Search for rare top quark decays

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Introduction

Although absent at tree level due to the GIM mechanism, the Flavour Changing Neutral Current (FCNC) top quark decays occur in the Standard Model (SM) at loop level with very small Branching Ratios (BR). These BRs can be significantly enhanced in some SM extensions, up to 10^{-3}:

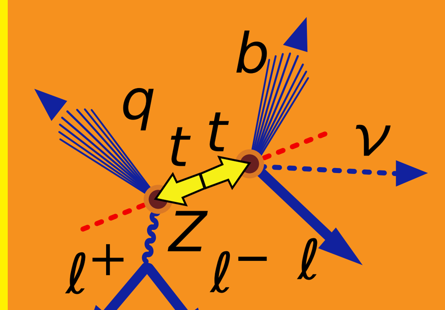
Process	SM	QS	2HDM	FC 2HDM	MSSM	$\not R$ SUSY	TC2	RS
$t\to qZ$	$\sim10^{-14}$	$\sim10^{-4}$	$\sim10^{-7}$	$\sim10^{-10}$	$\sim10^{-6}$	$\sim10^{-5}$	$\sim10^{-4}$	$\sim10^{-5}$
$t\to q\gamma$	$\sim10^{-14}$	$\sim10^{-9}$	$\sim10^{-6}$	$\sim10^{-9}$	$\sim10^{-6}$	$\sim10^{-6}$	$\sim10^{-6}$	$\sim10^{-9}$
$t\to qg$	$\sim10^{-12}$	$\sim10^{-7}$	$\sim10^{-4}$	$\sim10^{-8}$	$\sim10^{-5}$	$\sim10^{-4}$	$\sim10^{-4}$	$\sim10^{-9}$
$t\to qH$	$\sim10^{-15}$	$\sim10^{-5}$	$\sim10^{-3}$	$\sim10^{-5}$	$\sim10^{-5}$	$\sim10^{-6}$	—	—

FCNC top-quark decays have been searched by several experiments. These are the best current direct search limits:

Process	LEP	HERA	Tevatron	LHC
BR($t\to qZ$)	7.8%	30% (tuZ)	3.2%	0.07%
BR($t\to q\gamma$)	2.4%	0.47% ($tu\gamma$)	3.2%	—
BR($t\to qg$)	17%	13%	2.0×10^{-4} (ug) 3.9×10^{-3} (cg)	3.1×10^{-5} (ug) 1.6×10^{-4} (cg)
BR($t\to qH$)	—	—	—	0.83%

$t\to qZ$ analysis

$\sqrt{s}=7$ TeV $\mathcal{L}=2.1$ fb^{-1}



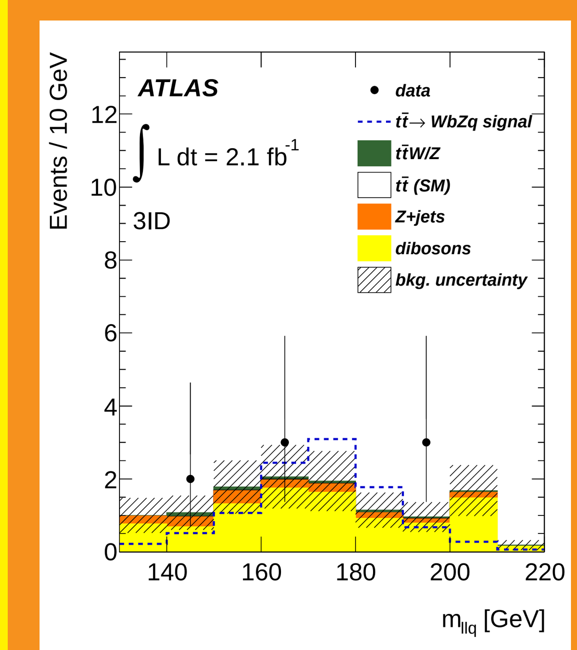
Topology
(Leptonic Z and W decays)

Leptons selected either using the full ATLAS detector (3ID), or using 2 ID leptons and a high quality inner detector track (2ID+TL).

ν, m_t^{FCNC}, m_t^{SM}, etc. are determined by minimising a χ^2:

$$\chi^2=\frac{\left(m^{\rm reco}_{j_a\ell_a\ell_b}-m_t\right)^2}{\sigma_t^2}+\frac{\left(m^{\rm reco}_{j_b\ell_c\nu}-m_t\right)^2}{\sigma_t^2}+\frac{\left(m^{\rm reco}_{\ell_c\nu}-m_W\right)^2}{\sigma_W^2}+\frac{\left(m^{\rm reco}_{\ell_a\ell_b}-m_Z\right)^2}{\sigma_Z^2}$$

with the values: m_t = 172.5 GeV, m_W = 80.4 GeV, m_Z = 91.2 GeV, σ_t = 14 GeV, σ_W = 10 GeV and σ_Z = 3 GeV.



	3ID	2ID+TL
ZZ, WZ	9.5 ± 4.4	$1.0\pm^{0.5}_{0.6}$
ttW, ttZ	0.51 ± 0.14	0.25 ± 0.05
$t\bar{t}$, WW	0.07 ± 0.02	
Z+jets	1.7 ± 0.7	7.6 ± 2.2
Single top	0.01 ± 0.01	
$2+3$ fake leptons	$0.0\pm^{0.2}_{0.0}$	
Total bckg	11.8 ± 4.4	8.9 ± 2.3
Data	8	8
Signal efficiency (%)	0.205 ± 0.024	0.045 ± 0.007

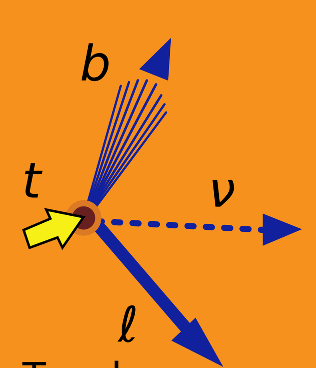
channel	observed	(-1σ)	expected	(+1σ)
3ID	0.81%	0.63%	0.95%	1.4%
2ID+TL	3.2%	2.15%	3.31%	4.9%
Combination	0.73%	0.61%	0.93%	1.4%

CLs method used to derive 95% CL limits on BRs.

$qg\to t$ analysis

$\sqrt{s}=8$ TeV $\mathcal{L}=14.2$ fb^{-1}

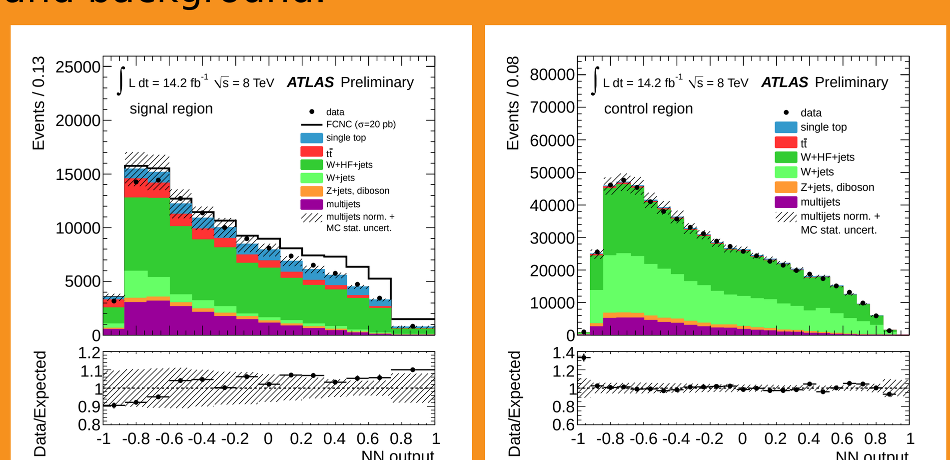
A gluon interacts with a u or c quark to produce single top quark event.



Topology
(Leptonic W decays)

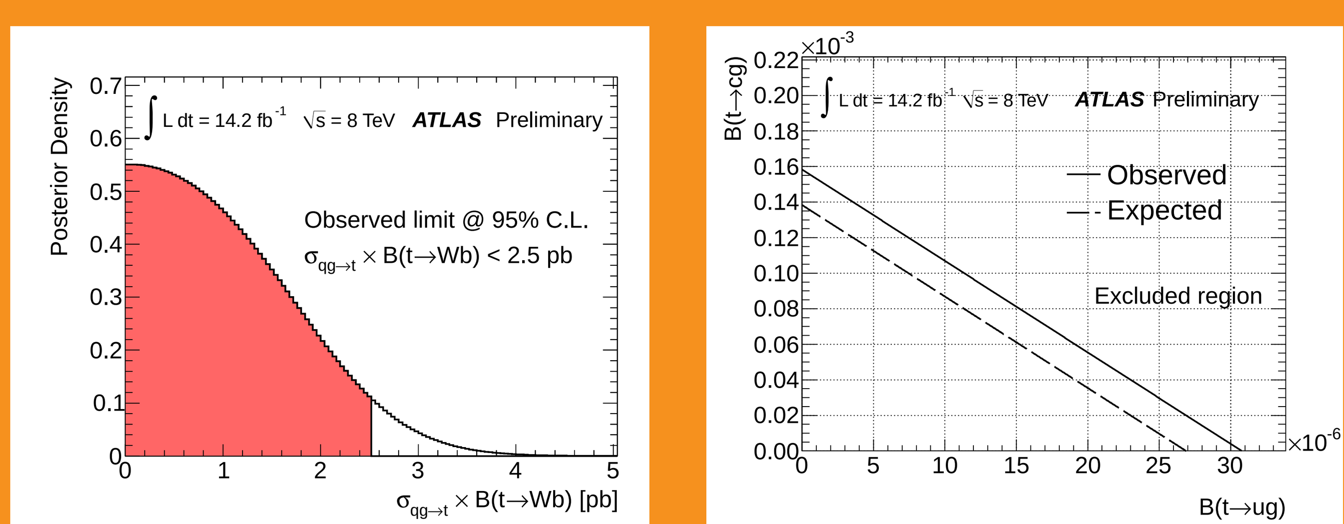
ν is determined by constraining the W mass, $(p_W)^2=(p_\ell+p_\nu)^2=m_W^2=(80.4\text{ GeV})^2$ and choosing the smaller $|p^z_\nu|$.

A neural-network method provides discrimination between signal and background.



Neural-network output distributions for signal (left) and a CR (right).

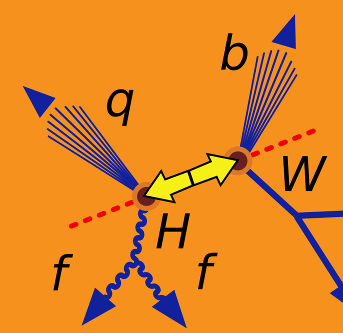
This CR is defined so that resulting sample is W+jets dominated.

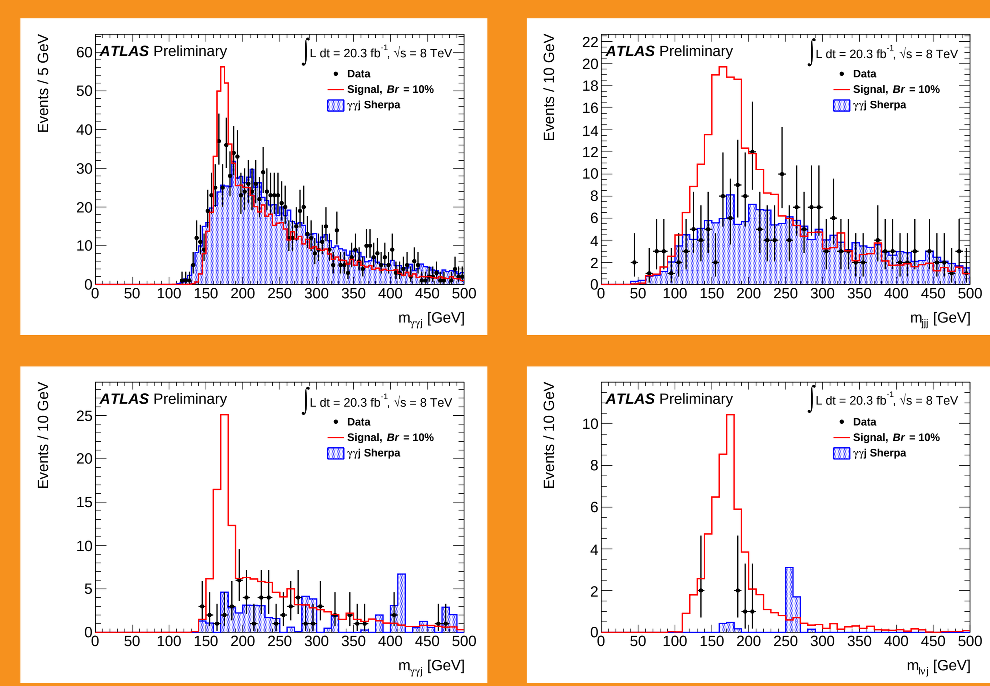


BR($t\to ug$) $<3.1\times10^{-5}$ BR($t\to cg$) $<1.6\times10^{-4}$

$t\to cH$ analysis

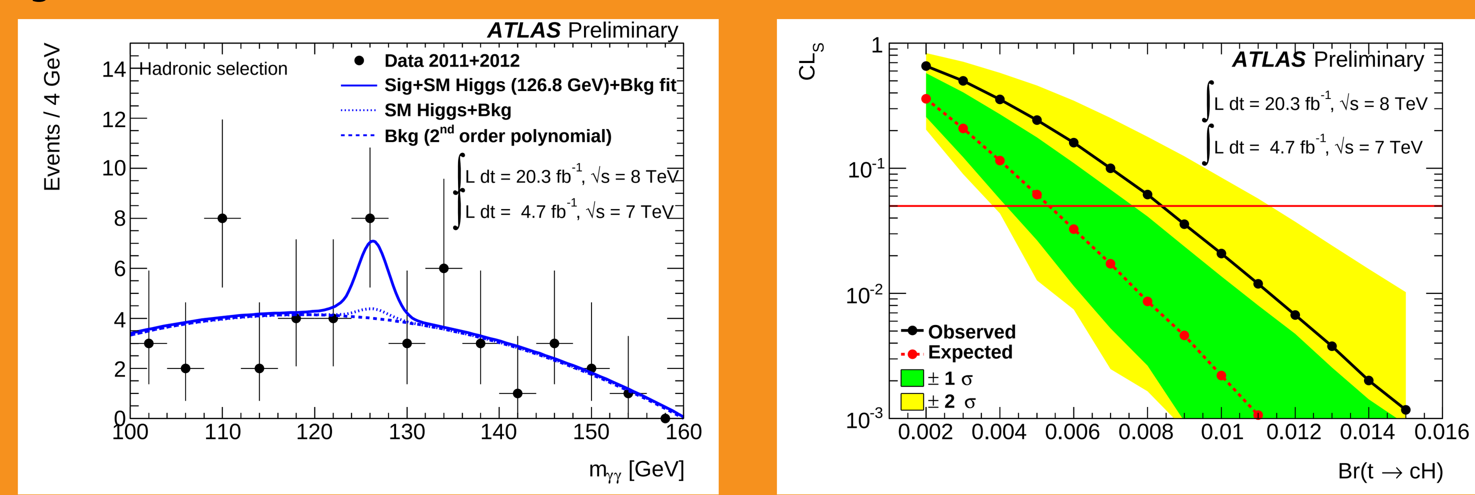
$\sqrt{s}=8$ TeV $\mathcal{L}=20$ fb^{-1}
$+\sqrt{s}=7$ TeV $\mathcal{L}=5$ fb^{-1}





Invariant masses of the reconstructed top quarks before the mass cuts (8 TeV). Hadronic W decay (top) and leptonic W decay (bottom).

A maximum likelihood fit is performed on the selected data (50 hadronic and 1 leptonic events). The $m_{\gamma\gamma}$ in the hadronic channel is shown together with the fitted background shape and the signal shape (left) and CLs evolution with BR (right).



	observed	expected
BR($t\to cH$)	0.83%	0.53%

High Luminosity LHC: $t\to qZ, t\to q\gamma$ sensitivity

Backgrounds for 14 TeV with 3000 fb^{-1} were obtained extrapolating from the number of events at 7 TeV:

$$(\sigma_{14\text{ TeV}}/\sigma_{7\text{ TeV}})_{ZZ,\,WZ,\,Zj,\,Wj}\sim2.2\quad(\sigma_{14\text{ TeV}}/\sigma_{7\text{ TeV}})_{t\bar{t}}\sim5.1$$

$$B_{q\gamma}\sim655\text{k}\quad B_{qZ}\sim35\text{k}$$

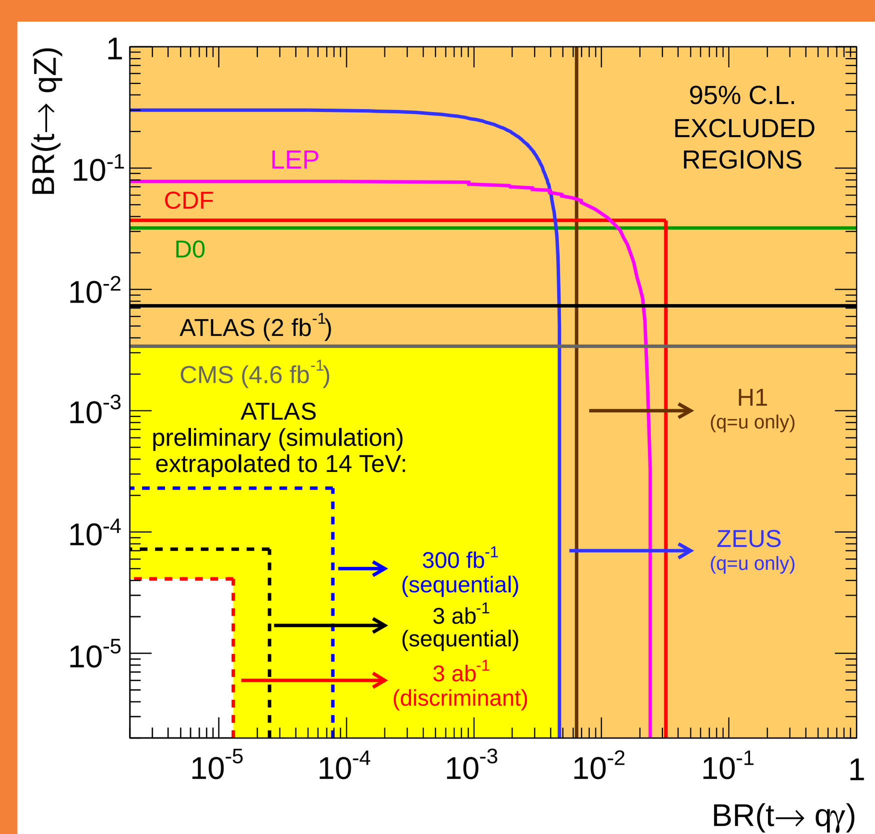
Also, it is possible to improve the analysis using discriminant variables built from relevant pdf after the final selection (as done in [18]).

Projected limits

	(-1σ)	expected	(+1σ)
$q\gamma$	9.2×10^{-6}	1.3×10^{-5}	1.7×10^{-5}
qZ	2.8×10^{-5}	4.1×10^{-5}	5.7×10^{-5}

CLs method used to derive 95% CL limits on BRs. Statistical and systematic uncertainties were taken into account as $\sqrt{B}$

The present 95% CL observed limits on the BR($t\to q$) vs. BR($t\to qZ$) plane are shown as full lines for the LEP, ZEUS, H1, D0, CDF, ATLAS and CMS collaborations. The expected sensitivity at ATLAS is also represented by the dashed lines. Limits are represented for an integrated luminosity of L = 3000 fb^{-1} and $L=300$ fb^{-1}.



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