Highlights of top quark measurements with the ATLAS experiment

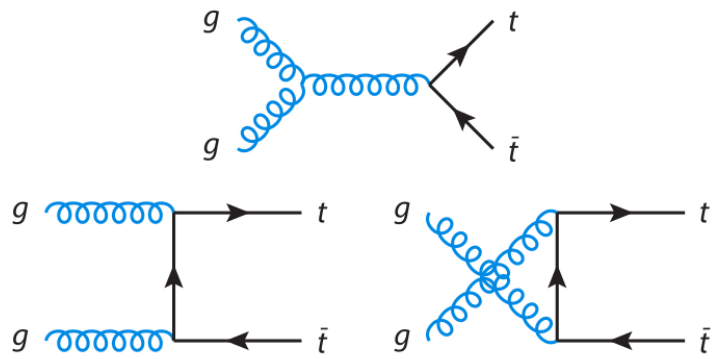
Lepton Photon Conference 2021 · **January 11th, 2022**

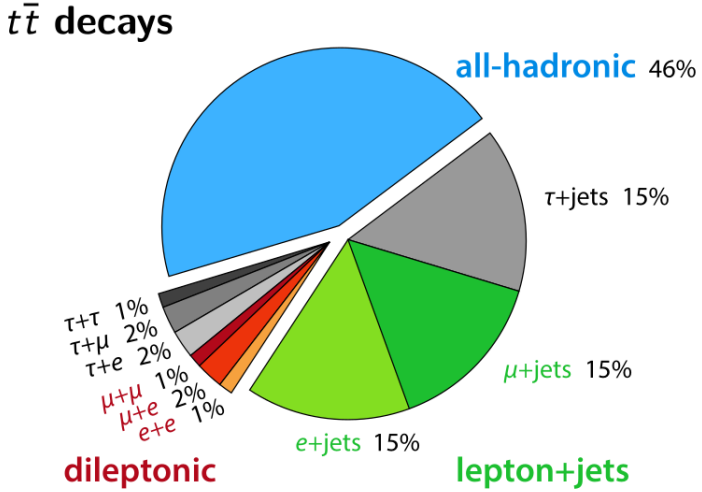
Ana Peixoto (LPSC Grenoble)
on behalf of the ATLAS Collaboration

ATLAS EXPERIMENT

Top quark

- Heaviest known elementary particle ($m_t \approx 173$ GeV)
- Extremely short mean lifetime ($\approx 10^{-25}$ s)
- Top quark decays before hadronisation





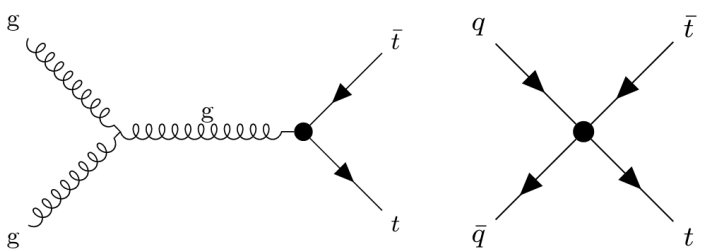
At the Large Hadron Collider:

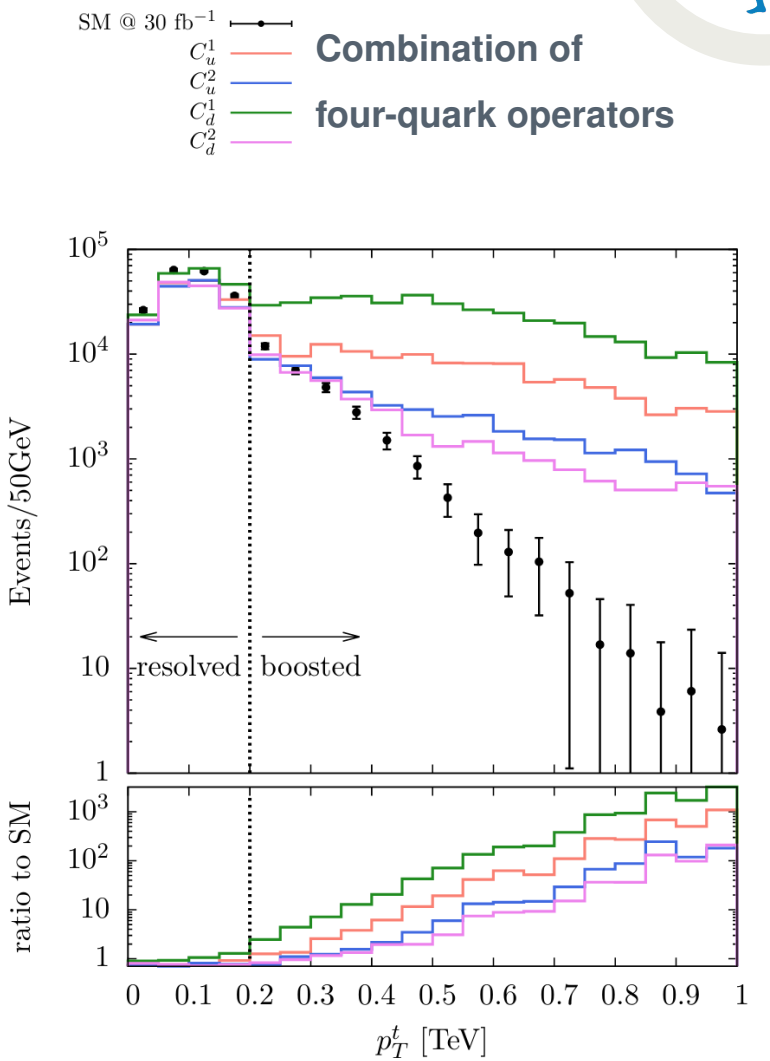
- Dominated by gluon-gluon fusion ($\approx 90\%$ at $\sqrt{s} = 13$ TeV)
- Abundant production of top quarks, mostly in pairs

$\Rightarrow$ Essential for Standard Model (SM) precision measurements

Differential $t\bar{t}$ cross-section

- Test predictions at high energy scales by unfolding differential $t\bar{t}$ measurements in distinct final states
- One focus on high p_T (boosted) top quarks
  - $t\bar{t}$ production with boosting sensitive to deviations from the SM
  - Well-known discrepancies with NLO MC predictions
  - Better sensitivity to four-quark EFT operators





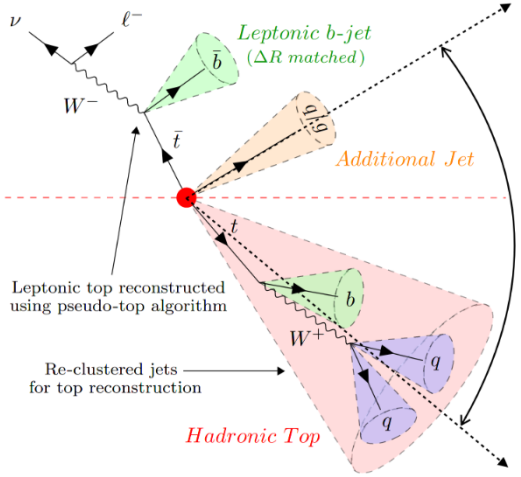
C. Englert, L. Moore, K. Nordstrom, M. Russell, PLB 763 (2016) 9

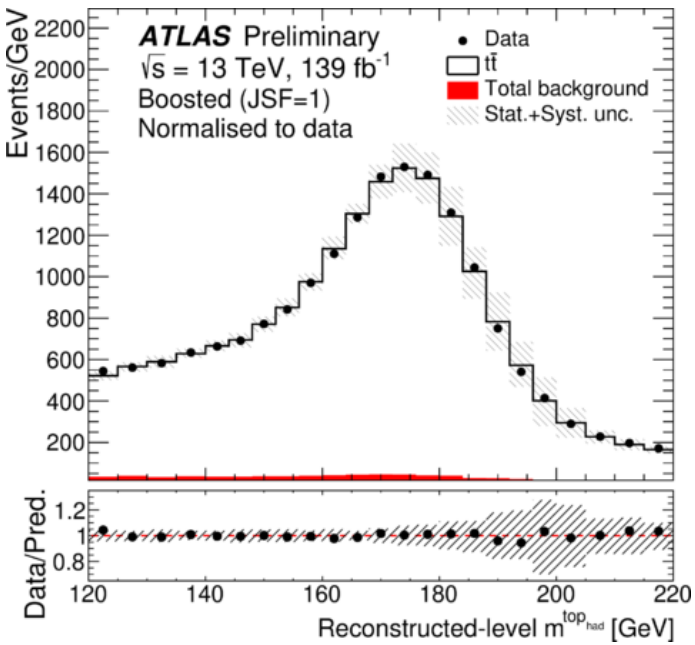
Boosted differential $\sigma_{t\bar{t}}$ ℓ+jets

13 TeV, 139 fb^{-1}, $t\bar{t}$+jets, ATLAS-CONF-2021-031

- **Event selection:** = 1 ℓ, $\geq$ 2 b-tagged jets, $\geq$ 1 re-clustered jet with p_T (t) > 355 GeV and 120 < m < 220 GeV
- Iterative bayesian unfolding at particle level
- Minimising the impact of Jet Energy Scale uncertainties
  - Derivation of a scaling factor (JSF) for small-R jet energies

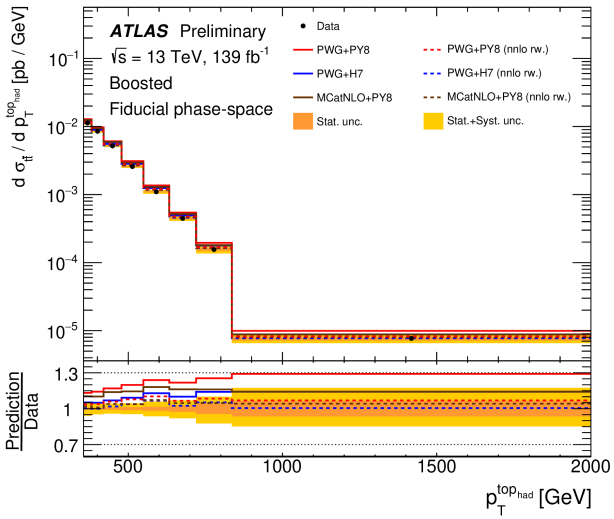
    JSF = 1.00035 ± 0.00087
  - Increase on the sensitivity to m_{top} modelling

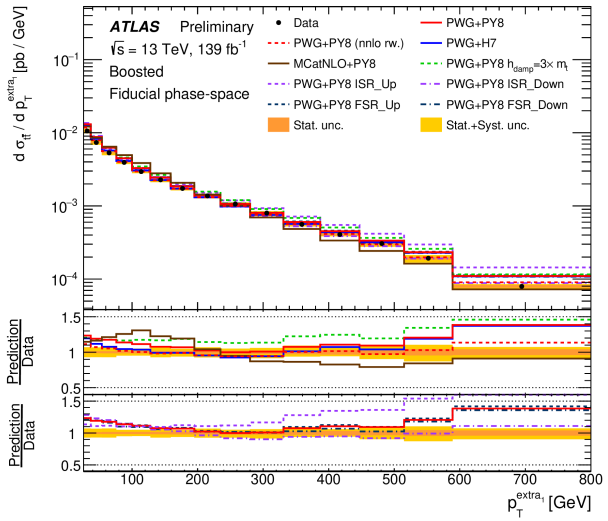




Boosted differential $\sigma_{t\bar{t}}$ ℓ+jets

13 TeV, 139 fb^{-1}, $t\bar{t}$+jets, ATLAS-CONF-2021-031



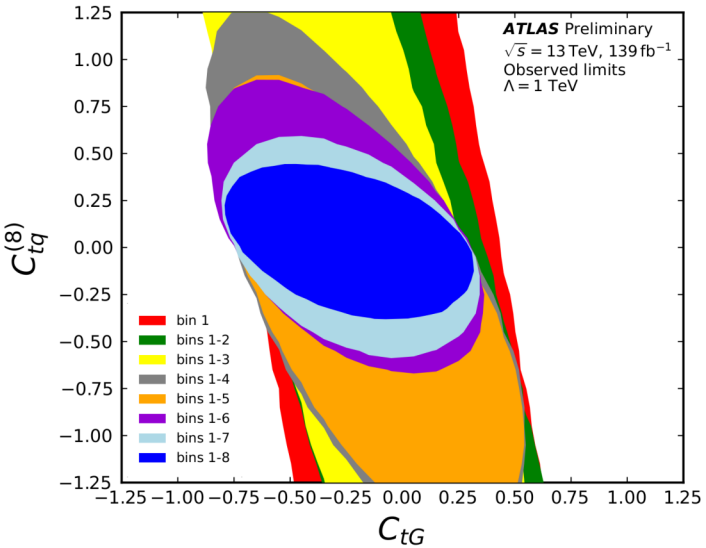


- Comparison to NLO MC predictions re-weighted to NNLO (QCD) + NLO (EW) for tops and $t\bar{t}$ system and additional radiation
  - NNLO reweighting improving agreement
- Reduction of jet uncertainties impact from 4.2% on σ_{total} to 0.7%
- Fiducial cross-section with a relative precision of 4.2%

$$\sigma_{t\bar{t}} = 1.267 \pm 0.005 \text{ (stat)} \pm 0.053 \text{ pb (syst)}$$

Boosted differential $\sigma_{t\bar{t}}$ ℓ+jets

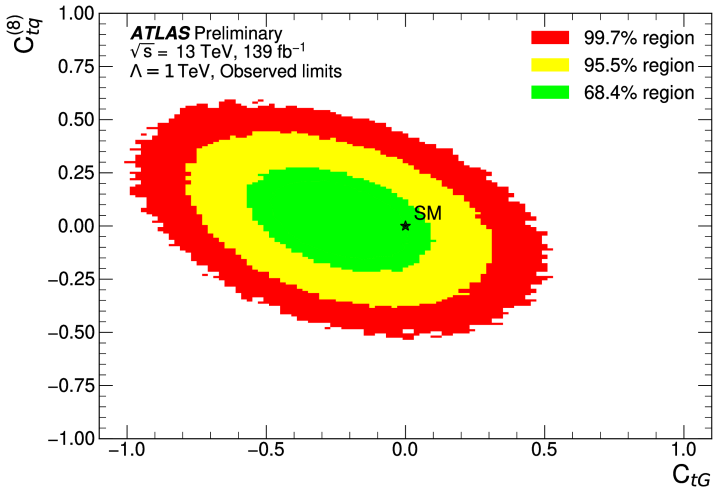
13 TeV, 139 fb^{-1}, $t\bar{t}$+jets, ATLAS-CONF-2021-031



- High p_T affecting more $C_{tq}^{(8)}$ while C_{tG} effects mostly seen on $\sigma_{t\bar{t}}$
- Constraining power on $C_{tq}^{(8)}$ dominated by the measurements at high p_T of the hadronic top

- Fitted Wilson coefficients consistent with zero (C_{tG} = -0.24, $C_{tq}^{(8)}$ = 0.03)
- Stringent limits on EFT coefficients set at 95% CL

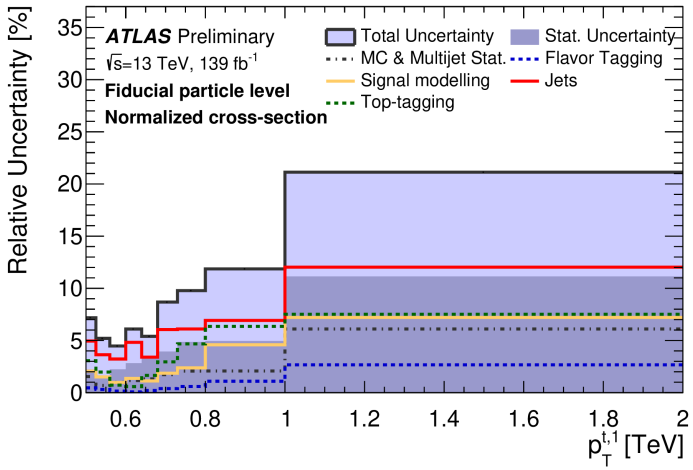
$C_{tG} \in$ [-0.68,0.21], $C_{tq}^{(8)} \in$ [-0.30,0.36]

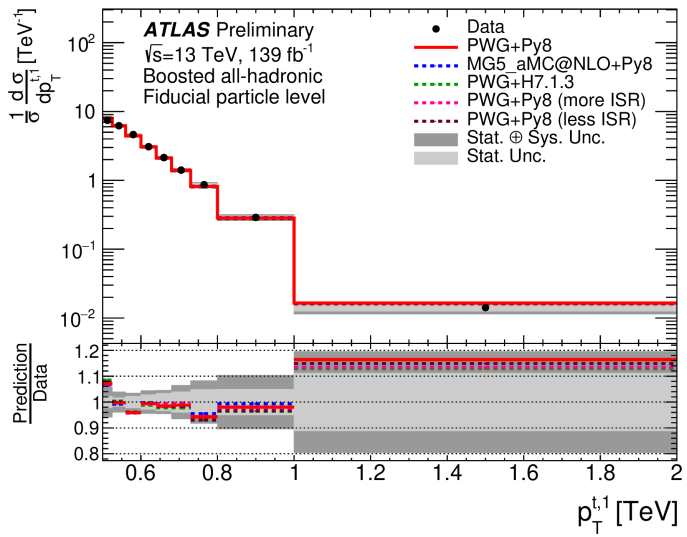


Boosted differential $\sigma_{t\bar{t}}$ all-hadronic

13 TeV, 139 fb^{-1}, $t\bar{t}$, ATLAS-CONF-2021-50

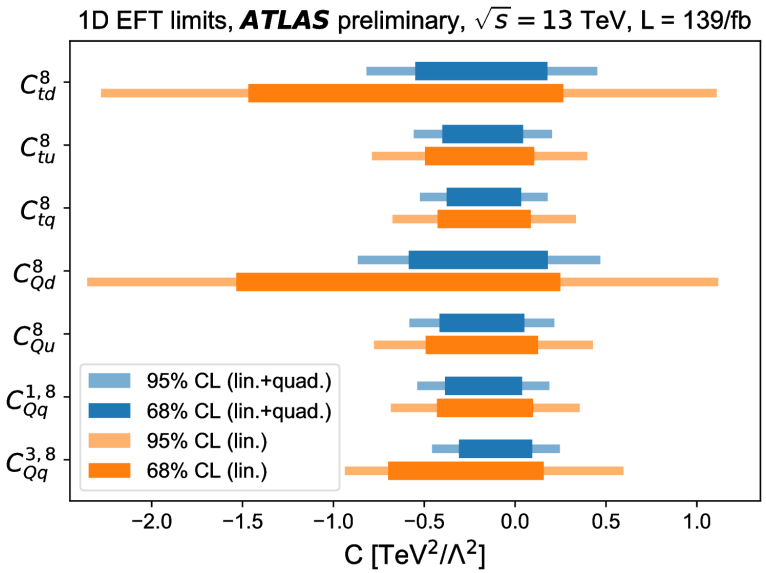
- **Event selection:** $\geq$ 2 large-R jets and p_T (t) $>$ 500 (350) GeV
- Top-tagging: Deep Neural Network top-tagger based on large-R jets substructure variables (at 80% efficiency and matched to b-tagged jets)
- b-tagging: large-R jets matched to b-tagged tracked jets
- Main backgrounds: Multijet, $t\bar{t}$ non-all-hadronic, single-top and $t\bar{t} + X$
- Multijet estimation from non-top/b-tagged regions

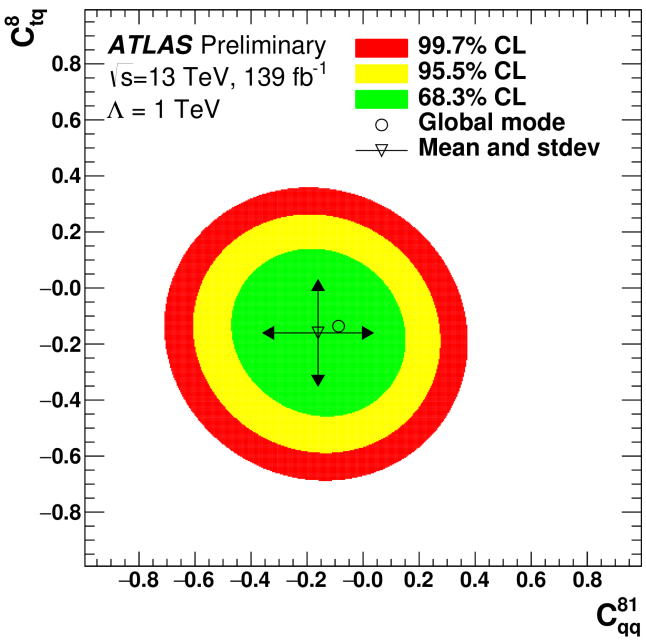




Boosted differential $\sigma_{t\bar{t}}$ all-hadronic

13 TeV, 139 fb^{-1}, $t\bar{t}$, ATLAS-CONF-2021-50

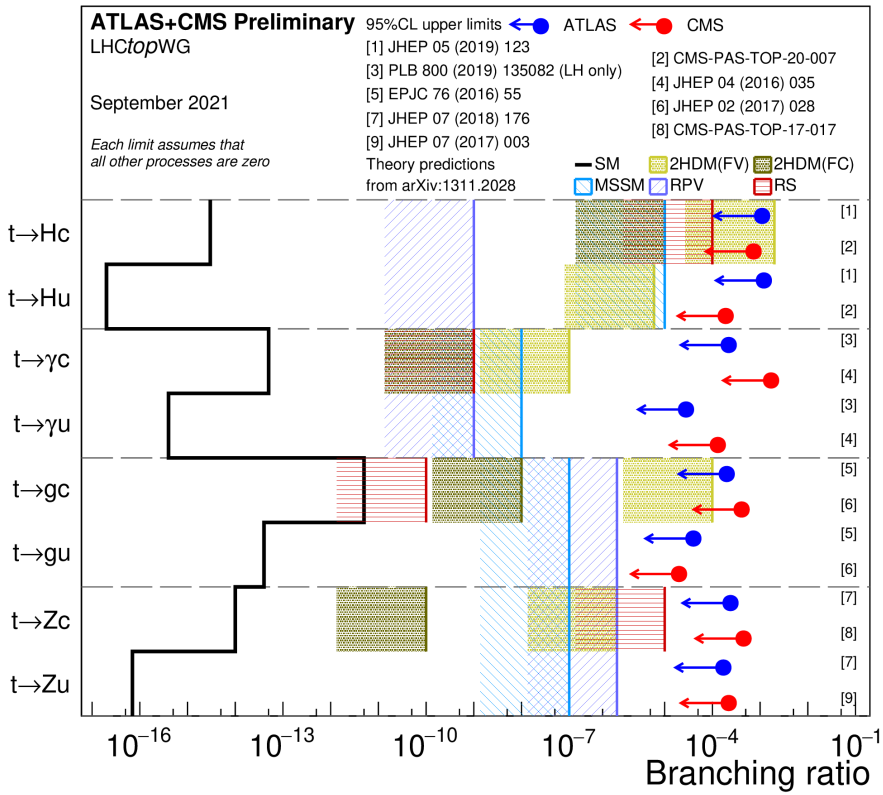




- Parton-level distributions used to measure differential cross-section
- Top p_T as a differential variable to fit $\Rightarrow$ Results compatible with SM only hypothesis
- Main systematics: modelling as ISR/FSR/scale and parton shower and jet-related (JES, JER, top-tagging)
- Interpretation in terms of EFT disentangles O_{tG} and 4-quark operators: fits of seven Wilson coefficients performed with 95% CL limits within the range of (-0.8,+0.5) TeV^2/Λ^2

Flavour Changing Neutral Currents

- Top quark coupling to an **up-type quark** (u or c) and a **neutral boson** (H,γ,g,Z)
- **Forbidden at tree level in the SM** and heavily suppressed at loop correction by the GIM mechanism (BR $< 10^{-12}$)
- Beyond the SM models **enhance** FCNC processes up to a BR $\sim 10^{-4}$
- Possible both in $t\bar{t}$ and single-top quark production

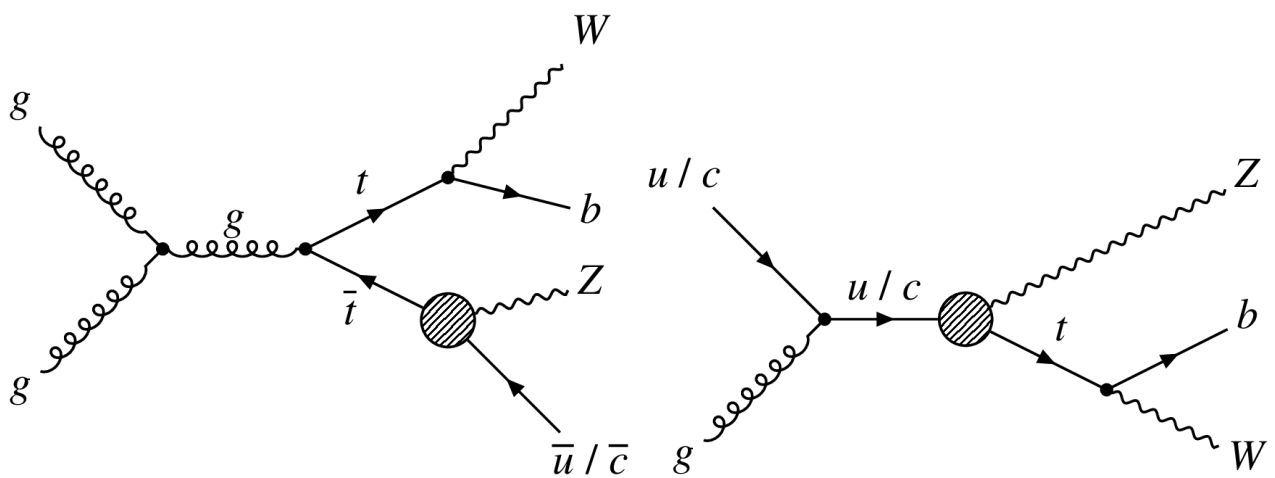


Great place for indirect evidence / constraint on New Physics!

FCNC tZq with $Z \to \ell^+\ell^-$

13 TeV, 139 fb^{-1}, $t\bar{t}$ and single-top production, ATLAS-CONF-2021-49

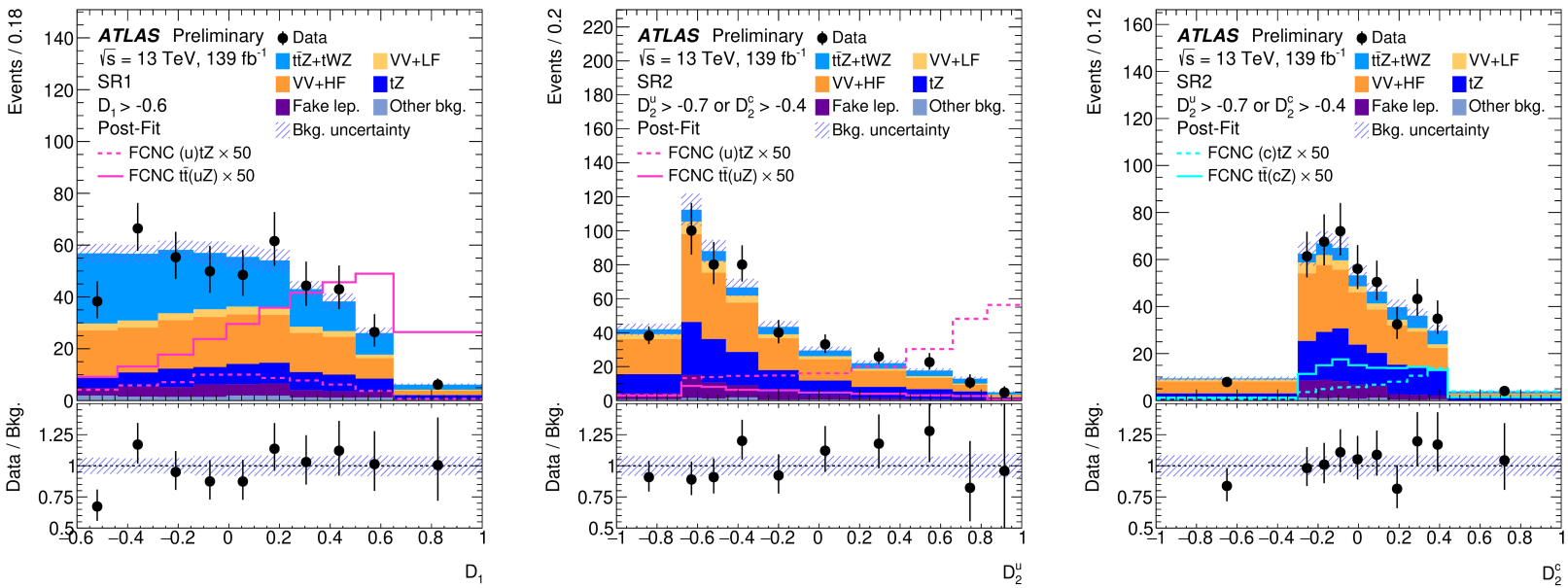
- **Trileptonic topology:** $\ell^+\ell^-\ell$ (e,μ) + $\geq$ 1 jet (b-tagged) + E_T^{miss}
  - Only leptonic Z and W boson decays considered as signal
- **Main backgrounds:**
  - $t\bar{t}Z$, diboson (WZ and ZZ processes) and SM tZ production
- Two signal regions targeting FCNC in decay and production:
  - SR1 ($t\bar{t}$ decay): $\geq$ 2 jets, 1 b-tag
  - SR2 (tZ production): =1,2 jets, 1 b-tag
- Reconstruction of the SM ($t \to bW$) and FCNC ($t \to qZ$) top-quarks via χ^2 minimisation of kinematic properties of the final state objects
  - Orthogonality in 2 jets events with top quark mass veto



FCNC tZq with $Z \to \ell^+\ell^-$

13 TeV, 139 fb^{-1}, $t\bar{t}$ and single-top production, ATLAS-CONF-2021-49

- Gradient Boosted Decision Trees (GBDT) trained to better distinguish signal from background: discriminants focusing on the FCNC $t\bar{t}$ decay, tZu production and tZc production processes
- Four separate fits performed to extract left- and right-handed results for tZu and tZc anomalous couplings:
  - SRs defined by cuts on GBDT discrimant
  - CRs: SRs mass side-bands, $t\bar{t}$ CR and $t\bar{t}Z$ CR



FCNC tZq with $Z \to \ell^+\ell^-$

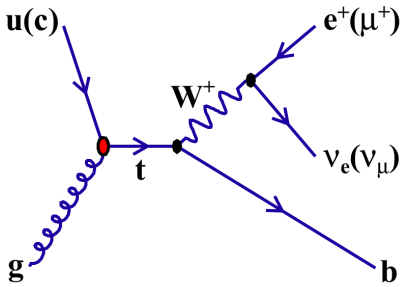
13 TeV, 139 fb^{-1}, $t\bar{t}$ and single-top production, ATLAS-CONF-2021-49

- Good agreement between MC predictions and data
- Most stringent limits up to date on the $t \to Zq$ branching ratios obtained at 95% CL
  - Improvement by a factor of 2-3 on previous limits
  - Translation into limits on relevant EFT Wilson coefficients for both vertices

Observable	Vertex	Coupling	Observed	Expected
$\mathcal{B}(t \to Zq)$ [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	$0.19^{+0.04}_{-0.03}$

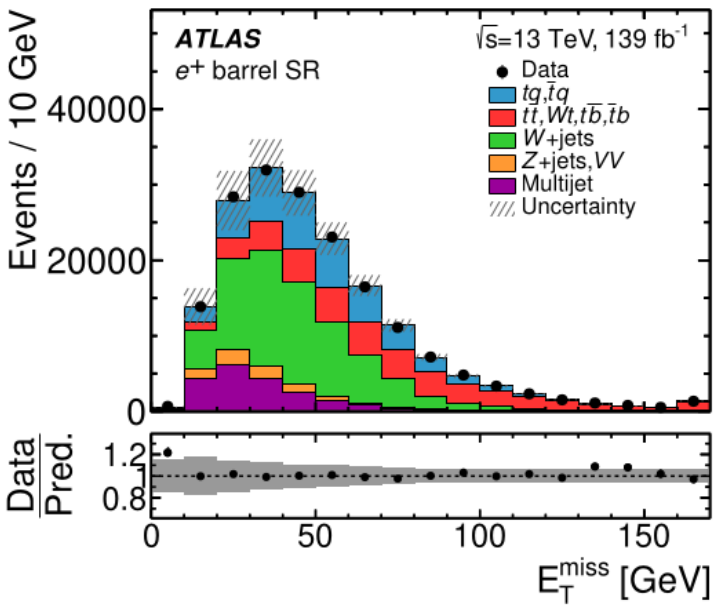
FCNC tgq with $t \to \ell\nu b$

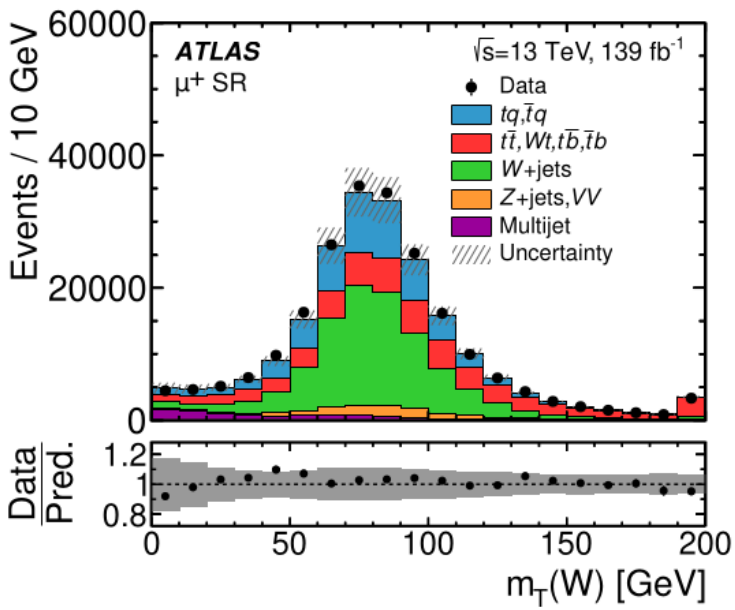
13 TeV, 139 fb^{-1}, single-top production, 2112.01302



- **Targeted topology:** ℓ + b-tagged jet + E_T^{miss}
- **Main backgrounds:** $W + b\bar{b}$, t-channel single-top and $t\bar{t}$ production

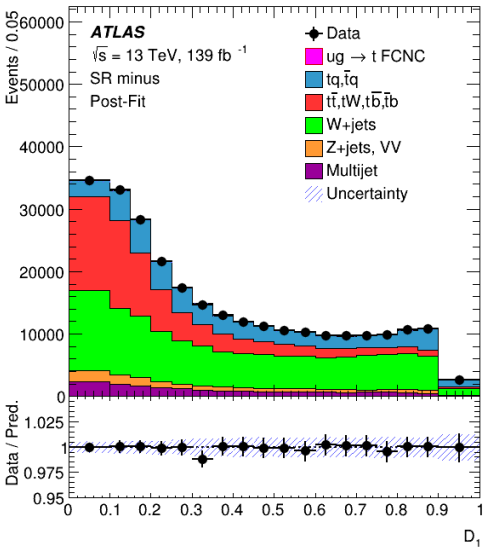
- Dedicated 30% working point for b-tagging efficiency
- Multijet contribution determined in a data-driven way by fitting E_T^{miss} and $m_T(W)$

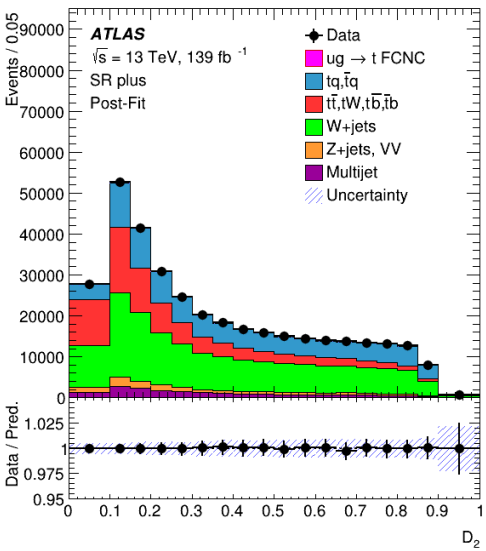




FCNC tgq with $t \to \ell\nu b$

13 TeV, 139 fb^{-1}, single-top production, 2112.01302





- Common requirements on E_T^{miss} (> 30 GeV), $m_T(W)$ (> 50 GeV), jet multiplicity and lepton p_T
- Neural Network (NN) used to construct two discriminants:
  - D_1 targeting top antiquark production ($\bar{u}/\bar{c} + g \to \bar{t}$): signal region for cgt and ugt in ℓ^- channel
  - D_2 aimed at direct top quark production ($u + g \to t$): signal region for ugt in ℓ^+ channel
- Three validation regions defined for W+jets, $t\bar{t}$ and tq production with different b-tagging efficiencies and cuts on NN discriminants

FCNC tgq with $t \to \ell\nu b$

13 TeV, 139 fb^{-1}, single-top production, 2112.01302

- Binned maximum-likehood fit performed separately to *ugt* and *cgt* FCNC processes
- Leading systematic uncertainties related to the W+jets process for the *ugt* fit and the modelling of the parton shower for the *cgt* fit
- Measured data consistent with background-only hypothesis
- Limits for FCNC tgq couplings set at the 95% CL for cross-sections, branching ratios and further interpreted in terms of EFT coefficients
  - A factor of three more restrictive than the previous ATLAS results

Coupling	$\sigma(q + g \to t)$	$\mathcal{B}(t \to gq)$	$\lvert C_{uG}^{qt}\rvert/\Lambda^2$
tgu	3.0 pb	$0.61\ (0.49) \times 10^{-4}$	0.057
tgc	4.7 pb	$3.7\ (2.0) \times 10^{-4}$	0.14

Conclusions

- **Wide variety** of new top quark results using the **full Run-2 data**
  $\Rightarrow$ Talk from Andrea Knue
- **Precision regime** with $t\bar{t}$ differential cross-section analyses using **boosted topologies**
- Effects from **FCNC processes in the top quark sector** studied with different **anomalous couplings** and **production modes**
- **Strong effort** to parametrise the current measurements in terms of **Effective Field Theory**
- Boosted $t\bar{t}$ **cross-section measurements** well suited to **constrain distinct four-fermion operators**
- **Future analyses** will be probing top quarks at **even higher energy scales**

Thanks for listening!

For more information: complete list of ATLAS top public results