Comparison of the ATLAS and CMS FCNC t→Zq searches

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LPCC

LHC TOP WG meeting, 15th May 2018

LIP

Universidade do Minho
Escola de Ciências

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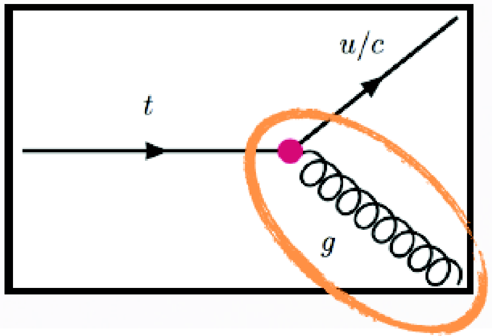
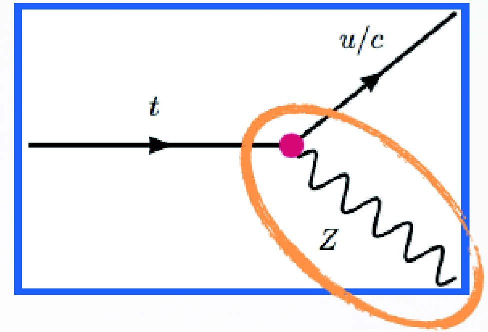
IF/00050/2013, CERN/FIS-NUC/0005/2015

FCNCs at the top sector

Top + gluon





Top + Z

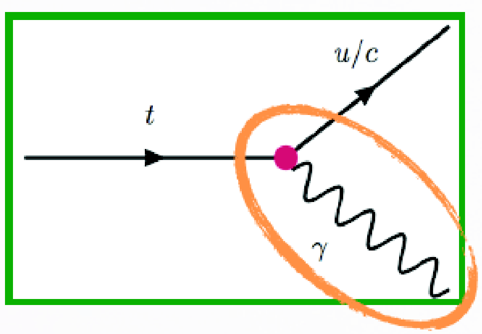
$$\mathcal{L} = \sum_{q=u,c} \Big[\sqrt{2} g_s \frac{\kappa_{gqt}}{\Lambda} \bar{t}\sigma^{\mu\nu} T_a (f^L_{Gq} P_L + f^R_{Gq} P_R) q G^a_{\mu\nu} +$$

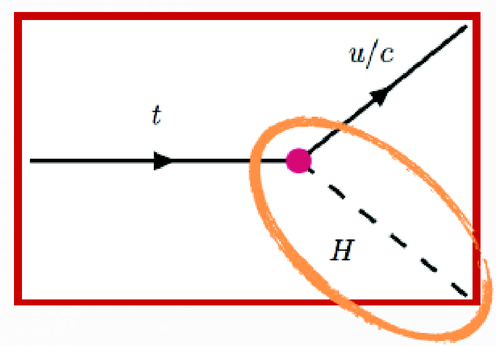
$$+ \frac{g}{\sqrt{2} c_W} \frac{\kappa_{zqt}}{\Lambda} \bar{t}\sigma^{\mu\nu} (f^L_{Zq} P_L + f^R_{Zq} P_R) q Z_{\mu\nu} + \frac{g}{4 c_W} \zeta_{zqt} \bar{t}\gamma^{\mu} (f^L_{Zq} P_L + f^R_{Zq} P_R) q Z_{\mu} -$$

$$- e \frac{\kappa_{\gamma qt}}{\Lambda} \bar{t}\sigma^{\mu\nu} (f^L_{\gamma q} P_L + f^R_{\gamma q} P_R) q A_{\mu\nu} +$$

$$+ \frac{g}{\sqrt{2}} \bar{t} \kappa_{Hqt} (f^L_{Hq} P_L + f^R_{Hq} P_R) q H \Big] + h.c.$$

Top + gamma

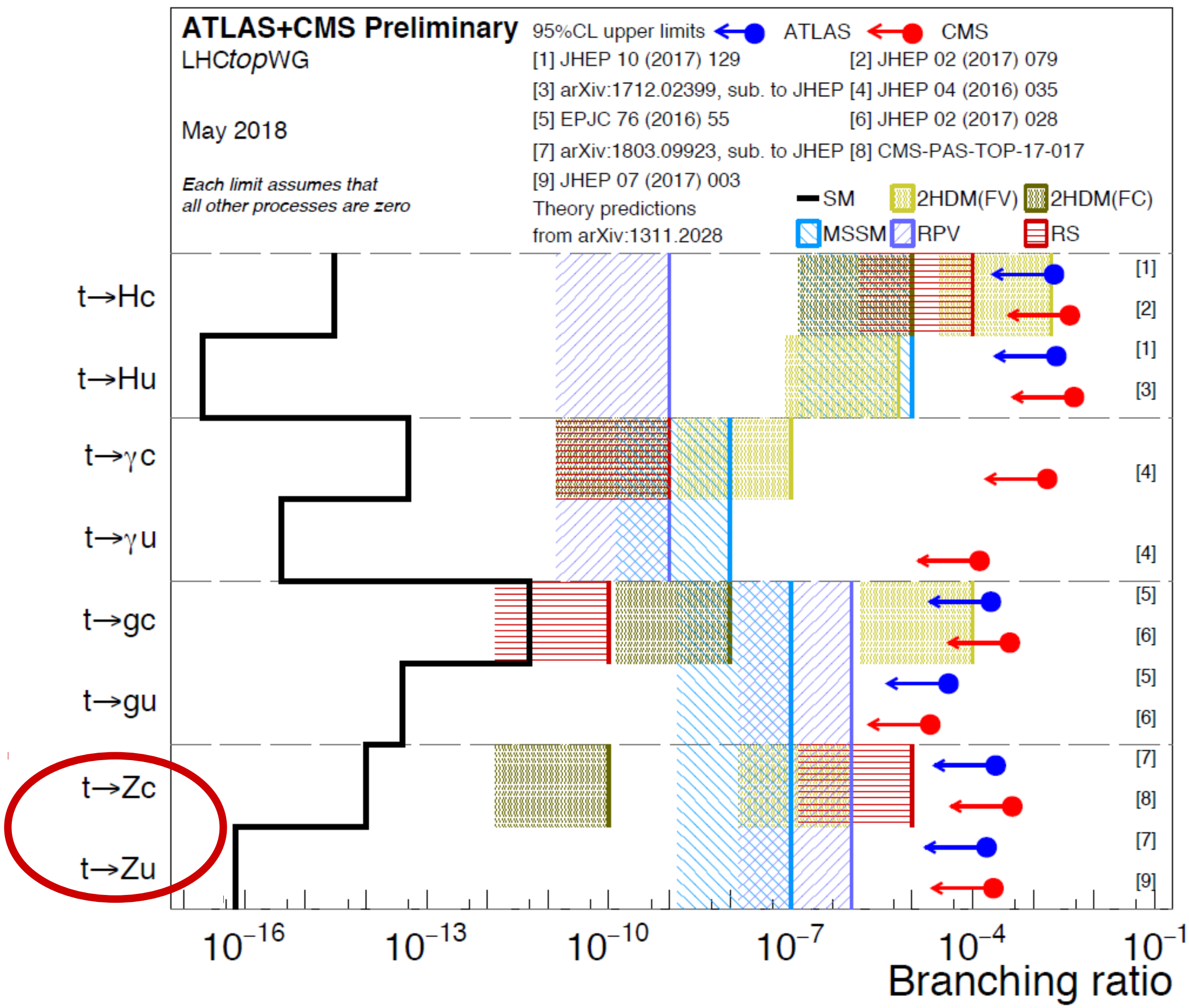




Top + Higgs

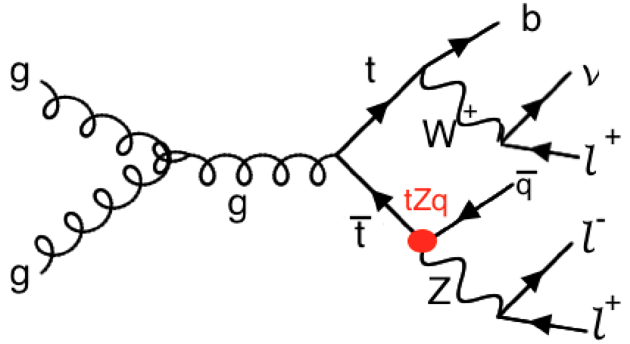
FCNCs at the top sector

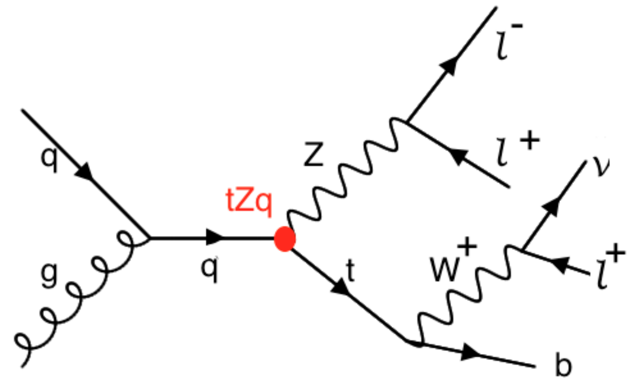
Model:	SM	QS	2HDM	FC 2HDM	MSSM	RPV SUSY	RS	EMF
$\mathcal{B}(t \to qZ)$:	10^{-14}	10^{-4}	10^{-6}	10^{-10}	10^{-7}	10^{-6}	10^{-5}	10^{-6}



Search for t→qZ at the LHC (ATLAS and CMS)

- The tZq vertex can be probed both in $t\bar{t}$ events (where t→qZ) and tZ production via FCNC





- The present talk will focus on the comparison of the ATLAS and CMS results at 13 TeV:
  - ATLAS arXiv:1803.099923 [hep-ex] → decay
  - CMS PAS TOP-17-017 → production+decay

Search for t→qZ at the LHC (ATLAS and CMS)

- Signal generation:

ATLAS	CMS
• MG5_aMC@NLO (NLO)	• MG5_aMC@NLO (LO)
• Top FCNC UFO model (http://feynrules.irmp.ucl.ac.be/wiki/TopFCNC)	• Private implementation of the lagrangian in Feynrules / UFO
• Λ = 1 TeV • only one eff. operator coef. different from 0 (choice equivalent to a tensor LH coupling)	• Tensor RH coupling

Search for t→qZ at the LHC (ATLAS and CMS)

- Trigger and object definitions

	ATLAS	CMS
triggers	• Single lepton (e ou μ) triggers	• Combination of single, dilepton and trilepton triggers
electrons	• E_T > 15 GeV • $\lvert\eta\rvert$ < 2.5	• E_T > 35 GeV • $\lvert\eta\rvert$ < 2.1
muons	• p_T > 15 GeV • $\lvert\eta\rvert$ < 2.5	• p_T > 30 GeV • $\lvert\eta\rvert$ < 2.4
Jets (ΔR=0.4)	• p_T > 25 GeV • $\lvert\eta\rvert$ < 2.5	• p_T > 30 GeV • $\lvert\eta\rvert$ < 2.4
B-tag eff.	• 77 %	• 83 %

Analysis strategy

- Basic selection
  - ATLAS considers only the decay channel
  - CMS considers both production and decay channels

ATLAS	CMS
• Exactly 3 leptons (at least 1 OSSF pair)	• Exactly 3 leptons (at least 1 OSSF pair)
• At least 2 jets	• Exactly 1 jet (ST) • 2 or 3 jets (TT)
• Exactly 1 b-tagged jet	• Exactly 1 b-tagged jet (ST) • At least 1 b-tagged jet (TT)
• MET > 20 GeV	• $M_T(W) < 300$ GeV
• Z candidate within 15 GeV of m_Z	• Z candidate within 7.5 GeV of m_Z

Analysis strategy

- Signal and control regions used in the fit:

ATLAS

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

CMS

	WZ control region (WZCR)	single top quark signal region (STSR)	top quark pair signal region (TTSR)	single top quark control region (STCR)	top quark pair control region (TTCR)
Number of jets	$\geq 1, \leq 3$	1	$\geq 2, \leq 3$	1	$\geq 2, \leq 3$
Number of b jets	0	1	≥ 1	1	≥ 1
$\lvert M(Z_{\text{reco}}) - M_Z\rvert < 7.5$ GeV	Yes	Yes	Yes	No	No

Analysis strategy

- Evaluation of normalization of the non-prompt leptons (NPL) background (shape from MC templates)

  - ATLAS
    - Normalization factors from dedicated regions

Z+jets and DY		$t\bar{t}$	
"Light" region – e	"Light" region – μ	"Heavy" region – e	"Heavy" region – μ
eee or $e\mu\mu$, OSSF	$\mu\mu\mu$ or μee, OSSF	$e\mu\mu$, OS no OSSF	μee, OS no OSSF
$\lvert m_{\ell\ell} - 91.2$ GeV$\rvert < 15$ GeV	$\lvert m_{\ell\ell} - 91.2$ GeV$\rvert < 15$ GeV		
≥ 1 jet	≥ 1 jet	≥ 2 jet	≥ 2 jet
$E_{\mathrm{T}}^{\mathrm{miss}} < 40$ GeV	$E_{\mathrm{T}}^{\mathrm{miss}} < 40$ GeV		
$m_{\mathrm{T}} \leq 50$ GeV	$m_{\mathrm{T}} \leq 50$ GeV		

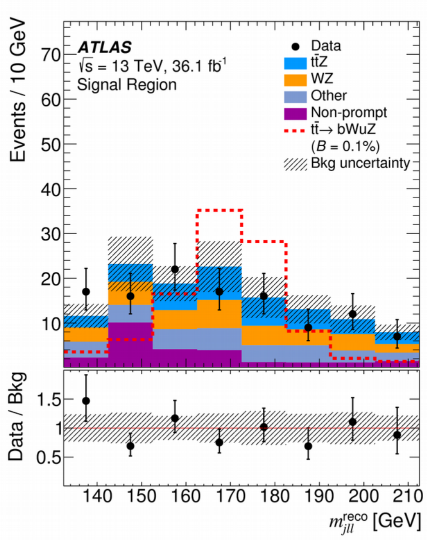
  - CMS
    - NPL normalization from $t\bar{t}$ derived using TTCR and STCR
    - NPL normalization from Z+jets and DY derived using WZCR

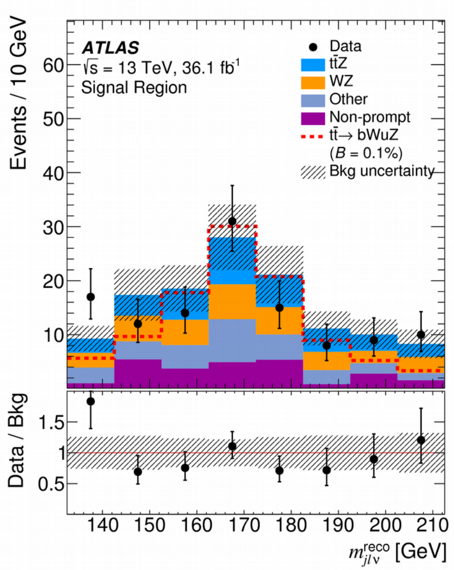
Event reconstruction / MVA

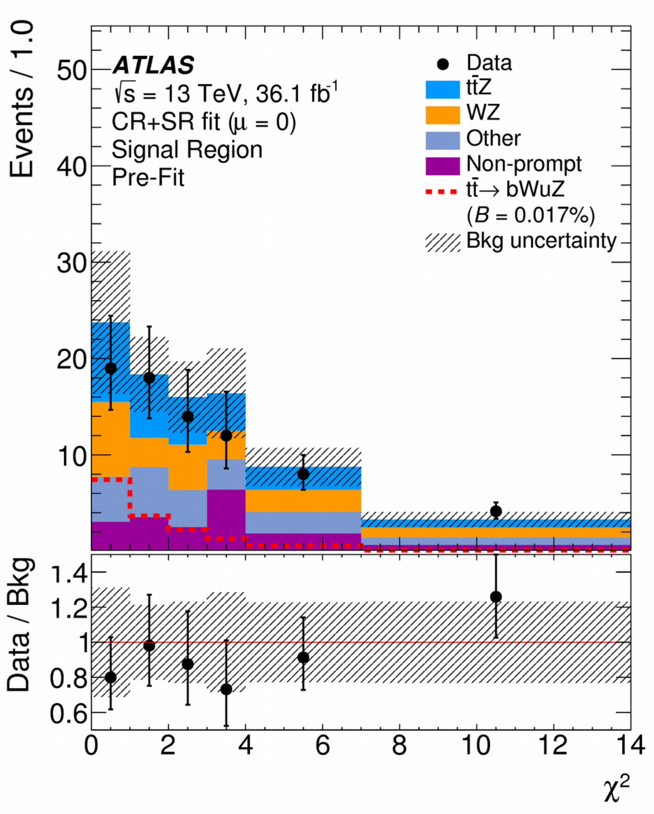
- ATLAS uses a χ^2 method for event reconstruction:

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

which is used as fitting variable

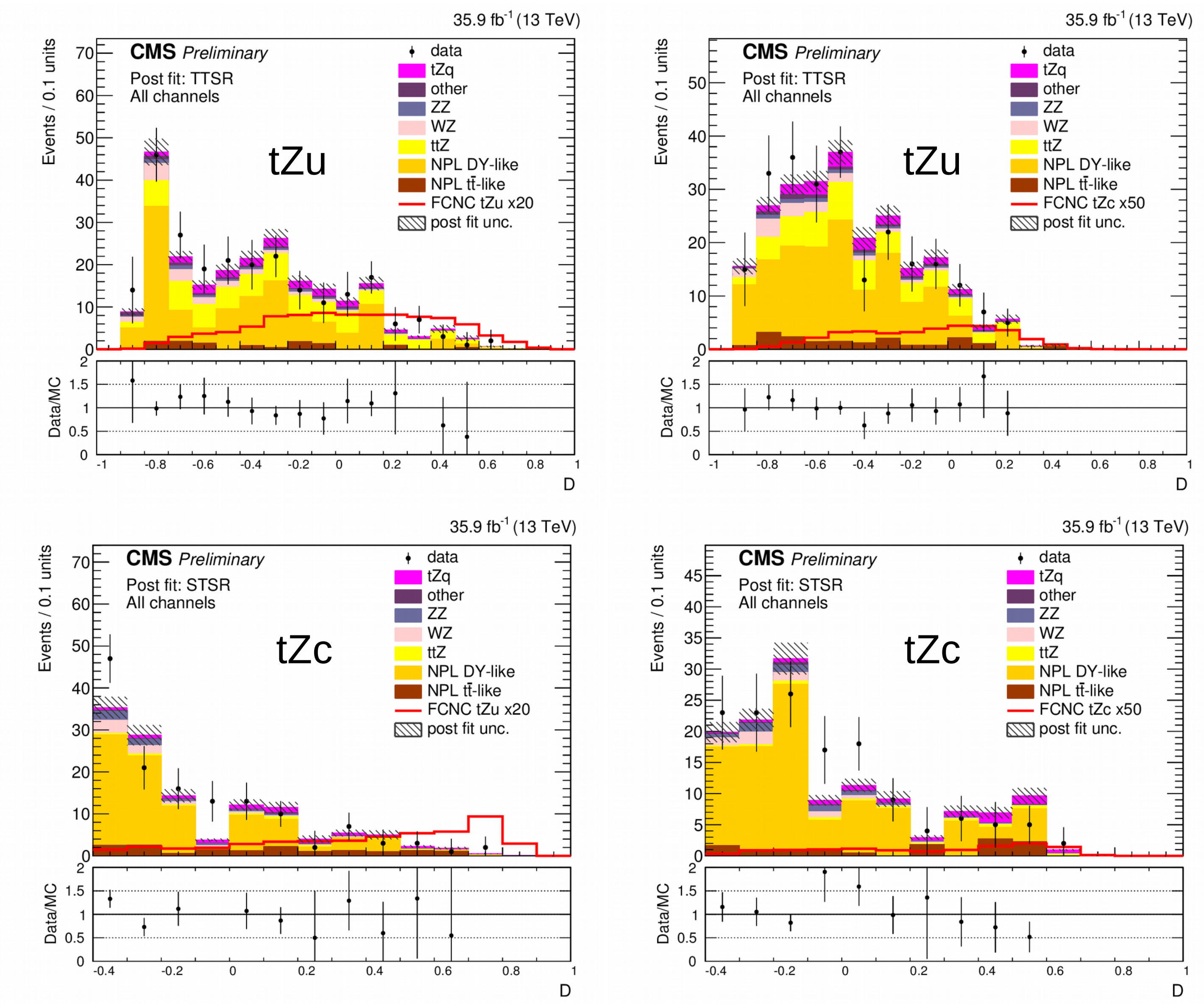






Event reconstruction / MVA

- CMS
  uses a BDT



Systematic uncertainties

- ATLAS

Pre-fit Source	$t\bar{t}Z$ CR B [%]	WZ CR B [%]	ZZ CR B [%]	Non-prompt lepton CR0 B [%]	Non-prompt lepton CR1 B [%]	SR B [%]	SR S [%]
Event modelling	29	40	13	24	40	30	5
Leptons	2.1	2.4	3.0	2.6	2.9	2.6	1.9
Jets	6	8	15	10	4	9	4
b-tagging	7	1.5	0.6	2.3	3.0	5	3.4
$E_{\mathrm{T}}^{\mathrm{miss}}$	0.4	4	2.6	3.0	0.8	5	1.4
Non-prompt leptons	1.1	1.3	—	12	15	6	—
Pile-up	5	1.3	5	3.5	1.8	4	2.3
Luminosity	2.0	2.0	2.1	1.3	0.8	1.7	2.1

Post-fit Source	$t\bar{t}Z$ CR B [%]	WZ CR B [%]	ZZ CR B [%]	Non-prompt lepton CR0 B [%]	Non-prompt lepton CR1 B [%]	SR B [%]	SR S [%]
Event modelling	22	10	11	9	23	18	5
Leptons	2.0	2.4	2.9	2.6	2.9	2.6	1.8
Jets	5	6	11	8	4	8	4
b-tagging	7	1.4	0.6	2.1	2.8	4	3.1
$E_{\mathrm{T}}^{\mathrm{miss}}$	0.3	3.3	2.5	2.8	0.7	4	1.4
Non-prompt leptons	1.1	1.1	—	8	12	5	—
Pile-up	5	1.2	5	3.3	1.7	3.5	2.2
Luminosity	2.0	2.0	2.1	1.3	0.8	1.6	2.1

Systematic uncertainties

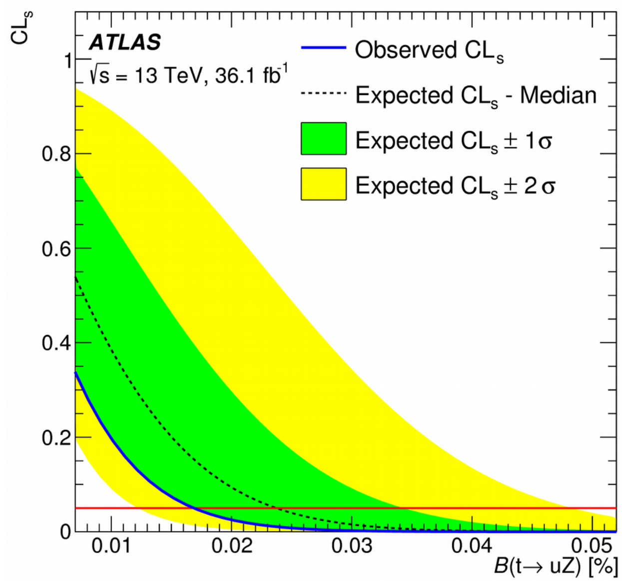
- CMS

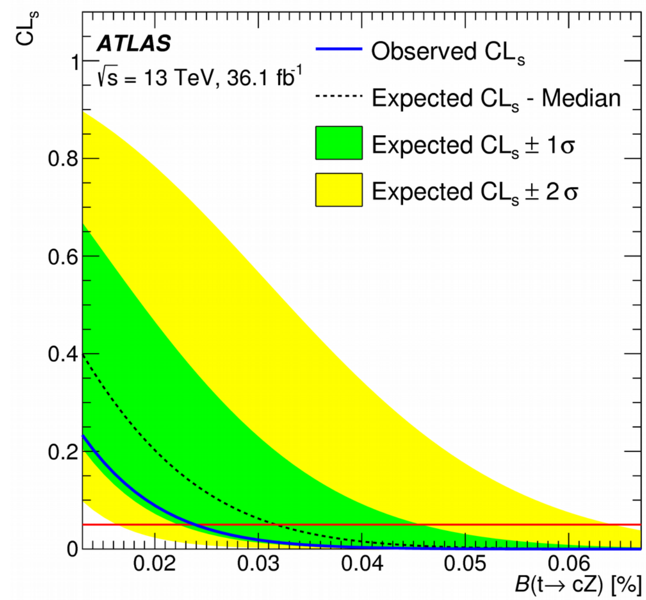
Source	Systematic input	Type
NPL muon	50%	normalization
NPL electron	50%	normalization
background $t\bar{t}Z$	30%	normalization
background WZ	30%	normalization
background tZq	30%	normalization
background ZZ	30%	normalization
background other MC	30%	normalization
trigger	1% (5%)	normalization
lepton identification	$\pm\sigma(p_{\mathrm{T}}, \eta)$	shape
JES	$\pm\sigma(p_{\mathrm{T}}, \eta)$	shape
JER	$\pm\sigma(p_{\mathrm{T}}, \eta)$	shape
b-tagging	$\pm\sigma(p_{\mathrm{T}}, \eta)$	shape
pileup	$\pm\sigma$ of min. bias cross section	shape
PDF	PDF4LHC recipe	shape (WZ, tZq, ttZ, ZZ)
luminosity	2.5%	normalization
renorm. and fact. scales	varying each indep. and corr.	shape

Results

ATLAS

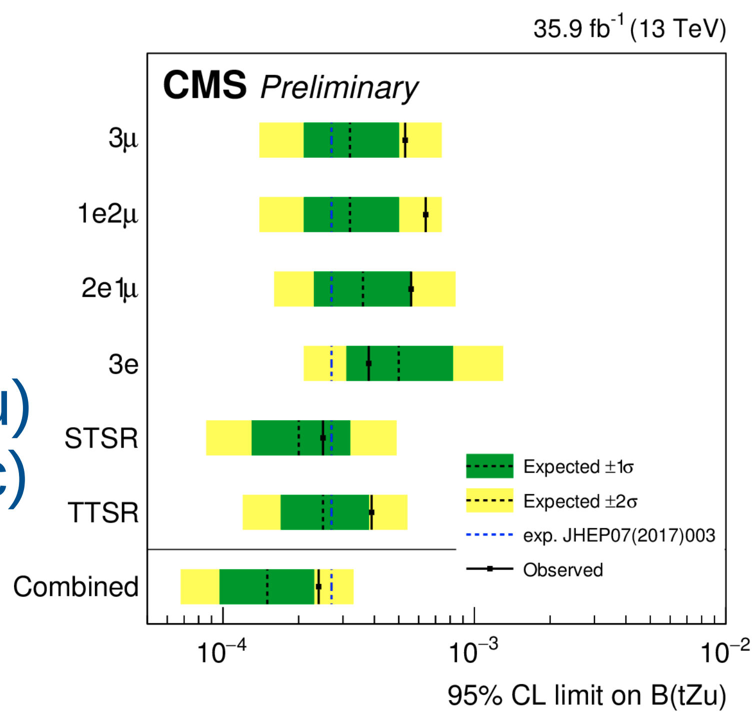
exp BR @ 95% CL:
0.024 % (u)
0.032 % (c)

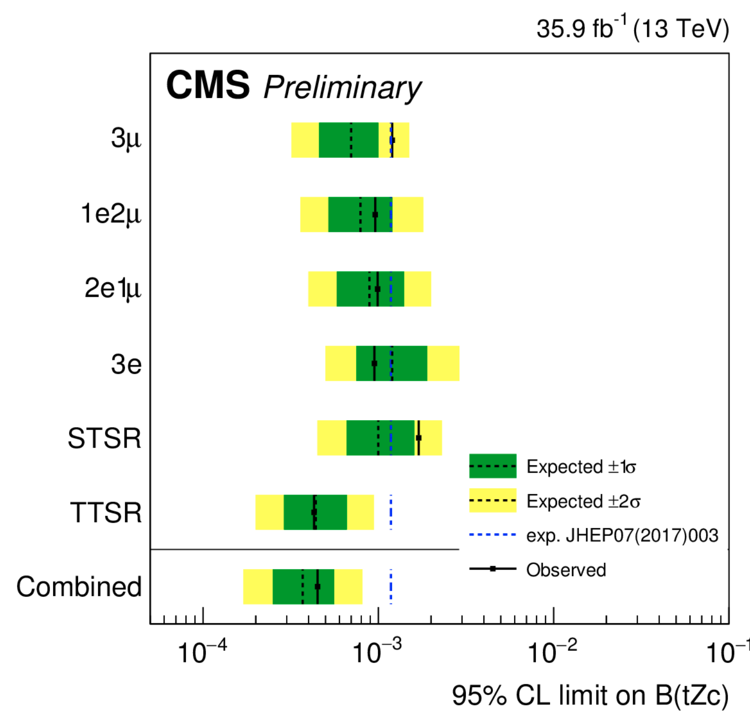




CMS

exp BR @ 95% CL:
0.015 % (u)
0.037 % (c)

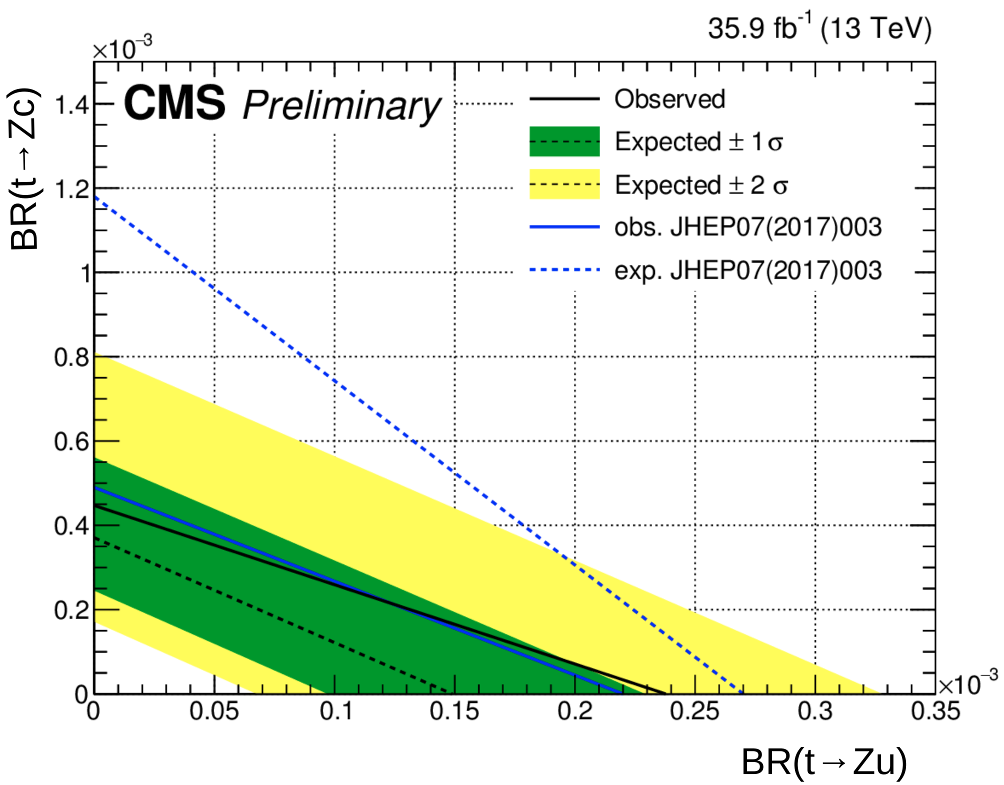


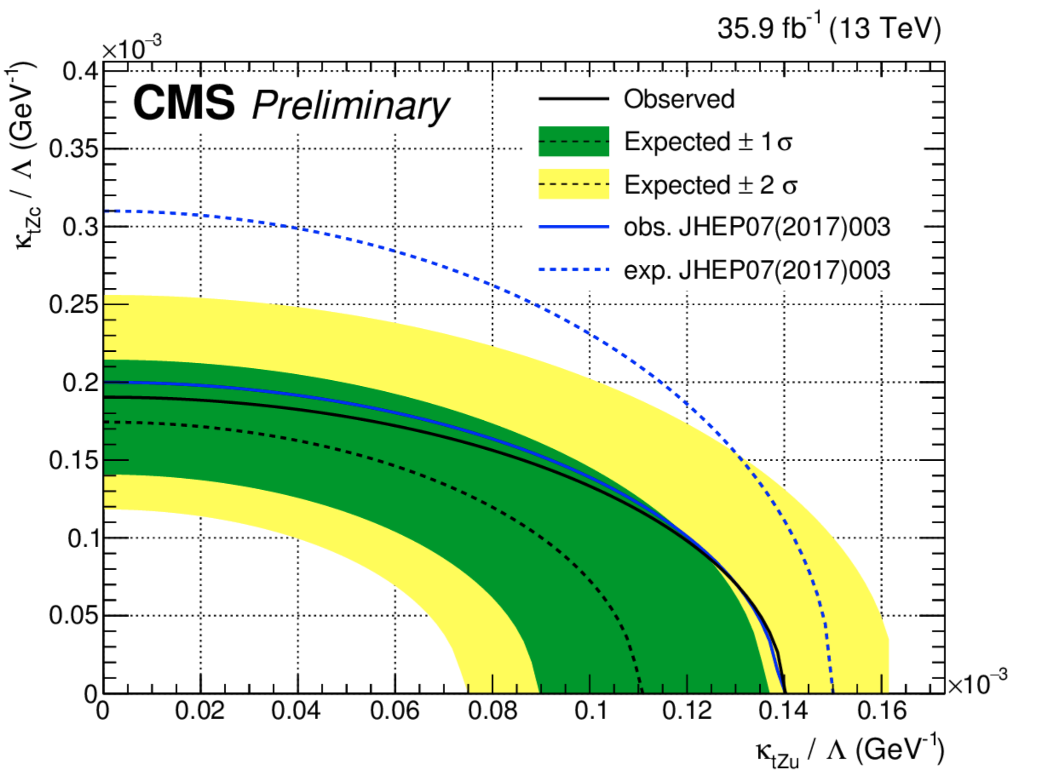


Results

- Limits on xsec / BR can be converted into coupling limits

CMS





Results

- Limits on BR can be interpreted in terms of coefficients of EFT operators

ATLAS

Operator	Observed	Expected
$\lvert C_{uB}^{(31)}\rvert$	0.25	0.30
$\lvert C_{uW}^{(31)}\rvert$	0.25	0.30
$\lvert C_{uB}^{(32)}\rvert$	0.30	0.34
$\lvert C_{uW}^{(32)}\rvert$	0.30	0.34

$$\Lambda = 1\,\mathrm{TeV}$$

Z boson - tensor

$$\frac{g_W}{4\cos\theta_W m_Z} K_{ut}^L = \frac{v}{\sqrt{2}}\left(g_W \frac{C_{uW}^*}{\Lambda^2}\cos\theta_W - g_Y \frac{C_{uB}^*}{\Lambda^2}\sin\theta_W\right)$$

$$\frac{g_W}{4\cos\theta_W m_Z} K_{ut}^R = \frac{v}{\sqrt{2}}\left(g_W \frac{C_{tW}}{\Lambda^2}\cos\theta_W - g_Y \frac{C_{tB}}{\Lambda^2}\sin\theta_W\right)$$

$$\frac{g_W}{4\cos\theta_W m_Z} K_{ct}^L = \frac{v}{\sqrt{2}}\left(g_W \frac{C_{ctW}^*}{\Lambda^2}\cos\theta_W - g_Y \frac{C_{ctB}^*}{\Lambda^2}\sin\theta_W\right)$$

$$\frac{g_W}{4\cos\theta_W m_Z} K_{ct}^R = \frac{v}{\sqrt{2}}\left(g_W \frac{C_{tcW}}{\Lambda^2}\cos\theta_W - g_Y \frac{C_{tcB}}{\Lambda^2}\sin\theta_W\right)$$

Z boson - vector

$$C_{\phi u}^{1+3} = -\frac{\Lambda^2}{v^2} X_{ut}^R$$

$$C_{\phi u}^{2+3} = -\frac{\Lambda^2}{v^2} X_{ct}^R$$

$$C_{\phi q}^{1,1+3} - C_{\phi q}^{3,1+3} = -\frac{\Lambda^2}{v^2} X_{ut}^L$$

$$C_{\phi q}^{1,2+3} - C_{\phi q}^{3,2+3} = -\frac{\Lambda^2}{v^2} X_{ct}^L$$

Summary

- Stringent limits on the FCNC Ztq vertex obtained by ATLAS and CMS
  - Orders of magnitude away from the SM but approaching some BSM extensions
  - Tri-lepton topologies chosen by both Collaborations
  - Result is still dominated by statistical uncertainty
  - Different approaches:
    - ATLAS: cut-based analysis + profiled likelihood fit on χ^2 (decay channel only)
    - CMS: BDT (production + decay channels)

BACKUP SLIDES

Background modeling

- ATLAS

Sample	$t\bar{t}Z$ CR	WZ CR	ZZ CR	Non-prompt lepton CR0	Non-prompt lepton CR1
$t\bar{t}Z$	61 ± 9	16.3 ± 3.1	0 ± 0	6.1 ± 1.2	22.1 ± 3.2
WZ	9 ± 9	560 ± 240	0 ± 0	150 ± 70	20 ± 9
ZZ	0.07 ± 0.03	48 ± 11	92 ± 20	58 ± 16	9.0 ± 2.3
Non-prompt leptons	3 ± 6	28 ± 16	0 ± 0	150 ± 50	140 ± 70
Other backgrounds	13.4 ± 2.7	22 ± 5	1.0 ± 0.6	17 ± 6	32 ± 6
Total background	87 ± 15	670 ± 240	93 ± 20	380 ± 90	230 ± 70
Data	81	734	87	433	260
Data / Bkg	0.94 ± 0.19	1.1 ± 0.4	0.94 ± 0.23	1.13 ± 0.28	1.1 ± 0.4