Searches for BSM and FCNC with top quarks in ATLAS

Adrian Salvador Salas
On behalf of the ATLAS collaboration
LHCP2023
25 May 2023

Exploring Beyond the SM (BSM) with the top quark

- Various BSM theories that complete the SM
  - 2HDM, DM models, composite Higgs…
- The role of the top quark in BSM
  - Attractive due its large mass, close to the EW scale
  - Highest coupling to the Higgs boson
  - Primary decay t→Wb, while other decays are rare
  - Many models modify the top quark couplings or predict interactions with new particles
- The Large Hadron Collider - a top quark factory
  - Prime source for top quark production
  - Numerous ATLAS analyses involve the production and decay of top quarks

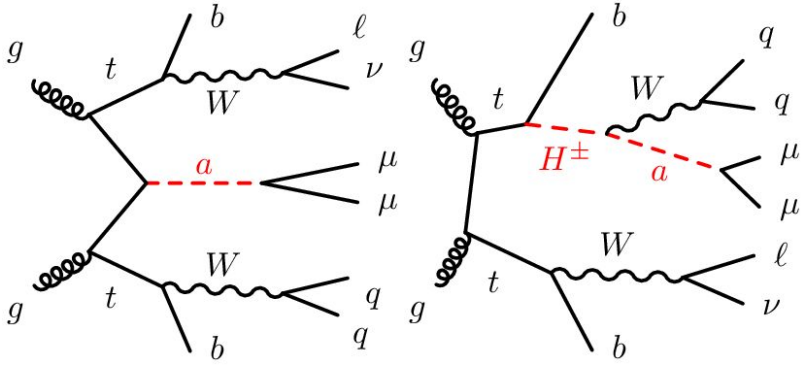
Kalemegdan

Avala Tower

Belgrade Waterfront

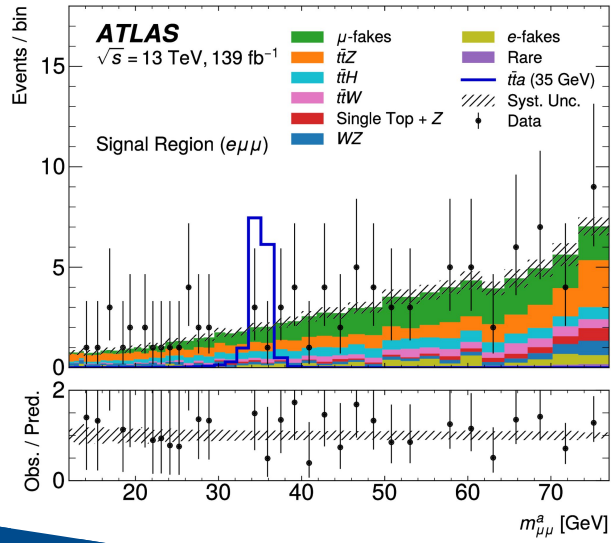
tta, a→μμ

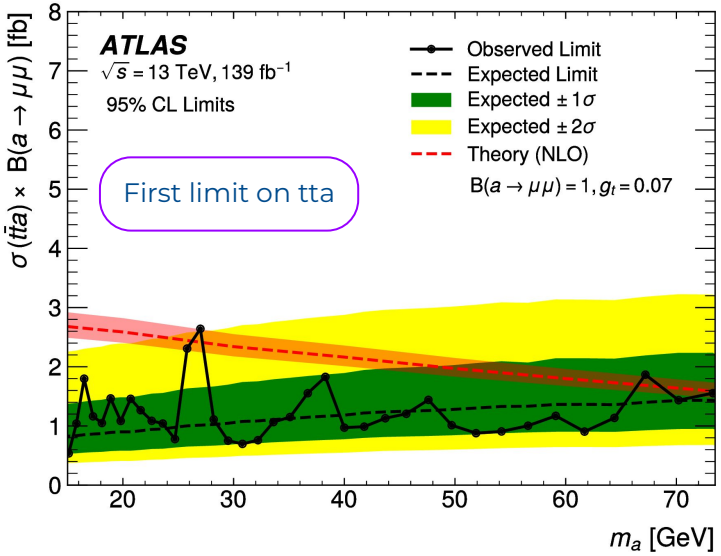
arXiv:2304.14247



- Light scalars predicted in 2HDM+a, NMSSM… with large couplings to top quarks

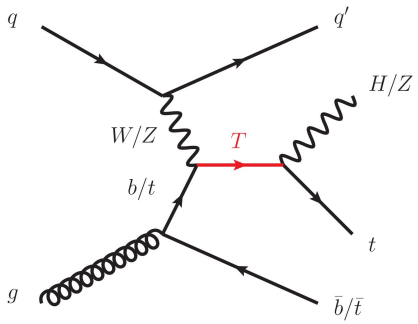
- Search for resonance in $e\mu\mu$ or $\mu\mu\mu$, with multiple jets
  - m_a 15 - 72 GeV and m_{H+} 120 - 160 GeV
  - Main backgrounds: prompt muons from $t\bar{t}Z$, non-prompt from $t\bar{t}$ and Z+jets





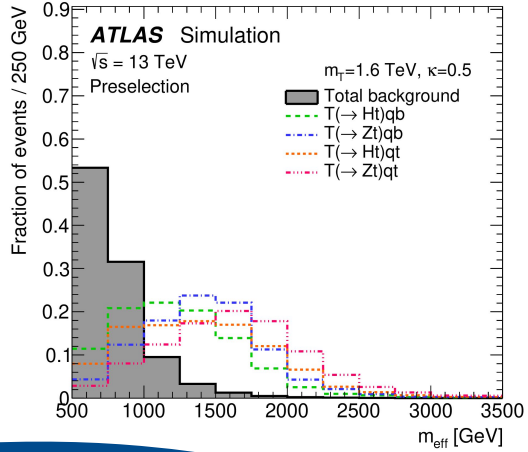
Ht/Zt+X single VLQ analysis

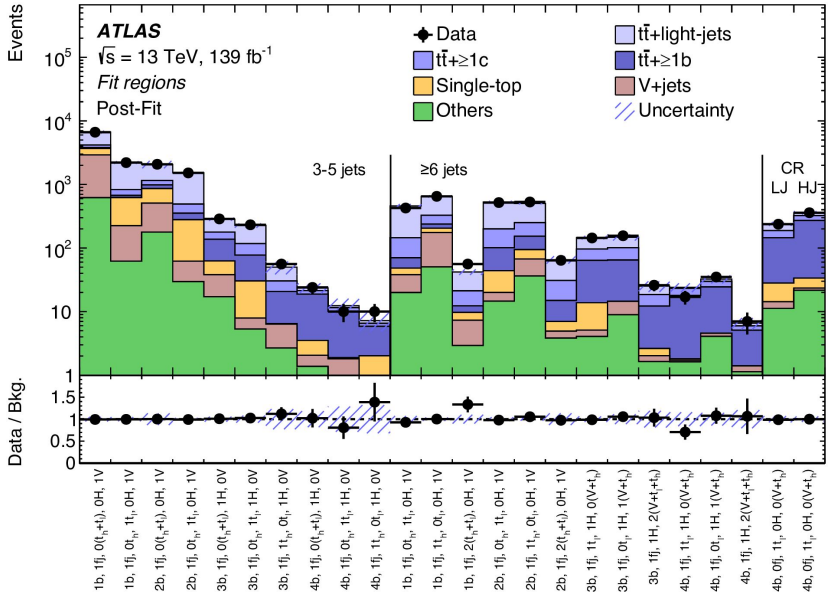
arXiv:2305.03401



- Vector-like T quarks (VLQ) are fermionic partners of the top quark in many BSM
- Search focused on T → Ht and T → Zt in singlet and doublet configurations
  - Single-lepton final state with regions defined with different multiplicity of jets, b-jets, forward jets and boosted tagged objects
  - Set of regions to target the different signal channels and to control tt̄ background

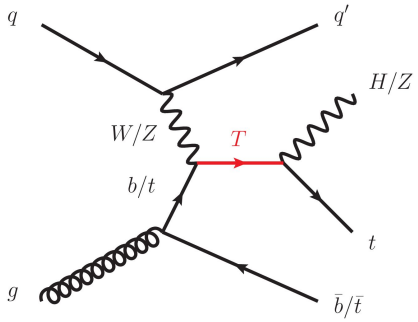
Discriminating variable: $\sum_{\text{central jets}} p_{\mathrm{T}}^{j} + \sum_{\text{leptons}} p_{\mathrm{T}}^{\ell} + E_{\mathrm{T}}^{\mathrm{miss}}$





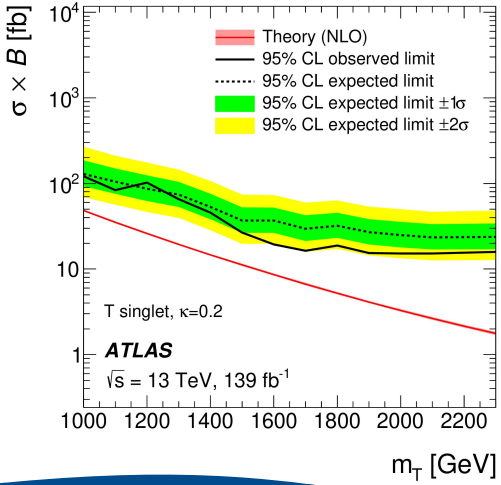
Ht/Zt+X single VLQ analysis

arXiv:2305.03401

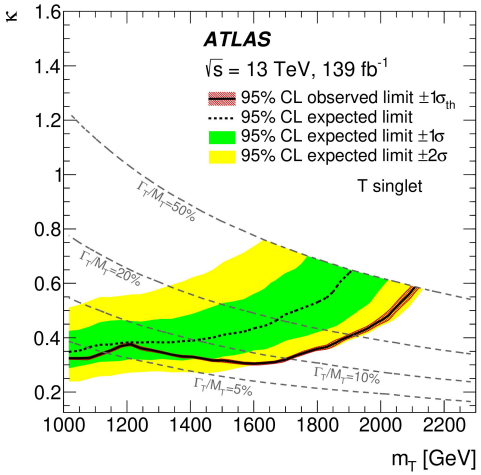


- Vector-like T quarks (VLQ) are fermionic partners of the top quark in many BSM
- Search focused on T → Ht and T → Zt in singlet and doublet configurations
  - Single-lepton final state with regions defined with different multiplicity of jets, b-jets, forward jets and boosted tagged objects
  - Set of regions to target the different signal channels and to control $t\bar{t}$ background

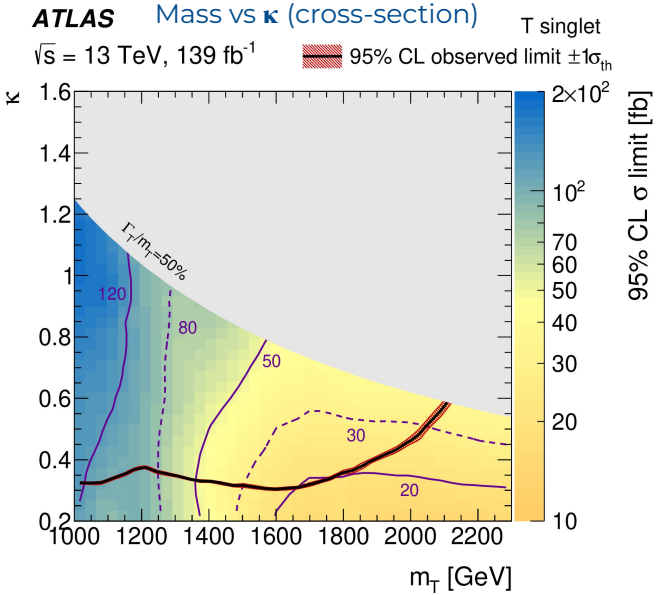
Mass vs cross-section



Mass vs common coupling (κ)

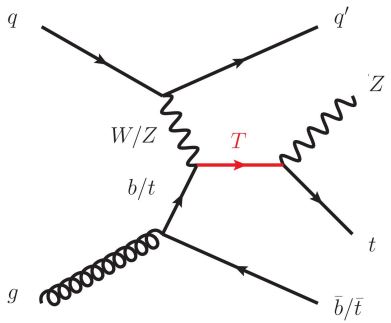


Mass vs κ (cross-section)

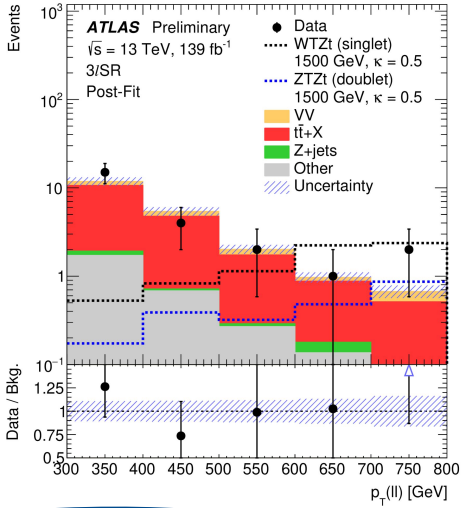


Single VLQ in multi-lepton final states

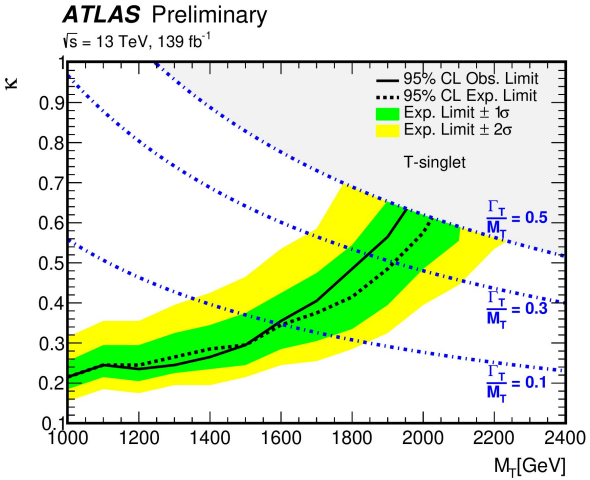
ATLAS-CONF-2023-020



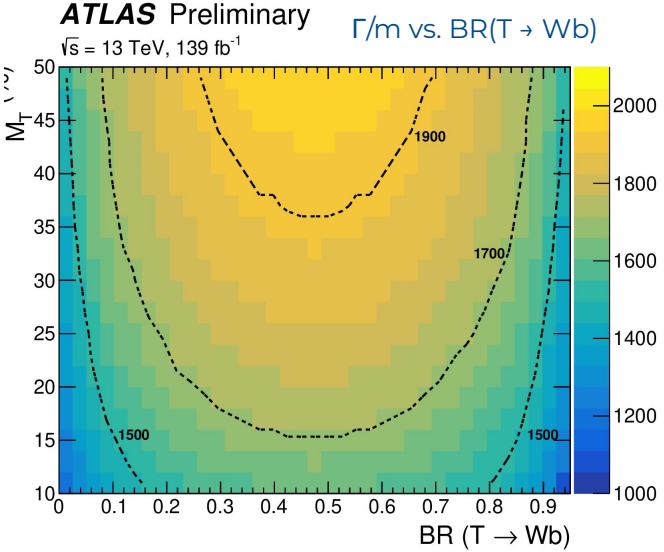
- Most extensive VLQ-T signal range to date, m_T 1-2.7 TeV and k 0.1 to 1
- Search focused on WTZt and ZTZt in singlet and doublet configurations
  - Multi-lepton selection defined with different multiplicity of jets, b-jets, forward jets and boosted tagged objects
  - Di-lepton regions dominated by Z+jets background, tri-lepton by VV and $t\bar{t}$+Z



Mass vs common coupling (κ)

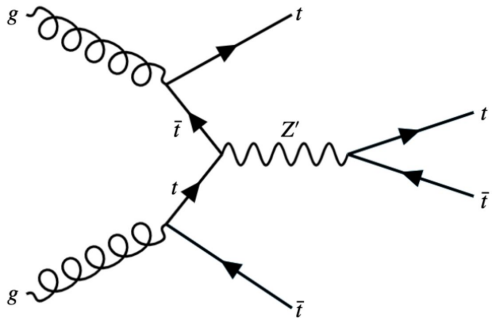


Γ/m vs. BR(T → Wb)

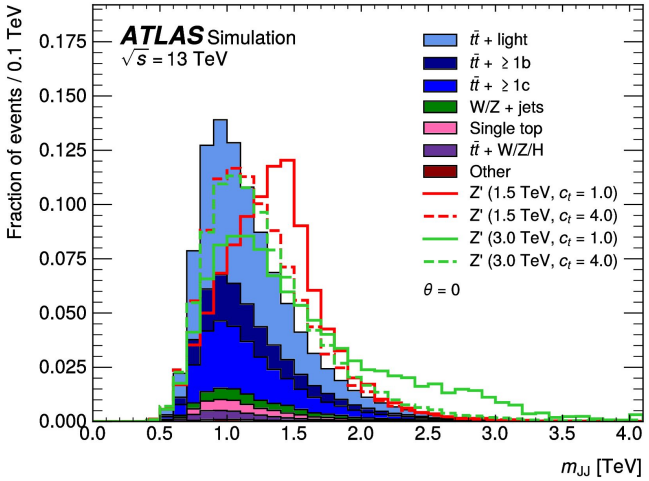


Top-philic heavy resonant search

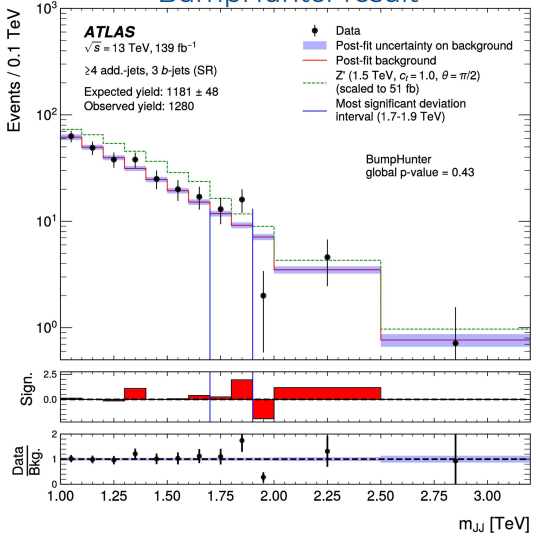
arXiv:2304.01678



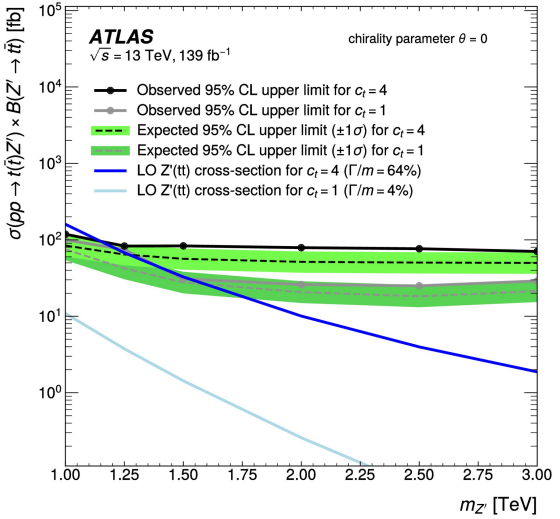
- Heavy BSM vector resonances coupling strongly to top quarks
- Search for a resonance between 1 and 3.2 TeV in fully hadronic decay mode
  - Resonance mass reconstruction using two reclustered jets
  - Dijet background estimated in signal-depleted region
  - Performed a bump hunt and a model-dependent likelihood fit



BumpHunter result

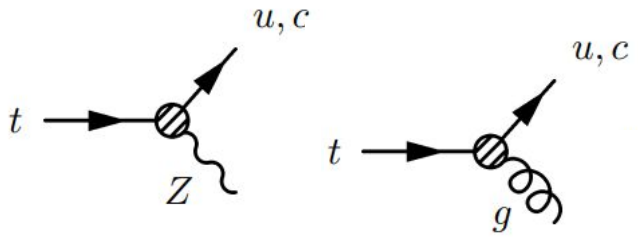


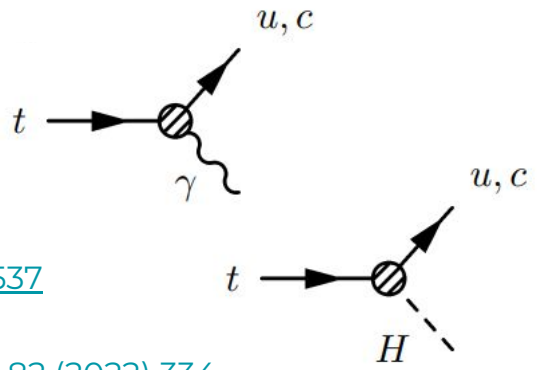
Cross-section upper limits



FCNC couplings with top quarks

- FCNC interactions are very suppressed in the SM
  - Absent at tree level and the GIM mechanism
- Enhanced couplings in many BSM
  - Quark-singlet models, 2HDM, Supersymmetry, composite Higgs…
- Main top FCNC couplings measured in ATLAS using 139 fb^{-1}

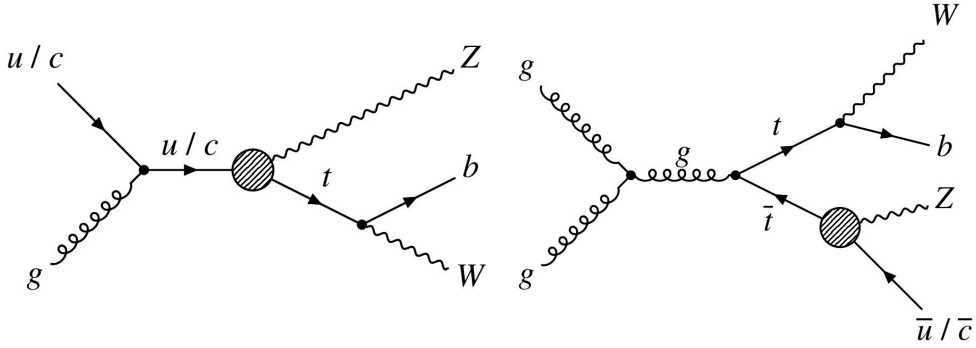




Process	SM	ATLAS	
$t \to u\gamma$	$4 \cdot 10^{-16}$	$0.85 \cdot 10^{-5}$	arXiv:2205.02537
$t \to c\gamma$	$5 \cdot 10^{-14}$	$4.2 \cdot 10^{-5}$	
$t \to ug$	$4 \cdot 10^{-14}$	$0.61 \cdot 10^{-4}$	Eur. Phys. J. C 82 (2022) 334
$t \to cg$	$5 \cdot 10^{-12}$	$3.7 \cdot 10^{-4}$	
$t \to uZ$	$8 \cdot 10^{-17}$	$6.2 \cdot 10^{-5}$	arXiv:2301.11605
$t \to cZ$	$1 \cdot 10^{-14}$	$13 \cdot 10^{-5}$	
$t \to uH$	$2 \cdot 10^{-17}$	$6.9 \cdot 10^{-4} (H \to \tau\tau)$	arXiv:2208.11415
		$7.6 \cdot 10^{-4} (H \to bb)$	
$t \to cH$	$3 \cdot 10^{-15}$	$9.4 \cdot 10^{-4} (H \to \tau\tau)$	arXiv:2301.03902
		$8.8 \cdot 10^{-4} (H \to bb)$	

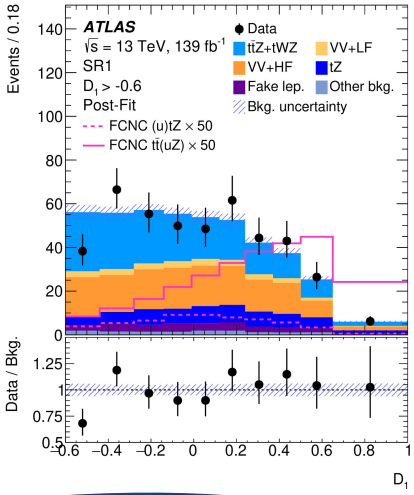
FCNC t→qZ

arXiv:2301.11605

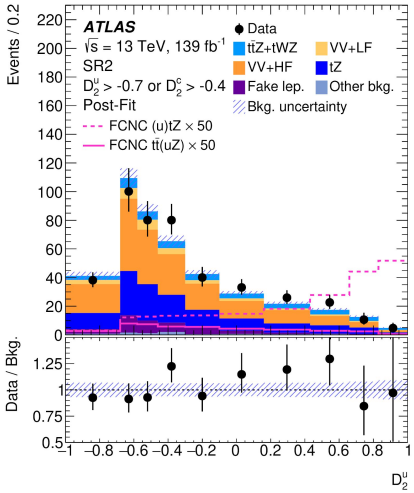


- Excellent probe for new physics: SM BR(t→qZ)~10^{-14}
- Search either for the tZu or tZc coupling
  - Three leptons in the final state
  - Main backgrounds: prompt leptons from tt̄Z and VV
  - Different BDTs targeting separately the tZu production, the tZc production and the tt̄ decay process

tt̄ discriminant



tZu LH discriminant

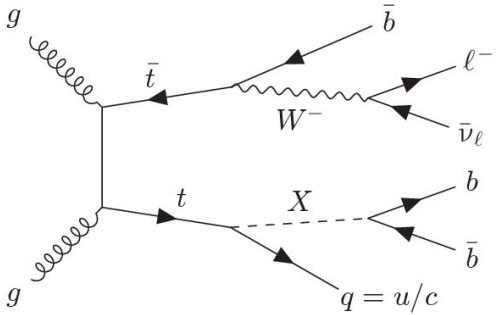


Observable	Vertex	Coupling	Observed	Expected
	SRs+CRs			
$\mathcal{B}(t \to Zq)$	tZu	LH	6.2×10^{-5}	$4.9\,^{+2.1}_{-1.4} \times 10^{-5}$
$\mathcal{B}(t \to Zq)$	tZu	RH	6.6×10^{-5}	$5.1\,^{+2.1}_{-1.4} \times 10^{-5}$
$\mathcal{B}(t \to Zq)$	tZc	LH	13×10^{-5}	$11\,^{+5}_{-3} \times 10^{-5}$
$\mathcal{B}(t \to Zq)$	tZc	RH	12×10^{-5}	$10\,^{+4}_{-3} \times 10^{-5}$

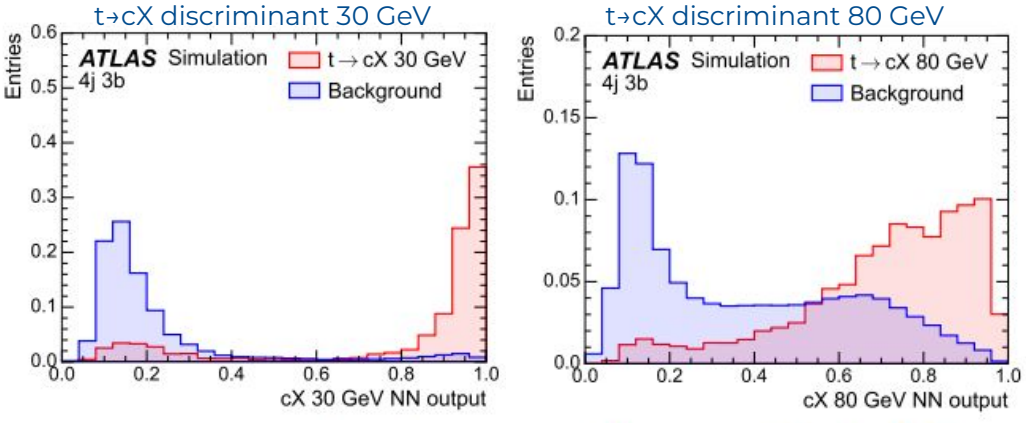
Factor 3 (2) improvement compared to tZu (tZc) 36.1 fb^{-1} results

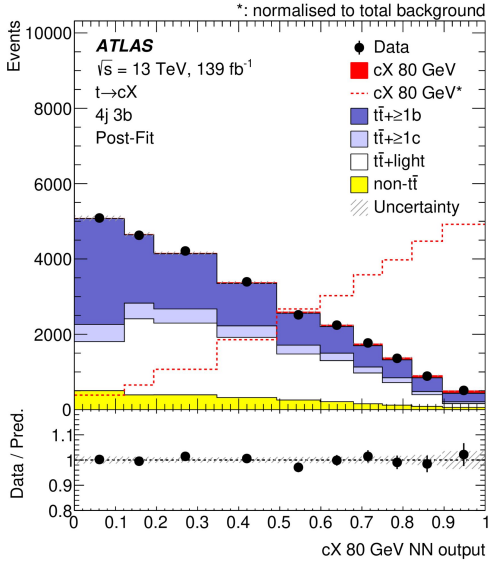
FCNC t→qX(bb)

arXiv:2301.03902



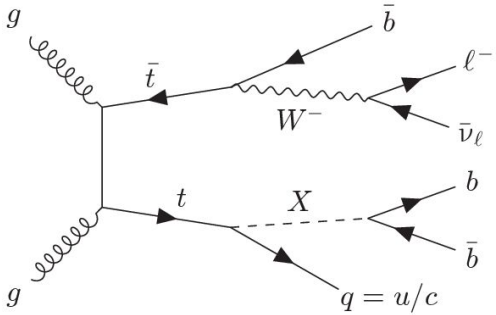
- FCNC couplings enhanced by introducing a scalar with flavour charge (flavon)
- Search for a neutral scalar in FCNC top decays in tt̄ events
  - Performed separately for t→uX and t→cX with X→bb
  - Discrimination using NN trained on jet and lepton kinematics and m_{bb}
  - Upper limits also extracted for the process involving the SM Higgs t→qH(bb)





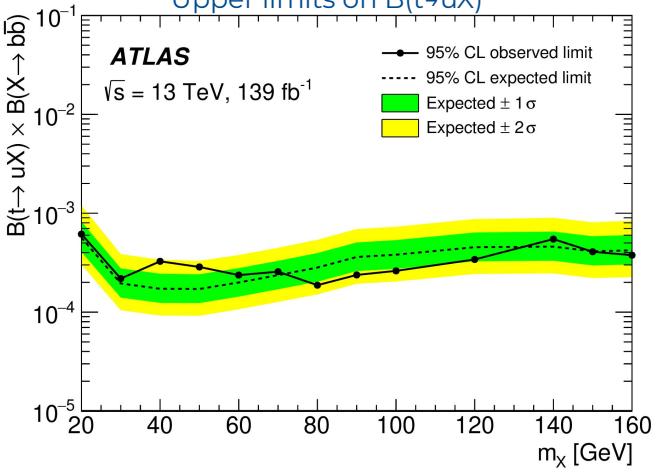
FCNC t→qX(bb)

arXiv:2301.03902



- FCNC couplings enhanced by introducing a scalar with flavour charge (flavon)
- Search for a neutral scalar in FCNC top decays in tt̄ events
  - Performed separately for t→uX and t→cX with X→bb
  - Discrimination using NN trained on jet and lepton kinematics and m_{bb}
  - Upper limits also extracted for the process involving the SM Higgs t→qH(bb)

Upper limits on B(t→uX)

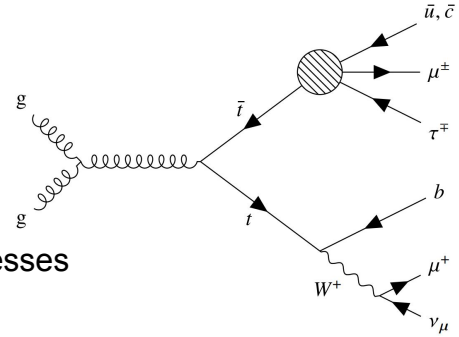


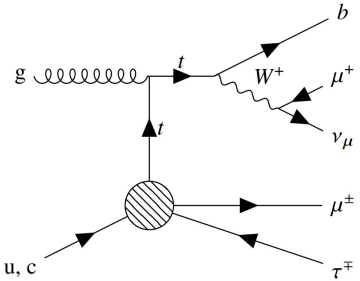
- Upper limits on BR(t→uX) and BR(t→cX) reach ~$2 \cdot 10^{-4}$
- Limits on BR(t→qH) significantly improved with respect to 36 fb^{-1} result

BR Upper limit	ATLAS (139 fb^{-1})	ATLAS (36 fb^{-1})
$t \to uH(b\bar{b})$	0.077%	0.52%
$t \to cH(b\bar{b})$	0.12%	0.42%

cLFV tμτq

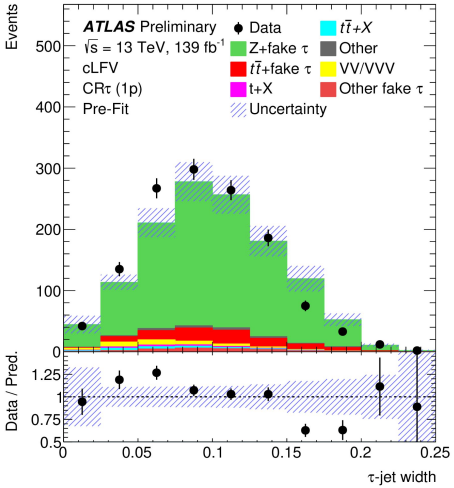
ATLAS-CONF-2023-001

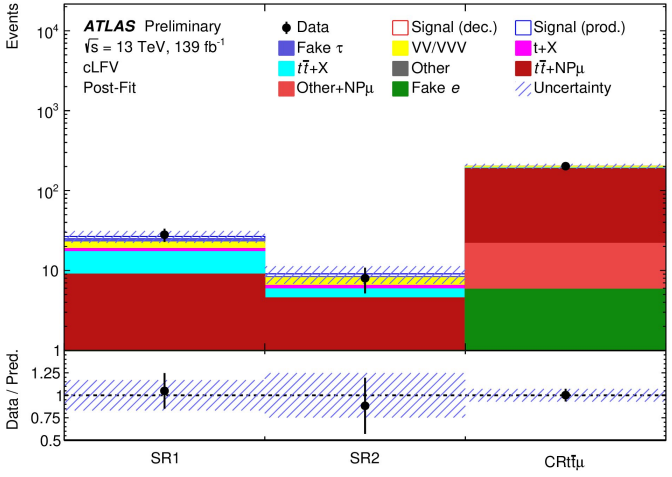




- Charged lepton flavour violation in BSM (leptoquarks)
- Search for cLFV vertex in both production and decay processes
  - Three lepton selection $\mu\mu\tau_{\text{had-vis}}$ / $\mu\mu\mu$ / e$\mu\mu$
  - Dedicated estimations for fake $\tau_{\text{had-vis}}$ and non-prompt muon backgrounds
  - Signal upper limits and EFT interpretation

τ fake estimation





	95% CL upper limits on BR($t \to \mu\tau q$)	
	Stat. only	All systematics
Expected	8×10^{-7}	10×10^{-7}
Observed	9×10^{-7}	11×10^{-7}

Analysis limited by statistics

Summary

- Presented recent ATLAS BSM and FCNC searches:
  - tta, a→μμ arXiv:2304.14247 27 April 2023
  - Ht/Zt+X single VLQ analysis ATLAS-CONF-2023-001 5 January 2023
  - Single VLQ in multi-lepton final states ATLAS-CONF-2023-020 26 March 2023
  - Top-philic heavy resonant search arXiv:2304.01678 4 April 2023
  - FCNC t→qZ arXiv:2301.11605 27 January 2023
  - FCNC t→qX(bb) arXiv:2301.03902 10 January 2023
  - cLFV μτ ATLAS-CONF-2023-001 5 January 2023

- The top quark offers plenty of opportunities for new physics

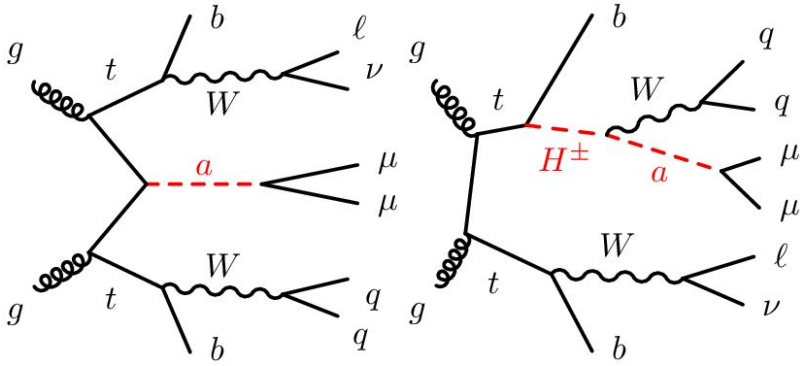
- Extensive ATLAS efforts to look for new signatures using the top quark
  - Full list of publications and conference notes

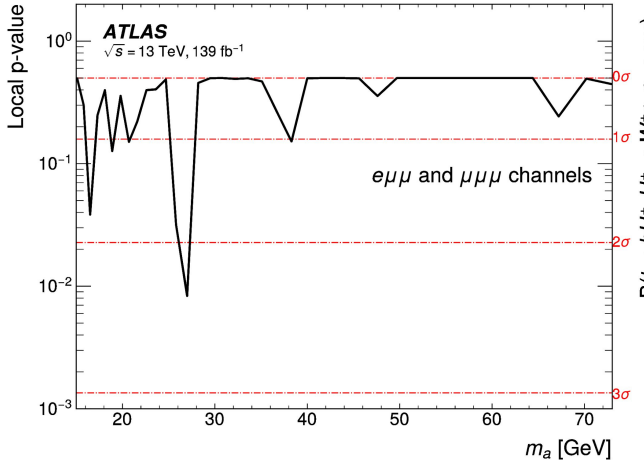
- Looking forward to uncovering more in Run-3 with innovations in reconstruction techniques and background modelling

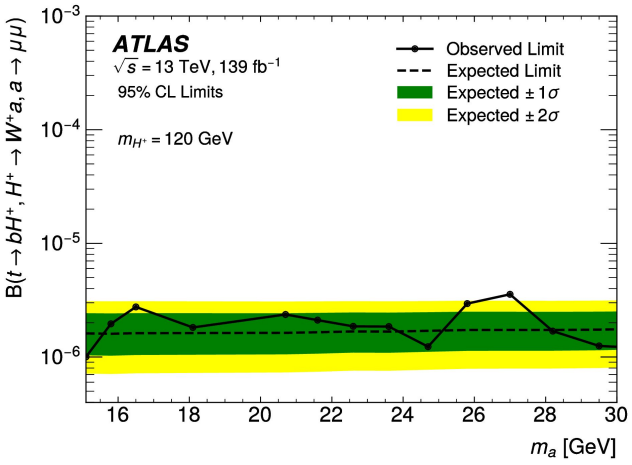
BACKUP

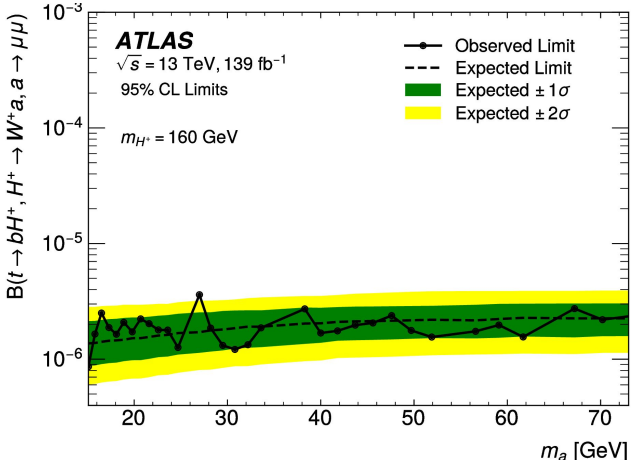
tta, a→μμ

arXiv:2304.14247





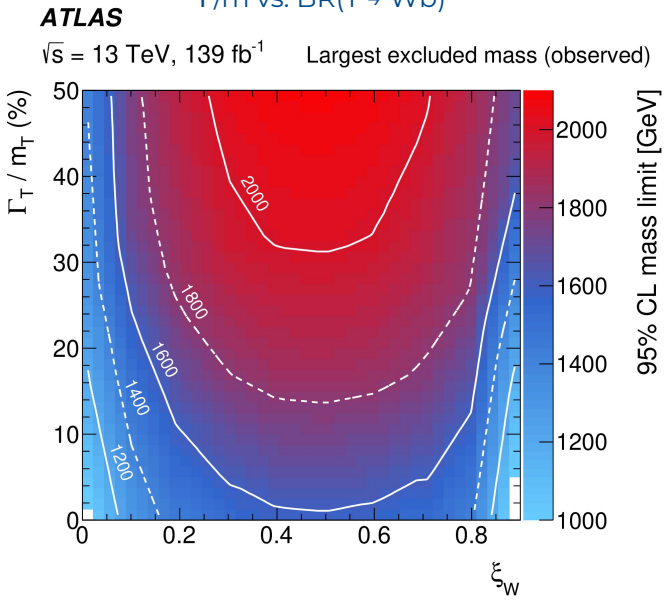




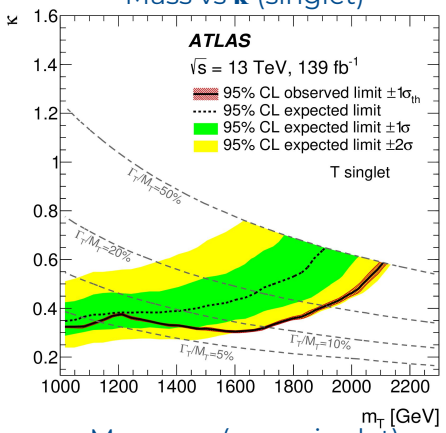
Ht/Zt+X single VLQ analysis

arXiv:2305.03401

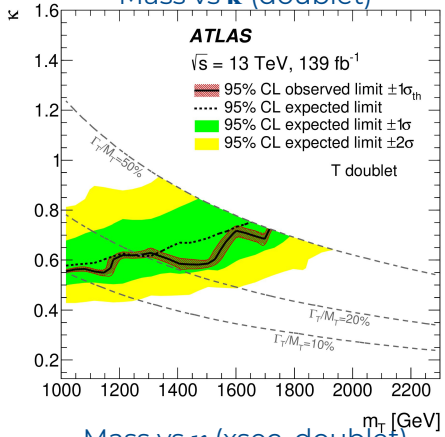
Γ/m vs. BR(T → Wb)



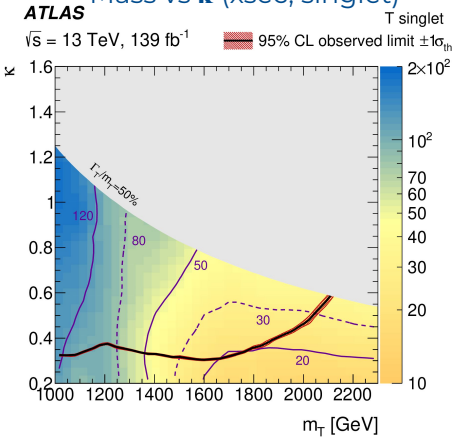
Mass vs κ (singlet)



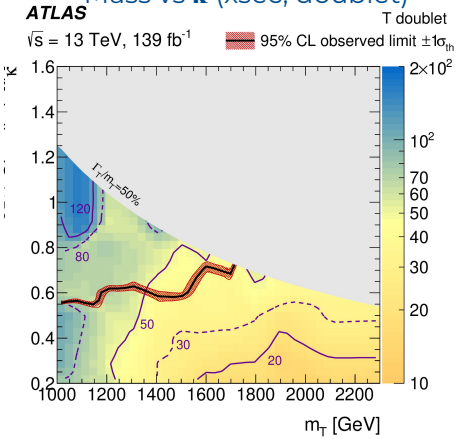
Mass vs κ (doublet)



Mass vs κ (xsec, singlet)

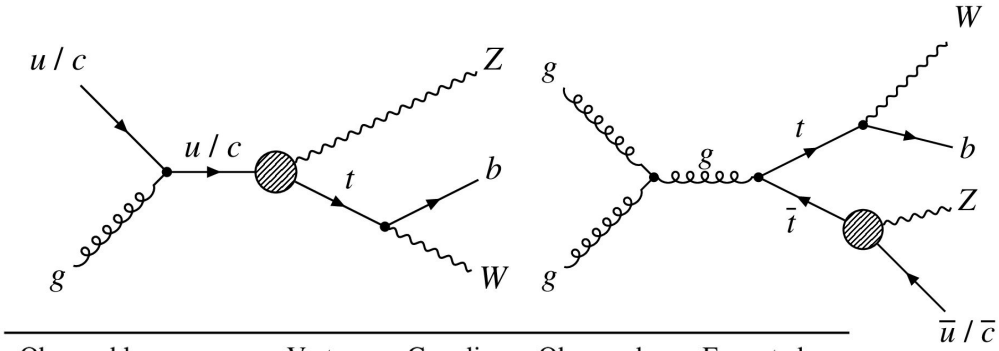


Mass vs κ (xsec, doublet)



FCNC t→qZ

arXiv:2301.11605

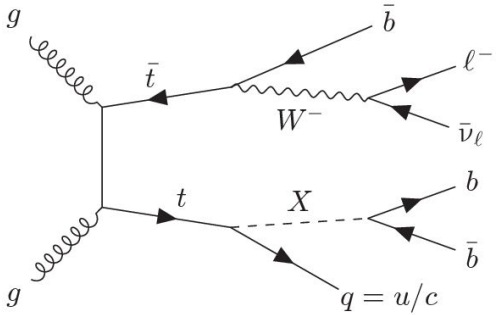


Vertex	Coupling	μ
tZu	LH	$0.08 \pm 0.12\ (\text{stat.}) \pm 0.08\ (\text{syst.})$
tZu	RH	$0.10 \pm 0.12\ (\text{stat.}) \pm 0.08\ (\text{syst.})$
tZc	LH	$0.10 \pm 0.17\ (\text{stat.}) \pm 0.14\ (\text{syst.})$
tZc	RH	$0.06 \pm 0.16\ (\text{stat.}) \pm 0.13\ (\text{syst.})$

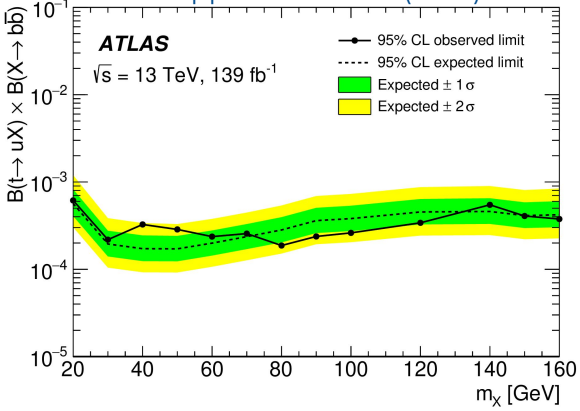
Observable	Vertex	Coupling	Observed	Expected
	SRs+CRs			
$\mathcal{B}(t \to Zq)$	tZu	LH	6.2×10^{-5}	$4.9\,^{+2.1}_{-1.4}\times10^{-5}$
$\mathcal{B}(t \to Zq)$	tZu	RH	6.6×10^{-5}	$5.1\,^{+2.1}_{-1.4}\times10^{-5}$
$\mathcal{B}(t \to Zq)$	tZc	LH	13×10^{-5}	$11\,^{+5}_{-3}\times10^{-5}$
$\mathcal{B}(t \to Zq)$	tZc	RH	12×10^{-5}	$10\,^{+4}_{-3}\times10^{-5}$
$\lvert C_{uW}^{(13)*}\rvert$ 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	$0.19\,^{+0.04}_{-0.03}$
	SR1+CRs			
$\mathcal{B}(t \to Zq)$	tZu	LH	9.7×10^{-5}	$8.6\,^{+3.6}_{-2.4}\times10^{-5}$
$\mathcal{B}(t \to Zq)$	tZu	RH	9.5×10^{-5}	$8.2\,^{+3.4}_{-2.3}\times10^{-5}$
	SR2+CRs			
$\mathcal{B}(t \to Zq)$	tZu	LH	7.8×10^{-5}	$6.1\,^{+2.7}_{-1.7}\times10^{-5}$
$\mathcal{B}(t \to Zq)$	tZu	RH	9.0×10^{-5}	$6.6\,^{+2.9}_{-1.8}\times10^{-5}$

FCNC t→qX(bb)

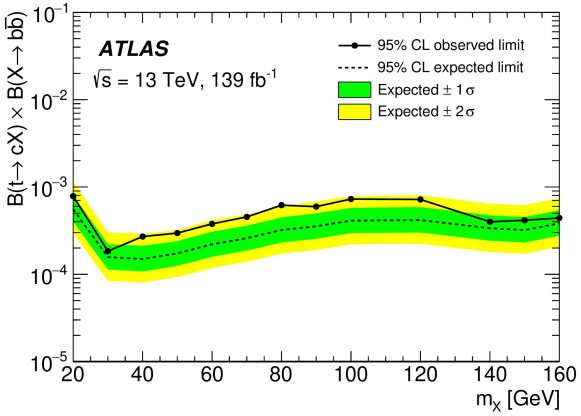
arXiv:2301.03902

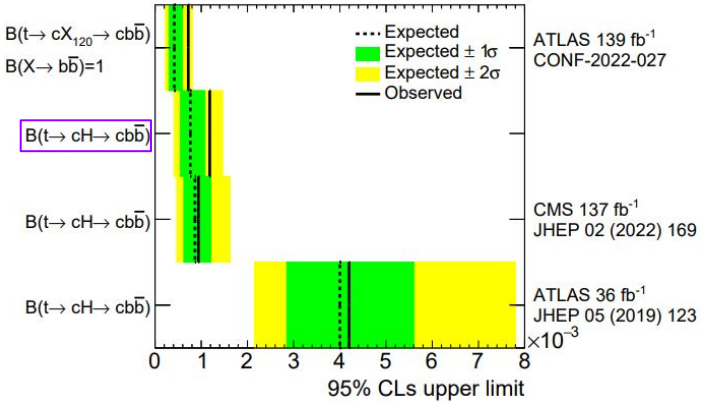


Upper limits on B(t→uX)



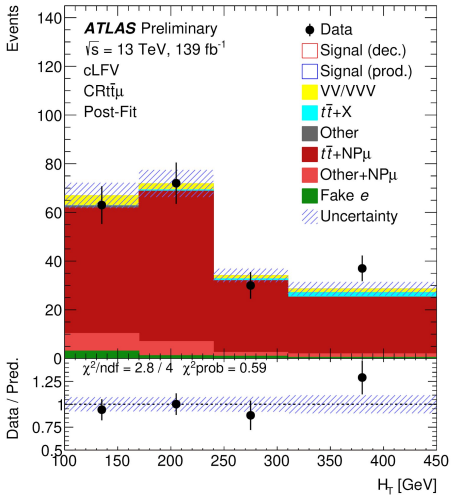
Upper limits on B(t→cX)

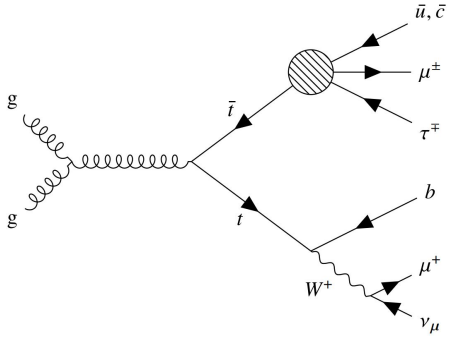


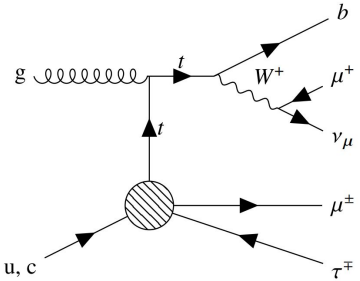


cLFV tμτq

ATLAS-CONF-2023-001







	95% CL upper limits on Wilson coefficients c/Λ^2 [TeV^{-2}]							
	$c_{lq}^{-(ijk3)}$	$c_{eq}^{(ijk3)}$	$c_{lu}^{(ijk3)}$	$c_{eu}^{(ijk3)}$	$c_{lequ}^{1(ijk3)}$	$c_{lequ}^{1(ij3k)}$	$c_{lequ}^{3(ijk3)}$	$c_{lequ}^{3(ij3k)}$
Previous (u) [22]	12	12	12	12	26	26	3.4	3.4
Expected (u)	0.47	0.44	0.43	0.46	0.49	0.49	0.11	0.11
Observed (u)	0.49	0.47	0.46	0.48	0.51	0.51	0.11	0.11
Previous (c) [22]	14	14	14	14	29	29	3.7	3.7

	95% CL upper limits on BR($t \to \mu\tau q$) ($\times 10^{-7}$)							
	$c_{lq}^{-(ijk3)}$	$c_{eq}^{(ijk3)}$	$c_{lu}^{(ijk3)}$	$c_{eu}^{(ijk3)}$	$c_{lequ}^{1(ijk3)}$	$c_{lequ}^{1(ij3k)}$	$c_{lequ}^{3(ijk3)}$	$c_{lequ}^{3(ij3k)}$
Expected (u)	4.6	4.2	4.0	4.5	2.5	2.5	5.8	5.8
Observed (u)	5.1	4.6	4.4	5.0	2.8	2.8	6.4	6.4
Expected (c)	54	51	51	52	35	35	61	61
Observed (c)	60	56	56	57	38	38	68	68