Searches for rare top quark couplings with the ATLAS detector

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On behalf of ATLAS collaboration
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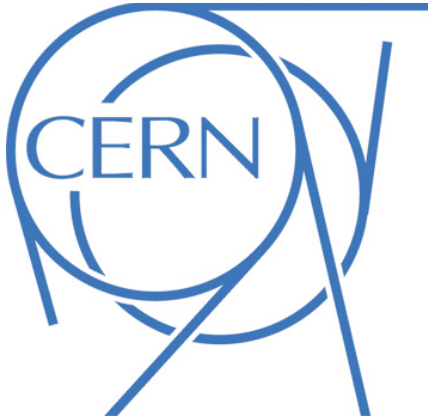


Outline

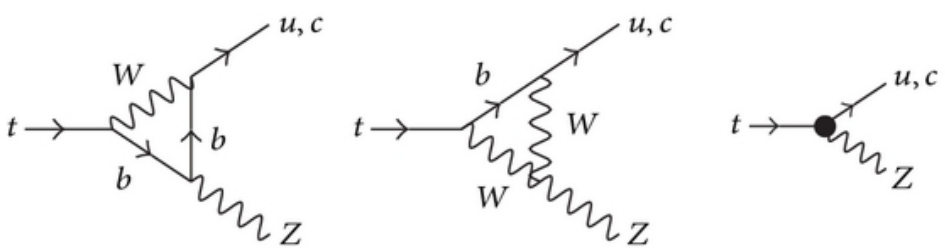
- Introduction
- Search for $t \to qH, H \to \gamma\gamma$ (arxiv: 1707.01404)
- Search for $t \to qH, H \to$ Multi-Lepton (arxiv: 1805.03483)
- Search for $t \to qZ, Z \to l^+l^-$ (arxiv: 1803.09923)
- Summary

Introduction

- Top quark decays, $t \to H/Z + q$ ($q = u, c$), are Flavor-Changing-Neutral-Current (FCNC) processes.
- Highly suppressed in the SM ($\mathcal{B} \sim 10^{-14}$ or even less).
- Enhanced in many beyound-SM (BSM) models, like quark-singlet (QS) model, two-Higgs-Doublet model (2HDM), MSSM, extra-dimensinal models (RS).

Model:	SM	QS	2HDM	FC 2HDM	MSSM	RPV SUSY	RS	EMF
$\mathcal{B}(t \to qZ)$:	10^{-14}	10^{-4}	10^{-6}	10^{-10}	10^{-7}	10^{-6}	10^{-5}	10^{-6}

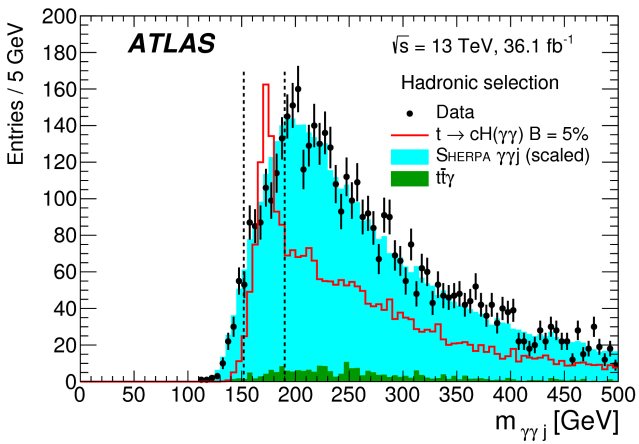
- Especially for $t \to cH$, the Cheng-Sher ansatz gives $\mathcal{B} \sim 1.5 \times 10^{-3}$, close to the Run2 sensitivity using the pp data of 36 fb^{-1}.



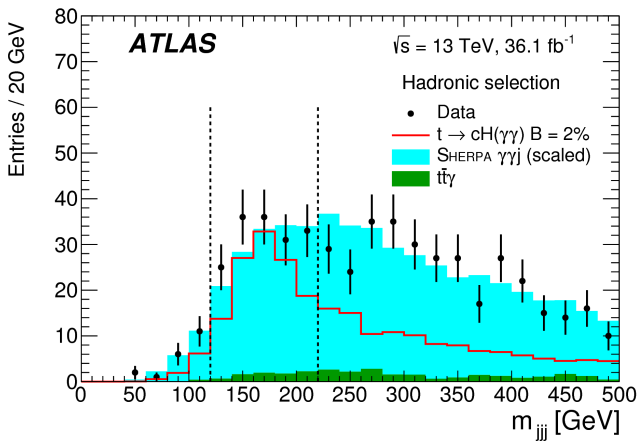
Search for $t \to qH, H \to \gamma\gamma$

Signal topoloy: $t \to qH \to q\gamma\gamma, t \to Wb$ with $W \to qq$ or $W \to l\nu$. A diphoton trigger is used ($E_T > 35/25$ GeV).
Hadronic selection:

- At least 4 jets with $p_T > 30$ GeV and select 4 leading ones
- One of them is b-tagged
- Top mass window: Top1 (FCNC): $152 < M_1(\gamma\gamma j) < 190$ GeV, Top2 (Wb): $120 < M_2(jjj) < 220$ GeV
- All jet combinations are considered. Category 1: pass M_1, M_2 requirements, Category 2: pass M_1, but fail M_2.
- Main backgounds: non-resonant $\gamma\gamma j$, $t\bar{t}\gamma$ and $t\bar{t}H$



$M_1(\gamma\gamma j)$

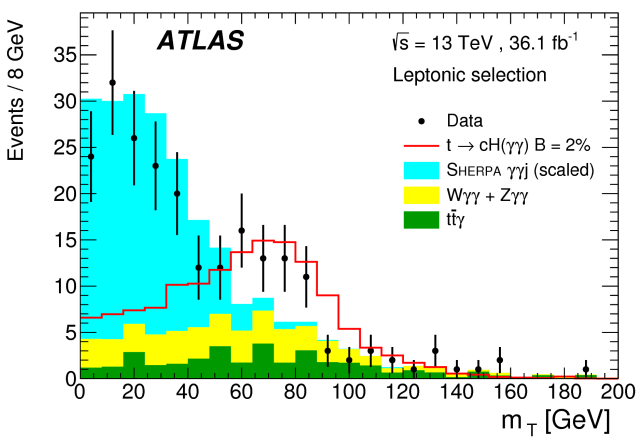


$M_2(jjj)$

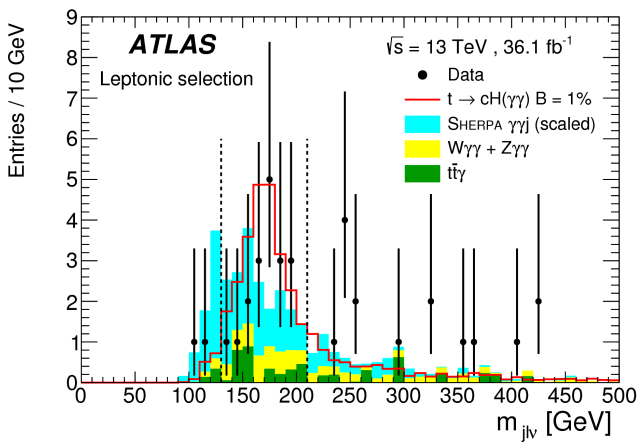
Search for $t \to qH, H \to \gamma\gamma$

Signal topoloy: $t \to qH \to q\gamma\gamma, t \to Wb$ with $W \to qq$ or $W \to l\nu$. A diphoton trigger is used ($E_T > 35/25$ GeV).
Leptonical selection:

- At least 2 jets with $p_T > 30$ GeV and select 2 leading ones
- One lepton candidate e/μ with $p_T^e > 15$ GeV (or $p_T^\mu > 10$ GeV)
- Use the missing energy information and the W boson mass constraint, $m_T > 30$ GeV.
- Top mass window: Top1 (FCNC): $152 < M_1(\gamma\gamma j) < 190$ GeV, Top2 (Wb): $130 < M_2(jl\nu) < 210$ GeV



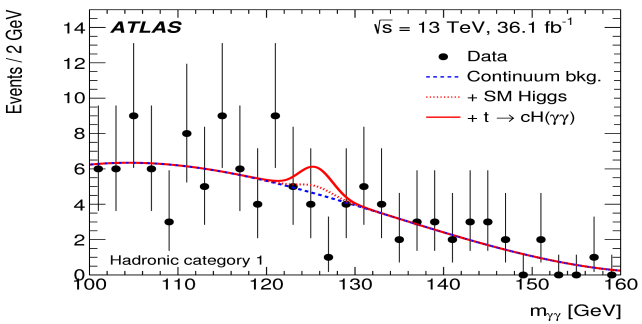
M_T



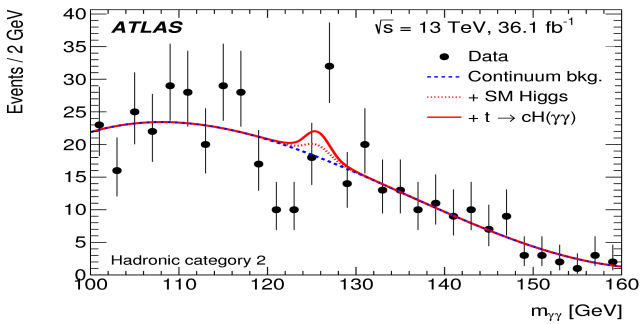
$M_2(jl\nu)$

Search for $t \to qH, H \to \gamma\gamma$

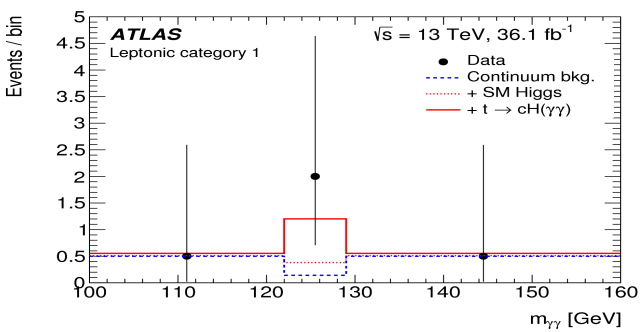
- Signal: Crystal-Ball function, Background: Polynomial/event counting
- Dominant systematic uncertainties: signal MC generation, ISR/FSR/Hadronisation, theory
- Observed (expected) upper limit of $t \to cH$ is $2.2(1.6) \times 10^{-3}$
- Observed (expected) upper limit of $t \to uH$ is $2.4(1.7) \times 10^{-3}$.



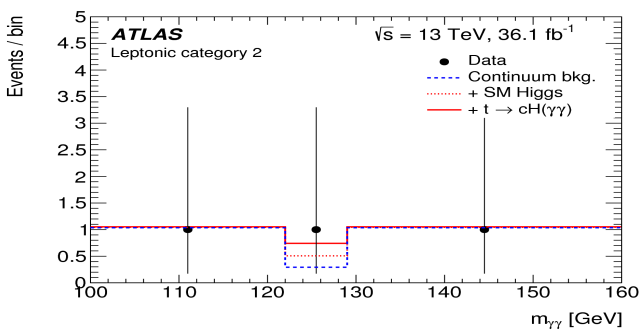
$M(\gamma\gamma)$ in Hadronic Category1



$M(\gamma\gamma)$ in Hadronic Category2



$M(\gamma\gamma)$ in Leptonic Category1



$M(\gamma\gamma)$ in Leptonic Category2

Search for $t\bar{t} \to (qH)(Wb) \to q +$ Multi-Lepton $+ X$

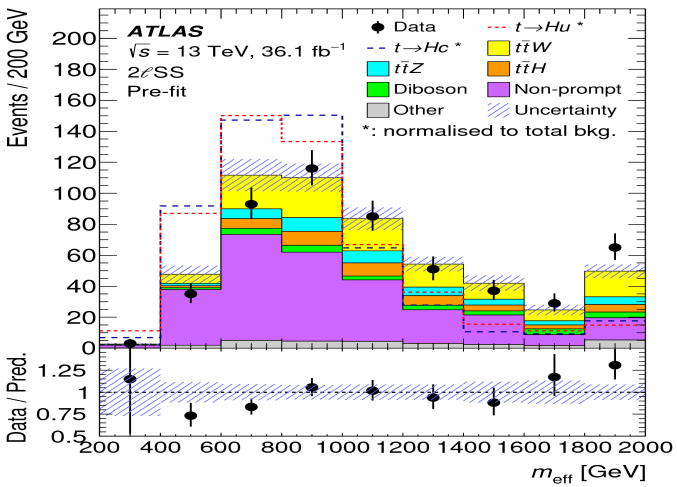
Signal topology: $t \to qH \to q(WW^*/\tau\tau/ZZ^*)$ including 2lSS and 3l.
2lSS selection:

- Two same-sign leptons with $p_T > 20$ GeV, no hadronic τ candidate
- At least 4 jets with $p_T > 30$ GeV, one of them is b-tagged.

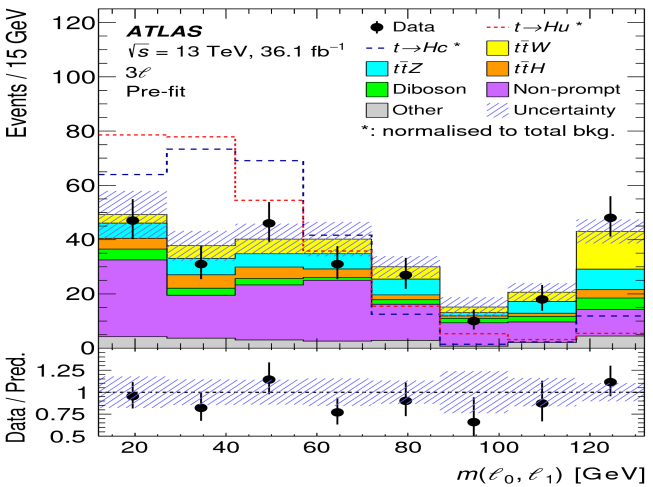
3l selection:

- 3 leptons with $l_0^{\pm} l_1^{\mp} l_2^{\mp}$ and $|M(l^+l^-$ or $3l) - 91.2| > 10$ GeV, no hadronic τ candidate
- At least 4 jets, one of them is b-tagged.

Dominant backgrounds: non-prompt lepton background and ttW.



$m_{eff} \equiv E_T^{\text{miss}} + H_T$



$m_{l_0 l_1}$

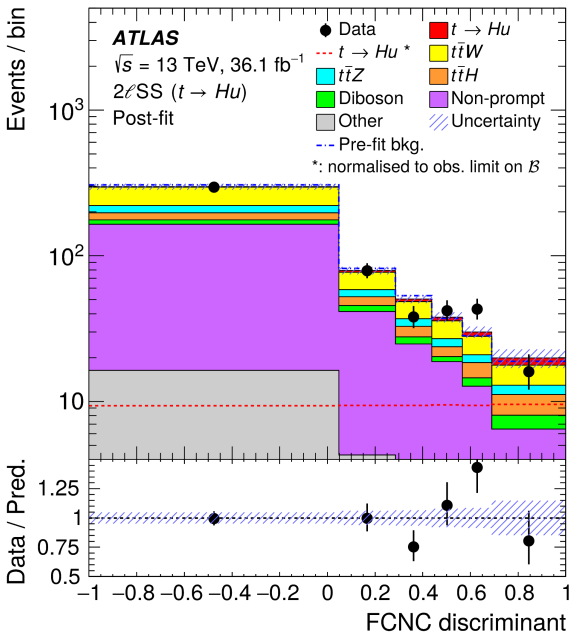
Search for $t\bar{t} \to (qH)(Wb) \to q +$ Multi-Lepton $+ X$

Train BDT in both signal regions. Fits to the BDT discriminant distribution.

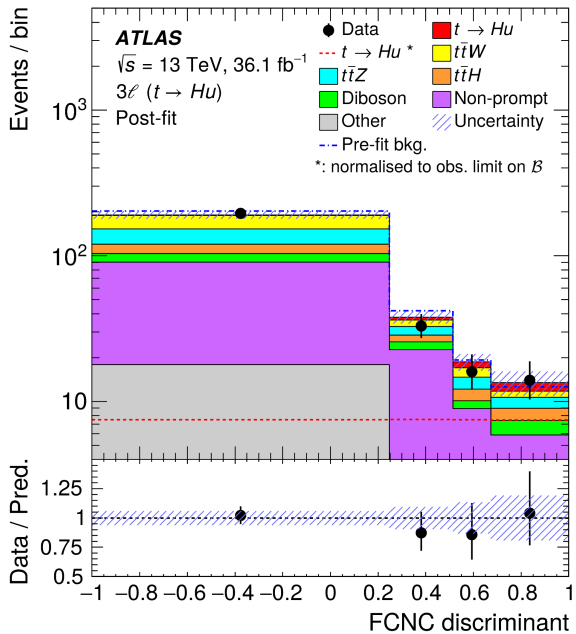
Variable	2ℓSS	3ℓ
p_{T} of higher-p_{T} lepton	×	
p_{T} of lower-p_{T} lepton	×	
p_{T} of lepton ℓ_0		×
p_{T} of lepton ℓ_1		×
p_{T} of lepton ℓ_2		×
Dilepton invariant masses (all combinations)	×	×
Trilepton invariant mass		×
Best Z candidate invariant mass		×
Maximum lepton $\lvert\eta\rvert$	×	
Lepton flavor	×	
Number of jets	×	×
Number of b-tagged jets	×	×
p_{T} of highest-p_{T} jet		×
p_{T} of second highest-p_{T} jet		×
p_{T} of highest-p_{T} b-tagged jet		×
$\Delta R(\ell_0, \ell_1)$		×
$\Delta R(\ell_0, \ell_2)$		×
ΔR(higher-p_{T} lepton, closest jet)	×	
ΔR(lower-p_{T} lepton, closest jet)	×	
$\Delta R(\ell_1$, closest jet)		×
Smallest $\Delta R(\ell_0$, b-tagged jet)		×
$E_{\mathrm{T}}^{\mathrm{miss}}$	×	
m_{eff}	×	×

Search for $t\bar{t} \to (qH)(Wb) \to q +$ Multi-Lepton $+ X$

- Observed (expected) upper limit of $t \to cH$ is $1.6(1.5) \times 10^{-3}$
- Observed (expected) upper limit of $t \to uH$ is $1.9(1.5) \times 10^{-3}$.
- Dominant systematic uncertainties: signal MC generation, non-prompt background estimation



BDT in 2*l*SS signal region



BDT in 3*l* signal region

Search for $t \to qZ \to ql^+l^-$

Signal topology: $tt \to (Wb)(qZ) \to (l\nu b)(qll)$, fully reconstructed, single-lepton trigger is used.
Event Selection:

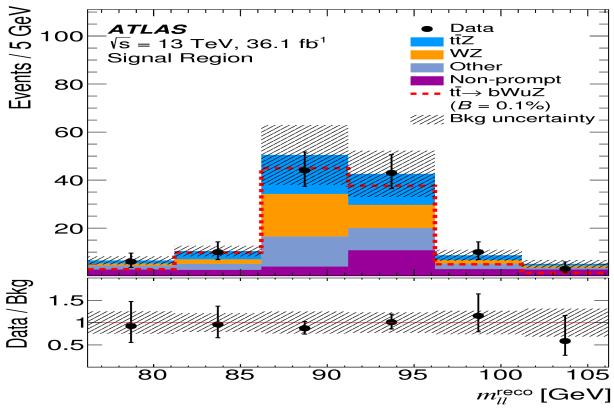
- Three isolated charged leptons
- At least two jets with $p_T > 25$ GeV, one of them is b-tagged.
- Missing $E_T > 20$ GeV
- Kinematic constraint:

$$\chi^2 = \frac{\left(m^{\text{reco}}_{j_a\ell_a\ell_b} - m_{t_{\text{FCNC}}}\right)^2}{\sigma^2_{t_{\text{FCNC}}}} + \frac{\left(m^{\text{reco}}_{j_b\ell_c\nu} - m_{t_{\text{SM}}}\right)^2}{\sigma^2_{t_{\text{SM}}}} + \frac{\left(m^{\text{reco}}_{\ell_c\nu} - m_W\right)^2}{\sigma^2_W}$$

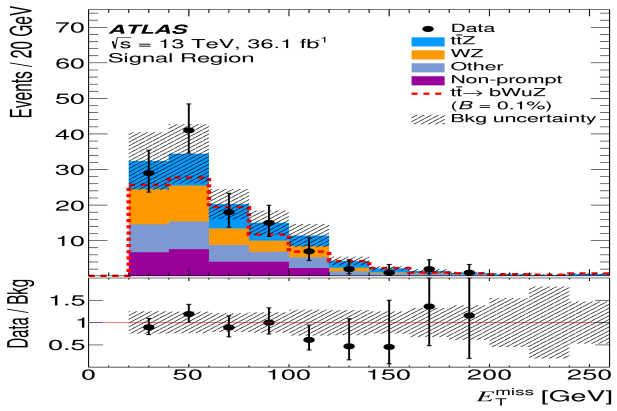
Here $m^{reco}_{j_a l_a l_b}$, $m^{reco}_{j_b l_c \nu}$ and $m^{reco}_{l_c \nu}$ are the reconstructed masses of the qZ, bW and $l\nu$ systems, respectively.

Search for $t \to qZ \to ql^+l^-$

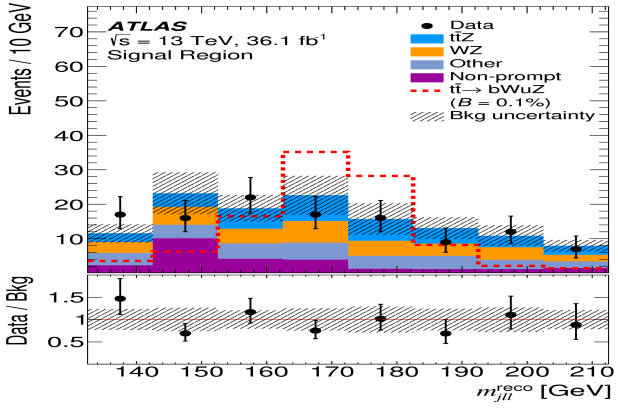
- Dominant backgrounds: $t\bar{t}Z$, WZ, ZZ and non-prompt lepton.



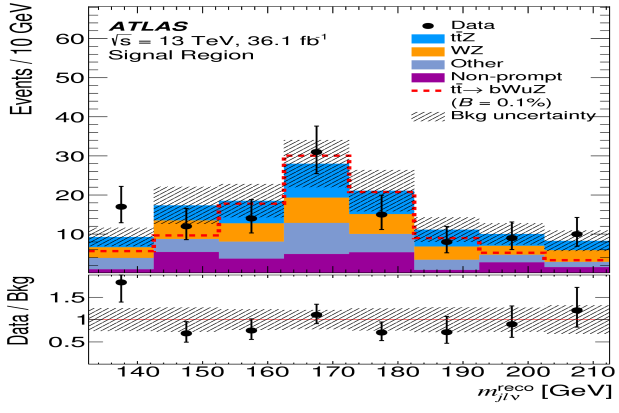
$m_{l^+l^-}$



E_T^{miss}



m_{jll} (FCNC top)



$m_{jl\nu}$ (SM top)

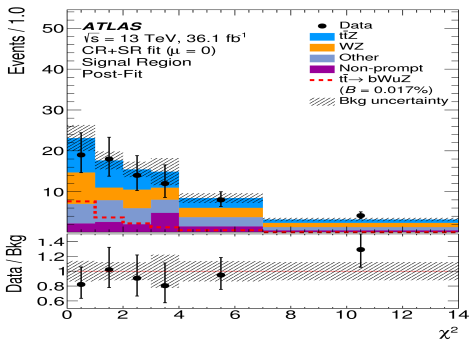
Search for $t \to qZ \to ql^+l^-$

- Signal topology: $tt \to (Wb)(qZ) \to (l\nu b)(qll)$, fully reconstructed, single-lepton trigger is used.
- Dominant backgrounds: $t\bar{t}Z$, WZ, ZZ and non-prompt lepton.
- Five control regions are defined to constrain the uncertainty.

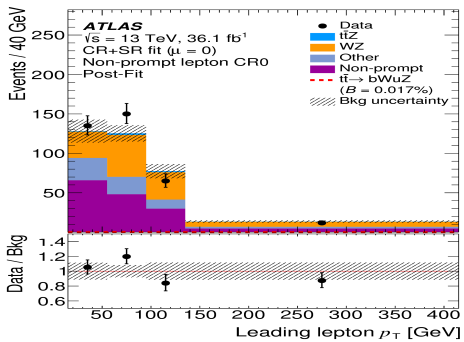
Selection	$t\bar{t}Z$ CR	WZ CR	ZZ CR	Non-prompt lepton CR0 (CR1)	SR
No. leptons	3	3	4	3	3
OSSF	Yes	Yes	Yes	Yes	Yes
$\lvert m_{\ell\ell}^{\text{reco}} - 91.2\ \text{GeV}\rvert$	< 15 GeV	< 15 GeV	< 15 GeV	> 15 GeV	< 15 GeV
No. jets	≥ 4	≥ 2	≥ 1	≥ 2	≥ 2
No. b-tagged jets	2	0	0	0 (1)	1
$E_{\text{T}}^{\text{miss}}$	> 20 GeV	> 40 GeV	> 20 GeV	> 20 GeV	> 20 GeV
$m_{\text{T}}^{\ell\nu}$	-	> 50 GeV	-	-	-
$\lvert m_{\ell\nu}^{\text{reco}} - 80.4\ \text{GeV}\rvert$	-	-	-	-	< 30 GeV
$\lvert m_{j\ell\nu}^{\text{reco}} - 172.5\ \text{GeV}\rvert$	-	-	-	-	< 40 GeV
$\lvert m_{j\ell\ell}^{\text{reco}} - 172.5\ \text{GeV}\rvert$	-	-	-	-	< 40 GeV

Search for $t \to qZ \to ql^+l^-$

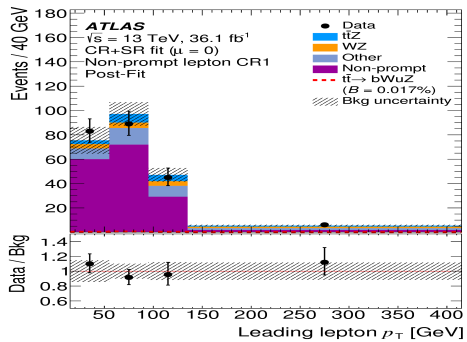
- Observed (expected) upper limit of $t \to cZ$ is $2.4(3.2) \times 10^{-3}$
- Observed (expected) upper limit of $t \to uZ$ is $1.7(2.4) \times 10^{-3}$.
- Dominant systematics: theory normalization, background modelling



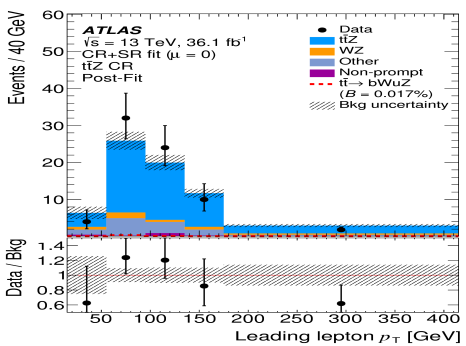
χ^2 in SR



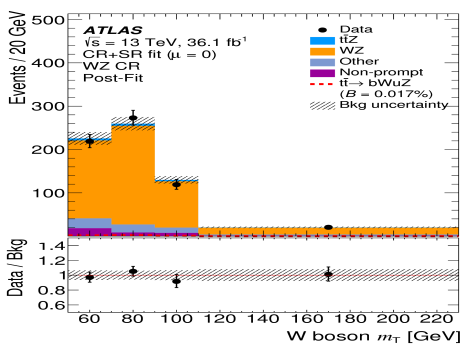
$p_T(l)$ in nonprompt CR0



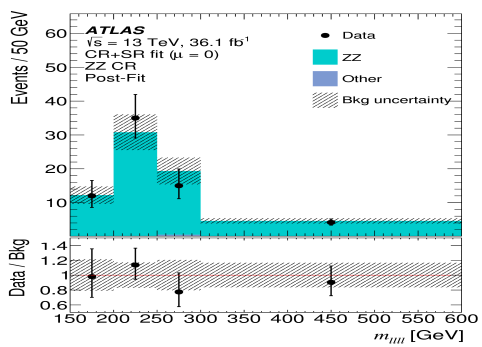
$p_T(l)$ in nonprompt CR1



$p_T(l)$ in ttZ CR



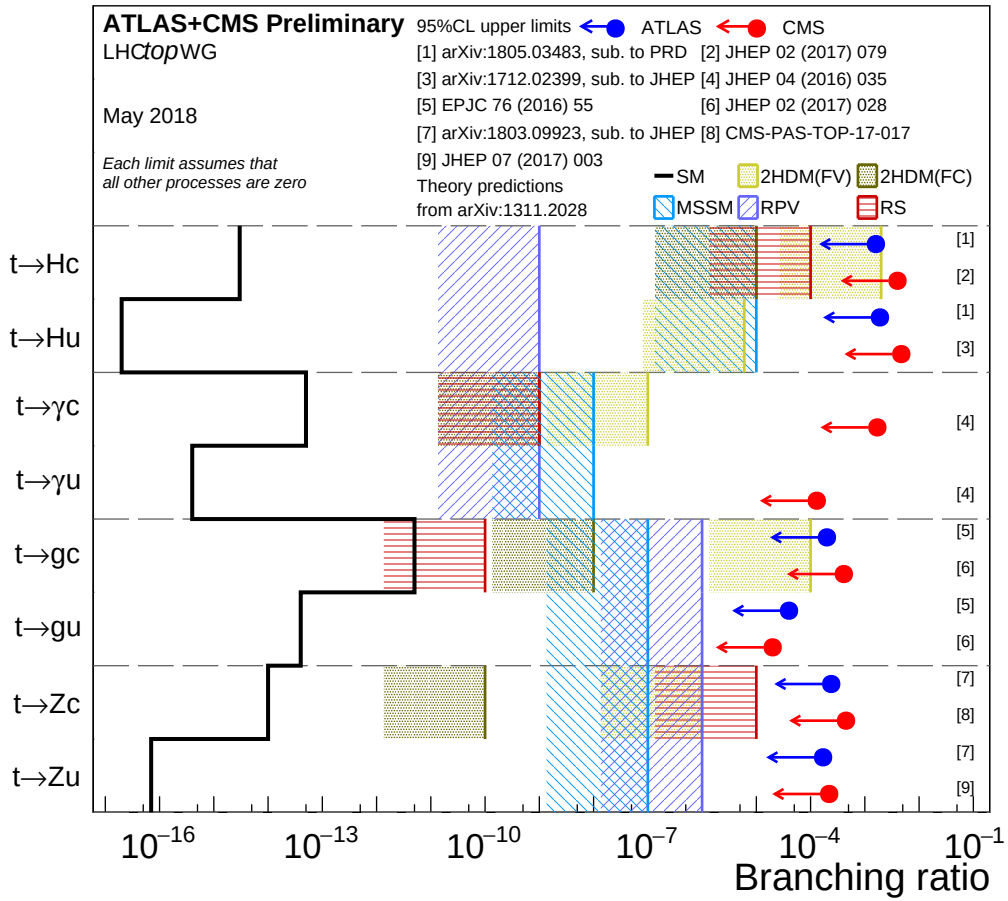
W mass in WZ CR



$m(llll)$ in ZZ CR

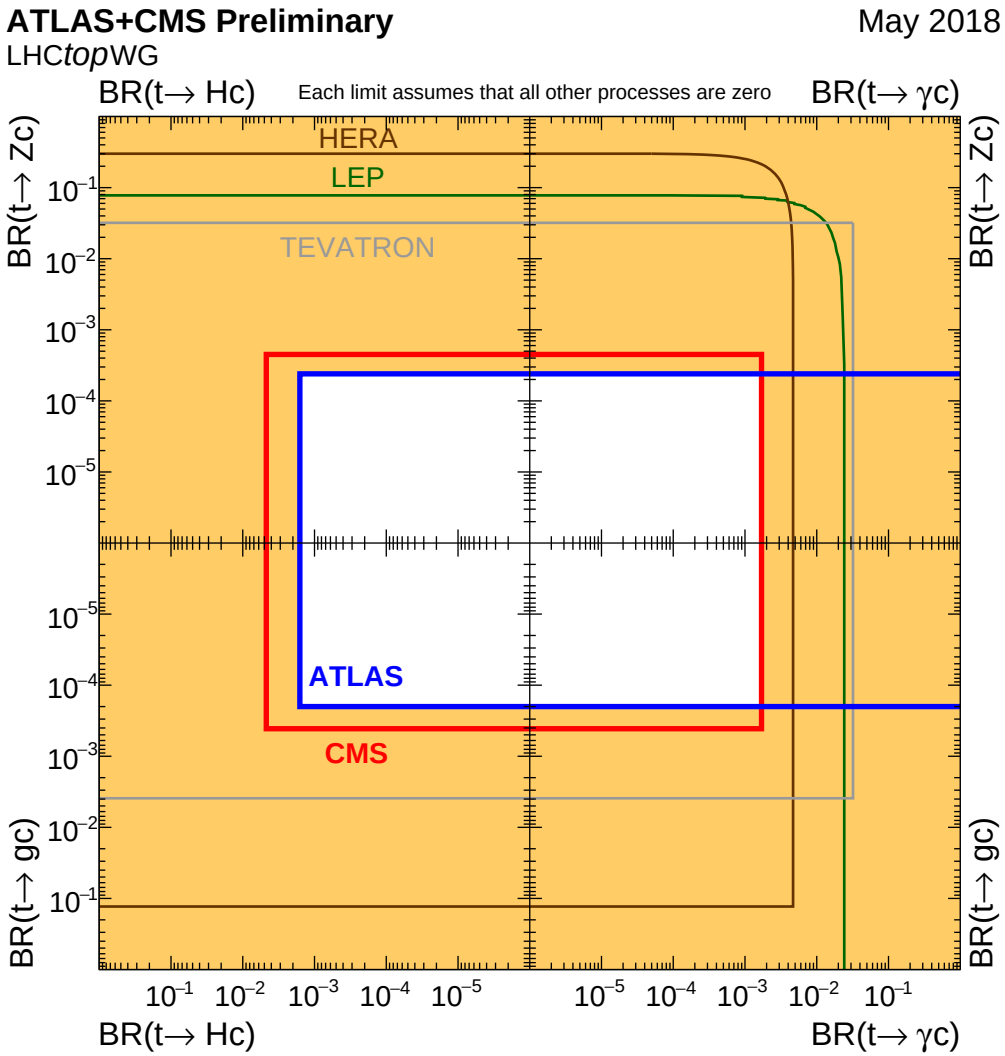
Searching for BSM top couplings

- Comparable results for ATLAS/CMS
- Start to reach the prediction of some models



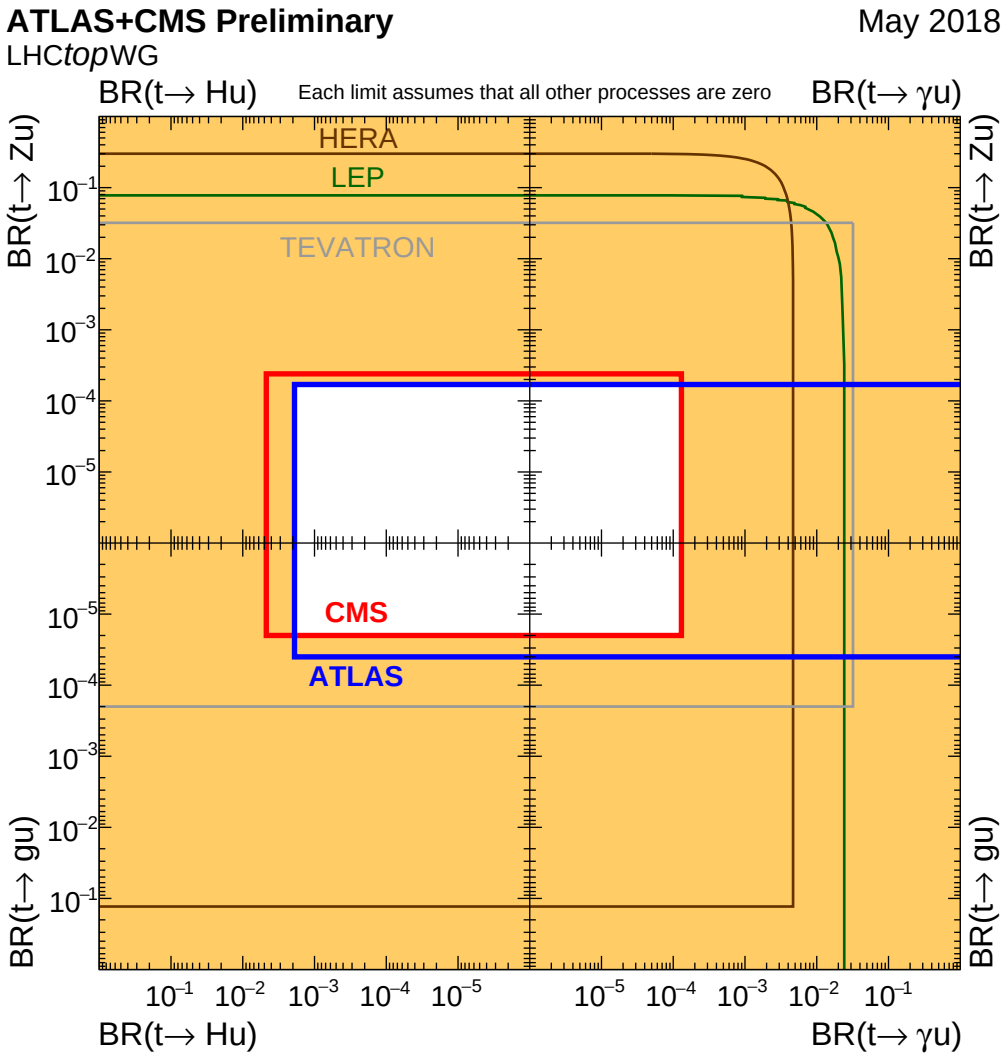
Searching for BSM top coupling $t \to cX$

- Overlay of ATLAS and CMS measurements
- White box is the survival region.



Searching for BSM top coupling $t \to uX$

- Overlay of ATLAS and CMS measurements
- White box is the survival region.



Summary

- FCNC $t \to qZ/H$ with $q = u, c$ searched using a data sample of 36 fb^{-1} with ATLAS.
- No significant excess is observed. The upper limits are the order of 10^{-3}.
- Limiting factors: signal MC generation, theory uncertainty and background modelling
- More interesting results coming, like searching for $t \to q + \text{gluon}/\gamma$
- Similar searches are ongoing using single-top production

BACK UP

BACK UP