

Rare decays at CMS

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CMS searches for flavour changing neutral currents (FCNC) in events with top quarks and the Z or the Higgs boson are presented. Upper limits at 95% confidence level are set on the branching fractions of $t \rightarrow qZ$ and $t \rightarrow qH$ decays. In addition, angular distributions of B^0 and B^+ decays are presented. These measurements are found to be consistent with predictions based on the standard model.

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1. Introduction

In the standard model (SM), flavour changing neutral currents (FCNC) are forbidden at tree level and highly suppressed at higher order. Several extensions of the SM enhance the FCNC branching fractions and can be probed at the LHC; the new couplings can also provide for flavour changing single top quark production in association with a Z or a Higgs boson.

2. FCNC in $tZq \rightarrow 3\ell$

This analysis [1] uses proton-proton collision data coming from the 2016 data taking period, corresponding to an integrated luminosity of 35.9 fb^{-1} at a centre-of-mass energy of 13 TeV collected by the CMS detector. The analysis focuses on the experimental search for evidence of a FCNC vertex (referred to as tZq) with a top quark, a Z boson, and a quark q that is either up or charm. In the final state we expect one jet originating from a b quark, a W boson, a Z boson, and (in the case of FCNC top quark decay) a jet originating from the up or charm quark. As we limit the analysis to leptonic decays of both the W and the Z boson, events are selected requiring exactly 3 leptons containing one opposite sign, same flavour pair; at least 1 jet and at most 3 jets; and the transverse mass of the W boson below 300 GeV. Four different lepton channels are considered ($3e$, $2e1\mu$, $1e2\mu$, 3μ) and two signal regions, the single top quark FCNC (STSR) and the top quark pair FCNC (TTSR), are constructed, using the jet multiplicity. A simultaneous global fit is performed taking into account both signal regions and background regions, for the four lepton channels with the help of boosted decision trees (BDT), used to discriminate between signals and backgrounds. The resulting discriminating output variables from each BDT are shown in Figure 1. The signal strength and significance are computed treating all systematic uncertainties as nuisance parameters and are constrained from the fit, which uses templates in the different signal and background regions for each of the four different lepton channels. The resulting observed (expected) limits where both couplings are non-vanishing are shown in Figure 2. No significant deviation is observed from the predicted background. Observed (expected) upper limits at 95% CL are set on the branching fractions of top quark decays: $\mathcal{B}(t \rightarrow uZ) < 0.024\%$ (0.015%) and $\mathcal{B}(t \rightarrow cZ) < 0.045\%$ (0.037%), assuming one non-vanishing coupling at a time.

3. FCNC in $tH \rightarrow b\bar{b}$

In this analysis [2] we also search for FCNC in events with the top quark and the Higgs boson, but considering the Higgs boson decays to b quarks. The tH FCNC interaction is studied in two channels: the associated production of a single top quark with the Higgs boson (ST), and the FCNC decays of top quarks in $t\bar{t}$ semileptonic events (TT). As before, the data sample corresponds to an integrated luminosity of 35.9 fb^{-1} . Events with exactly one isolated lepton (electron or muon) are selected, and at least three jets are required to be present. As signal events contain three b quarks, we require that at least two jets are identified as b quark jets by the combined secondary vertex (CSV) b-tagging algorithm. In order to optimize sensitivity to the signal event selection, events are split into five categories based on the total number of reconstructed jets and on the number of b-tagged jets. With the use of the energy and momenta of all particles, a full kinematic reconstruction of the event is performed for several signal (ST and TT) and background ($t\bar{t}$) hypotheses.

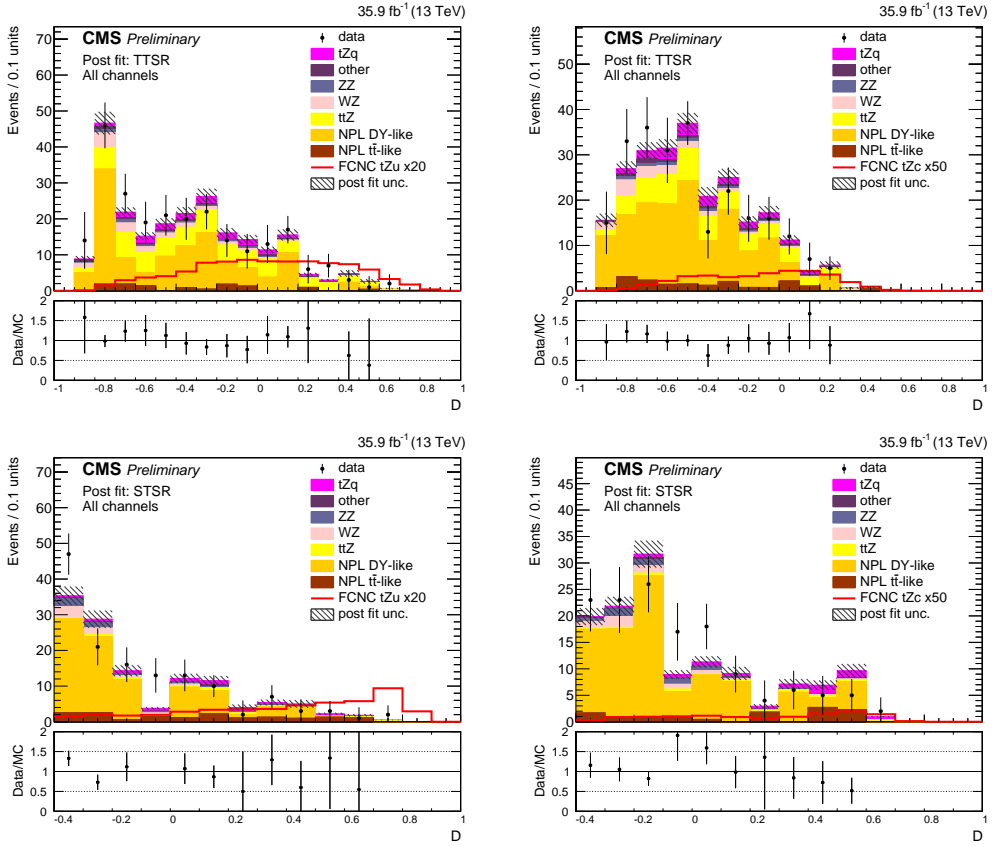


Figure 1: The discriminating variable distribution after the fit for all different leptonic channels. Upper left: top quark pair tZu ; upper right: top quark pair tZc ; lower left: single top quark tZu ; lower right: single top quark tZc .

The reconstruction is performed for all possible permutations of the b-tagged jets to be associated with the decay products of the Higgs boson or the top quark. The reconstructed kinematic variables for each permutation are then fed into a multivariate analysis that uses a BDT, trained to distinguish the correct from the wrong b jet assignments. In addition, kinematic variables from the event reconstruction are used to construct several BDTs to suppress backgrounds. The BDTs are trained for each jet multiplicity category to identify signal events that are generated either for κ_{Hut} (Hut) or κ_{Hct} (Hct) coupling against the sum of all background events. Separate trainings of the BDT for Hut and Hct are done. Distributions for some of the most discriminating BDT input variables, in the category with three jets, all of them b-tagged, can be seen in Figure 3. The final observable used to extract signal events is defined as the BDT score distribution. The resultant observed (expected) 95% CL exclusion limits on top quark FCNC decay branching fractions are $\mathcal{B}(t \rightarrow uH) < 0.47\%$ (0.34%) and $\mathcal{B}(t \rightarrow cH) < 0.47\%$ (0.44%). Two-dimensional limits are also shown in 4. We define a signal strength parameter $\mu = \sigma/\sigma_{\text{sig}}$, where σ is the cross section excluded at 95% CL and σ_{sig} is the predicted cross section for signal. A maximum likelihood fit is performed for the signal strength, and is shown in Figure 4.

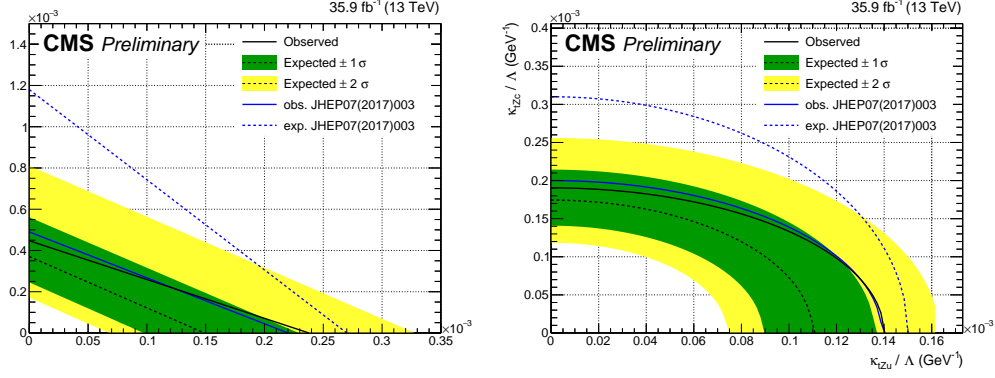


Figure 2: Exclusion regions at 95% CL on the FCNC branching fractions (left) and couplings (right) in the 2D plane of both the tZu and tZc variables. The CMS 8 TeV observed (expected) limit is given with a blue line (dashed line).

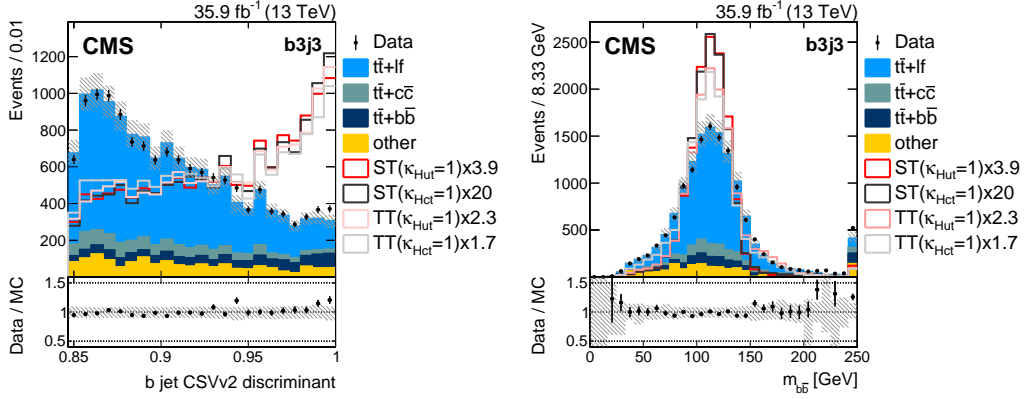


Figure 3: Comparison between data and simulation for some of the most discriminating BDT input variables in the category with three jets, all of them b-tagged: CSV discriminant value for one of the reconstructed b jets assigned to Higgs boson decay (left), and reconstructed invariant mass of two b jets associated with the Higgs boson decay (right).

4. Angular observables in $B^+ \rightarrow K^+ \mu^+ \mu^-$

[3] 5 6 (top distributions).

5. Angular observables in $B^0 \rightarrow K^{*0} \mu^+ \mu^-$

[6]
6 (bottom distributions).

6. Conclusions

A CMS and ATLAS summary of the current 95% CL observed limits on the branching ratios of the top quark decays via FCNC to a quark and a neutral boson is shown in Figure 7.

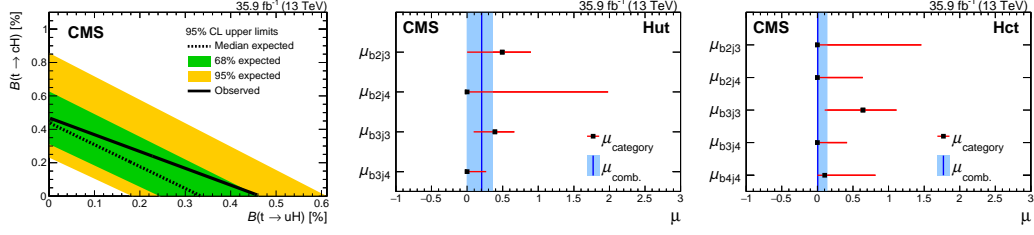


Figure 4: Upper limits on $\mathcal{B}(t \rightarrow uH)$ and $\mathcal{B}(t \rightarrow cH)$ at 95 % CL (left), and the best fit signal strength for Hut (center) and Hct (right), which is restricted to positive values in the fit.

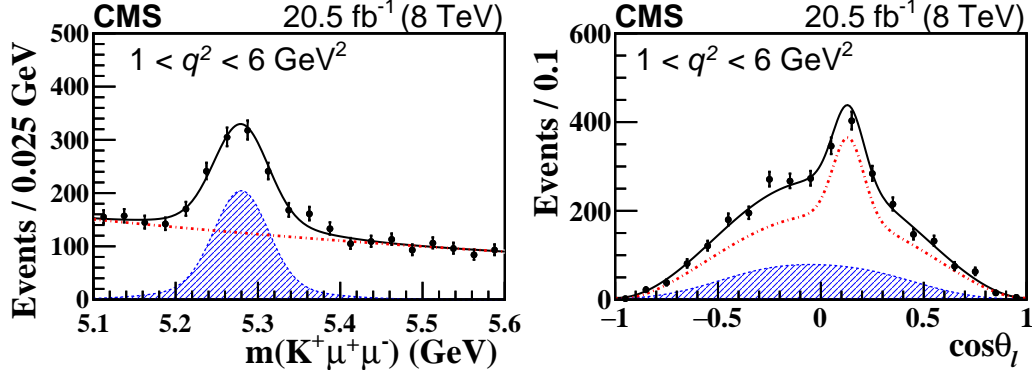


Figure 5: Projections of the $K^+ \mu^+ \mu^-$ invariant mass distribution (left) and the $\cos \theta_l$ distribution (right) from the two-dimensional fit of data, in the $1 < q^2 < 6 \text{ GeV}^2$ range. The solid lines show the total fit, the shaded area the signal contribution, and the dash-dotted lines the background.

References

- [1] CMS Collaboration, *Search for flavour changing neutral currents in top quark production and decays with three-lepton final state using the data collected at $\sqrt{s} = 13 \text{ TeV}$* , <https://cds.cern.ch/record/2292045>, CMS-PAS-TOP-17-017.
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- [3] CMS Collaboration, *Angular analysis of the decay $B^+ \rightarrow K^+ \mu^+ \mu^-$ at $\sqrt{s} = 8 \text{ TeV}$* , <https://cds.cern.ch/record/2621370> CERN-EP-2018-125 [hep-ex/1806.00636].
- [4] To be filled.
- [5] To be filled.
- [6] CMS Collaboration, *Measurement of angular parameters from the decay $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ at $\sqrt{s} = 8 \text{ TeV}$* , <https://cds.cern.ch/record/2287571>, CERN-EP-2017-240 [hep-ex/1710.02846].
- [7] To be filled.
- [8] To be filled.

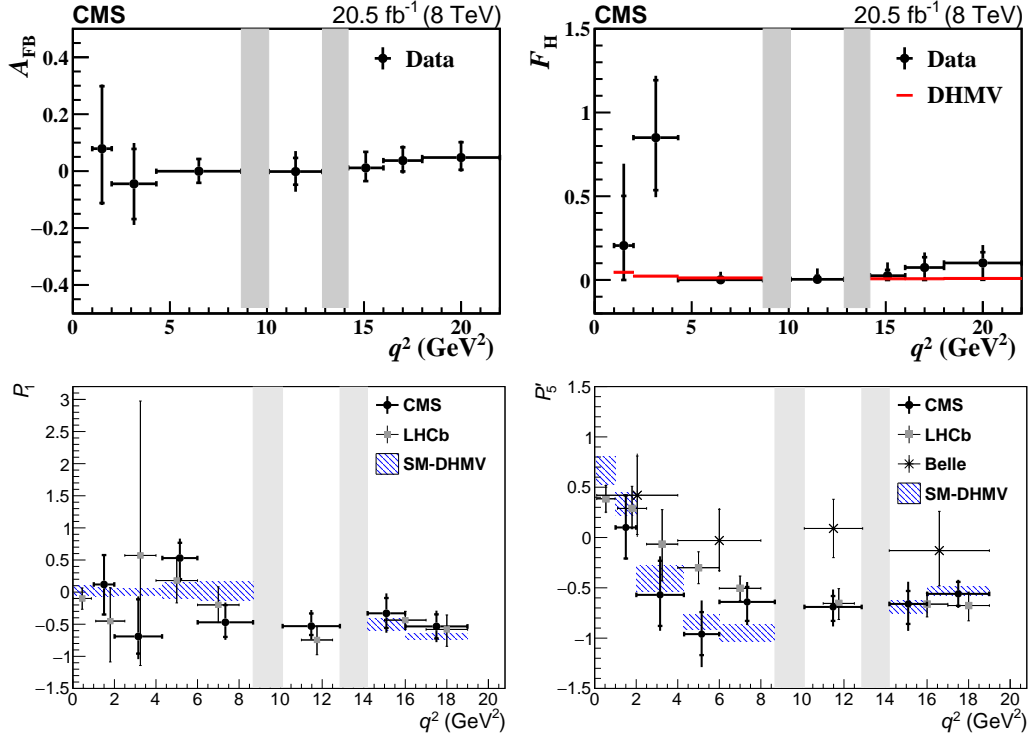


Figure 6: Measurements of the A_{FB} (top left) and F_H (top right) parameters versus q^2 for $B^+ \rightarrow K^+ \mu^+ \mu^-$ decays. Measurements of the P_1 (bottom left) and P'_5 (bottom right) angular parameters versus q^2 for $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ decays. The CMS results are compared to SM DHMV theoretical predictions [4, 5] and, for the P_1 and P'_5 parameters, they are also compared to results from the LHCb [7] and Belle [8] Collaborations.

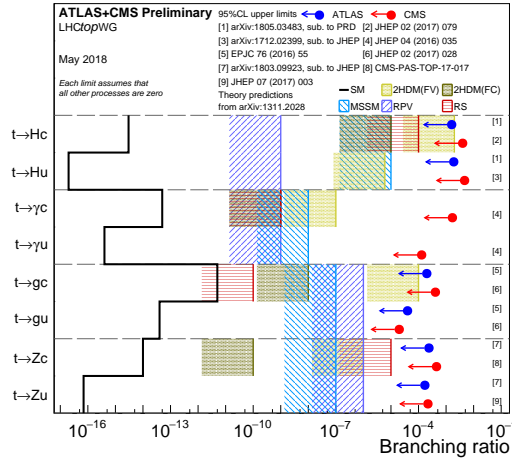


Figure 7: Summary of the current 95% confidence level observed limits on the branching ratios of the top quark decays via flavour changing neutral currents to a quark and a neutral boson by the ATLAS and CMS Collaborations compared to several new physics models.