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Search for flavor changing neutral currents in top quark decays in pp collisions at 7 TeV [☆]

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ABSTRACT

The results of a search for flavor changing neutral currents in top quark decays $t \to Zq$ in events with a topology compatible with the decay chain $t\bar{t} \to Wb + Zq \to \ell\nu b + \ell\ell q$ are presented. The search is performed with a data sample corresponding to an integrated luminosity of 5.0 fb^{-1} of proton–proton collisions at a center-of-mass energy of 7 TeV, collected with the CMS detector at the LHC. The observed number of events agrees with the standard model prediction and no evidence for flavor changing neutral currents in top quark decays is found. A $t \to Zq$ branching fraction greater than 0.21% is excluded at the 95% confidence level.

1. Introduction

The top quark decays with a branching fraction of nearly 100% to a bottom quark and a W boson, $t \to Wb$. However, some extensions of the standard model (SM) predict that the top quark can also decay through a neutral Z boson, $t \to Zq$, where q is a u or c quark. This decay is suppressed in the SM by the GIM mechanism [1] and occurs at the level of quantum loop corrections only. The branching fraction $\mathcal{B}(t \to Zq)$ is predicted to be $\mathcal{O}(10^{-14})$ [2], far below the experimental reach of the Large Hadron Collider (LHC). Detection of this signal would therefore be an indication of a large enhancement in the branching fraction and clear evidence for violations of the SM prediction. There are several models, for example R-parity-violating supersymmetric models [3] and topcolor-assisted technicolor models [4], that predict enhancements of the $t \to Zq$ decay where $\mathcal{B}(t \to Zq)$ could be as large as $\mathcal{O}(10^{-4})$.

Previous searches for the flavor changing neutral currents in top quark decays performed at the Tevatron by CDF and D0 determined a $\mathcal{B}(t \to Zq)$ upper limit of 3.7% [5] and 3.2% [6] at the 95% confidence level (CL), respectively. At a center-of-mass energy of 7 TeV, the $t\bar{t}$ production cross section at the LHC at the next-to-leading order is 157.5 pb for an assumed top quark mass of 172.5 GeV, which is twenty times larger than that at the Tevatron at a center-of-mass energy of 2 TeV. This enables event samples with leptonically decaying vector bosons to be used more effectively. These samples have well determined backgrounds. A recent search in the three-lepton channels performed at ATLAS with an integrated luminosity of 2.1 fb^{-1} reported a $\mathcal{B}(t \to Zq)$ upper limit of 0.73% [7].

We expect $\mathcal{B}(t \to Zq)$ to be small and look for $t\bar{t} \to Zq + Wb \to \ell\ell q + \ell\nu b$ final state events, which produce three-lepton ($eee, ee\mu, \mu\mu e, \mu\mu\mu$) final states. This choice results in a measurement with reduced background and fewer signal events. The analysis uses a data sample corresponding to an integrated luminosity of 5.0 fb^{-1} of proton–proton collisions at $\sqrt{s} = 7$ TeV, recorded by the Compact Muon Solenoid (CMS) experiment during 2011.

2. The CMS detector

The central feature of the CMS apparatus is a superconducting solenoid, 13 m in length and 6 m in diameter, which provides an axial magnetic field of 3.8 T. Within the field volume there are several particle detection systems. Charged particle trajectories are measured by silicon pixel and silicon strip trackers, covering $0 \leqslant \phi \leqslant 2\pi$ in azimuth and $|\eta| < 2.5$ in pseudorapidity, where η is defined as $-\log[\tan\theta/2]$ and θ is the polar angle of the trajectory of the particle with respect to the counterclockwise proton beam direction. A crystal electromagnetic calorimeter and a brass/scintillator hadron calorimeter surround the tracking volume, providing energy measurements of photons, electrons and hadron jets. Muons are identified and measured in gas-ionization detectors embedded in the steel return yoke outside the solenoid. The detector is nearly hermetic, allowing energy balance measurements

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in the plane transverse to the beam direction. A two-tier trigger system selects the most interesting proton–proton collision events for use in physics analysis. A more detailed description of the CMS detector can be found in Ref. [8].

3. Basic selection

Events with two opposite-sign, isolated leptons (e or μ) consistent with a Z-boson decay and an extra charged lepton are selected, $e^+e^-e^\pm$, $e^+e^-\mu^\pm$, $\mu^+\mu^-e^\pm$, $\mu^+\mu^-\mu^\pm$. All three leptons must be isolated and have transverse momentum $p_T > 20$ GeV, and the electrons (muons) must have $|\eta| < 2.5$ ($|\eta| < 2.4$). Events are required to pass at least one of the ee or $\mu\mu$ high-p_T double-lepton triggers. Their efficiencies for events containing two leptons satisfying the analysis selection are measured to be 99%, 98%, 91% and 93% for the eee, eeμ, $\mu\mu$e and $\mu\mu\mu$ channels, respectively.

Muon candidates are reconstructed with a global fit of trajectories using hits in the tracker and the muon system. The muon candidate must have associated hits in the silicon strip and pixel detectors, have segments in the muon chambers, and have a high-quality global fit to the track trajectory. The efficiency for these muon selection criteria is at least 99% [9].

Electron reconstruction starts from clusters of energy deposits in the electromagnetic calorimeter, which are matched to hits in the silicon strip and the pixel detectors. Electrons are identified using variables which include the ratio between the energy deposited in the hadron and the electromagnetic calorimeters, the shower width in η, and the distance between the calorimeter shower and the particle trajectory in the tracker, measured in both η and ϕ. The selection criteria used are optimized [9] to maintain an efficiency of approximately 95% for the electrons from W or Z decays.

The invariant mass of at least one e^+e^- or $\mu^+\mu^-$ pair is required to be between 60 GeV and 120 GeV. If two dilepton pairs lie in this mass window, the one closest to the Z mass is taken. Due to the high instantaneous luminosity of the LHC, there are multiple interactions per bunch crossing (pileup). Therefore, events are required to have at least one good primary vertex, which is chosen as the vertex with the highest $\sum p_T^2$ of its associated tracks. All leptons, which are used to select or reject events, must come from the same primary vertex. The $\mu^+\mu^-$ pair opening angle is required to differ from π radians by more than 0.05 radians to reject cosmic rays.

Electrons and muons from Z and W decays are expected to be isolated from other particles. A cone of size $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.3$ is constructed around the lepton momentum direction. The lepton relative isolation is quantified by summing the transverse energy (as measured in the calorimeters) and the transverse momentum (as measured in the silicon tracker) of all objects within this cone, excluding the lepton, and then dividing by the lepton transverse momentum [10]. The resulting quantity, corrected for additional underlying event activity due to pileup events, is required to be less than 0.125 (0.1) for $Z \to \ell^+\ell^-$ ($W \to \ell\nu$). This requirement rejects misidentified leptons and background arising from hadronic jets.

The third lepton in the event should be the result of a leptonic decay of a W boson. In order to increase the electron purity, more stringent reconstruction requirements are used for $W \to e\nu$ candidates. In this case the selection criteria are optimized [9] to reject the background from jets while maintaining an efficiency of 80% for the electrons from W or Z decays. The muon purity for the Z selection described above is high and the same reconstruction requirements are used to identify $W \to \mu\nu$ candidates. Events with a fourth lepton satisfying the $W \to \ell\nu$ criteria are rejected.

The jets and the missing transverse energy vector ($-\sum \vec{p}_T$) and its magnitude ($\not{E}_T$) are reconstructed using a particle-flow technique [11]. An anti-k_T clustering algorithm [12] with a distance parameter of 0.5 is used for jet reconstruction. The energy calibration [13] is performed separately for each particle type in the jet, and the resulting jet energies require only a small correction accounting for thresholds and residual inefficiencies. In addition, a correction for pileup is included and jets are required to satisfy identification criteria that eliminate jets originating from noisy channels in the calorimeters [14,15]. Jets are required to have $p_T > 30$ GeV, $|\eta| < 2.4$, and to be separated by $\Delta R > 0.4$ from leptons passing the analysis selection. Neutrinos from W-boson decays escape detection and produce a significant momentum imbalance in the detector. We require the missing transverse energy to be larger than 30 GeV.

The samples of Drell–Yan events with invariant mass of lepton pairs $m_{\ell\ell}$ larger than 50 GeV, SM $t\bar{t}$, $Zt\bar{t}$, $Wt\bar{t}$ and WZ are generated using MadGraph [16]. The samples of WW and ZZ diboson events are simulated using pythia [17], while single-top-quark events are generated using powheg [18–20]. The signal sample $pp \to t\bar{t} \to Zq + Wb \to \ell^+\ell^-q + \ell^\pm\nu b$ ($\ell = e, \mu, \tau$) is generated with MadGraph and the top quarks decay and hadronize through pythia. Due to the loss of top quark spin information for FCNC in pythia, events are reweighted according to the SM prediction of the helicity distribution. This study is not sensitive to the choice of anomalous coupling settings, which are taken into account in systematic uncertainties. The set of parton distribution functions used is CTEQ6L [21]. The CMS detector response is simulated using a Geant4-based [22] model, and the events are reconstructed and analyzed using the same software used to process collision data. The simulated events are weighted so that the trigger efficiencies, reconstruction efficiencies and the distribution of reconstructed vertices observed in data are reproduced.

The observed and expected yields based on MC after the basic event selection described above are listed in Table 1. The initial data sample of 1.3 (1.6) million Z to ee ($\mu\mu$) events is reduced to less than 100 events per three-lepton channel. All entries in Table 1 also include the τ decay mode contributions. Single-top-quark production is dominated by the Wt channel. The total yields are dominated by diboson production and a reasonable agreement is observed between data and simulation. The details of the background estimations are discussed in Section 5.

Fig. 1 shows the distributions for data and simulated events of the missing transverse energy, transverse mass of the W boson candidate (m_T), and the scalar sum of the transverse energy S_T, after the trigger, Z boson, third lepton, fourth-lepton veto, missing transverse energy, and the additional requirement of two or more jets. The S_T variable is defined as $\sum p_{T\ell} + \sum p_{Tj} + \not{E}_T$, where only the three leptons and two jets from the $t\bar{t}$ candidate are considered. The m_T is calculated using the transverse momentum and azimuthal direction of the third lepton and the magnitude and direction of the missing transverse energy, as $\sqrt{2p_{T\ell}\not{E}_T(1-\cos(\Delta\phi))}$.

4. Signal reconstruction

For the $t \to Zq \to \ell^+\ell^-j$ signal, a full reconstruction of the top quark mass m_{Zj} is possible and straightforward, but the possibility of a combinatorial background arises since there is no unambiguous way to pair multiple light-quark jets with the Z boson. Therefore all possible combinations are examined.

The invariant mass of the W and b jet system (m_{Wb}) can be reconstructed by assuming that the transverse components of the neutrino momentum are given by the missing transverse energy vector information, while the longitudinal component is calculated as

Table 1
Event yields and background predictions based on simulated events for all three-lepton channels after the basic event selection, which includes the trigger, Z boson, third lepton, fourth-lepton veto and missing transverse energy requirements for an integrated luminosity of 5.0 fb^{-1}. The uncertainties include the statistical and systematic components separately (in that order).

Channel	$\mu\mu e$	$\mu\mu\mu$	eee	$ee\mu$
Drell–Yan	2.0 ± 0.9 ± 0.3	0.9 ± 0.6 ± 0.1	2.8 ± 1.1 ± 0.4	0.9 ± 0.6 ± 0.1
WZ	46.1 ± 0.3 ± 6.1	60.3 ± 0.4 ± 8.0	40.9 ± 0.3 ± 5.4	48.6 ± 0.4 ± 6.4
ZZ	17.7 ± 0.2 ± 2.3	21.7 ± 0.2 ± 2.9	15.1 ± 0.2 ± 2.0	18.2 ± 0.1 ± 2.4
Zt$\bar{\text{t}}$	2.2 ± 0.1 ± 1.4	2.4 ± 0.1 ± 1.5	2.0 ± 0.1 ± 1.2	2.3 ± 0.1 ± 1.4
Wt$\bar{\text{t}}$	0.31 ± 0.02 ± 0.21	0.26 ± 0.02 ± 0.18	0.21 ± 0.02 ± 0.14	0.29 ± 0.02 ± 0.20
WW	$\leqslant$ 0.001	$\leqslant$ 0.001	0.18 ± 0.06 ± 0.01	$\leqslant$ 0.001
t$\bar{\text{t}}$	$\leqslant$ 0.001	0.5 ± 0.2 ± 0.1	0.9 ± 0.5 ± 0.1	0.9 ± 0.4 ± 0.1
Single top	$\leqslant$ 0.001	0.14 ± 0.09 ± 0.02	$\leqslant$ 0.001	$\leqslant$ 0.05
Total	69 ± 1 ± 7	86 ± 1± 9	62 ± 1 ± 6	72 ± 1 ± 7
Observed	73	87	85	61

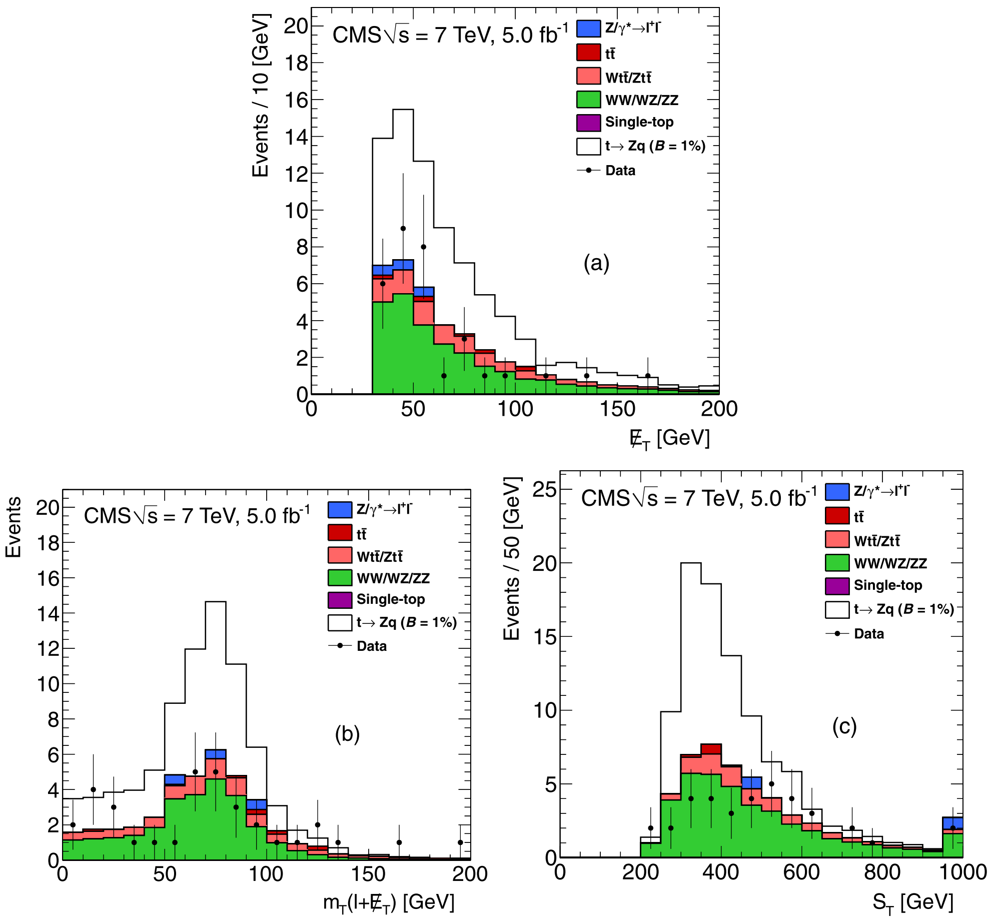

Fig. 1. Comparison between data and simulated events for an integrated luminosity of 5.0 fb^{-1}, after the basic event selection described in Section 3 and requiring at least two jets, for: (a) the missing transverse energy distribution, (b) the reconstructed $\ell\nu$ transverse mass of the W boson candidate, and (c) the scalar sum of the transverse energy for the jets, charged leptons, and neutrino, S_T. The data are represented by the points with error bars and the open histogram shows the expected signal assuming $\mathcal{B}(\text{t} \to \text{Zq})$ is equal to 1%. Stacked solid histograms represent the dominant backgrounds. The statistical uncertainties of these backgrounds are around a few percent level and are not drawn.

$$p_{z\nu} = \frac{p_{z\ell}(p_{x\ell}p_{x\nu} + p_{y\ell}p_{y\nu} + m_{\text{W}}{}^2/2)}{E_\ell^2 - p_{z\ell}^2} \pm \frac{E_\ell\sqrt{(p_{x\ell}p_{x\nu} + p_{y\ell}p_{y\nu} + m_{\text{W}}{}^2/2)^2 - E_{\text{T}\nu}^2(E_\ell^2 - p_{z\ell}^2)}}{E_\ell^2 - p_{z\ell}^2},$$

where E_ℓ, $p_{x\ell}$, $p_{y\ell}$, and $p_{z\ell}$ are the energy and momentum components for the lepton, while the neutrino $E_{\text{T}\nu}$, $p_{x\nu}$ and $p_{y\nu}$ are estimated from the reconstructed missing transverse energy magnitude and direction, and imposing the constraint that the invariant mass of the lepton and the neutrino is equal to the W-boson mass (m_{W}). If the discriminant is found to be negative, it is set equal to zero. In events in which there are two possible solutions for $p_{z\nu}$, the solution with the smaller magnitude of $p_{z\nu}$ is taken; studies with simulated signal events show that this solution is the correct one more than 60% of the time.

Next, we add the requirements on jets, m_{Zj}, and m_{Wb} to the basic selection described in Section 3, and search for $\text{t}\bar{\text{t}} \to \text{Wb} + \text{Zq}$ in two ways. One selection requires a minimum value of S_T and loose requirements on m_{Zj} and m_{Wb}. The second selection is

Table 2
Signal selection efficiency for each three-lepton channels in percent. The efficiency is calculated as the fraction of events with leptonically (e, μ, τ) decaying W and Z bosons passing the selection. Only statistical uncertainties are shown.

Channel	S_T selection [%]	b-tag selection [%]
eee	(12.4 ± 1.1)	(3.8 ± 0.6)
eeμ	(13.8 ± 1.2)	(5.0 ± 0.7)
$\mu\mu$e	(14.8 ± 1.2)	(5.1 ± 0.7)
$\mu\mu\mu$	(14.7 ± 1.2)	(5.3 ± 0.7)

stricter, with tight requirements on the m_{Zj} and m_{Wb} quantities and the requirement that one of the jets should be consistent with the hadronization of a b quark, namely a “b jet”. In this Letter, we refer to these two selections as the “S_T” and “b-tag” selections, respectively. The first selection is the more sensitive and hence is taken as the reference analysis. Table 2 shows the estimates of the overall signal efficiency determined from simulated events.

4.1. S_T selection

In the S_T selection, at least two jets with $p_T > 30$ GeV are required, which are assumed to come from the primary vertex. A constituent track candidate in a jet is removed from the reconstruction if it does not point to the same vertex, but there is no association requirement between jets and the Z candidate which is chosen in the basic selection.

A candidate event is required to have S_T above 250 GeV, m_{Zj} and m_{Wb} are required to be between 100 GeV and 250 GeV. The S_T requirement reduces the boson-jet combinations. The S_T distribution of the best candidate is shown in Fig. 1. All possible $t\bar{t}$ combinations are examined and the reconstructed $t\bar{t}$ pair that has the largest separation in azimuthal angle is selected. Fig. 2 (top) shows the comparison of the distributions of m_{Zj} and m_{Wb} in data and simulation after the basic event selection described in Section 3 (Table 1), combined with the two or more jets and the S_T requirements.

4.2. b-tag selection

To further reduce the background from diboson events, a b-tag based selection is performed. In this selection, at least two jets are required to be associated with the primary vertex associated with the Z candidate and the event can contain only one b jet.

The b jets are identified by the track counting high-efficiency b-tagging algorithm described in Ref. [23], which relies on tracks with large impact parameter significance. This tagging method has an identification efficiency of 65% to 85% for b jets with transverse momentum between 30 GeV to 100 GeV and a misidentification rate below 15%.

The jet which gives the invariant mass of m_{Zj} closest to the top mass is selected and the reconstructed top quark mass m_{Zj}

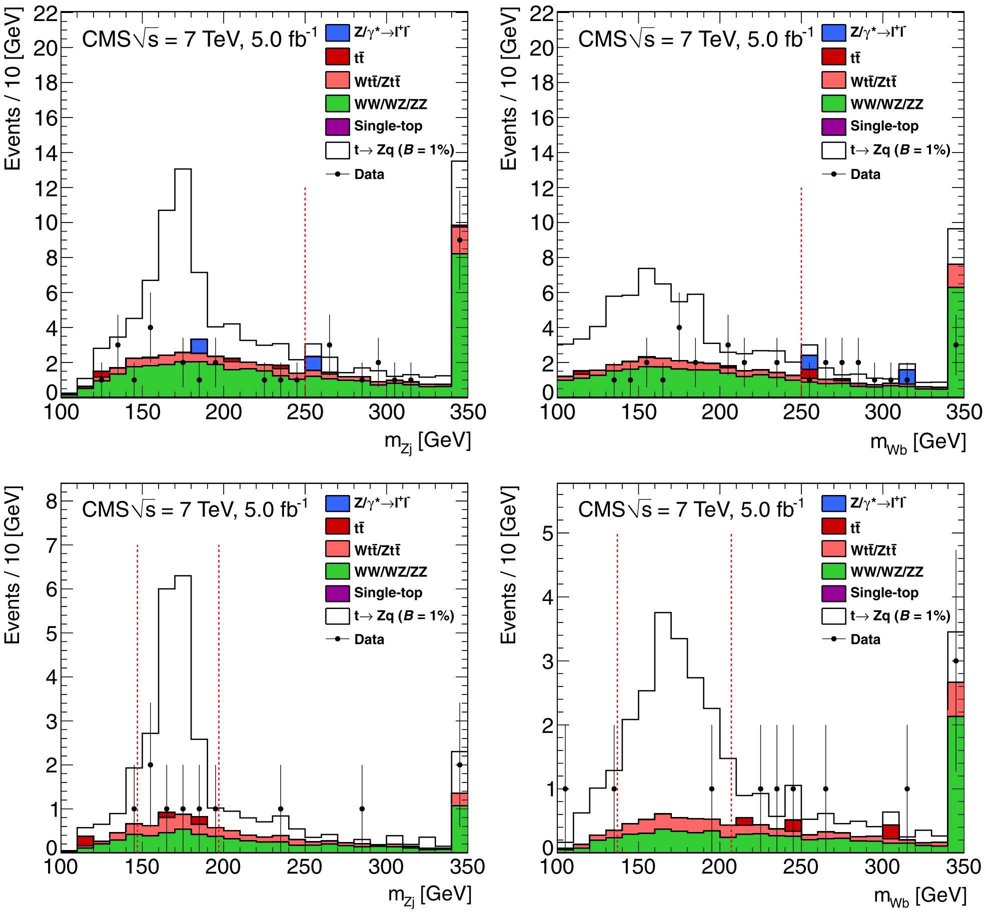

Fig. 2. Comparison between data and simulated events of the m_{Zj} and m_{Wb} distributions after the basic event selection described in Section 3 for an integrated luminosity of 5.0 fb^{-1}, requiring at least two jets and: (top) the minimum S_T value, as required in the S_T selection; (bottom) exactly one b jet as required in the b-tag based selection. The data are represented by the points with error bars and the open histogram is the expected signal assuming $\mathcal{B}(t \to Zq)$ is equal to 1%. Stacked solid histograms represent the dominant backgrounds. The statistical uncertainties of these backgrounds are around a few percent level and are not drawn. The last bin contains all the overflow events. The red dotted lines show the boundaries of the allowed mass region. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this Letter.)

is required to be within 25 GeV of the assumed top quark mass, $m_{\mathrm{t}} = 172.5$ GeV, while m_{Wb} is required to be within 35 GeV of m_{t}.

Fig. 2 (bottom) shows the comparison between data and simulated events for m_{Zj} and m_{Wb} after the basic event selection and requiring at least two jets, one of which is a b jet.

5. Background estimation

Backgrounds are estimated from the yields of simulated events passing the full selection for WW, WZ, ZZ, $\mathrm{Wt\bar{t}}$, $\mathrm{Zt\bar{t}}$, and single-top-quark production, while estimates based on data are made for Drell–Yan and $\mathrm{t\bar{t}}$ backgrounds. The uncertainties in the background estimation given below include, in order, the statistical and systematic components.

The WZ and ZZ production are the dominant diboson backgrounds. The production of W pairs has a higher cross section, but is unlikely to contain both an extra high-p_{T} lepton and a b jet. The diboson background estimates are $13.6 \pm 0.2 \pm 2.6$ $(0.72 \pm 0.01 \pm 0.15)$ and $1.09 \pm 0.02 \pm 0.21$ $(0.058 \pm 0.001 \pm 0.012)$ for the WZ and ZZ processes in the S_{T} (b-tag) selection. These estimates have been rescaled by 1.3 ± 0.1 to take into account the overall normalization difference observed between data and simulation for the zero jet events, after the event selection given in Section 3. The uncertainty of the rescaling factor estimated from statistical fluctuations in the data contributes to the systematic uncertainties on the diboson background estimates. The single-top-quark background is smaller than 0.01 at the 95% CL in both selections.

The $\mathrm{Zt\bar{t}}$ and $\mathrm{Wt\bar{t}}$ cross sections are of the same order [24]. The corresponding background estimates are $3.75 \pm 0.06 \pm 2.30$ $(0.260 \pm 0.004 \pm 0.160)$ and $0.54 \pm 0.03 \pm 0.36$ $(0.039 \pm 0.002 \pm 0.026)$ for the $\mathrm{Zt\bar{t}}$ and $\mathrm{Wt\bar{t}}$ processes in the S_{T} (b-tag) selection.

The Drell–Yan background is small due to the minimum 30 GeV requirement of missing transverse energy. Other backgrounds from QCD multijet events in which a jet could be misidentified as a lepton are negligible. It is possible for SM $\mathrm{t\bar{t}}$ to satisfy the Z selection when both W bosons decay leptonically into the same flavor, but the third lepton and the top quark mass requirements will reject these events.

The Drell–Yan and $\mathrm{t\bar{t}}$ background estimates are based on two data samples. The first sample is composed of all events satisfying the basic event selection with two or more jets and loose requirements in S_{T}, m_{Zj}, and m_{Wb}. The second sample also has loose requirements in S_{T}, m_{Zj}, and m_{Wb}, but in addition it also has a less stringent isolation criteria for the third lepton. Therefore, the second sample is an admixture of the purer three-lepton sample plus events with a misidentified lepton, originating from jets or heavy-flavor decays, or genuine three-lepton events that were lost in the signal sample due to the more stringent isolation requirement. The number of events in the two samples are then related by the efficiency of events with nominal lepton isolation and the probability of a jet to be misidentified as a lepton. Using the genuine and misidentified lepton efficiencies, which are both determined from data, the yield of genuine and misidentified three-lepton events is found. This measurement is turned into an estimate of the Drell–Yan and $\mathrm{t\bar{t}}$ background after subtracting the contribution from dibosons and taking into account the change in acceptances and efficiencies (e.g. b-tagging) after the full signal selections are made. The total contribution of Drell–Yan and $\mathrm{t\bar{t}}$ events, after the S_{T} and b-tag selections are estimated to be $1.5 \pm 0.5 \pm 0.4$ and $0.06 \pm 0.02 \pm 0.01$, respectively. The statistical and systematic uncertainties are estimated from the amounts of the events of these two data samples and the uncertainty of the lepton isolation efficiencies measured with data. These estimates are compatible with the expectations based on simulated events. The total estimated backgrounds are given in Table 3.

Table 3

Background composition, observed and expected yields, and limits at the 95% CL for all three-lepton channels combined for the selections for an integrated luminosity of 5.0 fb^{-1}. The uncertainties in the background estimation include the statistical and systematic components separately (in that order).

Selection	S_{T}	b-tag
WZ background	$13.59 \pm 0.20 \pm 2.58$	$0.718 \pm 0.011 \pm 0.150$
ZZ background	$1.09 \pm 0.02 \pm 0.21$	$0.058 \pm 0.001 \pm 0.012$
Drell–Yan and $\mathrm{t\bar{t}}$ background	$1.52 \pm 0.46 \pm 0.41$	$0.055 \pm 0.017 \pm 0.012$
$\mathrm{Zt\bar{t}}$ background	$3.75 \pm 0.06 \pm 2.30$	$0.260 \pm 0.004 \pm 0.160$
$\mathrm{Wt\bar{t}}$ background	$0.54 \pm 0.03 \pm 0.36$	$0.039 \pm 0.002 \pm 0.026$
Total background prediction	$20.49 \pm 0.51 \pm 3.51$	$1.13 \pm 0.02 \pm 0.22$
Observed events	11	0
Expected limit at the 95% CL	$\mathcal{B}(\mathrm{t} \to \mathrm{Zq}) < 0.40\%$	$\mathcal{B}(\mathrm{t} \to \mathrm{Zq}) < 0.41\%$
Observed limit at the 95% CL	$\mathcal{B}(\mathrm{t} \to \mathrm{Zq}) < 0.21\%$	$\mathcal{B}(\mathrm{t} \to \mathrm{Zq}) < 0.30\%$

Table 4

Summary of the systematic uncertainties for the event selection in percent for the S_{T} and b-tag selections. There is an additional 2.2% uncertainty due to the luminosity measurement.

Source	S_{T} selection [%]	b-tag selection [%]
Trigger efficiency	4	4
Parton distribution functions	6	6
Lepton selection	7	7
Pileup events	7	7
Missing transverse energy resolution	8	8
Cross sections and rescaling	8	8
b tagging	–	9
Jet energy scale	10	10
Total	19	21

6. Systematic uncertainties

The systematic uncertainties come from the trigger efficiency, choice of parton distribution functions, lepton selection, pileup modeling, missing transverse energy resolution, uncertainty on the $\mathrm{t\bar{t}}$ cross section and diboson rescaling, b-tagging efficiency for high-p_{T} b jets [23], and jet energy scale [13]. The prescription given in [25] is used to determine the uncertainty from the choice of parton distribution functions.

In addition, there is a 2.2% uncertainty on the luminosity measurement [26]. All these sources combine to give a 19% (21%) relative uncertainty on the signal acceptance times efficiency in the S_{T} (b-tag) selection.

The systematic uncertainties are summarized in Table 4. The systematic uncertainty of the background estimation is listed with the total background prediction given in Table 3.

7. Results

In the S_{T} (b-tag) selection, we expect 20.5 ± 3.5 (1.1 ± 0.2) events from the SM background processes and we observe 11 (0) events for all four channels combined. When all statistical and systematic uncertainties are taken into account, the probability for the expected number of events, 20.5, to fluctuate to 11 events, as observed, or fewer is 5%. No excess beyond the SM background is observed and a 95% CL upper limit on the branching fraction of $\mathrm{t} \to \mathrm{Zq}$ is determined using the modified frequentist approach ($\mathrm{CL_s}$ method [27,28]). A summary of the observed and predicted yields and limits are presented in Table 3.

The calculation of the upper limit is based on the information provided by the observed event count combined with the values and the uncertainties of the luminosity measurement, the background prediction, and the fraction of all $t\bar{t} \to Zq + Wb \to \ell\ell q + \ell b$ events expected to be selected. The signal event yield is obtained from the efficiency times acceptance and branching fraction for simulated events. As $\mathcal{B}(t \to Zq)$ is expected to be small, the possibility of both top quarks decaying via flavor changing neutral currents is not considered.

The best observed and expected 95% CL upper limits on the branching fraction $\mathcal{B}(t \to Zq)$ are 0.21% and 0.40%, respectively, obtained in the S_T selection from the combined three-lepton analyses. The one-sigma boundaries of the expected limit are 0.30–0.59%. The corresponding observed and expected upper limits, and one-sigma boundaries for the b-tag selection are 0.30%, 0.41% and 0.30–0.53%, respectively. The expected limit for the S_T and b-tag selections show that they have comparable sensitivity. The one with slightly better expected limit is taken as the final result.

8. Summary

A search for flavor changing neutral currents in top quark decays in $t\bar{t}$ events produced in proton–proton collisions at $\sqrt{s} = 7$ TeV is presented. A sample of three-lepton events is selected from data recorded by CMS during 2011 corresponding to an integrated luminosity of 5.0 fb^{-1}. These events are compatible with a $pp \to t\bar{t} \to Zq + Wb \to \ell\ell q + \ell\nu b$ ($\ell = e, \mu$) topology. Since three-lepton events originating from the SM processes are rare the background contributions are small. No excess of events over the SM background is observed and a $\mathcal{B}(t \to Zq)$ branching fraction larger than 0.21% is excluded at the 95% confidence level.

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