Institute for Research in Fundamental Sciences
School of Particles and Accelerators

SEARCH FOR FLAVOR CHANGING NEUTRAL CURRENT IN TOP QUARK EVENTS IN PP COLLISIONS

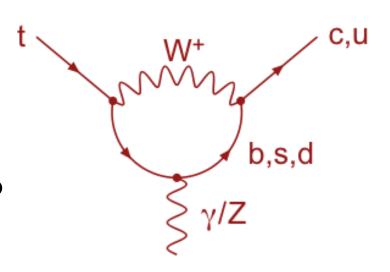## IPMLHC2013: Second IPM Meeting on LHC Physics

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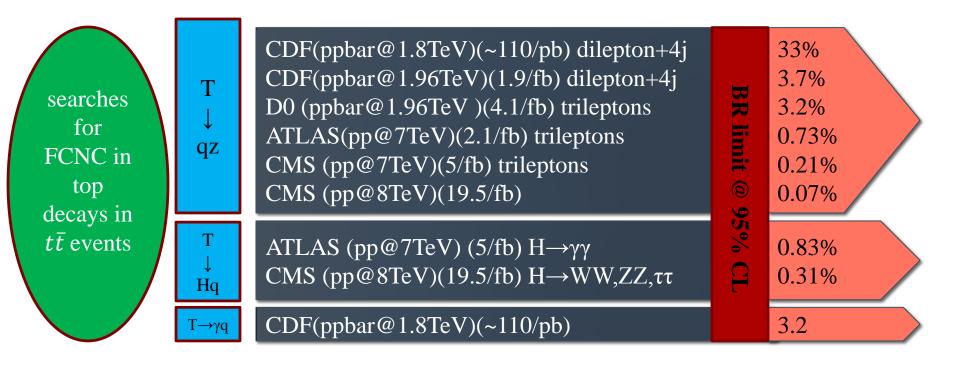
October 7, 2013

MOTIVATION

➢ **In the Standard Model (SM), flavor changing neutral current (FCNC) processes are forbidden at tree level and highly suppressed at higher orders due to the GIM mechanism.**
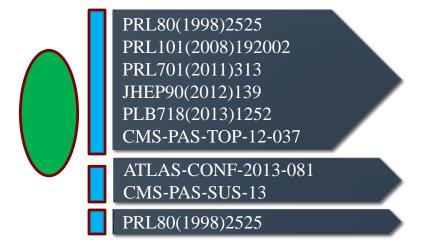

➢ **FCNC processes cross section can be enhanced significantly in some new physics models.**
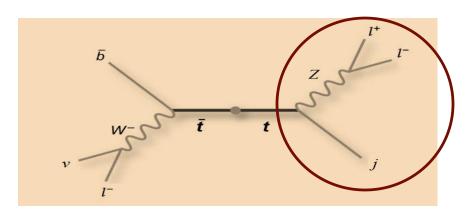
BR=O(10^{-14})
↓
BR=O(10^{-4})

Any Evidence of
FCNC Will indicate the existence of
new physics

➢ **At LHC, search for FCNC processes can be done in top decay or production. They can be associated with Z, Higgs, gluon or photon.**

searches for FCNC in top decays in $t\bar{t}$ events

T ↓ qz

CDF(ppbar@1.8TeV)(~110/pb) dilepton+4j
CDF(ppbar@1.96TeV)(1.9/fb) dilepton+4j
D0 (ppbar@1.96TeV)(4.1/fb) trileptons
ATLAS(pp@7TeV)(2.1/fb) trileptons
CMS (pp@7TeV)(5/fb) trileptons
CMS (pp@8TeV)(19.5/fb)

BR limit @ 95% CL

33%
3.7%
3.2%
0.73%
0.21%
0.07%

T ↓ Hq

ATLAS (pp@7TeV) (5/fb) H→γγ
CMS (pp@8TeV)(19.5/fb) H→WW,ZZ,ττ

0.83%
0.31%

T→γq

CDF(ppbar@1.8TeV)(~110/pb)

3.2

PRL80(1998)2525
PRL101(2008)192002
PRL701(2011)313
JHEP90(2012)139
PLB718(2013)1252
CMS-PAS-TOP-12-037

ATLAS-CONF-2013-081
CMS-PAS-SUS-13

PRL80(1998)2525

FCNC IN TOP DECAYS INTO A Z BOSON AND A QUARK

➤signature

➤Basic Event Selection:

two opposite-sign, isolated leptons (e or µ) consistent with a Z-boson decay (be between 78 GeV and 102 GeV) and an extra charged lepton are selected

At least two jets are required to have pT > 30 GeV, |η| < 2.4, and to be separated by DR > 0.4 from leptons

Events with a fourth lepton candidate are rejected

require the missing transverse energy to be larger than 30 GeV

One and only one b tagged jet in the event is required.

Zj And Wb Pairing To Reconstruct Top quarks

➤Backgrounds to our signal:

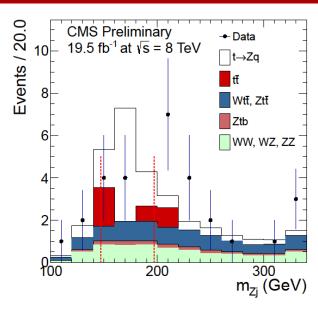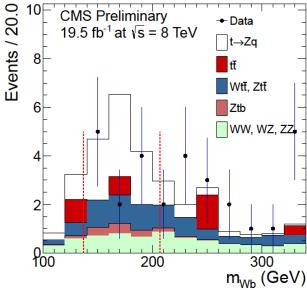| Signal MC |
|---|
| TTJetsToWbZj (W to All, Z to 2L) |
| **Background MC** |
| DYJetsToLL |
| TTJets |
| WWJetsTo2L2Nu |
| WZJetsTo2L2Q / 3l nu |
| ZZJetsTo2L2Nu/ 2l 2q / 4l |
| Single Top(s, t, tWchannel) |
| TTWJets |
| TTZJets |

➢ The background contribution are estimated from data using the b tagging information.

➢ The processes are divided into three categories based on the b jet multiplicity: the di-boson and Drell–Yan events have no b jets, top FCNC events would have only one b jet, and the $t\bar{t}$, tbZ,W $t\bar{t}$ and Z $t\bar{t}$ processes have two b jets.

$$\begin{pmatrix} N_{all} \\ N_{0b} \\ N_{1b} \end{pmatrix} = \mathbf{T} \begin{pmatrix} N_{VV} \\ N_{FCNC} \\ N_{XTT} \end{pmatrix}$$

Number of events for each category is estimated by inverting the above matrix and counting the number of events in each b-tag category.

Dominant Systematics uncertainties: Factorization And Renormalization scales, PDFs And $\sigma_{t\bar{t}}$.

No excess of events over the SM background.

➢ In the following table Background composition, observed and expected yields, and limits at the 95% CL for all three-lepton channels combined tag selections for an integrated luminosity of 19.5 fb^{-1} are shown. The uncertainties in the background estimation include the statistical and systematic components separately (in that order).

Selection	data-driven estimation	SM MC prediction
$t \rightarrow Zq \, (B = 0.1\%)$	—	$6.36 \pm 0.08 \pm 1.27$
WZ		$0.87 \pm 0.10 \pm 0.62$
ZZ	$1.54 \pm 0.12 \pm 0.74$	$0.07 \pm 0.01 \pm 0.05$
Drell-Yan		$0.00 \pm 0.03 \pm 0.02$
$t\bar{t}$		$0.74 \pm 0.70 \pm 0.52$
$Zt\bar{t}$	$1.60 \pm 4.96 \pm 0.44$	$1.09 \pm 0.13 \pm 0.77$
$Wt\bar{t}$		$0.09 \pm 0.05 \pm 0.06$
tbZ		$0.33 \pm 0.02 \pm 0.23$
Total background	$3.14 \pm 4.97 \pm 1.17$	$3.19 \pm 0.72 \pm 2.26$
Observed events	1	—
Expected limit	$\mathcal{B}(t \rightarrow Zq) < 0.10\%$	—
Observed limit	$\mathcal{B}(t \rightarrow Zq) < 0.07\%$	

FCNC IN TOP DECAYS INTO A HIGGS BOSON AND A QUARK

Process	SM	QS	2HDM-III	FC-2HDM	MSSM
$t \to u\gamma$	$3.7 \cdot 10^{-16}$	$7.5 \cdot 10^{-9}$	—	—	$2 \cdot 10^{-6}$
$t \to uZ$	$8 \cdot 10^{-17}$	$1.1 \cdot 10^{-4}$	—	—	$2 \cdot 10^{-6}$
$t \to uH$	$2 \cdot 10^{-17}$	$4.1 \cdot 10^{-5}$	$5.5 \cdot 10^{-6}$	—	10^{-5}
$t \to c\gamma$	$4.6 \cdot 10^{-14}$	$7.5 \cdot 10^{-9}$	$\sim 10^{-6}$	$\sim 10^{-9}$	$2 \cdot 10^{-6}$
$t \to cZ$	$1 \cdot 10^{-14}$	$1.1 \cdot 10^{-4}$	$\sim 10^{-7}$	$\sim 10^{-10}$	$2 \cdot 10^{-6}$
$t \to cH$	$3 \cdot 10^{-15}$	$4.1 \cdot 10^{-5}$	$1.5 \cdot 10^{-3}$	$\sim 10^{-5}$	10^{-5}

➢ H→γγ is considered as final state.
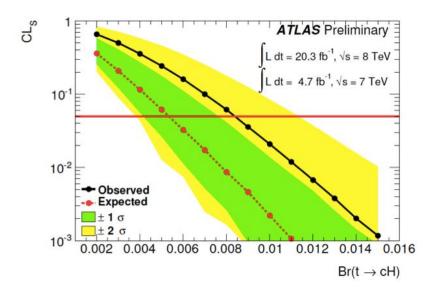➢ Two final states are searched for: the hadronic and leptonic channels from top decay.

Backgrounds:
➢ SM sources of Higgs boson production followed by a decay in two photon
➢ Higgs-strahlung associated production (WH,ZH)
➢ Non-resonant production of two photon

Main selection:
➢ Two high PT isolated photon
➢ Top mass windows for the reconstructed top masses
➢ Isolated lepton selection or rejection (due to final state)

No significant excess of events over the SM background.

For $m_H = 126.8$, BR(t→cH)<0.83% @ 95% CL

searches for FCNC in single top events

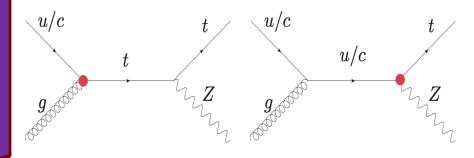| CDF(ppbar@1.96TeV)(2.2/fb) $pp \to t$		$t \to gu$ 0.039 $t \to gc$ 0.57
D0(ppbar@1.96TeV)(2.3/fb) $pp \to t+g/q$		$t \to gu$ 0.02 $t \to gc$ 0.39
ATLAS(pp@7TeV)(2.05/fb) $pp \to t$		$t \to gu$ 0.0057 $t \to gc$ 0.027
CMS (pp@7TeV)(5/f) $pp \to t+z$		$t \to gu$ 0.56 $t \to gc$ 7.12 $t \to zu$ 0.51 $t \to zc$ 11.40
ATLAS(pp@8TeV)(14.2/fb) $pp \to t$		$t \to gu$ 0.0031 $t \to gc$ 0.016

BR limit @ 95% CL

PRL 102 (2009) 151801
PLB 693 (2010) 81
PLB 712 (2012) 351
CMS-PAS-TOP-12-021
ATLAS-CONF-2013-063

FCNC IN TZ EVENTS IN PP COLLISIONS AT $\sqrt{s} = 7$ TEV

search for anomalous top couplings in single top quark production in association with a Z-boson (tZ) in about 5 fb^{-1} of proton-proton collisions at a center-of-mass energy of $\sqrt{s} = 7$ TeV.

➤ tri-leptonic decay channels: the top quark and the Z boson decays into electrons or muons. this signature is simultaneously sensitive to both Zqt and gqt anomalous vertices.

➤ top-quark anomalous couplings are parameterizede by means of effective operators independent of the underlying theory.

$$\mathcal{L} = \sum_{q=u,c} \left[\sqrt{2}g_s \frac{\kappa_{gqt}}{\Lambda} \bar{t}\sigma^{\mu\nu}T_a(f_q^L P_L + f_q^R P_R)q\, G_{\mu\nu}^a \right.$$

$$\left. + \frac{g}{\sqrt{2}c_W}\frac{\kappa_{Zqt}}{\Lambda} \bar{t}\sigma^{\mu\nu}(\hat{f}_q^L P_L + \hat{f}_q^R P_R)q\, Z_{\mu\nu} \right] + \text{h.c.}$$

➢ Basic Event Selection:

Events with exactly three isolated leptons with a transverse momentum, $P_T > 20$ GeV and $|\eta| < 2.4$ for muon and $|\eta| < 2.5$ for electrons are selected

Pairs of leptons with the same flavor, opposite charge and invariant mass the closest to the Z mass are attributed to the Z decay, and are required to have invariant mass lying within 76 and 106 GeV. The remaining lepton is attributed to the W boson.

Events with more than one b-tagged jet are vetoed

➢ The SM background has two main components:
  ➢ A component arises from WZ/ZZ+jets and tZq+jets events that contain at least three leptons.
  ➢ There is also a reducible contribution from Z+jets, $t\bar{t}$ +jets, SM single top-quark in the tW channel and WW+jets background, when one or more jets is misreconstructed as a lepton, or when a non-isolated lepton is issued from heavy-flavored hadron decays.

as the rate of non-prompt leptons is imperfectly known. The normalization of these events is estimated by performing a template fit of the reconstructed W transverse mass.
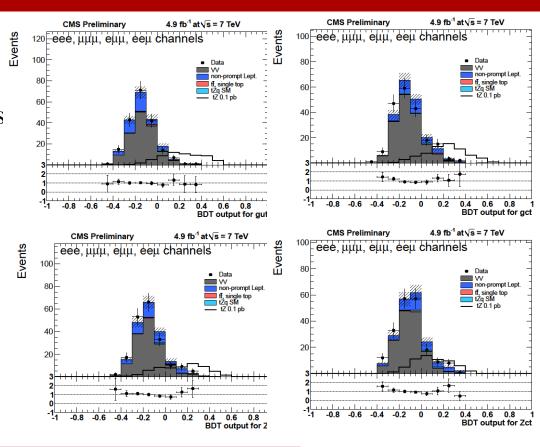
➢In order to discriminate signal from WZ+jets events, a multi-variate approach is followed. (Boosted Decision Tree (BDT))

➢The BDT is trained on simulated WZ+jets and signal events and is constructed by treating all four decay channels together.

➢The list of variables used to construct the BDT is :

- ➢ reconstructed top-quark mass,
- ➢ $\Delta\varphi(l_w - b)$, azimuthal angle between the lepton from the W candidate and the b-jet candidate,
- ➢ $q|\eta|$, with q and $|\eta|$ the electric charge and the pseudorapidity of the W candidate, respectively,
- ➢ P_T of the Z boson candidate,
- ➢ $|\eta|$ of the Z boson candidate,
- ➢ jet multiplicity,
- ➢ b-tagged jet multiplicity,
- ➢ $\Delta\varphi(Z - E_T)$, azimuthal angle between the Z candidate and the direction of the E_T vector,
- ➢ CSV b-tagging discriminator,
- ➢ $|\eta|$ of the leading jet,
- ➢ $\Delta\varphi(l_w - Z)$, azimuthal angle between the lepton from the W candidate and the Z candidate,
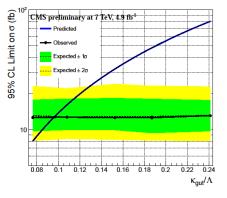
plots show BDT output distributions for gut (top left), gct (top right), Zut (bottom left) and Zct (bottom-right) searches, summed for the four tri-lepton channels. Total uncertainties are shown as hatched regions. The signal is scaled to a cross section of 0.1 pb.
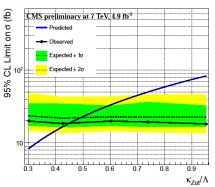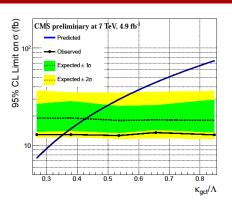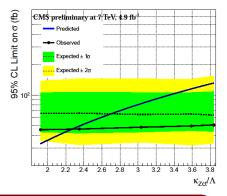
No excess of events over the SM background.

All systematic uncertainties are taken into account as nuisance parameters, which could either affect the normalization and/or the shape of the BDT distributions. The 95% CL exclusion limits are calculated as functions of the $\kappa_{\mathrm{g}qt}/\Lambda$ and κ_{zqt}/Λ parameters.

➢ 95% exclusion limit for the gut (top left), gct (top-right), Zut (bottom left) and Zct (bottom right) couplings as functions of the κ/Λ parameters. The blue lines shows the predicted cross-section, as calculated by MADGRAPH.

In the following table, Expected and observed exclusion limits at 95% CL, and the corresponding limits on the top-quark-decay branching ratios is shown.

couplings	Expected	Observed	$\mathcal{B}(t \to gq/Zq)$
κ_{gut}/Λ	0.096	0.096	0.56 %
κ_{gct}/Λ	0.427	0.354	7.12 %
κ_{Zut}/Λ	0.492	0.451	0.51 %
κ_{Zct}/Λ	2.701	2.267	11.40 %

Whereas the limits obtained on the gqt anomalous couplings are found to be non-competitive compared to results derived from the single top-quark production mode, this result provides an interesting cross-check in a different physics process.
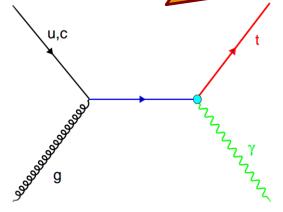
The limits on the Zqt interactions are found to be of a similar order of magnitude compared to bounds determined from $t\bar{t}$ events produced in 5 fb^{-1} of 7 TeV proton-proton collisions. Therefore, a combination could be foreseen to improve the current limits.

On different footings, statistical uncertainties have a large impact on the results presented in this work. Consequently, an update with the larger 2012 dataset, recorded at a collision energy of 8 TeV, is expected to lead to a significant improvement.

SINGLE TOP PRODUCTION DUE TO ANOMALOUS $tq\gamma$ COUPLINGS

Another search for FCNC processes in top sector can be done in production of single top quark in association with a photon.

In signal topology, we expect a high P_T photon, an isolated lepton and missing transverse energy and a b-jet from top decay.

u,c

t

g

γ

This analysis is being performed at CMS in our group at IPM and is in final steps.

SUMMARY

➤ The results of different searches for top-quark anomalous couplings in the FCNC processes are reviewed.

➤ The observed number of events are compatible with the standard model prediction and no evidence for flavor changing neutral currents in top quark decays and production is found. upper limits at 95% confidence level are determined.

➤ LHC researchers will continue searching for FCNC at higher energy and luminosity. (CMS-PAS-FTR-13-016)

$\mathcal{B}(t \rightarrow Zq)$	$19.5 \, \text{fb}^{-1}$ @ 8 TeV	$300 \, \text{fb}^{-1}$ @ 14 TeV	$3000 \, \text{fb}^{-1}$ @ 14 TeV
Exp. bkg. yield	3.2	26.8	268
Expected limit	< 0.10%	< 0.027%	< 0.010%
1σ range	0.06 − 0.13%	0.018 − 0.038%	0.007 − 0.014%
2σ range	0.05 − 0.20%	0.013 − 0.051%	0.005 − 0.020%