic uncertainties for background and expected signal yields.

	Source	Uncertainty (%)
Background estimates	$t\bar{t}$+jets	10–50
	Drell–Yan	50–100
	Diboson	30
	Single top quark	30
	MC statistics	10–30
Expected signal yield	Jet energy scale	5
	b tagging scale factor	1–3
	Integrated luminosity	2.6
	Lepton identification	3
	Electron energy scale	2
	Muon momentum scale	0.9
	Trigger efficiency	1
	Lepton isolation	5
	MC statistics	2–7

Since the $t\bar{t}$ correction factor for the simulated sample is estimated from a control sample of $e^{\pm}\mu^{\mp}$ events in data, the systematic uncertainty in this background is given by the statistical uncertainty in the control sample. This uncertainty ranges from 10 to 50%, depending on the value of N_{jets} and of S_T^{min}. The uncertainties related to lepton trigger, identification, and isolation are negligible. For the small DY background, we take 50 (100)% of correction factor as the systematic uncertainty on the correction in 5 ($\geq$6) jet bin(s). We assign a 30% uncertainty to the diboson and single top quark background contributions to account for the difference between the NLO theoretical calculation and the CMS measurements of the WW and ZZ cross sections [53] and the single top cross sections [54]. The statistical uncertainty due to the finite size of the simulated background samples is 10–30%, depending on the N_{jets} bin and S_T^{min} value.

The following systematic uncertainties in the signal efficiency are included: jet energy scale (5%) [31], jet b-tagging efficiencies (3%), integrated luminosity (2.6%) [55], lepton identification and reconstruction efficiency (3%), electron energy scale (2%), muon momentum scale (0.9%), and trigger efficiency (1%). Noting the effect of the b-tagging uncertainty on the signal prediction is evaluated by varying the efficiency and misidentification rates by their uncertainties [32, 56], and the effect on the signal prediction. The uncertainty related to the lepton isolation requirement for signal events with many jets is estimated using a $\mathrm{t\bar{t}}$ control sample selected as shown in Table 1, but with ≥ 7 jets, and is determined to be 5%. The uncertainty due to the limited size of the simulated signal sample varies from 2 to 7%. The impact of uncertainties related to the PDF set choice, modeling of the top quark p_{T} spectrum, and pileup modeling is determined to be negligible.

7 Results

Figure 2 shows the observed distributions of jet multiplicity, the estimated background distributions, and the expected distributions for signals with a mass $M_{\tilde{t}}$ of either 300 GeV or 900 GeV. In Tables 3 and 4 we present the numbers of expected and observed events for each value of N_{jets}, for each $M_{\tilde{t}}$ hypothesis and corresponding $S_{\mathrm{T}}^{\min}$ value. The signal expectations are based on NLO cross sections [51]. The data are in agreement with the SM expectation in each bin. The corresponding distributions are displayed graphically in Fig. A.1 of Appendix A.

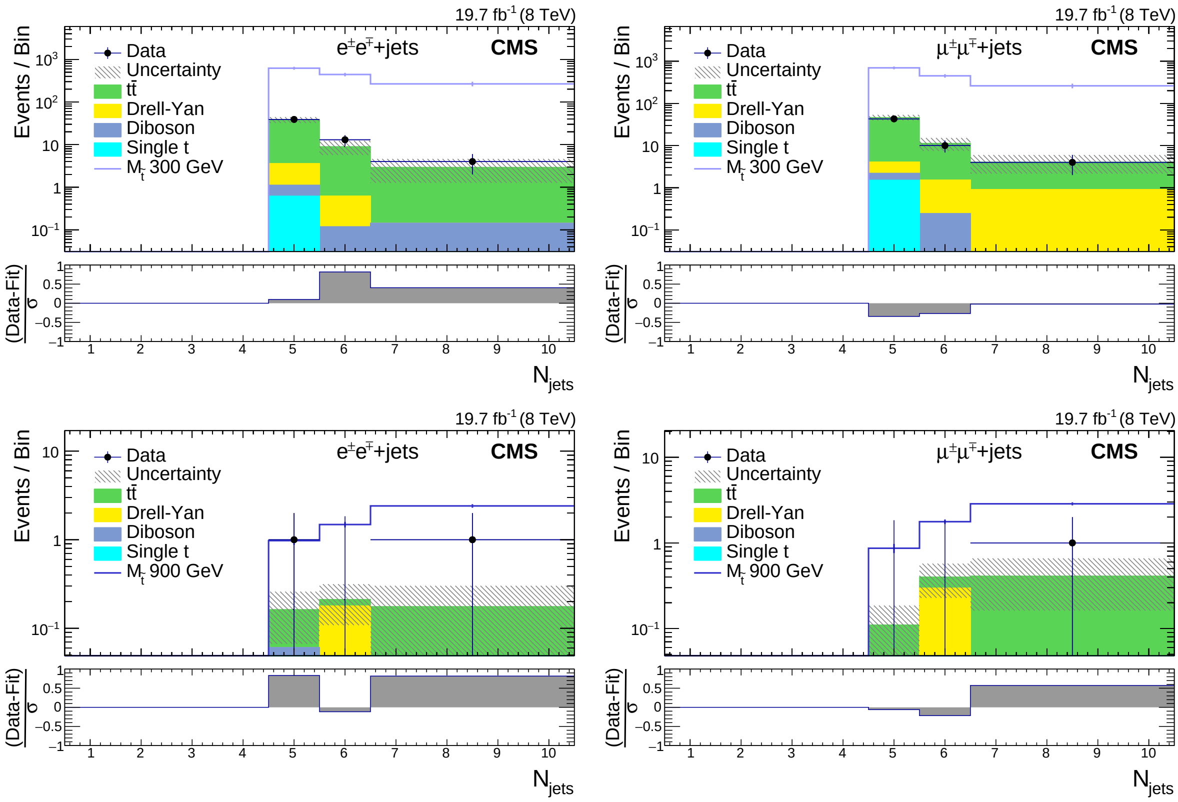

Figure 2: Jet multiplicity distributions for $\mathrm{e}^{\pm}\mathrm{e}^{\mp}$(left) and $\mu^{\pm}\mu^{\mp}$ (right) for selections optimized for $M_{\tilde{t}}$ hypotheses of 300 GeV (top) and 900 GeV (bottom). The expected signal is shown by an open histogram superimposed on the expected SM background. The asymmetric error bars indicate the central confidence intervals for Poisson-distributed data. The systematic uncertainties for the SM contributions are indicated by hatched bands. Under each histogram is shown a plot in gray as the ratio of difference of data from background expectation to the sum of their uncertainties, including the systematic uncertainties in background expectation.

We use these results to determine 95% confidence level (CL) limits, as a function of $M_{\tilde{t}}$, on the product of the top-squark pair-production cross section and the square of the branching fraction $\mathcal{B}$ for the decay $\widetilde{t} \rightarrow b\ell^{\pm}qq$. We use the modified frequentist CL_s method [57] with profiling of nuisance parameters. For each $M_{\widetilde{t}}$ hypothesis, the Poisson likelihoods of the three N_{jets} bins are combined. Systematic uncertainties are incorporated into the test statistic as nuisance parameters. The nuisance parameter probability density function (pdf) for the $t\bar{t}$ background normalization, which is estimated from background control regions containing limited numbers of events in high N_{jets} bins, is described by a gamma function. All other uncertainties are treated with log-normal pdfs. With the exception of uncertainties related to the finite size of a control sample, we assume the systematic uncertainties are fully correlated across different N_{jets} bins.

The observed and expected limits on the product of the cross section and the branching fraction squared are shown in Fig. 3. The green (yellow) band corresponds to a variation of one (two) standard deviation(s) on the expected limit. The dotted curve shows the signal cross section, with the width of the associated band showing the sensitivity to uncertainties in the renormalization and factorization scales and the PDF uncertainties [51]. Comparing the observed cross section limits to the signal cross section, we exclude top squarks with masses less than 890 (1000) GeV for the electron (muon) channel. The expected mass exclusion is 950 (970) GeV for the electron (muon) channel.

These cross section limits strictly apply to models with mass difference $\Delta M_{\widetilde{t},\widetilde{\chi}_1^{\pm}} = 100\,\text{GeV}$; however, the sensitivities for models with $\Delta M_{\widetilde{t},\widetilde{\chi}_1^{\pm}} > 50\,\text{GeV}$ are similar. The mass exclusions assume $\mathcal{B} = 100\%$. As described earlier, the limits for the electron channel apply equally to models with nonzero λ'_{111}, λ'_{112}, λ'_{121}, or λ'_{122} and the limits for the muon channel apply equally to models with nonzero λ'_{211}, λ'_{212}, λ'_{221}, or λ'_{222}. Because the coupling strength does not affect the production cross section and the branching fraction is assumed to be 100%, the value of λ'_{ijk} is not important as long as it is sufficiently large to ensure that the sneutrino decays promptly. For coupling values smaller than 10^{-5}, the decay lengths are of order 1 mm or greater, resulting in a decreased signal reconstruction efficiency and sensitivity. These are the first limits on chargino-mediated top squark decays via a single LQD coupling λ'_{ijk} with $(i, j, k \leq 2)$.

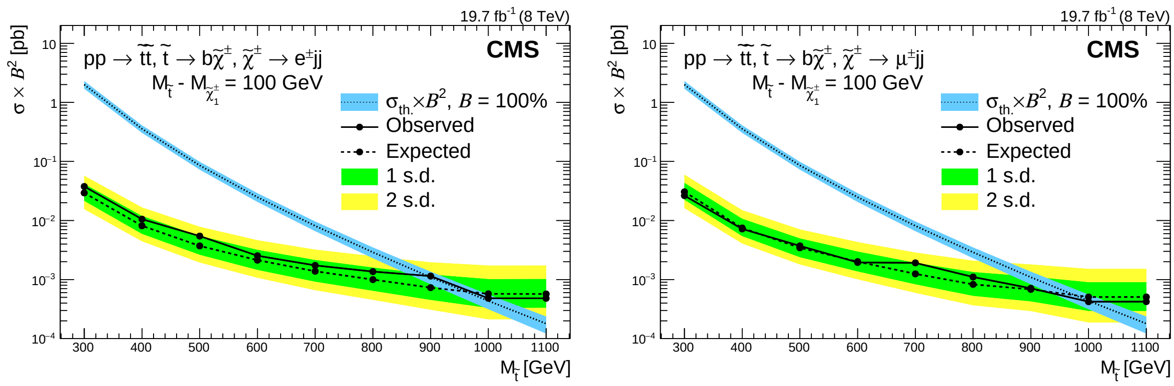

Figure 3: Observed and expected 95% CL upper limits on the product of the cross section and the branching fraction ($\mathcal{B}$) squared, for $e^{\pm}e^{\mp}$(left) and $\mu^{\pm}\mu^{\mp}$ (right). The green (inner) and yellow (outer) bands show the 1 s.d. and 2 s.d. uncertainty ranges in the expected limits, respectively. The dotted curve shows the expected top squark cross section computed at NLO+NLL. The difference $M_{\widetilde{t}}$-$M_{\widetilde{\chi}_1^{\pm}}$ is assumed to be 100 GeV for the signal model.

8 Summary

A search for new phenomena using events with two oppositely charged electrons or muons, at least five jets, with at least one b-tagged jet, and low missing transverse momentum has been performed. No excess over the estimated background is observed. The results are interpreted in the framework of chargino-mediated, R-parity violating top squark decays, assuming a 100% branching fraction for the top squark decay chain, $\widetilde{t} \to b\widetilde{\chi}_1^{\pm}, \widetilde{\chi}_1^{\pm} \to \ell^{\pm} + jj$. In models with a single nonzero λ'_{ijk} coupling with $(i, j, k \leq 2)$, the results exclude top squarks with mass less than 890 (1000) GeV for the electron (muon) channel at 95% confidence level. These limits are the first obtained for this model.

Table 3: Observed events, estimated background, and expected signal yields, for $N_{jets} = 5$, 6, and $\geq$7, along with the optimized value of S_T^{min}, for different $M_{\widetilde{t}}$ in the electron channel. The signal and background uncertainties include both statistical and systematic contributions.

$M_{\widetilde{t}}$ (GeV)	N_{jets}	S_T^{min} (GeV)	Data	Estimated background	Expected signal	Signal efficiency(%)
300	5	325	39	38.1±5.9	622±49	2.4±0.2
300	6	325	13	9.0±3.3	442±41	1.8±0.1
300	≥7	325	4	2.9±1.7	266±33	0.9±0.1
400	5	525	27	28.7±5.6	256±14	5.6±0.2
400	6	325	13	9.0±3.3	245±13	5.3±0.2
400	≥7	325	4	2.9±1.7	180±11	3.8±0.2
500	5	725	12	14.1±3.3	69.2±3.3	6.0±0.2
500	6	675	9	5.3±2.5	88.1±3.7	7.9±0.3
500	≥7	675	4	2.2±1.4	89.7±3.8	8.1±0.3
600	5	925	1	3.4±1.1	19.0±0.9	5.8±0.2
600	6	875	3	2.7±1.0	28.8±1.1	8.9±0.3
600	≥7	825	4	1.8±0.9	38.7±1.3	11.6±0.3
700	5	1025	1	1.6±0.5	7.1±0.3	6.6±0.2
700	6	975	2	1.3±0.5	10.5±0.4	9.6±0.3
700	≥7	975	2	1.1±0.6	14.8±0.5	13.6±0.3
800	5	1225	1	0.4±0.2	2.7±0.1	7.0±0.2
800	6	1175	0	0.4±0.2	3.6±0.2	9.5±0.3
800	≥7	1075	2	0.7±0.4	5.7±0.2	15.1±0.4
900	5	1325	1	0.2±0.1	1.0±0.1	6.7±0.3
900	6	1375	0	0.2±0.1	1.5±0.1	10.1±0.3
900	≥7	1375	1	0.2±0.1	2.4±0.1	16.4±0.4
1000	5	1475	0	0.06±0.07	0.34±0.10	5.7±0.2
1000	6	1425	0	0.18±0.10	0.61±0.09	10.6±0.3
1000	≥7	1525	0	0.05±0.06	0.98±0.09	16.6±0.4
1100	5	1475	0	0.06±0.07	0.12±0.04	5.3±0.2
1100	6	1425	0	0.18±0.10	0.26±0.04	11.2±0.3
1100	≥7	1525	0	0.05±0.06	0.42±0.04	17.6±0.4

Table 4: Observed events, estimated background, and expected signal yields, for $N_{\rm jets} = 5$, 6, and $\geq$7, along with the optimized value of $S_{\rm T}^{\rm min}$, for different $M_{\tilde{\rm t}}$ in the muon channel. The signal and background uncertainties include both statistical and systematic contributions.

$M_{\tilde{\rm t}}$ (GeV)	$N_{\rm jets}$	$S_{\rm T}^{\rm min}$ (GeV)	Data	Estimated background	Expected signal	Signal efficiency(%)
300	5	475	43	46.4±7.2	696±52	2.5±0.2
300	6	475	10	11.3±3.8	450±43	1.7±0.1
300	≥7	325	4	4.1±1.9	261±33	0.9±0.1
400	5	525	39	36.8±7.2	266±13	5.4±0.2
400	6	525	10	10.8±3.9	281±14	5.3±0.2
400	≥7	325	4	4.1±1.9	223±12	4.3±0.2
500	5	725	16	16.0±3.8	81.1±4.0	6.3±0.3
500	6	675	9	7.3±3.2	114.4±4.8	8.8±0.3
500	≥7	675	3	3.1±1.6	101.8±4.5	8.3±0.3
600	5	875	5	5.2±1.5	23.7±1.1	6.6±0.3
600	6	825	5	4.6±1.6	36.0±1.3	10.0±0.3
600	≥7	825	2	2.4±1.0	44.2±1.5	12.3±0.3
700	5	1075	2	1.3±0.4	7.7±0.4	6.3±0.2
700	6	975	4	2.4±0.8	13.2±0.5	11.2±0.3
700	≥7	975	2	1.0±0.5	17.8±0.5	14.9±0.4
800	5	1175	0	0.9±0.3	2.9±0.2	6.8±0.3
800	6	1175	2	0.8±0.3	4.5±0.2	10.6±0.3
800	≥7	1125	1	0.4±0.3	7.3±0.2	17.6±0.4
900	5	1475	0	0.1±0.1	0.9±0.1	5.6±0.2
900	6	1325	0	0.4±0.2	1.8±0.1	11.0±0.3
900	≥7	1175	1	0.4±0.3	2.9±0.1	18.1±0.4
1000	5	1575	0	0.07±0.06	0.4±0.1	5.9±0.2
1000	6	1525	0	0.01±0.04	0.6±0.1	10.0±0.3
1000	≥7	1425	0	0.25±0.16	1.2±0.1	18.9±0.4
1100	5	1575	0	0.07±0.06	0.13±0.04	5.2±0.3
1100	6	1525	0	0.01±0.04	0.25±0.04	9.9±0.3
1100	≥7	1425	0	0.25±0.16	0.50±0.04	19.7±0.4

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A Supplementary Material

Figure A.1 shows the number of observed and predicted events in each optimized $S_{\mathrm{T}}^{\mathrm{min}}$ selection for 5th, 6th, and $\geq$ 7th jets for electron and muon channels. The event counts correspond to Tables 3 and 4 respectively.

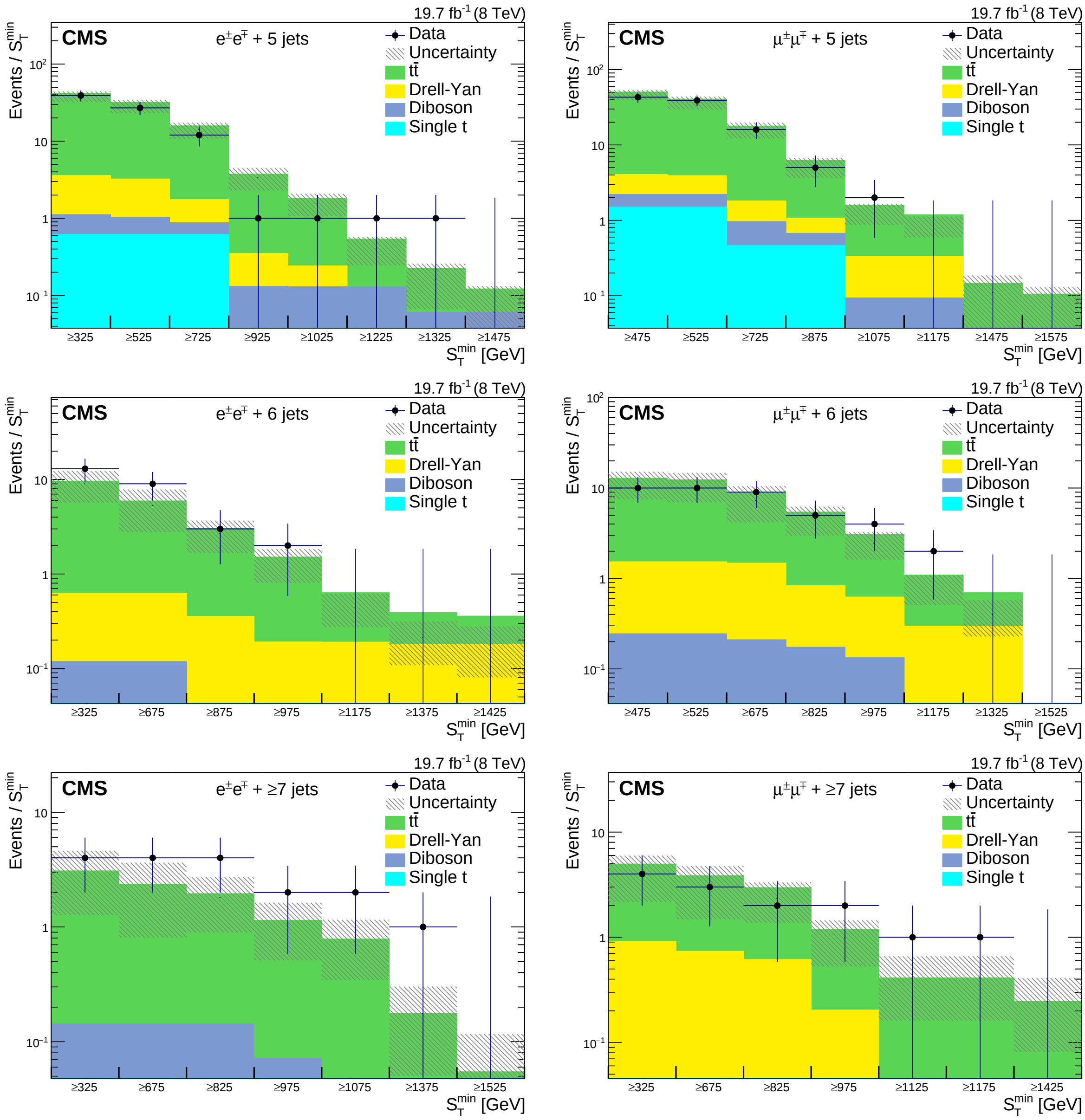

Figure A.1: Events per $S_{\mathrm{T}}^{\mathrm{min}}$ for 5th, 6th, and $\geq$7th jets for $e^{\pm}e^{\mp}$(left) and $\mu^{\pm}\mu^{\mp}$ (right). The $S_{\mathrm{T}}^{\mathrm{min}}$ selections are optimized for $M_{\tilde{t}}$ ranging from 300 to 1100 GeV. The asymmetric error bars indicate the central confidence intervals for Poisson-distributed data.

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5: Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
6: Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
7: Also at Universidade Estadual de Campinas, Campinas, Brazil

8: Also at Centre National de la Recherche Scientifique (CNRS) - IN2P3, Paris, France
9: Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
10: Also at Joint Institute for Nuclear Research, Dubna, Russia
11: Also at British University in Egypt, Cairo, Egypt
12: Now at Suez University, Suez, Egypt
13: Also at Cairo University, Cairo, Egypt
14: Also at Fayoum University, El-Fayoum, Egypt
15: Also at Université de Haute Alsace, Mulhouse, France
16: Also at Tbilisi State University, Tbilisi, Georgia
17: Also at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
18: Also at University of Hamburg, Hamburg, Germany
19: Also at Brandenburg University of Technology, Cottbus, Germany
20: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
21: Also at Eötvös Loránd University, Budapest, Hungary
22: Also at University of Debrecen, Debrecen, Hungary
23: Also at Wigner Research Centre for Physics, Budapest, Hungary
24: Also at Indian Institute of Science Education and Research, Bhopal, India
25: Also at University of Visva-Bharati, Santiniketan, India
26: Now at King Abdulaziz University, Jeddah, Saudi Arabia
27: Also at University of Ruhuna, Matara, Sri Lanka
28: Also at Isfahan University of Technology, Isfahan, Iran
29: Also at University of Tehran, Department of Engineering Science, Tehran, Iran
30: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran
31: Also at Laboratori Nazionali di Legnaro dell'INFN, Legnaro, Italy
32: Also at Università degli Studi di Siena, Siena, Italy
33: Also at Purdue University, West Lafayette, USA
34: Also at International Islamic University of Malaysia, Kuala Lumpur, Malaysia
35: Also at Malaysian Nuclear Agency, MOSTI, Kajang, Malaysia
36: Also at Consejo Nacional de Ciencia y Tecnología, Mexico city, Mexico
37: Also at Warsaw University of Technology, Institute of Electronic Systems, Warsaw, Poland
38: Also at Institute for Nuclear Research, Moscow, Russia
39: Now at National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia
40: Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia
41: Also at California Institute of Technology, Pasadena, USA
42: Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia
43: Also at INFN Sezione di Roma; Università di Roma, Roma, Italy
44: Also at National Technical University of Athens, Athens, Greece
45: Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy
46: Also at National and Kapodistrian University of Athens, Athens, Greece
47: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
48: Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland
49: Also at Gaziosmanpasa University, Tokat, Turkey
50: Also at Mersin University, Mersin, Turkey
51: Also at Cag University, Mersin, Turkey
52: Also at Piri Reis University, Istanbul, Turkey
53: Also at Adiyaman University, Adiyaman, Turkey
54: Also at Ozyegin University, Istanbul, Turkey

55: Also at Izmir Institute of Technology, Izmir, Turkey
56: Also at Marmara University, Istanbul, Turkey
57: Also at Kafkas University, Kars, Turkey
58: Also at Istanbul Bilgi University, Istanbul, Turkey
59: Also at Yildiz Technical University, Istanbul, Turkey
60: Also at Hacettepe University, Ankara, Turkey
61: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
62: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
63: Also at Instituto de Astrofísica de Canarias, La Laguna, Spain
64: Also at Utah Valley University, Orem, USA
65: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
66: Also at Facoltà Ingegneria, Università di Roma, Roma, Italy
67: Also at Argonne National Laboratory, Argonne, USA
68: Also at Erzincan University, Erzincan, Turkey
69: Also at Mimar Sinan University, Istanbul, Istanbul, Turkey
70: Also at Texas A&M University at Qatar, Doha, Qatar
71: Also at Kyungpook National University, Daegu, Korea