Rare top decays (FCNC, CPV) at CMS and ATLAS

International Workshop on the CKM Unitarity Triangle

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Photo source: https://www.tripsavvy.com/best-time-to-visit-melbourne-4774145

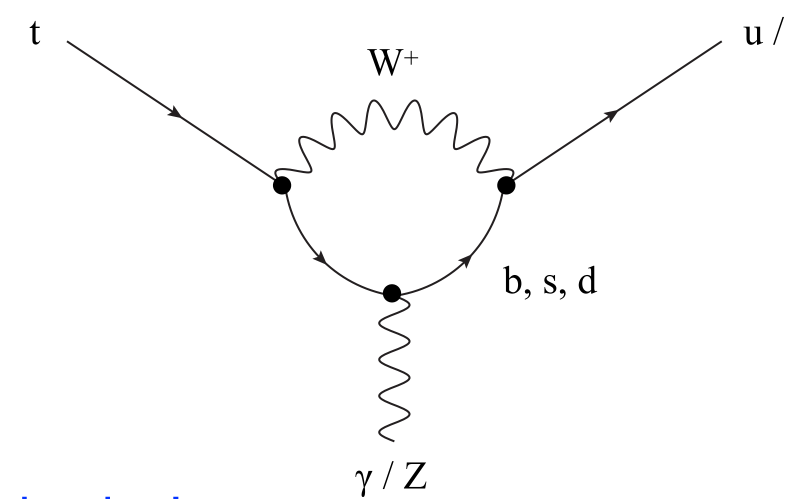
Introduction

- Standard model (SM) has been very successful at explaining experimental data
- Some unanswered questions
  - Nature of dark matter, matter-antimatter asymmetry, origin of flavor, neutrino mass, etc.
  - Some hints from SM deviations in the flavor sector
- Why rare top quark processes?
  - Large integrated luminosity proton-proton collision data collected by ATLAS and CMS
  - Certain physics in top sector is relatively less explored (ex. top CP property)
  - Various beyond SM theories (BSM) have predictions (ex. top flavor-changing neutral currents)
- Covered in this talk
  - Search for top flavor-changing neutral currents (top FCNC)
  - Search for top charged lepton flavor violation (top CLFV)
  - Search for top CP violation (top CPV)

Top FCNC

Flavor-changing neutral currents (FCNCs)

- FCNCs in SM
  - Forbidden at tree-level
  - Heavily suppressed due to GIM mechanism
    - BF($t \to Hu$) ~ $\mathcal{O}(10^{-17})$ and BF($t \to Hc$) ~ $\mathcal{O}(10^{-15})$
    - Well below LHC sensitivity!
  - Any observation of FCNCs would be an unambiguous sign of new physics!



- FCNCs in BSM
  - In general, lead to enhanced $t \to qM$ FCNC interactions
    - $M \in \{\gamma, g, Z, H\}$, $q \in \{u, c\}$

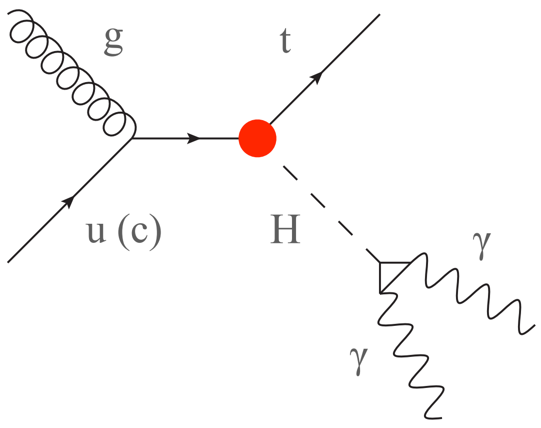
	SM	QS	2HDM	FC 2HDM	MSSM	$\not{R}$ SUSY
$t \to uZ$	8×10^{-17}	1.1×10^{-4}	–	–	2×10^{-6}	3×10^{-5}
$t \to u\gamma$	3.7×10^{-16}	7.5×10^{-9}	–	–	2×10^{-6}	1×10^{-6}
$t \to ug$	3.7×10^{-14}	1.5×10^{-7}	–	–	8×10^{-5}	2×10^{-4}
$t \to uH$	2×10^{-17}	4.1×10^{-5}	5.5×10^{-6}	–	10^{-5}	$\sim 10^{-6}$
$t \to cZ$	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}	$\sim 10^{-6}$

Aguilar-Saavedra, ACTA Phys. Pol. B 35(2004) 3

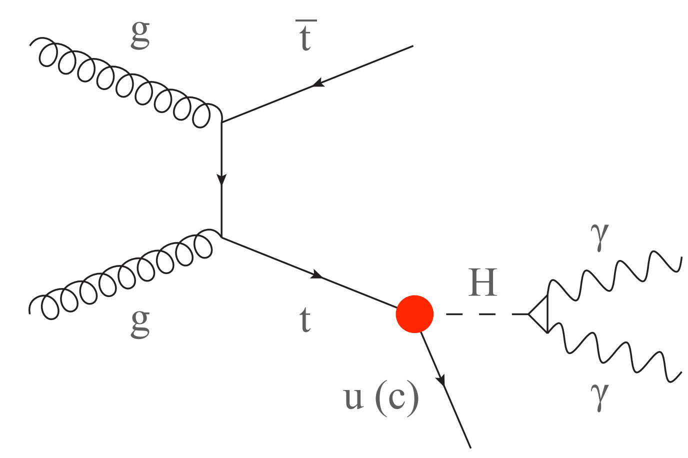
Search for the FCNC tHq H→γγ

CMS-TOP-20-007
137 fb^{-1}, 13 TeV

- Search for t→Hq (q=u, c), H→γγ
- Single top production (ST) and top decay (TT)
- Signal regions: 2 photons, $100<M_{\gamma\gamma}<180$ GeV
  - leptonic: ≥ 1 jet, ≥ 1 lepton
  - hadronic: ≥ 3 jet, ≥ 1 b-jet

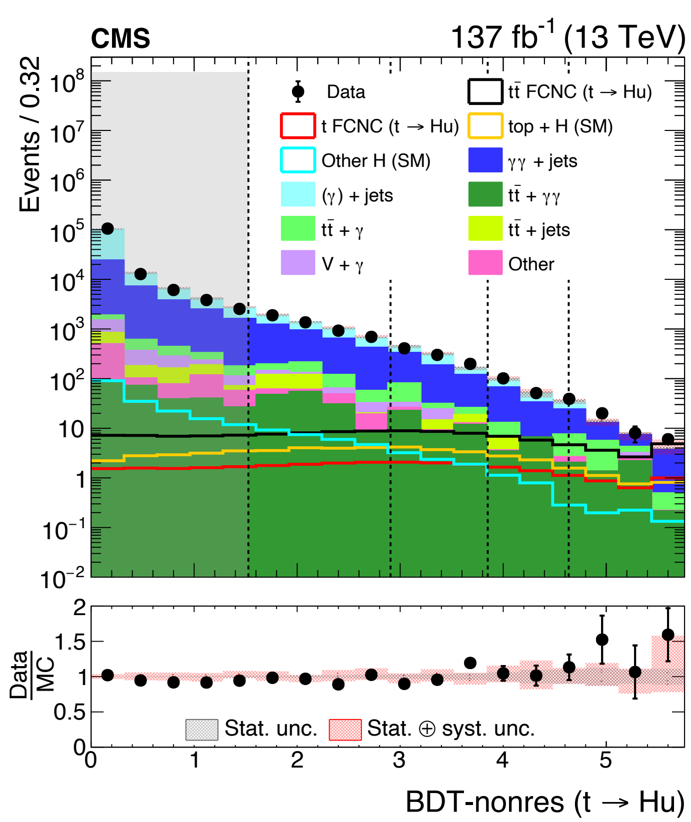


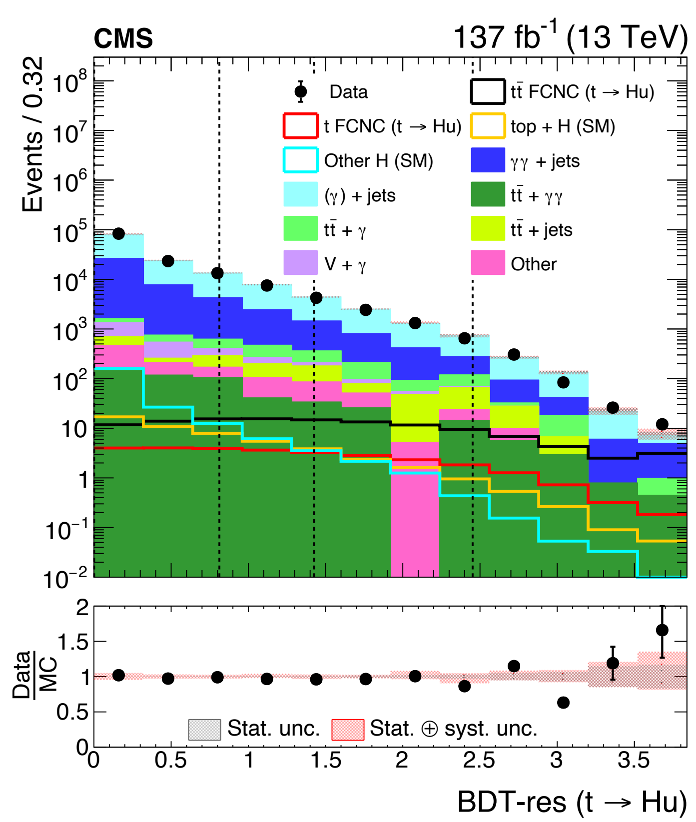
Single top production



top-quark pair decay

- Backgrounds
  - resonant: ttH, ggH, VH, VBF, tH, bbH
  - non-resonant: γγ+jets, (γ)+jets, tt+γ(γ), V+γ
- Strategy
  - 8 BDTs: {u, c}⊗{had, lep}⊗{res, non-res bkg}
  - 7 categories defined by BDT scores
  - 14 $m_{\gamma\gamma}$ distributions to fit





BDTs meant for suppressing non-resonant BG (left) and resonant BG (right)

Search for the FCNC tHq H→γγ

CMS-TOP-20-007

137 fb^{-1}, 13 TeV

- Signal modeling

$$\mathcal{L} = \sum_{q=u,c} \frac{g}{\sqrt{2}} \bar{t} \kappa_{Hqt} \left(F^{L}_{Hq} P_L + F^{R}_{Hq} P_R \right) qH + h.c.$$

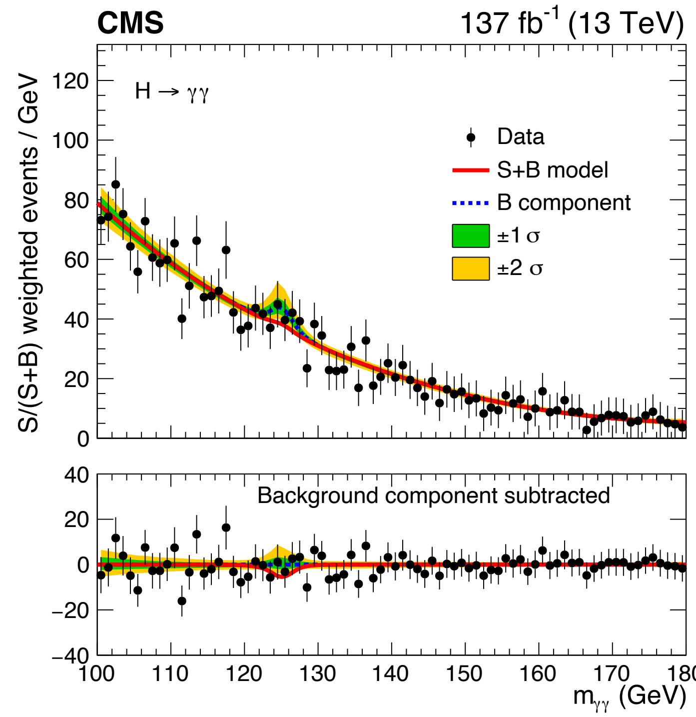
g: Weak coupling constant

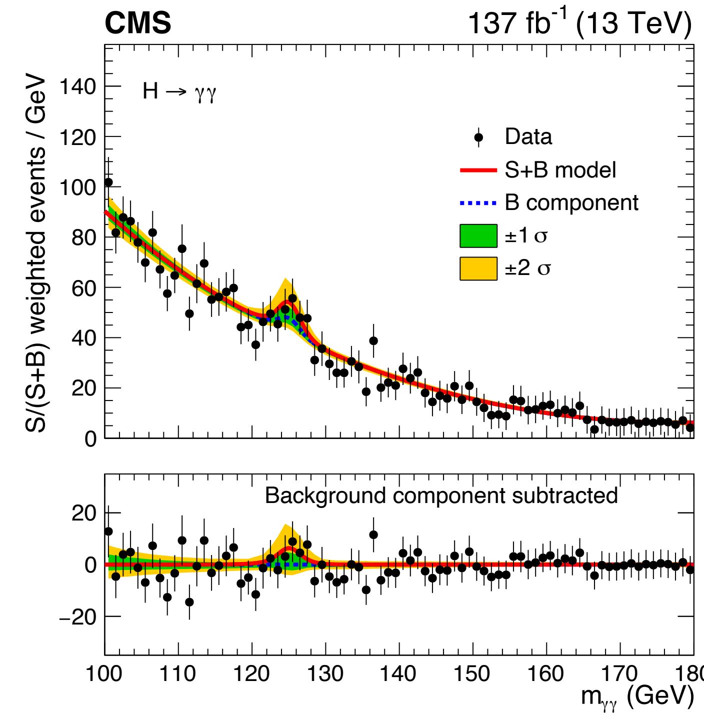
$$|F^{L}_{Hq}|^2 + |F^{R}_{Hq}|^2 = 1$$

κ_{Hqt}: Effective coupling constant

- Dominant systematic uncertainties: b-tagging and γ identification
- Data compatible with absence of signal
- Upper limits on the signal cross sections are translated to the strength of the tqH anomalous couplings and related branching fractions
- 95% CL upper limits:
  - B(t→Hu) < 0.019 % (exp. 0.031%)
  - B(t→Hc) < 0.073 % (exp. 0.051%)

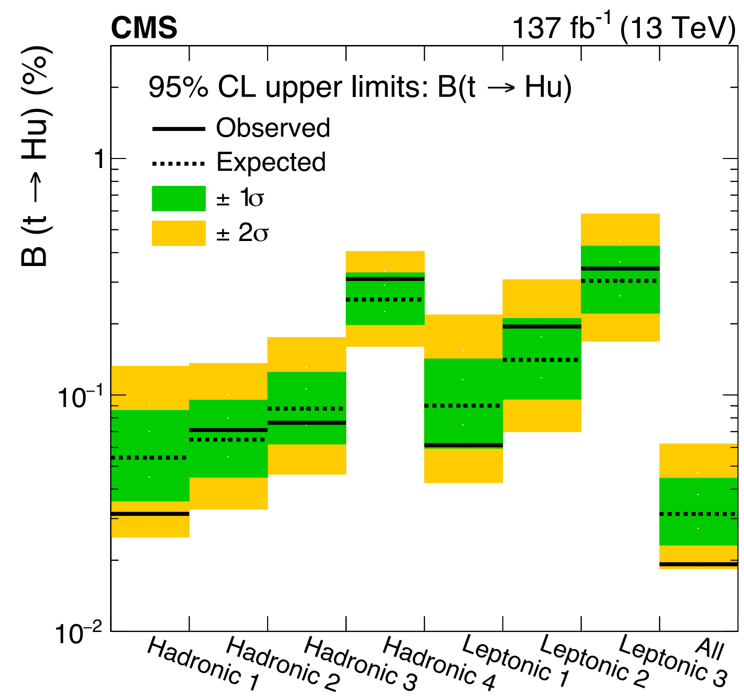
The most stringent limits to date in tHq FCNC searches

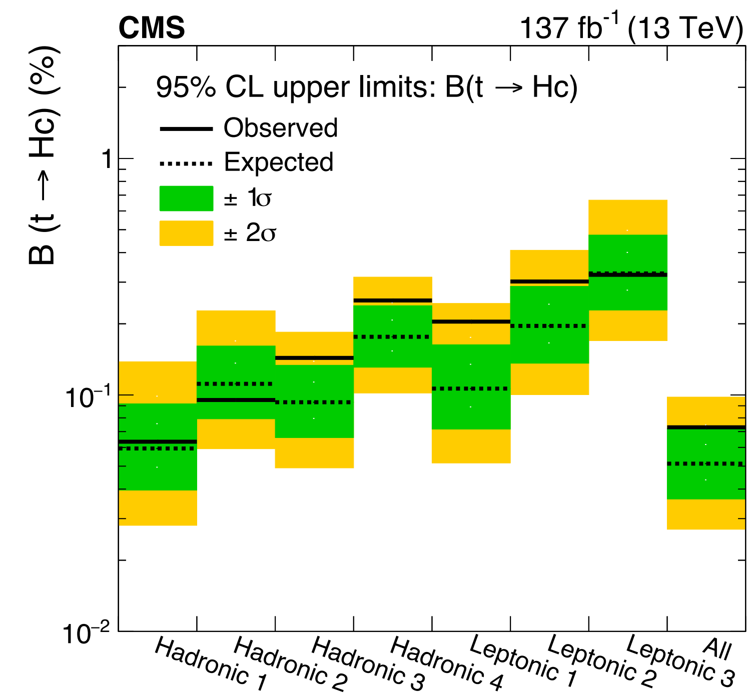




t→Hu

t→Hc

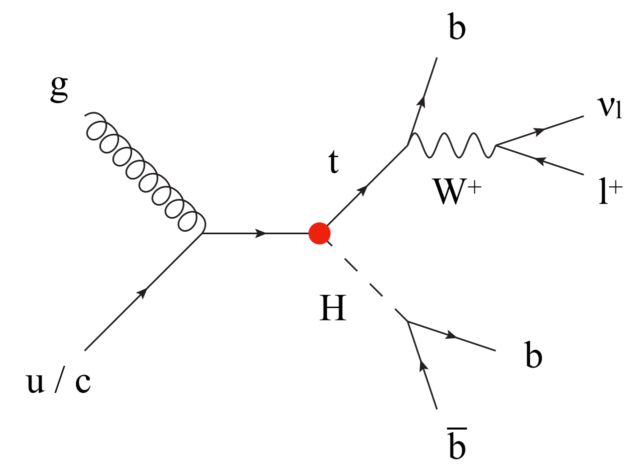




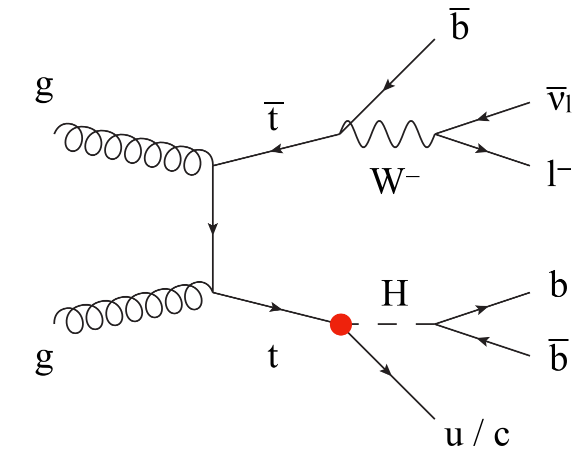
Search for the FCNC tHq H→bb

CMS-PAS-TOP-19-002
137 fb^{-1}, 13 TeV

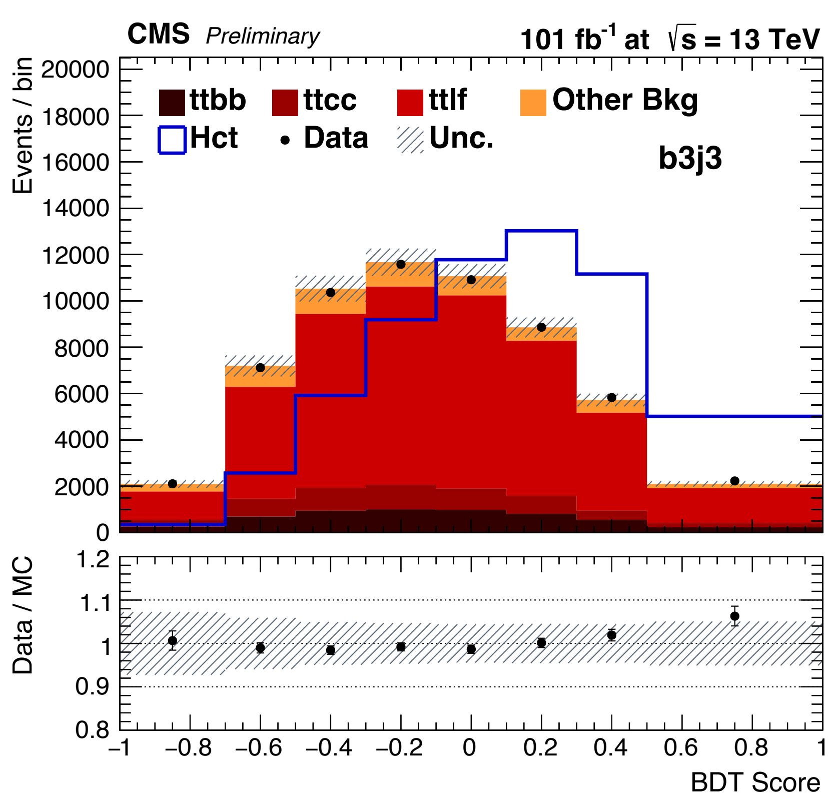
- Search for t→Hq (q=u, c), H→bb
- Single top production (ST) and top decay (TT)
- Signal regions: 1 lepton, ≥ 3 jets, ≥ 2 b-jets
- A deep neural network is used to associate the reconstructed objects to the generator-level final state
- BDTs are used to distinguish the signal from the background events

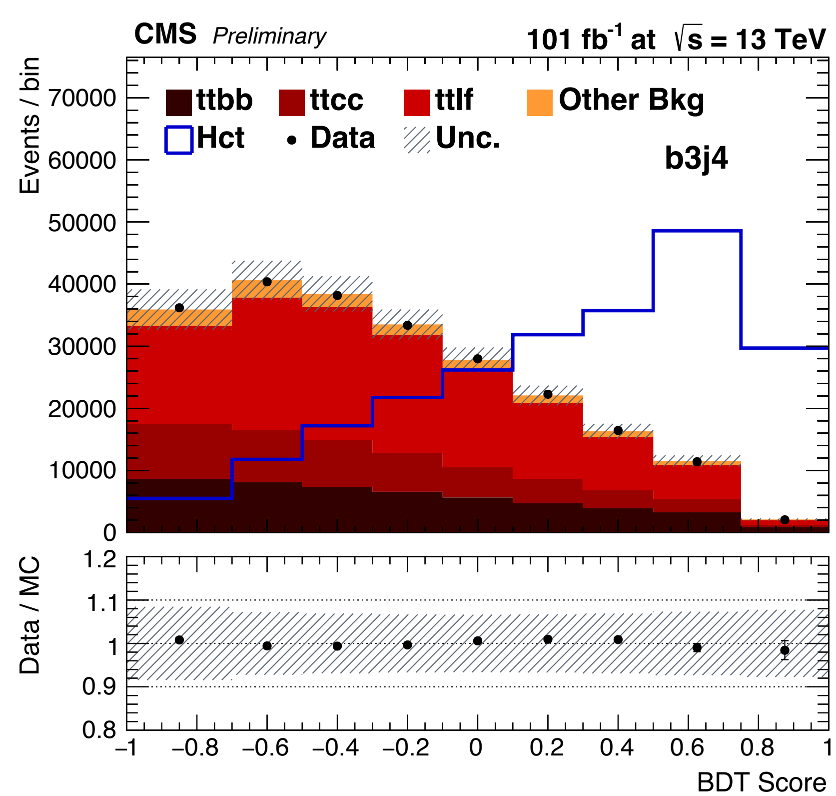


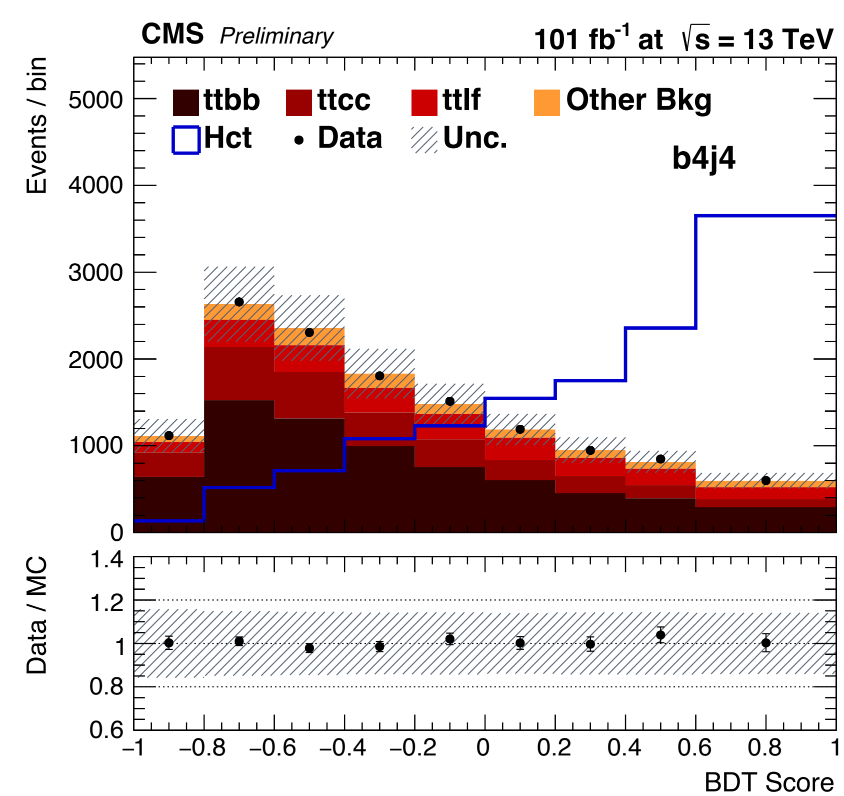
Single top production



Top-quark pair decay



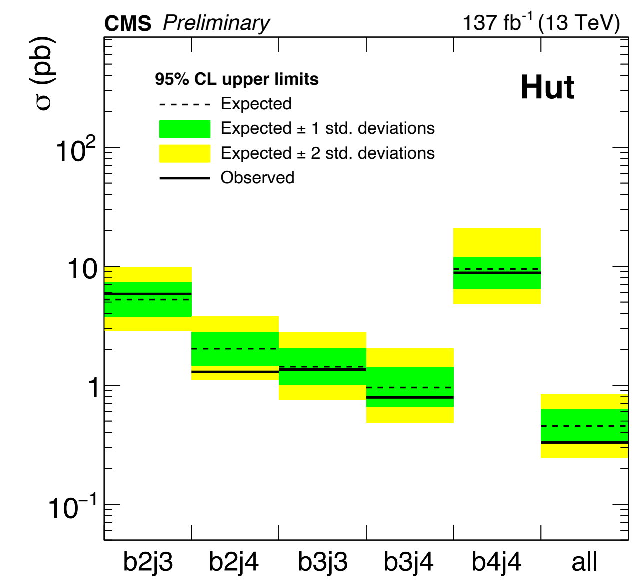




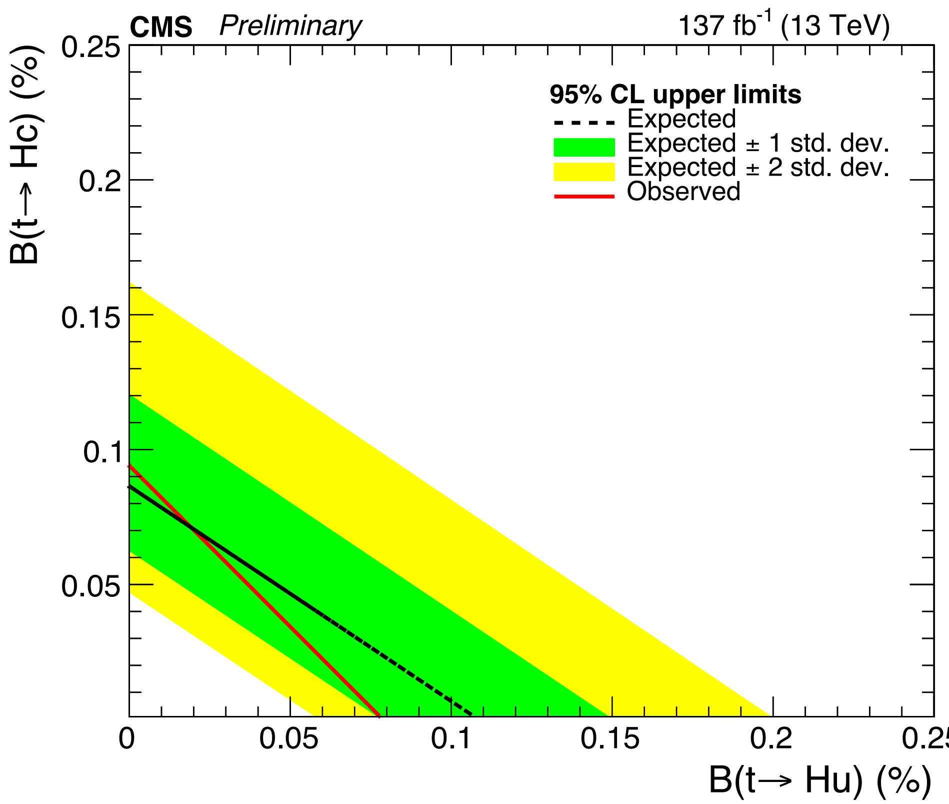
Search for the FCNC tHq H→bb

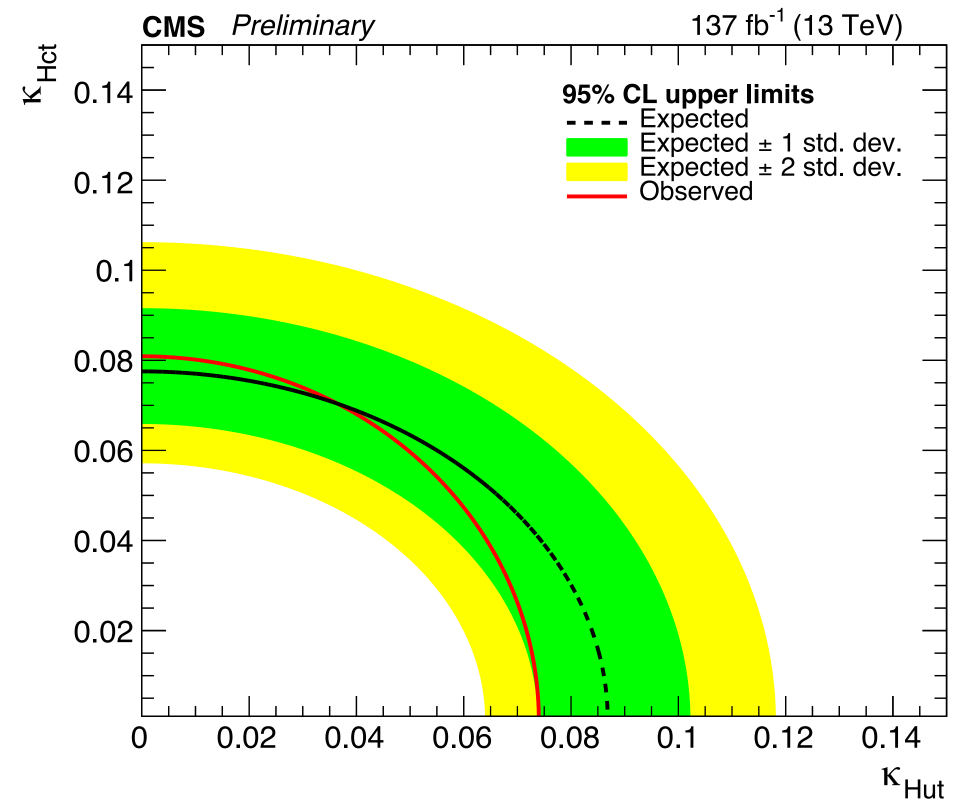
CMS-PAS-TOP-19-002

137 fb^{-1}, 13 TeV



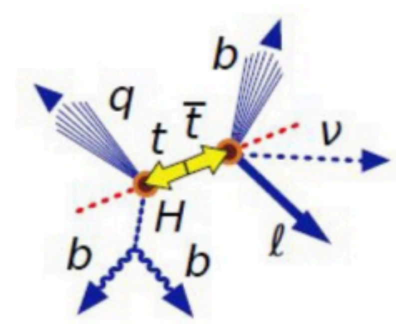
- All bjet-jet categories are combined
  - The b3j4 category has the highest sensitivity for both Hut and Hct couplings
- No significant excess with respect to the SM background expectations
- 95% CL upper limits:
  - B(t→Hu) < 0.079 % (exp. 0.11%)
  - B(t→Hc) < 0.094 % (exp. 0.086 %)
- Significant improvement with respect to the early run-2 search (JHEP 06 (2018) 102)
  - Full Run 2 luminosity
  - Advanced multivariate analysis techniques to perform the event reconstruction

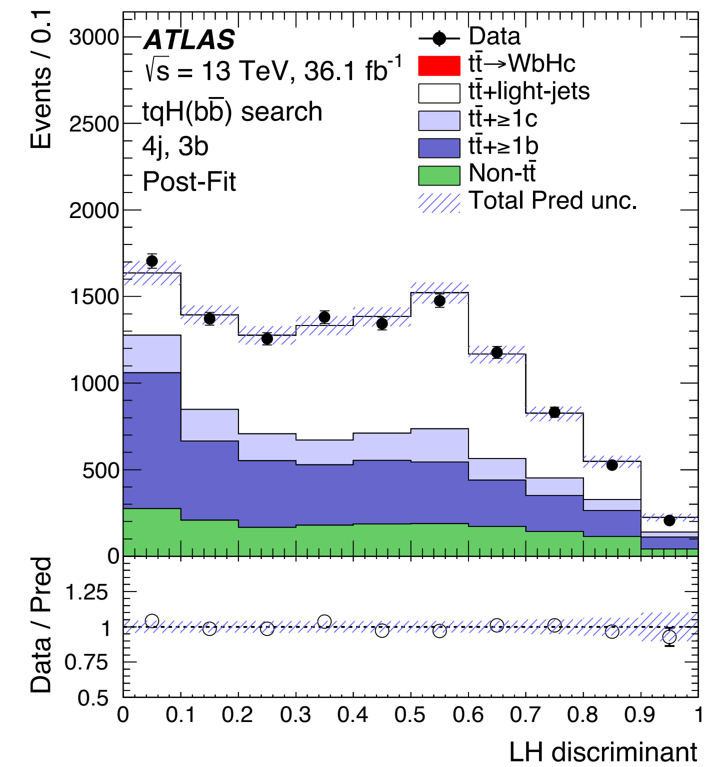




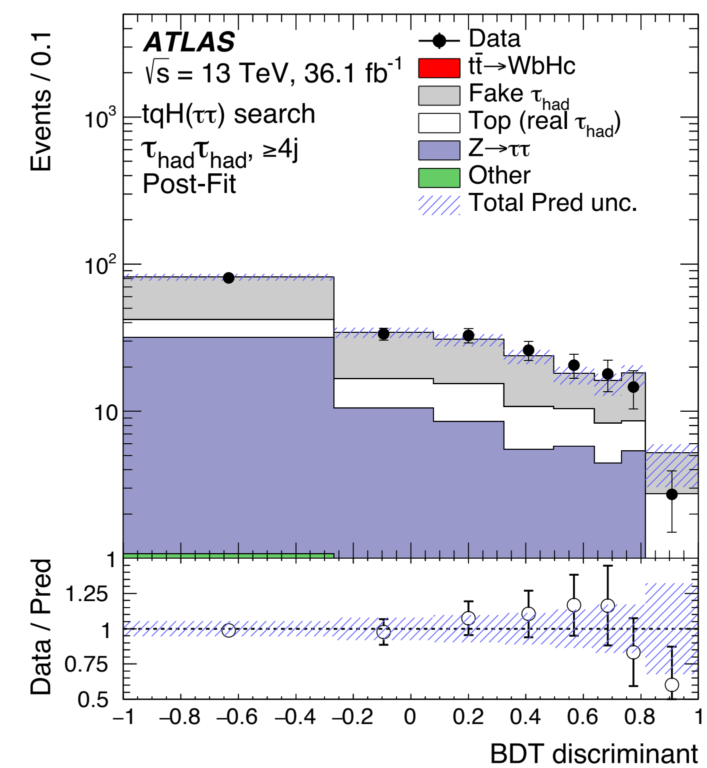
Search for the FCNC tHq interaction

- Search for t→Hq (q=u, c) FCNC decays in $t\bar{t}$ events
- H→bb
  - Single lepton, ≥ 4 jets (2 b-tagged)
  - Backgrounds: $t\bar{t}$ + HF/LF
  - Data-driven estimate for non prompt leptons
  - Event classification on the jet (4, 5, ≥ 6) and b-tagged jet (2, 3, ≥ 4)
  - Likelihood-based discriminant





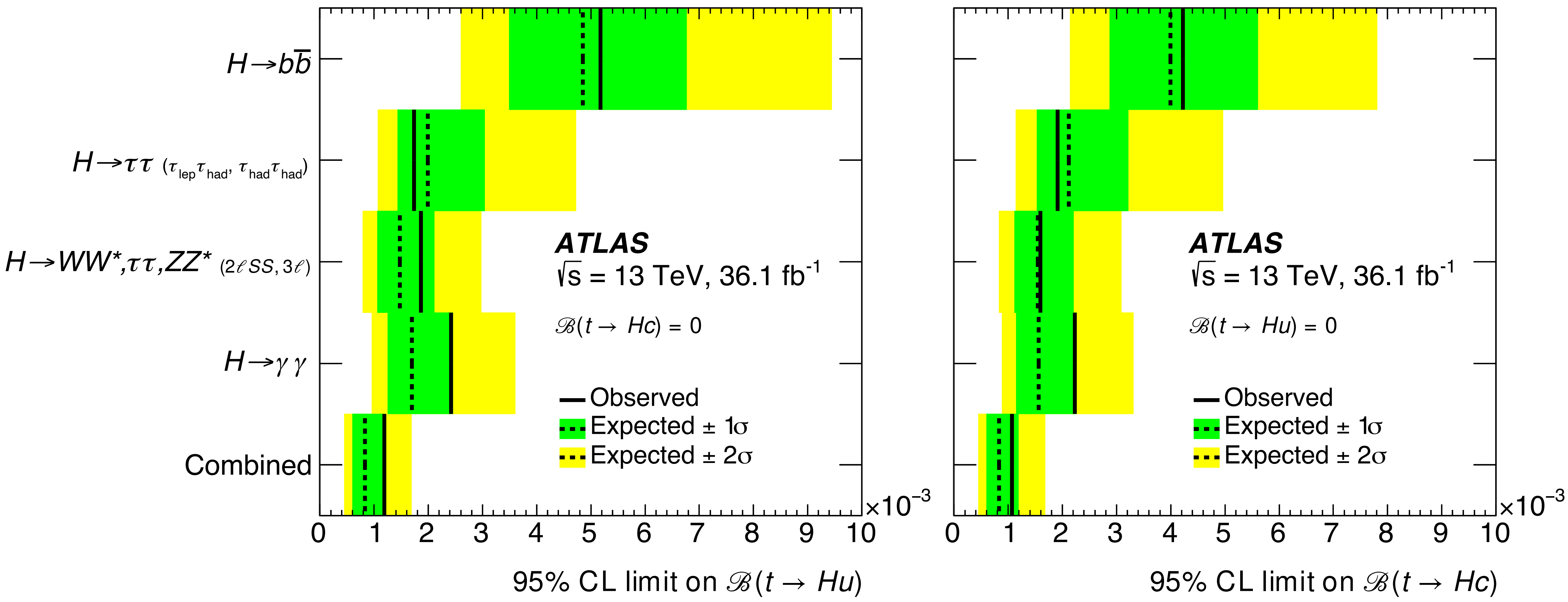
- H→ττ
  - Single lepton (τlep, τhad), di-tau (τhad, τhad), ≥ 3 jets (1 b-tagged)
  - Backgrounds: fakes ($t\bar{t}$), Z→ττ
  - Data-driven estimate for fake τhad
  - Event classification on the jet multiplicity (3j, ≥ 4j)
  - BDT discriminant



Search for the FCNC tHq interaction

JHEP 05 (2019) 123
36 fb^{-1}, 13 TeV

- Results are combined with
  - H→γγ [JHEP 10 (2017) 129]
  - H→WW*, ττ, ZZ* (2lvSS, 3l) [Phys. Rev. D 98 032002]



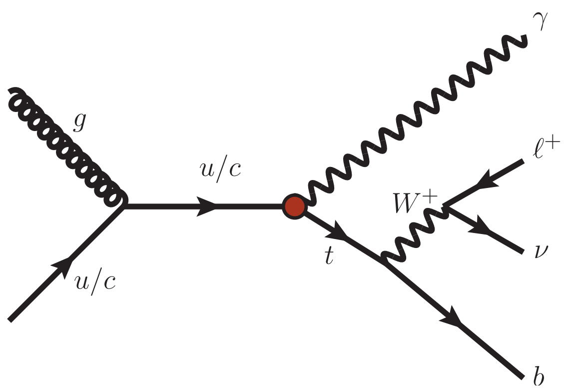
- No significant excess of events above the background expectation is found
  - 95% CL limits on B(t→Hu) < 0.11 % (exp. 0.083%)
  - 95% CL limits on B(t→Hc) < 0.12 % (exp. 0.083%)

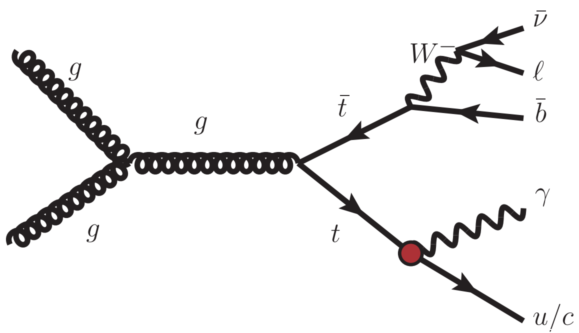
Search for the FCNC tγq interaction

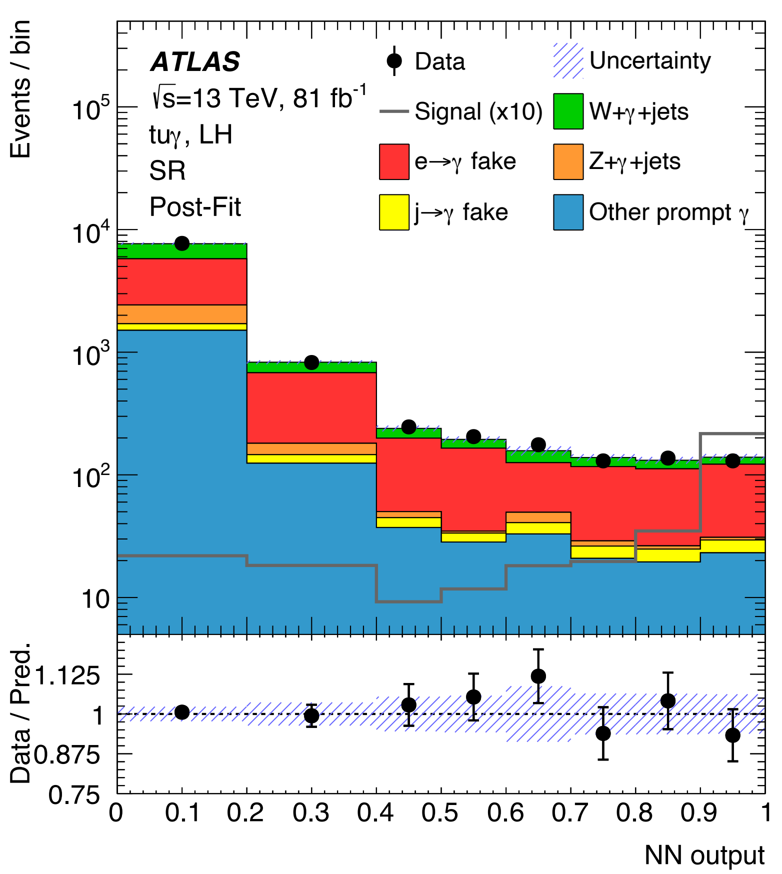
PLB 800 (2020) 135082

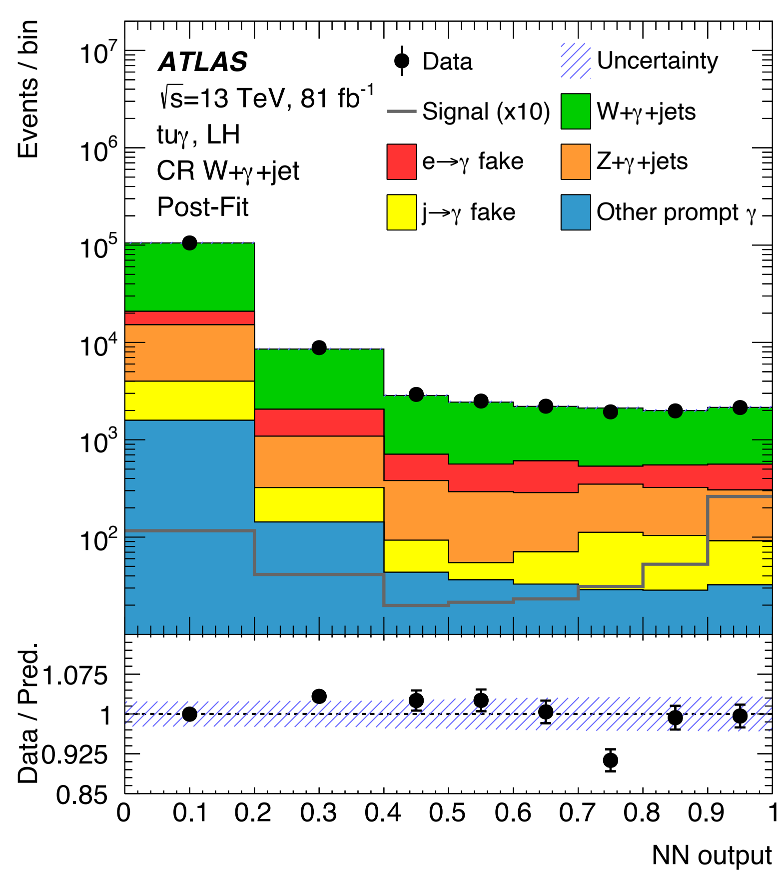
81 fb^{-1}, 13 TeV

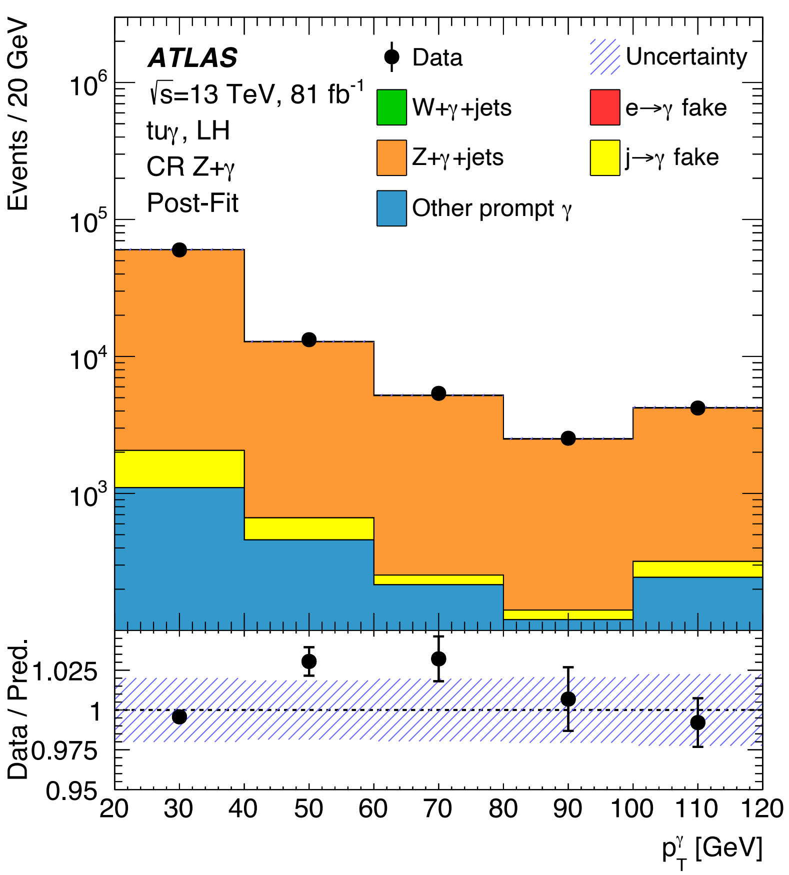
- Search for t→γq (q=u, c)
- Single top production (ST) and top decay (TT)
- Right-handed (RH) and left-handed (LH)
- Signal regions: exactly 1 photon, 1 e/μ, 1 b-jet, no further jet
- Background
  - Electrons / hadrons misidentified as photons → estimated from data
  - W/Z + γ +jets → estimated from MC in control regions
- NN is adopted to differentiate signal from background events
- Normalizations are extracted from a simultaneous binned likelihood fit











Search for the FCNC tγq interaction

PLB 800 (2020) 135082
81 fb^{-1}, 13 TeV

- The data are consistent with the background only hypothesis
- 95% CL upper limits are set on the strength of effective operators, cross-section of single top production, and branching fraction

The most stringent limits to date in tqγ FCNC searches

Observable	Vertex	Coupling	Obs.	Exp.
$\left\lvert C_{uW}^{(13)*} + C_{uB}^{(13)*} \right\rvert$	$tu\gamma$	LH	0.19	$0.22^{+0.04}_{-0.03}$
$\left\lvert C_{uW}^{(31)} + C_{uB}^{(31)} \right\rvert$	$tu\gamma$	RH	0.27	$0.27^{+0.05}_{-0.04}$
$\left\lvert C_{uW}^{(23)*} + C_{uB}^{(23)*} \right\rvert$	$tc\gamma$	LH	0.52	$0.57^{+0.11}_{-0.09}$
$\left\lvert C_{uW}^{(32)} + C_{uB}^{(32)} \right\rvert$	$tc\gamma$	RH	0.48	$0.59^{+0.12}_{-0.09}$
$\sigma(pp \to t\gamma)$ [fb]	$tu\gamma$	LH	36	52^{+21}_{-14}
$\sigma(pp \to t\gamma)$ [fb]	$tu\gamma$	RH	78	75^{+31}_{-21}
$\sigma(pp \to t\gamma)$ [fb]	$tc\gamma$	LH	40	49^{+20}_{-14}
$\sigma(pp \to t\gamma)$ [fb]	$tc\gamma$	RH	33	52^{+22}_{-14}
$\mathcal{B}(t \to q\gamma)$ [10^{-5}]	$tu\gamma$	LH	2.8	$4.0^{+1.6}_{-1.1}$
$\mathcal{B}(t \to q\gamma)$ [10^{-5}]	$tu\gamma$	RH	6.1	$5.9^{+2.4}_{-1.6}$
$\mathcal{B}(t \to q\gamma)$ [10^{-5}]	$tc\gamma$	LH	22	27^{+11}_{-7}
$\mathcal{B}(t \to q\gamma)$ [10^{-5}]	$tc\gamma$	RH	18	28^{+12}_{-8}

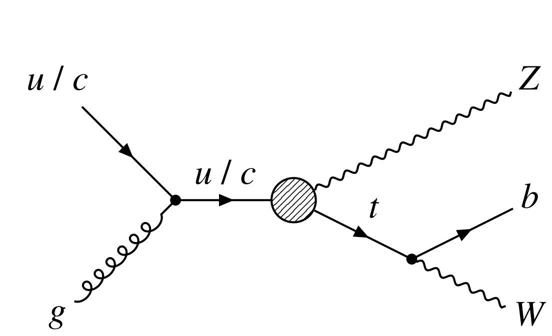
Search for the FCNC tZq interaction

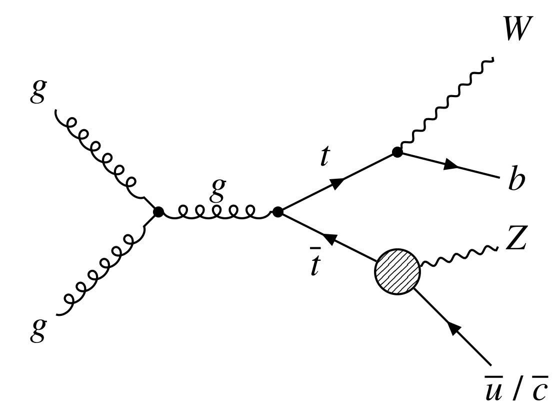
ATLAS-CONF-2021-049

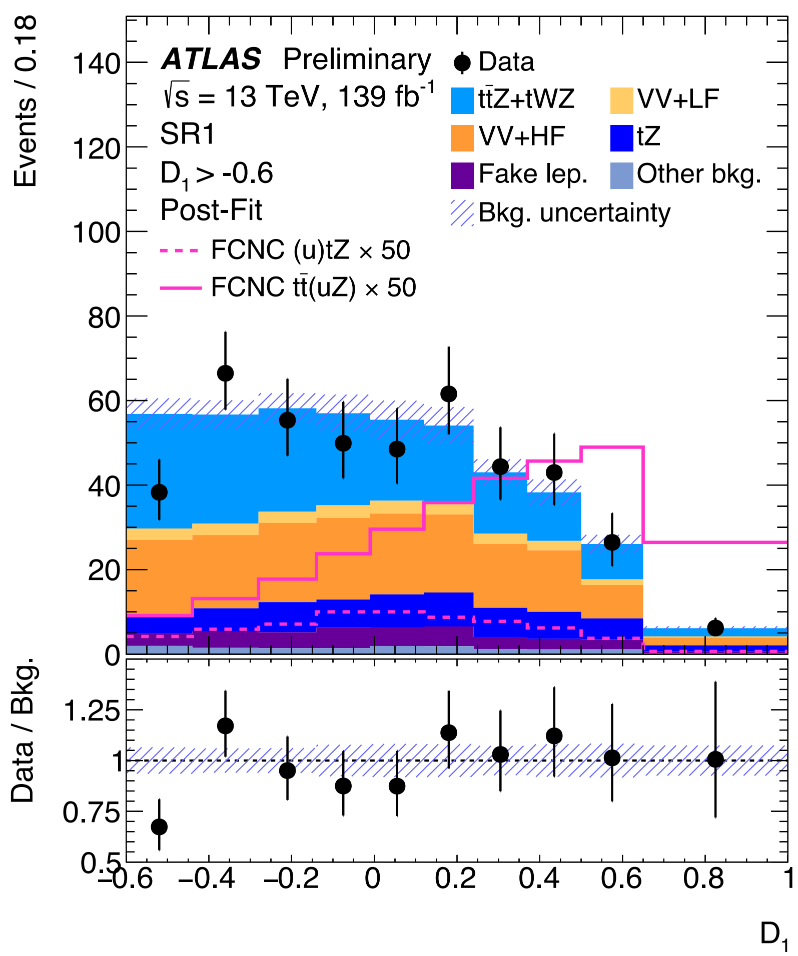
$139\ fb^{-1}$, 13 TeV

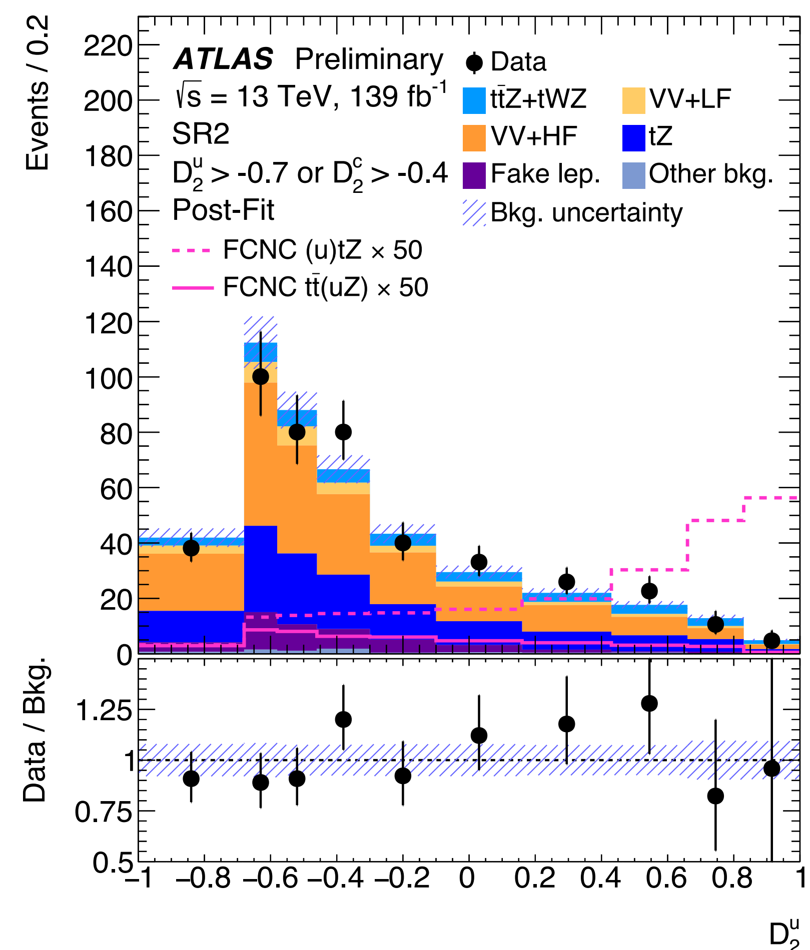
- Search for $t \to Zq$ (q=u, c), $Z \to \ell\ell$
- Single top production (ST) and top decay (TT)
- Consider right-handed (RH) and left-handed (LH)
- Signal regions: 3 leptons, ≥ 1 jets (with exactly 1 b-jet)
  - SR1: targeting TT
  - SR2: targeting ST

  → *orthogonality is ensured by using a mass cut on $M_{top(FCNC)}$*
- Gradient BDTs are adopted to distinguish signal from background events









Search for the FCNC tZq interaction

ATLAS-CONF-2021-049

139 fb^{-1}, 13 TeV

- All SRs are combined
  - For FCNC tZu vertex, SR2 has a higher contribution to the combined limits
- No evidence of a signal is found
- The results improved by a factor of 3 (2) compared to previous results (JHEP 07 (2018) 176)
  - Inclusion of FCNC single top production
  - Usage of multivariate analysis
  - Higher integrated luminosity
- 95% CL upper limits

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	$0.19^{+0.04}_{-0.03}$

The most stringent limits to date

in tZq FCNC searches

Top FCNC Summary

- Search for FCNC is performed in various channels
- Starting probing models predicting highest branching fractions

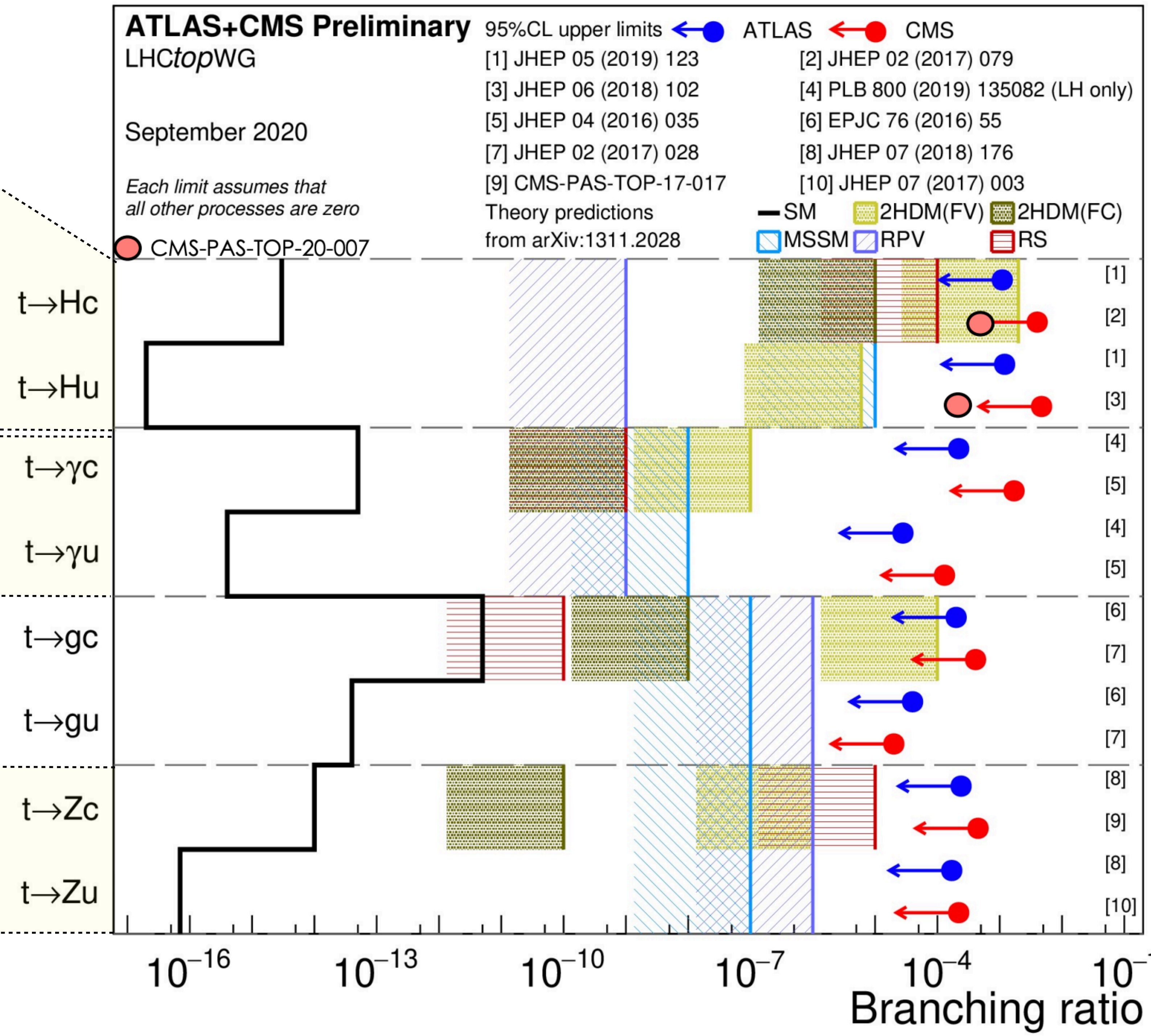
JHEP 05 (2019) 123
36 fb^{-1}, 13 TeV

CMS-PAS-TOP-19-002
137 fb^{-1}, 13 TeV

CMS-TOP-20-007
137 fb^{-1}, 13 TeV

PLB 800 (2020) 135082
81 fb^{-1}, 13 TeV

ATLAS-CONF-2021-049
139 fb^{-1}, 13 TeV



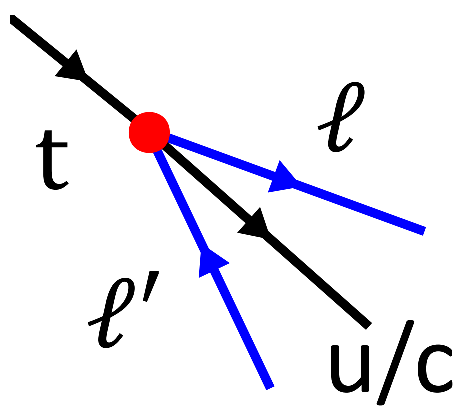
Top CLFV

Charged lepton flavor violation (CLFV)

- In the SM, lepton flavor is conserved in all interactions
- The neutrino mass terms predict CLFV at loop level

  → highly suppressed due to the tiny values of neutrino masses
- Many new physics models predict sizable CLFV

  ex. neutrino mass models, multi-Higgs doublet models, etc.



- If the new physics responsible for the CLFV is at scales beyond what the LHC can directly probe, the SM Lagrangian can be extended by dimension-6 operators

$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} + \mathcal{L}_{\mathrm{eff}} = \mathcal{L}_{\mathrm{SM}} + \sum_x \frac{C_x}{\Lambda^2} O_x + \ldots$$

- CLFV interaction types
  - Vector: O_{lq}^{ijkl}, O_{lu}^{ijkl}, O_{eq}^{ijkl}, O_{eu}^{ijkl}
  - Scalar: $O_{lequ}^{(1)ijkl}$
  - Tensor: $O_{lequ}^{(3)ijkl}$

$$\begin{aligned}
O_{\mathrm{lq}}^{(3)ijkl} &= (\bar{\mathrm{l}}_i \gamma^\mu \tau^I \mathrm{l}_j)(\bar{\mathrm{q}}_k \gamma^\mu \tau^I \mathrm{q}_l), \\
O_{\mathrm{lq}}^{(1)ijkl} &= (\bar{\mathrm{l}}_i \gamma^\mu \mathrm{l}_j)(\bar{\mathrm{q}}_k \gamma^\mu \mathrm{q}_l), \\
O_{\mathrm{lu}}^{ijkl} &= (\bar{\mathrm{l}}_i \gamma^\mu \mathrm{l}_j)(\bar{\mathrm{u}}_k \gamma^\mu \mathrm{u}_l), \\
O_{\mathrm{eq}}^{ijkl} &= (\bar{\mathrm{e}}_i \gamma^\mu \mathrm{e}_j)(\bar{\mathrm{q}}_k \gamma^\mu \mathrm{q}_l), \\
O_{\mathrm{eu}}^{ijkl} &= (\bar{\mathrm{e}}_i \gamma^\mu \mathrm{e}_j)(\bar{\mathrm{u}}_k \gamma^\mu \mathrm{u}_l), \\
O_{\mathrm{lequ}}^{(1)ijkl} &= (\bar{\mathrm{l}}_i \mathrm{e}_j)\ \varepsilon\ (\bar{\mathrm{q}}_k \mathrm{u}_l), \\
O_{\mathrm{lequ}}^{(3)ijkl} &= (\bar{\mathrm{l}}_i \sigma^{\mu\nu} \mathrm{e}_j)\ \varepsilon\ (\bar{\mathrm{q}}_k \sigma_{\mu\nu} \mathrm{u}_l),
\end{aligned}$$

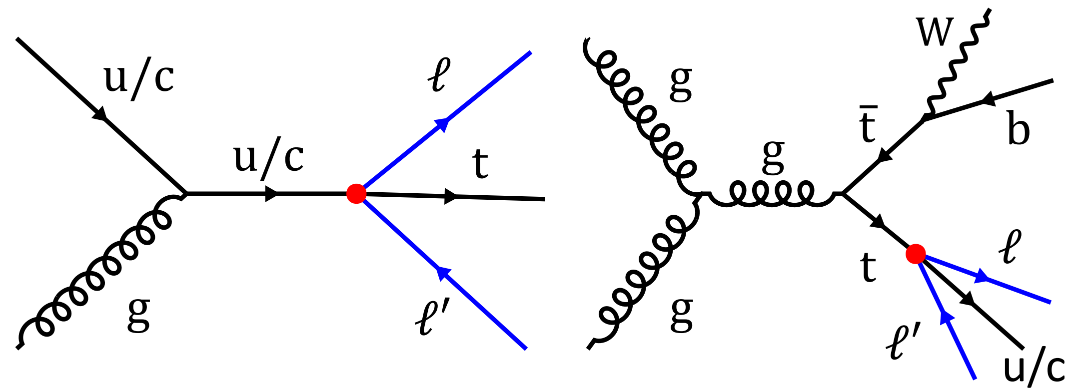
Search for the eμ LFV interactions

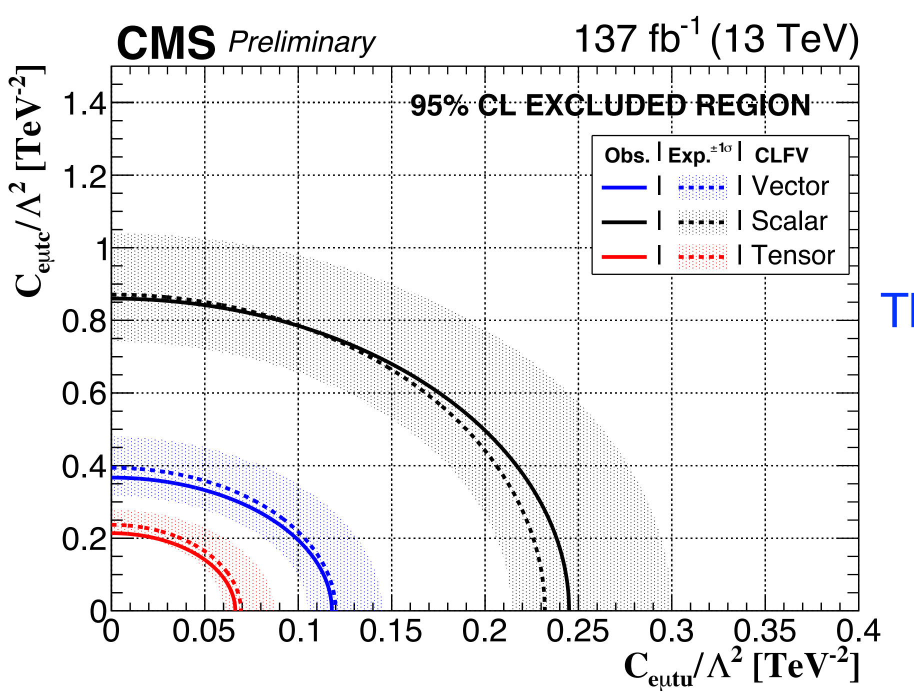
CMS-PAS-TOP-19-006

137 fb^{-1}, 13 TeV

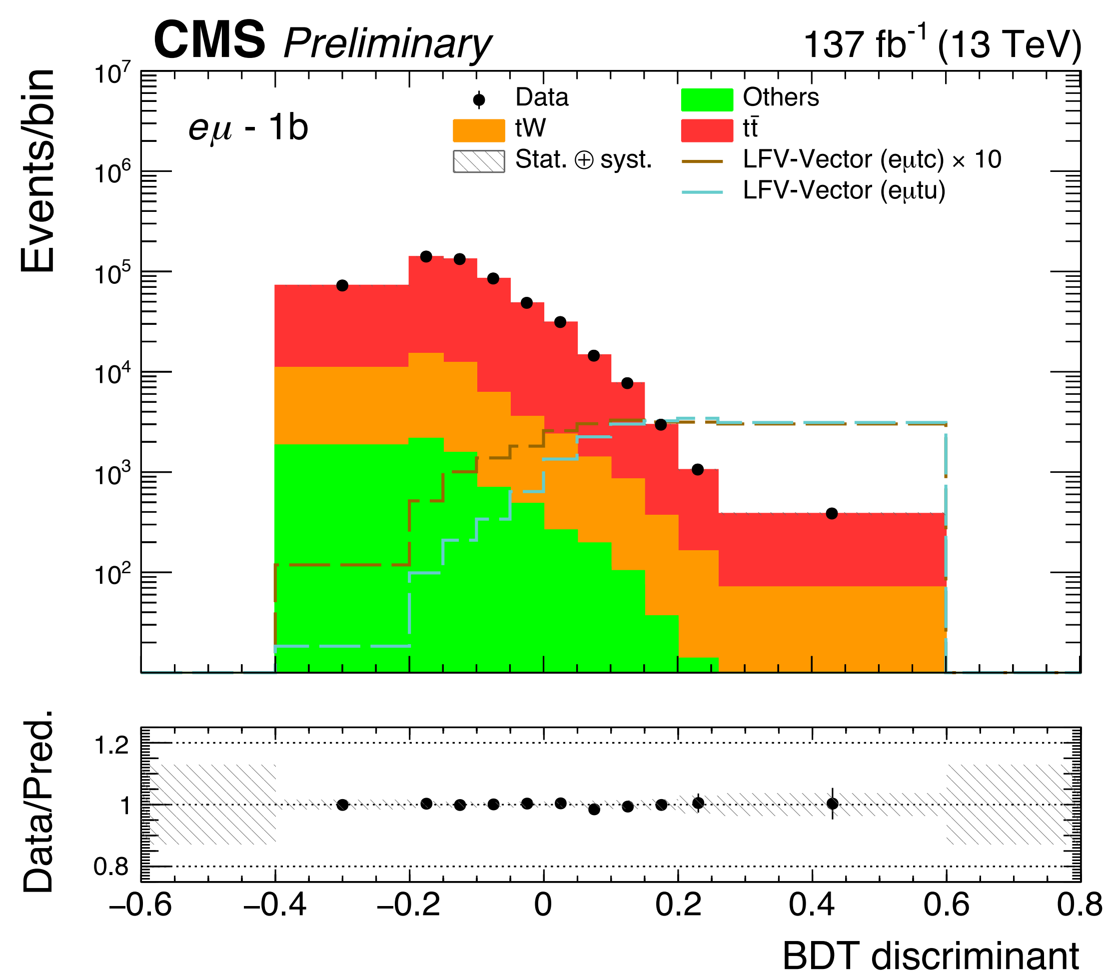
- Search for CLFV in eμ final state
- Signal: CLFV vector, scalar and tensor
- BDT is used to discriminate signal from BG events
- Dominant systematic uncertainties:

  b-tagging and jet energy scale & resolution
- Data consistent with SM expectation
  - $B_{scalar}(t \to e\mu u(c)) < 0.07\ (0.89) \times 10^{-6}$
  - $B_{vector}(t \to e\mu u(c)) < 0.135\ (1.3) \times 10^{-6}$
  - $B_{tensor}(t \to e\mu u(c)) < 0.25\ (2.59) \times 10^{-6}$





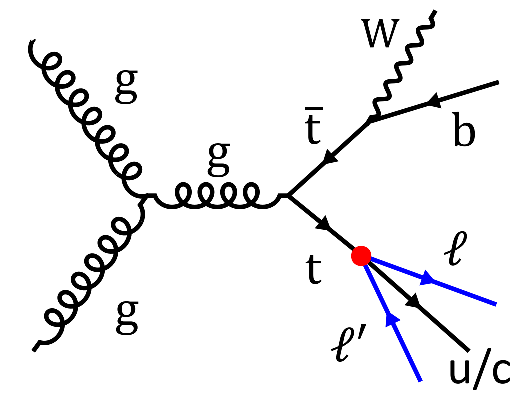
The most restrictive bound to date!



Search for the eμ LFV interactions

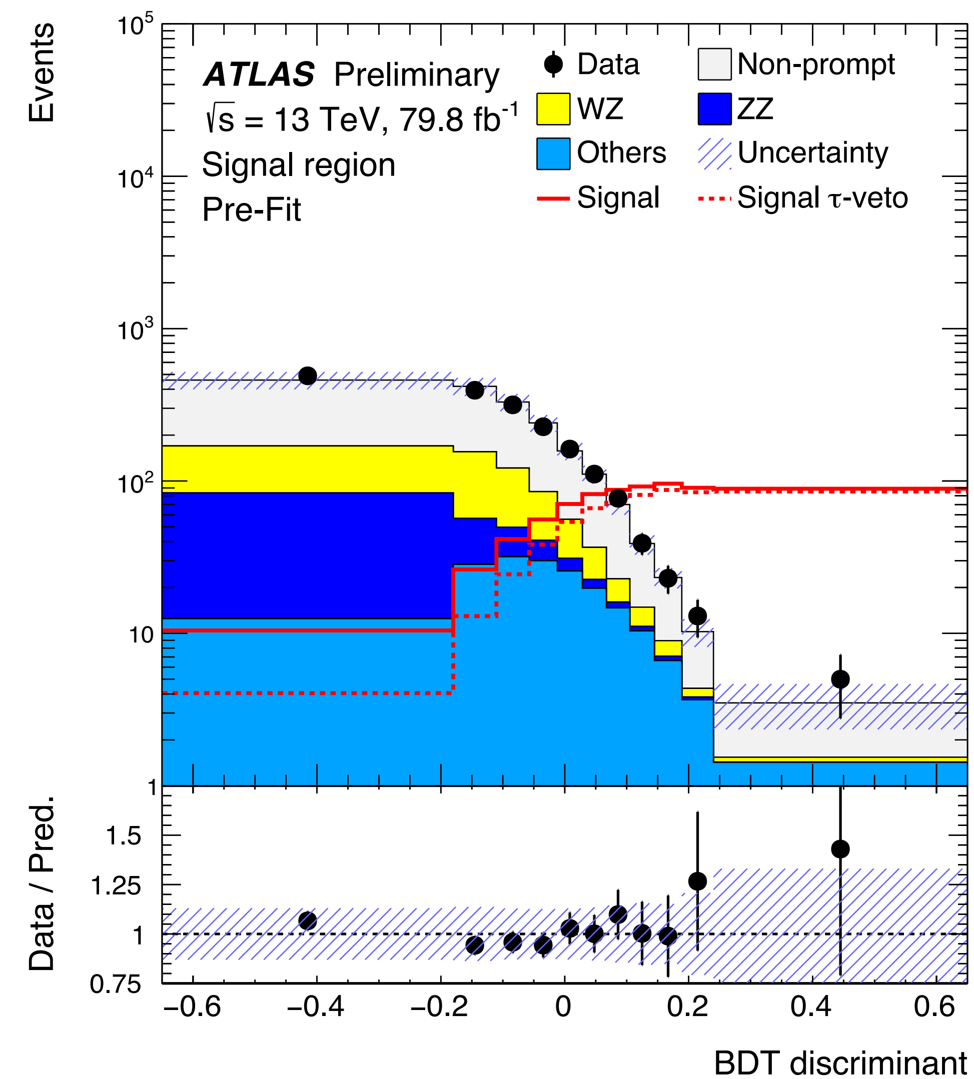
ATLAS-CONF-18-044

80 fb^{-1}, 13 TeV



- Search for CLFV in final states with three isolated charged leptons
- Consider only top decay process
- CLFV top reconstructed from two opposite sign different-flavour leptons and a jet
- Background
  - Prompt background: WZ, ZZ
  - Non-prompt background: $t\bar{t}$, Z+jets
- BDT is used to discriminate signal from BG events
- Dominant systematics:

  non-closure uncertainty and stat. on efficiencies
- Data consistent with SM expectation
- Upper limits are set at 95% CL
  - $B(t\to\ell\ell'q) < 1.86\ (1.36) \times 10^{-5}$ obs (exp)
  - $B(t\to e\mu q) < 6.6\ (4.8) \times 10^{-6}$ obs (exp)



Top CPV

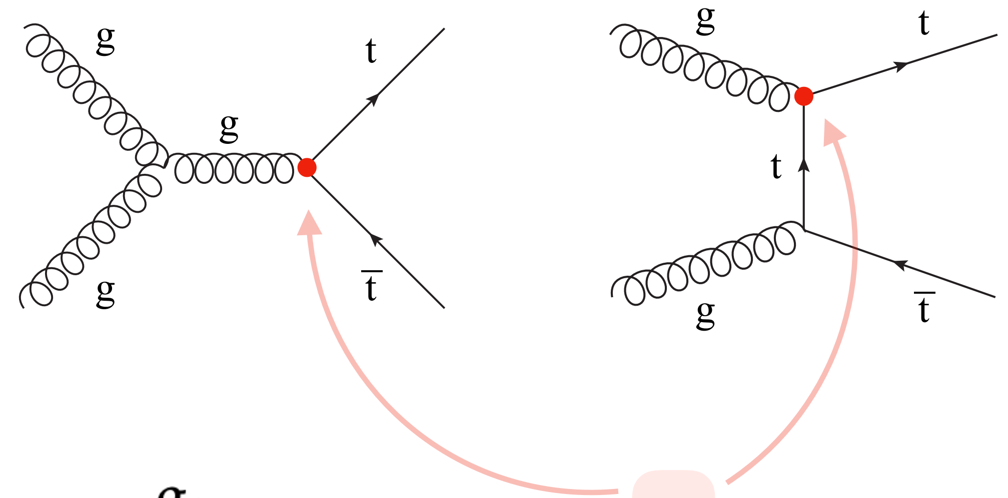
Search for CPV in the top sector

- CP violation in SM not large enough to describe the matter-antimatter asymmetry of the universe
- In the SM, CPV in the production and decay of top quark pairs is predicted to be very small
- Top-quark pair production and decay provide a unique opportunity to study CPV
- Simple CP odd observables
- triple-product observables of the form v1· (v2×v3)

  where vi are spin/four momentum of top decay products, Oi, are odd under CP transformation

$$A_i = \frac{N(O_i > 0) - N(O_i < 0)}{N(O_i > 0) + N(O_i < 0)}$$

- chromo-electric dipole moment (CEDM) of top quark in top pair production induces CPV



$$\mathcal{L} = \frac{g_S}{2}\bar{t}T^a\sigma^{\mu\nu}(a_t^g + i\gamma_5 d_t^g)tG^{\mu\nu}$$

chromo-electric dipole moment

Search for CPV interactions

CMS-PAS-TOP-18-007

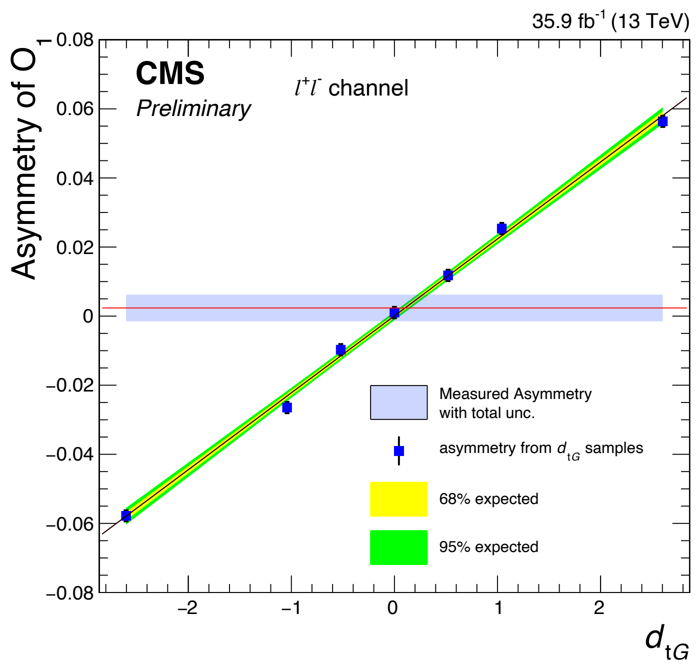
36 fb^{-1}, 13 TeV

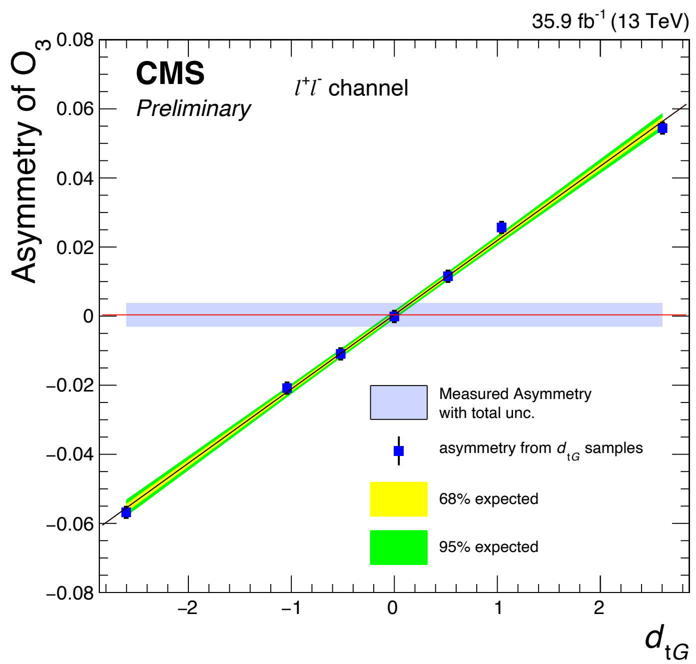
- Extract the asymmetry and CEDM in top pair events in the dilepton final states
- Observables; O_1 and O_3 Alper Hayreter and German Valencia, Phys. Rev. D 93, 014020 (2016)

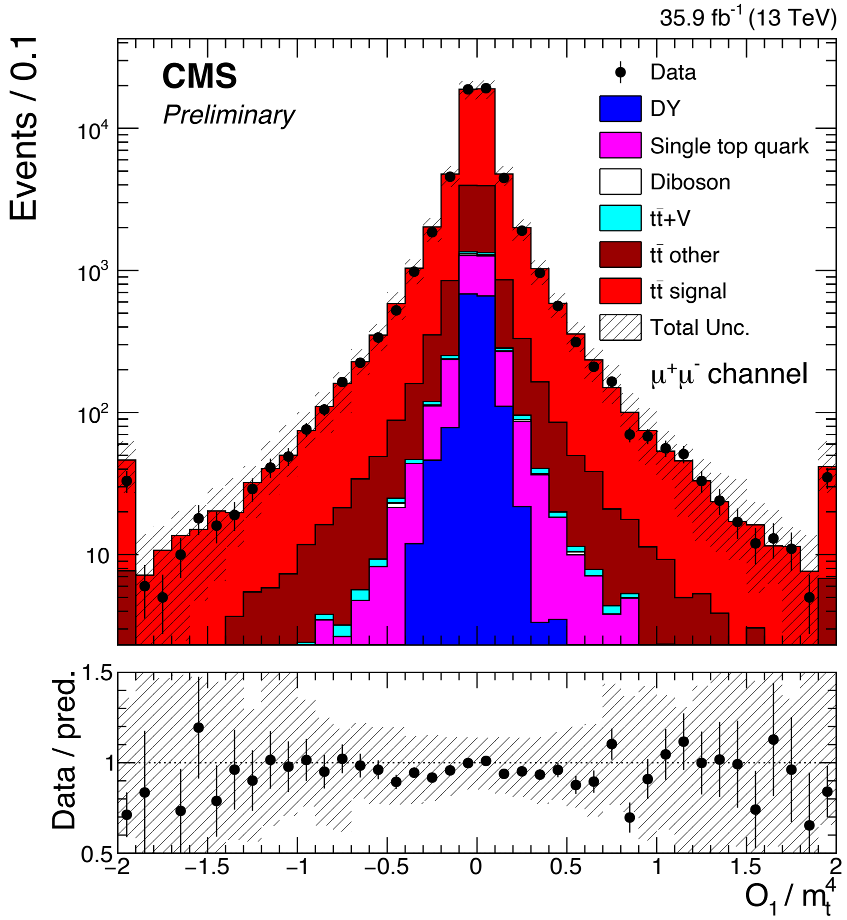
$$\mathcal{O}_1 = \epsilon(p_t, p_{\bar{t}}, p_{\ell^+}, p_{\ell^-}) = \begin{vmatrix} E_t & p_{t_x} & p_{t_y} & p_{t_z} \\ E_{\bar{t}} & p_{\bar{t}_x} & p_{\bar{t}_y} & p_{\bar{t}_z} \\ E_{\ell^+} & p_{\ell^+_x} & p_{\ell^+_y} & p_{\ell^+_z} \\ E_{\ell^-} & p_{\ell^-_x} & p_{\ell^-_y} & p_{\ell^-_z} \end{vmatrix} \qquad \mathcal{O}_3 = \epsilon(p_b, p_{\bar{b}}, p_{\ell^+}, p_{\ell^-}) = \begin{vmatrix} E_b & p_{b_x} & p_{b_y} & p_{b_z} \\ E_{\bar{b}} & p_{\bar{b}_x} & p_{\bar{b}_y} & p_{\bar{b}_z} \\ E_{\ell^+} & p_{\ell^+_x} & p_{\ell^+_y} & p_{\ell^+_z} \\ E_{\ell^-} & p_{\ell^-_x} & p_{\ell^-_y} & p_{\ell^-_z} \end{vmatrix}$$

- The measured asymmetries are consistent with the Standard Model prediction
- Asymmetry and CEDM have linear correlation
- CEDM is extracted by exploiting its correlation with the asymmetry

Physics observable	d_{tG}	CEDM (10^{-18} $g_s \cdot$ cm)
$\mathcal{O}_1$	$0.10 \pm 0.12(\text{stat}) \pm 0.12(\text{syst})$	$0.58 \pm 0.69(\text{stat}) \pm 0.70(\text{syst})$
$\mathcal{O}_3$	$0.00 \pm 0.13(\text{stat}) \pm 0.10(\text{syst})$	$-0.01 \pm 0.72(\text{stat}) \pm 0.58(\text{syst})$







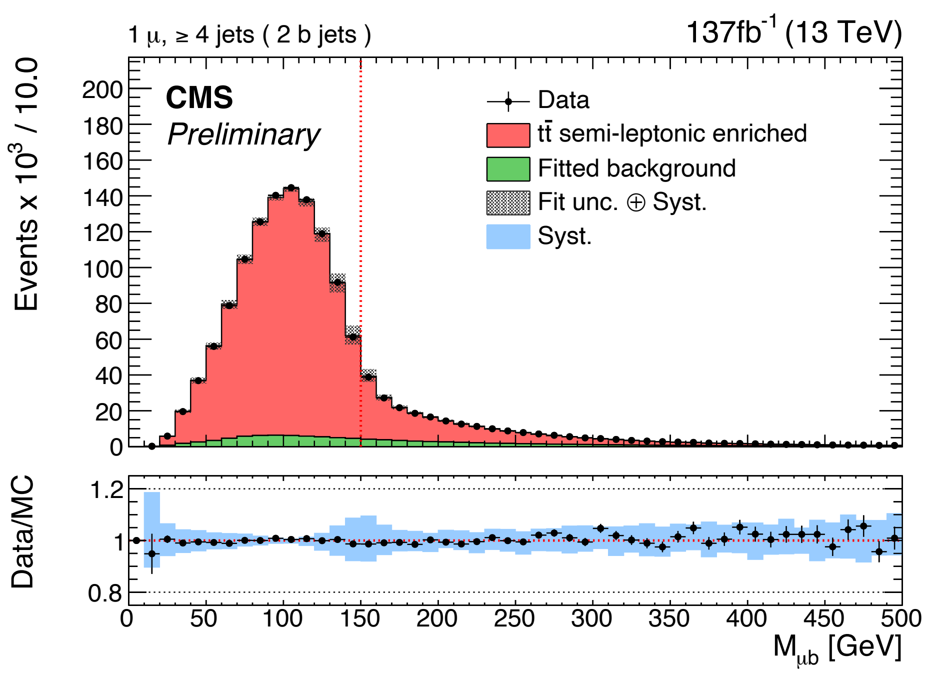
Search for CPV interactions

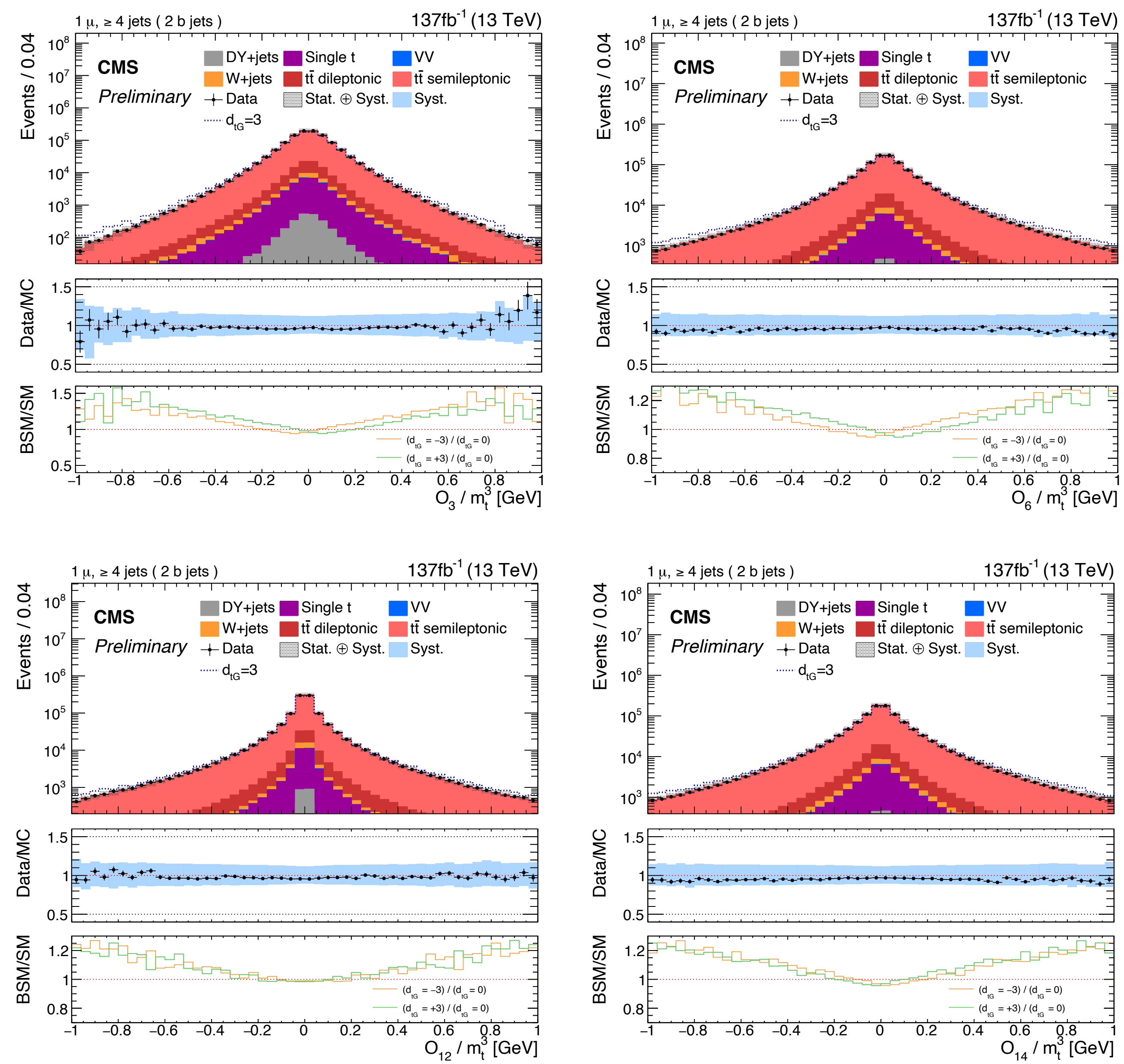
[CMS-PAS-TOP-20-005](CMS-PAS-TOP-20-005)
137 fb^{-1}, 13 TeV

- Lepton + jets final states
- Observables: O_3, O_6, O_{12} and O_{14} Alper Hayreter and German Valencia, Phys. Rev. D 93, 014020 (2016)

$$O_3 = Q_\ell \epsilon(p_b, p_{\bar{b}}, p_\ell, p_{j_1}) \propto Q_\ell \vec{p}'_b \cdot (\vec{p}'_\ell \times \vec{p}'_{j_1})$$
$$O_6 = Q_\ell \epsilon(P, p_b - p_{\bar{b}}, p_\ell, p_{j_1}) \propto Q_\ell (\vec{p}_b - \vec{p}_{\bar{b}}) \cdot (\vec{p}_\ell \times \vec{p}_{j_1})$$
$$O_{12} = q \cdot (p_b - p_{\bar{b}}) \epsilon(P, q, p_b, p_{\bar{b}}) \propto (\vec{p}_b - \vec{p}_{\bar{b}})_z \cdot (\vec{p}_b \times \vec{p}_{\bar{b}})_z$$
$$O_{14} = \epsilon(P, p_b + p_{\bar{b}}, p_\ell, p_{j_1}) \propto (\vec{p}_b + \vec{p}_{\bar{b}}) \cdot (\vec{p}_\ell \times \vec{p}_{j_1}).$$

- Top quark and antiquark candidates are reconstructed using a χ^2 sorting algorithm
- The background contribution in the signal region is estimated from a fit to the mass distribution M_{lb}





Search for CPV interactions

CMS-PAS-TOP-20-005

137 fb^{-1}, 13 TeV

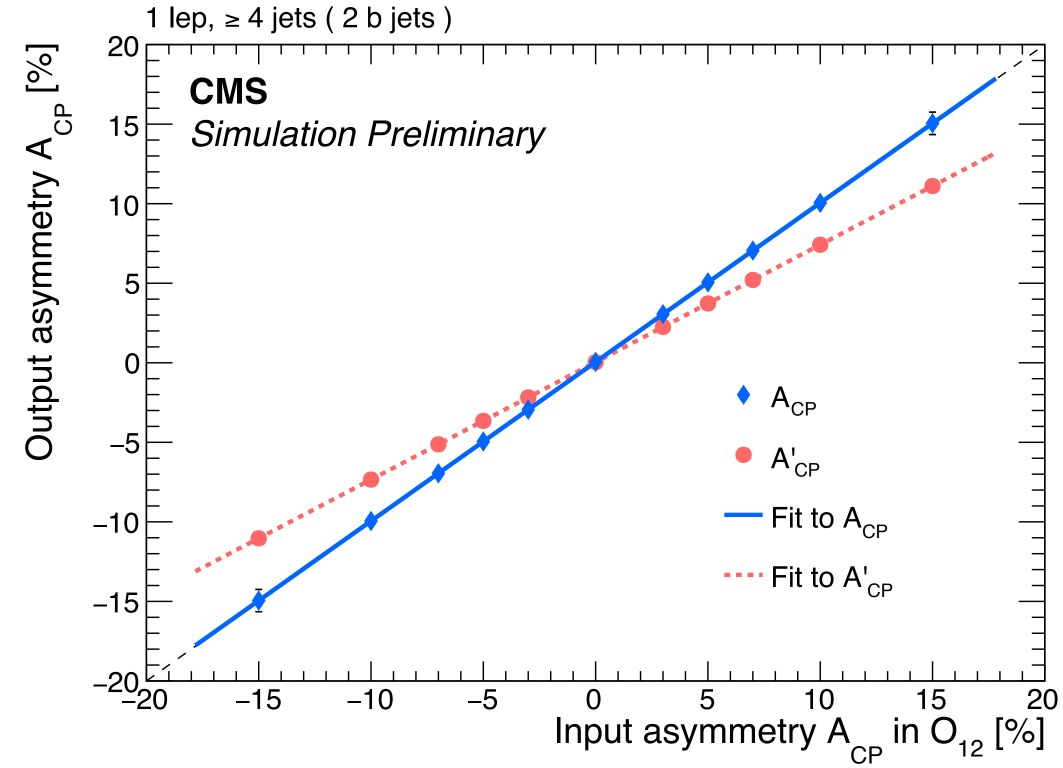
- Experimental factors that affect the measurements are parametrized with a dilution factor
  - Comparing GEN level to RECO level observable
  - Observable-dependent

$$D = \epsilon_c - \epsilon_w$$

ϵ_w: fraction of wrong sign events

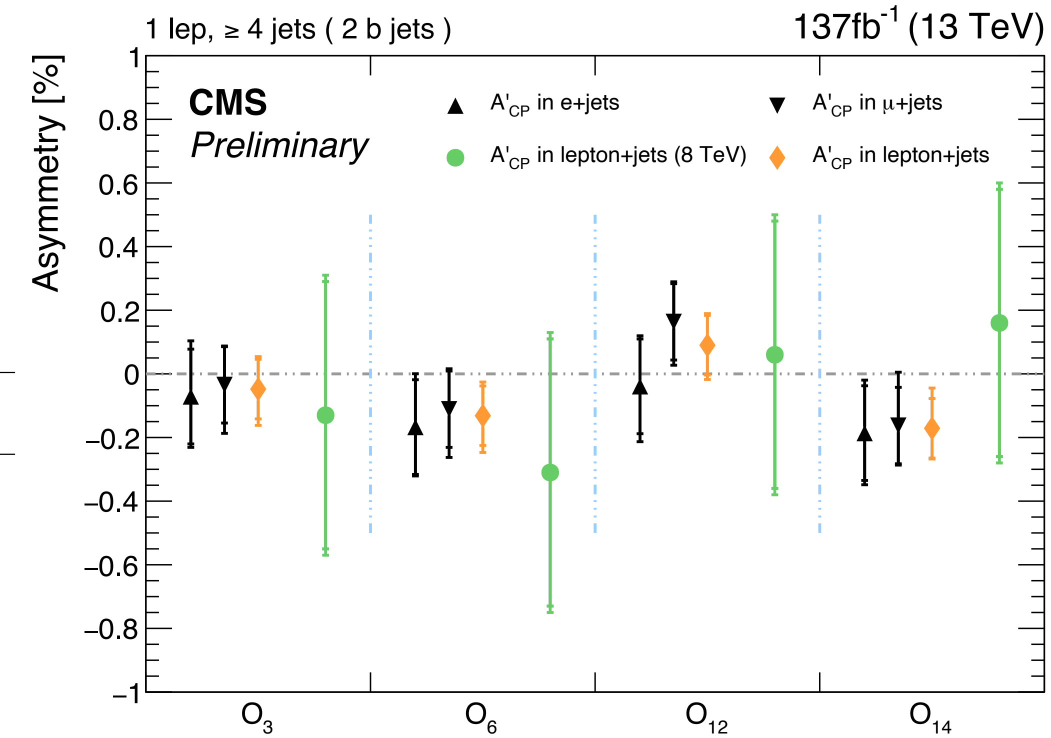
ϵ_c: fraction of correct sign events

Observable	Dilution factor D
O_3	$0.4642^{+0.0007}_{-0.0007}(\text{stat.})\ ^{+0.0135}_{-0.0167}(\text{syst.})$
O_6	$0.4368^{+0.0007}_{-0.0007}(\text{stat.})\ ^{+0.0124}_{-0.0152}(\text{syst.})$
O_{12}	$0.7381^{+0.0006}_{-0.0006}(\text{stat.})\ ^{+0.0129}_{-0.0171}(\text{syst.})$
O_{14}	$0.5989^{+0.0007}_{-0.0007}(\text{stat.})\ ^{+0.0112}_{-0.0143}(\text{syst.})$



- There is no significant evidence of CPV in each observable
  - Consistent with the SM prediction

	$A'_{CP}(\%)$		
	$e+jets$	$\mu+jets$	*Combined*
O_3	$-0.071 \pm 0.149(\text{stat.})^{+0.092}_{-0.058}(\text{syst.})$	$-0.035 \pm 0.120(\text{stat.})^{+0.022}_{-0.094}(\text{syst.})$	$-0.048 \pm 0.094(\text{stat.})^{+0.041}_{-0.065}(\text{syst.})$
O_6	$-0.167 \pm 0.149(\text{stat.})^{+0.077}_{-0.038}(\text{syst.})$	$-0.111 \pm 0.120(\text{stat.})^{+0.042}_{-0.093}(\text{syst.})$	$-0.131 \pm 0.094(\text{stat.})^{+0.049}_{-0.068}(\text{syst.})$
O_{12}	$-0.039 \pm 0.149(\text{stat.})^{+0.056}_{-0.090}(\text{syst.})$	$+0.163 \pm 0.120(\text{stat.})^{+0.038}_{-0.065}(\text{syst.})$	$+0.090 \pm 0.094(\text{stat.})^{+0.034}_{-0.053}(\text{syst.})$
O_{14}	$-0.186 \pm 0.149(\text{stat.})^{+0.075}_{-0.065}(\text{syst.})$	$-0.162 \pm 0.120(\text{stat.})^{+0.117}_{-0.032}(\text{syst.})$	$-0.171 \pm 0.094(\text{stat.})^{+0.085}_{-0.023}(\text{syst.})$



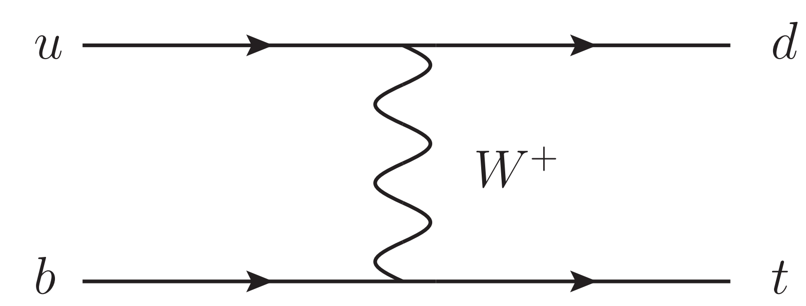
Measurement of Top Polarisation

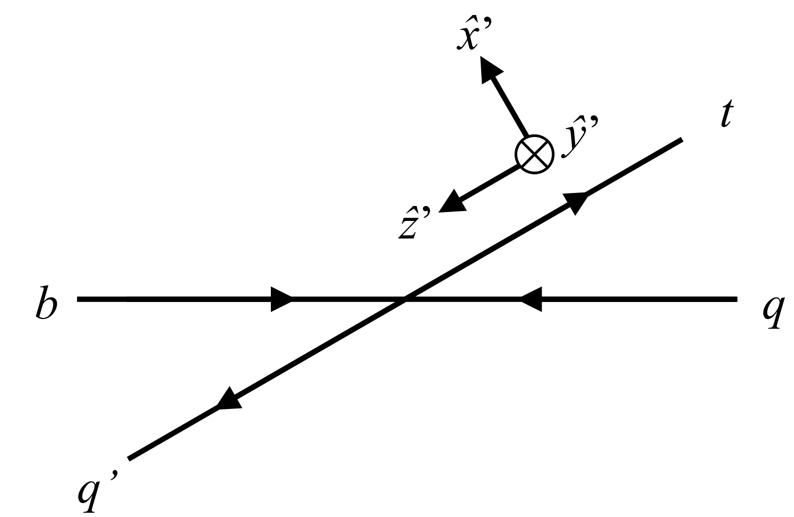
ATLAS-CONF-21-027
139 fb^{-1}, 13 TeV

- Sensitive to CPV (non-zero imaginary C_{tW})
- t-channel single top production
- SM effective field theory

$$\mathcal{L}_{\text{EFT}} = \mathcal{L}_{\text{SM}} + \sum_k \frac{C_k}{\Lambda^2} O_k^{[6]} + \dots$$

- Only the O_{tW} operator with its complex coefficient has an effect on the polarisation of the top quark
- Polarisation
  - $P_{x'}$ is affected by real C_{tW}
  - $P_{y'}$ is affected by imaginary C_{tW}
- Dominant uncertainties on $P_{y'}$: JER and Stat.
- Compatible with the SM predictions





	C_{tW}		C_{itW}	
	68% CL	**95% CL**	**68% CL**	**95% CL**
All terms	[-0.2, 0.9]	[-0.7, 1.5]	[-0.5, -0.1]	[-0.7, 0.2]
Order $1/\Lambda^4$	[-0.2, 0.9]	[-0.7, 1.5]	[-0.5, -0.1]	[-0.7, 0.2]
Order $1/\Lambda^2$	[-0.2, 1.0]	[-0.7, 1.7]	[-0.5, -0.1]	[-0.8, 0.2]

Best limits so far from high-energy experiments!

Parameter	Extracted value	(stat.)
t-channel norm.	$+1.045 \pm 0.022$	(± 0.006)
W+jets norm.	$+1.148 \pm 0.027$	(± 0.005)
$t\bar{t}$ norm.	$+1.005 \pm 0.016$	(± 0.004)
$P^t_{x'}$	$+0.01 \pm 0.18$	(± 0.02)
$P^{\bar{t}}_{x'}$	-0.02 ± 0.20	(± 0.03)
$P^t_{y'}$	-0.029 ± 0.027	(± 0.011)
$P^{\bar{t}}_{y'}$	-0.007 ± 0.051	(± 0.017)
$P^t_{z'}$	$+0.91 \pm 0.10$	(± 0.02)
$P^{\bar{t}}_{z'}$	-0.79 ± 0.16	(± 0.03)

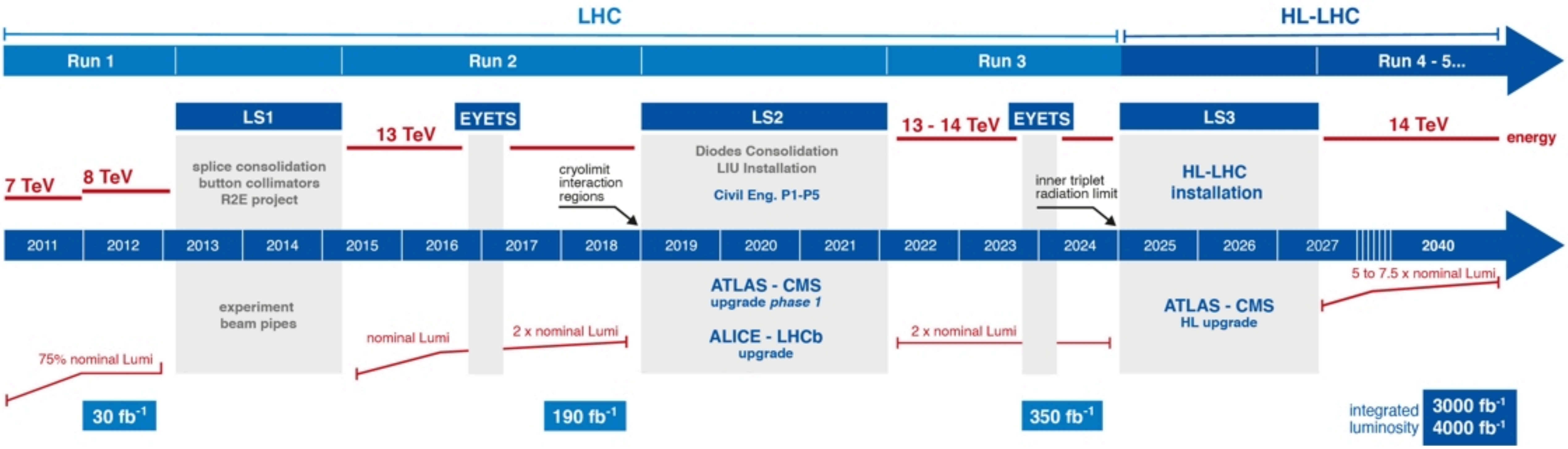
More details in "W helicity and top quark polarizations" by Marcel Vreeswijk

Run 2 update

- LHC is a top quark factory, allowing ATLAS and CMS to search for rare top quark interactions
- Results are consistent with the SM prediction, no significant deviation is observed
- Significant improvements with new methods & more luminosities

What's next?

- More searches are performed with full Run-II data and will be published soon
- More data is coming, stay tuned!




Thank You !