Recent results on FCNC by the ATLAS and the CMS collaborations

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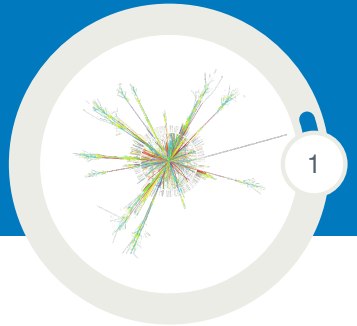
Motivation

Flavour Changing Neutral Currents



- Flavour Changing Neutral Currents (FCNC) processes, where a fermion changes its flavour via an interaction with a neutral boson, is a great example of a rare interaction in the Standard Model (SM) framework (with a branching ratio of $\sim 10^{-14}$):
  - Forbidden at tree level and heavily suppressed at loop correction by the GIM mechanism and CKM unitarity constraints
- Variety of New Physics models lead to FCNC contributions, often at tree level, by introducing new particles or interactions (with expected branching ratios between 10^{-5} and 10^{-10}):
  - Two-Higgs doublet models (2HDM), warped extra dimensions (RS), Minimal Supersymmetric Standard Model (MSSM), composite Higgs models and quark-singlet models, among others

Great place for indirect evidence / constraint on New Physics!

Motivation

Flavour Changing Neutral Currents

- Searches for FCNC processes can be performed in a model independent way using an Effective Field Theory (EFT) approach, being the SM Lagrangian extended by higher-dimensions operators

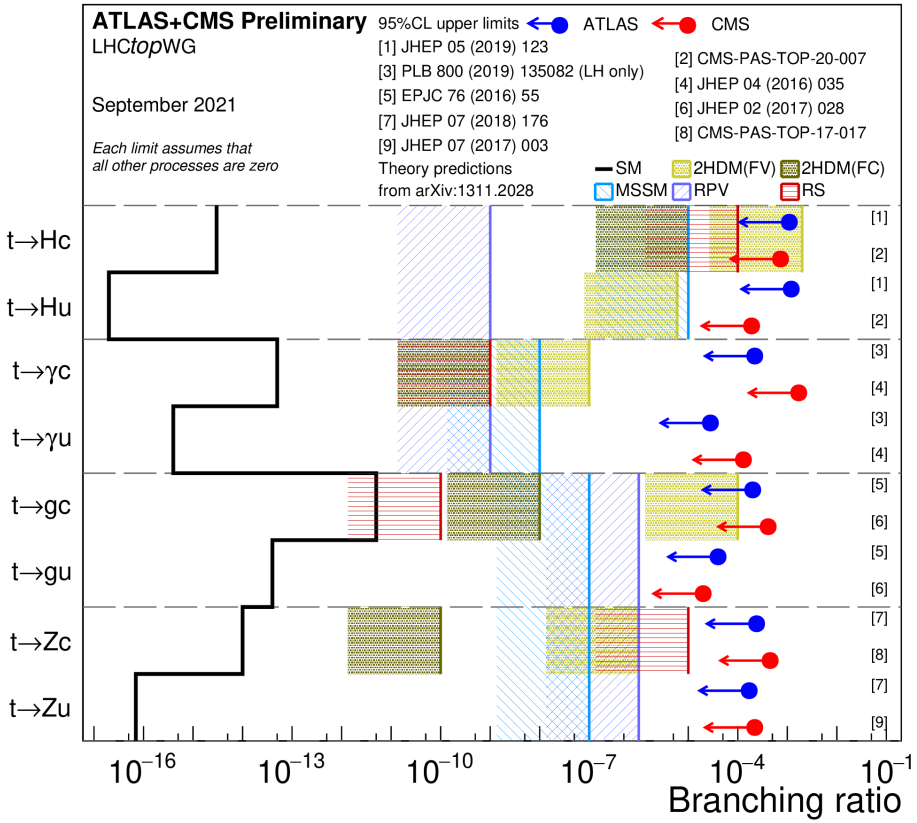
$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \frac{1}{\Lambda_{NP}^2} \sum_i C_i^{(6)} O_i^{(6)} + ...$$

- New Physics models predict a general enhancement of the FCNC top quark interactions with two possible production modes:
  - Single production: t+X production with X=γ, g, Z and $H \Rightarrow$ Particularly sensitive for tXu coupling due to the Parton Density Functions
  - Pair production: $t\bar{t}$ production usually assuming a top quark decaying through the SM ($t \rightarrow Wb$) and the other through a FCNC process ($t \rightarrow Xq$) $\Rightarrow$ No dependency of the cross-section with the tXq coupling

Motivation

Flavour Changing Neutral Currents

- Experimental limits still several orders of magnitude before SM suppression
- This talk focuses on the most recent results from the LHC FCNC analyses:
  - tZq with $Z \to \ell^+\ell^-$ and tgq with $t \to \ell\nu b$ from the ATLAS Collaboration
  - tHq with $H \to \gamma\gamma$ and tHq with $H \to b\bar{b}$ from the CMS Collaboration



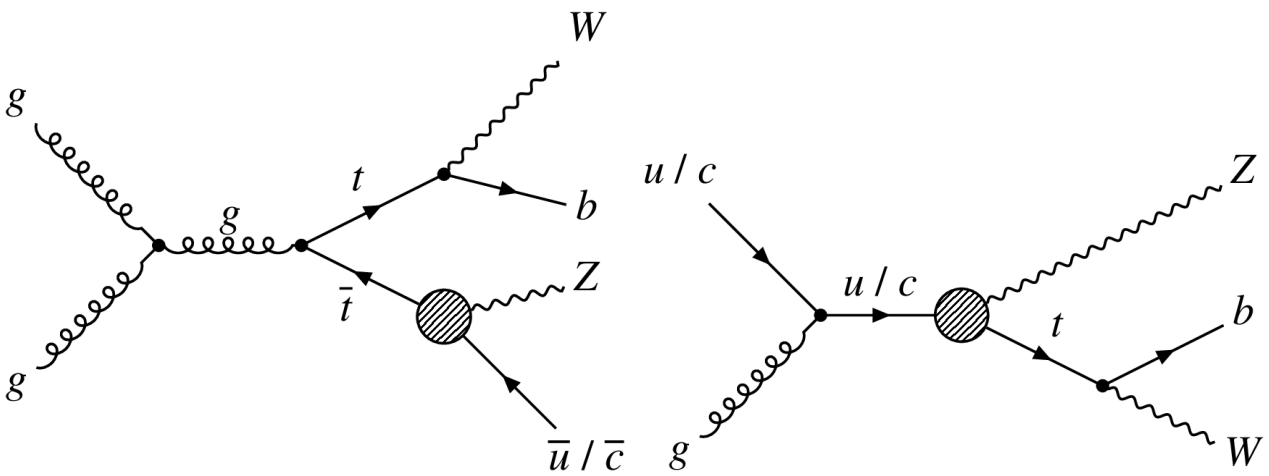
Part I

tZq with $Z \to \ell^+\ell^-$ at the ATLAS Collaboration

Strategy

FCNC tZq with $Z \to \ell^+\ell^-$ at ATLAS

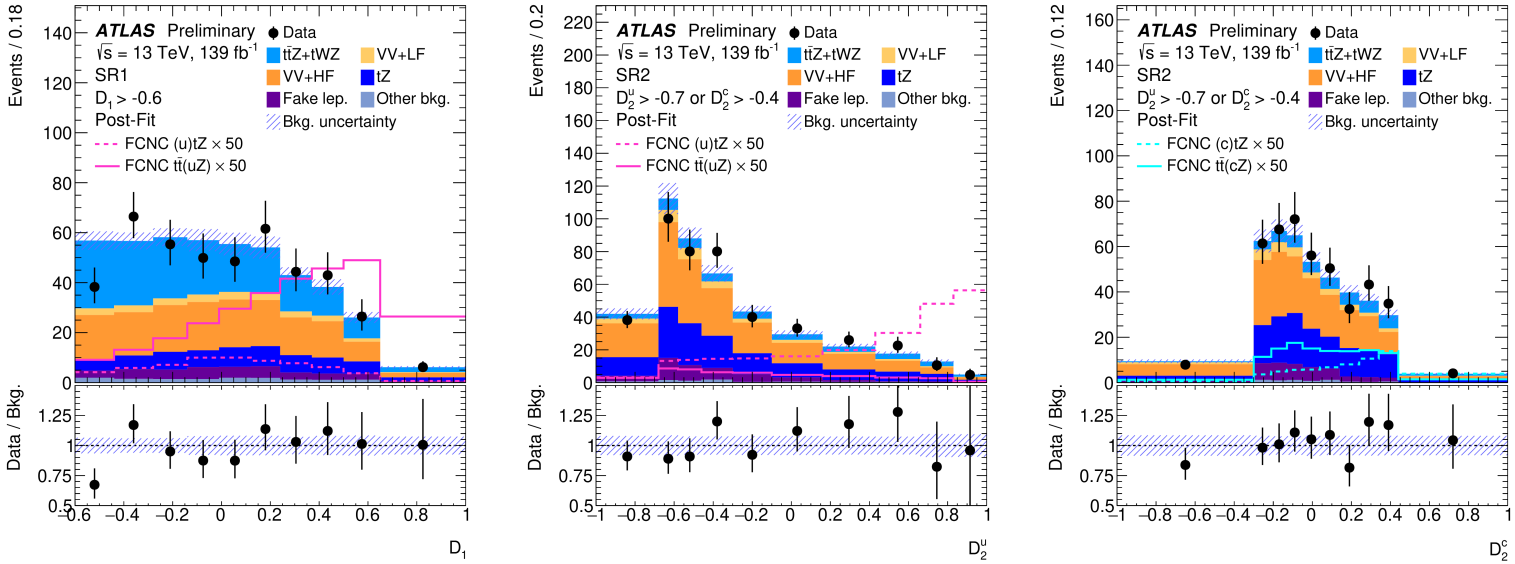
- Search for FCNC tZq processes combining both production and decay modes using full Run-2 ATLAS data (139 fb^{-1}):
  - **Trileptonic topology:**
    $\ell^+\ell^-$ + ℓ + b-tagged jet + Missing transverse energy
  - **Main backgrounds:**
    $t\bar{t}Z$, diboson (WZ and ZZ processes) and $t\bar{t}$ production
  - Analysis split into two dedicated searches considering only tZu and tZc (left- and right-handed) anomalous couplings
  - Signal generation with `TopFCNC` UFO model considering the Wilson coefficients C_{uW} and C_{uB}



Selection

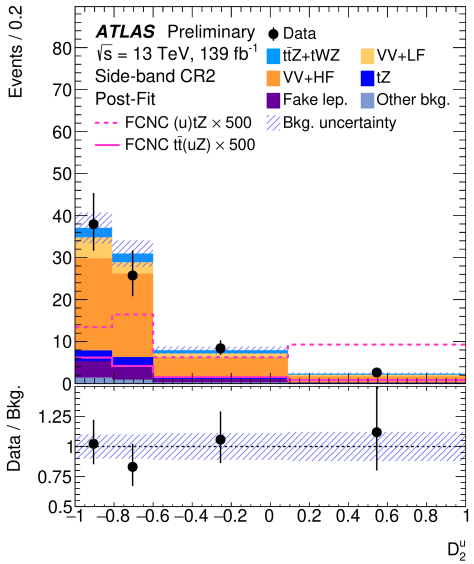
FCNC tZq with $Z \to \ell^+\ell^-$ at ATLAS

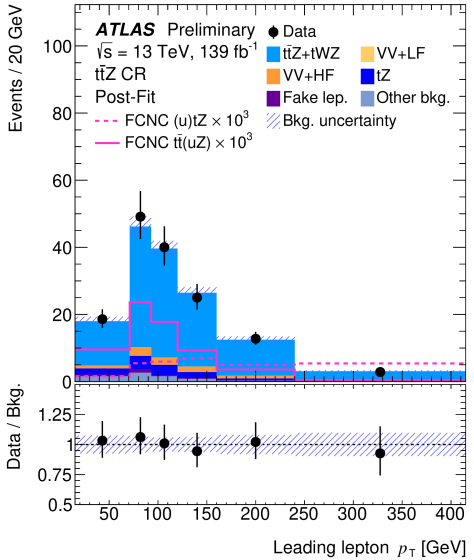
- Invariant mass of the SM ($t \to bW$) and FCNC ($t \to qZ$) top quarks reconstructed using the χ^2 minimization method
- Boosted Decision Trees (BDTs) trained to separate signal and background processes with a total of three discriminants focusing on the FCNC $t\bar{t}$ decay (left), FCNC tZu production (center) and FCNC tZc production (right)



Data and Monte Carlo comparison

FCNC tZq with $Z \to \ell^+\ell^-$ at ATLAS





- Common selection: $p_T(\ell_1) > 27$ GeV, $= 1$ b-jet and $|m_{\ell\ell} - m_Z| < 15$ GeV
- Two signal regions defined targeting the distinct production modes:
  - SR1 - $t\bar{t}$ decay: ≥ 2 jets and $|m^{\text{reco}}_{j_a\ell\ell} - m_t| < 2\sigma_{FCNC}$
  - SR2 - single-top production: $= 1,2$ jets, $m_T(\ell_W, \nu) > 40$ GeV, $|m^{\text{reco}}_{j_a\ell\ell} - m_t| > 2\sigma_{FCNC}$ and $|m^{\text{reco}}_{j_b\ell_W\nu} - m_t| > 2\sigma_{SM}$
- A total of four control regions focused on the main backgrounds:
  - Side-Band CR1: $|m^{\text{reco}}_{j_a\ell\ell} - m_t| > 2\sigma_{FCNC}$ and $|m^{\text{reco}}_{j_b\ell_W\nu} - m_t| > 2\sigma_{SM}$
  - Side-Band CR2: $|m^{\text{reco}}_{j_b\ell_W\nu} - m_t| > 2\sigma_{SM}$
  - $t\bar{t}Z$ CR: ≥ 4 jets and $= 2$ b-jets
  - $t\bar{t}$ CR: No OSSF pair of leptons and ≥ 1 jet

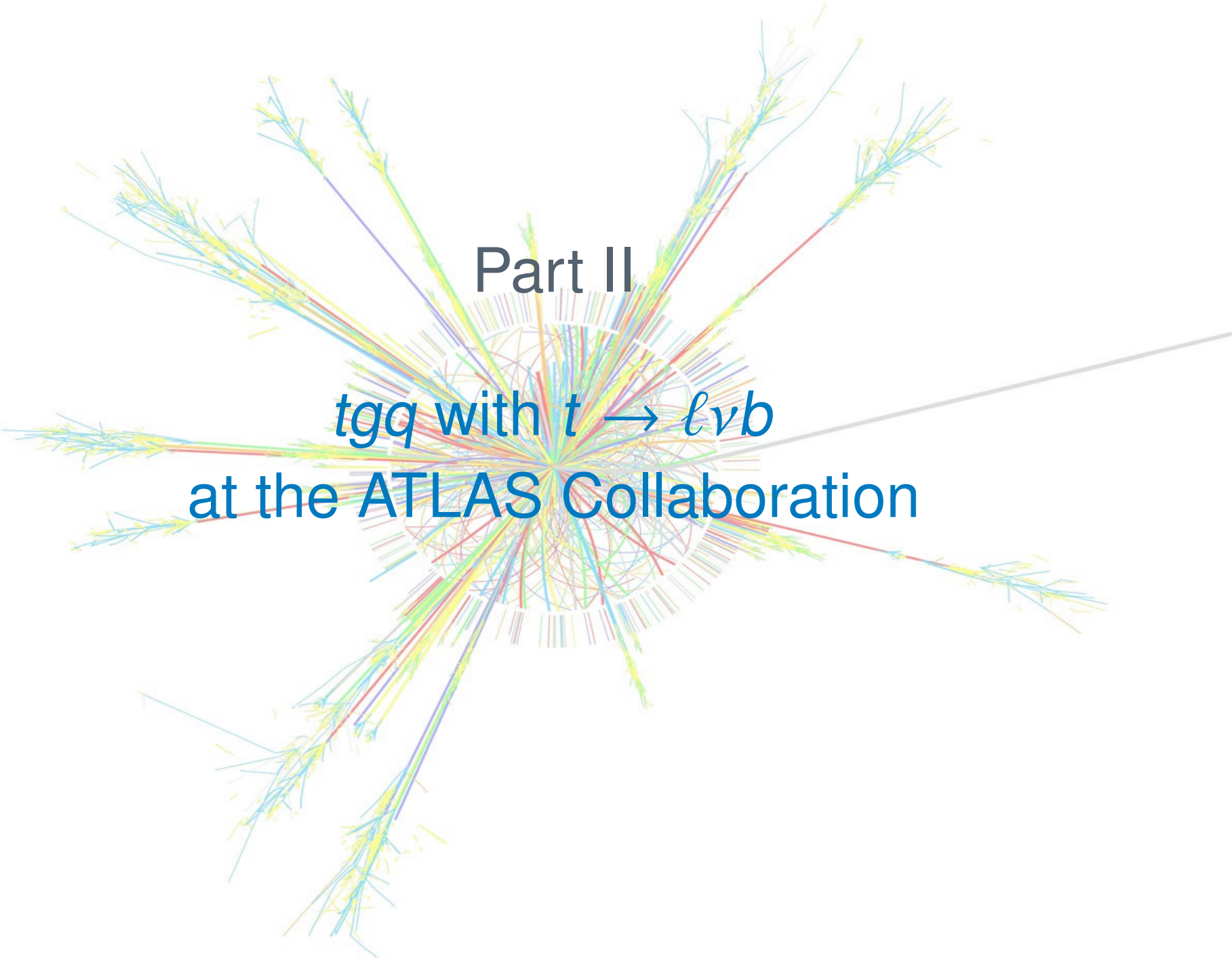
Limits

FCNC tZq with $Z \to \ell^+\ell^-$ at ATLAS

- No evidence of a signal is found ⇒ Limits on the $t \to Zq$ branching ratios at 95% CL were obtained for tZu and tZc vertices, being converted to limits on the Wilson coefficients
- Most stringent limits up to date for the tZq couplings with an improvement by a factor of 3 (2) for the tZu (tZc) couplings

Observable	Vertex	Coupling	Observed	Expected
$\mathcal{B}(t \to Zq)$ [10^{-5}]	tZu	LH	6.2	$4.9^{+2.1}_{-1.4}$
$\mathcal{B}(t \to Zq)$ [10^{-5}]	tZu	RH	6.6	$5.1^{+2.1}_{-1.4}$
$\mathcal{B}(t \to Zq)$ [10^{-5}]	tZc	LH	13	11^{+5}_{-3}
$\mathcal{B}(t \to Zq)$ [10^{-5}]	tZc	RH	12	10^{+4}_{-3}
$\lvert C_{uW}^{(13)*}\rvert$ and $\lvert C_{uB}^{(13)*}\rvert$	tZu	LH	0.15	$0.13^{+0.03}_{-0.02}$
$\lvert C_{uW}^{(31)}\rvert$ and $\lvert C_{uB}^{(31)}\rvert$	tZu	RH	0.16	$0.14^{+0.03}_{-0.02}$
$\lvert C_{uW}^{(23)*}\rvert$ and $\lvert C_{uB}^{(23)*}\rvert$	tZc	LH	0.22	$0.20^{+0.04}_{-0.03}$
$\lvert C_{uW}^{(32)}\rvert$ and $\lvert C_{uB}^{(32)}\rvert$	tZc	RH	0.21	$0.19^{+0.04}_{-0.03}$

More details in: ATLAS-CONF-2021-049



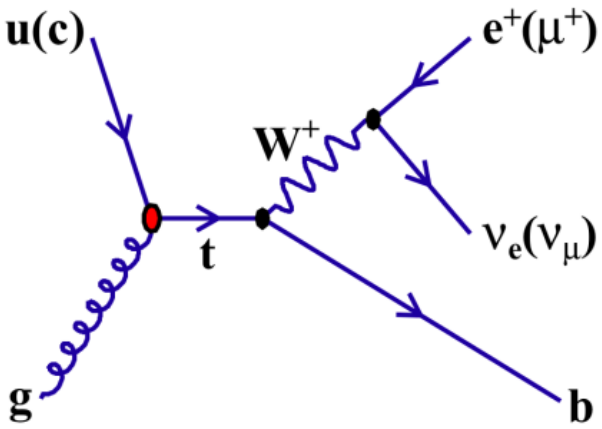
Part II

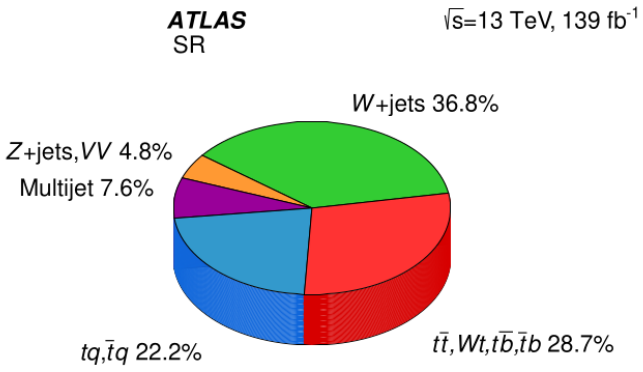
tgq with $t \to \ell\nu b$ at the ATLAS Collaboration

Strategy

FCNC *tgq* with $t \to \ell\nu b$ at ATLAS

- Search for FCNC *tgq* processes with single-top production using full Run-2 ATLAS data (139 fb^{-1}):
  - **Targeted topology:** ℓ + b-tagged jet + Missing transverse energy
  - **Main backgrounds:** $W + b\bar{b}$, t-channel single-top and $t\bar{t}$ production
  - Signal generation with `METOP` UFO model at next-to-leading order in QCD considering a left-handed *tgq* coupling

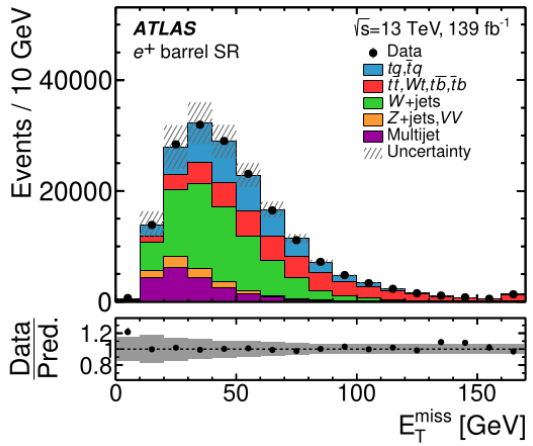


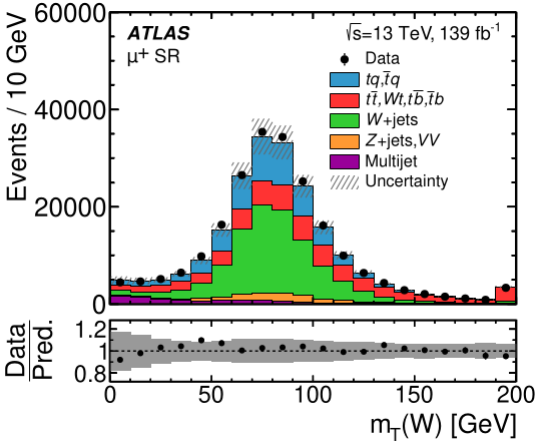


Selection

FCNC tgq with $t \to \ell\nu b$ at ATLAS

- Common requirements on the number of leptons (with different isolation), E_T^{miss} (> 30 GeV), $m_T(W)$ (> 50 GeV), jet multiplicity and lepton p_T
- Signal region with a b-tagged jet at the dedicated 30% working point efficiency
- Multijet determined in a data-driven way by fitting E_T^{miss} and $m_T(W)$
- Neural Networks (NNs) used to construct two discriminants:
  - D_1 targeting FCNC cgt: events with a sea quark or antiquark in the initial state
  - D_2 focusing on FCNC ugt: excluding charge-conjugate process of top-antiquark production

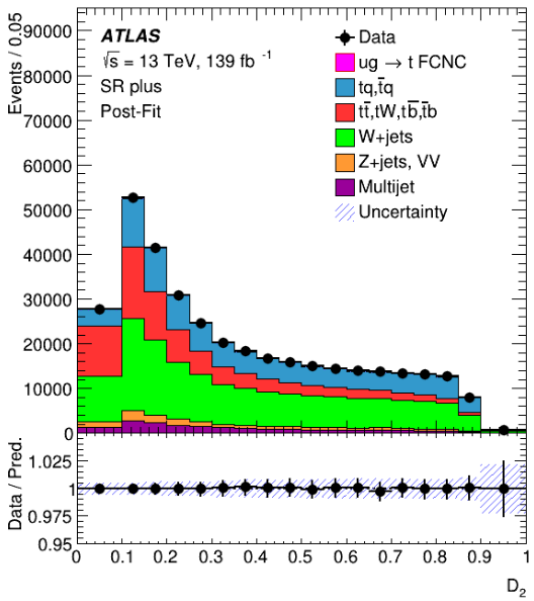


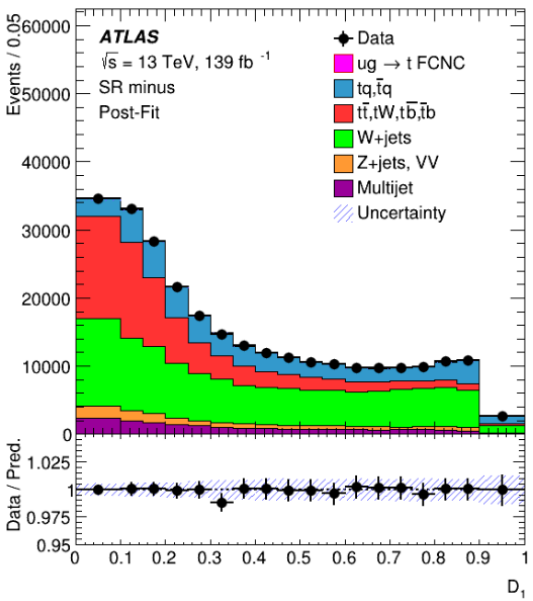


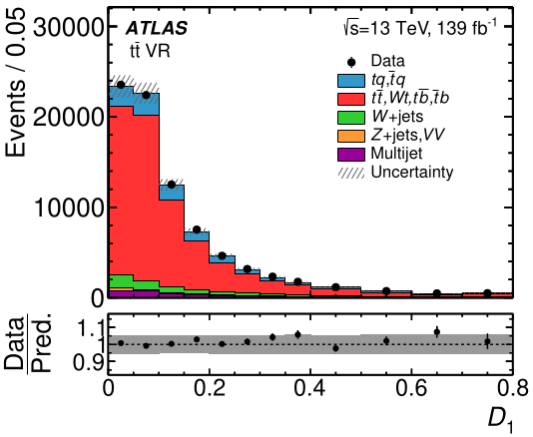
Data and Monte Carlo comparison

FCNC tgq with $t \to \ell\nu b$ at ATLAS

- Signal region for cgt uses only D_1 discriminant while the ugt analysis considers both discriminants (with two signal regions depending on the lepton charge):
  - D_1 in ℓ^- channel for top-antiquark production ($\bar{u} + g \to \bar{t}$)
  - D_2 in ℓ^+ channel aimed at direct top-quark production ($u + g \to t$)
- Three validation regions defined for the main backgrounds:
  - W+jets (= 1 b-jet at 60% WP and $0.3 < D_{1(2)} < 0.6$),
    $t\bar{t}$ (= 2 b-jets at 30% WP) and
    tq production (= 1 b-jet at 30% WP and $0.2 < D_{1(2)} < 0.4$)







Limits

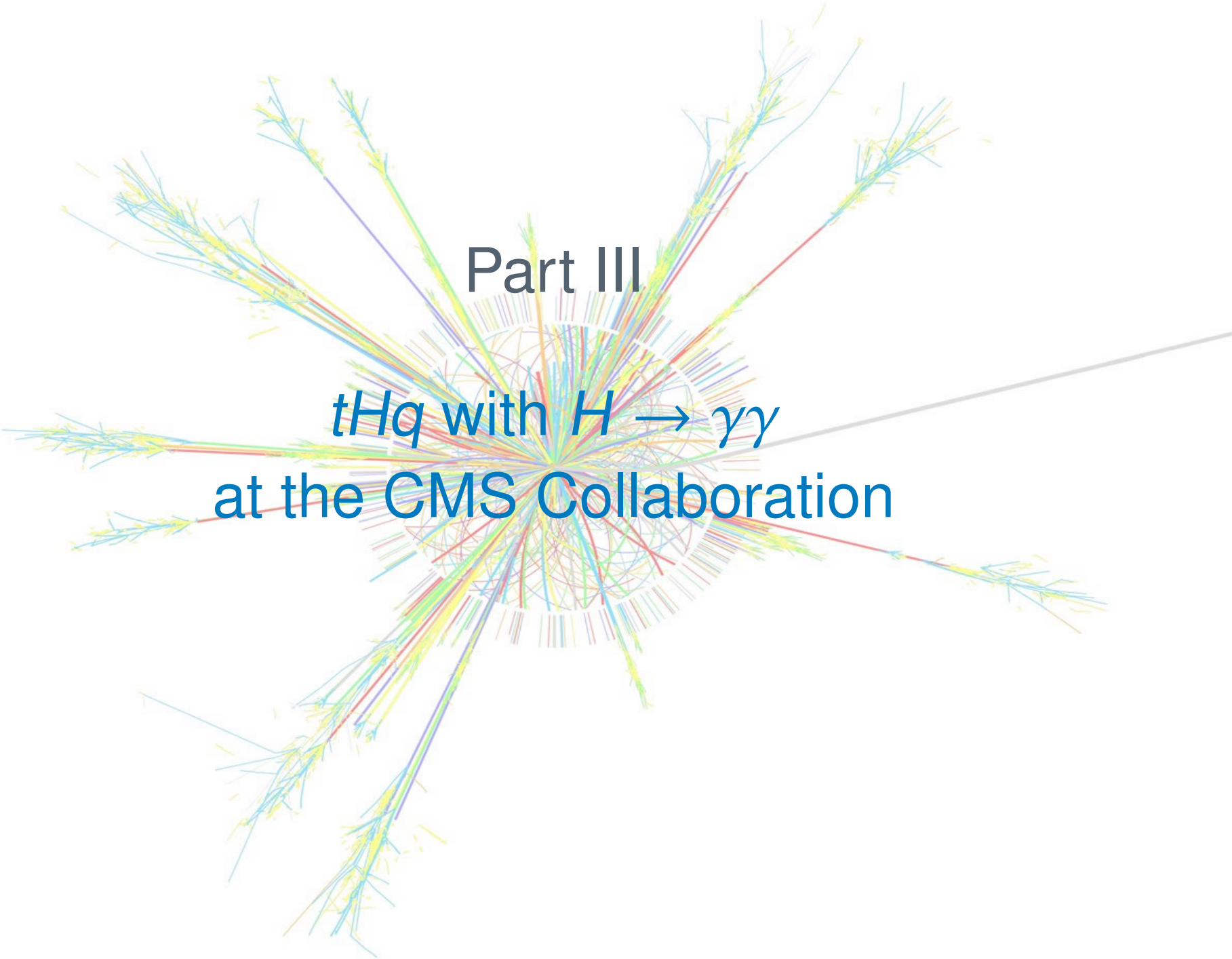
FCNC *tgq* with $t \to \ell\nu b$ at ATLAS

- Binned maximum-likehood fit performed separately to *ugt* and *cgt* FCNC processes
- Leading systematic uncertainties related to the W+jets process for the *ugt* fit and the modelling of the parton shower for the *cgt* fit
- Observed (expected) limits for FCNC *tgq* (improved by a factor of 2) with $\mathcal{B}(t \to gu)$ of 0.61 (0.49) $\times 10^{-4}$ and $\mathcal{B}(t \to gc)$ of 3.7 (2.0) $\times 10^{-4}$ and interpreted in terms of EFT coefficients C_{uG}^{qt}:

$$\mathcal{B}(t \to q + g) = 0.0186 \times \left(\frac{C_{uG}^{qt}}{\Lambda^2}\right)^2 \text{TeV}^4 \text{ resulting in}$$

$$\frac{|C_{uG}^{ut}|}{\Lambda^2} < 0.057\,\text{TeV}^{-2} \text{ and } \frac{|C_{uG}^{ct}|}{\Lambda^2} < 0.14\,\text{TeV}^{-2} \text{ at the 95\% CL}$$

More details available soon!



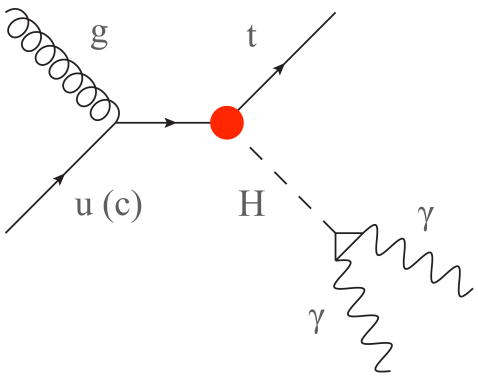
Part III

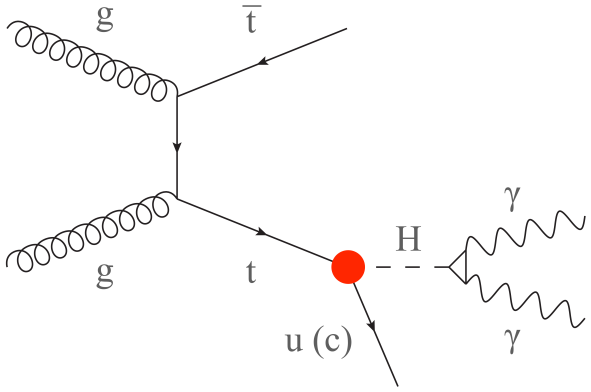
tHq with $H \to \gamma\gamma$ at the CMS Collaboration

Strategy

FCNC *tHq* with $H \to \gamma\gamma$ at CMS

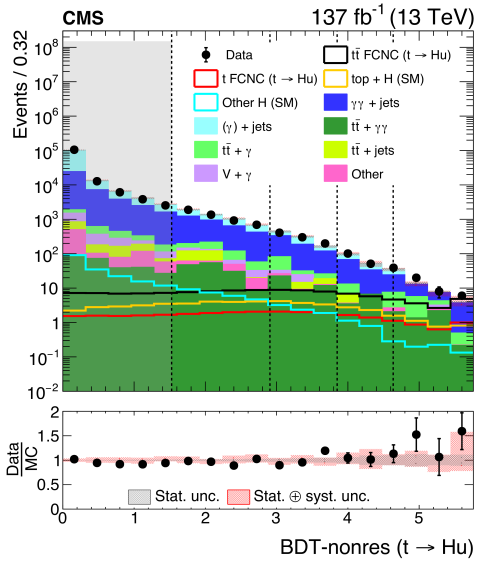
- Analysis focusing on the *tHq* anomalous coupling with the Higgs decaying to two photons with the full Run-2 CMS data (137 fb^{-1}):
  - Both production and decay modes considered
  - **Two orthogonal topologies:** $\gamma\gamma$ + ($\geq 1\ \ell$ + ≥ 1 jet) or ($0\ \ell$ + ≥ 3 jets)
  - **Main backgrounds:** $t\bar{t}$ + $\gamma(\gamma)$, $t\bar{t}$ + jets, $\gamma\gamma$ + jets, γ + jets and $t\bar{t}H$
  - Signal generation through the implementation of an effective Lagrangian and assuming a left-handed coupling parameter κ_{Hqt}

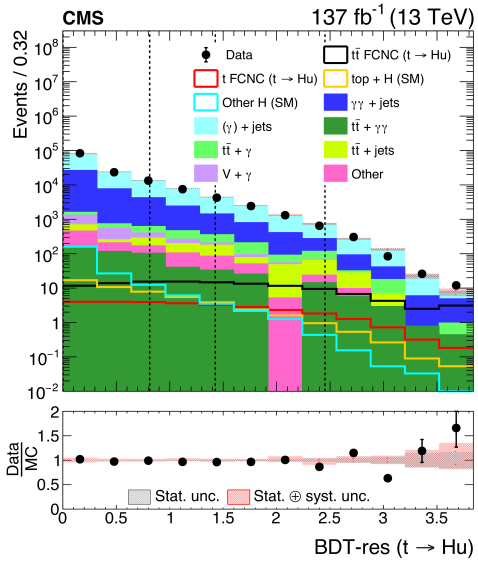




Selection

FCNC *tHq* with $H \to \gamma\gamma$ at CMS



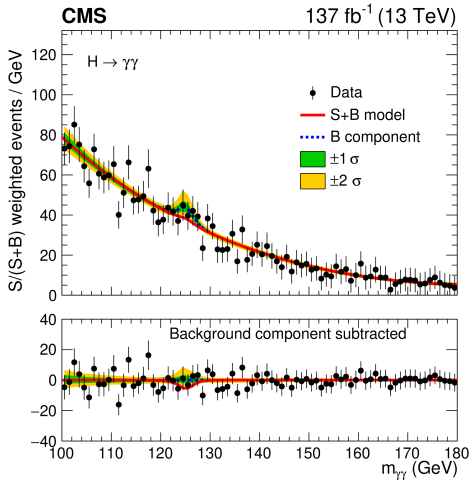


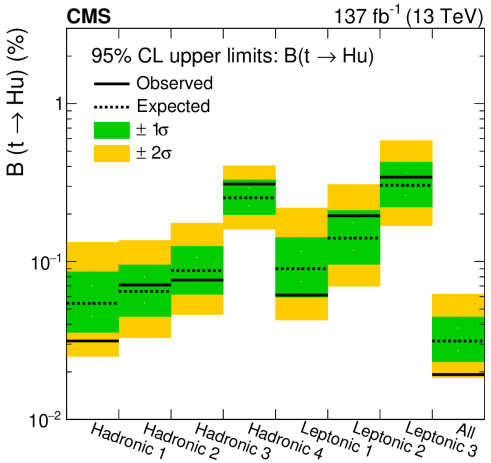
- Common selection requiring two high p_T isolated photons (with $100 < m_{\gamma\gamma} < 180$ GeV and $p_T(\gamma)/m_{\gamma\gamma} > 1/3$ and 1/4) and additional jets/leptons before splitting into different channels
- Separate BDTs for each coupling (*tHu*,*tHc*), each channel (hadronic or leptonic) and for each type of background (resonant and non-resonant SM Higgs background) with 8 BDTs in total
  - Input variables include the kinematic features of photons, diphoton system, jets and leptons
  - Variety of top quark reconstruction methods, including NN for top recontruction: 20-30% improvement in expected limits

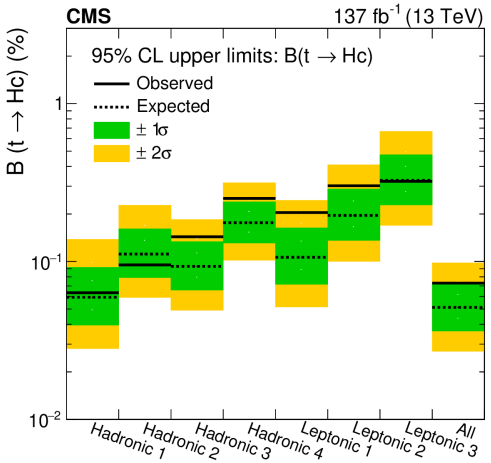
Limits

FCNC *tHq* with $H \to \gamma\gamma$ at CMS

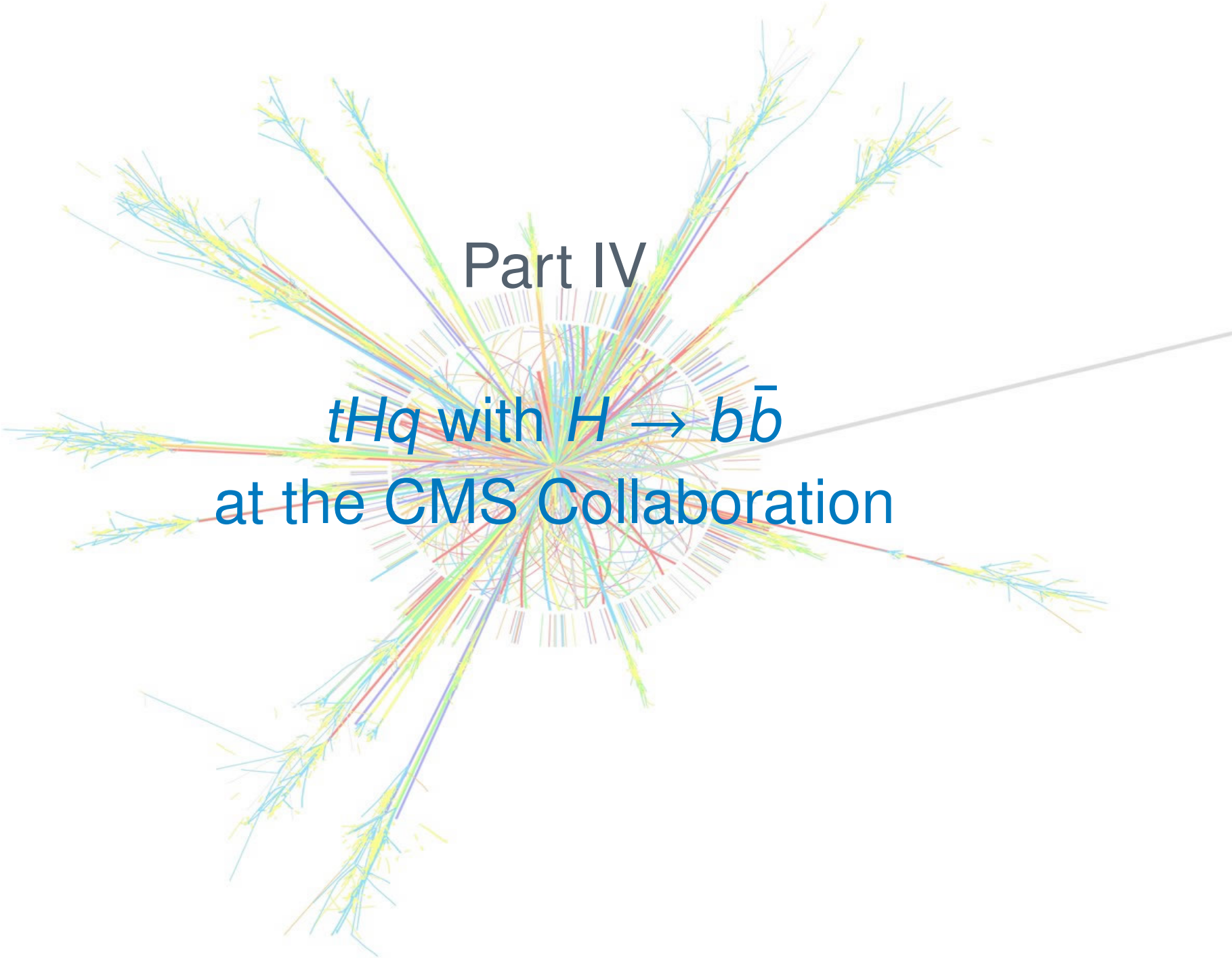
- Simultaneous fit of the diphoton invariant mass spectrum performed in all 7 signal regions
  - Non-resonant background model derived from data
  - Resonant (SM Higgs) background processes modeled from simulation
  - Dominant experimental uncertainties coming from the *b*-jet and photon identification (impact of $\leq 5\%$)
- Most stringent observed (expected) limits up to date: $\mathcal{B}(t \to Hu)$ of 1.9 (3.1) $\times 10^{-4}$ and $\mathcal{B}(t \to Hc)$ of 7.3 (5.1) $\times 10^{-4}$ and $|\kappa_{Hut}|$ with 0.037 (0.047) and $|\kappa_{Hct}|$ with 0.071 (0.060)







More details in: TOP-20-007



Part IV

tHq with $H \to b\bar{b}$ at the CMS Collaboration

Strategy

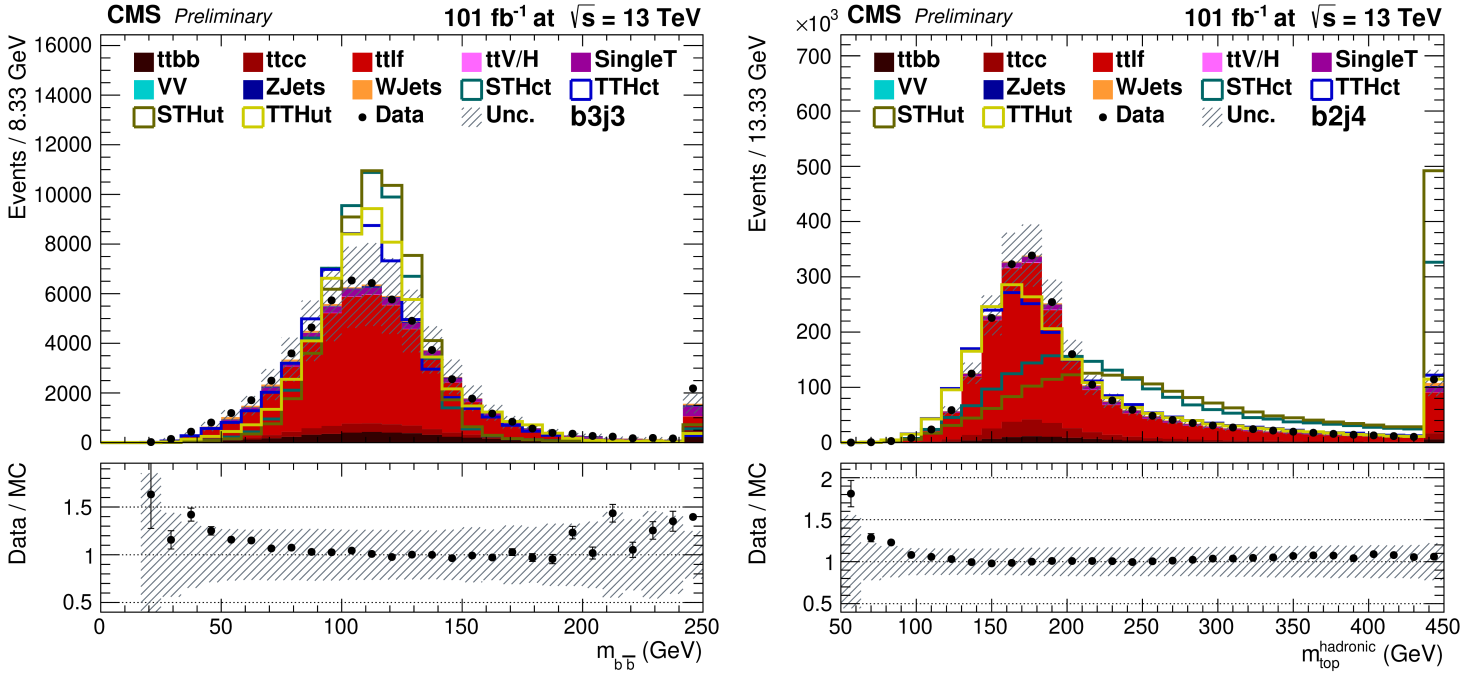
FCNC tHq with $H \to b\bar{b}$ at CMS

- Search for the FCNC tHq with $H \to b\bar{b}$ using the full Run-2 CMS data (137 fb^{-1})
  - Both production and decay modes considered
  - **Topology:** ℓ + $\geq$ 3 jets with $\geq$ 2 b-jets
  - **Main backgrounds:** $t\bar{t}$, $t\bar{t}$ + $b\bar{b}$ and $t\bar{t}$ + $c\bar{c}$ production
  - Signal generation using the same approach as the $H \to \gamma\gamma$ search with a coupling parameter κ_{Hqt} and assuming a left-handed anomalous coupling
- A total of five categories of events based on jet and b-jet multiplicity
  - Exactly 3 jets: 2 or 3 b-jets
  - At least 4 jets: 2, 3 or 4 b-jets

Selection

FCNC tHq with $H \to b\bar{b}$ at CMS

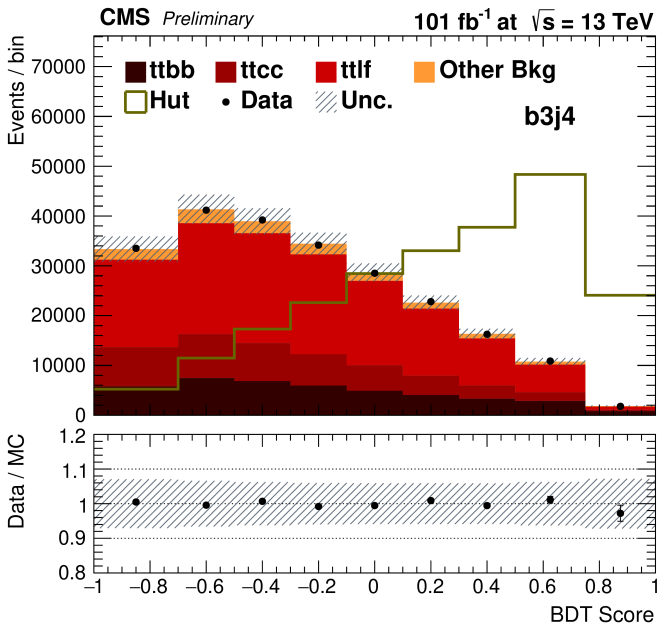
- Deep Neural Networks (DNN) used to assign jets as coming from the top quark or the Higgs decay:
  - Performance measured through reconstruction efficiency on signal events: fraction of events where all jets are correcty assigned
  - Ranges from 77% ($t\bar{t}$, tHc) to 86% (single-top, tHu) - a 5-15% improvement relative to kinematic fit method used in previous analysis

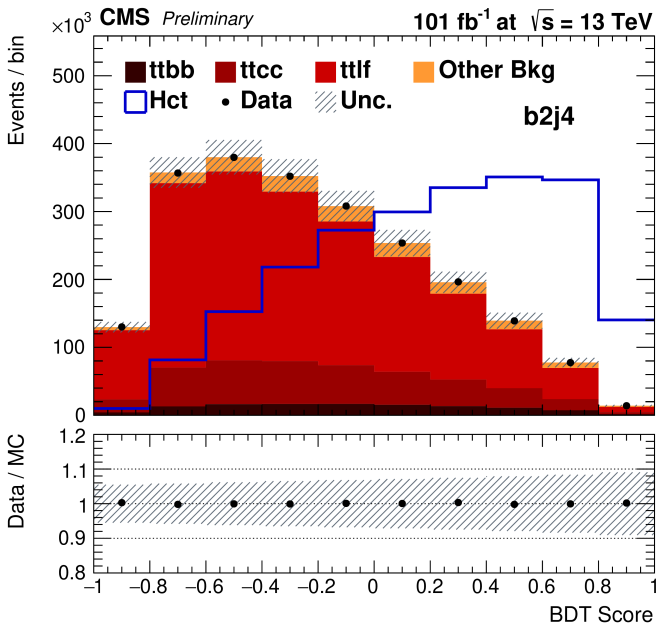


Data and Monte Carlo comparison

FCNC tHq with $H \to b\bar{b}$ at CMS

- Outputs from the DNN reconstruction among others kinematic variables are then fed to a BDT trained to distinguish signal from background
  - Signal: single-top and $t\bar{t}$ production FCNC events
  - Background: SM $t\bar{t}$ events
- BDT output distributions are then fitted to data using a binned maximum likelihood fit

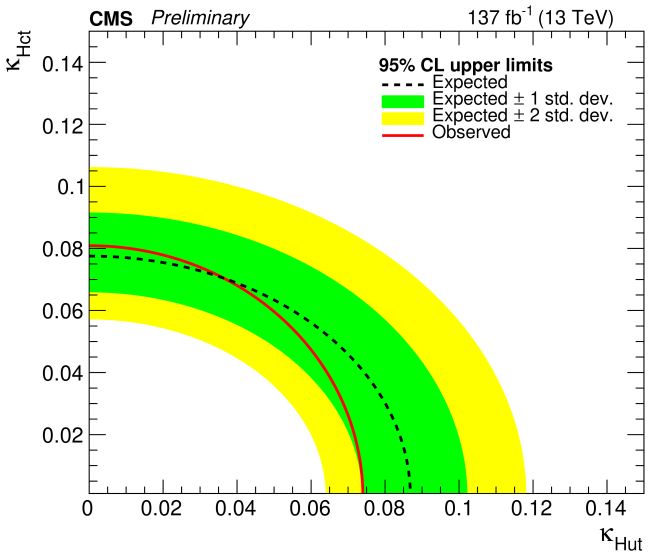


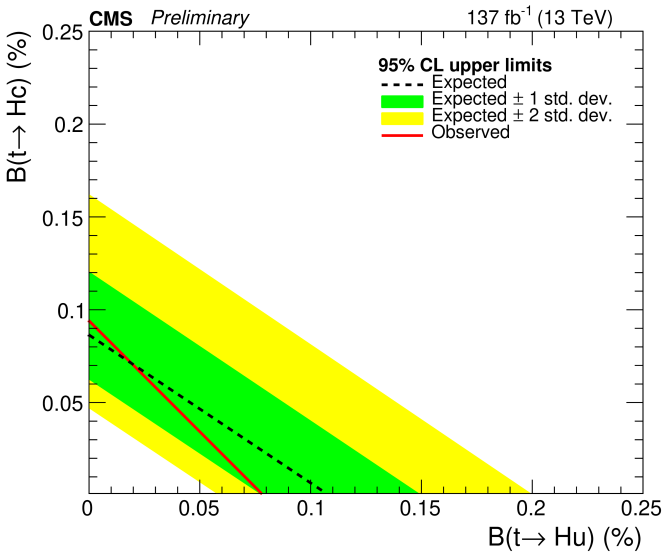


Limits

FCNC tHq with $H \to b\bar{b}$ at CMS

- Largest systematic uncertainty coming from the b-tagging identification (ranges from 12 to 25%) followed by the scale variation (from 10 to 17%)
- Observed (expected) limits on $\mathcal{B}(t \to Hu)$ of 7.9 (11.0) $\times 10^{-4}$ and $\mathcal{B}(t \to Hc)$ of 9.4 (8.6) $\times 10^{-4}$ and on $|\kappa_{Hut}|$ with 0.074 (0.087) and $|\kappa_{Hct}|$ with 0.081 (0.078) $\Rightarrow$ Improved by a factor of 3-6 compared to the previous results





More details in: CMS-PAS-TOP-19-002

Conclusions

- Top quark decays via FCNC presents a **powerful probe of New Physics** with many interesting signal topologies
- First series of results profitting from the **full Run-2 dataset** presents the most stringent limits up to date
  - Distinct signal processes targeted simultaneously with the inclusion of both **production and decay modes**
  - **Machine learning** techniques widely implemented in the current analyses, mostly for the correct reconstruction of the final objects
  - Interpretation in terms of **Effective Field Theory** complementing the limits on the branching ratio and cross-section
- **Future analyses** could benefit from a common approach on the **signal generation** while bringing an improvement on the results through a **combination** of the different decays of the neutral boson and the top quark

Analyses Overview

Coupling	*tZq*	*tgq*	*tHq*	*tHq*
Boson decay	$Z \to \ell\ell$	$t \to \ell\nu b$	$H \to \gamma\gamma$	$H \to b\bar{b}$
Topology	$\ell^+\ell^-\ell + b + E_T^{miss}$	$\ell + b + E_T^{miss}$	$\gamma\gamma$ + ($\geq 1\ell$+$\geq$1j) or (0ℓ+$\geq$3j)	ℓ + $\geq$3j + $\geq 2b$
Techniques	BDT	NN	BDT and NN	BDT and NN
Signal uncertainties	μ_f,μ_r, PS	μ_f, μ_r, PS, Matching	μ_f, μ_r, LO/NLO	μ_f, μ_r
$\mathcal{B}(t \to Xu)$	6.2×10^{-5}	0.61×10^{-4}	1.9×10^{-4}	7.9×10^{-4}
$\mathcal{B}(t \to Xc)$	13×10^{-5}	3.7×10^{-4}	7.3×10^{-4}	9.4×10^{-4}
EFT interpretation	C_{uW} and C_{uB}	C_{uG}^{qt}	κ_{Hct}	κ_{Hct}

Thanks for the attention!

Top quark reconstruction

FCNC tZq with $Z \to \ell^+\ell^-$ at ATLAS

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

	FCNC top quark		SM top quark		W boson	
	$m_{t_{\text{FCNC}}}$ [GeV]	σ_{FCNC} [GeV]	$m_{t_{\text{SM}}}$ [GeV]	σ_{SM} [GeV]	m_W [GeV]	σ_W [GeV]
FCNC in $t\bar{t}$ decay (LH)	171.0	11.1	166.5	23.2	80.5	15.4

Event Selection

FCNC tZq with $Z \to \ell^+\ell^-$ at ATLAS

Common selections		
Exactly 3 leptons with $p_{\mathrm{T}}(\ell_1) > 27$ GeV ≥ 1 OSSF pair, with $\lvert m_{\ell\ell} - m_Z \rvert < 15$ GeV		
SR1	SR2	
≥ 2 jets	1 jet	2 jets
1 b-jet	1 b-jet	1 b-jet
–	$m_{\mathrm{T}}(\ell_W, \nu) > 40$ GeV	$m_{\mathrm{T}}(\ell_W, \nu) > 40$ GeV
$\lvert m^{\mathrm{reco}}_{j_a \ell\ell} - m_t \rvert < 2\sigma_{t_{\mathrm{FCNC}}}$	–	$\lvert m^{\mathrm{reco}}_{j_a \ell\ell} - m_t \rvert > 2\sigma_{t_{\mathrm{FCNC}}}$
–	$\lvert m^{\mathrm{reco}}_{j_b \ell_W \nu} - m_t \rvert < 2\sigma_{t_{\mathrm{SM}}}$	$\lvert m^{\mathrm{reco}}_{j_b \ell_W \nu} - m_t \rvert < 2\sigma_{t_{\mathrm{SM}}}$

Common selections			
Exactly 3 leptons with $p_{\mathrm{T}}(\ell_1) > 27$ GeV			
$t\bar{t}$ CR	$t\bar{t}Z$ CR	Side-band CR1	Side-band CR2
≥ 1 OS pair, no OSSF	≥ 1 OSSF pair with $\lvert m_{\ell\ell} - m_Z \rvert < 15$ GeV	≥ 1 OSSF pair with $\lvert m_{\ell\ell} - m_Z \rvert < 15$ GeV	≥ 1 OSSF pair with $\lvert m_{\ell\ell} - m_Z \rvert < 15$ GeV
–	–	–	$m_{\mathrm{T}}(\ell_W, \nu) > 40$ GeV
≥ 1 jet	≥ 4 jets	≥ 2 jets	1 jet
1 b-jet	2 b-jets	1 b-jet	1 b-jet
–	–	$\lvert m^{\mathrm{reco}}_{j_a \ell\ell} - m_t \rvert > 2\sigma_{t_{\mathrm{FCNC}}}$	–
–	–	$\lvert m^{\mathrm{reco}}_{j_b \ell_W \nu} - m_t \rvert > 2\sigma_{t_{\mathrm{SM}}}$	$\lvert m^{\mathrm{reco}}_{j_b \ell_W \nu} - m_t \rvert > 2\sigma_{t_{\mathrm{SM}}}$

Event Yields

FCNC tZq with $Z \to \ell^+\ell^-$ at ATLAS

	SR1 (D_1 > -0.6)	SR2 (D_2^u > -0.7 or D_2^c > -0.4)
$t\bar{t}Z + tWZ$	137 ± 12	36 ± 6
VV + LF	18 ± 7	24 ± 8
VV + HF	114 ± 19	162 ± 26
tZ	46 ± 7	108 ± 18
$t\bar{t}$ + tW fakes	14 ± 4	27 ± 8
Other fakes	7 ± 8	5 ± 6
$t\bar{t}W$	4.2 ± 2.1	3.1 ± 1.6
$t\bar{t}H$	4.8 ± 0.7	0.89 ± 0.17
Other bkg.	2.0 ± 1.0	2.5 ± 2.9
FCNC $(u)tZ$	0.9 ± 1.7	4 ± 8
FCNC $t\bar{t}(uZ)$	5 ± 9	0.8 ± 1.5
Total background	348 ± 15	369 ± 21
Data	345	380

	Pre-fit		Post-fit	
	VR1	VR2	VR1	VR2
$t\bar{t}Z + tWZ$	70 ± 10	2.2 ± 0.6	70 ± 7	2.4 ± 0.6
VV + LF	10 ± 5	9.8 ± 3.4	10 ± 5	9.7 ± 3.0
VV + HF	56 ± 28	36 ± 14	60 ± 14	47 ± 8
tZ	6.5 ± 1.6	13.5 ± 2.7	6.6 ± 1.5	14.7 ± 2.6
$t\bar{t}$ + tW fakes	5.4 ± 2.6	4.5 ± 1.7	4.8 ± 2.1	3.8 ± 1.4
Other fakes	0.0 ± 0.6	1.4 ± 1.9	0.03 ± 0.24	0.8 ± 1.1
$t\bar{t}W$	2.3 ± 1.2	0.48 ± 0.26	2.3 ± 1.2	0.48 ± 0.25
$t\bar{t}H$	3.0 ± 0.5	0.101 ± 0.032	3.0 ± 0.5	0.108 ± 0.033
Other bkg.	0.8 ± 0.4	0.5 ± 0.7	0.8 ± 0.4	0.5 ± 0.6
Total background	154 ± 31	69 ± 15	158 ± 13	79 ± 7
Data	151	80	151	80
Data / Bkg.	0.98 ± 0.22	1.16 ± 0.29	0.96 ± 0.11	1.01 ± 0.15

Event Yields

FCNC tZq with $Z \to \ell^+\ell^-$ at ATLAS

	Side-band CR1	Side-band CR2	$t\bar{t}Z$ CR	$t\bar{t}$ CR
$t\bar{t}Z + tWZ$	102 ± 14	8.2 ± 1.4	230 ± 18	15.4 ± 1.5
VV + LF	27 ± 11	12 ± 4	0.23 ± 0.19	0.38 ± 0.25
VV + HF	166 ± 25	64 ± 9	17 ± 8	2.9 ± 0.5
tZ	22 ± 4	6.8 ± 1.4	21 ± 5	0.96 ± 0.19
$t\bar{t}$ + tW fakes	9.3 ± 2.6	7.2 ± 2.1	4.0 ± 1.3	93 ± 19
Other fakes	2 ± 4	2.0 ± 2.8	0.15 ± 0.18	0.08 ± 0.09
$t\bar{t}W$	4.5 ± 2.3	2.3 ± 1.2	3.0 ± 1.5	27 ± 13
$t\bar{t}H$	2.6 ± 0.4	0.33 ± 0.07	7.5 ± 1.2	14.1 ± 2.2
Other bkg.	3.3 ± 2.5	0.8 ± 0.4	1.9 ± 0.9	3.2 ± 1.5
FCNC $(u)tZ$	0.4 ± 0.7	0.17 ± 0.33	0.09 ± 0.18	0.05 ± 0.10
FCNC $t\bar{t}(uZ)$	0.14 ± 0.27	0.04 ± 0.07	0.11 ± 0.20	0.018 ± 0.035
Total background	338 ± 18	104 ± 8	284 ± 16	157 ± 13
Data	343	104	286	157

Event Selection

FCNC tgq with $t \to \ell\nu b$ at ATLAS

Observable	Common requirements
$n_{\text{Tight}}(e) + n_{\text{Medium}}(\mu)$	$= 1$
$n_{\text{Loose}}(e) + n_{\text{Loose}}(\mu)$	$= 1$
E_T^{miss}	> 30 GeV
$m_T(W)$	> 50 GeV
$n(j)$	≥ 1
$p_T(\ell)$	$> 50 \text{ GeV} \cdot \left(1 - \frac{\pi - \lvert\Delta\phi(j_1,\ell)\rvert}{\pi - 1}\right)$

	Analysis regions			
	SR	W+jets VR	$t\bar{t}$ VR	tq VR
$n(\lvert\eta(j)\rvert < 2.5)$	$= 1$	$= 1$	$= 2$	$= 1$
$n(b)$	$= 1$	$= 1$	$= 2$	$= 1$
ϵ_b	30%	60% (veto 30%)	30%	30%
$n(\lvert\eta(j)\rvert > 2.5)$	≥ 0	≥ 0	≥ 0	$= 1$
$D_{1(2)}$	–	$0.3 < D_{1(2)} < 0.6$	–	$0.2 < D_{1(2)} < 0.4$

Limits Comparison

FCNC *tgq* with $t \to \ell\nu b$ at ATLAS

Scenario	Description	$\mathcal{B}_{95}^{\text{exp}}(t \to u + g)$	$\mathcal{B}_{95}^{\text{exp}}(t \to c + g)$
(1)	Data statistical only	1.1×10^{-5}	2.4×10^{-5}
(2)	Experimental uncertainties also	3.1×10^{-5}	12×10^{-5}
(3)	All uncertainties except MC statistical	3.9×10^{-5}	18×10^{-5}
(4)	All uncertainties	4.9×10^{-5}	20×10^{-5}

Analysis	$\mathcal{B}_{95}^{\text{obs}}(t \to u + g)$	$\mathcal{B}_{95}^{\text{exp}}(t \to u + g)$	$\mathcal{B}_{95}^{\text{obs}}(t \to c + g)$	$\mathcal{B}_{95}^{\text{exp}}(t \to c + g)$
ATLAS 13 TeV	6.1×10^{-5}	4.9×10^{-5}	37×10^{-5}	20×10^{-5}
ATLAS 8 TeV	12×10^{-5}	11×10^{-5}	64×10^{-5}	57×10^{-5}
CMS 7 TeV $\oplus$ 8 TeV	2.0×10^{-5}	2.8×10^{-5}	41×10^{-5}	28×10^{-5}

Event Yields

FCNC tHq with $H \to b\bar{b}$ at CMS

Category	b2j3	b2j4	b3j3	b3j4	b4j4
Data	1 431 931	2 207 121	59 002	228 311	12 981
$t\bar{t}b\bar{b}$	33 038 ± 6500	115 300 ± 24 000	5452 ± 430	49 251 ± 3900	6974 ± 710
$t\bar{t}c\bar{c}$	115 968 ± 19 000	397 302 ± 61 000	5362 ± 840	45 055 ± 6500	2815 ± 830
$t\bar{t}$ LF	1 020 955 ± 22 000	1 547 909 ± 47 000	42 893 ± 990	120 172 ± 4500	2118 ± 230
Other	188 582 ± 17 000	146 711 ± 14 000	5508 ± 630	13 757 ± 1400	1061 ± 120
QCD	73 167 ± 13 000	-	-	-	-
Total	1 431 710 ± 37 000	2 207 222 ± 82 000	59 215 ± 1500	228 235 ± 8900	12 967 ± 1100

Table 1: Number of events in the combined 2017+2018 data and simulation, shown separately for each jet category, with uncertainties obtained from the fitting assuming a nonzero Hct coupling.

Limits

FCNC tHq with $H \to b\bar{b}$ at CMS