Searches and prospects for rare top decays at ATLAS and CMS

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on behalf of the ATLAS and CMS collaboration

For Precision Theory 2016

26/09/2016 at Quy Nhon, Vietnam

Outline

- Introduction
- Motivation
- Rare top decays through charged particle
- Rare top decays through neutral particle
- Perspectives at 14 TeV
- Conclusion

Introduction

- Top quark decays before hadronization.
  - almost 100% decays to b-quark and W boson in the SM.
- Decay to lighter down-type quarks (d or s) are allowed but suppressed due to CKM matrix.
- Flavor changing neutral currents (FCNC)
  - Transitions that change the flavor of a fermion without changing its charge.
  - FCNC is suppressed by GIM mechanism (can occur only at quantum loop corrections).
  - In the SM, the branching ratio of FCNC is expected to be smaller than 10^{-12}.

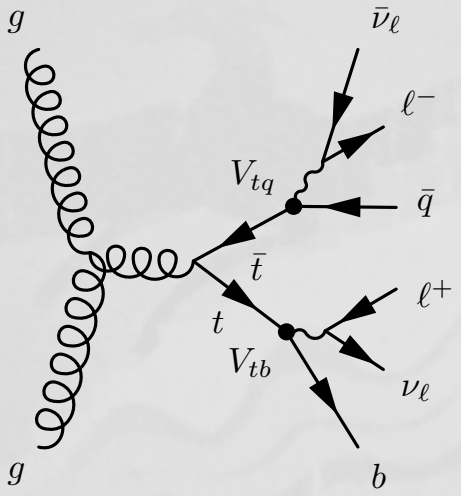
Motivation

- FCNCs are enhanced in many beyond the SM.
- Any small deviation would indicate new physics.
- Top rare decay should be sensitive to new physics already.
- Model independent searches using effective Lagrangian were pursued.
- More 2 M events produced with 30 fb^{-1} for Run2.

	SM	QS	2HDM	FC 2HDM	MSSM	$\not{R}$ SUSY
$t \to uZ$	8×10^{-17}	1.1×10^{-4}	–	–	2×10^{-6}	3×10^{-5}
$t \to u\gamma$	3.7×10^{-16}	7.5×10^{-9}	–	–	2×10^{-6}	1×10^{-6}
$t \to ug$	3.7×10^{-14}	1.5×10^{-7}	–	–	8×10^{-5}	2×10^{-4}
$t \to uH$	2×10^{-17}	4.1×10^{-5}	5.5×10^{-6}	–	10^{-5}	$\sim 10^{-6}$
$t \to cZ$	1×10^{-14}	1.1×10^{-4}	$\sim 10^{-7}$	$\sim 10^{-10}$	2×10^{-6}	3×10^{-5}
$t \to c\gamma$	4.6×10^{-14}	7.5×10^{-9}	$\sim 10^{-6}$	$\sim 10^{-9}$	2×10^{-6}	1×10^{-6}
$t \to cg$	4.6×10^{-12}	1.5×10^{-7}	$\sim 10^{-4}$	$\sim 10^{-8}$	8×10^{-5}	2×10^{-4}
$t \to cH$	3×10^{-15}	4.1×10^{-5}	1.5×10^{-3}	$\sim 10^{-5}$	10^{-5}	$\sim 10^{-6}$

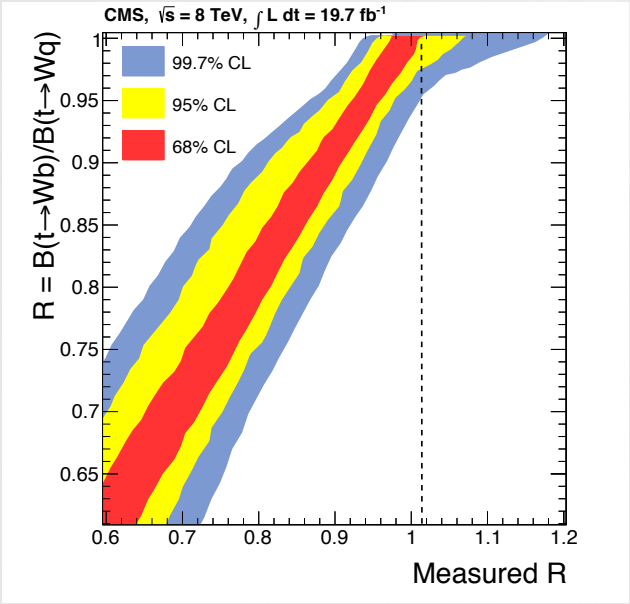
arXiv:hep-ph/0409342

Searches for $t\bar{t}, t \to qW$



$$R = \frac{B(t \to Wb)}{B(t \to Wq)} = |V_{tb}|^2$$

PLB 736 (2014) 33



Phys. Rev. D 92, 072005 (2015)

Branching ratio in top decays

	N_{ej} $N_{\mu j}$ $N_{\ell j}$	N_{ee}	$N_{\mu\mu}$ $N_{\ell\ell}$	$N_{e\mu}$	$N_{\ell\tau}$
Measured	30.62±0.26 30.57±0.29 61.19±0.40	3.06±0.12	3.19±0.10 12.31±0.20	6.06±0.12	6.39±0.30
SM	30.40±1.2 30.40±1.2 60.64±2.4	2.86±0.11	2.86±0.11 10.95±0.44	5.72±0.20	6.39±0.25

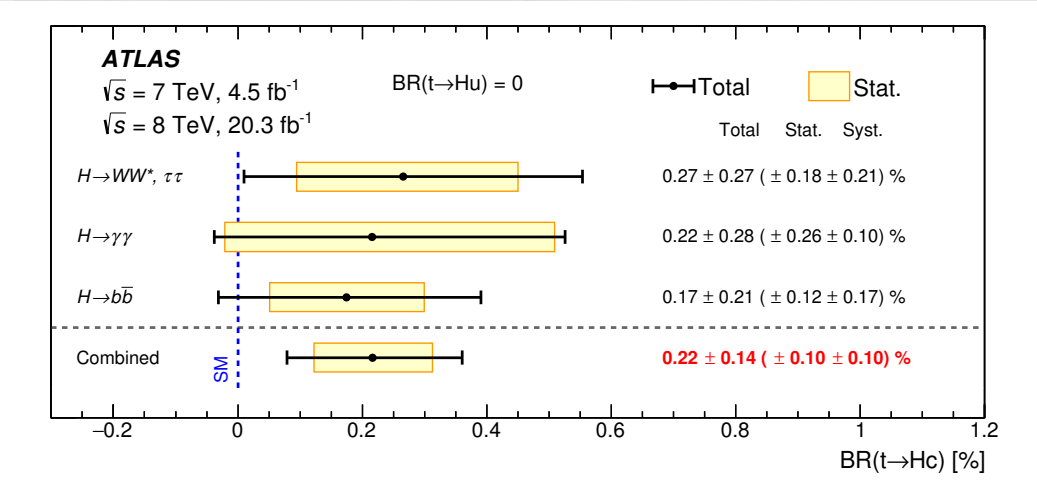
$|V_{tb}|$=1.007±0.016

R > 0.96 if R ≤ 1

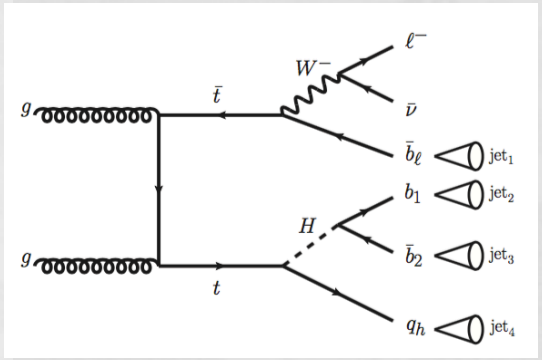
$t\bar{t}, t \to qH$ at ATLAS

- Combination of $H \to b\bar{b}$ with $H \to \gamma\gamma$ and $H \to WW^*, \tau\tau$ improves the sensitivity.

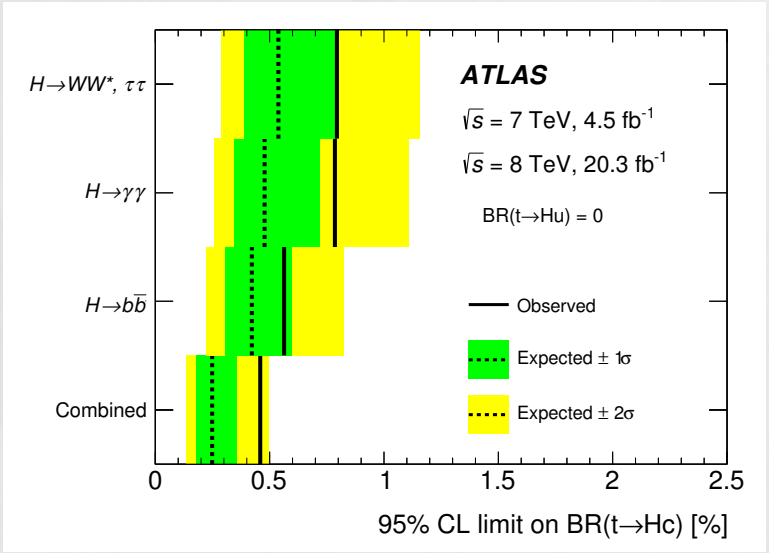
JHEP 12 (2015) 061



Best fit result



CL limit



Obs. (Exp.) B(t→cH) < 0.46% (0.25%)

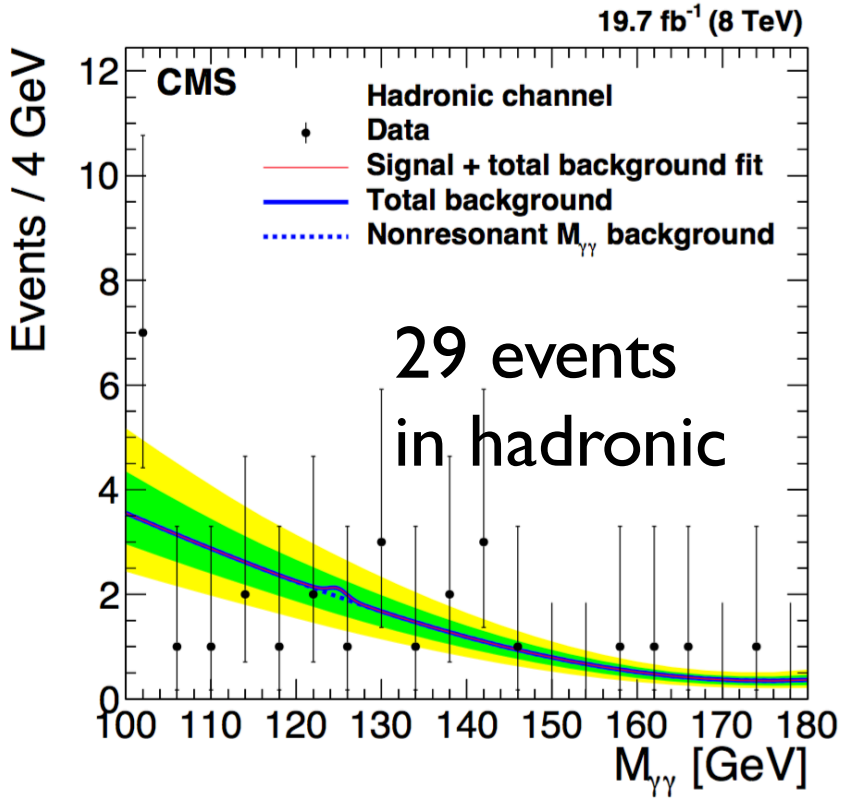
Obs. (Exp.) B(t→uH) < 0.45% (0.29%)

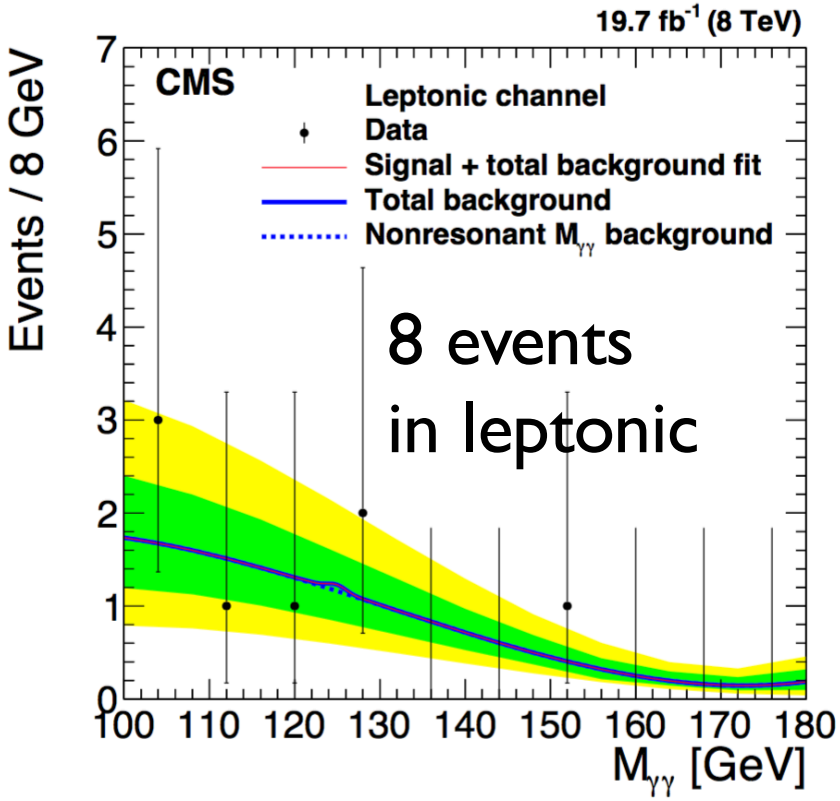
$t\bar{t}, t \to qH$ at CMS (8 TeV)

19.7 fb^{-1} at 8 TeV

CMS-PAS-TOP-13-007 (paper in preparation)

- Combination of $H \to \gamma\gamma, bb, WW, ZZ, \tau\tau$ decay modes.
- Most sensitive channel in $H \to \gamma\gamma$ decay mode (hadronic channel) with two highest photons. ($p_T > M_{\gamma\gamma}/3, p_T > M_{\gamma\gamma}/4$)

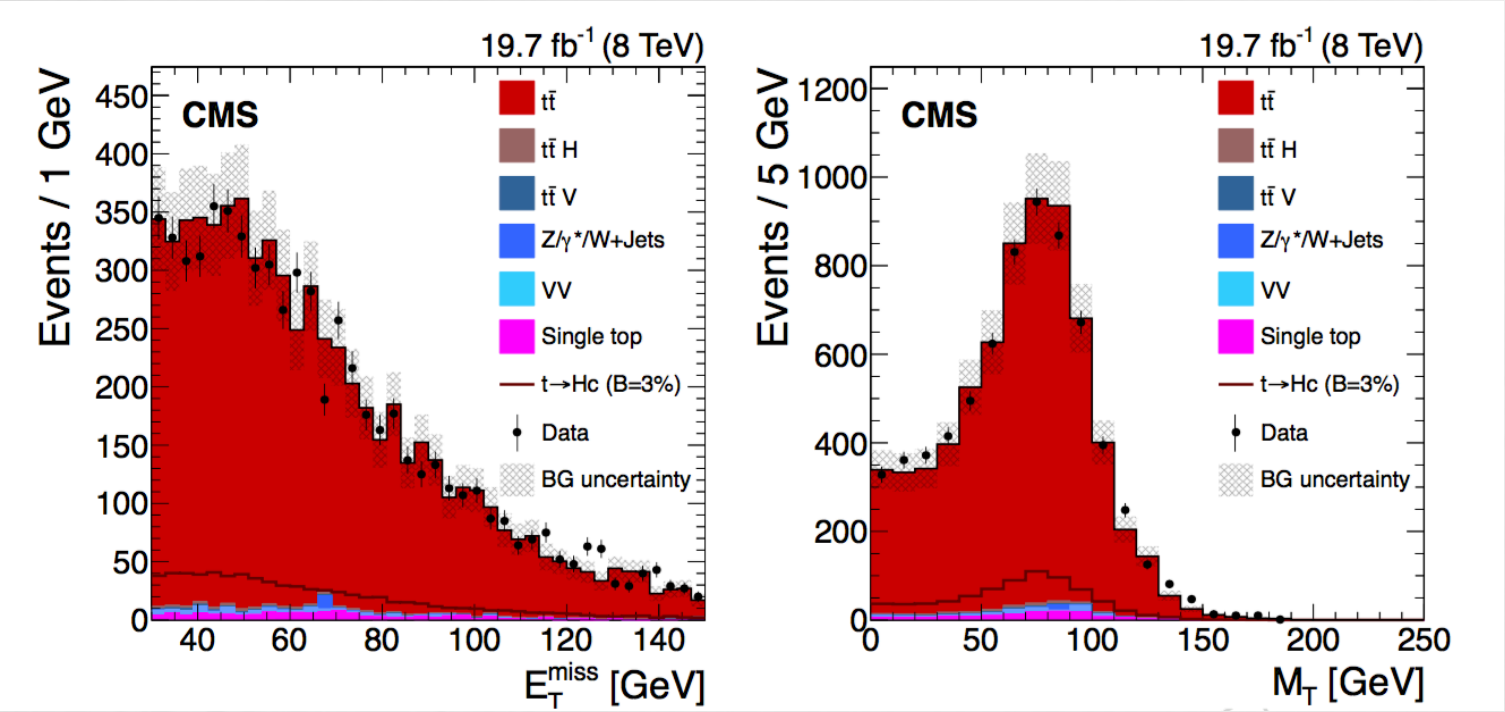




$t\bar{t}, t \to qH$ at CMS (8 TeV)

- 3 b jets + one lepton channel

CMS-PAS-TOP-13-007 (paper in preparation)



- Combination

  Obs. (Exp.) B(t→cH) < 0.40% (0.43%)

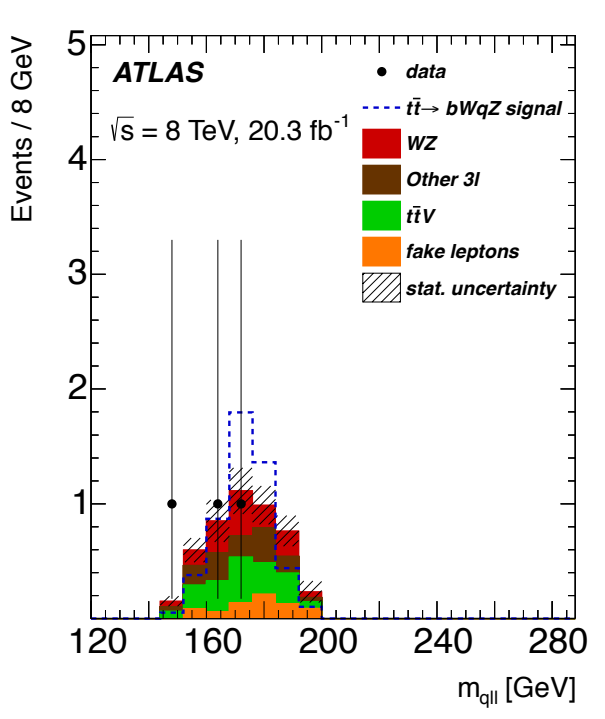
  Obs. (Exp.) B(t→uH) < 0.55% (0.40%)

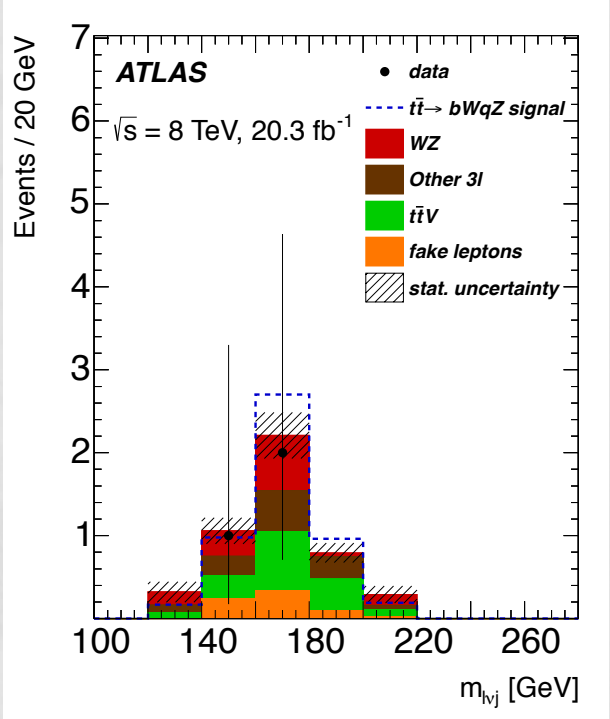
New!

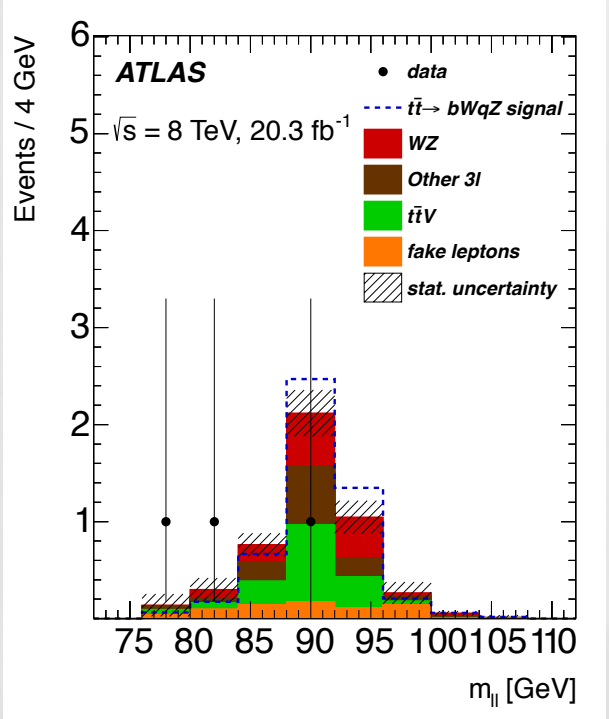
$t \to qZ, Z \to ll$ at ATLAS (8 TeV)

Eur. Phys. J. C (2016) 76:12

- Three isolated leptons, at least two jets, MET.
- Kinematic reconstruction using m_{top} and m_W.
- Correct assignment : $\epsilon_{tFCNC} = 79.9\%$ $\epsilon_{tSM} = 56.3\%$







$t \to qZ, Z \to ll$ at ATLAS (8 TeV)

Eur. Phys. J. C (2016) 76:12

- Main uncertainties on background are from its modeling.
- Uncertainties of the signal modelling are from the production cross section and ISR/FSR modelling , b-tagging.

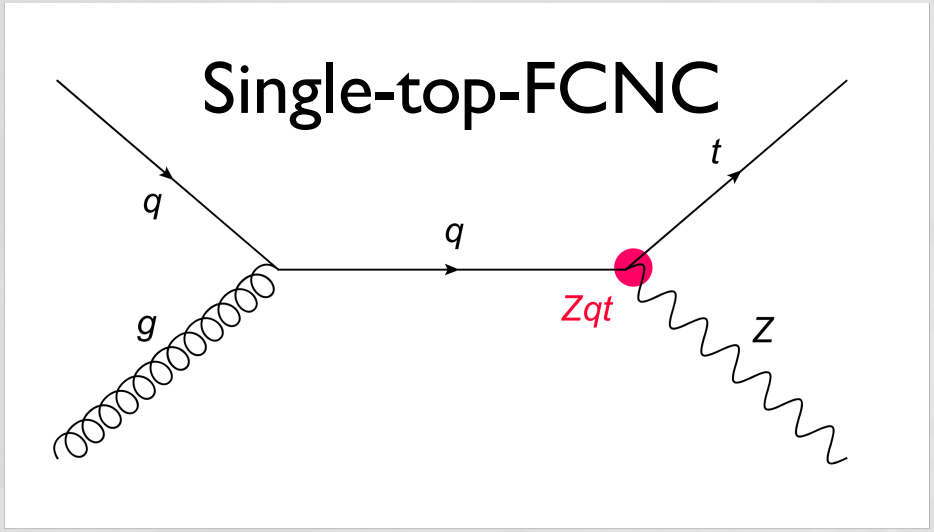
Sample	Yields
WZ	$1.3 \pm 0.2 \pm 0.6$
$t\bar{t}V$	$1.5 \pm 0.1 \pm 0.5$
tZ	$1.0 \pm 0.1 \pm 0.5$
Fake leptons	$0.7 \pm 0.3 \pm 0.4$
Other backgrounds	$0.2 \pm 0.1 \pm 0.1$
Total background	$4.7 \pm 0.4 \pm 1.0$
Data	3
Signal efficiency $[\times 10^{-4}]$	$7.8 \pm 0.1 \pm 0.8$

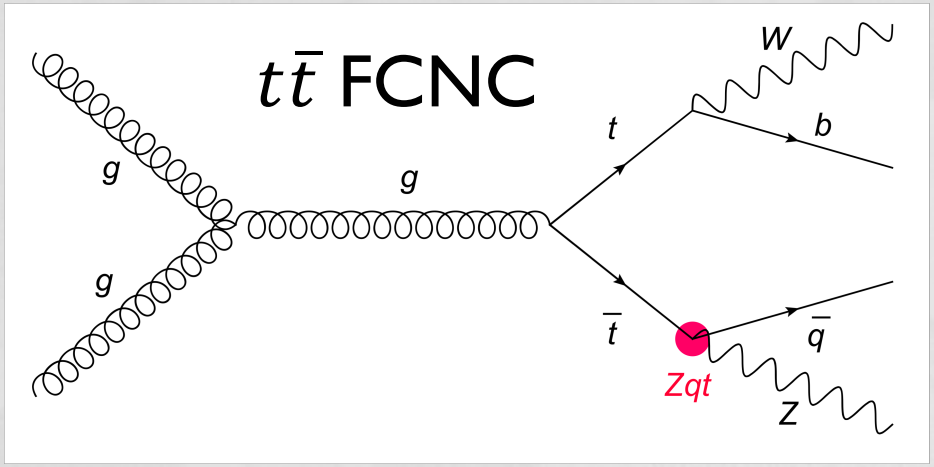
Observed	7×10^{-4}
(-1σ)	6×10^{-4}
Expected	8×10^{-4}
$(+1\sigma)$	12×10^{-4}

$t \to qZ, Z \to ll$ at CMS (8 TeV)

CMS-PAS-TOP-12-039

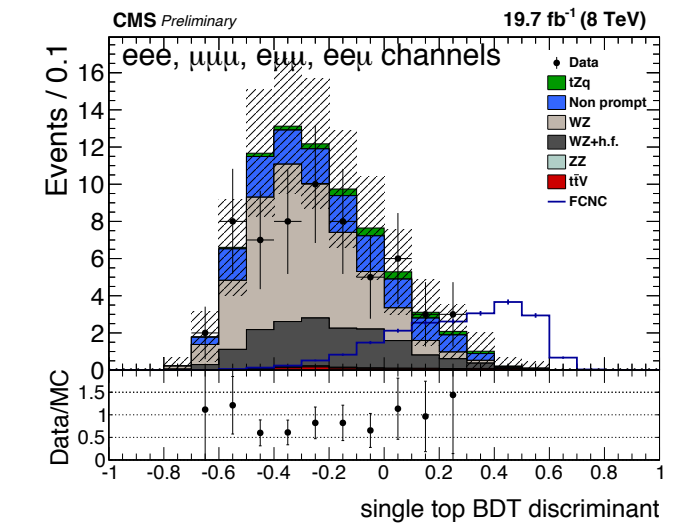
New!

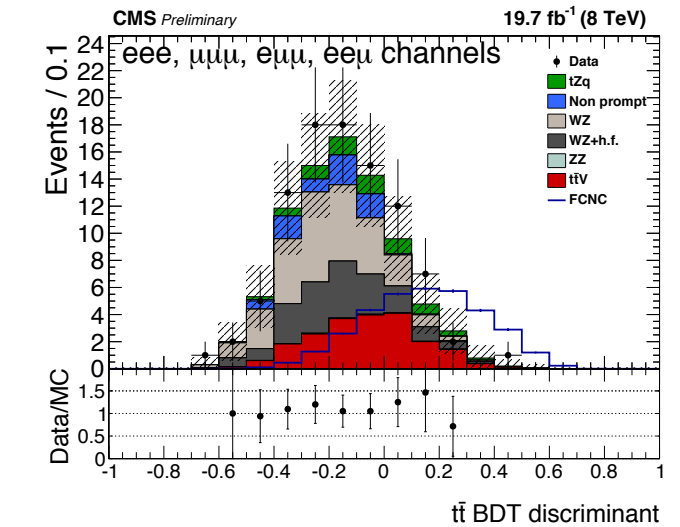




- New analysis searches for tZq-FCNC in single-top and $t\bar{t}$ production.
- Previous analysis PRL 112 (2014) 171802 in $t\bar{t}$ production : Br(t→ qZ) < 0.05%

$t \to qZ, Z \to ll$ at CMS (8 TeV)





CMS-PAS-TOP-12-039

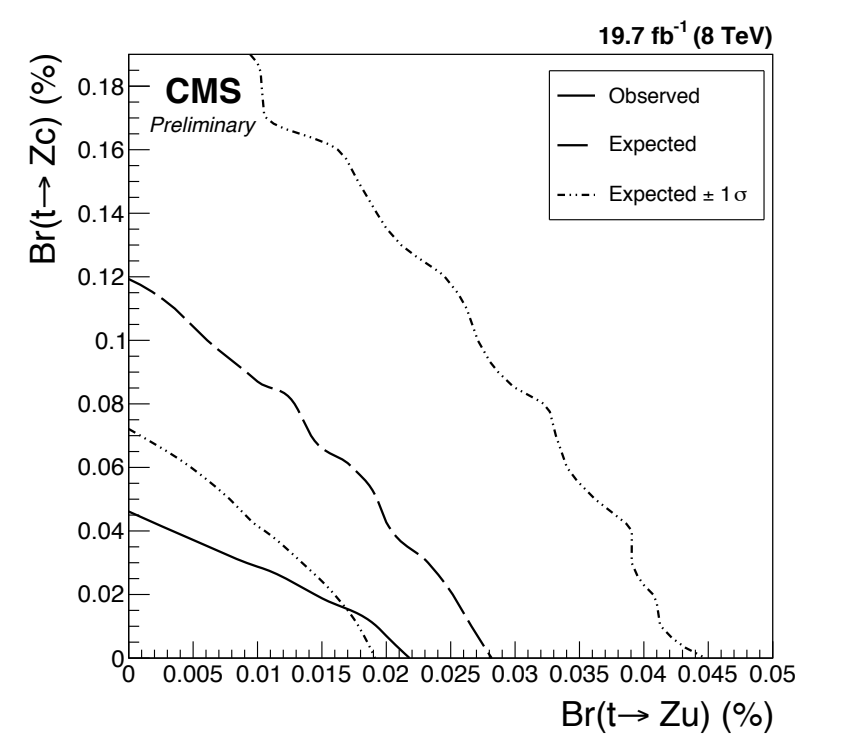
- Four decay modes : eee, $\mu\mu\mu$, e$\mu\mu$, eeμ.
- Single-top-FCNC : exclusively one b-tagged jet .
- $t\bar{t}$ FCNC : at least two jets with one b-tagged jet.
- Single-top-FCNC, $t\bar{t}$ FCNC and background-enriched samples are combined in a single fit.

$t \to qZ, Z \to ll$ at CMS (8 TeV)

CMS-PAS-TOP-12-039

Limits at 95% C.L. for different combinations of tZu and tZc couplings.

More stringent limit is observed on the tZu couplings for its larger cross section.

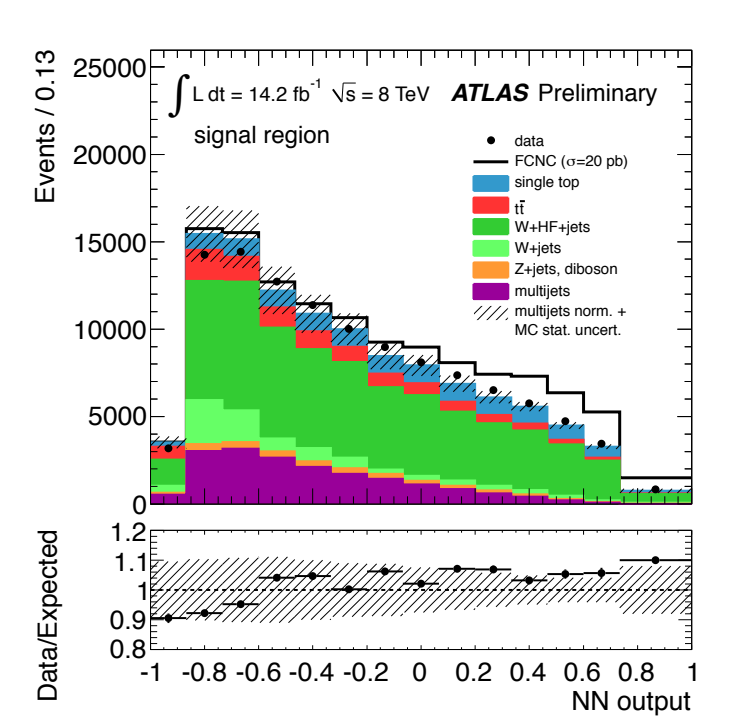


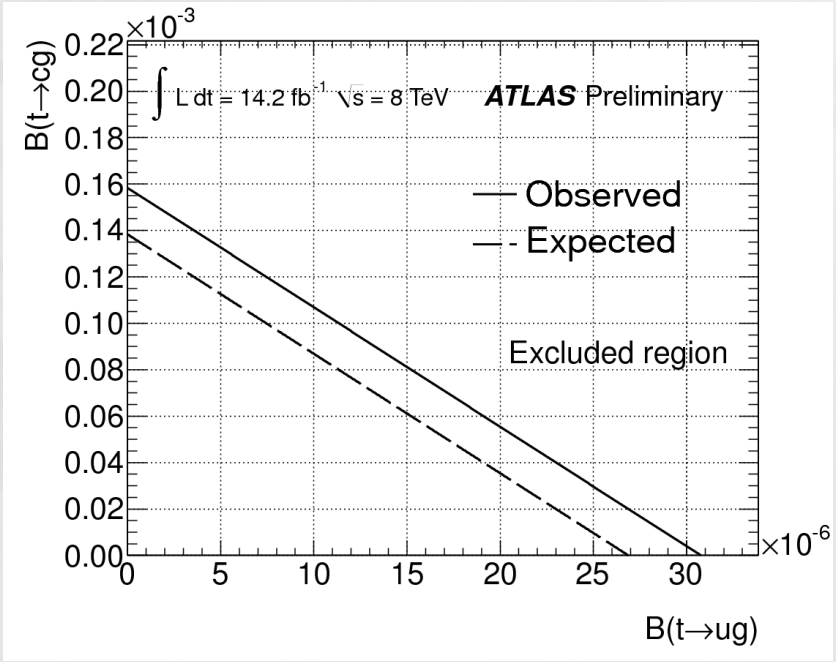
Branching ratio	Expected	1σ range	$2\,\sigma$ range	Observed
$\mathcal{BR}$(t→ Zu) (%)	0.027	0.018-0.042	0.014-0.065	0.022
$\mathcal{BR}$(t→ Zc) (%)	0.118	0.071-0.222	0.049-0.484	0.049

FCNC tcg and tug in single top

14.2 fb^{-1} at 8 TeV

ATLAS-CONF-2013-063





- $Br(t \to u + g) < 3.1\times10^{-5}$ (1.58×10^{-4})
- $Br(t \to c + g) < 1.6\times10^{-4}$ (1.05×10^{-3})

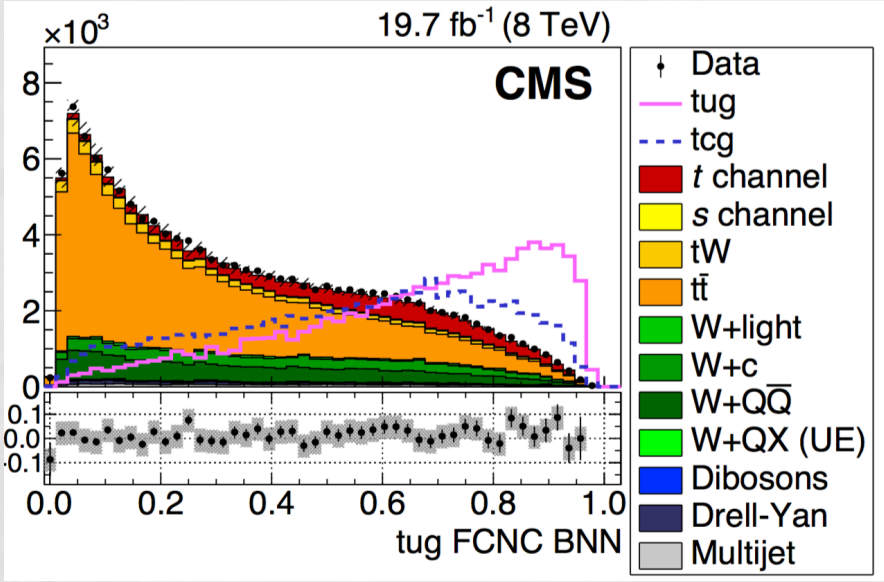
FCNC tcg and tug in single top

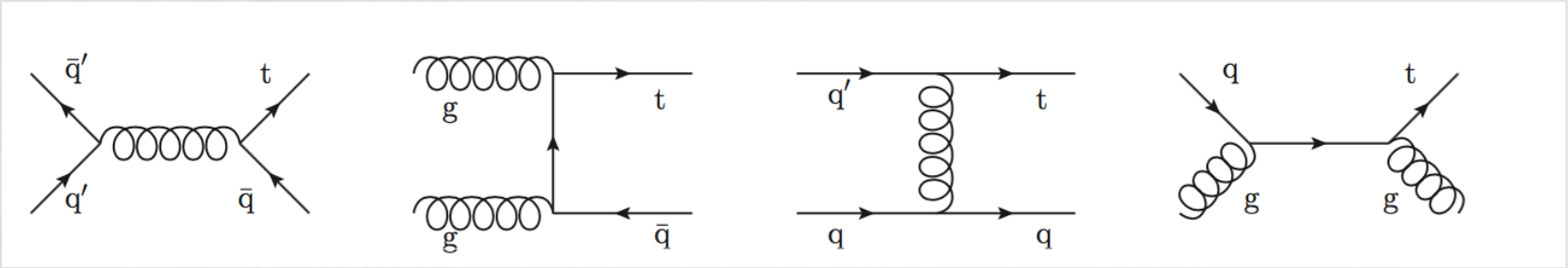
7 TeV and 8 TeV

CMS-PAS-TOP-14-007 (submitted)

New!

- Search for FCNC tcg and tug coupling in the t-channel single top production.
- one isolated μ, 2-3 jets, at least one b-tagged jet
- Using Bayesian Neural Network (BNN)
- $W + jets$ is one of the main uncertainty source.





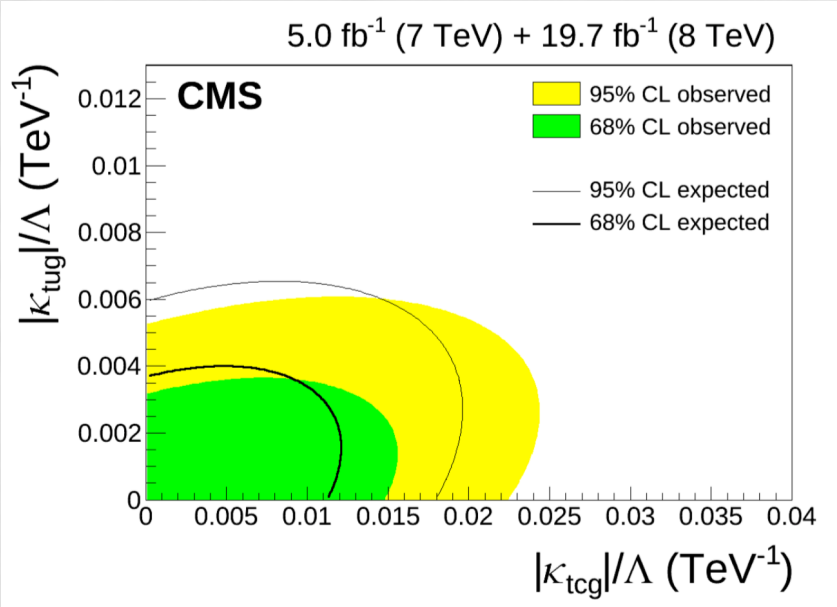
FCNC tcg and tug in single top

7 TeV and 8 TeV

CMS-PAS-TOP-14-007 (submitted)

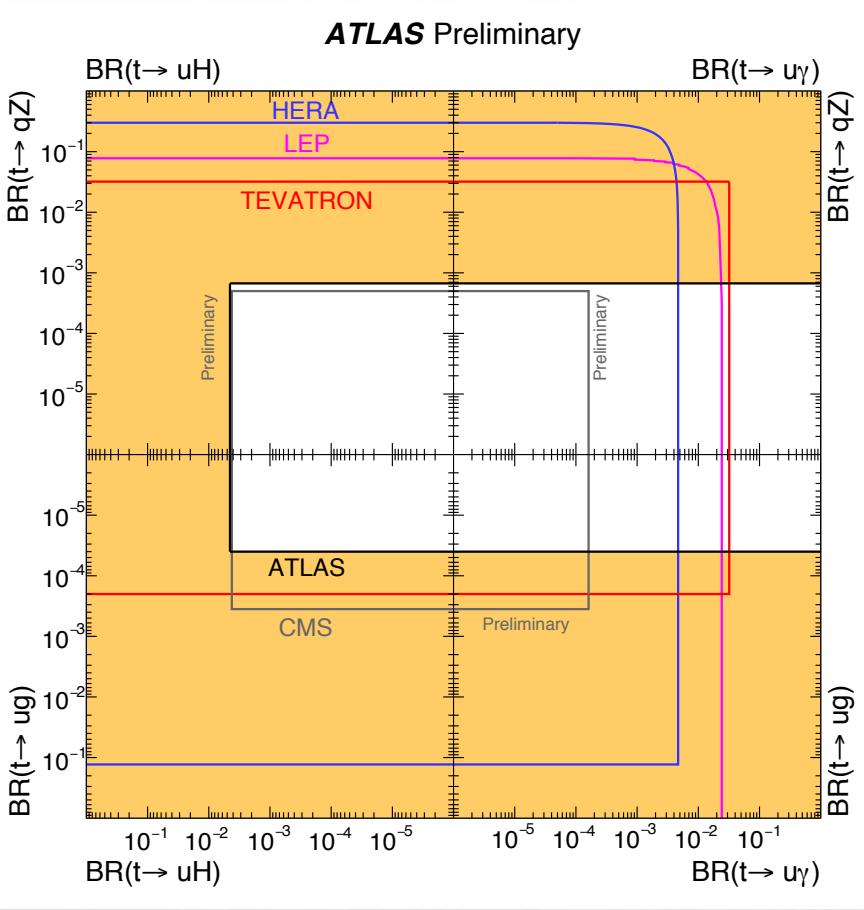
- Effective Lagrangian $\frac{\kappa_{tqg}}{\Lambda} g_s \bar{f} \sigma^{\mu\nu} \lambda^a t G^a_{\mu\nu}$

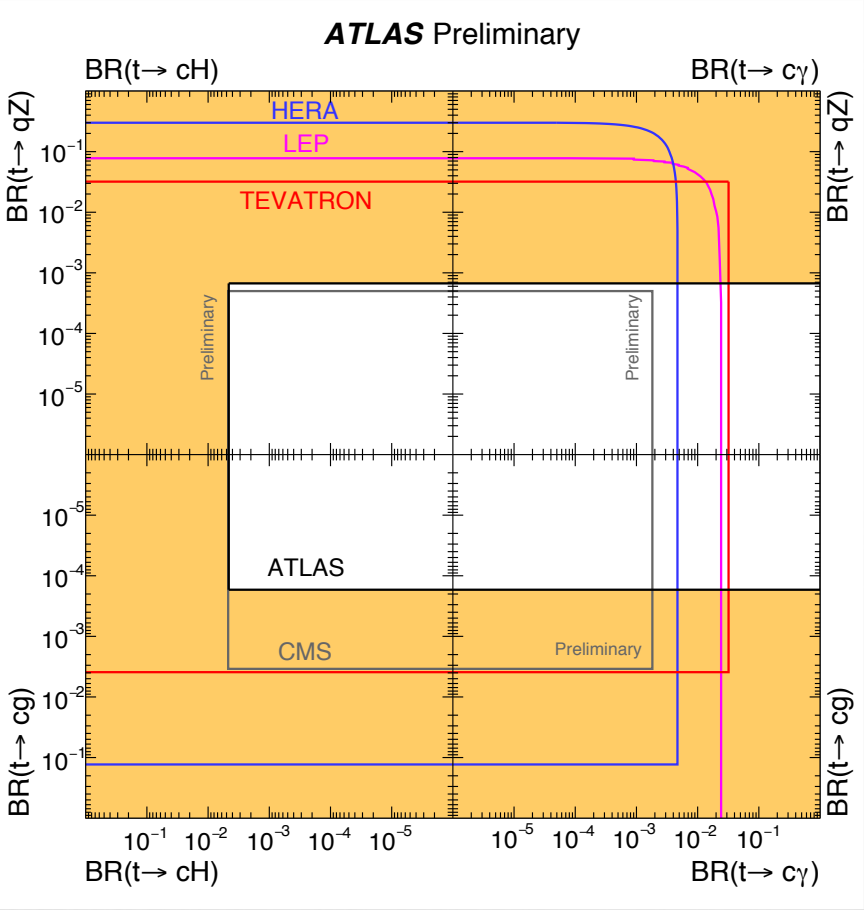
New!



- $Br(t \to u + g) < 2.0\ (2.8) \times 10^{-4}$ ← observed (expected)
- $Br(t \to c + g) < 4.1\ (2.8) \times 10^{-4}$

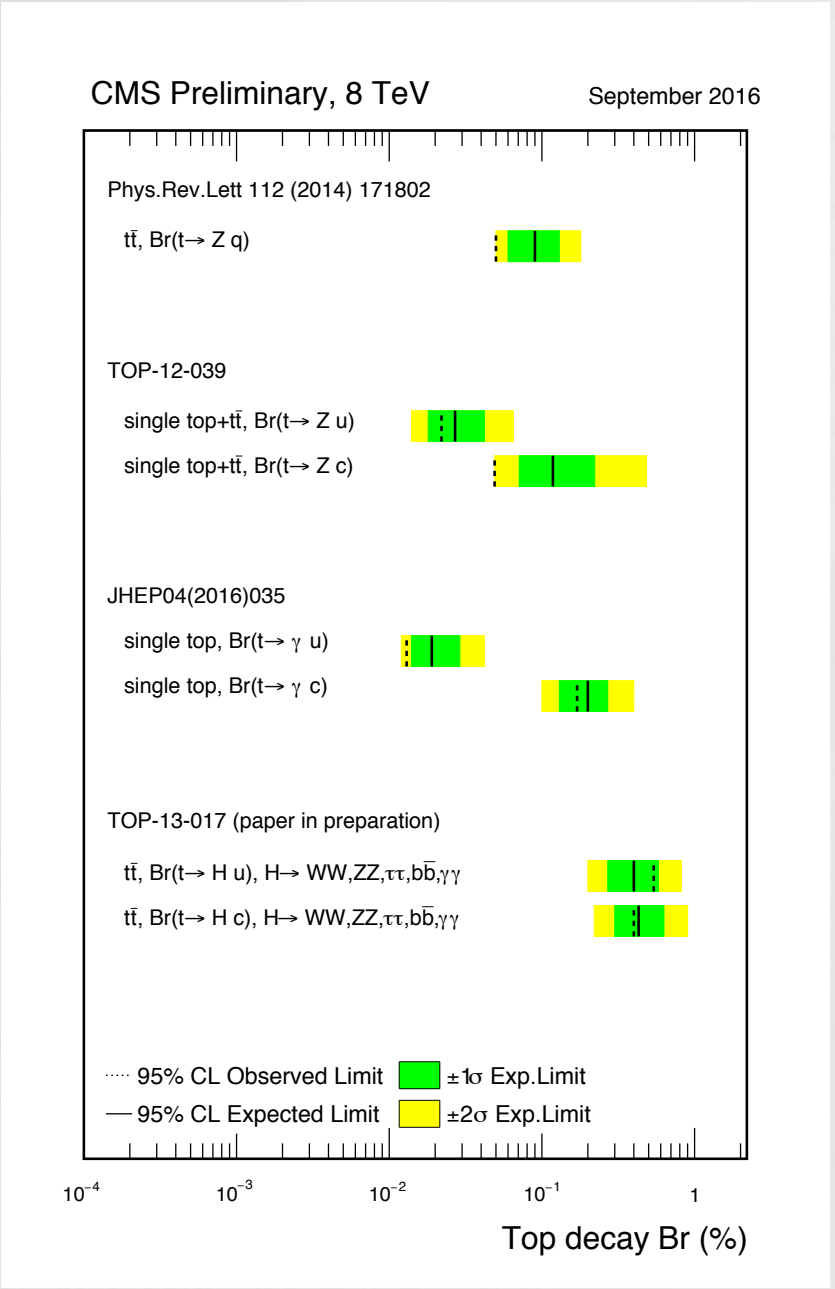
FCNC ATLAS summary





CMS summary

All FCNC results except the result of $tc(u)g$ coupling in TOP-14-007 →

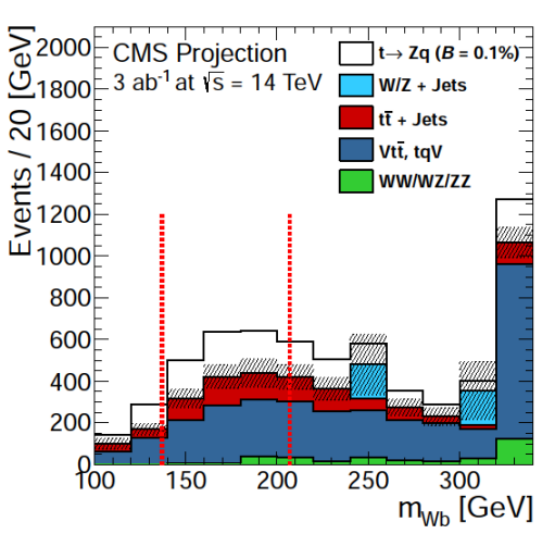


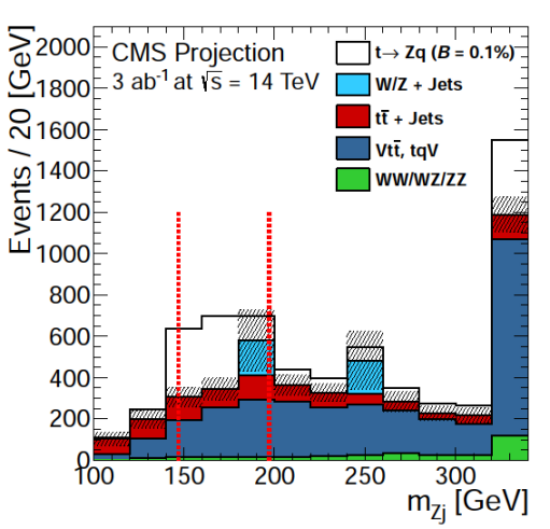
Projections of $t \to cZ$ at 14 TeV

3000fb^{-1} at 14 TeV

CMS-PAS-FTR-13-016

- Search for tqZ coupling in $t\bar{t}$ pair production with upgraded detector at 14 TeV scenario with high pileup conditions.
- 10 times better limit expected at 3000 fb^{-1}



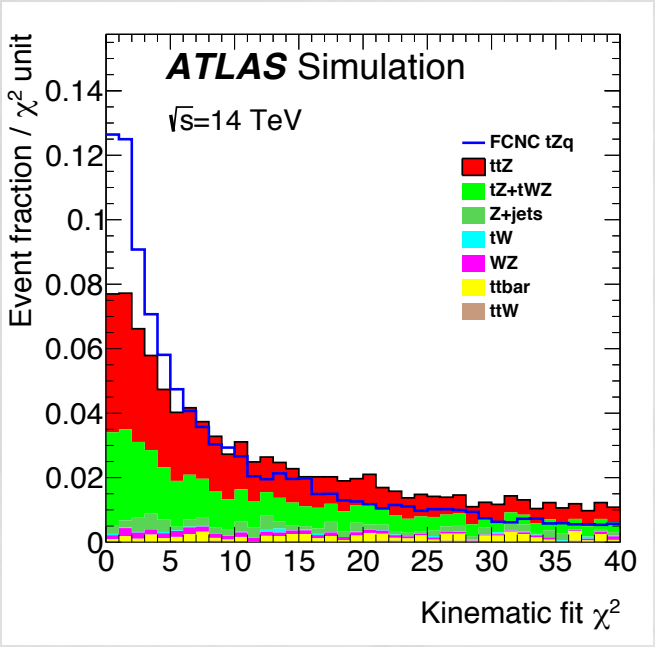


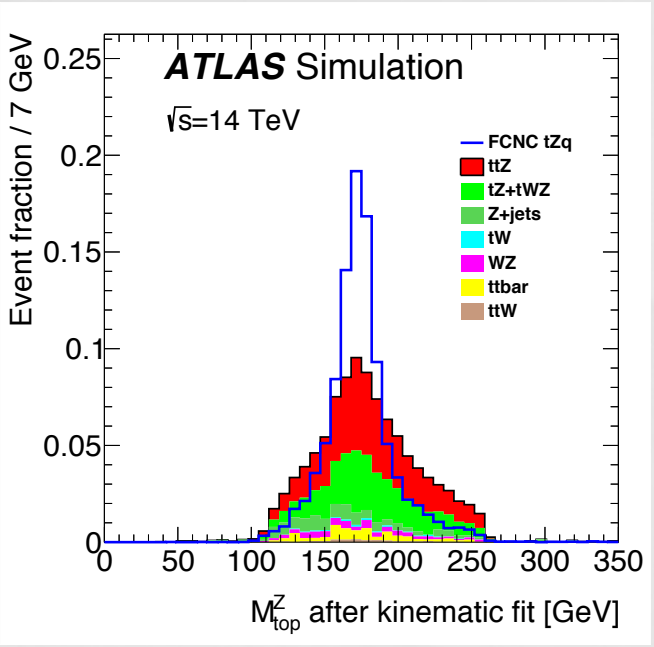
$\mathcal{B}(t \to Zq)$	19.5 fb^{-1} @ 8 TeV	300 fb^{-1} @ 14 TeV	3000 fb^{-1} @ 14 TeV
Exp. bkg. yield	3.2	26.8	268
Expected limit	$< 0.10\%$	$< 0.027\%$	$< 0.010\%$
1 σ range	$0.06 - 0.13\%$	$0.018 - 0.038\%$	$0.007 - 0.014\%$
2 σ range	$0.05 - 0.20\%$	$0.013 - 0.051\%$	$0.005 - 0.020\%$

Projections of $t \to cZ$ at 14 TeV

3000fb^{-1} at 14 TeV

ATL-PHYS-PUB-2016-019





Three different ATLAS detector upgrade scenario: reference, middle, low.

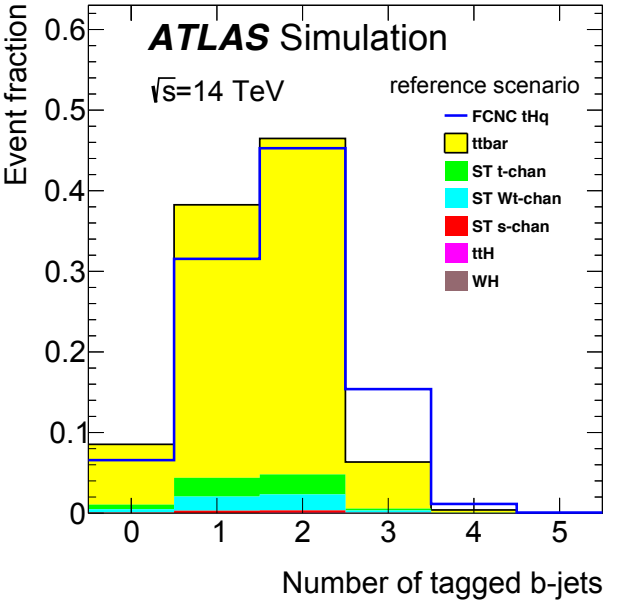
Layout	Set	"γ" $t \to Zu$	"σ" $t \to Zu$	"γ" $t \to Zc$	"σ" $t \to Zc$	"γ" $t \to Zu+Zc$	"σ" $t \to Zu+Zc$
Reference	A	$18 \cdot 10^{-5}$	$16 \cdot 10^{-5}$	$41 \cdot 10^{-5}$	$36 \cdot 10^{-5}$	$13 \cdot 10^{-5}$	$12 \cdot 10^{-5}$
	B	$13 \cdot 10^{-5}$	$13 \cdot 10^{-5}$	$24 \cdot 10^{-5}$	$23 \cdot 10^{-5}$	$8.9 \cdot 10^{-5}$	$8.3 \cdot 10^{-5}$
Middle	A	$18 \cdot 10^{-5}$	$18 \cdot 10^{-5}$	$44 \cdot 10^{-5}$	$40 \cdot 10^{-5}$	$13 \cdot 10^{-5}$	$13 \cdot 10^{-5}$
	B	$13 \cdot 10^{-5}$	$13 \cdot 10^{-5}$	$26 \cdot 10^{-5}$	$25 \cdot 10^{-5}$	$9.0 \cdot 10^{-5}$	$8.9 \cdot 10^{-5}$
Low	A	$18 \cdot 10^{-5}$	$17 \cdot 10^{-5}$	$48 \cdot 10^{-5}$	$43 \cdot 10^{-5}$	$14 \cdot 10^{-5}$	$13 \cdot 10^{-5}$
	B	$14 \cdot 10^{-5}$	$13 \cdot 10^{-5}$	$29 \cdot 10^{-5}$	$28 \cdot 10^{-5}$	$9.8 \cdot 10^{-5}$	$9.3 \cdot 10^{-5}$

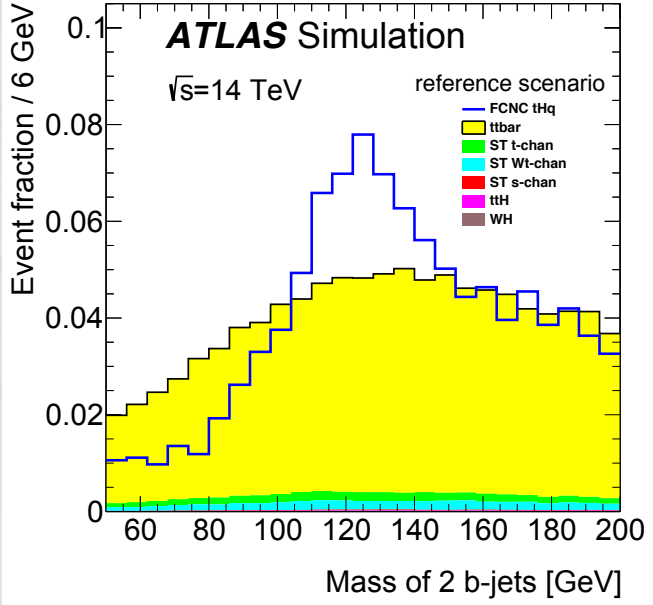
A : run I data driven fake rate
B : HL-LHC driven fake rate

Projections of $t \to cH$ at 14 TeV

3000fb^{-1} at 14 TeV

ATL-PHYS-PUB-2016-019





Three different ATLAS detector upgrade scenario: reference, middle, low.

Layout	Set	$t \to Hu$	$t \to Hc$	$t \to Hu+Hc$
Reference	A	$2.4 \cdot 10^{-4}$	$2.0 \cdot 10^{-4}$	$1.1 \cdot 10^{-4}$
	B	$2.4 \cdot 10^{-4}$	$2.0 \cdot 10^{-4}$	$1.1 \cdot 10^{-4}$
Middle	A	$2.9 \cdot 10^{-4}$	$2.4 \cdot 10^{-4}$	$1.3 \cdot 10^{-4}$
	B	$2.9 \cdot 10^{-4}$	$2.4 \cdot 10^{-4}$	$1.3 \cdot 10^{-4}$
Low	A	$3.5 \cdot 10^{-4}$	$3.0 \cdot 10^{-4}$	$1.7 \cdot 10^{-4}$
	B	$3.5 \cdot 10^{-4}$	$3.0 \cdot 10^{-4}$	$1.7 \cdot 10^{-4}$

A : run 1 data driven fake rate
B : HL-LHC driven fake rate

Similarly 10 times better limit expected at 3000 fb^{-1}

Conclusions

- LHC was indeed top quark factory. ATLAS and CMS have performed the rare top decay searches. Rare processes in top quark sector are now reachable.
- Exciting time is ahead of us for rare process searches with more data in 2016.
- The results at 13 TeV will be coming soon.

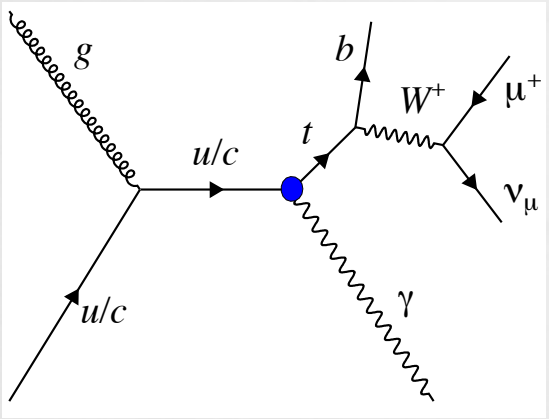
Backup

FCNC $tq\gamma$ in single top production

19.1 fb^{-1} at 8 TeV

JHEP 04 (2016) 035

- Search for anomalous $tq\gamma$ coupling in the single top production → The first at the LHC and the most stringent bounds on the FCNC $tq\gamma$ to date.
- only one isolated μ with 20 GeV, only one b-tagged jet, one isolated γ with 50 GeV
- Photon energy scale and $W\gamma + jets, W + jets$ (estimated in data driven way) are one of main uncertainties.
- Boosted decision tree (BDT)



- $Br(t \to u\gamma) < 0.013\%$
- $Br(t \to c\gamma) < 0.17\%$