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Searches for FCNC and lepton flavor violation in top quark interaction

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Introduction

- SM has been successful for many years, but recently several excesses are reported
  - Lepton flavor violation: Combined result of R(D) and R(D*) anomalies, 3.3σ deviation from SM [1]
  - W boson mass measurement from CDF II [2] reported 7.0σ of deviation
  - Muon g-2 measurement [3] recently showed 5.0σ discrepancy

- FCNC is highly suppressed in SM, due to Glashow-Iliopoulos-Maiani mechanism
  - FCNC top quark branching fractions (BF) ~ 10^{-12} - 10^{-17} in SM, can be enhanced as high as 10^{-4} - 10^{-6} in BSM
  - Theory predicts BF close to the sensitivity of LHC

- Considering recent experimental results, as well as theoretical motivations, various anomalous interactions have been explored in the top quark sector
  - Flavor-changing neutral currents (FCNC): tqH (H->$\tau\tau$) (ATLAS), tqγ (CMS), tqZ (ATLAS)
  - Lepton flavor violation (LFV): $e\mu$tq (trilepton, CMS), $\mu\tau$tq (ATLAS)
  - Effective field theory approach to the new physics -> EFT talk given by Andre, Aug 24

[1] HFLAV, Semileptonic B decay, 2023 (link)
[2] CDF Collaboration, Science 376 (2022) 6589, 170-176
[3] Muon g-2 Collaboration, arxiv:2308.06230

Search for tqH FCNC in H->$\tau\tau$

TOPQ-2019-17, JHEP 06 (2023) 155
L=139 fb^{-1}

ATLAS EXPERIMENT

- tqH FCNC where H->$\tau\tau$, in hadronic and leptonic τ decays
- Decay and production modes, interpreted in EFT:

$$\mathcal{L}_{EFT} = \frac{C_{u\phi}^{i3}}{\Lambda^2}(\phi^\dagger\phi)(\bar{q}_i t)\tilde{\phi} + \frac{C_{u\phi}^{3i}}{\Lambda^2}(\phi^\dagger\phi)(\bar{t} q_i)\tilde{\phi}$$

Decay: t -> u/c + H
Production: u/c -> t + H

- Signal channels (t_h: W->qq, t_l: W->$l\nu$, τ_{had}: hadrons + ν_τ, τ_{lep}: $l + \nu_l + \nu_\tau$)

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

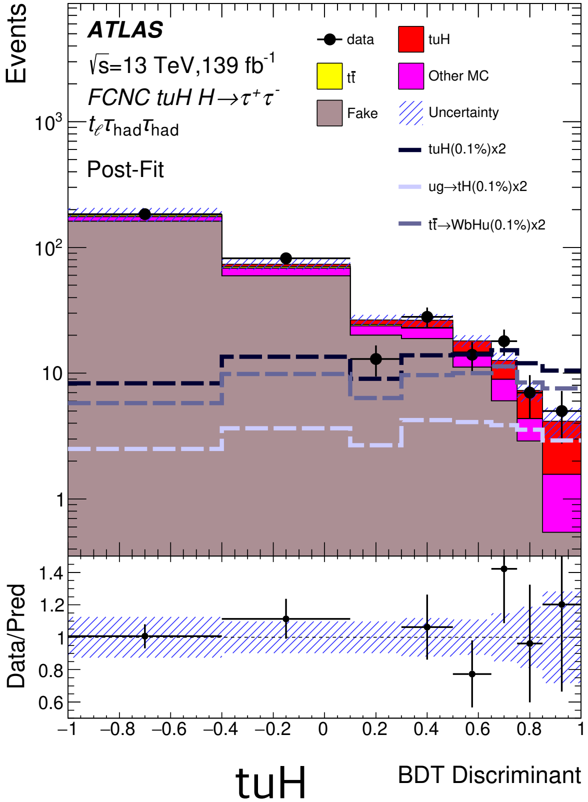
Further divided into 7 SRs based on light-jet multiplicity

  - τ_{had} is identified against jets with RNN based tagger, and e->τ_{had} fakes are suppresed by BDT
- Background estimation
  - Fake τ-leptons: Data-driven SF from $t\bar{t}$ CR (leptonic channel) or fake factor with loose τ identification
  - Fake light leptons: Data-drive ABCD method using loose identification and E_T^{miss}

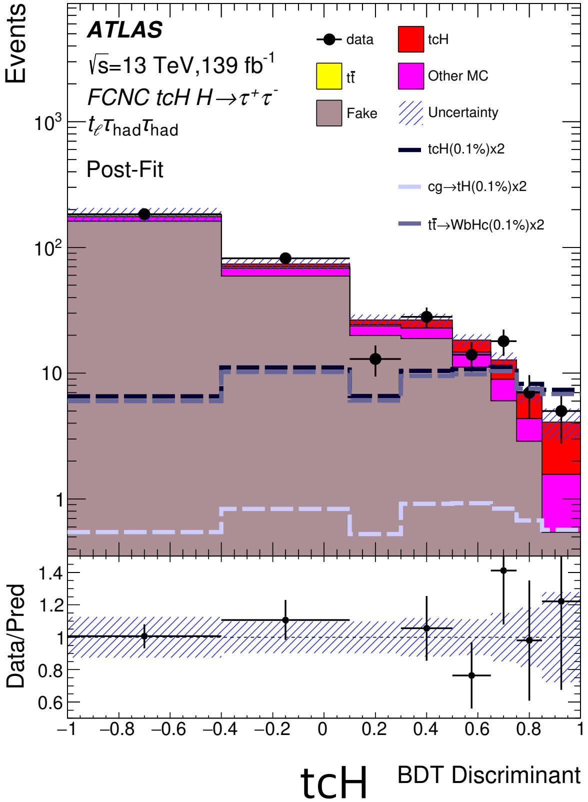
Search for tqH FCNC in H->$\tau\tau$

TOPQ-2019-17, JHEP 06 (2023) 155
L=139 fb^{-1}

- Signal extraction
  - 9 BDT for 7 SR + 2 validation region (SS τ_{had} pair)
  - Postfit distributions



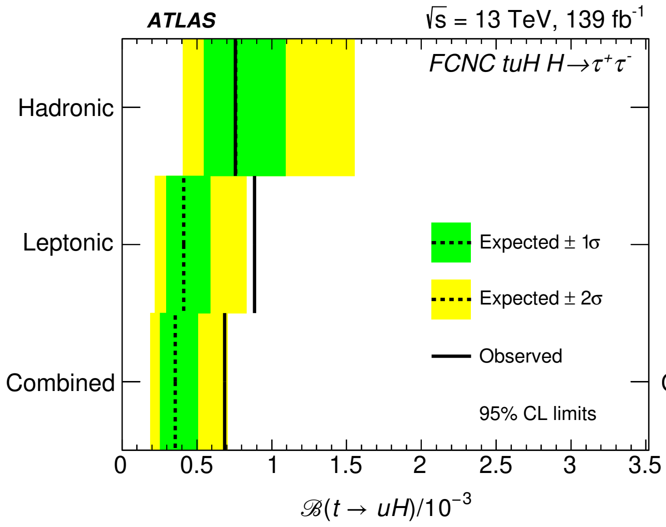
tuH

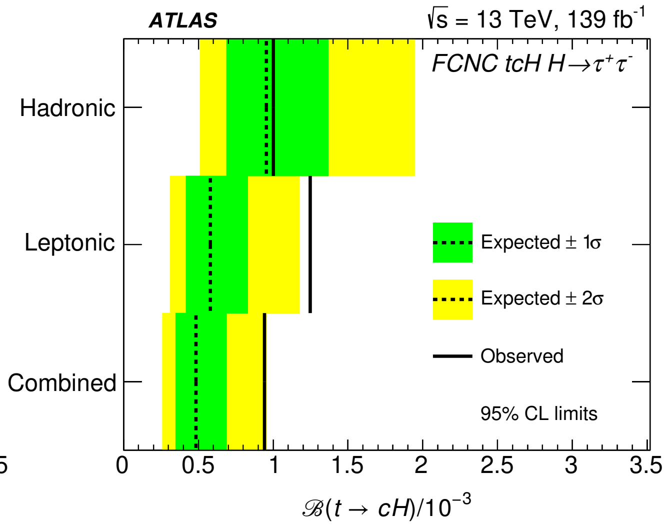


tcH

$t_l \, \tau_{had} \, \tau_{had}$ is the most sensitive channel

- Results
  - BF(t->uH) < 0.069% and BF(t->cH) < 0.094%





- Limits on the Wilson coefficients:
  $C_{u\phi} < 1.35, \;\; C_{c\phi} < 1.16$ ($C_{q\phi} = \sqrt{(C_{q\phi}^{i3})^2 + (C_{q\phi}^{3i})^2}$)
- Factor 2-4 improvement compared to previous ATLAS analyses [1,2] including τ leptons

[1] ATLAS tqH, H -> $\tau_{had}^{+}\tau_{had}^{-}$: JHEP 05 (2019) 123
[2] ATLAS tqH, H -> multilepton: Phys. Rev. D 98 (2018) 032002

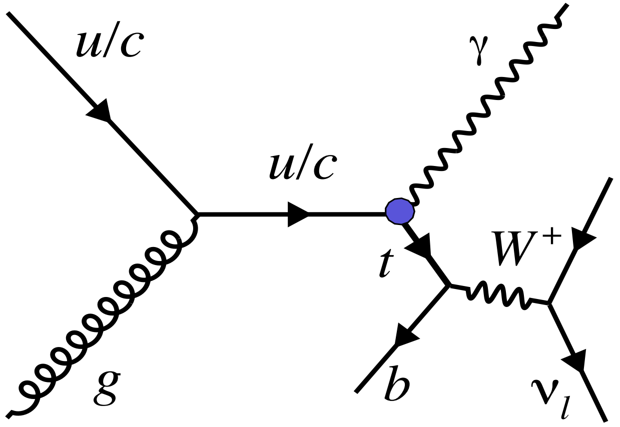
Search for tqγ FCNC

CMS TOP-21-013
L=138 fb^{-1}

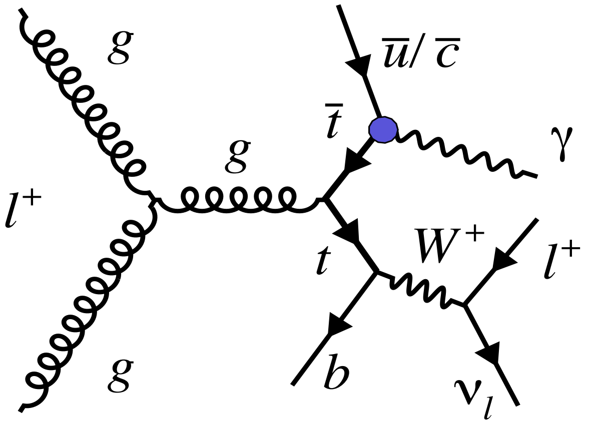
- FCNC search in tqγ coupling in single lepton final state
- Event signature

$$\mathcal{L}_{\text{eff}} = -e \sum_{\text{q=u,c}} \kappa_{\text{tq}\gamma} \bar{q}(\lambda^L_{\text{tq}\gamma} P_L + \lambda^R_{\text{tq}\gamma} P_R) \frac{i\sigma^{\mu\nu} q_\nu}{m_t} t A_\mu + h.c$$

  - 1 e or μ, 1 barrel γ, Z mass veto (e channel)
  - SR1: 1 b-jet (DeepCSV)
  - SR2: ≥ 2 jet, among which exactly 1 b-tagged

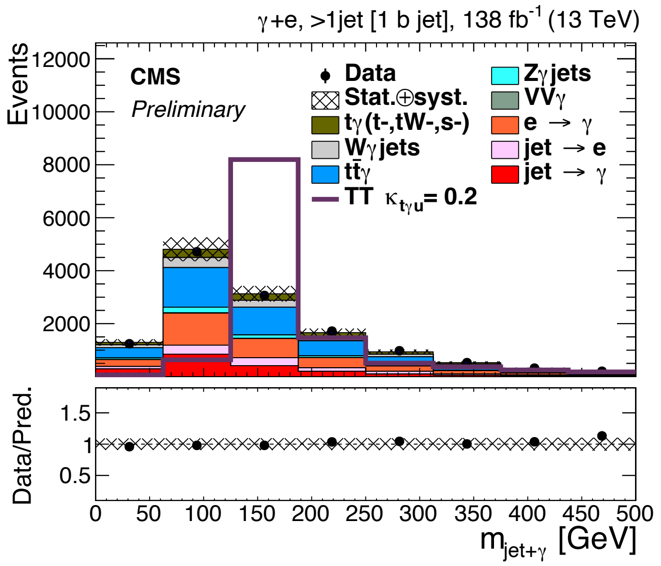


SR1 (production)



SR2 (decay)

- Background estimation
  - ttγ (≥2 b-jet), Z/Wγ (≥1 light jet) CR-> Fit to data gives normalization SF
  - Jet-> γ fake: ABCD using photon isolation and shower shape
  - Jet-> lepton fake: Fake rate using loose lepton identification
  - e -> γ fake: Correction factors are calculated in CR with Z mass window

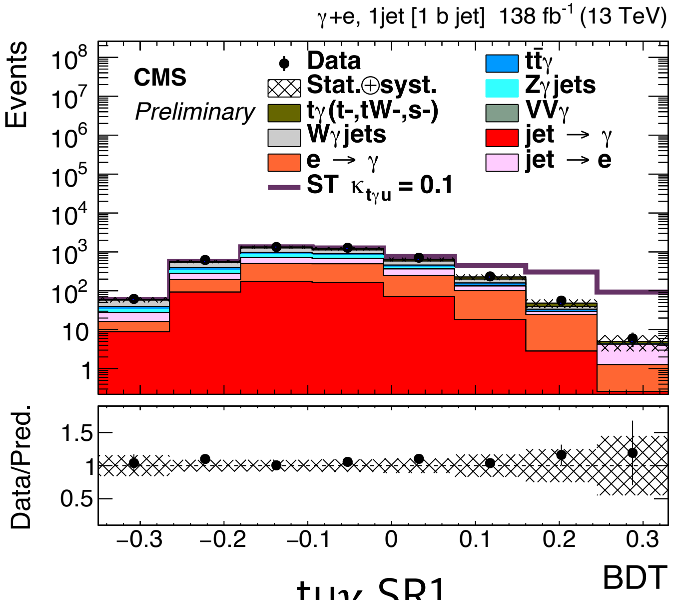


SR2, e channel

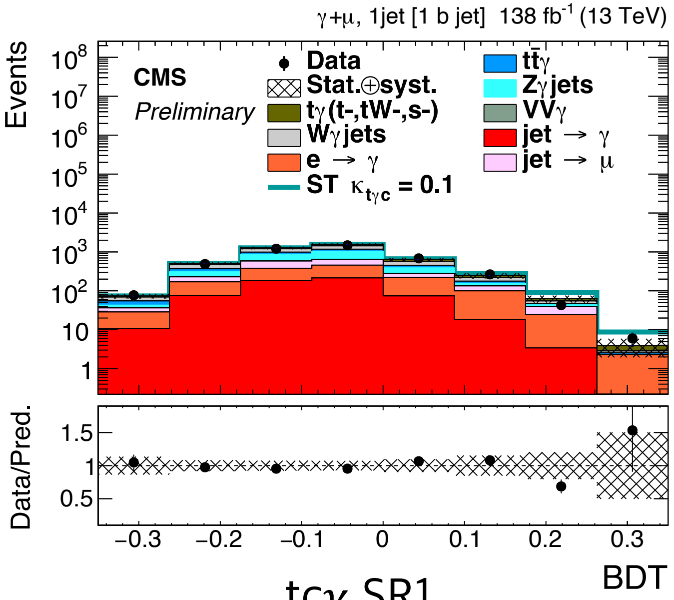
Search for tqγ FCNC

CMS TOP-21-013
L=138 fb^{-1}

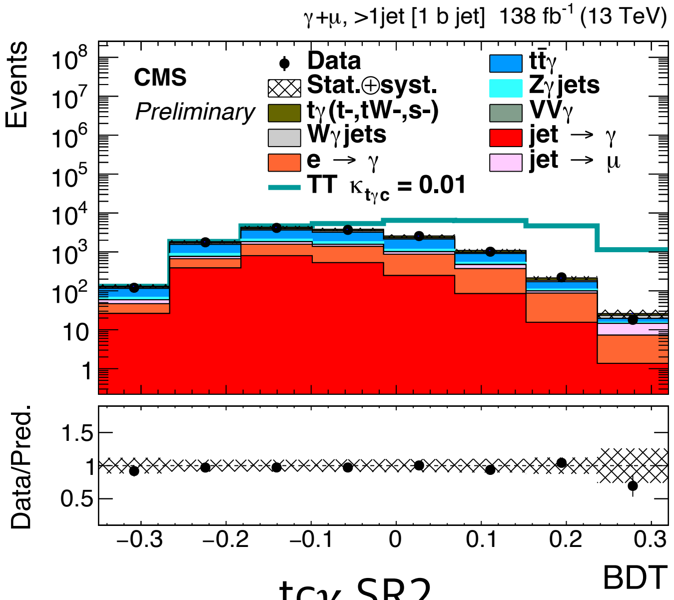
- BDT for each channel (e/μ), scenario (u/c), and SR
  - Postfit distributions show the benefit from SR1 in tuγ channel



tuγ SR1



tcγ SR1



tcγ SR2

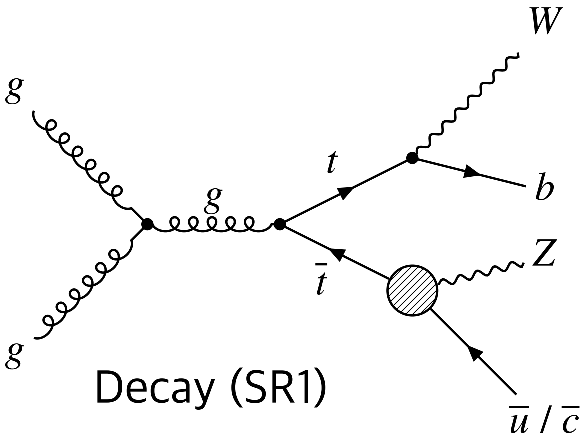
- Results
  - Limits on $\kappa_{tq\gamma}$ and BF
  - Best limit in tcγ channel

Combined	Obs. limit	Exp. limit
$\kappa_{\mathrm{tu}\gamma}$	6.2×10^{-3}	6.9×10^{-3}
$\kappa_{\mathrm{tc}\gamma}$	7.7×10^{-3}	7.8×10^{-3}
$\mathcal{B}(\mathrm{t} \to \mathrm{u} + \gamma)$	0.95×10^{-5}	1.20×10^{-5}
$\mathcal{B}(\mathrm{t} \to \mathrm{c} + \gamma)$	1.51×10^{-5}	1.54×10^{-5}

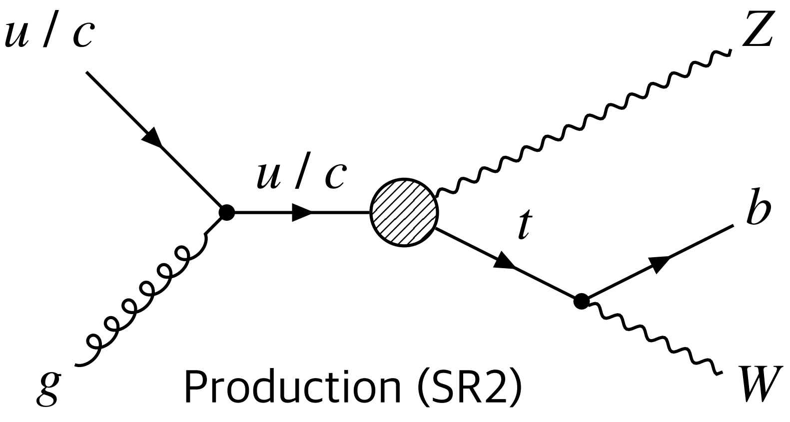
Search for tqZ FCNC

TOPQ-2019-06, arXiv:2301.11605
L=139 fb^{-1}

- Signal model based on EFT with dim-6 operators
  - 3 leptons, OSSF in Z mass window, jets, and b-tagging with DL1r algorithm



Decay (SR1)



Production (SR2)

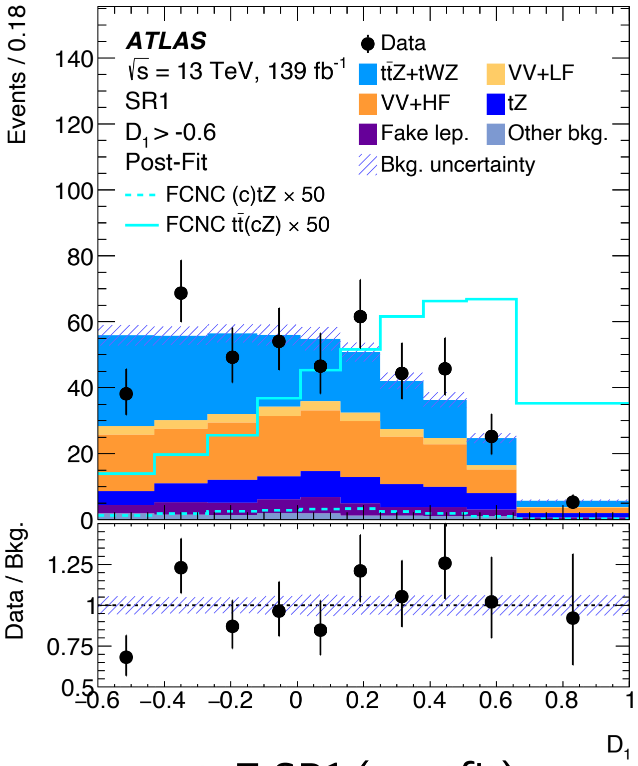
Coupling	Left-handed (LH)	Right-handed (RH)
tuZ	$C_{uB}^{(13)} + C_{uW}^{(13)}$	$C_{uB}^{(31)} + C_{uW}^{(31)}$
tcZ	$C_{uB}^{(23)} + C_{uW}^{(23)}$	$C_{uB}^{(32)} + C_{uW}^{(32)}$

  - SR1: ≥ 2 jet, exactly 1 b-tagged,   SR2: 1 or 2 jet, exactly 1 b-tagged
  - top quarks and W boson are reconstructed by χ^2 minimization
  - Reconstructed top quark masses are required within the 2 * resolution
- Backgrounds are estimated by MC prediction
- CR and side bands to handle normalization and systematic uncertainties
  - $t\bar{t}$ (OSOF), $t\bar{t}Z$ (≥ 4 jet, == 2 b-jet), and two side bands by inverting constraints on reconstructed mass

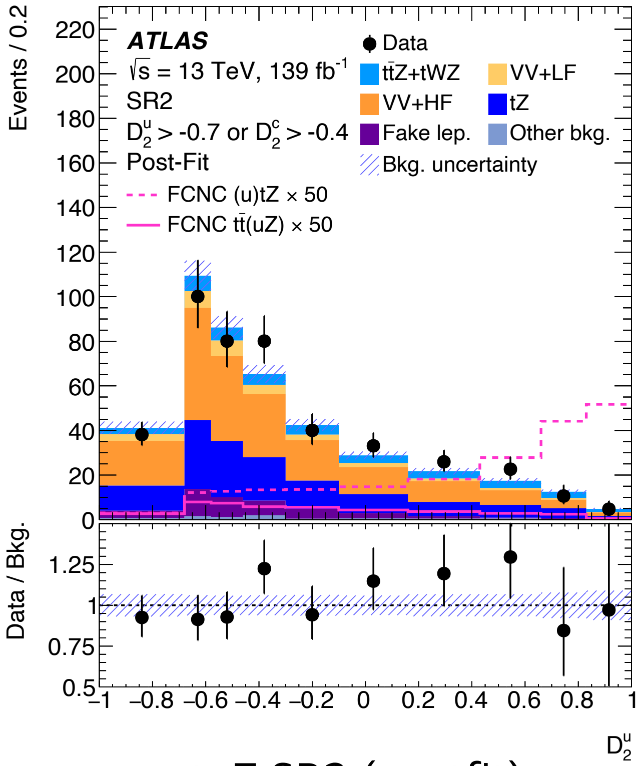
Search for tqZ FCNC

TOPQ-2019-06, arXiv:2301.11605
L=139 fb^{-1}

- Signal extraction using BDT
  - SR1: One BDT - tt signal vs all backgrounds (bkg.)
  - SR2: Separately for tuZ (st vs bkg.) and tcZ (st+tt vs bkg.), considering signal compositions
  - Cuts are applied to the BDT distributions to define validation regions to check fit stability



tcZ SR1 (postfit)



tuZ SR2 (postfit)

Results

- Factor 2-3 improvements compared to 36.1 fb^{-1} ATLAS results

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}	$10^{+4}_{-3}\times10^{-5}$

Summary of top FCNC result at LHC

- FCNC in top quark interaction couplings: tqH, tqγ, tqZ, tqg (q = up or charm)
  - Run 2 (137-139 fb^{-1}) are presented, unless specially marked
  - Only left-handed interactions are quoted
  - All observed limits approach the order of 10^{-4}-10^{-5}

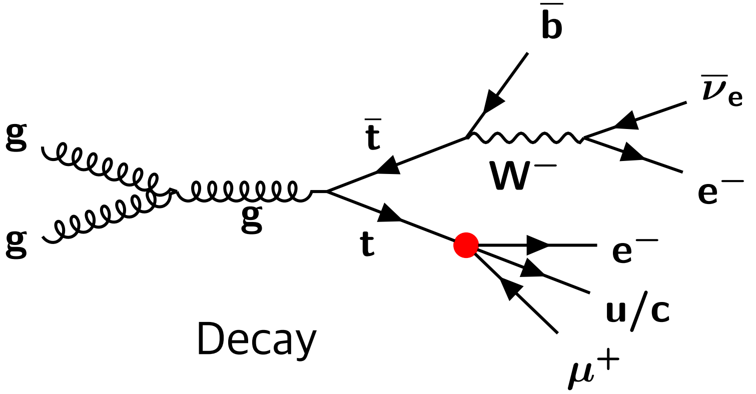
Covered in this talk

Process	SM	ATLAS	CMS	ATLAS ref.	CMS ref.
t -> uH	2×10^{-17}	6.9×10^{-4} ($\tau\tau$) 7.7×10^{-4} (bb)	1.9×10^{-4} ($\gamma\gamma$) 7.9×10^{-4} (bb)	JHEP 06 (2023) 155 ($\tau\tau$) JHEP 07 (2023) 199 (bb)	Phys. Rev. Lett. 129 (2022) 032001 ($\gamma\gamma$) JHEP 02 (2022) 169 (bb)
t -> cH	3×10^{-15}	9.4×10^{-4} ($\tau\tau$) 12×10^{-4} (bb)	7.3×10^{-4} ($\gamma\gamma$) 9.4×10^{-4} (bb)		
t -> uZ	8×10^{-17}	6.2×10^{-5}	2.4×10^{-4} (36 fb^{-1})	arXiv:2301.11605	CMS PAS-TOP-17-017
t -> cZ	1×10^{-14}	13×10^{-5}	4.5×10^{-4} (36 fb^{-1})		
t -> uγ	3.7×10^{-16}	0.85×10^{-5}	0.9×10^{-5}	Phys. Lett. B 842 (2023) 137379	CMS PAS-TOP-21-013
t -> cγ	4.6×10^{-14}	4.2×10^{-5}	1.51×10^{-5}		
t -> ug	3.7×10^{-14}	0.61×10^{-4}	0.2×10^{-4} (7+8 TeV)	Eur. Phys. J. C 82 (2022) 334	JHEP 02 (2017) 028
t -> cg	4.6×10^{-12}	3.7×10^{-4}	4.1×10^{-4} (7+8 TeV)		

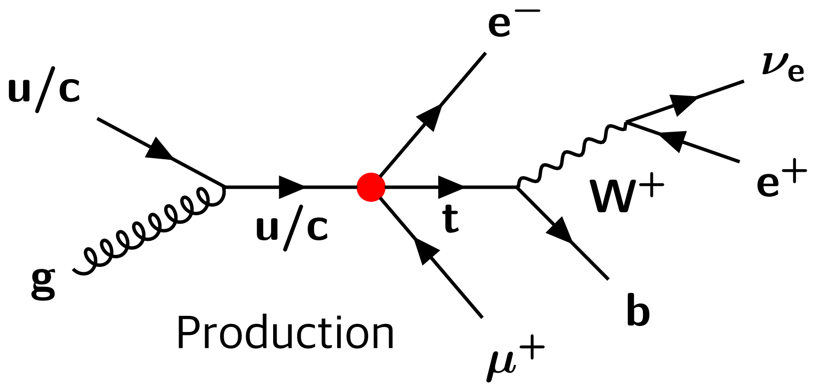
CLFV in $e\mu\ell$ channel

CMS TOP-22-005
L=138 fb^{-1}

- Charged Lepton Flavor Violation (CLFV) in trilepton channel
- Event signature: $e\mu$tu and $e\mu$tc vertices



Decay

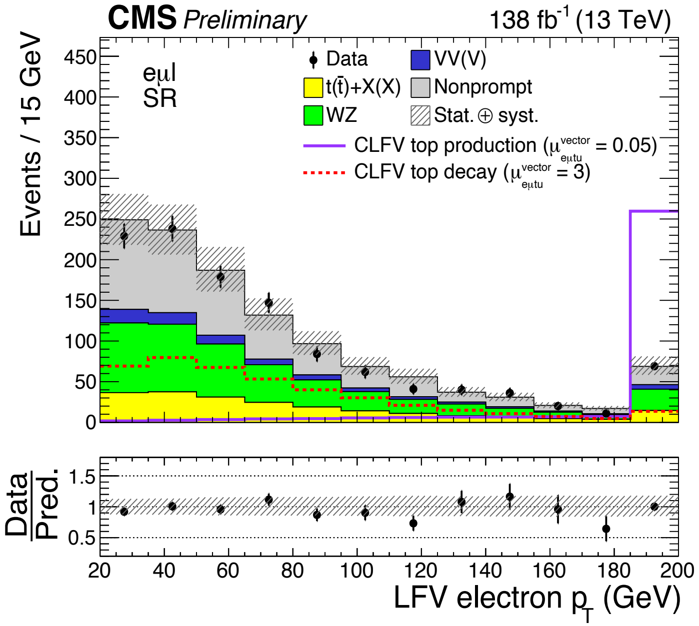


Production

$$\mathcal{L} = \mathcal{L}_{\rm SM}^{(4)} + \frac{1}{\Lambda^2}\sum_a C_a^{(6)} O_a^{(6)} + O(\frac{1}{\Lambda^4})$$

vector	$O_{lq}^{(1)ijkl}$	$(\bar{l}_i\gamma^\mu l_j)(\bar{q}_k\gamma^\mu q_l)$
	O_{lu}^{ijkl}	$(\bar{l}_i\gamma^\mu l_j)(\bar{u}_k\gamma^\mu u_l)$
	O_{eq}^{ijkl}	$(\bar{e}_i\gamma^\mu e_j)(\bar{q}_k\gamma^\mu q_l)$
	O_{eu}^{ijkl}	$(\bar{e}_i\gamma^\mu e_j)(\bar{u}_k\gamma^\mu u_l)$
scalar	$O_{lequ}^{(1)ijkl}$	$(\bar{l}_i e_j)\ \varepsilon\ (\bar{q}_k u_l)$
tensor	$O_{lequ}^{(3)ijkl}$	$(\bar{l}_i\sigma^{\mu\nu} e_j)\ \varepsilon\ (\bar{q}_k\sigma_{\mu\nu} u_l)$

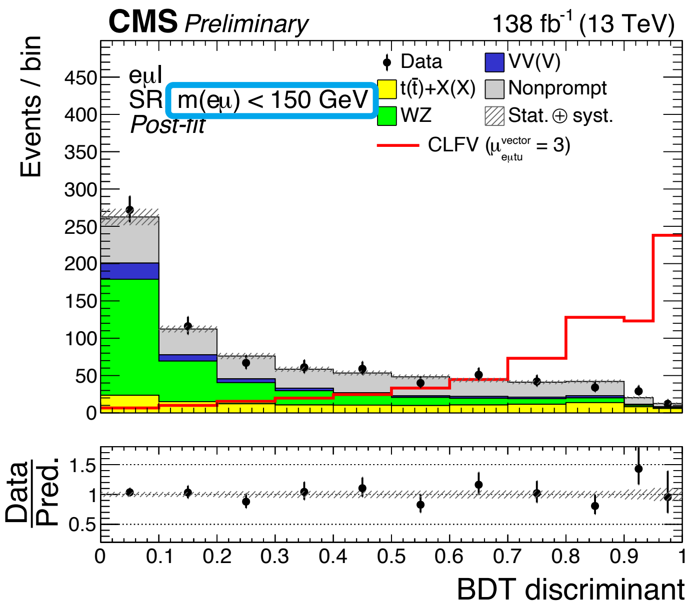
  - 3 leptons with OS $e\mu$ pair, leading lepton p_T > 38 GeV
  - SR ($e\mu l$): Off-Z, ≥ 1 jet, ≤ 1 b-jet (DeepJet)
- Background estimation
  - Prompt backgrounds rely on the simulation
  - Nonprompt backgrounds estimated by data-driven "Matrix method"
  - Estimated events are validated using control/validation regions

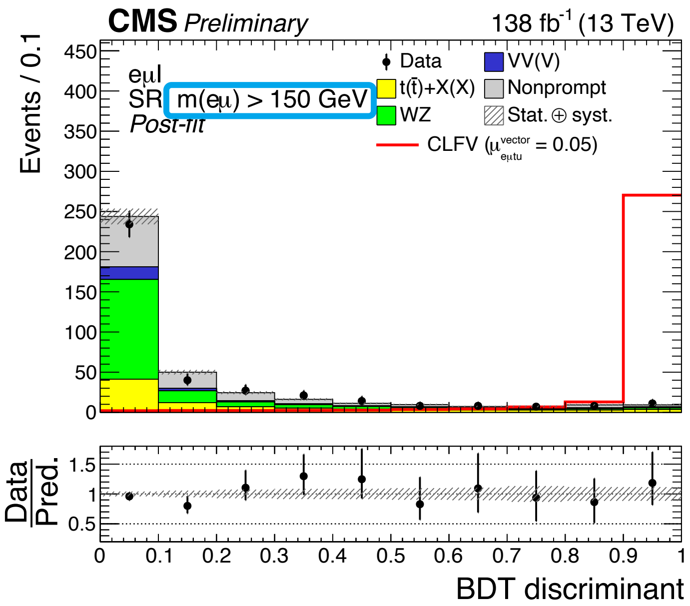


CLFV in $e\mu\ell$ channel

CMS TOP-22-005
L=138 fb^{-1}

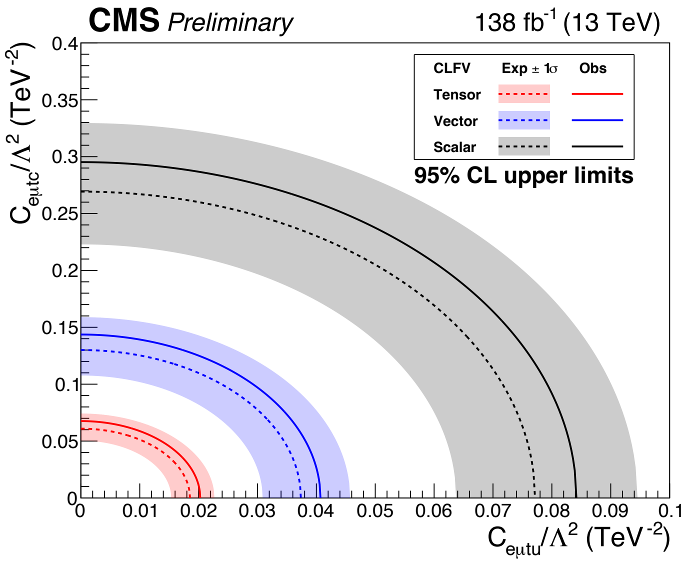
- BDT for signal extraction
  - Separately trained for top decay (m($e\mu$) < 150 GeV) and production (m($e\mu$) > 150 GeV) enriched regions





- Results
  - Tensor structure gives best constrains on operators due to higher cross sections
  - Interpolated limits are calculated
  - One order of magnitude improvement compared to previous CMS analysis [1]

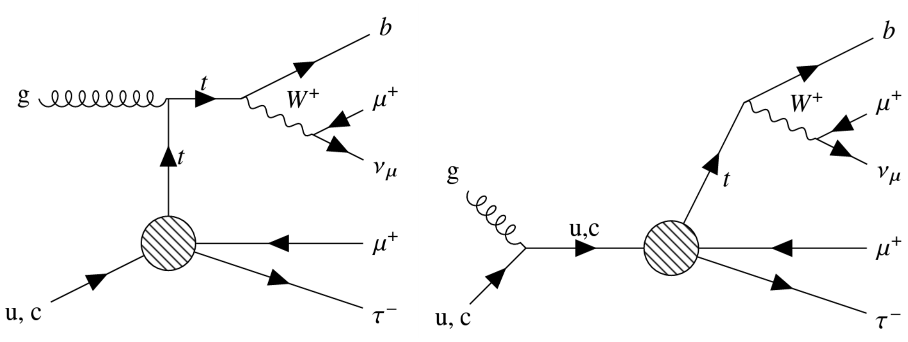
CLFV coupling	Lorentz structure	$C_{e\mu tq}/\Lambda^2$ (TeV^{-2}) exp ($-\sigma$, $+\sigma$)	obs	$\mathcal{B}(t \to e\mu q) \times 10^{-6}$ exp ($-\sigma$, $+\sigma$)	obs
$e\mu tu$	tensor	0.019 (0.015, 0.023)	**0.020**	0.019 (0.013, 0.029)	**0.023**
	vector	0.037 (0.031, 0.046)	**0.041**	0.013 (0.009, 0.020)	**0.016**
	scalar	0.077 (0.064, 0.095)	**0.084**	0.007 (0.005, 0.011)	**0.009**
$e\mu tc$	tensor	0.061 (0.050, 0.074)	**0.068**	0.209 (0.143, 0.311)	**0.258**
	vector	0.130 (0.108, 0.159)	**0.144**	0.163 (0.111, 0.243)	**0.199**
	scalar	0.269 (0.223, 0.330)	**0.295**	0.087 (0.060, 0.130)	**0.105**



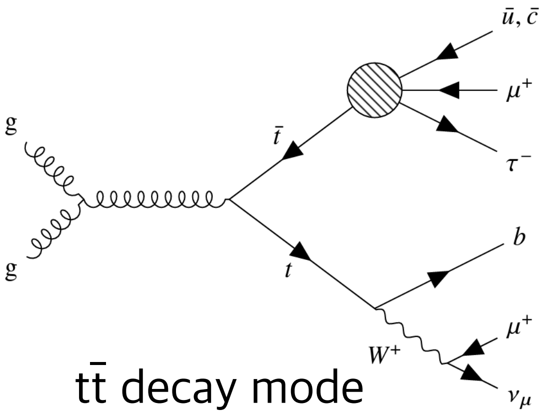
CLFV in $\mu\tau$tq channel

ATLAS-CONF-2023-001
L=139 fb^{-1}

- CLFV in the final state muons and hadronically decaying tau lepton



ST production modes

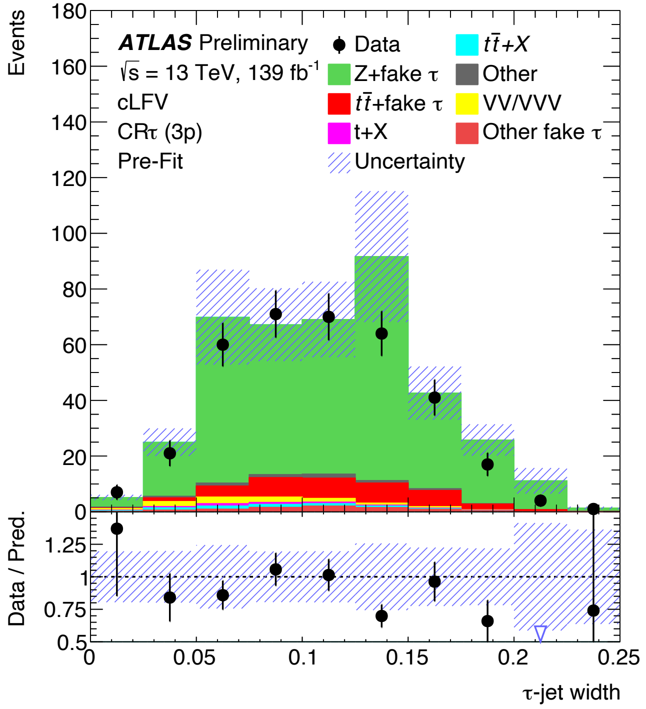


$t\bar{t}$ decay mode

- Similar set of EFT operator as CMS TOP-22-005
  - Defined $c_{lq}^{-(ijkl)} \equiv c_{lq}^{1(ijkl)} - c_{lq}^{3(ijkl)}$
  - Scalar, vector, and tensor structures

  - Hadronic tau with BDT (vs e) and RNN (vs jet) based identifications
  - SS muons, 1 hadronic τ, $\geq$ 1 jet, and exactly 1 b-jet
  - Not distinguish up and charm quark experimentally

- Background estimation
  - Measured SF of fake tau events in CRτ (OS muon)
  - Nonprompt muon contribution estimated by the fit in CRttμ ($e\mu\mu$)

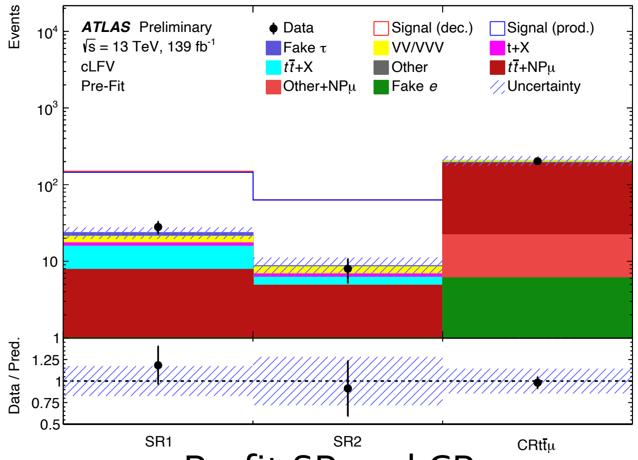


Prefit CRτ for 3-prong tau

CLFV in $\mu\tau$tq channel

ATLAS-CONF-2023-001
L=139 fb^{-1}

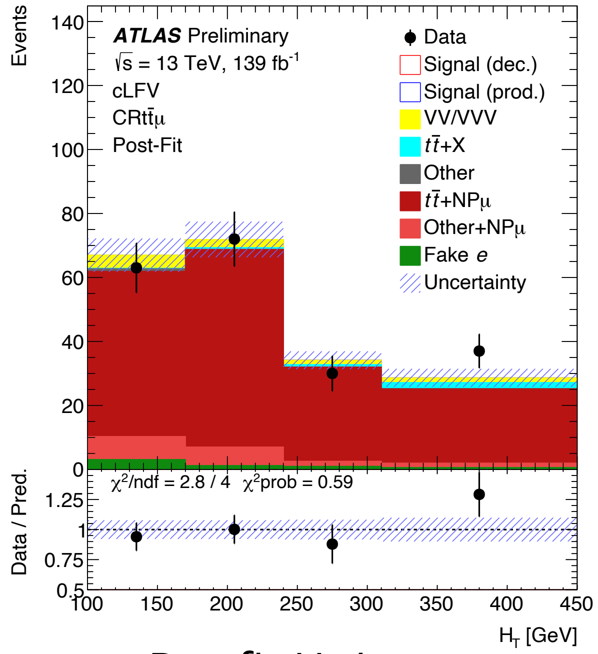
- Signal extraction
  - Signal and nonprompt muon contributions are estimated from the fit to data
    - Single bin for each SR and a HT distribution for the CR
    - Set upper limits on each EFT coupling, and BF(t->$\mu\tau$q) is calculated with total signal



Prefit SR and CR

- Results
  - Yields BF ~ 10^{-6} - 10^{-7} for each Wilson coefficient
  - Improve previous constraints [1] on $c_{lq}^{-(2323)}$ ($\mu\tau$tc) and $c_{lequ}^{1(2313)}$ ($\mu\tau$tu) by factor 8 and 51, respectively

[1] ATLAS tqZ FCNC: JHEP 07 (2018) 176



Postfit H_T in CRttμ

	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
	Vector				Scalar		Tensor	

	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}

Conclusion

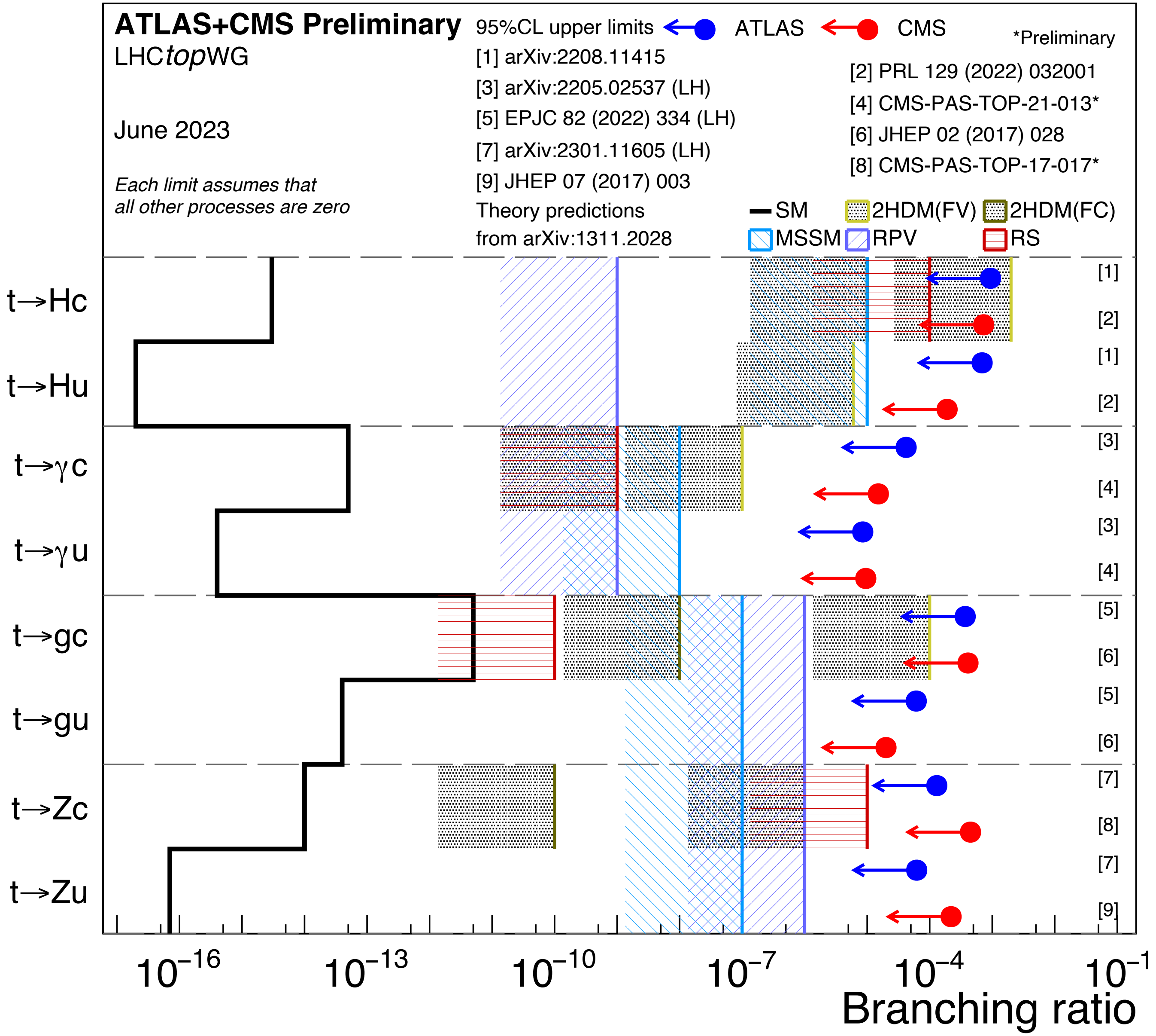
- ATLAS and CMS continue searching for FCNC and LFV in top quark interactions
  - With Run 2 (137–139 fb^{-1}) data set, SM has been tested at higher precision
- No sign of new physics beyond SM prediction so far
  - FCNC branching fraction limits at the order of 10^{-4} –10^{-5}
  - Constraints on BF of top quark CLFV interactions up to 10^{-6} - 10^{-8} using EFT
- Still, unfilled final states exist!

  More results will come with the full Run 2 data set as well as fresh Run 3 data

Backup

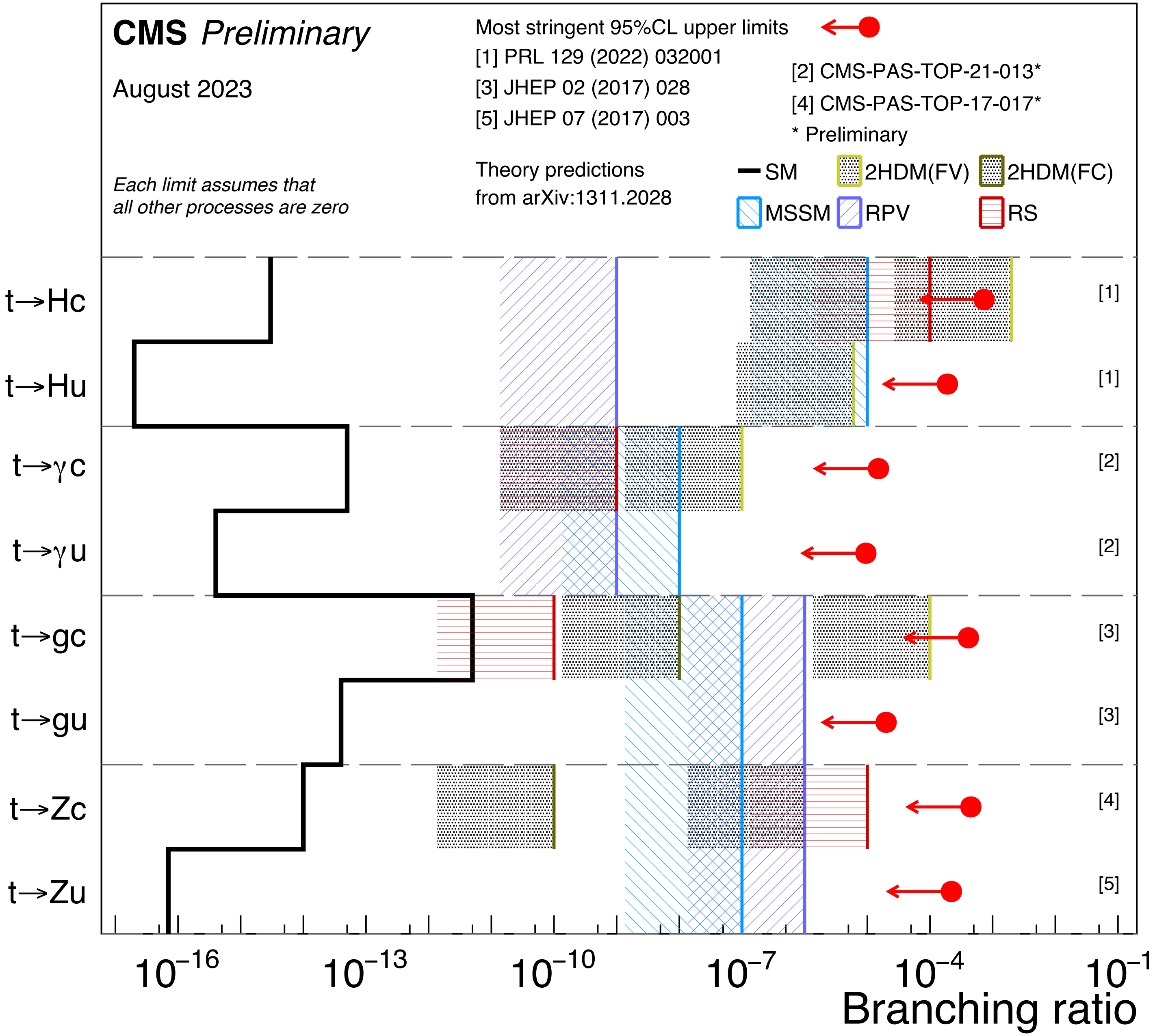
FCNC Summary plot

- As of June 2023



FCNC Summary plot

- CMS only, as of August



Search for tqH FCNC in H->$\tau\tau$

TOPQ-2019-06, JHEP 06 (2023) 155
L=139 fb^{-1}

ATLAS EXPERIMENT

- Tau decay modes

Decay mode	Resonance	$\mathcal{B}$ (%)	
Leptonic decays		35.2	
$\tau^- \to e^- \bar{\nu}_e \nu_\tau$			17.8
$\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$			17.4
Hadronic decays		64.8	
$\tau^- \to h^- \nu_\tau$			11.5
$\tau^- \to h^- \pi^0 \nu_\tau$	$\rho(770)$		25.9
$\tau^- \to h^- \pi^0 \pi^0 \nu_\tau$	$a_1(1260)$		9.5
$\tau^- \to h^- h^+ h^- \nu_\tau$	$a_1(1260)$		9.8
$\tau^- \to h^- h^+ h^- \pi^0 \nu_\tau$			4.8
Other			3.3

- SR, VR, and CR definitions

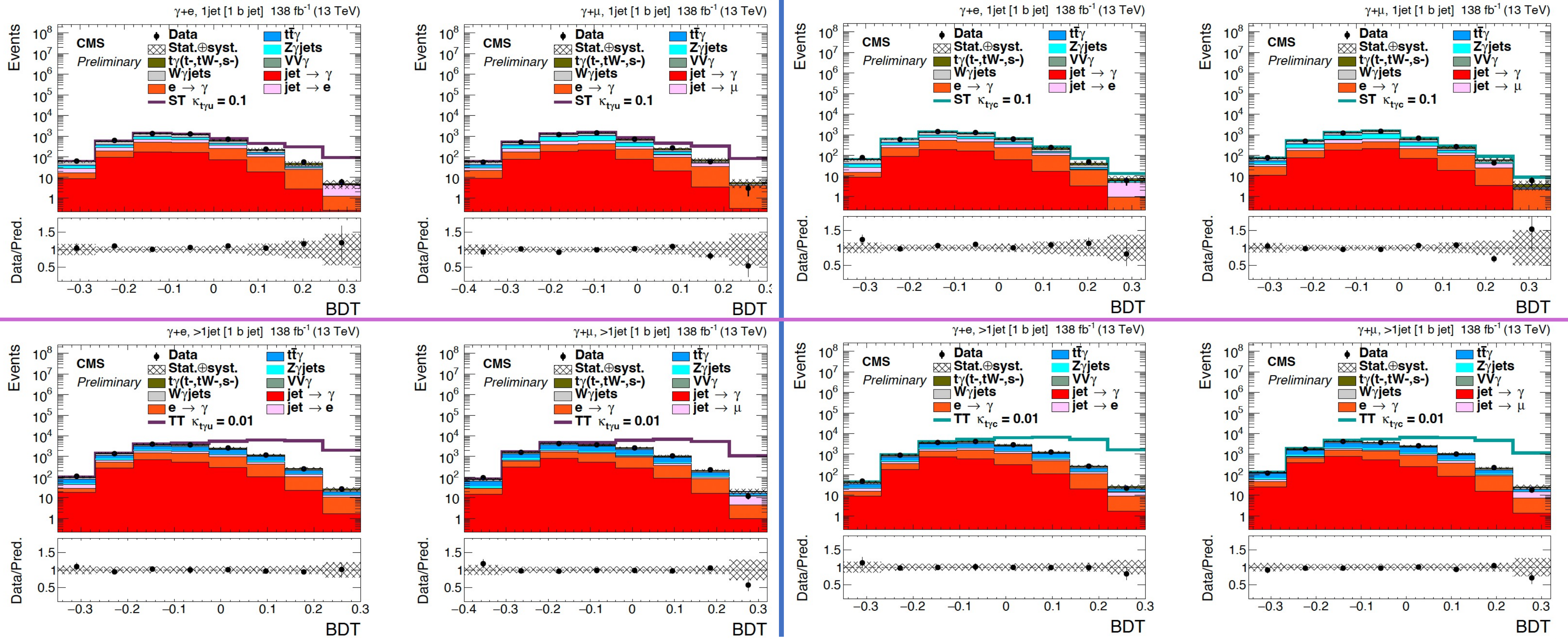
Regions		b-jets	Light-flavour jets	Leptons	Hadronic τ decays	Charge
SR	$t_\ell \tau_{had} \tau_{had}$	1	≥ 0	1	2	$\tau_{had}\tau_{had}$ OS
	$t_\ell \tau_{had}$-1j	1	1	1	1	$t_\ell \tau_{had}$ SS
	$t_\ell \tau_{had}$-2j	1	2	1	1	$t_\ell \tau_{had}$ SS
	$t_h \tau_{lep} \tau_{had}$-2j	1	2	1	1	$\tau_{lep}\tau_{had}$ OS
	$t_h \tau_{lep} \tau_{had}$-3j	1	≥ 3	1	1	$\tau_{lep}\tau_{had}$ OS
	$t_h \tau_{had} \tau_{had}$-2j	1	2	0	2	$\tau_{had}\tau_{had}$ OS
	$t_h \tau_{had} \tau_{had}$-3j	1	≥ 3	0	2	$\tau_{had}\tau_{had}$ OS
VR	$t_\ell \tau_{had} \tau_{had}$-SS	1	≥ 0	1	2	$\tau_{had}\tau_{had}$ SS
	$t_h \tau_{had} \tau_{had}$-3j SS	1	≥ 3	0	2	$\tau_{had}\tau_{had}$ SS
CRtt	$t_\ell t_\ell 1b \tau_{had}$	1	≥ 0	2	1	$t_\ell t_\ell$ OS
	$t_\ell t_\ell 2b \tau_{had}$	2	≥ 0	2	1	$t_\ell t_\ell$ OS
	$t_\ell t_h 2b \tau_{had}$-2jSS	2	2	1	1	$t_\ell \tau_{had}$ SS
	$t_\ell t_h 2b \tau_{had}$-2jOS	2	2	1	1	$t_\ell \tau_{had}$ OS
	$t_\ell t_h 2b \tau_{had}$-3jSS	2	≥ 3	1	1	$t_\ell \tau_{had}$ SS
	$t_\ell t_h 2b \tau_{had}$-3jOS	2	≥ 3	1	1	$t_\ell \tau_{had}$ OS

Search for tqγ FCNC

CMS TOP-21-013
L=138 fb^{-1}

- tuγ (left four) and tcγ (right)

SR1 (production, up)



SR2 (decay, down)

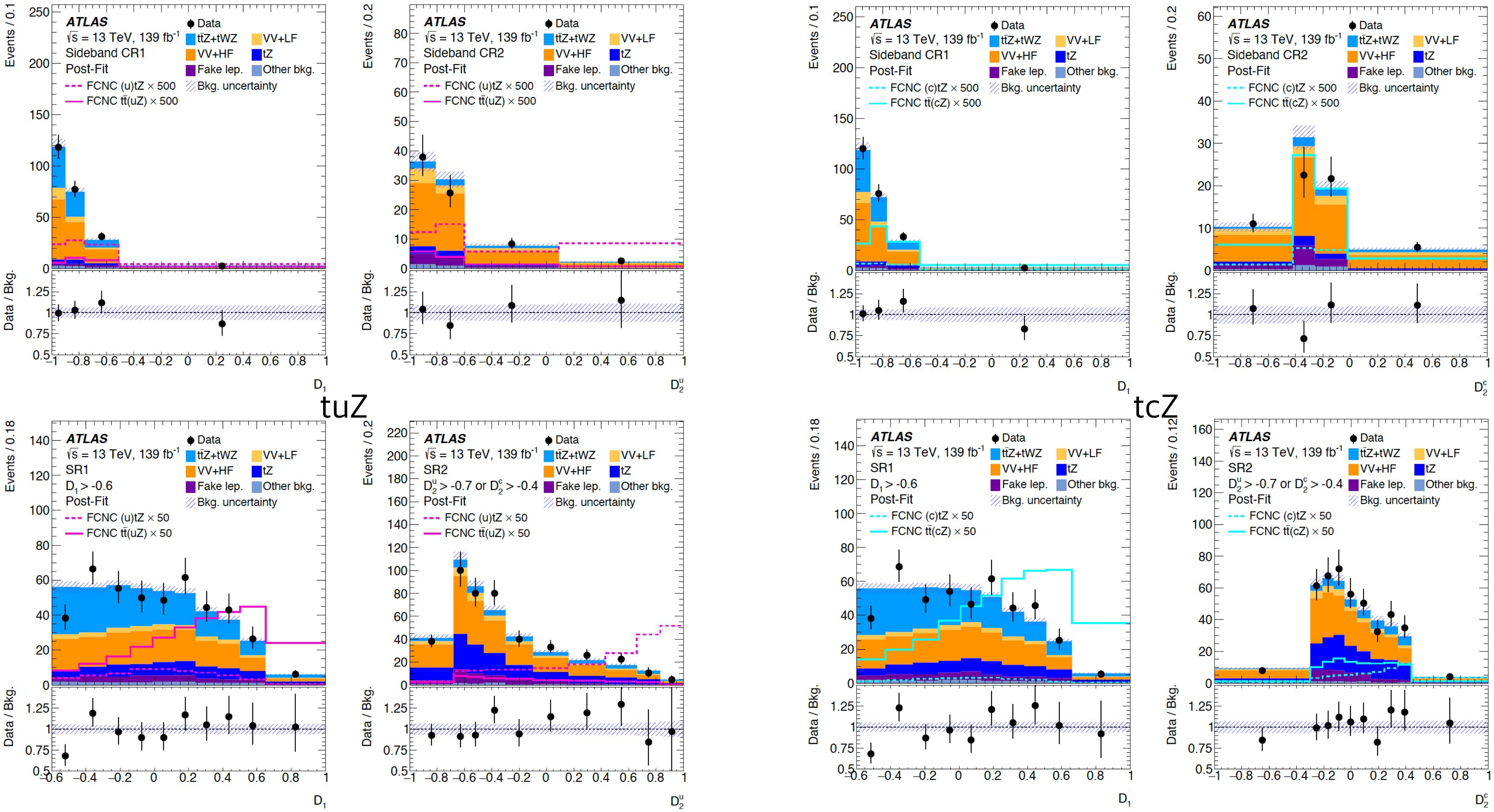
Search for tqZ FCNC

TOPQ-2019-06, arXiv:2301.11605
L=139 fb^{-1}

ATLAS EXPERIMENT

- BDT distributions in mass side band (up) and SR (down)

SR1: Decay, SR2: Production



Search for tqZ FCNC

TOPQ-2019-06, arXiv:2301.11605
L=139 fb^{-1}

ATLAS EXPERIMENT

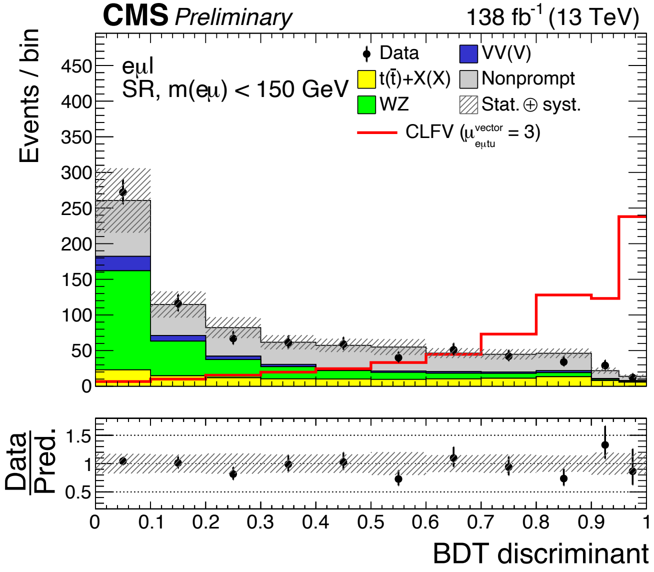
- Limits on B (LH, RH separately, SRs together or separately) and Wilson coefficient

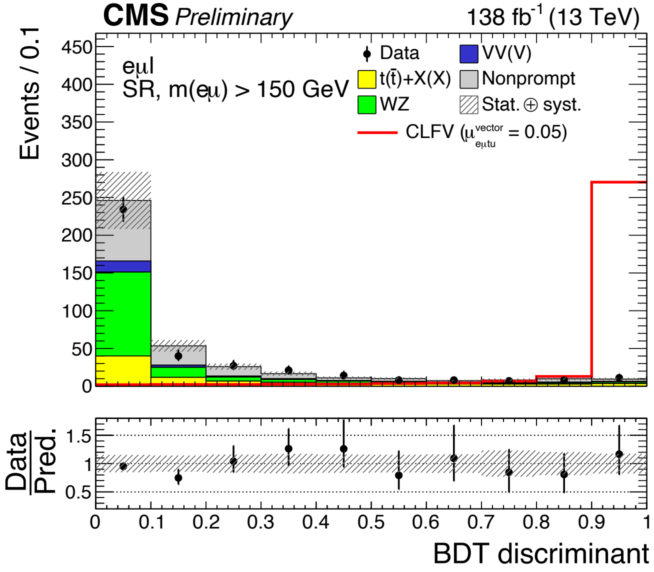
Observable	Vertex	Coupling	Observed	Expected
	SRs+CRs			
$\mathcal{B}(t \to Zq)$	tZu	LH	6.2×10^{-5}	$4.9\,^{+2.1}_{-1.4} \times 10^{-5}$
$\mathcal{B}(t \to Zq)$	tZu	RH	6.6×10^{-5}	$5.1\,^{+2.1}_{-1.4} \times 10^{-5}$
$\mathcal{B}(t \to Zq)$	tZc	LH	13×10^{-5}	$11\,^{+5}_{-3} \times 10^{-5}$
$\mathcal{B}(t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

CLFV in $e\mu\ell$ channel

CMS TOP-22-005
L=138 fb^{-1}

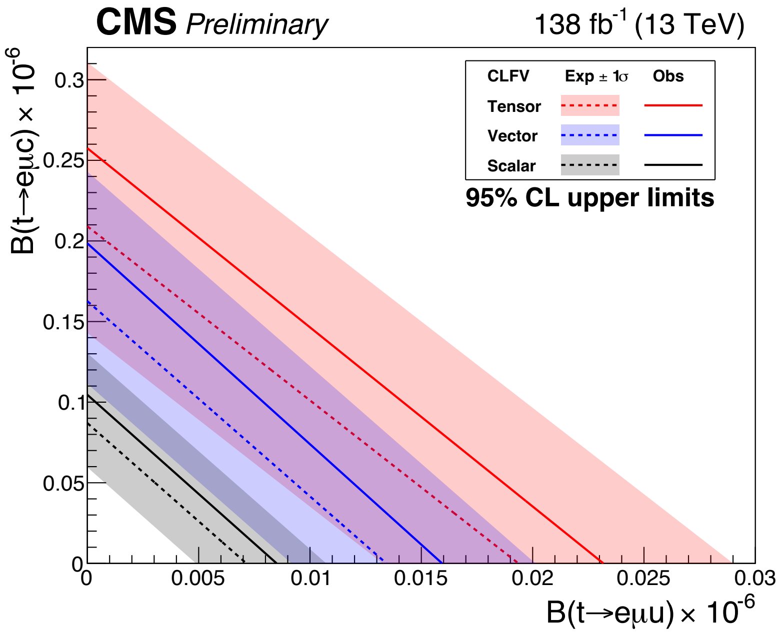
- Prefit BDT distributions





- 2D limit interpolation for branching fractions

$$\kappa^2_{\mathrm{tqH}}\,\Gamma_{\mathrm{tqH}} = \mathcal{B}(t \to \mathrm{qH})\,\Gamma_{\mathrm{t}}$$



CLFV in $\mu\tau$tq channel

ATLAS-CONF-2023-001
L=139 fb^{-1}

ATLAS EXPERIMENT

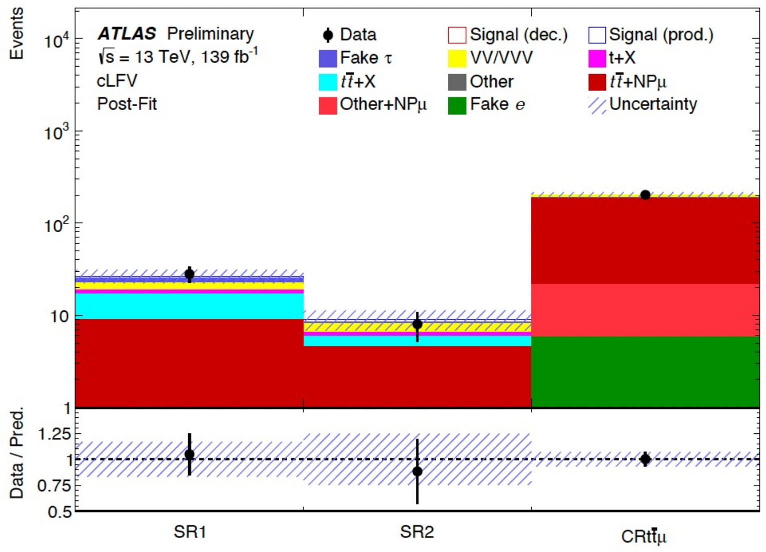
- EFT operators and width & cross section calculations

Operator	Lorentz Structure	
$O_{lq}^{1(ijkl)}$	$(\bar{l}_i\gamma^\mu l_j)(\bar{q}_k\gamma_\mu q_l)$	Vector
$O_{lq}^{3(ijkl)}$	$(\bar{l}_i\gamma^\mu\sigma^I l_j)(\bar{q}_k\gamma_\mu\sigma^I q_l)$	Vector
$O_{eq}^{(ijkl)}$	$(\bar{e}_i\gamma^\mu e_j)(\bar{q}_k\gamma_\mu q_l)$	Vector
$O_{lu}^{(ijkl)}$	$(\bar{l}_i\gamma^\mu l_j)(\bar{u}_k\gamma_\mu u_l)$	Vector
$O_{eu}^{(ijkl)}$	$(\bar{e}_i\gamma^\mu e_j)(\bar{u}_k\gamma_\mu u_l)$	Vector
$^\ddagger O_{lequ}^{1(ijkl)}$	$(\bar{l}_i e_j)\varepsilon(\bar{q}_k u_l)$	Scalar
$^\ddagger O_{lequ}^{3(ijkl)}$	$(\bar{l}_i\sigma^{\mu\nu} e_j)\varepsilon(\bar{q}_k\sigma_{\mu\nu} u_l)$	Tensor

$$\Gamma(t\to\ell_i^+\ell_j^-q_k)=\frac{m_t}{6144\pi^3}\left(\frac{m_t}{\Lambda}\right)^4\left\{4|c_{lq}^{-(ijk3)}|^2+4|c_{eq}^{(ijk3)}|^2+4|c_{lu}^{(ijk3)}|^2+4|c_{eu}^{(ijk3)}|^2+|c_{lequ}^{1(jik3)}|^2+|c_{lequ}^{1(ij3k)}|^2+48|c_{lequ}^{3(jik3)}|^2+48|c_{lequ}^{3(ij3k)}|^2\right\}$$

	Cross section $\sigma^{+\text{scale}}_{-\text{scale}}\pm$ PDF (fb)		
	$c_{\text{vector}}^{(ijk3)}$	$c_{lequ}^{1(ijk3)}$	$c_{lequ}^{3(ijk3)}$
Production $\ell\ell' ut$	$118^{+24}_{-19}\pm 1$	$101^{+21}_{-16}\pm 1$	$2150^{+410}_{-320}\pm 20$
Production $\ell\ell' ct$	$7.9^{+1.2}_{-1.0}\pm 1.6$	$6.1^{+1.0}_{-0.8}\pm 1.5$	$153^{+21}_{-18}\pm 29$
Decay $\ell\ell' qt$	$6.9^{+1.8}_{-1.3}\pm 0.1$	$3.46^{+0.90}_{-0.66}\pm 0.03$	$166^{+43}_{-32}\pm 2$

- Postfit of observed yields



	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
Expected (c)	1.6	1.6	1.5	1.6	1.8	1.8	0.35	0.35
Observed (c)	1.7	1.6	1.6	1.6	1.9	1.9	0.37	0.37