

Flavor Changing Neutral Current searches in the top quark sector

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1 Introduction

- FCNC in SM
- FCNC in BSM

2 Results

- FCNC searches in $t \rightarrow u/c + \gamma$ at CMS and HERA
- FCNC searches in $t \rightarrow u/c + Z$ at CMS, ATLAS, CDF and HERA
- FCNC searches in $t \rightarrow u/c + g$ at CMS, ATLAS and DØ
- FCNC searches in $t \rightarrow u/c + H$ at CMS and ATLAS

3 Summary

4 Conclusions

- Flavor-Changing Neutral Current (FCNC) changes the flavor of a fermion current without altering its electric charge.
- In the top quark sector :

FCNC decays:

$$t \rightarrow u + \gamma$$

$$t \rightarrow c + \gamma$$

$$t \rightarrow u + Z$$

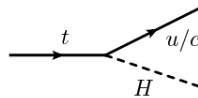
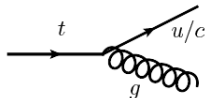
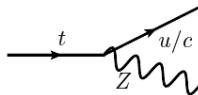
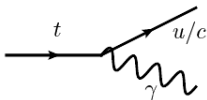
$$t \rightarrow c + Z$$

$$t \rightarrow u + g$$

$$t \rightarrow c + g$$

$$t \rightarrow u + H$$

$$t \rightarrow c + H$$

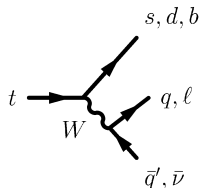


Charged current decays:

$$t \rightarrow b + W \quad (BR \sim 100\%)$$

$$t \rightarrow s + W \quad (BR \sim 0.18\%)$$

$$t \rightarrow d + W \quad (BR \sim 0.02\%)$$



- In the Standard Model (SM) : FCNC amplitudes at tree level are forbidden by the Glashow-Iliopoulos-Maiani (GIM) mechanism.
- However, highly GIM-suppressed FCNC transitions are possible in the SM in the higher orders via loop induced processes.

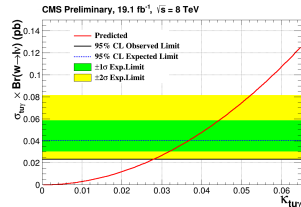
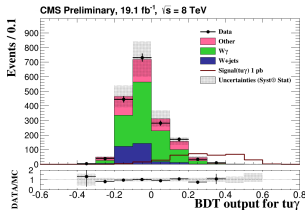
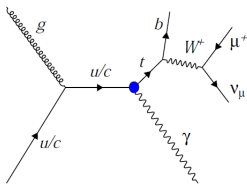
Process	Branching ratios
$t \rightarrow u + \gamma$	4×10^{-16}
$t \rightarrow c + \gamma$	5×10^{-14}
$t \rightarrow u + Z$	7×10^{-17}
$t \rightarrow c + Z$	1×10^{-14}
$t \rightarrow u + g$	4×10^{-14}
$t \rightarrow c + g$	5×10^{-12}
$t \rightarrow u + H$	2×10^{-17}
$t \rightarrow c + H$	3×10^{-15}

- This essentially guarantees that any measurable branching ratio for top FCNC decays is an indication of new physics.

- Many models for new physics predict new contributions to top FCNCs that are orders of magnitude in excess of SM expectations.

Process	SM	2HDM(FV)	2HDM(FC)	MSSM	RPV	RS
$t \rightarrow u + \gamma$	4×10^{-16}	-	-	$\leq 10^{-8}$	$\leq 10^{-9}$	-
$t \rightarrow c + \gamma$	5×10^{-14}	$\leq 10^{-7}$	$\leq 10^{-9}$	$\leq 10^{-8}$	$\leq 10^{-9}$	$\leq 10^{-9}$
$t \rightarrow u + Z$	7×10^{-17}	-	-	$\leq 10^{-7}$	$\leq 10^{-6}$	-
$t \rightarrow c + Z$	1×10^{-14}	$\leq 10^{-6}$	$\leq 10^{-10}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-5}$
$t \rightarrow u + g$	4×10^{-14}	-	-	$\leq 10^{-7}$	$\leq 10^{-6}$	-
$t \rightarrow c + g$	5×10^{-12}	$\leq 10^{-4}$	$\leq 10^{-8}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-10}$
$t \rightarrow u + H$	2×10^{-17}	6×10^{-6}	-	$\leq 10^{-5}$	$\leq 10^{-9}$	-
$t \rightarrow c + H$	3×10^{-15}	2×10^{-3}	$\leq 10^{-5}$	$\leq 10^{-5}$	$\leq 10^{-9}$	$\leq 10^{-4}$

- The branching ratio (BR) : the ratio of the flavor-violating partial width relative to the dominant top quark partial width, $t \rightarrow b + W$.

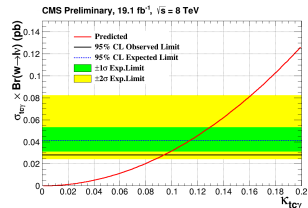
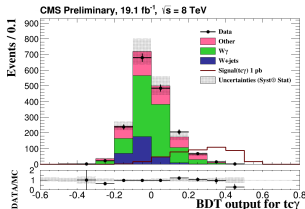


Final State :

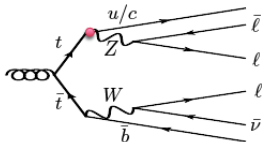
1 isolated μ , 1 γ , \cancel{E}_T and 1 b -tagged jet

Background : $t + \gamma$, $t\bar{t}$, $t\bar{t} + \gamma$, $W\gamma + \text{jets}$, $W + \text{jets}$, $Z\gamma + \text{jets}$, DrellYan, Diboson.

The dominant uncertainty : the data-driven background estimation.

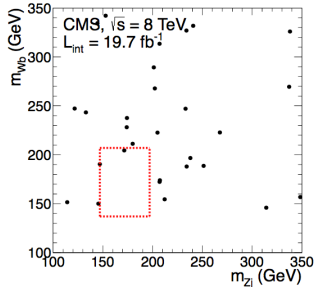
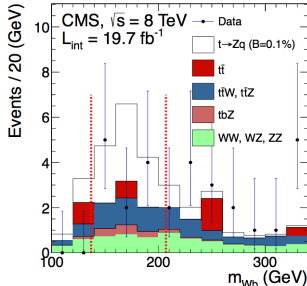
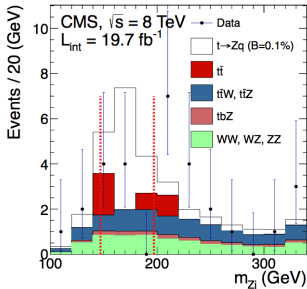


Process	Br Limit	Experiment	Search	Dataset	References
$t \rightarrow u + \gamma$	1.3×10^{-4}	CMS	$t \rightarrow Wb \rightarrow \mu\nu b$	19.8 fb^{-1} , 8 TeV	JHEP1604(2016)035
$t \rightarrow c + \gamma$	1.7×10^{-3}				



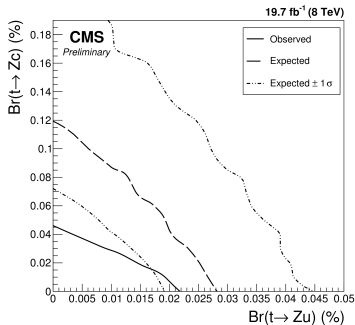
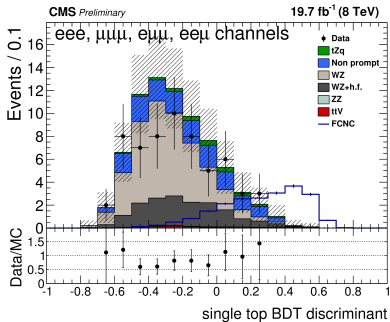
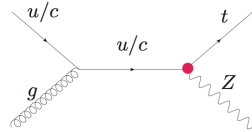
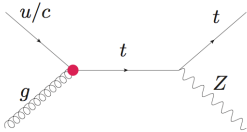
Final State :
 3 isolated e, μ
 ≥ 2 jets, 1
 b-tag
 E_T^{miss}

Main Background :
 $t\bar{t}, t\bar{t}Z, WZ$

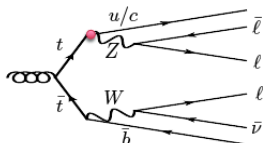


Process	Br Limit	Experiment	Search	Dataset	References
$t \rightarrow u/c + Z$	5×10^{-4}	CMS	$t\bar{t} \rightarrow Zq+Wb \rightarrow llq+l\nu b$	19.7 fb^{-1} , 8 TeV Phys.Rev.Lett.112(2014)171802	

FCNC searches in $t \rightarrow u/c + Z$ at CMS

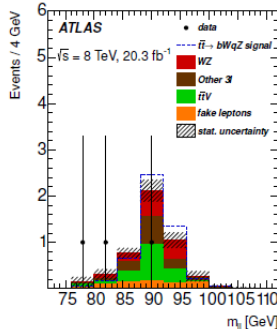
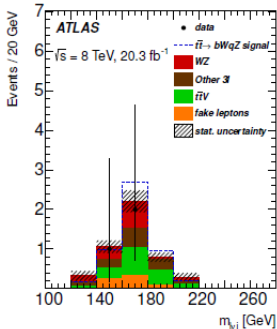
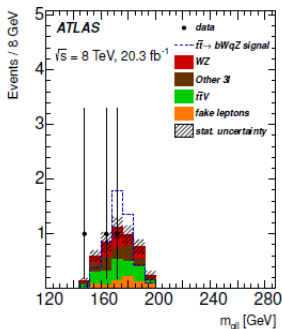


Process	Br Limit	Experiment	Search	Dataset	References
$t \rightarrow u + Z$	2.2×10^{-4}	CMS	$tZq \rightarrow l\nu b^+ l^- q$	19.7 fb ⁻¹ , 8 TeV	CMS-PAS-TOP-12-039
$t \rightarrow c + Z$	4.9×10^{-4}				

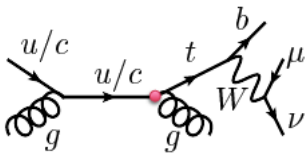


Final State :

3 isolated e, μ
 ≥ 2 jets, 1 b-tag
 E_T^{miss}



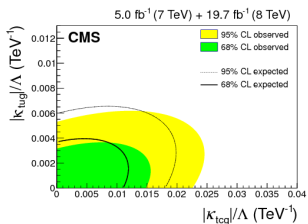
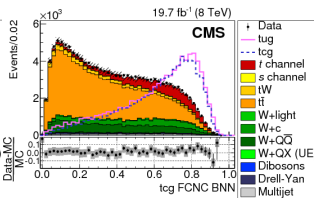
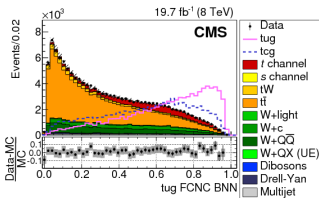
Process	Br Limit	Experiment	Search	Dataset	References
$t \rightarrow u/c + Z$	7×10^{-4}	ATLAS	$t\bar{t} \rightarrow Zq+Wb \rightarrow llq+l\nu/b$	20.3 fb^{-1} , 8 TeV	Eur.Phys.J.C76(2016)no.1,12



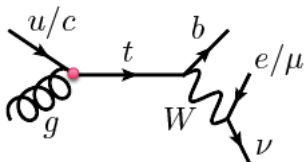
Final State :

1 isolated μ ,

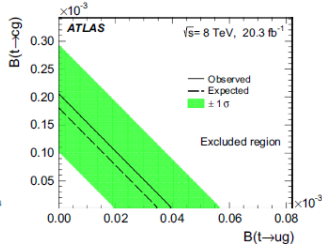
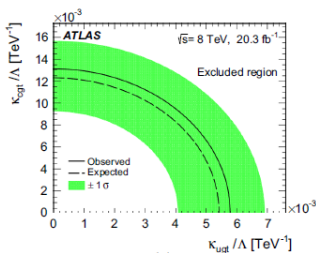
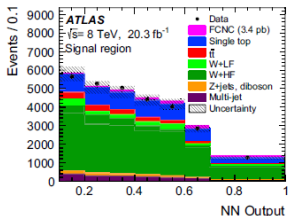
2-3 jets (≥ 1 b-tag, ≥ 1 veto)



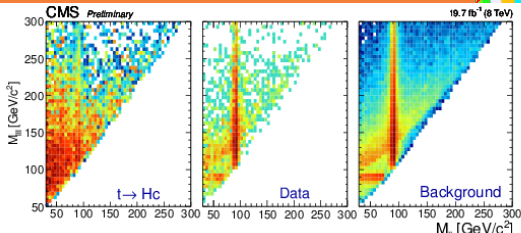
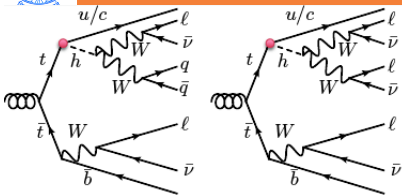
Process	Br Limit	Experiment	Search	Dataset	References
$t \rightarrow u + g$	2×10^{-5}	CMS	Single top t-channel	5 & 19.7 fb^{-1} , 7 & 8 TeV	CMS-PAS-TOP-14-007
$t \rightarrow c + g$	4.1×10^{-4}				



Final State :
 1 isolated e/μ ,
 1 b-tagged jet

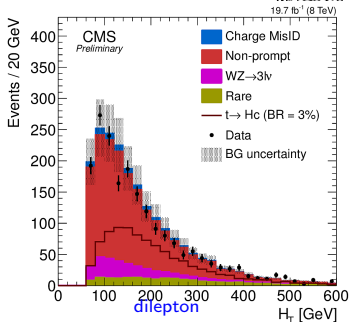
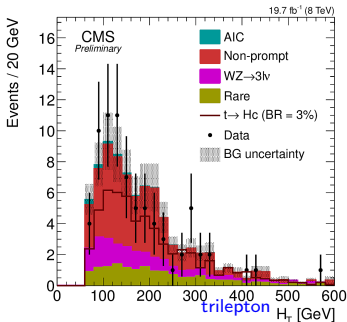


Process	Br Limit	Experiment	Search	Dataset	References
$t \rightarrow u + g$	4×10^{-5}	ATLAS	$t \rightarrow Wb \rightarrow l\nu b$	$20.3 \text{ fb}^{-1}, 8 \text{ TeV}$	Eur.Phys.J.C76(2016)no.2,55
$t \rightarrow c + g$	2×10^{-4}				

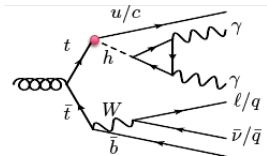


Final State :

- 3 or 2 (same sign of electric charge)
- isolated leptons (e, μ), jets and \cancel{E}_T



Process	Br Limit	Experiment	Search	Dataset	References
$t \rightarrow u + H$	5.5×10^{-3}	CMS	$t\bar{t} \rightarrow Hq + W\bar{b} \rightarrow WWq + l\nu\bar{b}$	$19.7 \text{ fb}^{-1}, 8 \text{ TeV}$	CMS-PAS-TOP-13-017
$t \rightarrow c + H$	4×10^{-3}				



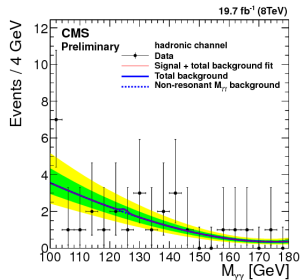
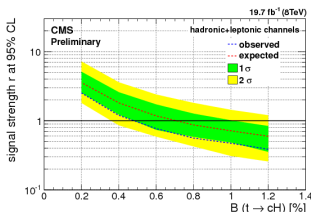
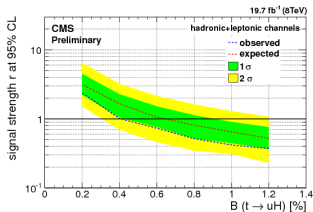
Final State :

≥ 2 photons

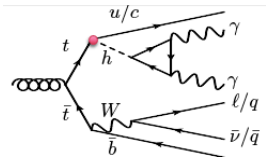
Had: ≥ 4 jets, i b-tag

Lep: 1 isolated e/μ ,

≥ 2 jets, 1 b-tag



Process	Br Limit	Experiment	Search	Dataset	References
$t \rightarrow u + H$	4.7×10^{-3}	CMS	$t\bar{t} \rightarrow Hq+W\bar{b} \rightarrow \gamma\gamma q+l\nu\bar{b}$	19.7 fb^{-1} , 8 TeV	CMS-PAS-TOP-14-019
$t \rightarrow c + H$	4.2×10^{-3}				



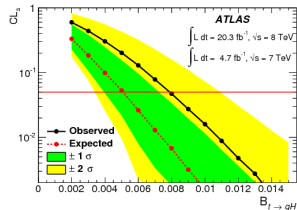
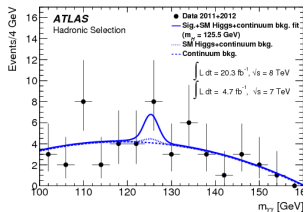
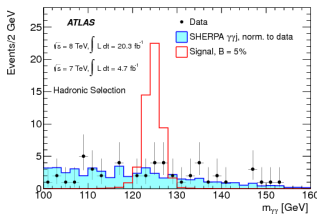
Final State :

≥ 2 photons

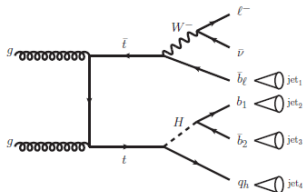
Had: ≥ 4 jets, 1 b-tag

Lep: 1 isolated e/μ , ≥ 2 jets, 1

b-tag



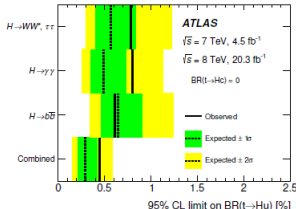
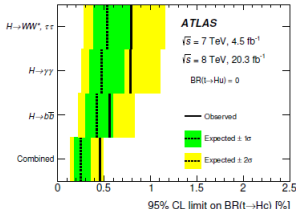
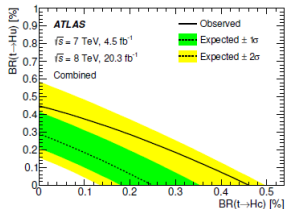
Process	Br Limit	Experiment	Search	Dataset	References
$t \rightarrow u/c + H$	7.9×10^{-3}	ATLAS	$t\bar{t} \rightarrow Hq + W\bar{b} \rightarrow \gamma\gamma q + W\bar{b}$	4.7 & 20.3 fb^{-1} , 7 & 8 TeV	JHEP06(2014)008



Final State :

≥ 4 jets, ≥ 3 b-tag

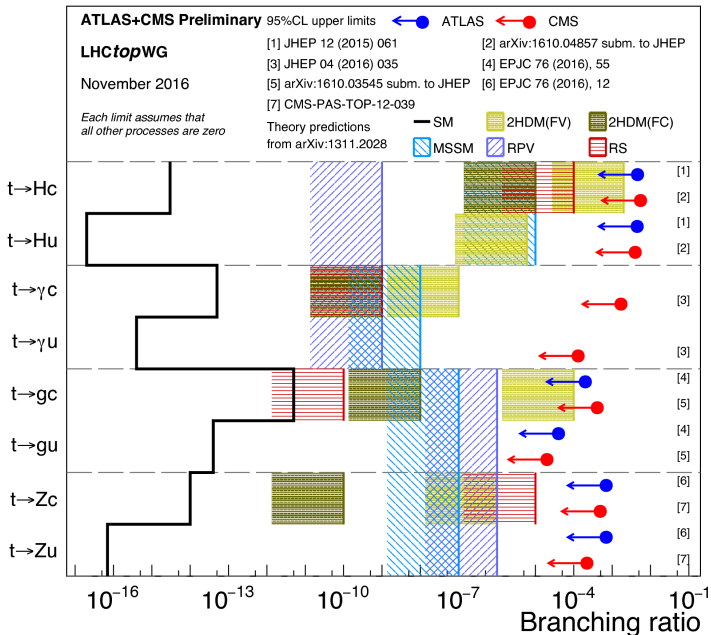
Le p : 1 isolated e/μ , \cancel{E}_T



This is the most sensitive analysis at the LHC.

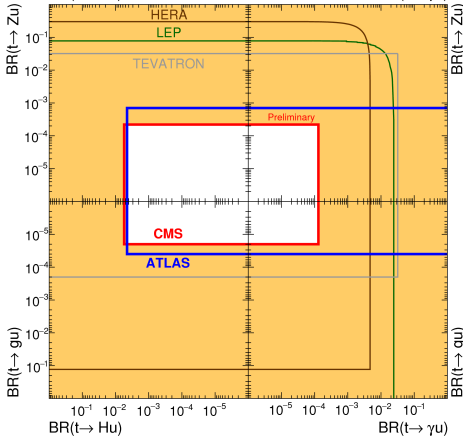
Process	Br Limit	Experiment	Search	Dataset	References
$t \rightarrow u + H$	6.1×10^{-3}	ATLAS	$t\bar{t} \rightarrow Hq+W\bar{b} \rightarrow b\bar{b}q+W\bar{b}$	4.7 & 20.3 fb^{-1} , 7 & 8 TeV	JHEP1512(2015)061
$t \rightarrow c + H$	5.6×10^{-3}				

Process	Br Limit	Experiment	Search	Dataset	References
$t \rightarrow u + \gamma$	1.3×10^{-4}	CMS	$t \rightarrow Wb \rightarrow \mu\nu b$	19.8 fb^{-1} , 8 TeV	JHEP1604(2016)035
$t \rightarrow c + \gamma$	1.7×10^{-3}				CMS-PAS-TOP-14-003
$t \rightarrow u + \gamma$	6.4×10^{-3}	H1	$e^{\pm} p \rightarrow (t \text{ or } \bar{t}) + X$	474 pb^{-1} , 300 GeV	Phys.Lett. B678 (2009) 450-458
$t \rightarrow u/c + \gamma$	4.1×10^{-2}	L3	$e^+ e^- \rightarrow Z/\gamma \rightarrow tq$	634 pb^{-1} , 189 to 209 GeV	Phys.Lett. B549:290-300,2002
$t \rightarrow u/c + Z$	5×10^{-4}	CMS	$t\bar{t} \rightarrow Zq+Wb \rightarrow llq+l\nu b$	19.7 fb^{-1} , 8 TeV	Phys.Rev.Lett.112(2014)171802
$t \rightarrow u + Z$	5.1×10^{-3}	CMS	$tZq \rightarrow l\nu b l^+ l^- q$	4.9 fb^{-1} , 7 TeV	CMS-PAS-TOP-12-021
$t \rightarrow c + Z$	11.4×10^{-2}				
$t \rightarrow u + Z$	2.2×10^{-4}			19.7 fb^{-1} , 8 TeV	CMS-PAS-TOP-12-039
$t \rightarrow c + Z$	4.9×10^{-4}				
$t \rightarrow u/c + Z$	7.3×10^{-3}	ATLAS	$t\bar{t} \rightarrow Zq+Wb \rightarrow llq+l\nu b$	2 fb^{-1} , 7 TeV	JHEP1209(2012)139
$t \rightarrow u/c + Z$	7×10^{-4}			20.3 fb^{-1} , 8 TeV	Eur.Phys.J.C76(2016)no.1,12
$t \rightarrow u/c + Z$	3.7×10^{-2}	CDF	$t\bar{t} \rightarrow Zq+Wb \rightarrow Zq+q\bar{q}b$	1.9 fb^{-1} , 1.96 TeV	Phys.Rev.Lett.101:192002,2008
$t \rightarrow u + Z$	4×10^{-2}	ZEUS	$ep \rightarrow epX$	0.50 fb^{-1} , 315 GeV	Phys.Lett.B708:27-36,2012
$t \rightarrow u/c + Z$	1.37×10^{-3}	L3	$e^+ e^- \rightarrow Z/\gamma \rightarrow tq$	634 pb^{-1} , 189 to 209 GeV	Phys.Lett.B549:290-300,2002
$t \rightarrow u + g$	2×10^{-5}	CMS	Single top t-channel	$5 \text{ \& } 19.7 \text{ fb}^{-1}$, 7 & 8 TeV	CMS-PAS-TOP-14-007
$t \rightarrow c + g$	4.1×10^{-4}				arXiv:1610.03545
$t \rightarrow u + g$	4×10^{-5}	ATLAS	$t \rightarrow Wb \rightarrow l\nu b$	20.3 fb^{-1} , 8 TeV	Eur.Phys.J.C76(2016)no.2,55
$t \rightarrow c + g$	2×10^{-4}				arxiv:1509.00294
$t \rightarrow u + g$	5.7×10^{-5}			2.05 fb^{-1} , 7 TeV	PhysicsLettersB712(2012)351369
$t \rightarrow c + g$	2.7×10^{-4}				
$t \rightarrow u + g$	2×10^{-4}	DØ	single top + jet	2.3 fb^{-1} , 1.96 TeV	Phys.Lett.B693:81-87,2010
$t \rightarrow c + g$	3.9×10^{-3}				
$t \rightarrow u + H$	5.5×10^{-3}	CMS	$t\bar{t} \rightarrow Hq+W\bar{b} \rightarrow WWq+l\nu\bar{b}$	19.7 fb^{-1} , 8 TeV	CMS-PAS-TOP-13-017
$t \rightarrow c + H$	4×10^{-3}				
$t \rightarrow u + H$	4.7×10^{-3}	CMS	$t\bar{t} \rightarrow Hq+W\bar{b} \rightarrow \gamma\gamma q+l\nu\bar{b}$	19.7 fb^{-1} , 8 TeV	CMS-PAS-TOP-14-019
$t \rightarrow c + H$	4.2×10^{-3}				
$t \rightarrow u/c + H$	7.9×10^{-3}	ATLAS	$t\bar{t} \rightarrow Hq+W\bar{b} \rightarrow \gamma\gamma q+W\bar{b}$	$4.7 \text{ \& } 20.3 \text{ fb}^{-1}$, 7 & 8 TeV	JHEP06(2014)008
$t \rightarrow u + H$	6.1×10^{-3}	ATLAS	$t\bar{t} \rightarrow Hq+W\bar{b} \rightarrow b\bar{b}q+W\bar{b}$	$4.7 \text{ \& } 20.3 \text{ fb}^{-1}$, 7 & 8 TeV	JHEP1512(2015)061
$t \rightarrow c + H$	5.6×10^{-3}				



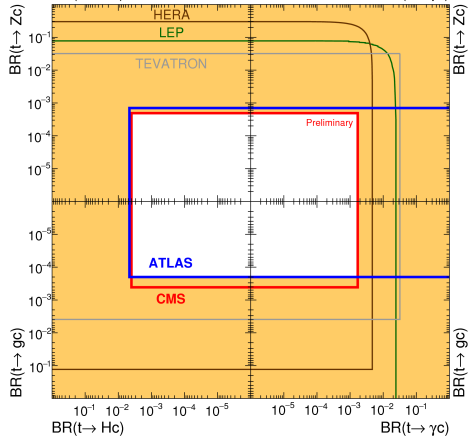
ATLAS+CMS Preliminary LHCtopWG November 2016

$BR(t \rightarrow Hu)$ Each limit assumes that all other processes are zero $BR(t \rightarrow \gamma u)$



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$BR(t \rightarrow Hc)$ Each limit assumes that all other processes are zero $BR(t \rightarrow \gamma c)$



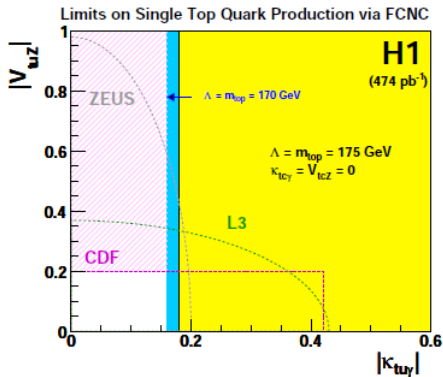
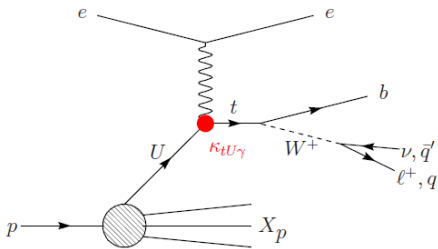


- A review on FCNC searches in the top quark sector has been presented with the results from different experiment.
- It has covered all known types of FCNC couplings of top quark with various final states.
- FCNC processes play an important role as a test for the SM as well as for different BSM models.
- Still there is no evidence for new physics.
- The ATLAS and the CMS experiments have significantly improved the exclusion limits for FCNC couplings with Run I data.
- The higher center of mass energy and luminosity of Run II will allow us to study FCNC processes with an unprecedented precision.

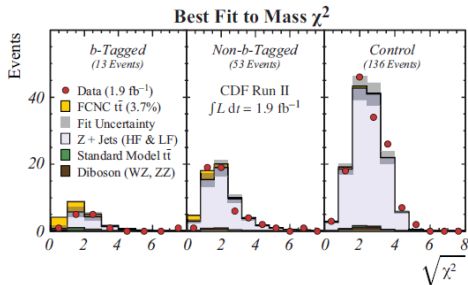
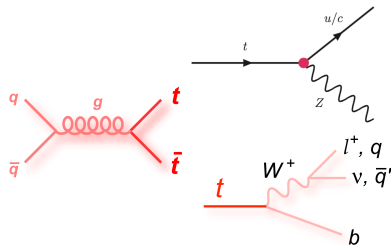
Thanks



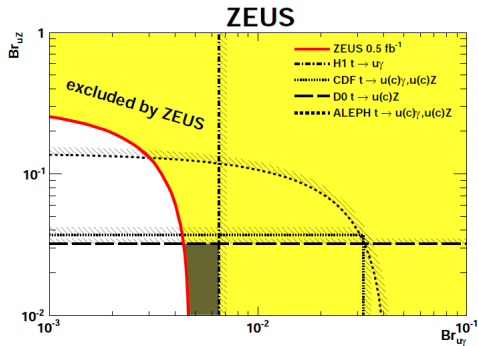
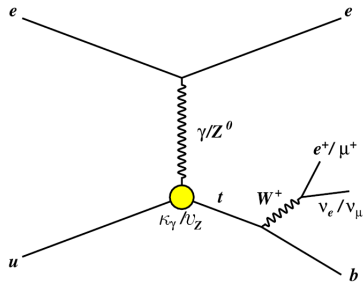
Backup



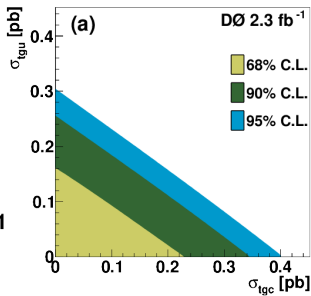
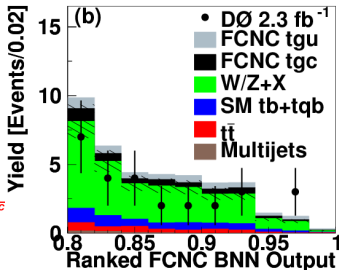
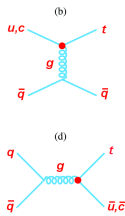
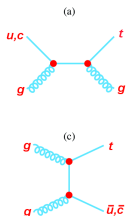
Process	Br Limit	Experiment	Search	Dataset	References
$t \rightarrow u + \gamma$	6.4×10^{-3}	H1	$e^\pm p \rightarrow (t \text{ or } \bar{t}) + X$	474 pb^{-1} , 300 GeV	Phys.Lett. B678 (2009) 450-458



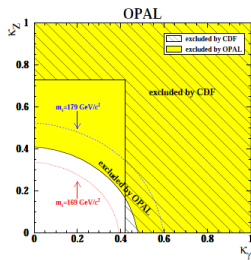
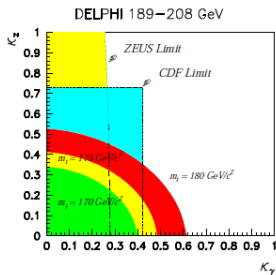
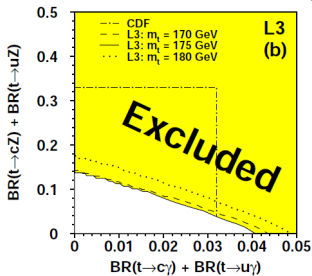
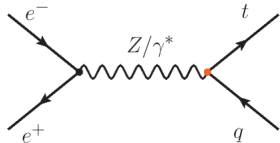
Process	Br Limit	Experiment	Search	Dataset	References
$t \rightarrow u/c + Z$	3.7×10^{-2}	CDF	$t\bar{t} \rightarrow Zq+Wb \rightarrow Zq+q\bar{q}b$	1.9 fb^{-1} , 1.96 TeV	Phys.Rev.Lett.101:192002



Process	Br Limit	Experiment	Search	Dataset	References
$t \rightarrow u + Z$	4×10^{-2}	ZEUS	$ep \rightarrow epX$	0.50 fb^{-1} , 315 GeV	Phys.Lett.B708:27-36,2012



Process	Br Limit	Experiment	Search	Dataset	References
$t \rightarrow u + g$	2×10^{-4}	$D\phi$	single top + jet	2.3 fb^{-1} , 1.96 TeV	Phys.Lett.B693:81-87,2010
$t \rightarrow c + g$	3.9×10^{-3}				



Process	Br Limit	Experiment	Search	Dataset	References
$t \rightarrow u/c + \gamma$	4.1×10^{-2}	L3	$e^+e^- \rightarrow Z/\gamma \rightarrow tq$	634 pb ⁻¹ , 189 to 209 GeV	Phys.Lett.B549:290-300,2002
$t \rightarrow u/c + Z$	1.37×10^{-3}	DELPHI OPAL			Phys.Lett. B590(2004)21-34 Phys.Lett.B521:181-194,2001