SEARCHES FOR RARE TOP QUARK DECAY AND BSM TOP INTERACTIONS

Lucio Cerrito

University and INFN, Roma Tor Vergata

Università di Roma Tor Vergata

INFN

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New Phenomena at the TeV Scale With Top Quarks
NPTEV-TQP2020

on behalf of the ATLAS Collaboration

RARE **FCNC** TOP QUARK DECAYS

Top quark Flavour-Changing Neutral decays in the SM and selected BSM

	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}	$\sim 10^{-6}$

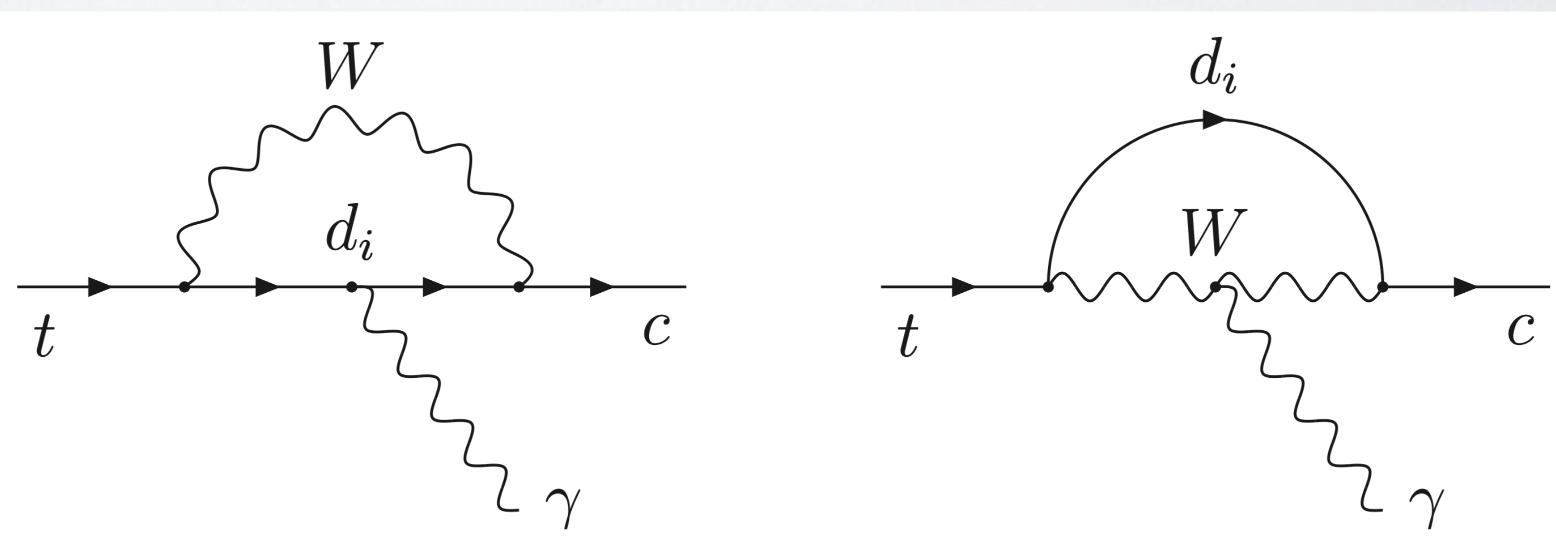
Table 1: Branching ratios for top FCN decays in the SM, models with $Q = 2/3$ quark singlets (QS), a general 2HDM, a flavour-conserving (FC) 2HDM, in the MSSM and with R parity violating SUSY.

[from J. A. Aguilar-Saavedra, Acta Phys.Polon.B 35:2695-2710, 2004
for more recent BSM, particularly 2HDM and tqH see references [10-26] in arxiV:2208.11415 (2022)

PURPLE: discussed in this talk

Relevant to the topic also the talks on EFT analyses on Tuesday

Example: SM diagrams contributing to tcγ vertex



Search for FCNC *tqg*: u+g→t and c+g→t

Rather than looking for t→ug and t→cg in *ttbar* decay, we search for the FCNC production of a single top quark.

NEW Eur. Phys. J. C 82 (2022) 334, July 2022. Follows 2 previous publications, at 7 and 8 TeV.

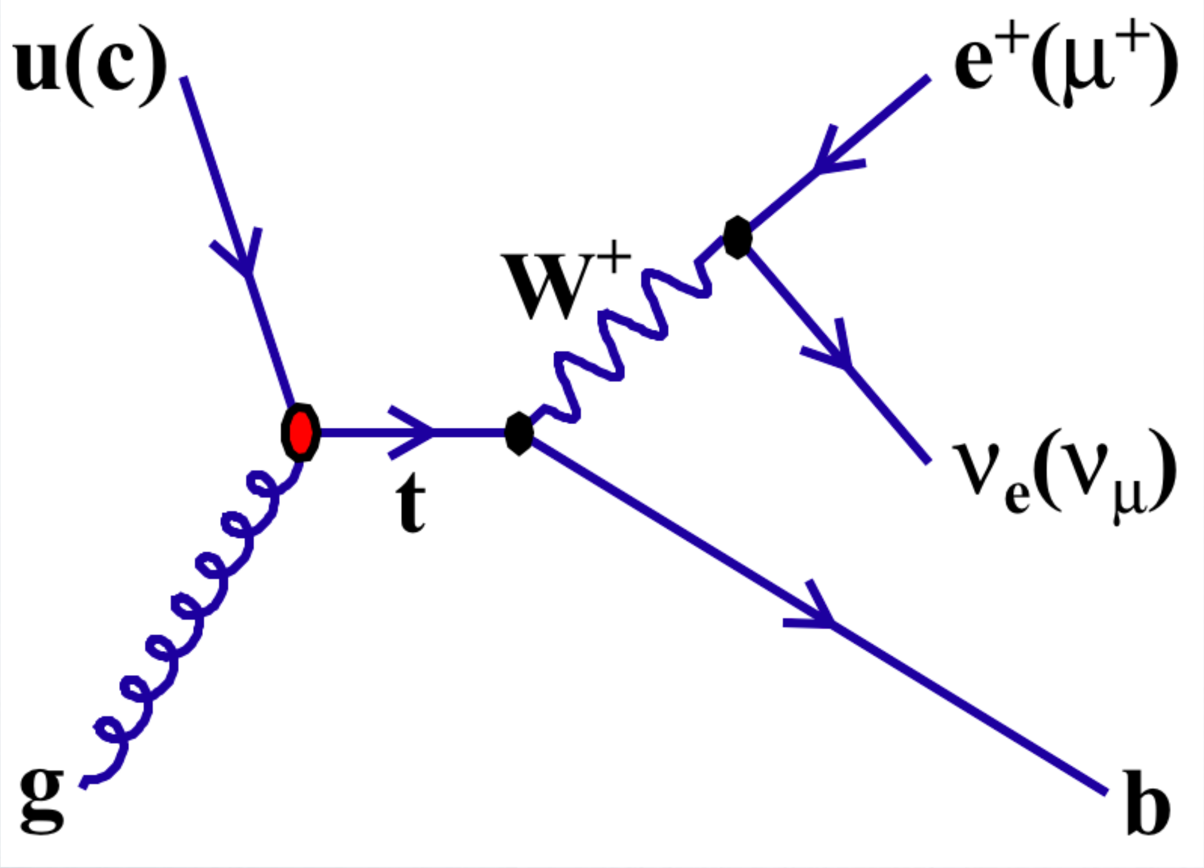
Signature: 1 isolated *e*/μ, 1 b-jet and large MET

Method: Artificial Neural Networks separation of signal and background. Interpretation into B(t→ug) and B(t→cg) with TopFCNC [Degrande]

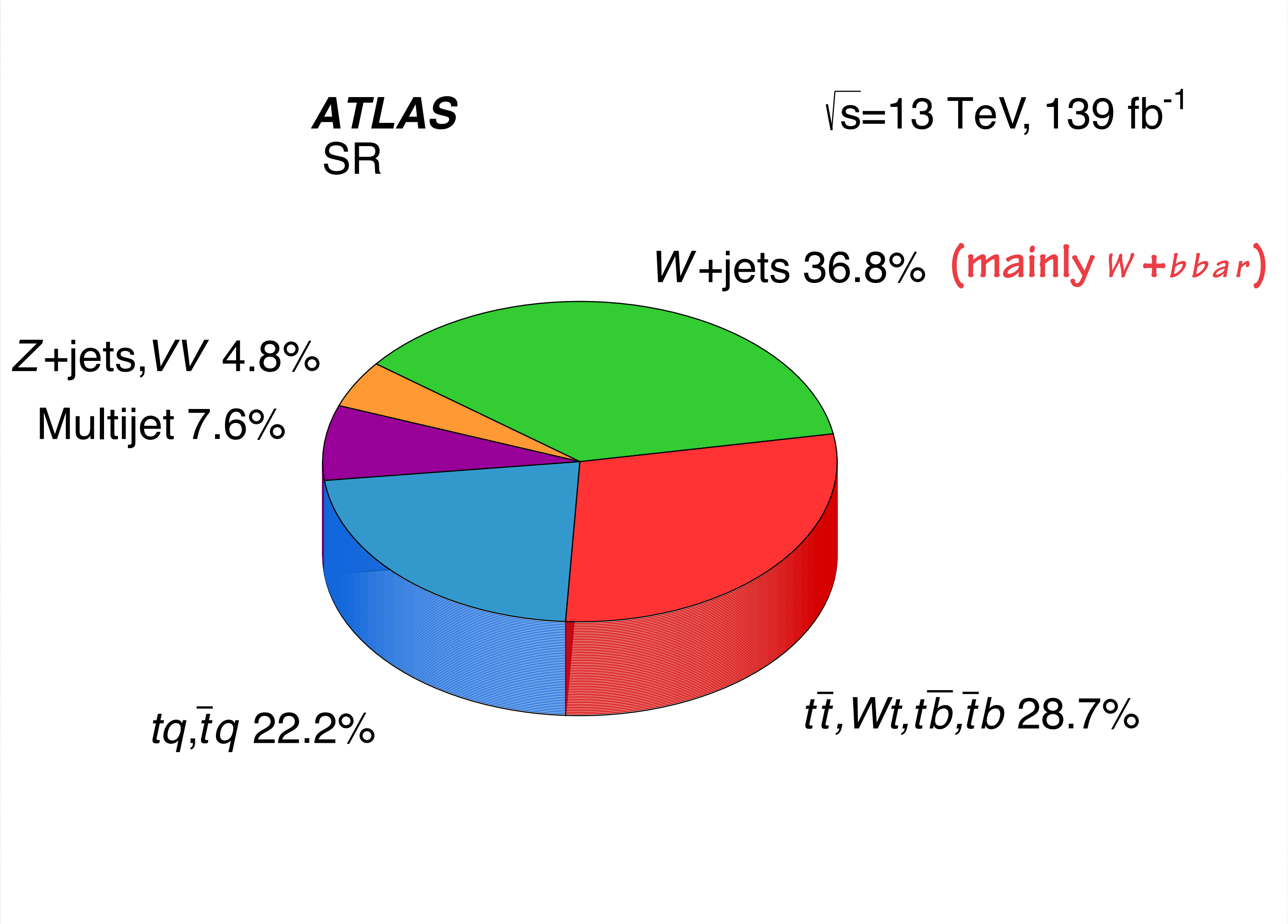
[Degrande: Phys. Rev. D **91** (2015) 034024]

13 TeV, 139 fb^{-1}

LO non-SM production of single top



Background composition of the Signal Region



Search for *tqg*: u+g→t and c+g→t

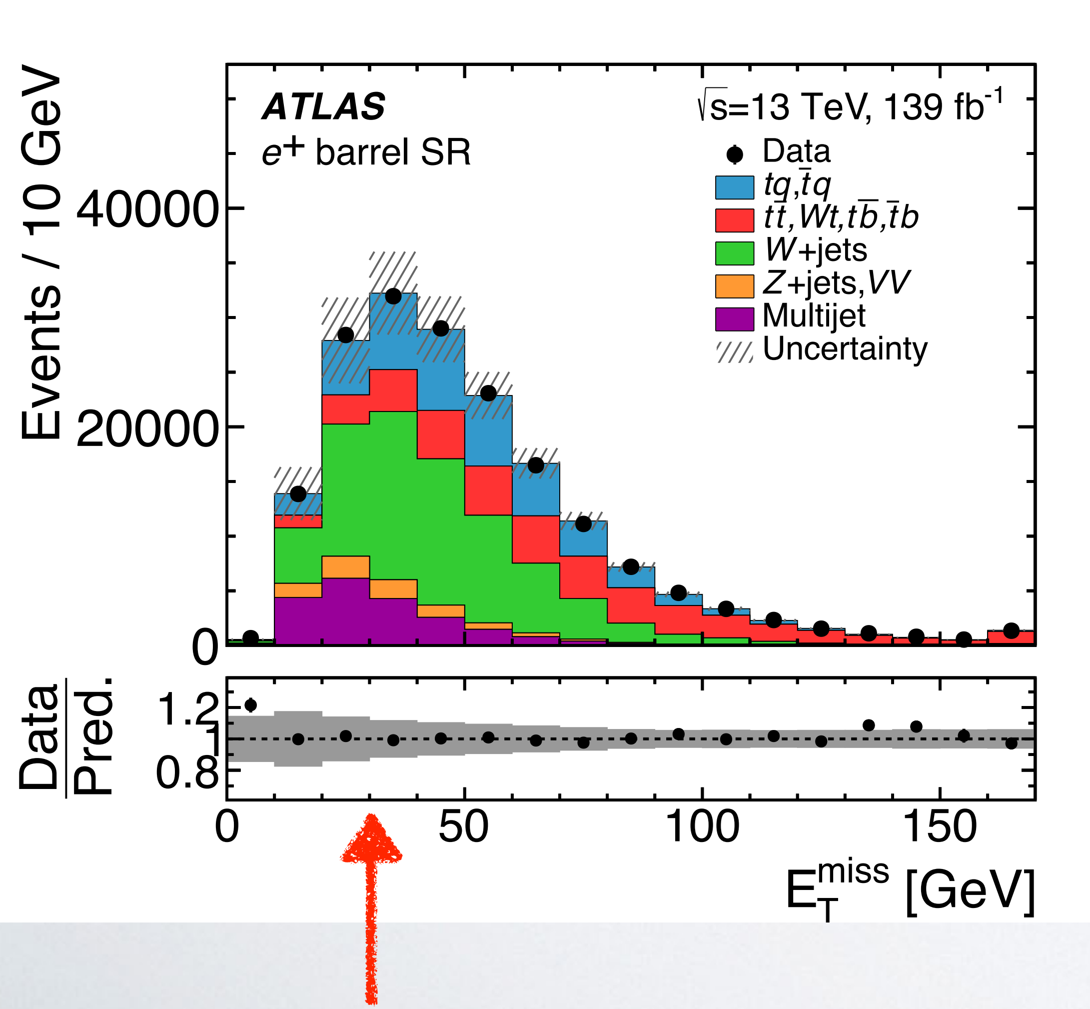
NEW

Eur. Phys. J. C 82 (2022) 334

13 TeV, 139 fb^{-1}

- Initial estimation of backgrounds based on data fit for multijets and simulated events with theoretical cross-sections
- Neural Networks forming discriminants D$_1$ (optimised for sea c-quark) and D$_2$ (optimised for valence u-quark)

Estimation of the multijet background by fitting E_T^{miss}; barrel SR, e$^+$ region.
Initial input to the final statistical analysis



Input variables based on: upper limit sensitivity; modelling quality; ranking in pre-processing with NeuroBayes

Variable	Definition
	Variables common to the D_1 and D_2 NNs
$p_T(b)$	Transverse momentum of the b-tagged jet.
$m(\ell b)$	Invariant mass of the charged lepton (ℓ) and the b-tagged jet (b).
$m_T(W)$	Transverse mass of the reconstructed W boson.
$\Delta R(W,b)$	Distance in the η–ϕ plane between the reconstructed W boson and the b-tagged jet
$\|\Delta\phi(W,b)\|$	Azimuthal angle between the reconstructed W boson and the b-tagged jet.
$m(\ell\nu b)$	Top-quark mass reconstructed from the charged lepton, neutrino, and b-tagged jet.
	Variables used only for the D_1 NN
$\mathrm{sgn}\, q(\ell)$	Sign of the charge of the primary lepton.
$H_T(\ell, b, E_T^{miss})$	Scalar sum of the transverse momenta of all reconstructed objects.
$\eta(W)$	Pseudorapidity of the reconstructed W boson.
$\|\Delta\phi(\ell, \vec{p}_T^{miss})\|$	Azimuthal angle between the charged lepton and $\vec{p}_T^{miss}$.
$\|\Delta\phi(W,\ell)\|$	Azimuthal angle between the reconstructed W boson and the charged lepton.
$p_T(\ell\nu b)$	Transverse momentum of the reconstructed top quark.
	Variables used only for the D_2 NN
$\eta(b)$	Pseudorapidity of the b-tagged jet.
$p_T(W)$	Transverse momentum of the reconstructed W boson.
$\Delta R(\ell\nu b, W)$	Distance in the η–ϕ plane between the reconstructed top quark and W boson.

Search for *tqg*: u+g→t and c+g→t

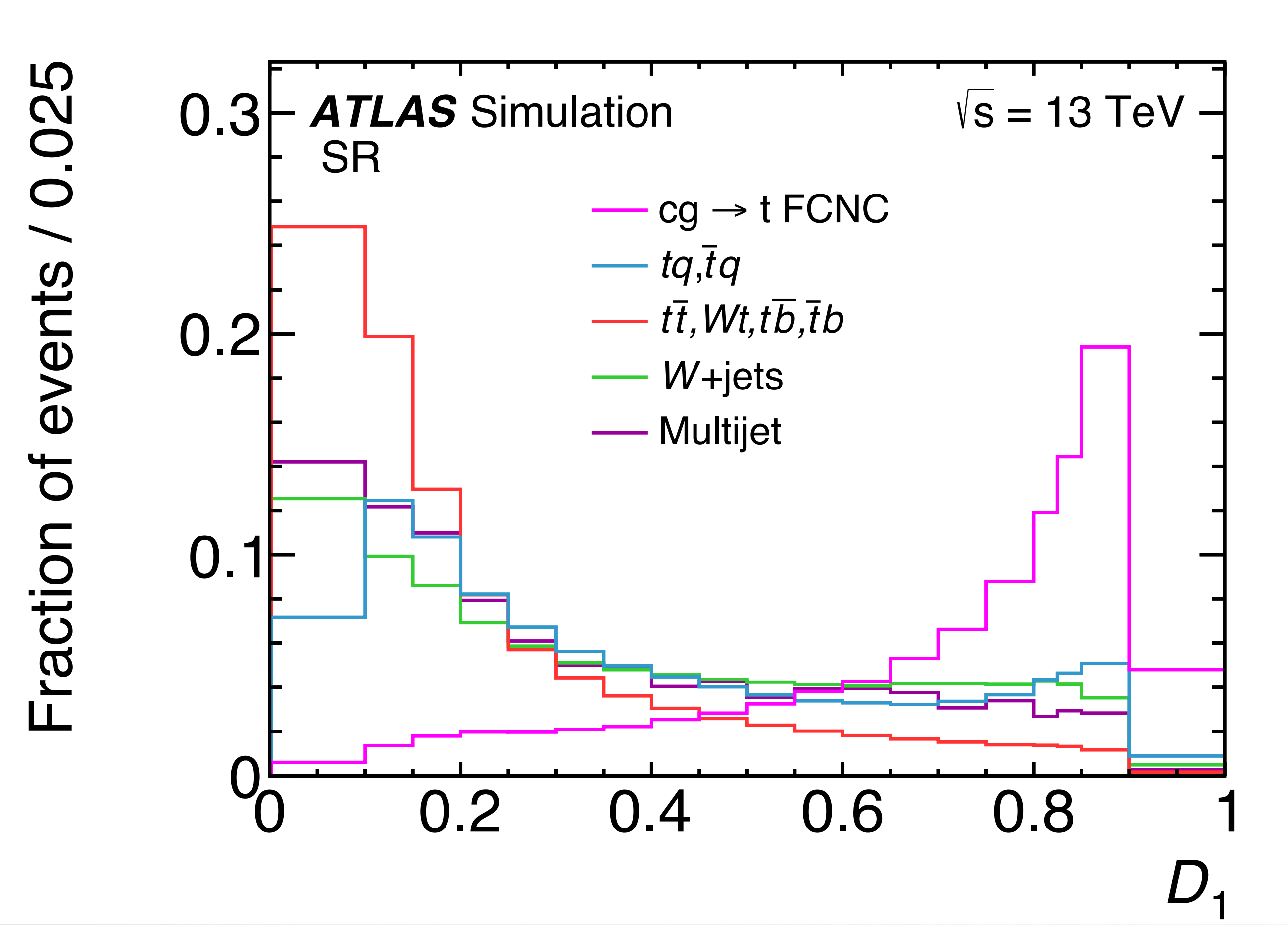
NEW

Eur. Phys. J. C 82 (2022) 334

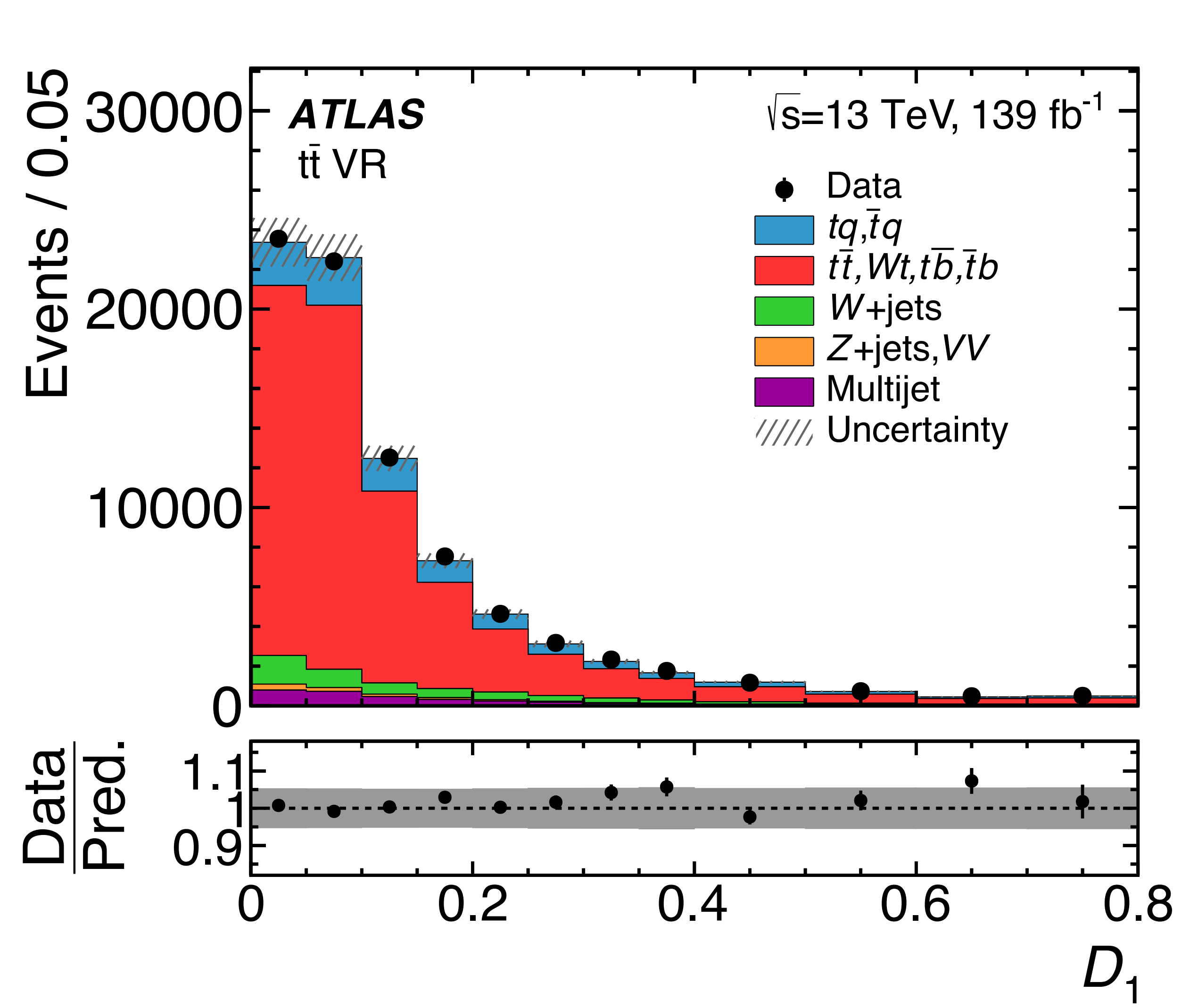
13 TeV, 139 fb^{-1}

- Two separate analyses performed: *ugt* and *cgt*
- Likelihood fit of the NN outputs for signal and *W+j*
- One Signal Region and 3 Validation regions (for modelling of backgrounds) are defined

D_1 discriminant for Signal and Background



Validation Region, ttbar, with D_1 distribution



Search for *tqg*: u+g→t and c+g→t

NEW

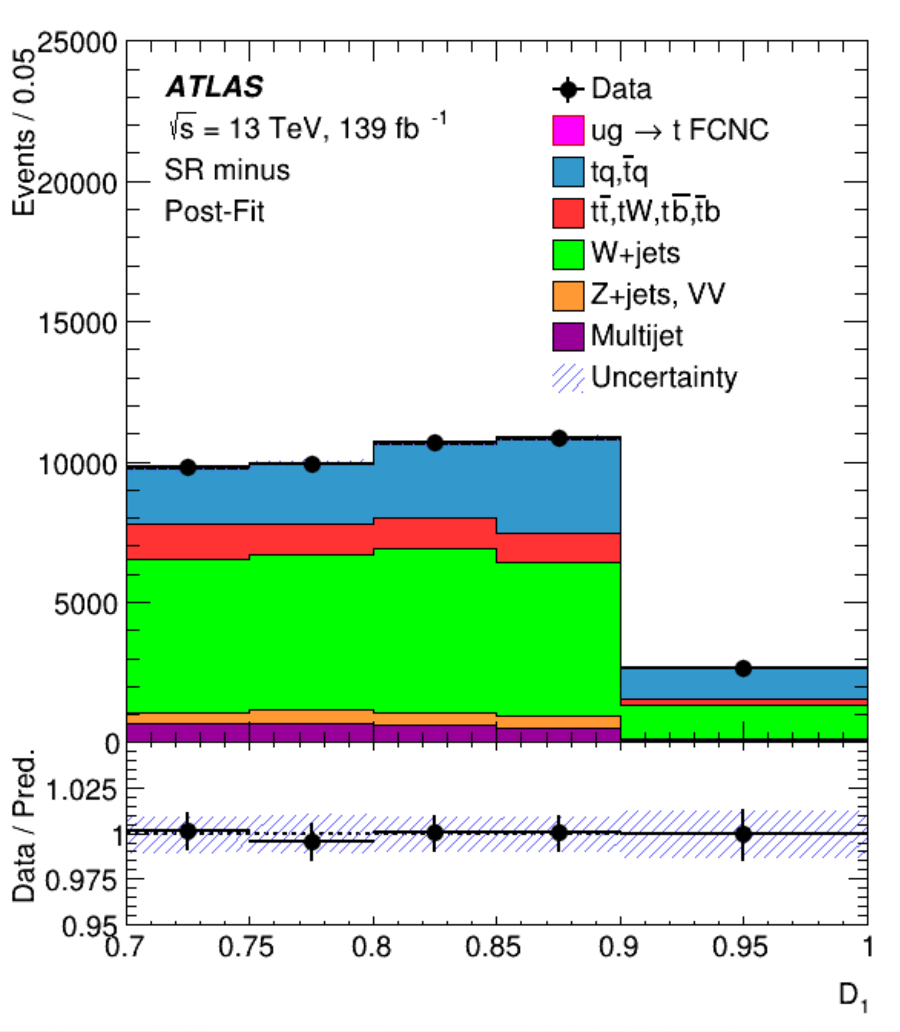
Eur. Phys. J. C 82 (2022) 334

13 TeV, 139 fb^{-1}

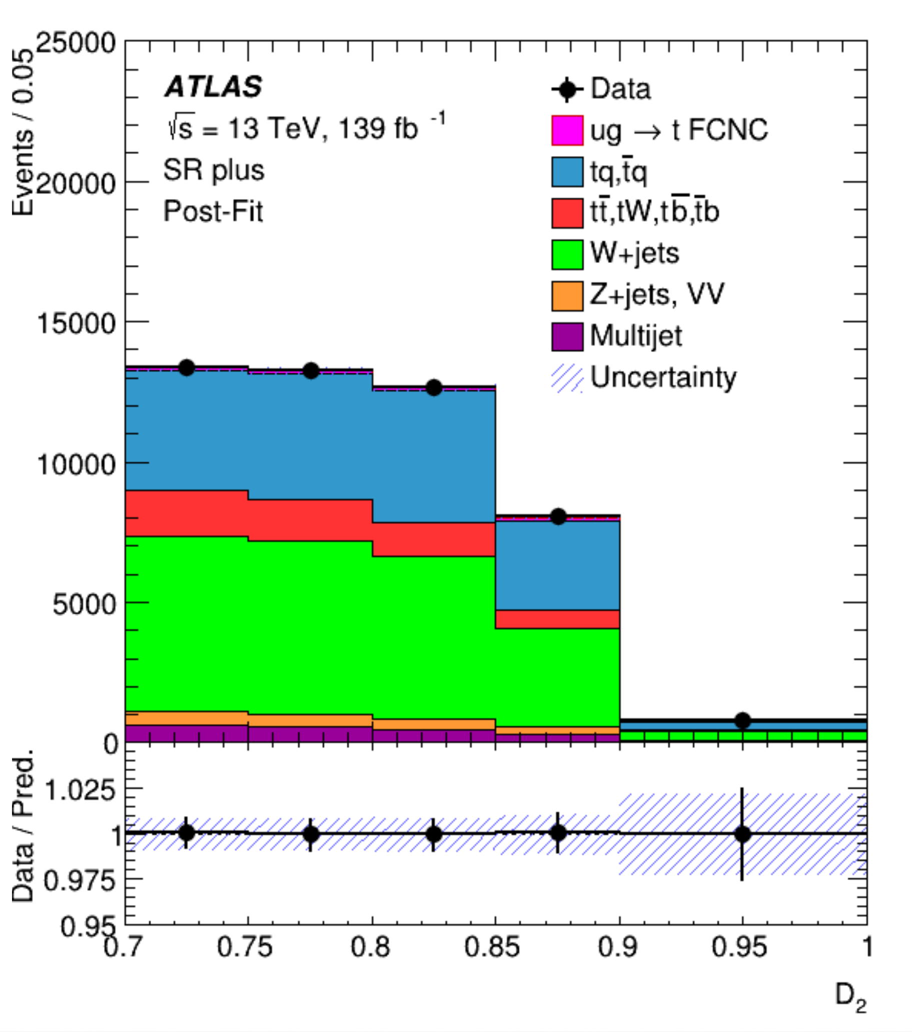
ATLAS EXPERIMENT

- Modelling of the input variables is seen appropriate in Signal and Validation Regions
- Trained NNs are applied also to Validation Regions, using input variables as in the SR
- D_1 is used for the *cgt* search, and both D_1 and D_2 are used for the *ugt* search

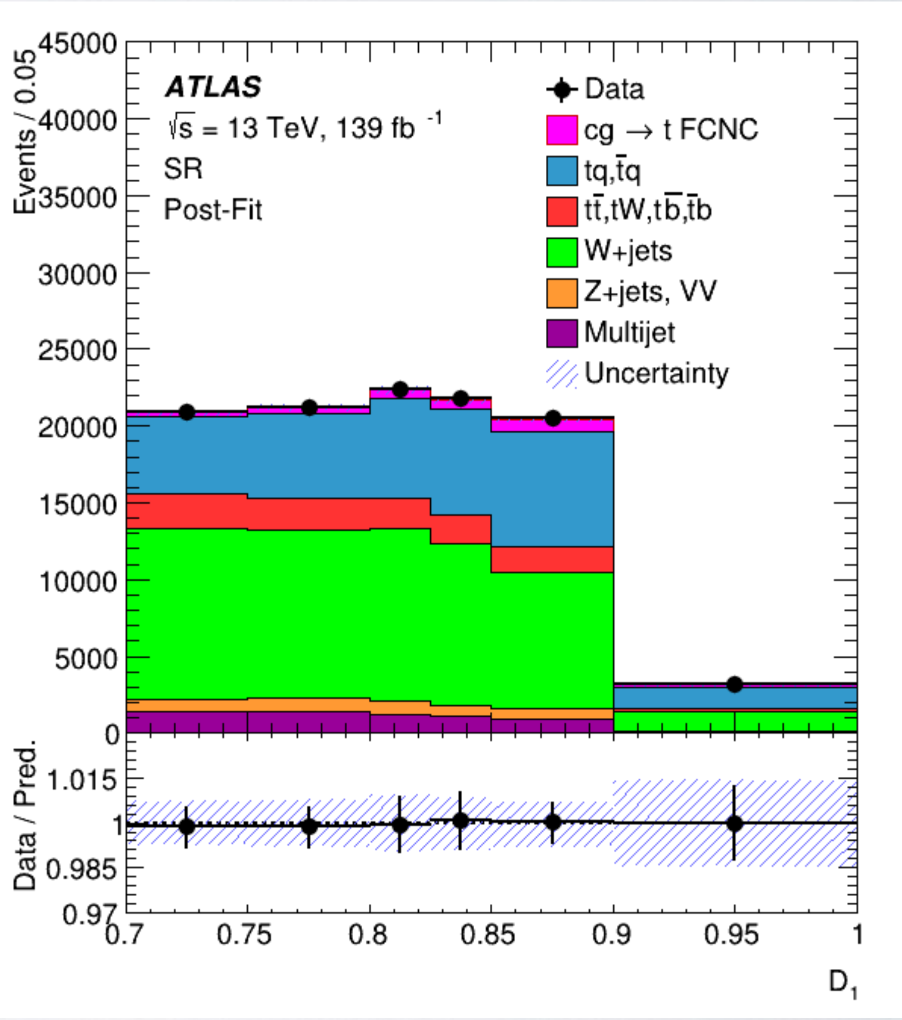
NN D_1 for the ugt search



NN D_2 for the ugt search



NN D_1 for the cgt search



Search for *tqg*: u+g→t and c+g→t

NEW

Eur. Phys. J. C 82 (2022) 334

13 TeV, 139 fb^{-1}

ATLAS EXPERIMENT

- Cross-section upper limits of 3.0 pb and 4.7 pb, respectively, translated via EFT coefficients into Branching Ratios; improvement x2 over 8 TeV mainly from larger dataset.
- Observed limits slightly higher (worse) than expected

Results, upper limits on BR:

$$\mathcal{B}(t \to u + g) < 0.61 \times 10^{-4}$$

$$\mathcal{B}(t \to c + g) < 3.7 \times 10^{-4}$$

Post-fit event yields

Process	Pre-fit	Post-fit cgt	Post-fit ugt
ugt FCNC process	0	0	1200 ± 2100
cgt FCNC process	0	4100 ± 4500	0
tq	138 600 ± 9300	149 200 ± 9400	150 000 ± 10 000
$t\bar{t}$, tW, $t\bar{b}$	179 000 ± 17 000	179 000 ± 14 000	175 200 ± 9700
W+jets	229 000 ± 30 000	281 000 ± 21 000	292 000 ± 18 000
Z+jets, VV	29 700 ± 6000	30 000 ± 6000	29 800 ± 6000
Multijet	47 000 ± 14 000	45 000 ± 14 000	40 000 ± 12 000
Total	650 000 ± 46 000	688 600 ± 2400	688 700 ± 3500
Observed	688 380	688 380	688 380

- Impact of systematic uncertainties much larger than data statistics, led by MC modelling of W+jets, W+c and Parton Shower uncertainties

Expected upper-limits

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}

Search for FCNC *tqγ*: u/c→t+γ and t→u/c+γ

Optimised Neural-Network search in both the *single-top* production mode and the *ttbar* decay mode

NEW

Accepted by PLB, arxiv: 2205.02537 (May 2022)

Supercedes a previous publication on the production-only mode w. 81 fb^{-1}

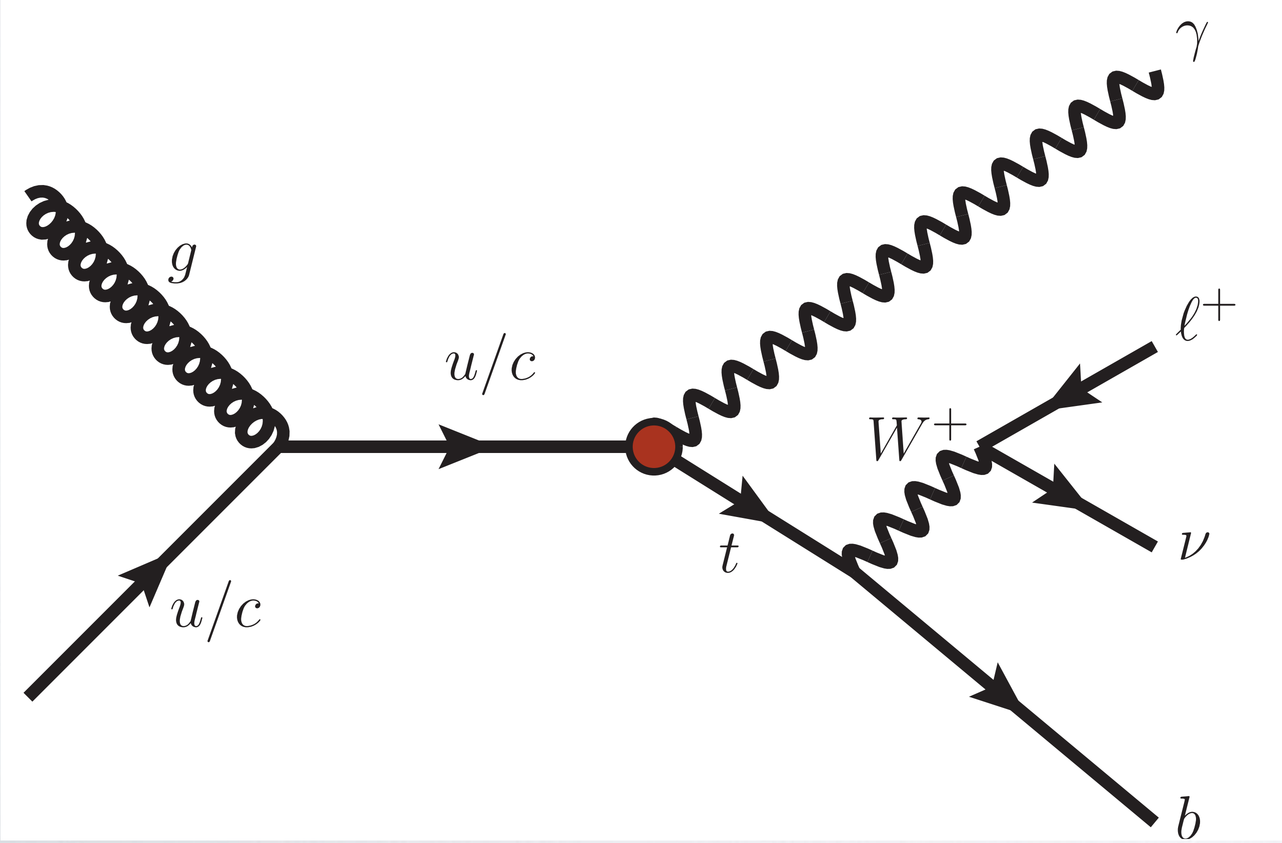
13 TeV, 139 fb^{-1}

Signature: 1 high-p_T γ, 1 e/*μ*, 1 b-jet, and large MET (+ add.nal jets)

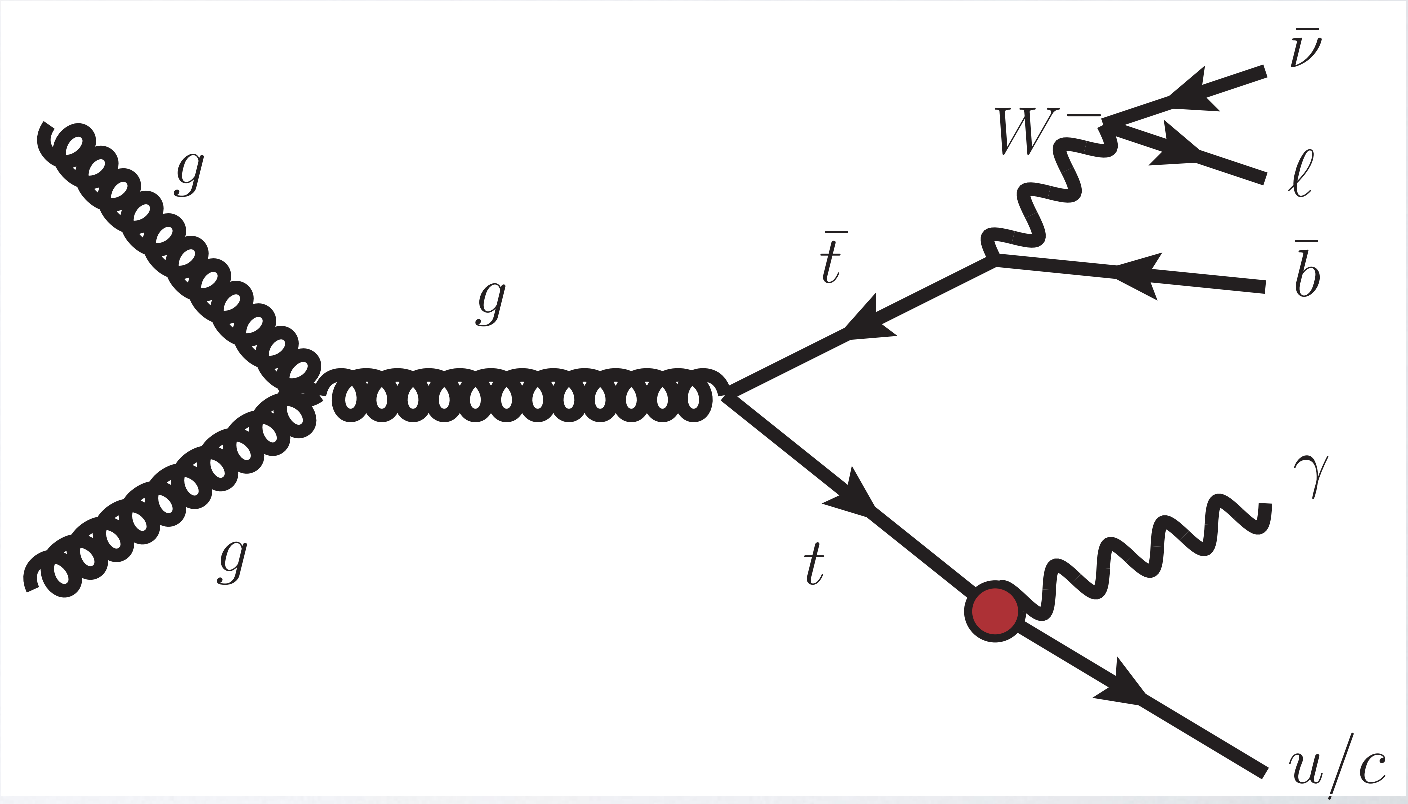
Method: Neural Networks classifier with 3 output nodes (2 Signal + 1 Background) combined into a one-dimensional classifier of S versus B.

Binned profile likelihood fit of the classifier; separate training for *tuγ* and *tcγ* vertex events.

Tree-level diagram for FCNC (tqγ) single-top production (LH or RH couplings)



Tree-level diagram for FCNC (tqγ) tt decay



Search for $tq\gamma$: u/c→t+γ and t→u/c+γ

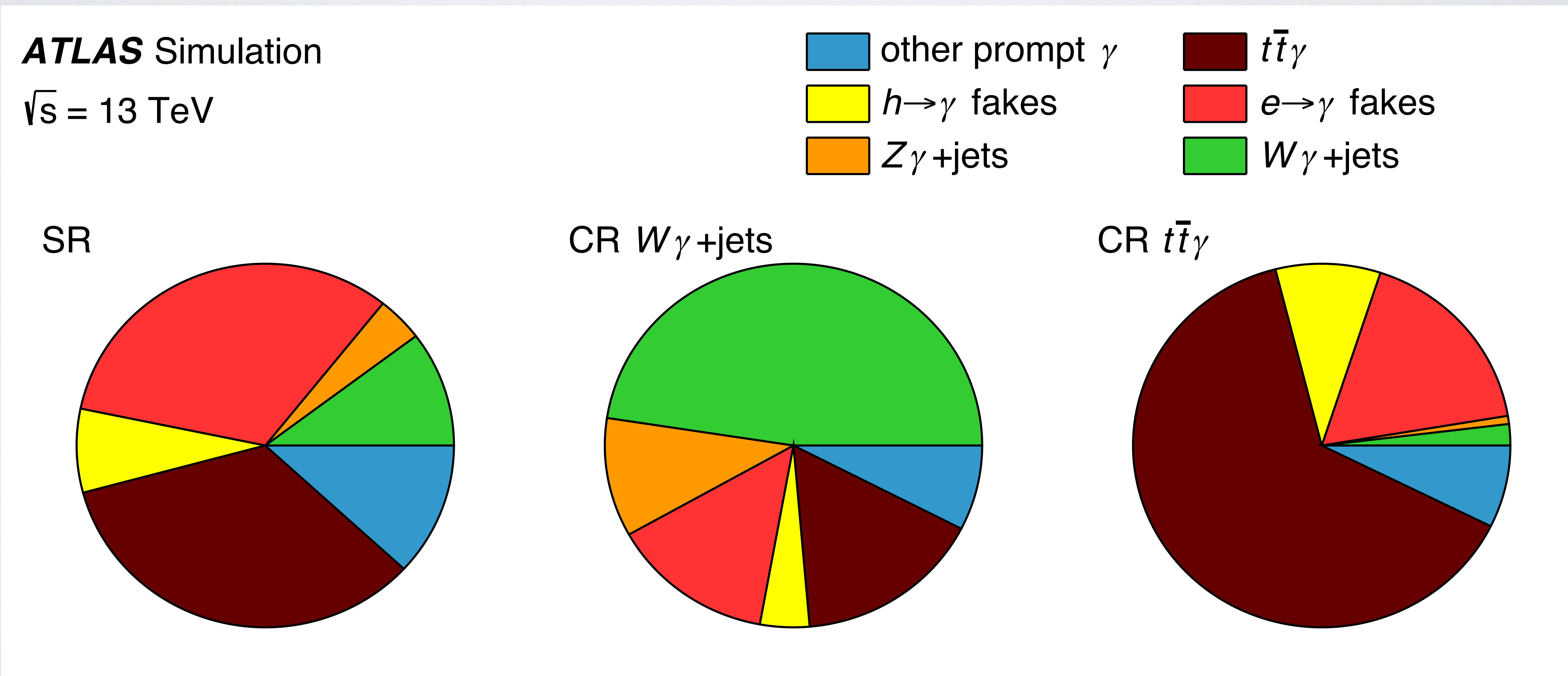
NEW

arxiv: 2205.02537 (2022)

13 TeV, 139 fb^{-1}

- LH and RH couplings in production and LH in decay (similar RH) are simulated as Signal
- Decay diagram dominant for the $tc\gamma$ coupling. Similar contribution from production and decay diagrams for the $tu\gamma$ coupling
- Data-driven estimate of probability $f_{e\rightarrow\gamma}$ for e→γ fakes

Expected composition of Signal Region and Control Regions



Search for $tq\gamma$: u/c→t+γ and t→u/c+γ

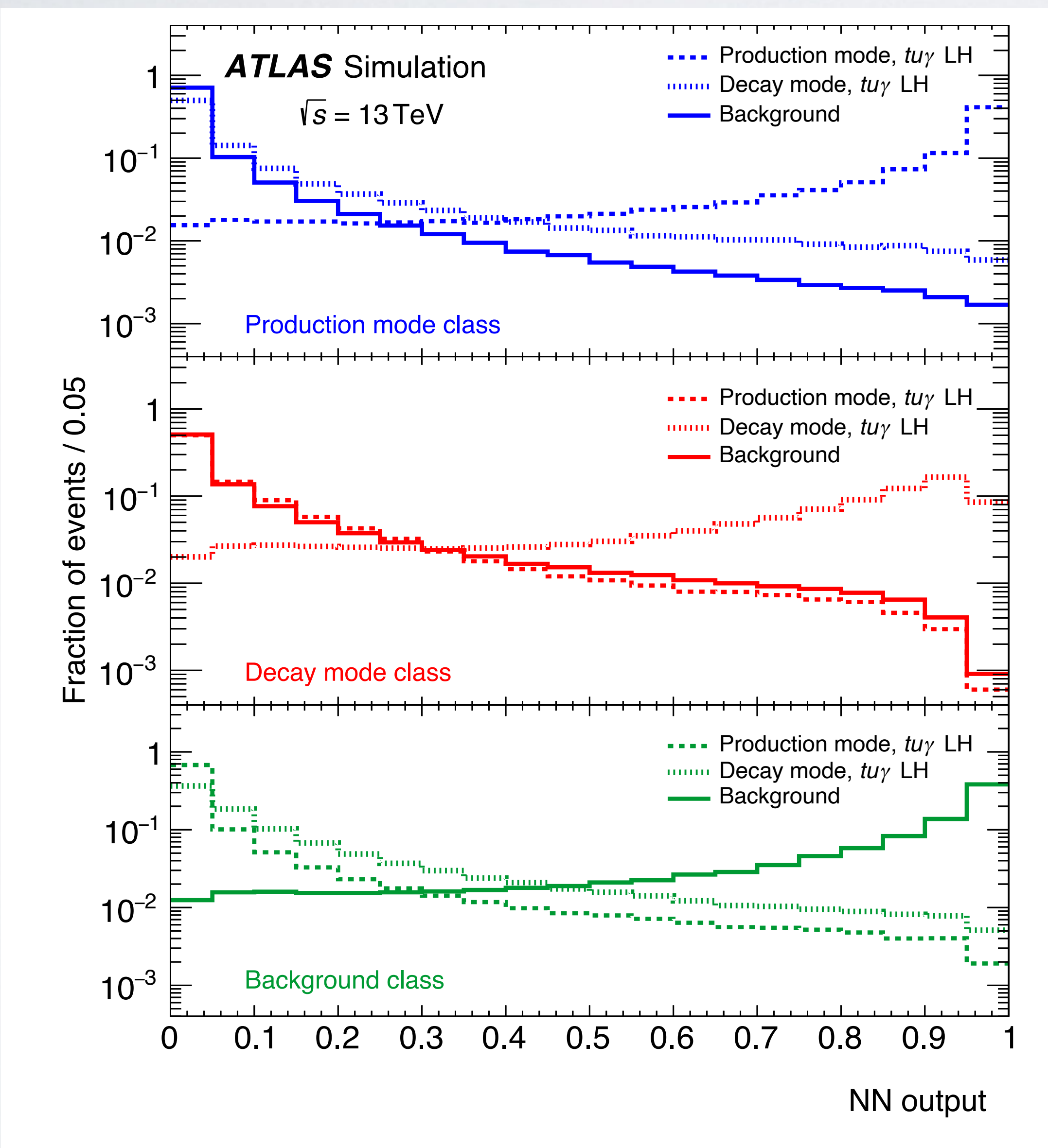
NEW

arxiv: 2205.02537 (2022)

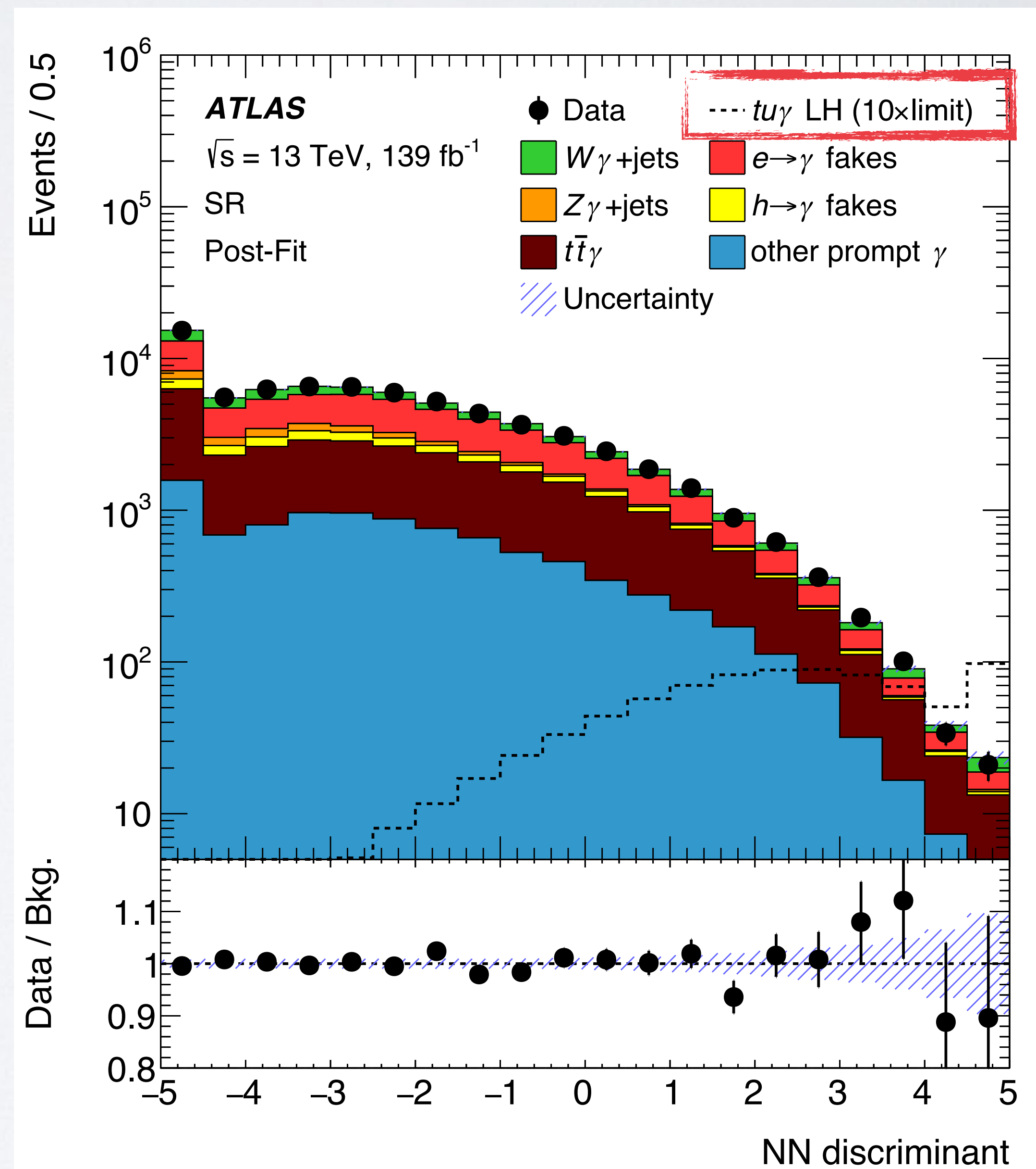
13 TeV, 139 fb^{-1}

- 37 variables as input, 6 hidden layers, optimised on S:B separation using expected limit without systematic uncertainties.
- 3 output nodes for the 3 classes: FCNC production, decay, and SM background.
- Forming a one-dimensional unbound NN discriminant

Classifier Output of the multiclass NN for *tuγ* LH coupling



Post-fit distribution of the background-only fit to the NN discriminant in the SR



Search for $tq\gamma$: u/c→t+γ and t→u/c+γ

NEW

arxiv: 2205.02537 (2022)

13 TeV, 139 fb^{-1}

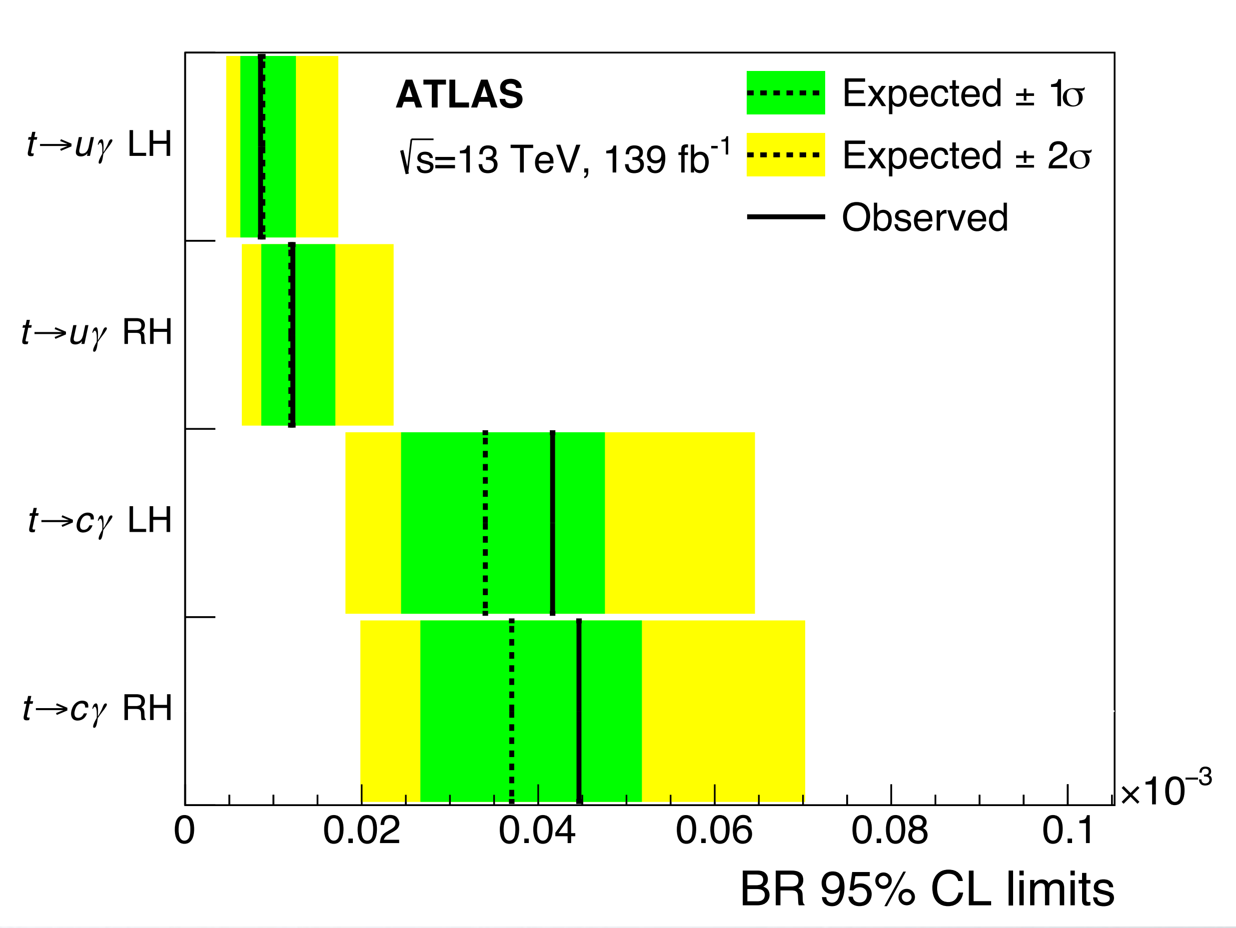
- The dominant source of uncertainty for the $tu\gamma$ couplings is the statistical uncertainty. All systematic uncertainties worsen the limit by only about 20%.
- For the $tc\gamma$ couplings, the effect of the systematic uncertainties worsens the limit by about 40%, so the statistical uncertainties also play an important role.
- For the $tc\gamma$ coupling, the dominant syst. uncertainty is the cross-section of SM associated $tq\gamma$

95% C.L. limits on effective coupling constants and BRs.

Effective coupling	Coefficient limits Expected	Coefficient limits Observed	Coupling	BR limits $[10^{-5}]$ Expected	BR limits $[10^{-5}]$ Observed
$\lvert C_{uW}^{(13)*} + C_{uB}^{(13)*}\rvert$	$0.104^{+0.020}_{-0.016}$	0.103	$t \to u\gamma$ LH	$0.88^{+0.37}_{-0.25}$	0.85
$\lvert C_{uW}^{(31)} + C_{uB}^{(31)}\rvert$	$0.122^{+0.023}_{-0.018}$	0.123	$t \to u\gamma$ RH	$1.20^{+0.50}_{-0.33}$	1.22
$\lvert C_{uW}^{(23)*} + C_{uB}^{(23)*}\rvert$	$0.205^{+0.037}_{-0.031}$	0.227	$t \to c\gamma$ LH	$3.40^{+1.35}_{-0.95}$	4.16
$\lvert C_{uW}^{(32)} + C_{uB}^{(32)}\rvert$	$0.214^{+0.039}_{-0.032}$	0.235	$t \to c\gamma$ RH	$3.70^{+1.47}_{-1.03}$	4.46

- The obtained limits are the most stringent to date and improve on the previous ATLAS limits by factors of 3.3 to 5.4.
- Improvement owed to larger dataset, events with more than 1 jet, and improved S:B

Observed and expected 95% C.L. limits on the BRs



Search for FCNC *tqH*: u/c→t+H and t→u/c+H

- Targets H→ττ in both tt→WbHq and production pp→tH modes
- Improved treatment of mis-ID τ and multi-jets. Boosted decision trees MVA to separate Signal and Background

NEW

arXiv: 2208.11415 (2022) submitted to JEHP

Follows **5** previous publications, at 7, 8 and 13 TeV (36 fb^{-1})

13 TeV, 139 fb^{-1}

Signature: Four types: $t_h\, \tau_{lep}\, \tau_{had}$ / $t_{lep}\, \tau_{had}\, \tau_{had}$ / $t_{lep}\, \tau_{had}$ / $t_h\, \tau_{had}\, \tau_{had}$ devided into **7** Signal Regions based on the number of light leptons, τ_{had} candidates and number of light-flavoured jets

Method: Boosted Decision Trees MVA to separate Signal and Background combined into a one-dimensional classifier of S versus B.

Summary of Preselection Requirements

Requirement	Leptonic channels			Hadronic channel
	$t_h\tau_{\text{lep}}\tau_{\text{had}}$	$t_\ell\tau_{\text{had}}\tau_{\text{had}}$	$t_\ell\tau_{\text{had}}$	$t_h\tau_{\text{had}}\tau_{\text{had}}$
Trigger	single-lepton trigger			di-τ trigger
Leptons	=1 isolated e or μ			=0 isolated e or μ
τ_{had}	=1 τ_{had}	=2 τ_{had}	=1 τ_{had}	=2 τ_{had}
Electric charge (Q)	$Q_\ell \times Q_{\tau_{\text{had1}}} = -1$	$Q_{\tau_{\text{had1}}} \times Q_{\tau_{\text{had2}}} = -1$	$Q_\ell \times Q_{\tau_{\text{had1}}} = 1$	$Q_{\tau_{\text{had1}}} \times Q_{\tau_{\text{had2}}} = -1$
Jets	$\geq$3 jets	$\geq$1 jets	$\geq$2 jets	$\geq$3 jets
b-tagging	=1 b-jets			=1 b-jets

Search for *tqH*: u/c→t+H and t→u/c+H

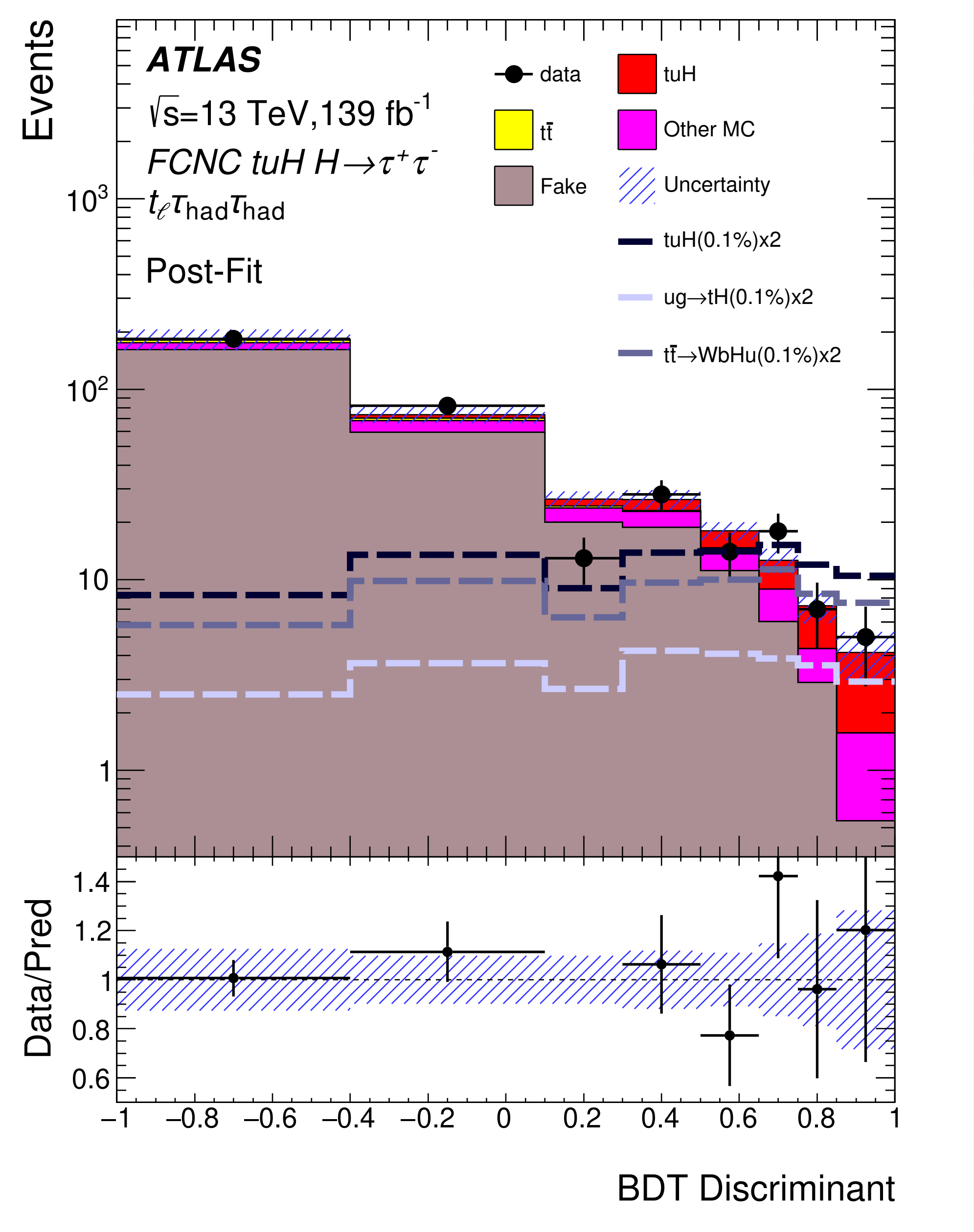
NEW

arXiv: 2208.11415 (2022)

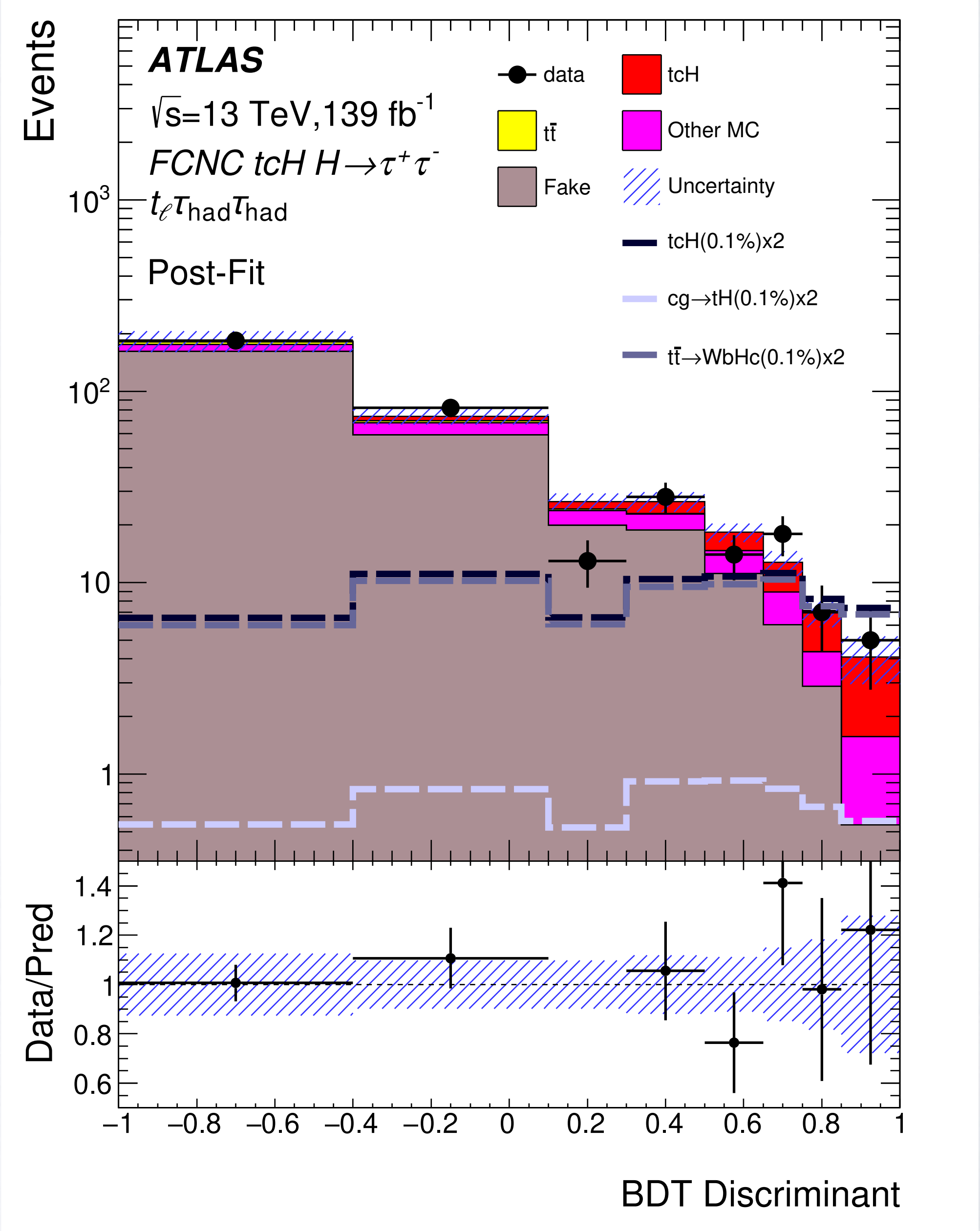
13 TeV, 139 fb^{-1}

- 9 BDT outputs fitted for *tuH* and 9 for *tcH* (7 SR +2 VR)
- Joined binned-likelihood function for signal extraction

BDT output distribution obtained from a signal+background fit to the data for the ***tuH*** search (most sensitive channel)



BDT output distribution obtained from a signal+background fit to the data for the ***tcH*** search (most sensitive channel)



Search for *tqH*: u/c→t+H and t→u/c+H

NEW

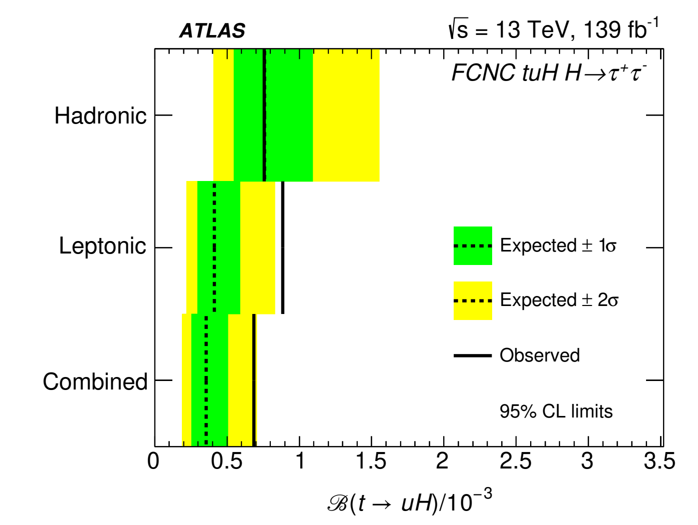
arXiv: 2208.11415 (2022)

13 TeV, 139 fb^{-1}

ATLAS EXPERIMENT

- Upper limits are derived using the CLs method and observed (expected) limits are set on B(t → cH) assuming B(t → uH) = 0 and vice-versa
- Measurement limited by stat. uncertainties, while MC statistics, τ ID and fake are the main systematic uncertainties
- The expected sensitivity has been improved upon the previous ATLAS result by x5 (2 from the dataset, 2.5 from tH production, additional lept. channels and improved techniques)
- A slight excess of data is observed above background, with a significance of 2.3σ

Results, upper limits on BR:



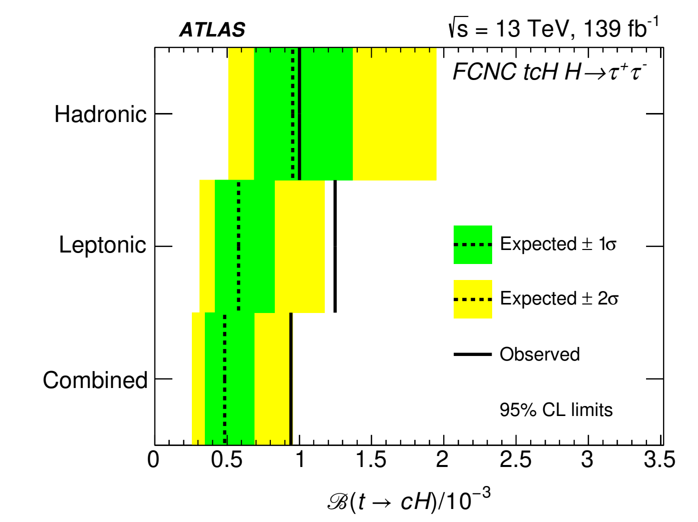


Table 1: Summary of 95% CL upper limits on $\mathcal{B}(t \to cH)$ and $\mathcal{B}(t \to uH)$, significance and best-fit branching ratio in the signal regions with a benchmark branching ratio of $\mathcal{B}(t \to qH) = 0.1\%$. The expected significance is obtained from an Asimov fit with a signal injection corresponding to a branching ratio of 0.1%.

	$t \to cH$			$t \to uH$		
Signal Region	95% CL upper limit [10^{-3}] Observed (Expected)	Significance	$\mathcal{B}$ [10^{-3}]	95% CL upper limit [10^{-3}] Observed (Expected)	Significance	$\mathcal{B}$ [10^{-3}]
$t_h\tau_{\rm had}\tau_{\rm had}$-2j	$1.80\,(2.72^{+1.18}_{-0.76})$	−0.96 (0.78)	$-1.03^{+1.03}_{-1.03}$	$1.07\,(1.60^{+0.71}_{-0.45})$	−0.90 (1.31)	$-0.55^{+0.58}_{-0.58}$
$t_h\tau_{\rm had}\tau_{\rm had}$-3j	$1.14\,(1.02^{+0.45}_{-0.29})$	0.34 (1.87)	$0.16^{+0.47}_{-0.47}$	$0.97\,(0.86^{+0.38}_{-0.24})$	0.36 (2.25)	$0.14^{+0.40}_{-0.40}$
Hadronic combination	$1.00\,(0.95^{+0.42}_{-0.27})$	0.26 (1.99)	$0.11^{+0.43}_{-0.43}$	$0.76\,(0.76^{+0.33}_{-0.21})$	0.12 (2.52)	$0.04^{+0.34}_{-0.34}$
$t_\ell\tau_{\rm had}$-2j	$4.77\,(4.23^{+1.72}_{-1.18})$	0.41 (0.47)	$0.85^{+2.06}_{-2.06}$	$3.84\,(3.48^{+1.42}_{-0.97})$	0.36 (0.58)	$0.61^{+1.68}_{-1.68}$
$t_\ell\tau_{\rm had}$-1j	$3.80\,(3.56^{+1.51}_{-0.99})$	0.22 (0.58)	$0.36^{+1.70}_{-1.70}$	$2.98\,(2.78^{+1.17}_{-0.78})$	0.22 (0.73)	$0.29^{+1.33}_{-1.33}$
$t_h\tau_{\rm lep}\tau_{\rm had}$-2j	$4.71\,(5.71^{+2.68}_{-1.60})$	−0.52 (0.38)	$-1.36^{+2.56}_{-2.56}$	$2.50\,(2.97^{+1.25}_{-0.83})$	−0.47 (0.70)	$-0.66^{+1.38}_{-1.38}$
$t_h\tau_{\rm lep}\tau_{\rm had}$-3j	$2.71\,(2.71^{+1.25}_{-0.76})$	−0.03 (0.77)	$-0.03^{+1.26}_{-1.26}$	$2.02\,(2.03^{+0.86}_{-0.57})$	−0.05 (0.99)	$-0.03^{+0.98}_{-0.98}$
$t_\ell\tau_{\rm had}\tau_{\rm had}$	$1.35\,(0.61^{+0.27}_{-0.17})$	2.64 (3.31)	$0.74^{+0.33}_{-0.33}$	$0.97\,(0.44^{+0.19}_{-0.12})$	2.64 (4.38)	$0.53^{+0.24}_{-0.24}$
Leptonic combination	$1.25\,(0.58^{+0.25}_{-0.16})$	2.61 (3.46)	$0.69^{+0.31}_{-0.31}$	$0.88\,(0.41^{+0.18}_{-0.11})$	2.60 (4.62)	$0.49^{+0.22}_{-0.22}$
Combination	$0.94\,(0.48^{+0.20}_{-0.14})$	2.34 (4.02)	$0.51^{+0.24}_{-0.24}$	$0.69\,(0.35^{+0.15}_{-0.10})$	2.31 (5.18)	$0.37^{+0.18}_{-0.18}$

Search for FCNC *tqZ*: u/c→t+Z and t→u/c+Z

- Single-top production most sensitive to *tZu*, while ttbar decay equally sensitive to *tZu* and *tZc*
- Trileptonic final state

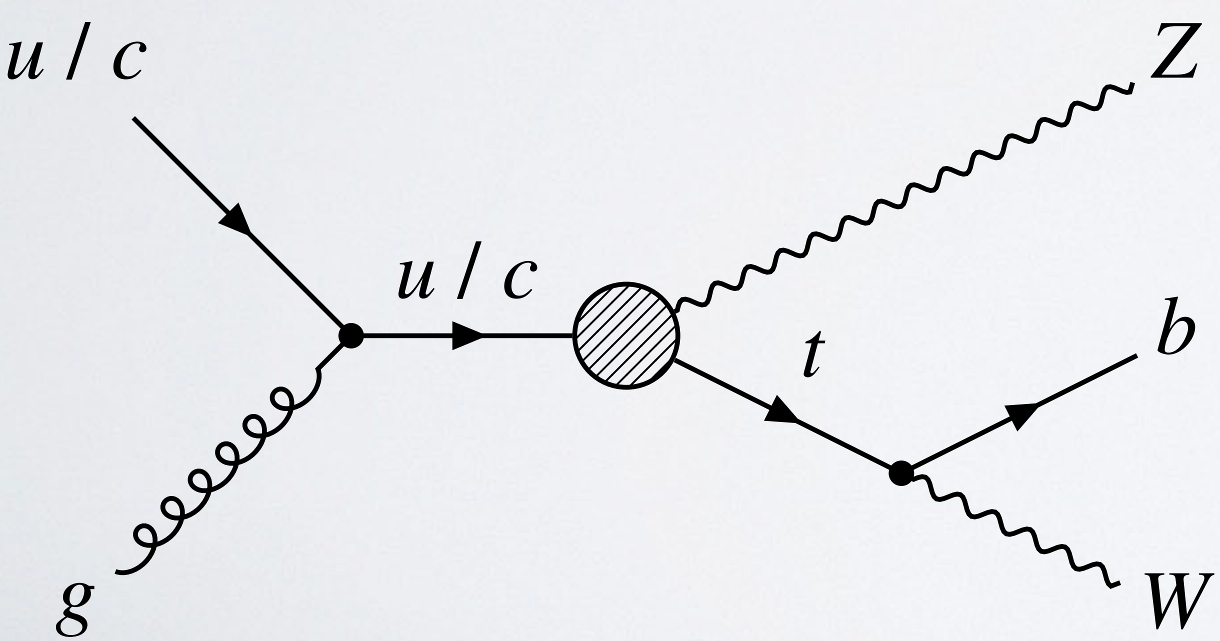
ATLAS-CONF-2021-049 (2021)
To be submitted to journal. Follows a previous publications, at 13 TeV (36 fb^{-1}).

13 TeV, 139 fb^{-1}

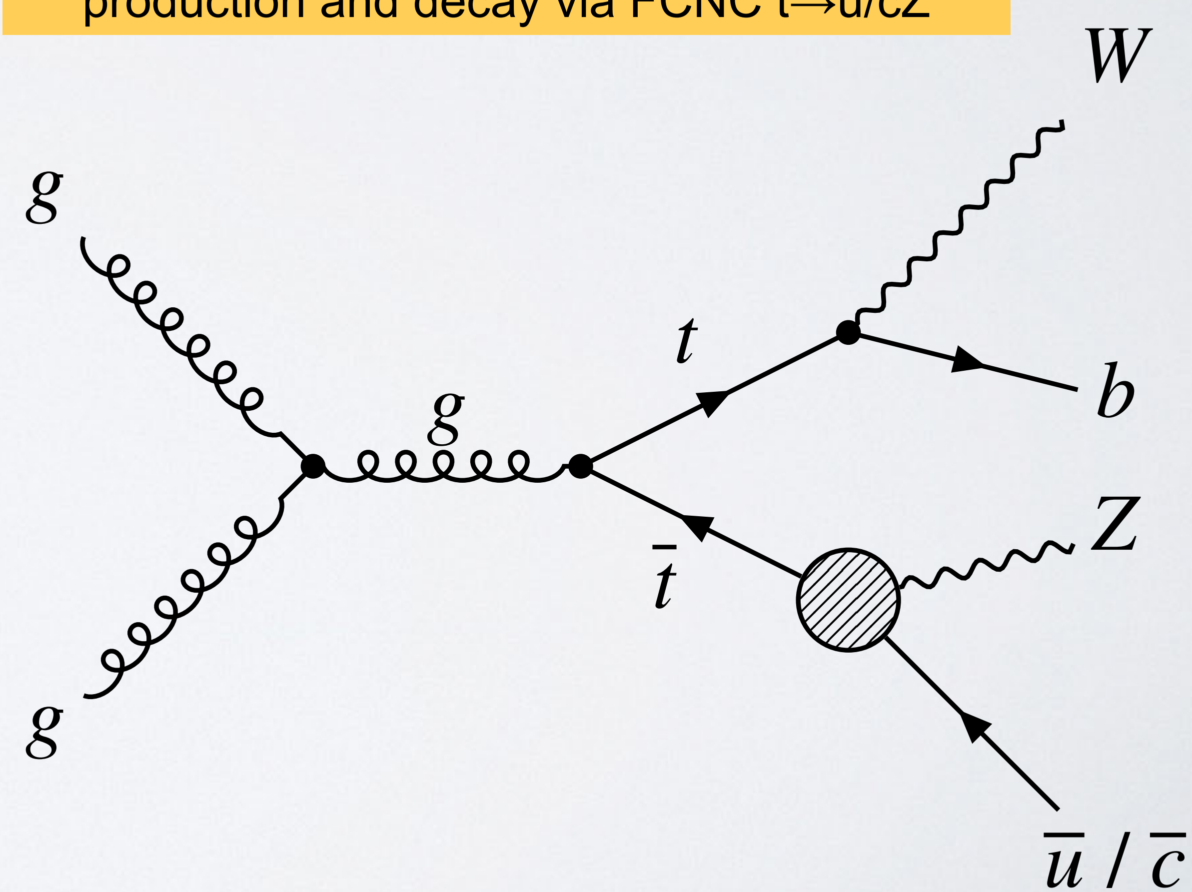
Signature: 3 leptons (e/μ), 2 jets (1 b-jet), and large MET || For single top: 3 leptons (e/μ), <= 2 jets (1 b-jet), and large MET. **Two** Signal Regions defined.

Method: Gradient Boosted Decision Trees MVA to separate Signal and Background, trained with separate LH and RH signal. **Three** one-dimensional classifiers of S versus B.

Lowest-order Feynman diagram for single-top production via FCNC in the s-channel



Lowest-order Feynman diagram for tt production and decay via FCNC t→u/cZ



Search for *tqZ*: u/c→t+Z and t→u/c+Z

ATLAS-CONF-2021-049 (2021)

13 TeV, 139 fb^{-1}

ATLAS EXPERIMENT

- Two classes of backgrounds: 3 leptons, and 2 leptons + non-prompt or fake lepton
- Four Control Regions

Definition of Signal Regions 1 and 2

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

Definition of Control Regions

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

Search for *tqZ*: u/c→t+Z and t→u/c+Z

ATLAS-CONF-2021-049 (2021)

13 TeV, 139 fb^{-1}

- Backgrounds from theory are fit-adjusted and checked in Control Regions and in 2 Validation Regions
- Limits on each FCNC *tZq* branching ratio are computed with the CL_S method

Predicted and observed yields in the two SRs considered in the fit (post-fit)

	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

Search for *tqZ*: u/c→t+Z and t→u/c+Z

ATLAS-CONF-2021-049 (2021)

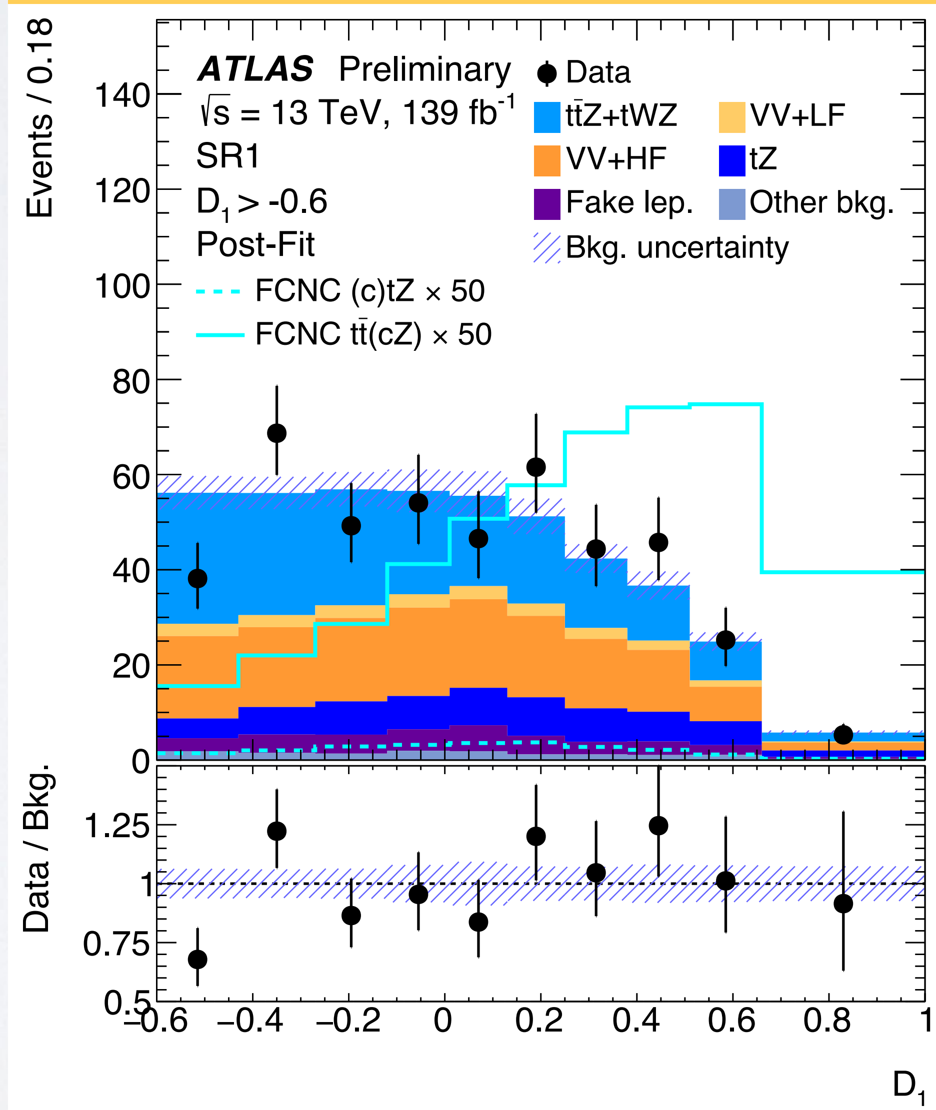
13 TeV, 139 fb^{-1}

- 20—25% impact on the limits from systematic uncertainties, mainly from VV+heavy-flavour
- These results improve by a factor of 3 (2) the previous observed limits on $t \to Zu$ ($t \to Zc$) and by a factor of 5 (3) the previous expected limits.
- Improvement from larger dataset, FCNC production mode, and MVA usage

Observed and expected 95% CL limits on the FCNC t→Zq branching ratios and the effective coupling strengths for different vertices and couplings (bottom eight rows).

Observable	Vertex	Coupling	Observed	Expected
SR1+CRs				
$\mathcal{B}(t \to Zq)$ $[10^{-5}]$	tZu	LH	9.7	$8.6^{+3.6}_{-2.4}$
$\mathcal{B}(t \to Zq)$ $[10^{-5}]$	tZu	RH	9.5	$8.2^{+3.4}_{-2.3}$
SR2+CRs				
$\mathcal{B}(t \to Zq)$ $[10^{-5}]$	tZu	LH	7.8	$6.1^{+2.7}_{-1.7}$
$\mathcal{B}(t \to Zq)$ $[10^{-5}]$	tZu	RH	9.0	$6.6^{+2.9}_{-1.8}$
SRs+CRs				
$\mathcal{B}(t \to Zq)$ $[10^{-5}]$	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	$0.19^{+0.04}_{-0.03}$

FCNC tZc LH coupling extraction from the fitted distribution of the D_1 discriminant in SR1



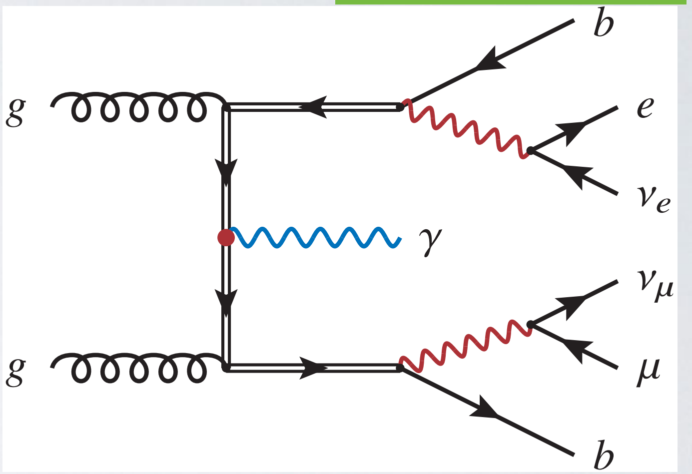
Other BSM-sensitive top interactions (not discussed)

- **Measurement of ttZ cross section in LHC Run 2** — Eur. Phys. J. C 81 (2021) 737 — 13 TeV, 139 fb^{-1}

$$\sigma(pp \to t\bar{t}Z) = 0.99 \pm 0.05\,(\text{stat.}) \pm 0.08\,(\text{syst.})\ \text{pb.}$$

- **Measurement of ttγ and tWγ cross section in LHC Run 2** — JHEP 09 (2020) 049 — 13 TeV, 139 fb^{-1}

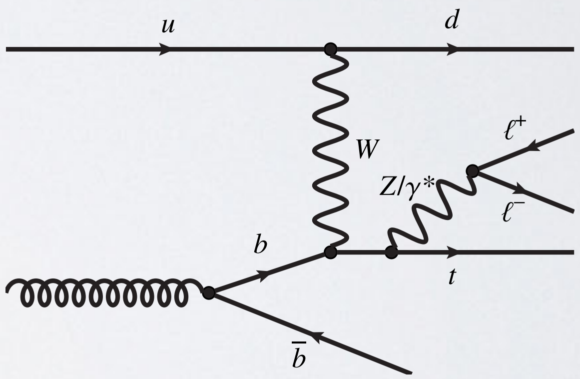
$$\sigma = 39.6^{+2.7}_{-2.3}\ \text{fb}$$



- **Observation of tγ** — ATLAS-CONF-2022-013 — NEW — 13 TeV, 139 fb^{-1}

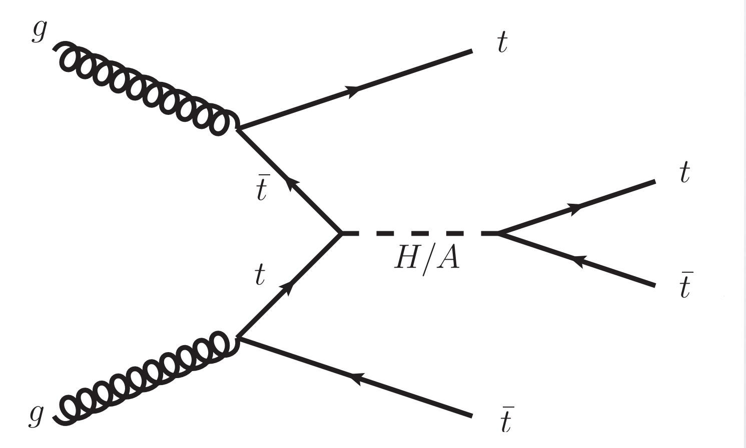
$$\sigma(tq\gamma)\,B(t \to \mu\nu b) = 580 \pm 19(\text{stat.}) \pm 63(\text{syst.})\ \text{fb}$$

- **Observation of tZ** — JHEP 07 (2020) 124 — 13 TeV, 139 fb^{-1}



$$\sigma^{\text{fid.}}_{tZq} = 97 \pm 13(\text{stat.}) \pm 7(\text{syst.})\ \text{fb}$$

- **Search for ttH/A →tttt** — ATLAS-CONF-2022-008 — NEW — 13 TeV, 139 fb^{-1}



$\sigma(pp \to t\bar{t}H/A) \times BR(H/A \to t\bar{t})$ [pb] < 6–14 fb @ 95% C.L.

SUMMARY

Top quark Flavour-Changing Neutral decays in the SM and selected BSM

	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}	$\sim 10^{-6}$

Table 1: Branching ratios for top FCN decays in the SM, models with $Q = 2/3$ quark singlets (QS), a general 2HDM, a flavour-conserving (FC) 2HDM, in the MSSM and with R parity violating SUSY.

ATLAS Limits (95% C.L.) and perspectives

$<6.2 \times 10^{-5}$ (LH)
$<0.8 \times 10^{-5}$ (LH)
$<6.1 \times 10^{-5}$
$<6.9 \times 10^{-4}$
$<13 \times 10^{-5}$ (LH)
$<4.2 \times 10^{-5}$ (LH)
$<3.7 \times 10^{-4}$
$<9.4 \times 10^{-4}$

: Mainly limited by statistical uncertainties

: Mainly limited by ID/systematic uncertainties

Find out more at:

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults