Search for flavour-changing neutral-current interactions of a top quark and a gluon with the ATLAS detector in *pp* collisions at $\sqrt{s} = 13$ TeV

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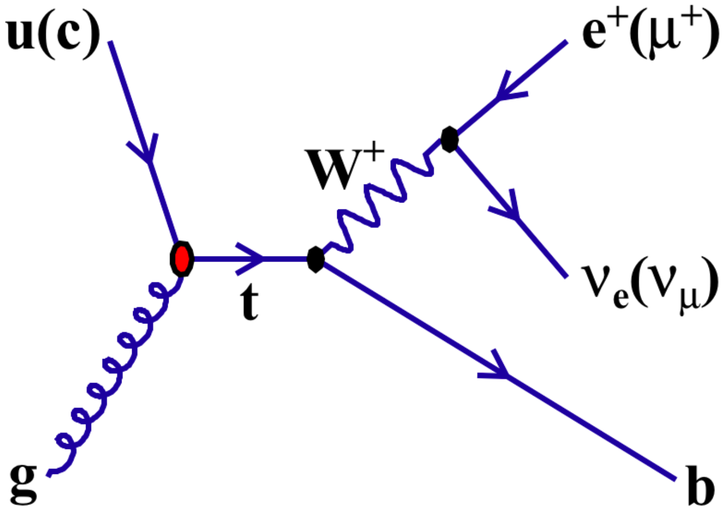
- arXiv: 2112.01302
- Accepted by Eur. Phys. J. C
- Public web page: TOPQ-2018-06 including auxiliary material



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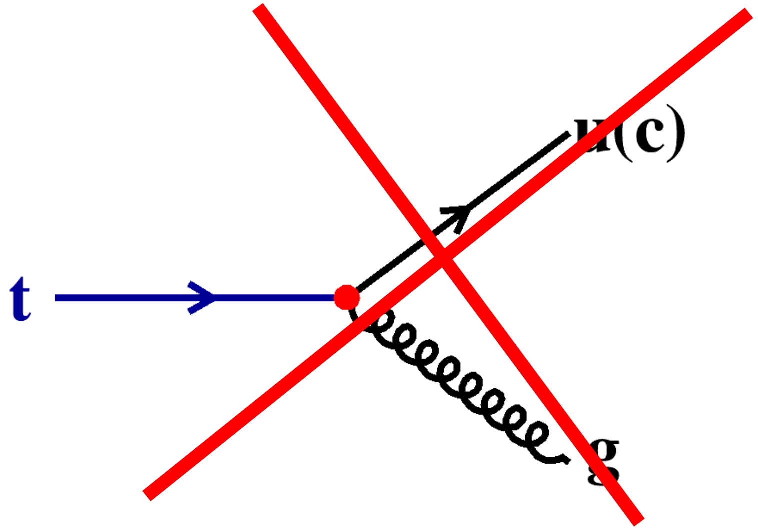
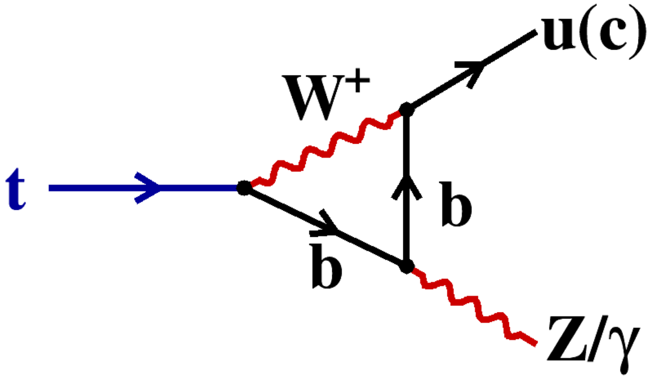
Flavour-changing neutral currents (FCNC)

- The SM does not include FCNC at tree (Born) level.

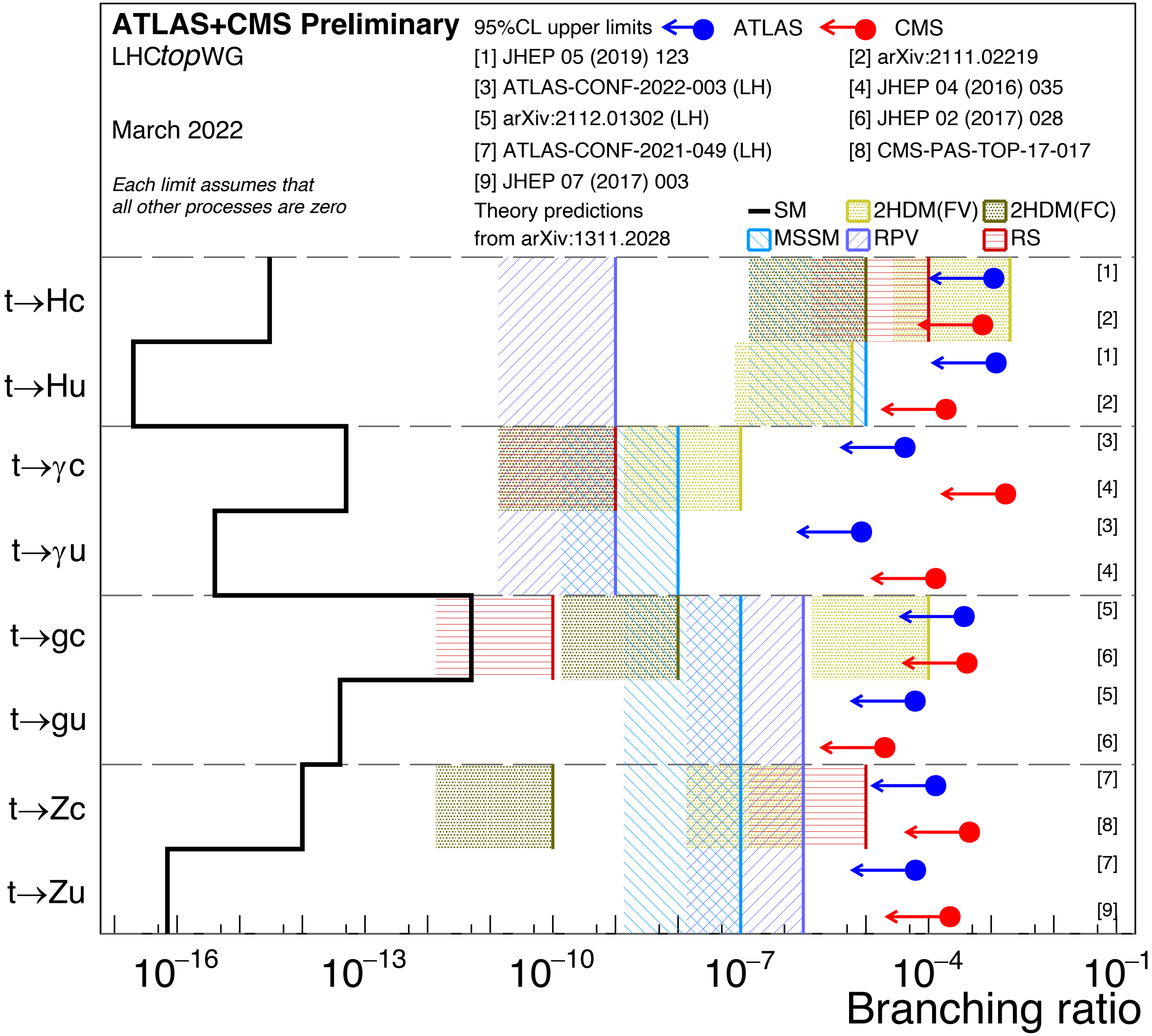


- FCNC exist at loop level, but they are strongly suppressed by the GIM mechanism (CKM unitarity).



	$Br(t \to q\gamma)$	$Br(t \to qZ)$	$Br(t \to qg)$
$q = u$	3.7×10^{-16}	8×10^{-17}	3.7×10^{-14}
$q = c$	4.6×10^{-14}	1×10^{-14}	4.6×10^{-12}

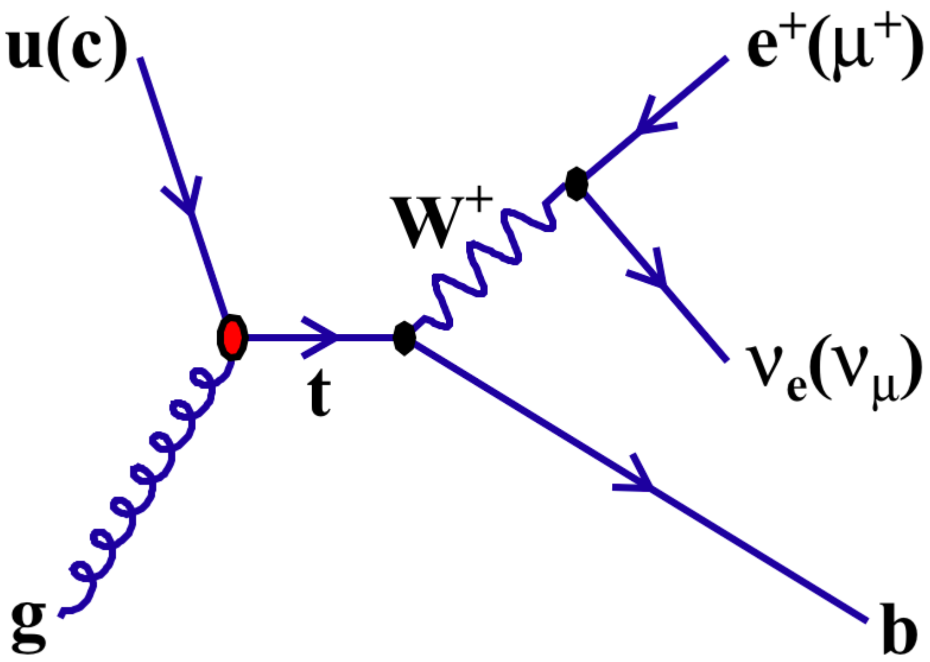
Top-Quark FCNC in BSM models and ...



... current experimental limits

Some 2HDM with flavour-violation predict $\mathcal{B}(t \to gc)$ as large as 10^{-4}.

Single top-quark production via top-gluon FCNC



- Process also called *direct* top-quark production.
- Consider ugt and cgt processes.
- Experimental signature
  - 1 single *b*-jet
  - 1 charged high-p_{T} lepton (electron or muon)
  - Large $E_{\mathrm{T}}^{\mathrm{miss}}$

Event selection and validation regions

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

	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	$= 1$
$D_{1(2)}$	–	$0.3 < D_{1(2)} < 0.6$	–	$0.2 < D_{1(2)} < 0.4$

- Use extra-tight working point of the b-tagging algorithm (30% efficiency)
  ↪ suppress the large $W + c$-jets and W + light-quark-jets

Estimation of the multijet background

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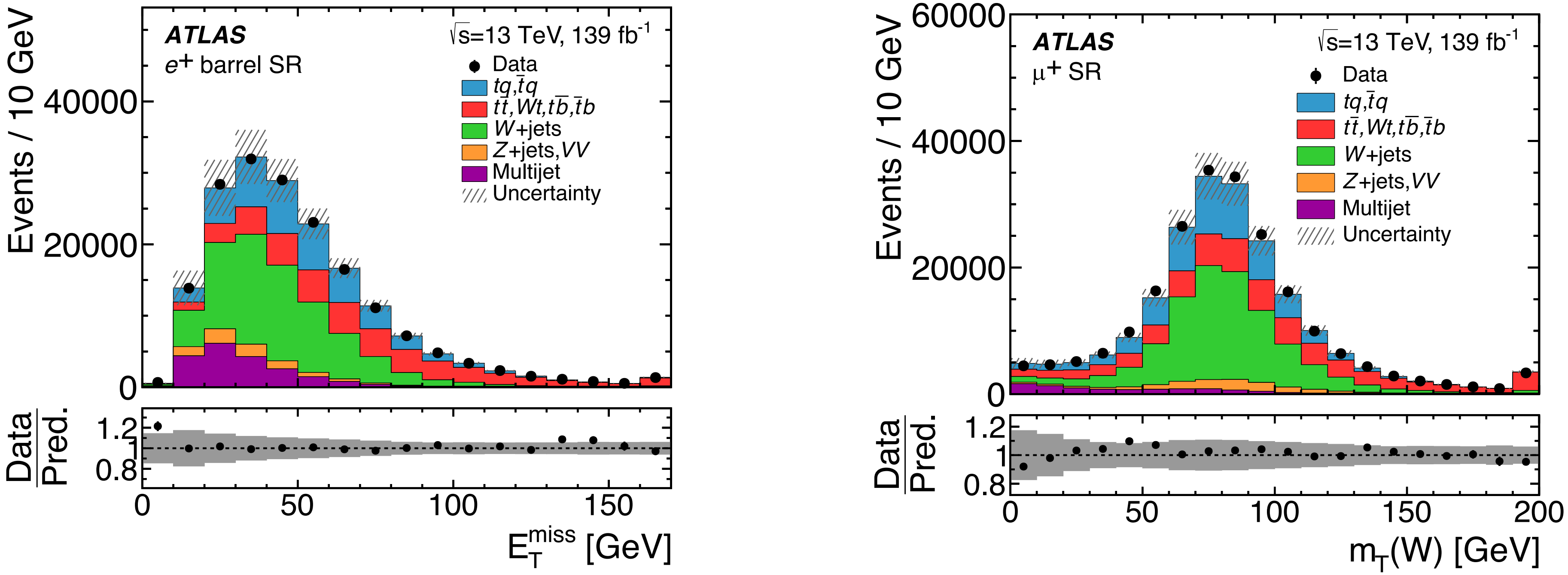
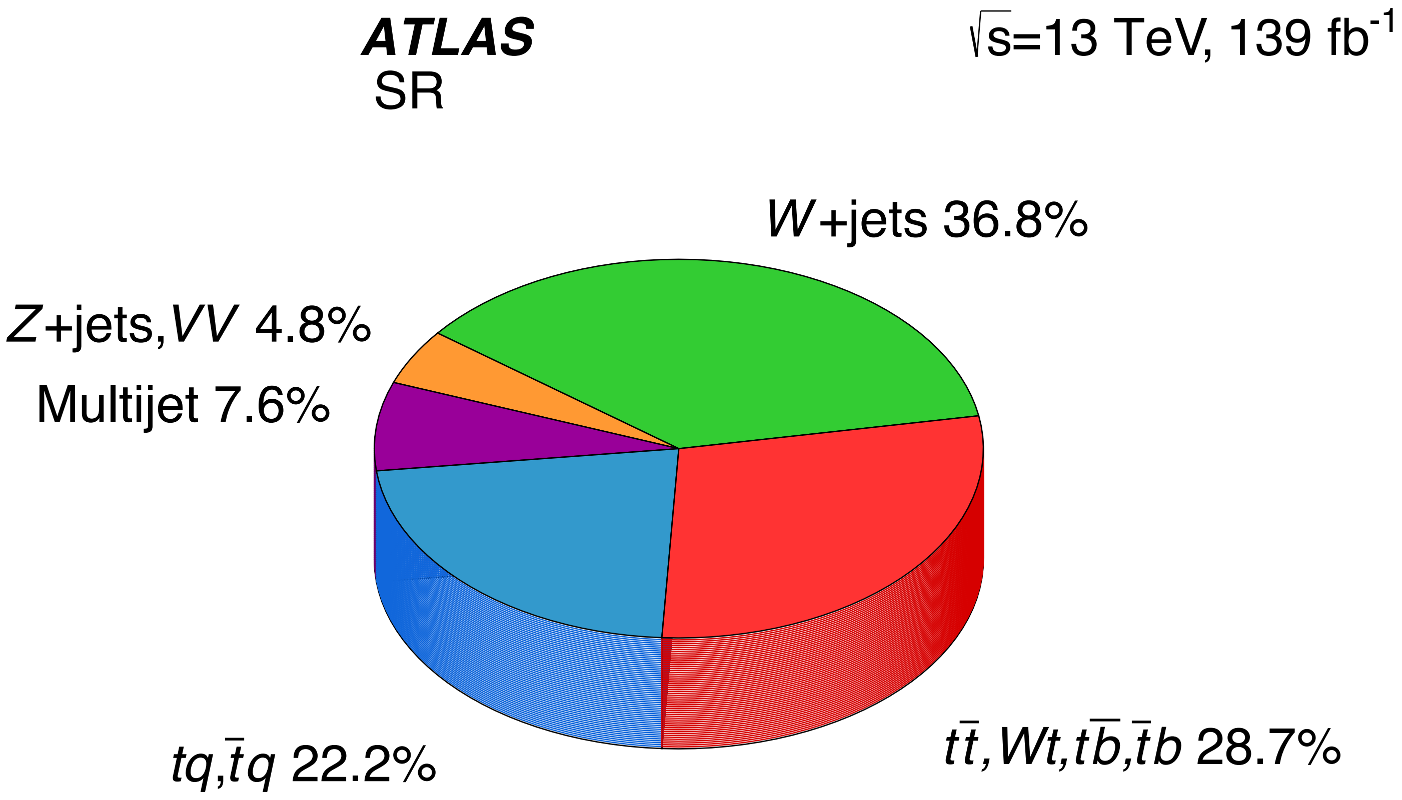
- The rate of mis-identifying jets as charged leptons is not well described in simulation.
- The rate is determined in a data-driven way.
- The $E_{\mathrm{T}}^{\mathrm{miss}}$ (electrons) and $m_{\mathrm{T}}(W)$ (muons) distributions are fitted for estimating the rate of the multijet background.
- The shape is modelled with the jet-electron model (dijet MC with labelling jets electrons) and the anti-muon model (collision data with inverting some identification cuts).



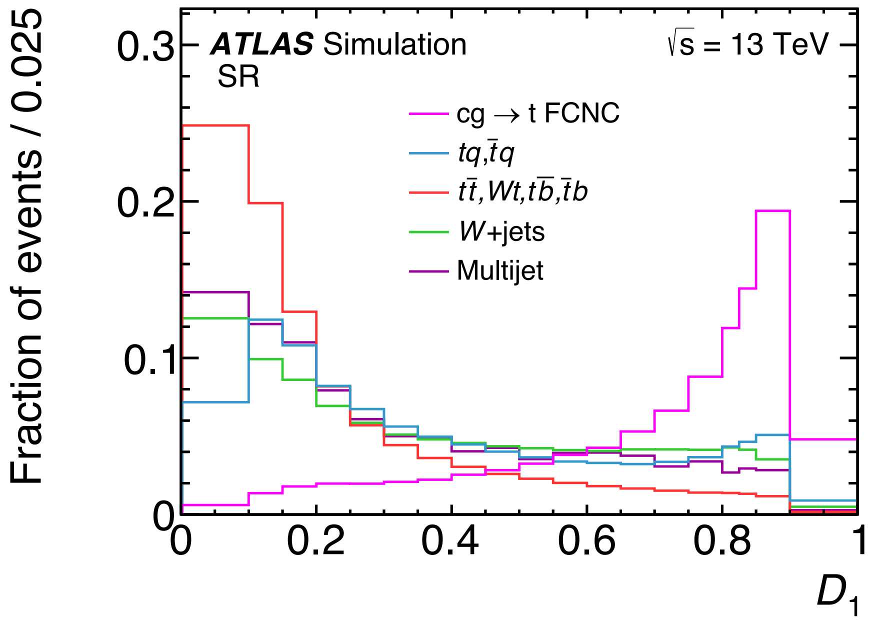
Background composition

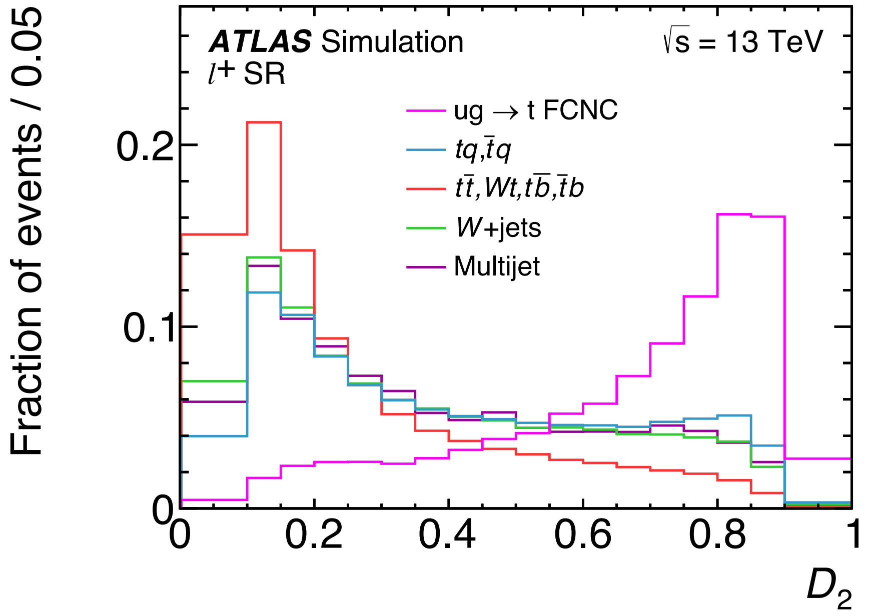
... in the signal region (1-jet-1-*b*-tag):



Separating signal and background events

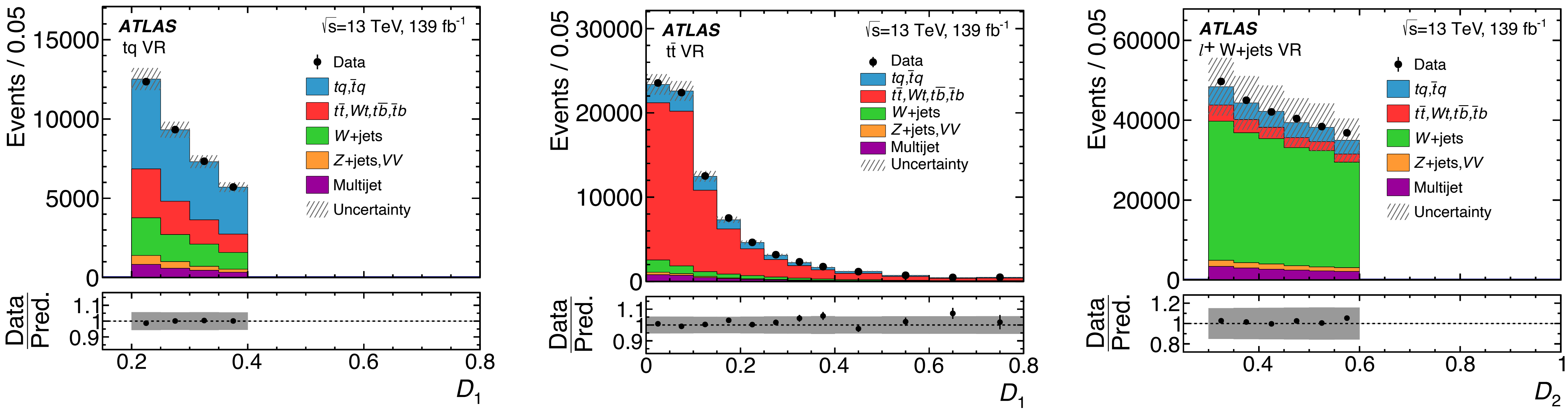
- Train artificial neural networks (NeuroBayes package) to obtain discriminants separating signal and background.





- One network trained with the cgt process as signal: $\Longrightarrow$ D_1 discriminant, used for the cgt analysis and $\bar{u} + g \rightarrow \bar{t}$ signal of the ugt analysis (sea quarks in the initial state).
- The 2nd network is trained with $u + g \rightarrow t$ events: $\Longrightarrow$ D_2 discriminant

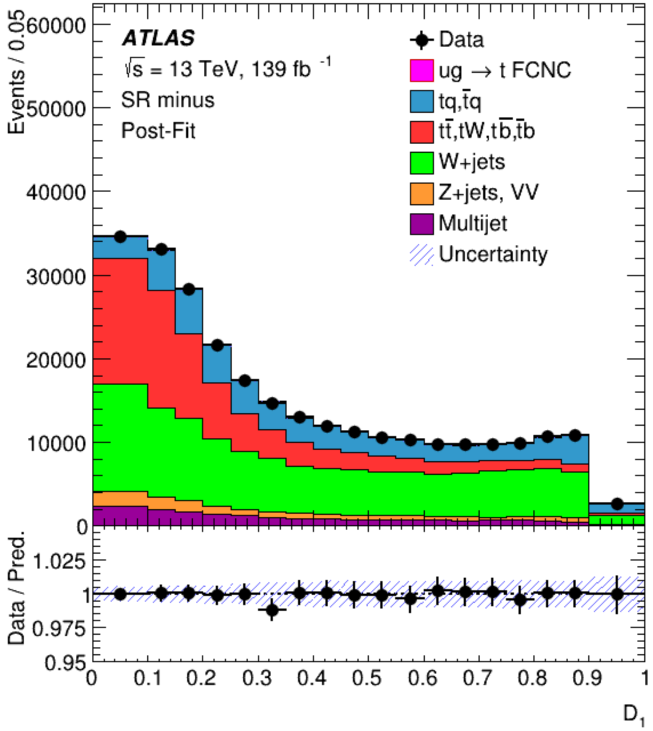
Evaluation of MC modelling

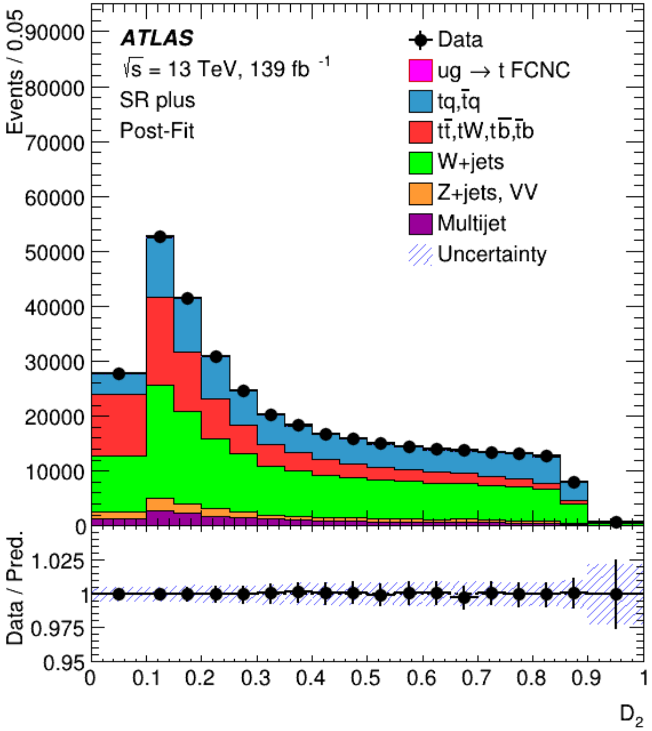


- Evaluate modelling of input variables in validation regions (VRs) and evaluate discriminants in these regions.
- The tq VR and the $W+$ jets VR is defined by using the discriminants D_1 and D_2.

Result of the maximum likelihood fit

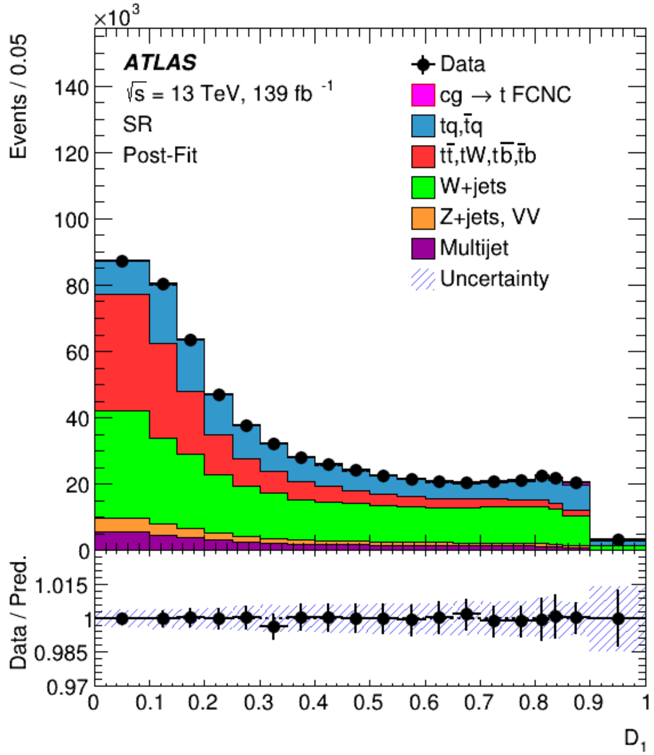
ugt analysis





Process	μ
W^+ + jets	$1.25^{+0.15}_{-0.14}$
W^- + jets	$1.32^{+0.17}_{-0.16}$
$u + g \ \rightarrow t$	$0.10^{+0.19}_{-0.17}$

cgt analysis



Process	μ
W + jets	$1.19^{+0.15}_{-0.14}$
c+$g \ \rightarrow t$	$0.15^{+0.19}_{-0.14}$

Post-fit event yield table

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

Fitted signal yields are compatible with zero!

Zoom-in plots with excluded signal contribution

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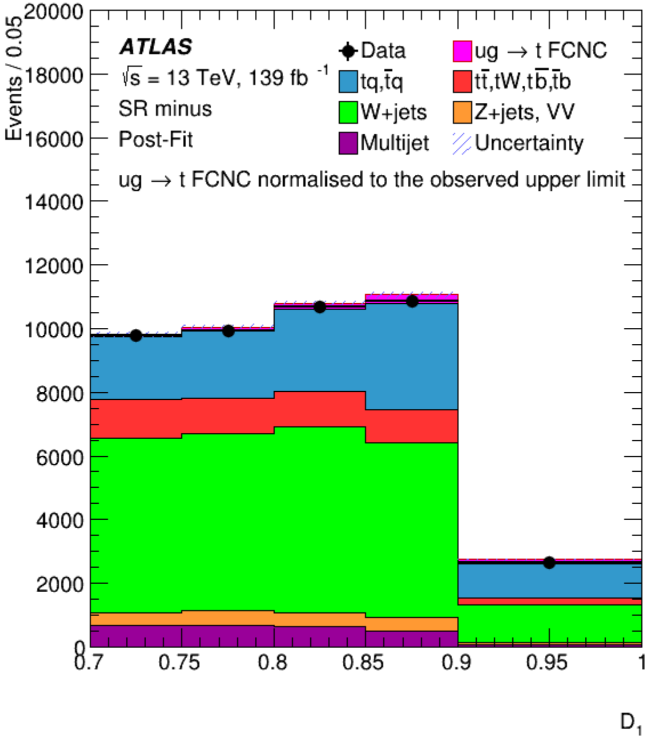
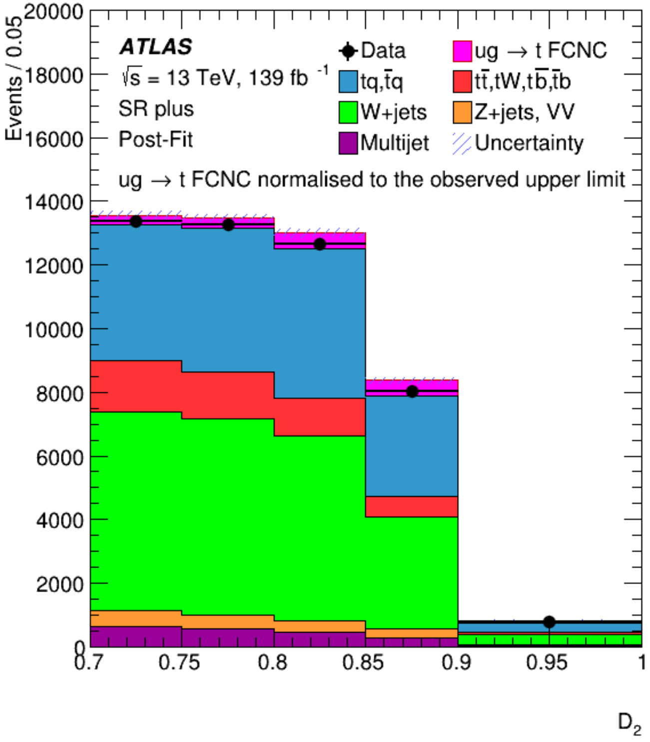
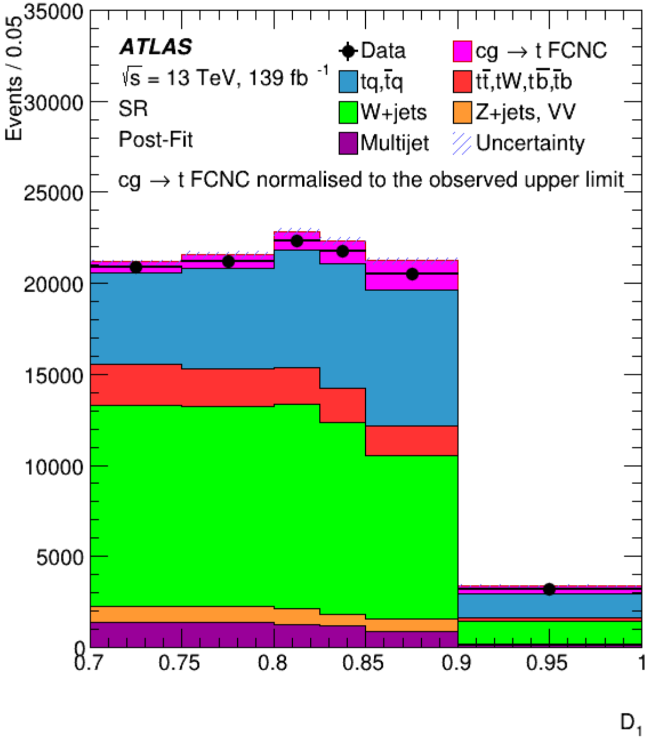
ugt analysis





cgt analysis



Cross-section limits

- No significant excess observed → upper limits on $\sigma(ug \to t) \times \mathcal{B}(t \to Wb) \times \mathcal{B}(W \to \ell\nu)$

CLs method

Test statistic

$$\tilde{q}_\mu = \begin{cases} -2\ln\left(\frac{\mathcal{L}\left(\mu,\hat{\hat{\vec{\theta}}}(\mu)\right)}{\mathcal{L}\left(0,\hat{\hat{\vec{\theta}}}(0)\right)}\right) & \text{if } \hat{\mu} < 0, \\ -2\ln\left(\frac{\mathcal{L}\left(\mu,\hat{\hat{\vec{\theta}}}(\mu)\right)}{\mathcal{L}\left(\hat{\mu},\hat{\vec{\theta}}\right)}\right) & \text{if } 0 \le \hat{\mu} \le \mu, \\ 0 & \text{if } \hat{\mu} > \mu. \end{cases}$$

- Observed upper limits:

$$\sigma(ugt) \times \mathcal{B}(t \to Wb) \times \mathcal{B}(W \to \ell\nu) < 3.0\,\text{pb}$$
$$\sigma(cgt) \times \mathcal{B}(t \to Wb) \times \mathcal{B}(W \to \ell\nu) < 4.7\,\text{pb}$$

Expected limits: 2.4 pb and 2.5 pb, respectively.

Interpretation in an EFT

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Use the TopFCNC model based on the FeynRules 2.0 framework inside MadGraph5_aMC@NLO to interpret the cross-section limits in the context of an effective field theory.

Based on the model we establish the relations (@ NLO):

$$\sigma(u+g \rightarrow t) = 2773 \times \left(\frac{C_{uG}^{ut}}{\Lambda}\right)^2 \text{pb TeV}^2 \qquad \sigma(c+g \rightarrow t) = 719 \times \left(\frac{C_{uG}^{ct}}{\Lambda}\right)^2 \text{pb TeV}^2$$

These relations lead to limits on the EFT coefficients:

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

The EFT (arXiv: 1412.7166) is further used to predict branching ratios of FCNC decays:

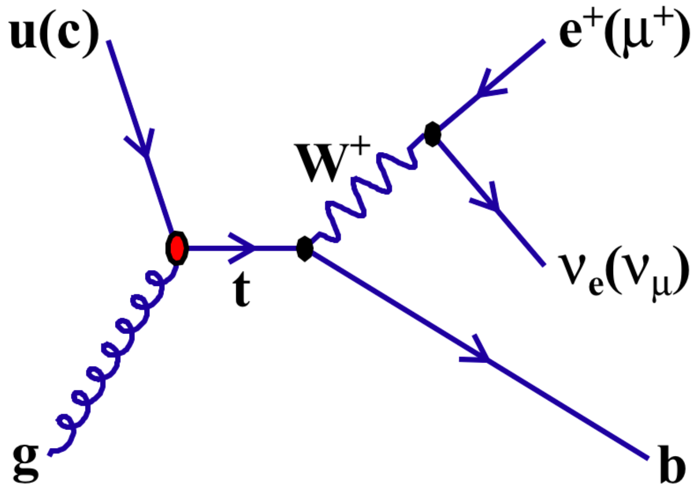
$$\mathcal{B}(t \rightarrow q+g) = 0.0186 \times \left(\frac{C_{uG}^{qt}}{\Lambda}\right)^2 \text{TeV}^2$$

Limits on the branching ratios:

$$\mathcal{B}(t \rightarrow u+g) < 0.61 \times 10^{-4} \quad \text{and} \quad \mathcal{B}(t \rightarrow c+g) < 3.7 \times 10^{-4}$$

New results improve previous ATLAS limits by approximately a factor of 2.

Conclusions



- No significant excess of

  $ug \rightarrow t$ or $cg \rightarrow t$ events is observed.

  ↪ upper limits on production cross sections

  ↪ limits on EFT coefficients $|C_{uG}^{ut}|$ and $|C_{uG}^{ut}|$

  ↪ limits on branching ratios

$$\mathcal{B}(t \rightarrow u + g) < 0.61 \times 10^{-4} \quad \text{and} \quad \mathcal{B}(t \rightarrow c + g) < 3.7 \times 10^{-4}$$

- ATLAS limits from 8 TeV analysis are improved by a factor of 2.
- Sensitivity limited by systematic uncertainties.

  ↪ need a new strategy to improve limits in the future

- Looks at $pp \rightarrow t\bar{t} \rightarrow \ell^+ \nu b + \bar{u}g$?

Backup: Modelling of input variables

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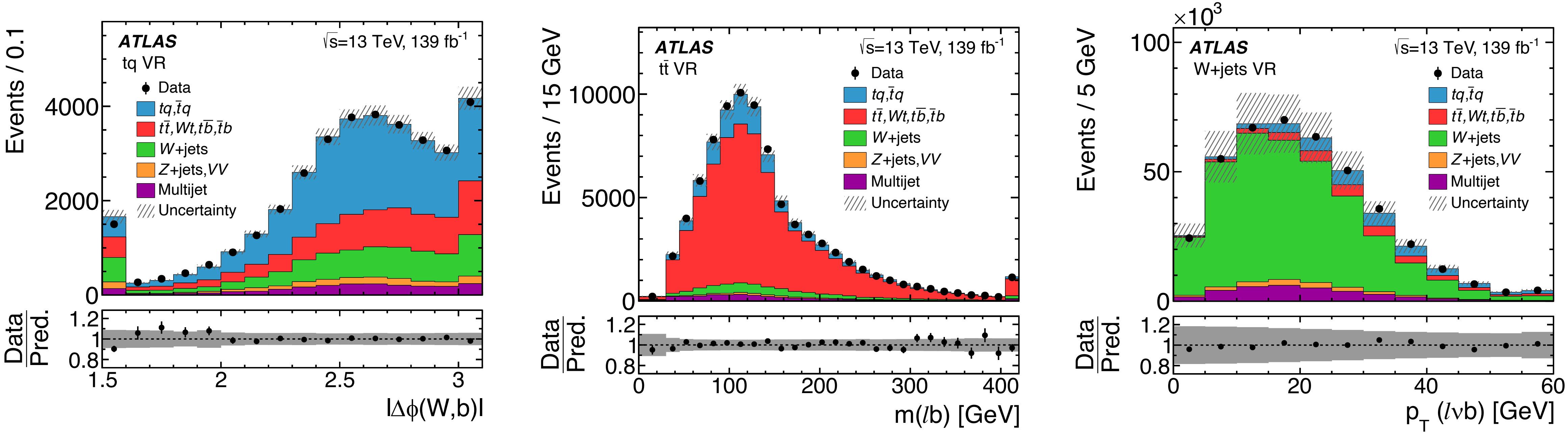

Limiting uncertainties (@ 13 TeV)

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 only	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}

Experimental and modelling uncertainties contribute to the limitation of the sensitivity.