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Search for Top Quark Flavour-changing Neutral-current Decays at 8 TeV

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We present a search for top quark flavor-changing neutral-current (FCNC) decays by the CMS Experiment. The data correspond to an integrated luminosity of 19.5 fb^{-1} collected in proton-proton collisions at the LHC at a centre-of-mass energy $\sqrt{s} = 8$ TeV. The analysis uses background estimation techniques that are improved with respect to previous measurements. An upper limit for the branching fraction is determined.

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The top quark is the heaviest known elementary particle. It decays with a branching fraction of nearly 100% to a bottom quark and a W boson, $t \to Wb$. The flavor changing neutral current (FCNC) $t \to Zq$ decay, in which the top quark decays through a Z boson and a light up-type quark (u or c) is highly suppressed in the standard model (SM) by the GIM mechanism [1] and occurs at the level of quantum loop corrections. The predicted branching fraction $\mathscr{B}(t \to Zq)$ is $\mathscr{O}(10^{-14})$ [2] well below the sensitivity of the Large Hadron Collider (LHC). The detection of such a signal would be clear evidence of physics beyond the SM. The LHC experiments, ATLAS and CMS, have reported 95% confidence level (CL) upper limits on $\mathscr{B}(t \to Zq)$ of 0.73% [3] and 0.21% [4] with integrated luminosities of $2.1\,\mathrm{fb}^{-1}$ and $5.0\,\mathrm{fb}^{-1}$, respectively, at a center-of-mass energy of 7 TeV. The measurement described in these proceedings uses a data sample corresponding to an integrated luminosity of $19.5\,\mathrm{fb}^{-1}$ of proton-proton collisions at $\sqrt{s} = 8\,\mathrm{TeV}$, recorded by the CMS experiment during 2012.

The MC samples of Drell–Yan events, SM $t\bar{t}$, $Zt\bar{t}$, $Wt\bar{t}$ and tbZ, diboson (WW, WZ, and ZZ) events are simulated using MADGRAPH, while single-top-quark events are generated using POWHEG. 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. One of the top quarks of a pair is forced to decay as $t \to Zq$, where $q = u, c$ with equal probability, while the other decays to Wb. The ratio between the dimension-4 vector and axial-vector couplings of the FCNC model is assumed to be SM-like [5]. The CMS detector [6] response for all MC samples is simulated using a GEANT4-based model, and the events are reconstructed and analysed 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 search is performed by looking for $t\bar{t}$ events where one top quark decays into Zq and the other decays into Wb with both vector bosons decaying leptonically. The analysis follows closely the search performed at 7 TeV [4]. The event selection requirements are optimized for an integrated luminosity of $30\,\mathrm{fb}^{-1}$, using Monte Carlo (MC) simulated events, before looking at the data to avoid possible biases.

Events are required to pass at least one of the ee or $\mu\mu$ high transverse momenta (p_T) dilepton triggers. Events with two opposite-sign, same-flavor, isolated leptons (e or μ) having an invariant mass between 78 GeV and 102 GeV, consistent with a Z-boson decay, and one extra charged lepton are selected. The Z candidate with invariant mass closest to the nominal value is taken. All three leptons must satisfy the following kinematic requirements: $p_\mathrm{T} > 20\,\mathrm{GeV}$ and $|\eta| < 2.5$ for electrons and $|\eta| < 2.4$ for muons. Leptons and jet constituent charged particle tracks not originating from the chosen primary vertex candidate, which has the highest $\Sigma {p_\mathrm{T}}^2$ of its associated tracks, are ignored in the analysis. Because the analysis looks for leptons originating from the decays of W and Z bosons, they are required to be isolated as defined in Ref. [7]. Neutrinos from W-boson decays escape detection and produce a significant momentum imbalance in the detector in the plane transverse to the beams. The missing transverse momentum ($-\Sigma\vec{p}_\mathrm{T}$) and its magnitude ($\not{E}_\mathrm{T}$) are reconstructed using the CMS particle-flow technique [8]. We require the $\not{E}_\mathrm{T}$ to be larger than 30 GeV. The W-boson candidates can be reconstructed from the momentum of the third lepton and the missing transverse momentum (assumed to originate from an undetected neutrino), by constraining the resulting invariant mass to be equal to the W-boson mass. The requirements of dilepton-triggered events, a Z boson candidate, the presence of a third lepton, the veto on a fourth lepton, and the

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requirement of $\not\!\!E_{\mathrm{T}}$ described above are defined as the "basic event selection".

To reduce the background from diboson events we require at least two jets, reconstructed also using a particle-flow technique [8], with $p_{\mathrm{T}} > 30\,\mathrm{GeV}$ and $|\eta| < 2.4$. Exactly one of these jets should be tagged as a b jet. The b jet identification is performed using the combined secondary vertex b-tagging algorithm described in Ref. [9].This tagging method has an identification efficiency of $\approx 62\%$ for b jets with transverse momentum between 30 GeV and 100 GeV and a misidentification rate below 4%. The invariant mass of the W boson and b-tagged jet system m_{Wb} is required to be within 35 GeV of the top-quark mass, which is assumed to be 172.5 GeV in the simulation. A non-b jet is combined with the Z candidate to form another top quark candidate. By examining all possible pairings, the top-quark candidate which has the largest separation in azimuthal angle to the first top quark is selected, and the reconstructed top-quark mass m_{Zj} is required to be within 25 GeV of the assumed top-quark mass. The mass requirements were remained unchanged with respect to the 7 TeV study [4], which were chosen a priori.

The background contribution can be estimated from data using the b-tagging information. These processes can be categorized into three groups based on the b jet multiplicity: a) N_{VV}, the number of diboson and Drell–Yan events with no b jets; b) N_{sig}, top-quark FCNC decay events with only one b jet; c) N_{bbx}, the $t\bar{t}$, tbZ, $Wt\bar{t}$, and $Zt\bar{t}$ processes with two b jets. Events passing the basic event selection, with two jets to be paired with W and Z bosons are divided into three samples: a) N_{1b}, events with exactly one b-tagged jet; b) N_{0b}, events with no b-tagged jets; and c) N_{all}, the total number of the events. The numbers of events in those three samples (N_{0b}, N_{1b}, and N_{all}) can be related to the yields of the three groups (N_{VV}, N_{sig}, and N_{bbx}) based on the b-tagging efficiencies for b jets (ε_b), c jets (ε_c), or light jets (ε_l), which are measured using data. For example, in events with zero b-tagged jets can be expressed as $N_{\mathrm{0b}} = \alpha_1 N_{\mathrm{VV}} + \alpha_2 N_{\mathrm{sig}} + \alpha_3 N_{\mathrm{bbx}}$. As examples, α_1 is equal $(1-\varepsilon_l)\times(1-\varepsilon_l)$, $\alpha_2 = (1-0.5\times(\varepsilon_l+\varepsilon_c))\times(1-\varepsilon_b)$. Then the numbers of events in three groups are then turned into an estimation of these yields via a linear 3×3 system of equations to be solved before the top-quark mass requirements. The overall contribution of WZ plus ZZ and Drell–Yan background is estimated to be 1.5 ± 0.1 (stat.) ±0.7 (syst.) events. The yields of $Wt\bar{t}$, $Zt\bar{t}$, tbZ, and $t\bar{t}$ backgrounds are estimated to be 1.6 ± 5.0 (stat.) ±0.4 (syst.) events. The statistical and systematic uncertainties are estimated from the number of the events of these three data samples and the uncertainty of the b-tagging efficiency scaling factors is measured in control data samples.

To calculate the expected significance, the systematic uncertainties from the trigger efficiency, lepton selection efficiency, pileup modeling, missing transverse energy resolution, high-p_{T} b-jet tagging efficiency [9], and jet energy scale are included. After applying all the criteria and adding all four channels, $3.1^{+5.1}_{-3.1}$ events are expected from SM background processes and 1 event is observed in data. A 95% CL upper limit on the branching fraction of the $t\to Zq$ decay is determined using the modified frequentist approach. The observed and expected 95% confidence level (CL) upper limits on the branching fraction $\mathscr{B}(t\to Zq)$ are 0.07% and 0.10%, respectively and the 1σ and 2σ ranges are 0.04–0.51% and 0.02–0.66%, respectively.

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