Highlights on top quark physics with the ATLAS experiment at the LHC

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on behalf of the ATLAS collaboration

2023-01-10
HEP 2023
8th International Conference on High Energy Physics in the LHC Era

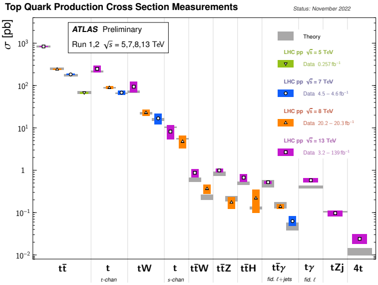
Outline

- Motivation
- **First run 3 results**
- Cross-section measurement at 5.02 TeV
- Mass measurements
- Charge asymmetry measurements
- W polarisation in top decays
- New Observation of $t\gamma q$
- Search for charged lepton flavour violation (cLFV)

Motivation

Why top-quark physics?

- LHC is a top-quark factory:
  - Run 2 produced $> 10^8$ top quarks
- Due to short lifetime ($\approx 10^{-25}$ s):
  - Properties directly accessible
- Increasing precision on measurements like:
  - cross sections
  - mass
  - width
  - couplings
- Rare processes accessible for observation/search, e.g.:
  - 4 tops
  - Flavour changing neutral currents (FCNC)
  - cLFV

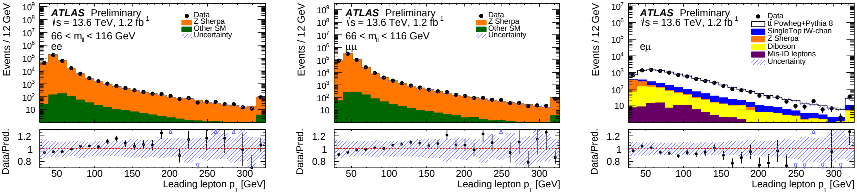


$t\bar{t}$ @ 13.6 TeV
ATLAS-CONF-2022-070

- Run 3 started in 2022, $t\bar{t}$ and Z serve as standard candle
- Dilepton events used to measure $\sigma_{t\bar{t}}$ and $R = \sigma_{t\bar{t}}/\sigma_Z$
- b-tag counting method + profile likelihood fit

$$N_1 = \mathcal{L}\sigma_{t\bar{t}}\epsilon_{e\mu}2\epsilon_b(1-\epsilon_b C_b) + N_{1,bkg} \quad N_2 = \mathcal{L}\sigma_{t\bar{t}}\epsilon_{e\mu}(\epsilon_b)^2 C_b + N_{2,bkg}$$

- ϵ_b related to tagging efficiency and detector acceptance and tagging correlation C_b
- In $l\bar{l}$ channel m_{ll} distribution around Z-mass
- $\sigma_{t\bar{t}}$ measured in $e\mu$ channel, R measured in $l\bar{l}$ channel
- Cross section ratio benefits from cancellations of uncertainties (e.g. luminosity)



$t\bar{t}$ @ 13.6 TeV
ATLAS-CONF-2022-070

ATLAS EXPERIMENT

- Although only 1.2 fb^{-1} of data used, analysis is dominated by systematics: Luminosity, flavour tagging, Z scale variations

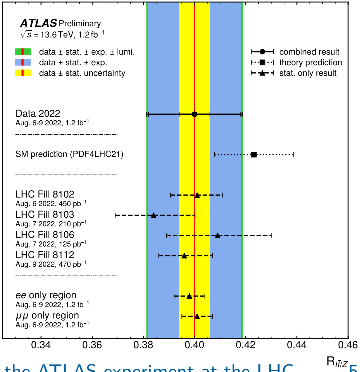
Results

$\sigma_{t\bar{t}} = 830 \pm 12(\text{stat.}) \pm 27(\text{syst.}) \pm 86(\text{lumi.})$ pb
$\sigma^{m_{ll}>40}_{Z\to ll} = 2075 \pm 2(\text{stat.}) \pm 98(\text{syst.}) \pm 199(\text{lumi.})$ pb

Predictions

$\sigma_{t\bar{t}} = 924^{+32}_{-40}(\text{scale} + \text{PDF})$ pb
$\sigma^{m_{ll}>40}_{Z\to ll} = 2182^{+42}_{-45}(\text{scale} + \text{PDF})$ pb

	Category	**Uncert.** [%]		
		$\sigma_{t\bar{t}}$	$\sigma^{m_{\ell\ell}>40}_{Z\to\ell\ell}$	$R_{t\bar{t}/Z}$
$t\bar{t}$	$t\bar{t}$ parton shower/hadronisation	0.6	0.2	0.7
	$t\bar{t}$ scale variations	0.5	0.1	0.5
Z	Z scale variations	0.2	2.9	2.9
Bkg.	Single top modelling	0.6	< 0.01	0.6
	Diboson modelling	0.1	< 0.01	0.5
	Mis-Id leptons	0.6	< 0.01	0.6
Lept.	Electron reconstruction	1.6	2.3	1.1
	Muon reconstruction	1.3	2.4	0.3
	Lepton trigger	0.2	1.3	1.1
Jets/tagging	Jet reconstruction	0.2	< 0.01	0.2
	Flavour tagging	1.9	< 0.01	1.9
	PDFs	0.5	1.4	1.3
	Luminosity	10.3	9.6	1.3
	Systematic Uncertainty	10.8	10.7	4.4
	Statistical Uncertainty	1.5	0.1	1.5
	Total Uncertainty	11	10.7	4.7



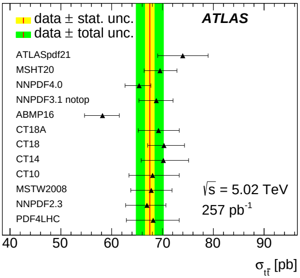
$t\bar{t}$ Cross-Section @5.02 TeV

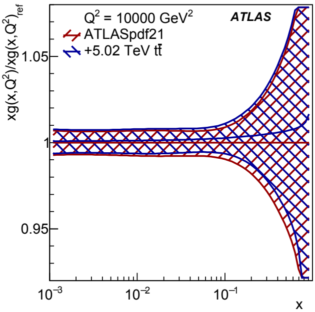
arXiv:2207.01354

- Testing theory predictions at intermediate $\sqrt{s}$
- Done in dilepton and single-lepton channels + combination
- Boosted decision tree (BDT) used in single-lepton channel
- Overall uncertainty of 3.9% (similar to 13 TeV measurement)
- Measurement helps to constrain parton density functions (PDFs)

Result

$\sigma_{\text{meas.}} = 67.5 \pm 0.9(\text{stat.}) \pm 2.3(\text{syst.}) \pm 1.1(\text{lumi.}) \pm 0.2(\text{beam})$ pb





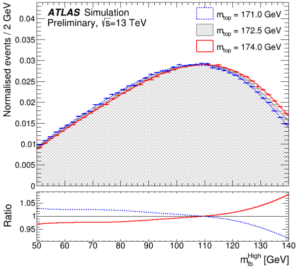
Mass measurements

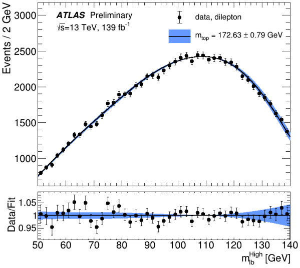
Template method (ATLAS-CONF-2022-058)

- Dilepton channel used; partial event reconstruction via neural network (NN)
- Parametrising templates: sum of two Gaussians and a Cosine function
- Unbinned likelihood fit used
- Dominated by jet-energy and modelling uncertainties
  - Matrix element matching, jet energy scale (JES), recoil effects

Result

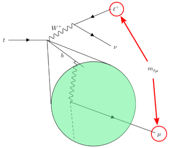
$m_{top} = 172.63 \pm 0.2\ (\text{stat.}) \pm 0.67\ (\text{syst.}) \pm 0.37\ (\text{recoil})\ \text{GeV}$



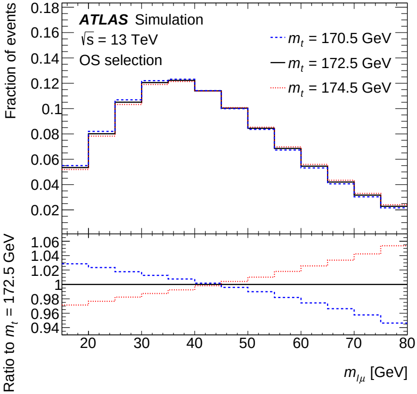


Mass measurements

Soft muons (arXiv:2209.00583)



- l+jets channel with additional soft muon; $m_{l\mu}$ is used to extract m_{top}
- Improved fit for *b*-quark fragmentation to LEP and SLC data
- Interpolation with piece-wise linear functions
- Dominated by b, c hadron branching rations (BR) and QCD initial state radiation (ISR)



Result

$m_t = 174.41 \pm 0.39\,(\text{stat.}) \pm 0.66\,(\text{syst.}) \pm 0.25\,(\text{recoil})$ GeV

Charge Asymmetry ($t\bar{t}$)

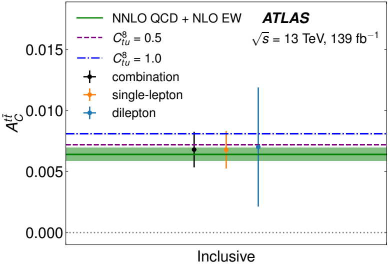
arXiv:2208.12095

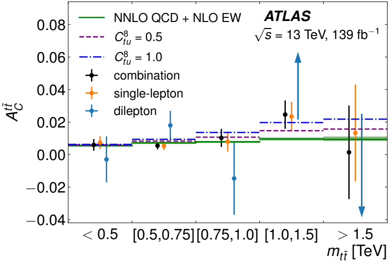
- Asymmetry expected at NLO due to asymmetries in PDFs for q and $\bar{q}$
- $A_C^{t\bar{t}}$ and $A_C^{l\bar{l}}$ measured inclusively and differentially in m, p_T and β_z
- $A_C^{t\bar{t}}$ in single-lepton channel in boosted and resolved topology

Results

$$A_C^{t\bar{t}} = 0.0068 \pm 0.0015 \quad A_C^{l\bar{l}} = 0.0054 \pm 0.0026$$

- $A_C^{t\bar{t}}$ 4.7σ away from null-hypothesis
- Statistically limited

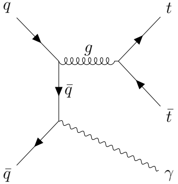




Charge Asymmetry ($t\bar{t}V$)

arXiv:2212.10552 & ATLAS-CONF-2022-062

- Asymmetry due to interference between ISR and final state radiation (FSR)
- Bosons from decay products of the top-quark dilute measurable effect
- In $t\bar{t}W$ trilepton channel used and BDT for lepton to top assignment
- In $t\bar{t}\gamma$ NN to enhance signal ($t\bar{t}\gamma$ with photon from production)
- Compatible with SM prediction but also with null-hypothesis; stat. limited

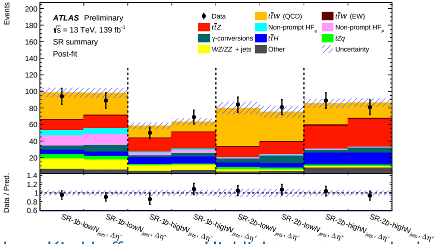


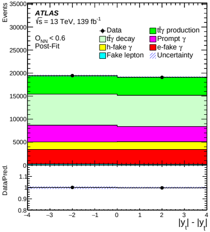
Result

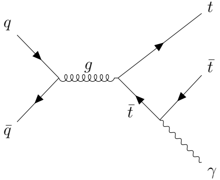
$A_C = -0.006 \pm 0.024(\text{stat.}) \pm 0.018(\text{syst.}) \quad t\bar{t}\gamma$

$A_C^l = -0.123 \pm 0.136(\text{stat.}) \pm 0.051(\text{syst.}) \quad t\bar{t}W$

$A_C^{l,PL} = -0.112 \pm 0.170(\text{stat.}) \pm 0.055(\text{syst.}) \quad t\bar{t}W$







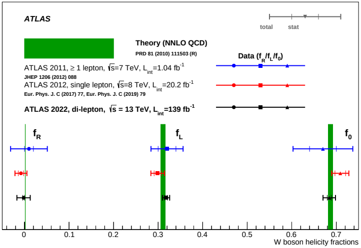
W-helicity in top-decays

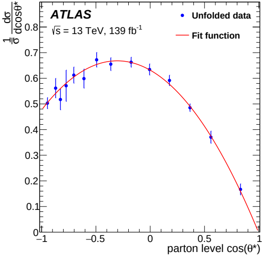
arXiv:2209.14903

- Dilepton channel used
- Using W rest-frame requires top-reconstruction
- Neutrino weighting used (90% efficiency for signal)
- Unfolding done to particle level
- Fractions extracted with χ^2 minimisation, f_L and f_R free floating
- Modelling dominate uncertainties, especially matrix element matching

Results

$f_0 = 0.684 \pm 0.005(\text{stat.}) \pm 0.014(\text{syst.})$ $f_L = 0.318 \pm 0.003(\text{stat.}) \pm 0.008(\text{syst.})$
$f_R = -0.002 \pm 0.002(\text{stat.}) \pm 0.014(\text{syst.})$





Observation of $t\gamma q$

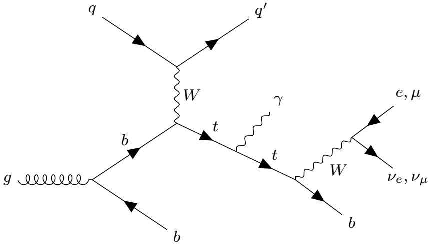
ATLAS-CONF-2022-013

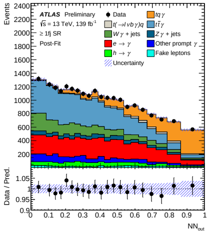
ATLAS EXPERIMENT

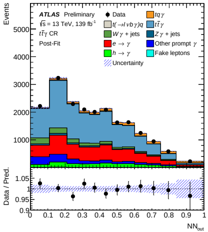
- $t\gamma q$ process is very rare, allows to probe electroweak top coupling
- 2 signal regions (SRs) and 2 control regions (CRs); NN used to separate signal and background
- Profile likelihood fit used to extract cross section with free floating parameters for background
- Observed (expected) significance: 9.1σ (6.7σ); Prediction: 406^{+25}_{-32} fb
- Dominated by modelling uncertainties as $t\bar{t}\gamma$, $t\bar{t}$ and MC statistics

Result

$\sigma_{t\gamma q} \times \mathcal{B}(t \to l\nu b) = 580 \pm 19(\text{stat.}) \pm 63(\text{syst.})$ fb



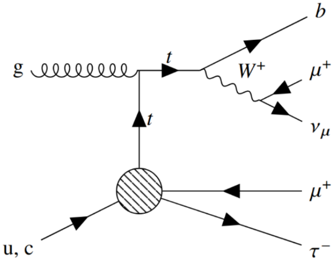


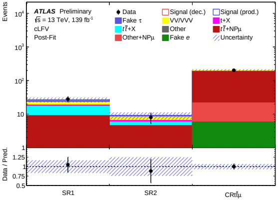


cLFV interactions ($\tau\mu tq$)

ATLAS-CONF-2023-001 (hot of the press!)

- $\mu\tau$ channel used for the first time!
- Sensitive to many different BSM scenarios (leptoquarks, SUSY, technicolor)
- Model-independent search, EFT approach
- Looking in single top production and $t\bar{t}$ decay
- Largest background $t\bar{t}$+heavy flavour μ decays, free floating, leading systematic
- Currently limited by statistics





	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

[22] JHEP04 (2019) 014

Inclusive limit @95% CL: BR($t \to \mu\tau q$) $< 11 \cdot 10^{-7}$

Summary

- 2022 was a busy year for top physics in ATLAS with many Run 2 analyses finishing and Run 3 having begun
- could only show a few results here, all of them can be found here:

  https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults
- Further results from the ATLAS top working group were shown yesterday by Rebeca Gonzalez Suarez
- Results shown here include a very first look at the Run 3 data by measuring the $t\bar{t}$ cross-section
- Together with the cross-section at 5 TeV and previous measurements, they show remarkable agreement of QCD predictions with data
- Rare $t\gamma q$ has been observed
- Presented recent charge asymmetry measurements, currently limited by the statistical uncertainty of the data
- Large dataset allows to search for BSM induced processes like cLFV
- Need to reduce signal and background modelling uncertainties as they dominate many measurements

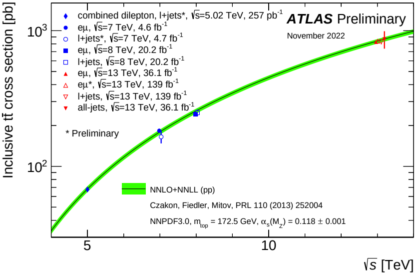
Thank you for your attention!

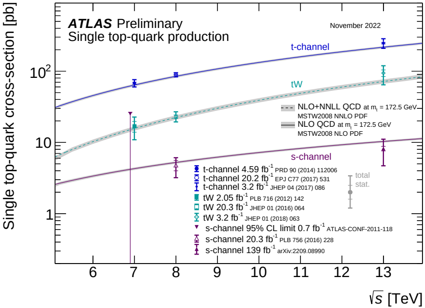
Backup

Top cross sections

Introduction

- Cross section σ is main theory prediction
- Understand production and decay mechanisms
  - Measuring different detector signatures, i.e. looking for reconstructed objects with certain features
- Expected events given by $N_{events} = \frac{\sigma \mathcal{L}}{C}$
  - $\mathcal{L}$: integrated luminosity; C: correction factor for reconstruction efficiency and event migration
- Theory calculations give good and precise predictions





$t\bar{t}$ Cross-Section @5.02 TeV

arXiv:2207.01354

Dilepton:

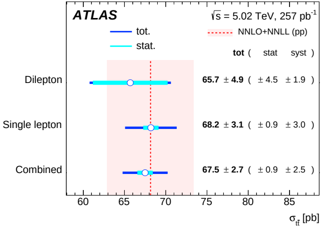
- 2 OS leptons (18 GeV)
- $m_{ll} > 15/40$ GeV for $e\mu/ll$ channel
- $E_T^{miss} > 30$ GeV, 1.2 b-tagged jets (@85%)
- fit m_{ll} distribution
- limited by stat. uncertainties

Event counts	$N^{ee}_{1,\text{off}-Z}$	$N^{ee}_{1,\text{on}-Z}$	$N^{e\mu}_{1}$	$N^{\mu\mu}_{1,\text{off}-Z}$	$N^{\mu\mu}_{1,\text{on}-Z}$
Data	47	113	121	65	106
$t\bar{t}$	30.1 ± 3.8	6.0 ± 0.7	95.6 ± 10.0	36.6 ± 3.6	7.5 ± 0.8
Wt single top	4.0 ± 0.6	0.75 ± 0.12	13.9 ± 1.5	4.5 ± 0.5	0.90 ± 0.12
Z + jets	14.7 ± 1.5	80.1 ± 6.0	6.8 ± 1.7	27.1 ± 3.3	111.3 ± 8.8
Diboson	0.83 ± 0.17	2.3 ± 0.5	2.6 ± 0.5	0.90 ± 0.18	2.5 ± 0.5
Misidentified leptons	0.9 ± 0.4	0.05 ± 0.03	1.7 ± 0.8	0.23 ± 0.17	0.16 ± 0.15
Total prediction	50.5 ± 3.7	89.2 ± 5.9	120.6 ± 9.7	69.4 ± 4.7	122.4 ± 8.6
Event counts	$N^{ee}_{2,\text{off}-Z}$	$N^{ee}_{2,\text{on}-Z}$	$N^{e\mu}_{2}$	$N^{\mu\mu}_{2,\text{off}-Z}$	$N^{\mu\mu}_{2,\text{on}-Z}$
Data	31	15	113	31	17
$t\bar{t}$	28.7 ± 5.3	6.0 ± 1.1	107.6 ± 10.3	26.6 ± 5.9	5.5 ± 1.2
Wt single top	0.88 ± 0.15	0.21 ± 0.07	3.0 ± 0.6	1.00 ± 0.27	0.17 ± 0.05
Z + jets	1.2 ± 1.0	8.5 ± 2.6	1.3 ± 0.5	2.8 ± 1.0	11.5 ± 3.8
Diboson	0.06 ± 0.01	0.16 ± 0.03	0.20 ± 0.04	0.06 ± 0.01	0.30 ± 0.06
Misidentified leptons	0.15 ± 0.15	0.04 ± 0.04	0.6 ± 0.6	0.10 ± 0.11	0.05 ± 0.06
Total prediction	31.0 ± 5.1	14.9 ± 2.6	112.8 ± 10.3	30.6 ± 5.6	17.6 ± 3.5

Lepton+jets:

- 1 lepton (25 GeV); ≥ 2 jets and ≥ 1 b-jet
- 6 SRs according to jet and b-jet multiplicity
- W/Z modelling as leading systematics

	$\ell + 2j \geq 1b$	$\ell + 3j\ 1b$	$\ell + 3j\ 2b$	$\ell + \geq 4j\ 1b$	$\ell + 4j\ 2b$	$\ell + \geq 5j\ 2b$
$t\bar{t}$	194 ± 27	310 ± 33	199 ± 24	690 ± 60	318 ± 32	380 ± 60
Single top	195 ± 22	98 ± 12	38 ± 5	67 ± 9	22 ± 4	15.9 ± 2.7
W+jets	1700 ± 400	690 ± 210	58 ± 23	350 ± 120	30 ± 14	19 ± 10
Other bkg.	110 ± 40	55 ± 23	7.2 ± 3.0	29 ± 12	3.5 ± 1.5	3.7 ± 1.7
Misidentified leptons	250 ± 130	110 ± 60	10 ± 5	60 ± 30	6 ± 3	8 ± 5
Total	2500 ± 400	1260 ± 210	312 ± 34	1200 ± 160	380 ± 40	430 ± 70
Data	2411	1214	293	1135	375	444



$t\bar{t}$ Cross-Section @5.02 TeV
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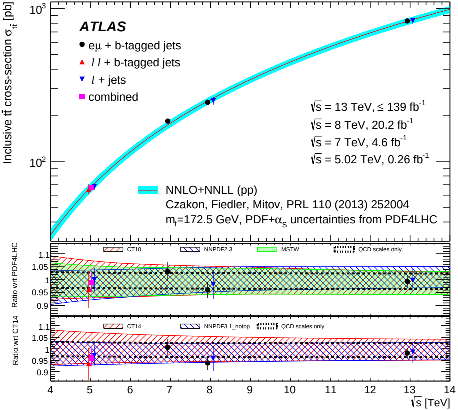
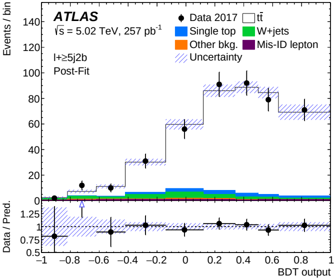
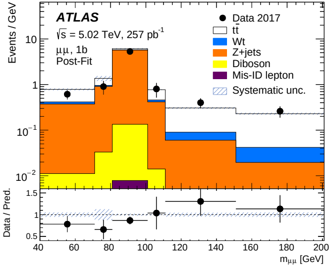


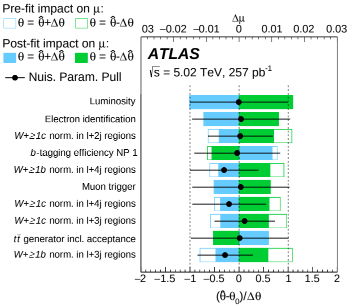




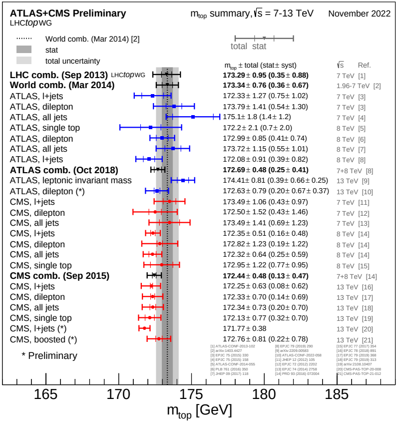
$t\bar{t}$ Cross-Section @5.02 TeV

arXiv:2207.01354

Category	$\delta\sigma_{t\bar{t}}$ [%] Dilepton	Single lepton	Combination
$t\bar{t}$ generator[†]	1.2	1.0	0.8
$t\bar{t}$ parton-shower/hadronisation[*,†]	0.3	0.9	0.7
$t\bar{t}$ h_{damp} and scale variations[†]	1.0	1.1	0.8
$t\bar{t}$ parton distribution functions[†]	0.2	0.2	0.2
Single-top background	1.1	0.8	0.6
W/Z + jets background*	0.8	2.4	1.8
Diboson background	0.3	0.1	< 0.1
Misidentified leptons*	0.7	0.3	0.3
Electron identification/isolation	0.8	1.2	0.8
Electron energy scale/resolution	0.1	0.1	< 0.1
Muon identification/isolation	0.6	0.2	0.3
Muon momentum scale/resolution	0.1	0.1	0.1
Lepton-trigger efficiency	0.2	0.9	0.7
Jet-energy scale/resolution	0.1	1.1	0.8
$\sqrt{s}$ = 5.02 TeV JES correction	0.1	0.6	0.5
Jet-vertex tagging	< 0.1	0.2	0.2
Flavour tagging	0.1	1.1	0.8
$E_{\mathrm{T}}^{\mathrm{miss}}$	0.1	0.4	0.3
Simulation statistical uncertainty*	0.2	0.6	0.5
Data statistical uncertainty*	6.8	1.3	1.3
Total systematic uncertainty	3.1	4.2	3.7
Integrated luminosity	1.8	1.6	1.6
Beam energy	0.3	0.3	0.3
Total uncertainty	7.5	4.5	3.9



- Mass not predicted by SM
- Input for calculations
- Precise measurements needed for
  - Stability of SM vacuum
  - Extensions of SM
  - Internal consistency of SM (e.g. global EW-fits)



Mass measurements

Template method (ATLAS-CONF-2022-058)

- Preselection
  - Single-lepton trigger fired
  - Reconstructed primary vertx
  - 2 OS leptons (one of them activated the trigger)
  - $\geq$2 jets (25 GeV, $|\eta| < 2.5$)
  - $m_{ll} > 15$ GeV; $m_{ll} > 100$ GeV; $m_{ll} < 80$ GeV
- Final selection
  - $\mathrm{DNN_{High}} > 0.65$
  - $p_{T,lb} > 160$ GeV
  - Harder b-jet chosen for pairing

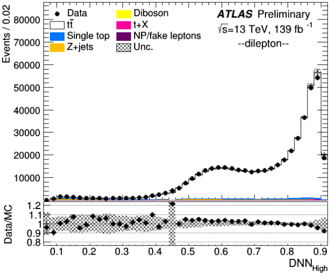
Data	454960
$t\bar{t}$ signal	445000 ± 28000
Single-top-quark signal	14320 ± 890
Z+jets	10200 ± 4400
Diboson	420 ± 210
$t\bar{t}+V$, tWZ, tZq	1320 ± 200
$t\bar{t}+H$	440 ± 45
NP/fake leptons	760 ± 760
Signal+background	472000 ± 29000
Expected background fraction	0.028 ± 0.010
Data/(Signal + background)	0.963 ± 0.059

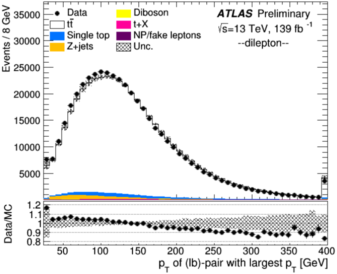
Data	83785
$t\bar{t}$ signal	90800 ± 5800
Single-top-quark signal	1144 ± 74
Z+jets	122 ± 49
Diboson	4.1 ± 2.2
$t\bar{t}+V$, tWZ, tZq	270 ± 41
$t\bar{t}+H$	86.9 ± 8.8
NP/fake leptons	100 ± 100
Signal+background	92500 ± 5800
Expected background fraction	0.006 ± 0.001
Data/(Signal + background)	0.905 ± 0.058

Mass measurements

Template method (ATLAS-CONF-2022-058)

- Simulated distributions created with different m_{top}-values
- Function fitted to these distributions to interpolate between them
- Fitting observed data to extract mass-value that fits best
- Dilepton channel used
- Partial event reconstruction via neural network
  - Identifying best *lb*-pair
  - Two pairings; correct one signal, false one background
  - NN applied to both pairings; higher NN score is chosen
  - Refined event selection based on NN output and p_T of selected *lb*-pair





Mass measurements

Template method (ATLAS-CONF-2022-058)

	m_{top} [GeV]
Result	172.63
Statistics	0.20
Method	0.05 ± 0.04
Matrix-element matching	0.35 ± 0.07
Parton shower and hadronisation	0.08 ± 0.05
Initial- and final-state QCD radiation	0.20 ± 0.02
Underlying event	0.06 ± 0.10
Colour reconnection	0.29 ± 0.07
Parton distribution function	0.02 ± 0.00
Single top modelling	0.03 ± 0.01
Background normalisation	0.01 ± 0.02
Jet energy scale	0.38 ± 0.02
b-jet energy scale	0.14 ± 0.02
Jet energy resolution	0.05 ± 0.02
Jet vertex tagging	0.01 ± 0.01
b-tagging	0.04 ± 0.01
Leptons	0.12 ± 0.02
Pile-up	0.06 ± 0.01
Recoil effect	0.37 ± 0.09
Total systematic uncertainty (without recoil)	0.67 ± 0.05
Total systematic uncertainty (with recoil)	0.77 ± 0.06
Total uncertainty (without recoil)	0.70 ± 0.05
Total uncertainty (with recoil)	0.79 ± 0.06

Recoil uncertainty:

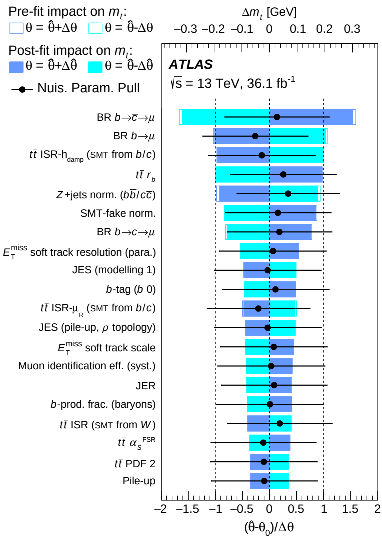
- Different recoil schemes
- Normally additional gluon jets recoil against b-jet
- Underestimates out-of-cone radiation
- New setup: top quark is recoiler for gluon radiation
- Setup theoretically more consistent
- Seems to verestimate out-of-cone radiation
- Difference as uncertainty

Mass measurements

Soft muons (arXiv:2209.00583)

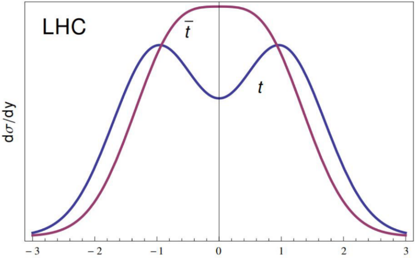
Process	Yield (OS)	Yield (SS)
$t\bar{t}$ (SMT from b- or c-hadron)	55 700 ± 3400	34 800 ± 2300
$t\bar{t}$ (SMT from $W \rightarrow \mu\nu$)	2190 ± 310	4.9 ± 3.6
$t\bar{t}$ (SMT fake)	1490 ± 210	1240 ± 170
Single top t-channel	770 ± 70	490 ± 40
Single top s-channel	63 ± 6	49 ± 4
Single top Wt channel	1840 ± 140	1260 ± 100
W+jets	1600 ± 400	1080 ± 240
Z+light jets	210 ± 80	15 ± 6
Z+HF jets	550 ± 180	310 ± 100
Diboson	17.2 ± 2.9	6.3 ± 1.4
Multijet	530 ± 140	480 ± 130
Total Expected	65 000 ± 4000	39 700 ± 2500
Data	66 891	42 087

Source	Unc. on m_t [GeV]	Stat. precision [GeV]
Statistical and datasets		
Data statistics	0.39	
Signal and background model statistics	0.17	
Luminosity	< 0.01	±0.01
Pile-up	0.07	±0.03
Modelling of signal processes		
Monte Carlo event generator	0.04	±0.06
b, c-hadron production fractions	0.11	±0.01
b, c-hadron decay BRs	0.40	±0.01
b-quark fragmentation r_b	0.19	±0.06
Parton shower α_S^{FSR}	0.07	±0.04
Parton shower and hadronisation model	0.06	±0.07
Initial-state QCD radiation	0.23	±0.08
Colour reconnection	< 0.01	±0.02
Choice of PDFs	0.07	±0.01
Modelling of background processes		
Soft muon fake	0.16	±0.03
Multijet	0.07	±0.02
Single top	0.01	±0.01
W/Z+jets	0.17	±0.01
Detector response		
Leptons	0.12	±0.01
Jet energy scale	0.13	±0.02
Soft muon jet p_T calibration	< 0.01	±0.01
Jet energy resolution	0.08	±0.07
b-tagging	0.10	±0.01
Missing transverse momentum	0.15	±0.01
Total stat. and syst. uncertainties (excluding recoil)	0.77	±0.03
Recoil uncertainty	0.25	
Total uncertainty	0.81	



- Asymmetry arises on higher order from $q\bar{q}$ and qg initial states
- LHC is a symmetric collider but PDFs different for quark and antiquark
- Valence quarks on average with higher momentum $\rightarrow$ top quark decays more in forward directions; Anti top quark decays more central

$$A_C^{t\bar{t}} = \frac{N(\Delta|y_{t\bar{t}}| > 0) - N(\Delta|y_{t\bar{t}}| < 0)}{N(\Delta|y_{t\bar{t}}| > 0) + N(\Delta|y_{t\bar{t}}| < 0)}$$



- $A_C^{t\bar{t}}$ is diluted due to dominant symmetric gg initial state
- Effect at $\mathcal{O}(1\%)$; $A_C \approx 0.006$
- $A_C^{t\bar{t}}$ enhanced in $t\bar{t}\gamma$ and $t\bar{t}W$ as $q\bar{q}/qg$ initial states enhanced due to ISR
- Effect already at LO

Charge Asymmetry ($t\bar{t}$)

arXiv:2208.12095

Single-lepton channel:

- 4 regions; resolved/boosted and $= 1$ btag/≥ 2 b-tags
- 1 lepton (28 GeV); 1 b-tagged small-R jet (25 GeV)
- Boosted topology: ≥ 1 large-R jet in addition
- Resolved topology: ≥ 3 small-R jets in addition
- Reconstruction with BDT using KLFitter, kinematic and b-tagging variables

Dilepton channel:

- 4 regions; $e\mu/ll$ and $= 1$ btag/≥ 2 b-tags
- 2 leptons (25/28 GeV); ≥ 2 small-R jets (25 GeV)
- At least one jet b-tagged
- Resolved topology: ≥ 3 small-R jets in addition
- Z-veto, *MET* cut, reconstruction via neutrino weighting

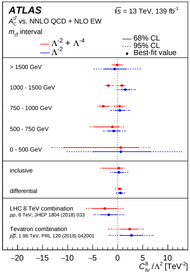
Charge Asymmetry ($t\bar{t}$)

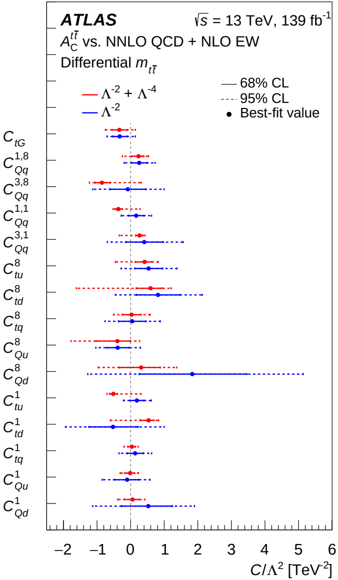
arXiv:2208.12095

SMEFT interpretation:

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{\Lambda^2} \sum_i C_i O_i + \mathcal{O}(\Lambda^{-4})$$

- 15 operators O taken into account
- Limits derived for individual C





Charge Asymmetry ($t\bar{t}$)

arXiv:2208.12095

8 operators with LL or RR chiral structure:

$$O^{1,8}_{Qq} = (\bar{Q}\gamma_\mu T^A Q)(\bar{q}_i\gamma^\mu T^A q_i), \qquad O^{1,1}_{Qq} = (\bar{Q}\gamma_\mu Q)(\bar{q}_i\gamma^\mu q_i),$$
$$O^{3,8}_{Qq} = (\bar{Q}\gamma_\mu T^A \tau^I Q)(\bar{q}_i\gamma^\mu T^A \tau^I q_i), \qquad O^{3,1}_{Qq} = (\bar{Q}\gamma_\mu \tau^I Q)(\bar{q}_i\gamma^\mu \tau^I q_i),$$
$$O^{8}_{tu} = (\bar{t}\gamma_\mu T^A t)(\bar{u}_i\gamma^\mu T^A u_i) \qquad O^{1}_{tu} = (\bar{t}\gamma_\mu t)(\bar{u}_i\gamma^\mu u_i)$$
$$O^{8}_{td} = (\bar{t}\gamma^\mu T^A t)(\bar{d}_i\gamma_\mu T^A d_i) \qquad O^{1}_{td} = (\bar{t}\gamma_\mu t)(\bar{d}_i\gamma^\mu d_i)\,.$$

6 operators with LR chiral structure:

$$O^{8}_{Qu} = (\bar{Q}\gamma_\mu T^A Q)(\bar{u}_i\gamma^\mu T^A u_i) \qquad O^{1}_{Qu} = (\bar{Q}\gamma_\mu Q)(\bar{u}_i\gamma^\mu u_i)$$
$$O^{8}_{Qd} = (\bar{Q}\gamma_\mu T^A Q)(\bar{d}_i\gamma^\mu T^A d_i) \qquad O^{1}_{Qd} = (\bar{Q}\gamma_\mu Q)(\bar{d}_i\gamma^\mu d_i)$$
$$O^{8}_{tq} = (\bar{t}\gamma^\mu T^A t)(\bar{q}_i\gamma_\mu T^A q_i) \qquad O^{1}_{tq} = (\bar{t}\gamma^\mu t)(\bar{q}_i\gamma_\mu q_i)\,.$$

1 operator with tensor structure:

$$O_{tG} = (\bar{t}\sigma^{\mu\nu} T^A t)\tilde{\varphi} G^A_{\mu\nu}.$$

Individual bounds (in units of TeV^{-2}) from the inclusive $A_C^{t\bar{t}}$ measurement.

Operator coefficient	*Linear* fit including terms $\propto \Lambda^{-2}$		*Quadratic* fit adding $(D6)^2$ terms $\propto \Lambda^{-4}$	
	68% CL	95% CL	68% CL	95% CL
C_{tG}/Λ^2	[−0.54, 0.37]	[−0.89, 1.03]	[−0.56, 0.37]	[−0.97, 0.99]
$C^{1,8}_{Qq}/\Lambda^2$	[−0.32, 0.61]	[−0.78, 1.10]	[−0.37, 0.51]	[−3.47, 0.84]
$C^{3,8}_{Qq}/\Lambda^2$	[−0.88, 1.63]	[−2.10, 2.94]	[−1.97, 0.90]	[−2.41, 1.33]
$C^{1,1}_{Qq}/\Lambda^2$	[−1.24, 2.29]	[−2.97, 4.13]	[−0.60, 0.48]	[−0.79, 0.67]
$C^{3,1}_{Qq}/\Lambda^2$	[−6.74, 3.73]	[−12.1, 8.99]	[−0.51, 0.57]	[−0.70, 0.75]
C^{8}_{tu}/Λ^2	[−0.60, 1.13]	[−1.44, 2.05]	[−2.93, 0.82]	[−3.38, 1.28]
C^{8}_{td}/Λ^2	[−0.97, 1.80]	[−2.30, 3.26]	[−4.34, 1.28]	[−5.05, 1.99]
C^{8}_{tq}/Λ^2	[−0.96, 0.54]	[−1.73, 1.29]	[−2.77, 0.45]	[−3.23, 0.93]
C^{8}_{Qu}/Λ^2	[−1.06, 0.59]	[−1.90, 1.41]	[−3.63, 0.51]	[−4.17, 1.06]
C^{8}_{Qd}/Λ^2	[−3.71, 2.08]	[−6.61, 5.02]	[−3.36, 1.29]	[−4.41, 2.35]
C^{1}_{tu}/Λ^2	[−0.81, 1.49]	[−1.93, 2.69]	[−0.80, 0.53]	[−1.02, 0.75]
C^{1}_{td}/Λ^2	[−17.6, 32.7]	[−41.8, 59.4]	[−0.98, 0.96]	[−1.32, 1.30]
C^{1}_{tq}/Λ^2	[−1.25, 2.31]	[−3.00, 4.16]	[−0.34, 0.47]	[−0.55, 0.68]
C^{1}_{Qu}/Λ^2	[−2.40, 4.40]	[−5.76, 7.92]	[−0.43, 0.53]	[−0.68, 0.78]
C^{1}_{Qd}/Λ^2	[−53.0, 88.0]	[−134, 152]	[−0.72, 0.74]	[−1.10, 1.12]

Individual bounds (in units of TeV^{-2}) from the differential $A_C^{t\bar{t}}$ measurement versus $m_{t\bar{t}}$.

Operator coefficient	*Linear* fit including terms $\propto \Lambda^{-2}$		*Quadratic* fit adding $(D6)^2$ terms $\propto \Lambda^{-4}$	
	68% CL	95% CL	68% CL	95% CL
C_{tG}/Λ^2	[−0.53, −0.11]	[−0.70, 0.14]	[−0.55, −0.11]	[−0.75, 0.14]
$C^{1,8}_{Qq}/\Lambda^2$	[0.03, 0.49]	[−0.20, 0.73]	[0.04, 0.39]	[−0.25, 0.53]
$C^{3,8}_{Qq}/\Lambda^2$	[−0.61, 0.45]	[−1.13, 1.00]	[−1.06, −0.61]	[−1.23, 0.31]
$C^{1,1}_{Qq}/\Lambda^2$	[−0.06, 0.39]	[−0.28, 0.62]	[−0.45, −0.25]	[−0.52, 0.28]
$C^{3,1}_{Qq}/\Lambda^2$	[−0.15, 0.98]	[−0.69, 1.56]	[0.15, 0.35]	[−0.34, 0.43]
C^{8}_{tu}/Λ^2	[0.12, 0.96]	[−0.28, 1.38]	[0.14, 0.63]	[−0.45, 0.82]
C^{8}_{td}/Λ^2	[0.18, 1.47]	[−0.45, 2.13]	[0.17, 0.92]	[−1.62, 1.21]
C^{8}_{tq}/Λ^2	[−0.36, 0.46]	[−0.76, 0.88]	[−0.25, 0.31]	[−0.51, 0.58]
C^{8}_{Qu}/Λ^2	[−0.71, −0.05]	[−1.03, 0.29]	[−1.03, −0.02]	[−1.78, 0.27]
C^{8}_{Qd}/Λ^2	[0.25, 3.46]	[−1.28, 5.14]	[−0.33, 0.89]	[−0.96, 1.37]
C^{1}_{tu}/Λ^2	[−0.02, 0.40]	[−0.21, 0.61]	[−0.62, −0.39]	[−0.70, 0.31]
C^{1}_{td}/Λ^2	[−1.24, 0.22]	[−1.94, 1.00]	[0.29, 0.70]	[−0.60, 0.84]
C^{1}_{tq}/Λ^2	[−0.10, 0.38]	[−0.35, 0.63]	[−0.08, 0.14]	[−0.20, 0.22]
C^{1}_{Qu}/Λ^2	[−0.47, 0.24]	[−0.85, 0.58]	[−0.18, 0.12]	[−0.31, 0.23]
C^{1}_{Qd}/Λ^2	[−0.27, 1.24]	[−1.13, 1.90]	[−0.19, 0.26]	[−0.39, 0.42]

Charge Asymmetry ($t\bar{t}\gamma$)

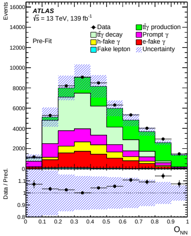
arXiv:2212.10552

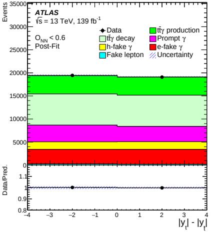
- Asymmetry arises due to interference between photon ISR and photon final state radiation (FSR)
- Photons from decay products of the top-quark dilute measurable effect
- $t\bar{t}\gamma$ events simulated in two samples (γ from prod. and decay separately)
- NN to enhance signal ($t\bar{t}\gamma$ with photon from production); $O_{NN} > 0.6$

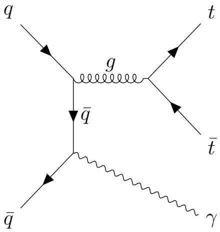
Result

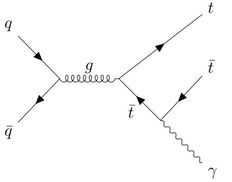
$A_C = -0.006 \pm 0.024(\text{stat.}) \pm 0.018(\text{syst.})$ limited by statistics

- Compatible with SM prediction of $-0.014 \pm 0.001(\text{scale})$...
- .. but also with null-hypothesis









Charge Asymmetry ($t\bar{t}\gamma$)

arXiv:2212.10552

Selection:

- 1 lepton (27 GeV), isolated photon (20 GeV)
- $\Delta R(l, \gamma) > 0.4$
- Z-veto for $m_{e\gamma}$
- ≥ 4 jets, ≥ 1 b-jet
- $t\bar{t}$ reconstruction with a kinematic likelihood fit (KLFitter)
- For final fit only events with NN score above 0.6

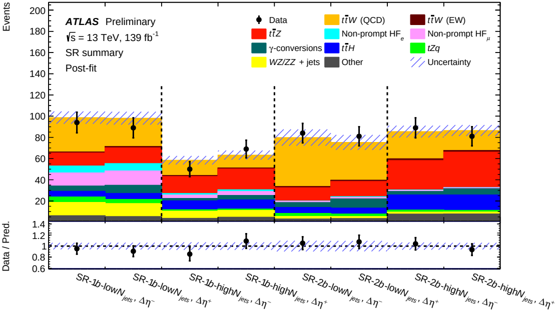
	$O_{\mathrm{NN}} < 0.6$	$O_{\mathrm{NN}} \geq 0.6$
$t\bar{t}\gamma$ prod (signal)	6660 ± 350	6910 ± 340
$t\bar{t}\gamma$ decay	14 100 ± 3100	1900 ± 560
h-fake γ	3400 ± 1400	790 ± 360
e-fake γ	6420 ± 860	1480 ± 260
Prompt γ	6400 ± 2000	1300 ± 400
Lepton fake	410 ± 110	57 ± 35
Total	37 400 ± 4500	12 400 ± 1100
Data	38 527	13 763

Total uncertainty	0.029
Statistical uncertainty	0.024
MC statistical uncertainties	
Background processes	0.008
$t\bar{t}\gamma$ production	0.004
Modelling uncertainties	
$t\bar{t}\gamma$ production modelling	0.003
Background modelling	0.002
Prompt background normalisation	0.002
Experimental uncertainties	
Jet	0.009
Fake-lepton background estimate	0.005
$E_{\mathrm{T}}^{\mathrm{miss}}$	0.005
Fake-photon background estimates	0.003
Photon	0.001
b-tagging	0.001
Other experimental	0.004

Charge Asymmetry ($t\bar{t}W$)

ATLAS-CONF-2022-062

- Trilepton channel used for good background suppression
- Charge asymmetry transfered to leptons
- A_C^l measured, needs no top-reconstruction



- Correct lepton assignment to $t/\bar{t}$ done with BDT (71% matching efficiency)
- Unfolding to particle level done, lepton assignment with m_{lb}
- Dominated by statistics; compatible with SM but also with null hypothesis

Results

$A_C^l = -0.123 \pm 0.136(\text{stat.}) \pm 0.051(\text{syst.})$
$A_C^{l,PL} = -0.112 \pm 0.170(\text{stat.}) \pm 0.055(\text{syst.})$

Charge Asymmetry ($t\bar{t}W$)

ATLAS-CONF-2022-062

	Pre-selection			
N_ℓ ($\ell = e/\mu$)	$= 3$			
p_{T}^{ℓ} ($1^{\mathrm{st}}/2^{\mathrm{nd}}/3^{\mathrm{rd}}$)	≥ 30 GeV, ≥ 20 GeV, ≥ 15 GeV			
Sum of lepton charges	± 1			
$m_{\ell\ell}^{\mathrm{OSSF}}$	≥ 30 GeV			
	Region-specific requirements			
	SR-1b-lowN_{jets}	**SR-1b-highN_{jets}**	**SR-2b-lowN_{jets}**	**SR-2b-highN_{jets}**
N_{jets}	[2, 3]	≥ 4	[2, 3]	≥ 4
$N_{b\text{-jets}}$	$= 1$	$= 1$	≥ 2	≥ 2
$E_{\mathrm{T}}^{\mathrm{miss}}$	≥ 50 GeV	≥ 50 GeV	–	–
$N_{Z\text{-cand.}}$	$= 0$			
Tight leptons	TTT			
e/γ ambiguity-cuts	all pass			
	CR-$t\bar{t}Z$	**CR-HF$_e$**	**CR-HF$_\mu$**	**CR-γ-conv**
$\ell^{\mathrm{1st/2nd/3rd}}$	$\ell\ell\ell$	$\ell\ell e$	$\ell\ell\mu$	$\ell\ell e$, $\ell e\ell$, $e\ell\ell$
N_{jets}	≥ 4	≥ 2	≥ 2	≥ 2
$N_{b\text{-jets}}$	≥ 2	$= 1$	$= 1$	≥ 1
$E_{\mathrm{T}}^{\mathrm{miss}}$	–	< 50 GeV	< 50 GeV	< 50 GeV
$N_{Z\text{-cand.}}$	$= 1$	$= 0$	$= 0$	$= 0$
Tight leptons	TTT	TT$\overline{\mathrm{T}}$	TT$\overline{\mathrm{T}}$	TTT
e/γ ambiguity-cuts	all pass	all pass	all pass	≥ 1 fail

Process	CR-$t\bar{t}Z$ $\Delta\eta^-$	CR-$t\bar{t}Z$ $\Delta\eta^+$	CR-HF$_e$ $\Delta\eta^-$	CR-HF$_e$ $\Delta\eta^+$	CR-HF$_\mu$ $\Delta\eta^-$	CR-HF$_\mu$ $\Delta\eta^+$	CR-γ-conv $\Delta\eta^-$	CR-γ-conv $\Delta\eta^+$
$t\bar{t}W$ (QCD)	3.2 ± 0.7	2.2 ± 0.7	1.8 ± 0.5	1.7 ± 0.5	2.6 ± 0.8	1.8 ± 0.8	7.0 ± 1.3	4.4 ± 1.3
$t\bar{t}W$ (EW)	0.18 ± 0.06	0.16 ± 0.05	0.10 ± 0.03	0.09 ± 0.03	0.09 ± 0.03	0.14 ± 0.04	0.23 ± 0.07	0.36 ± 0.11
$t\bar{t}Z$	114 ± 13	138 ± 14	1.45 ± 0.27	1.7 ± 0.4	2.3 ± 0.4	2.55 ± 0.35	4.3 ± 0.6	4.6 ± 0.6
Non-prompt HF$_e$	–	–	290 ± 18	346 ± 20	0.15 ± 0.02	0.19 ± 0.02	0.59 ± 0.27	0.52 ± 0.17
Non-prompt HF$_\mu$	0.13 ± 0.01	0.20 ± 0.02	0.20 ± 0.02	0.28 ± 0.03	516 ± 25	556 ± 25	0.8 ± 0.4	1.3 ± 0.8
γ–conversions	0.40 ± 0.18	0.52 ± 0.16	2.8 ± 2.2	6 ± 4	1.9 ± 2.0	4.2 ± 3.4	14 ± 6	22 ± 7
$t\bar{t}H$	3.3 ± 0.4	3.23 ± 0.31	0.86 ± 0.13	0.87 ± 0.10	1.16 ± 0.11	1.19 ± 0.22	1.49 ± 0.20	1.6 ± 0.4
tZq	12.6 ± 2.2	11.0 ± 1.9	0.47 ± 0.10	0.42 ± 0.08	0.95 ± 0.17	0.79 ± 0.14	0.68 ± 0.11	0.70 ± 0.12
WZ/ZZ + jets	10.2 ± 2.9	10.6 ± 3.1	2.6 ± 0.7	2.8 ± 0.7	6.3 ± 1.7	6.7 ± 1.8	2.6 ± 0.7	2.5 ± 0.6
Other	10.8 ± 3.2	10.0 ± 2.9	14 ± 4	13 ± 5	18 ± 7	18 ± 6	1.7 ± 0.8	1.7 ± 0.6
SM total	155 ± 12	175 ± 13	315 ± 18	373 ± 19	550 ± 23	591 ± 24	33 ± 6	40 ± 6
Data	156	176	315	373	551	592	34	40

Process	SR-1b-lowN_{jets} $\Delta\eta^-$	SR-1b-lowN_{jets} $\Delta\eta^+$	SR-1b-highN_{jets} $\Delta\eta^-$	SR-1b-highN_{jets} $\Delta\eta^+$	SR-2b-lowN_{jets} $\Delta\eta^-$	SR-2b-lowN_{jets} $\Delta\eta^+$	SR-2b-highN_{jets} $\Delta\eta^-$	SR-2b-highN_{jets} $\Delta\eta^+$
$t\bar{t}W$ (QCD)	32 ± 6	27 ± 6	14 ± 4	12.1 ± 3.4	46 ± 9	36 ± 8	26 ± 6	19 ± 5
$t\bar{t}W$ (EW)	1.04 ± 0.32	1.3 ± 0.4	1.04 ± 0.32	1.05 ± 0.32	1.2 ± 0.4	1.3 ± 0.4	1.8 ± 0.5	1.6 ± 0.5
$t\bar{t}Z$	12.4 ± 2.0	15.0 ± 2.2	16.0 ± 2.2	19.6 ± 2.3	12.3 ± 2.3	14.3 ± 2.6	27.6 ± 3.3	33.2 ± 3.5
Non-prompt HF$_e$	6.4 ± 1.0	6.8 ± 0.8	1.5 ± 0.5	1.7 ± 0.4	0.40 ± 0.20	0.79 ± 0.35	0.45 ± 0.14	0.39 ± 0.14
Non-prompt HF$_\mu$	12.5 ± 1.5	13.6 ± 2.5	3.1 ± 0.6	3.6 ± 0.9	1.30 ± 0.23	1.19 ± 0.19	1.04 ± 0.29	0.9 ± 0.5
γ-conversions	4.9 ± 2.3	7.7 ± 2.6	2.3 ± 1.1	4.3 ± 1.6	4.6 ± 2.1	8.8 ± 2.9	3.3 ± 1.5	5.9 ± 1.9
$t\bar{t}H$	5.4 ± 0.8	5.5 ± 0.8	8.4 ± 0.8	8.6 ± 0.8	5.5 ± 1.1	5.6 ± 1.0	14.3 ± 1.7	14.4 ± 1.7
tZq	5.0 ± 0.9	4.1 ± 0.7	1.38 ± 0.27	1.16 ± 0.24	2.8 ± 0.5	2.3 ± 0.4	1.93 ± 0.33	1.65 ± 0.29
WZ/ZZ + jets	12.6 ± 3.0	12.3 ± 3.0	6.7 ± 2.0	6.5 ± 1.8	2.5 ± 0.7	1.9 ± 0.5	1.9 ± 0.6	1.9 ± 0.5
Other	6.0 ± 2.1	5.2 ± 1.6	3.6 ± 1.8	4.6 ± 1.4	2.9 ± 1.2	3.3 ± 1.3	8 ± 4	8 ± 4
SM total	99 ± 6	98 ± 6	58 ± 4	63 ± 4	80 ± 8	75 ± 7	85 ± 6	86 ± 5
Data	94	89	50	69	84	81	89	81

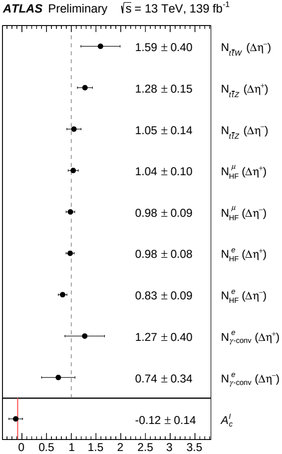
	$\Delta A_c^{\ell}(t\bar{t}W)$
Experimental uncertainties	
Jet energy resolution	0.013
Pile-up	0.007
b-tagging	0.005
Leptons	0.004
$E_{\mathrm{T}}^{\mathrm{miss}}$	0.004
Jet energy scale	0.003
Luminosity	0.001
MC modelling uncertainties	
$t\bar{t}W$ modelling	0.013
$t\bar{t}Z$ modelling	0.010
Non-prompt modelling	0.006
$t\bar{t}H$ modelling	0.005
Other uncertainties	
$\Delta\eta^{\pm}$ dependency	0.046
MC statistical uncertainty	0.019
Data statistical uncertainty	0.136
Total uncertainty	0.145

Charge Asymmetry ($t\bar{t}W$)

ATLAS-CONF-2022-062

Fiducial volume:

- Three leptons with $p_T > 25$ GeV and $|\eta| < 2.5$
- $m_{OSSF} > 25$ GeV; $m_{OSSF} > m_Z + 10$ GeV; $m_{OSSF} < m_Z - 10$ GeV;
- ≥ 2 jets with $p_T > 20$ GeV and $|\eta| < 2.5$; one of them b-tagged



	$\Delta A_c^{\ell}(t\bar{t}W)^{\mathrm{PL}}$
Experimental uncertainties	
Leptons	0.014
Jet energy resolution	0.011
Pile-up	0.008
Jet energy scale	0.004
$E_{\mathrm{T}}^{\mathrm{miss}}$	0.002
Luminosity	0.001
Jet vertex tagger	0.001
MC modelling uncertainties	
$t\bar{t}W$ modelling	0.022
$t\bar{t}Z$ modelling	0.017
Non-prompt modelling	0.015
Others modelling	0.015
$WZ/ZZ+$jets modelling	0.014
$t\bar{t}H$ modelling	0.006
Other uncertainties	
Unfolding bias	0.011
$\Delta\eta^{\pm}$ dependency	0.039
MC statistical uncertainty	0.027
Response matrix	0.009
Data statistical uncertainty	0.170
Total uncertainty	0.179

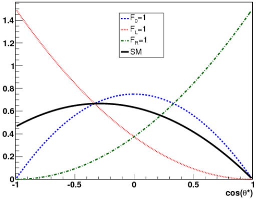
W-helicity in top-decays

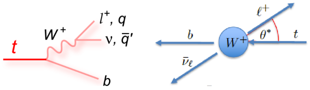
Introduction

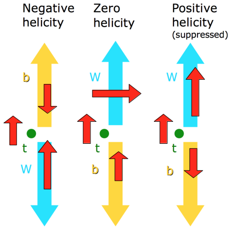
- W-boson has 3 spin states $\rightarrow$ 3 helicity states
- $V - A$ structure of tW-vertex defines the ratio between helicity states
- Helicity is not Lorentz-invariant $\rightarrow$ W-boson rest frame used
- θ^* used; angle between p of charged lepton and reversed b-jet p
- Following distribution predicted:

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta^*} = \frac{3}{4}(1-\cos^2\theta^*)f_0 + \frac{3}{8}(1-\cos^2\theta^*)f_L + \frac{3}{8}(1+\cos^2\theta^*)f_R$$

- Prediction: $f_0 = 0.687 \pm 0.005$; $f_L = 0.311 \pm 0.005$; $f_R = 0.0017 \pm 0.0001$







W-helicity in top-decays

arXiv:2209.14903

	Covariance			Correlation		
	f_0	f_L	f_R	f_0	f_L	f_R
f_0	2.125×10^{-4}	-3.665×10^{-5}	-1.758×10^{-4}	1	−0.308	−0.841
f_L	-3.665×10^{-5}	6.651×10^{-5}	-2.986×10^{-5}	−0.308	1	−0.255
f_R	-1.758×10^{-4}	-2.986×10^{-5}	2.057×10^{-4}	−0.841	−0.255	1

Category	σ_{f_0}	σ_{f_L}	σ_{f_R}
Detector modelling			
Jet reconstruction	0.008	0.004	0.010
Flavour tagging	0.003	0.001	0.001
Electron reconstruction	0.003	0.002	0.002
Muon reconstruction	0.003	0.003	$< 10^{-3}$
E_T^{miss} (soft term)	$< 10^{-3}$	0.002	$< 10^{-3}$
Pile-up	0.002	0.002	$< 10^{-3}$
Luminosity	0.001	0.001	$< 10^{-3}$
Signal and background modelling			
$t\bar{t}$ production	0.011	0.005	0.010
PDF	0.002	0.001	$< 10^{-3}$
Single top production	$< 10^{-3}$	0.002	$< 10^{-3}$
Other background	0.002	0.001	$< 10^{-3}$
Total systematic uncertainty	0.014	0.008	0.014
Data statistical uncertainty	0.005	0.003	0.002
Total uncertainty	0.015	0.008	0.014

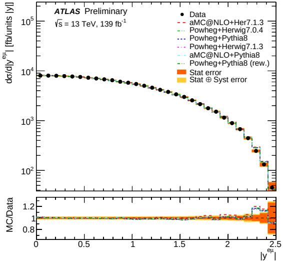
- 2 leptons (25/27 GeV)
- $\geq$ 2 jets, 1 tight b-tag
- Z-veto for same-flavour leptons
- MET>60 GeV
- $m_{ll} > 15$ GeV

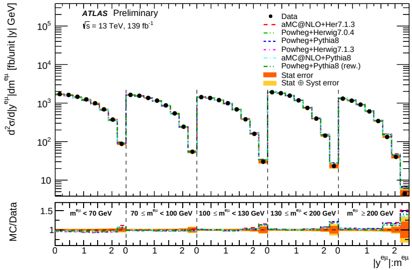
$t\bar{t}$ cross-section
Inclusive and diff. (ATLAS-CONF-2022-061)

- $e\mu$ channel for low background
- Two regions defined wrt. b-tag multiplicity

$$N_1^i = \mathcal{L}\sigma_{t\bar{t}}^i G_{e\mu}^i 2\epsilon_b^i(1-\epsilon_b^i C_b^i) + N_{1,bkg}^i \quad N_2^i = \mathcal{L}\sigma_{t\bar{t}}^i G_{e\mu}^i (\epsilon_b^i)^2 C_b^i + N_{2,bkg}^i$$

- Two unknowns (ϵ_b^i and $\sigma_{t\bar{t}}^i$) determined with log-likelihood fit
- Fit validation done with bootstrapping
- Higher granularity for differential measurements (unfolding to particle level)
- Double differential and inclusive measurements were done too
- Inclusive result and prediction: $\sigma_{meas.} = 838 \pm 20$ pb $\quad \sigma_{pred.} = 832 \pm 46$ pb
- No model can describe all distributions within their uncertainties





$t\bar{t}$ cross-section
Inclusive and diff. (ATLAS-CONF-2022-061)

Selection:

- 1 e and 1μ (25 GeV;$|\eta| < 2.5$)
- OS event used for measurement
- SS events used for lepton-misidentification estimation
- ≥ 2 jets (25 GeV;$|\eta| < 2.5$)
- 1 b-jet or 2 b-jets (2 regions defined)

Used variables:
$p_T^l, |\eta_l|, m^{e\mu}, p_T^{e\mu}, |y^{e\mu}|, E^e + E^\mu, p_T^e + p_T^\mu, \Delta\phi^{e\mu}$

	OS		SS	
	N_1	N_2	N_1	N_2
$t\bar{t}$	415470 ± 130	234071 ± 94	-	-
Single t	42605 ± 76	7238 ± 31	-	-
Z+jets	1551 ± 66	96.9 ± 7.5	-	-
Diboson	1395.1 ± 9.4	49.5 ± 1.1	221.3 ± 2.4	10.50 ± 0.30
Charge mis-id lepton	1.88 ± 0.14	0.609 ± 0.061	851 ± 11	361.1 ± 7.0
Mis-identified lepton	4890 ± 100	1993 ± 67	2531 ± 57	899 ± 34
Other	1183.2 ± 4.1	800.8 ± 3.3	403.4 ± 1.7	236.4 ± 1.3
Total MC	467090 ± 190	244250 ± 120	4008 ± 58	1507 ± 36
Data	468450	248560	3995	1501
Data/MC	1.003 ± 0.002	1.017 ± 0.002	0.997 ± 0.021	0.996 ± 0.035

Source of uncertainty	$\Delta\sigma_{t\bar{t}}^{\mathrm{fid}}/\sigma_{t\bar{t}}^{\mathrm{fid}}$ (%)	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)
Data statistics	0.15	0.15
MC statistics	0.04	0.04
Matrix Element	0.12	0.17
h_{damp} variation	0.01	0.01
Parton shower	0.08	0.22
$t\bar{t}$ + Heavy Flavour	0.34	0.34
top p_{T} reweighting	0.19	0.58
Parton distribution functions	0.04	0.43
Initial state radiation	0.11	0.37
Final state radiation	0.29	0.35
Electron energy scale	0.10	0.10
Electron efficiency	0.37	0.37
Electron isolation (in situ)	0.51	0.51
Muon momentum scale	0.13	0.13
Muon reconstruction efficiency	0.35	0.35
Muon isolation (in situ)	0.33	0.33
Lepton trigger efficiency	0.05	0.05
Vertex association efficiency	0.03	0.03
Jet energy scale/resolution	0.10	0.10
b-tagging efficiency	0.07	0.07
$t\bar{t}/Wt$ interference	0.37	0.37
Wt cross-section	0.52	0.52
Diboson background	0.18	0.18
$t\bar{t}\,V + t\bar{t}\,H$	0.03	0.03
Z+jets background	0.05	0.05
Misidentified leptons	0.32	0.32
Beam energy	0.23	0.23
Luminosity	1.90	1.90
Total uncertainty	2.3	2.4

Observation of $t\gamma q$

ATLAS-CONF-2022-013

Selection:

- 1 lepton (27 GeV),1 photon (20 GeV), 1 b-tagged jet (25 GeV), MET>30 GeV
- Z-veto on $m_{e\gamma}$
- 0 or $\geq$ 1 forward jets (2 SRs)
- norm factors in fit for $t\bar{t}\gamma$ and $W\gamma$

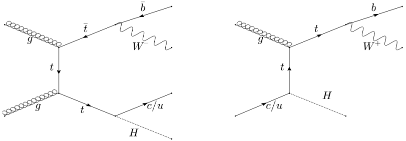
	$\geq$ 1fj SR	0fj SR	$t\bar{t}\gamma$ CR	$W\gamma$ CR
$tq\gamma$	2340 ± 250	2430 ± 310	880 ± 120	1250 ± 140
$t\,(\to \ell\nu b\gamma)\,q$	480 ± 160	660 ± 210	170 ± 60	320 ± 120
$t\bar{t}\gamma$ (production)	3100 ± 400	4700 ± 700	4200 ± 600	2670 ± 350
$t\bar{t}\gamma$ (radiative decay)	3700 ± 600	9100 ± 1300	5600 ± 600	4200 ± 900
$W\gamma$+jets	2500 ± 400	9400 ± 1300	1060 ± 190	31 800 ± 3000
$Z\gamma$+jets	990 ± 310	2800 ± 800	440 ± 150	7900 ± 2400
$e \to \gamma$ fake photons	5200 ± 500	10 400 ± 800	4900 ± 400	5500 ± 500
$h \to \gamma$ fake photons	1200 ± 400	2700 ± 800	1400 ± 500	2600 ± 800
Other prompt γ	1380 ± 350	2600 ± 900	1400 ± 400	4100 ± 500
Fake leptons	350 ± 170	900 ± 500	100 ± 50	3300 ± 1600
Total	21 250 ± 150	45 720 ± 240	20 180 ± 150	63 590 ± 320
Data	21 227	45 723	20 194	63 592

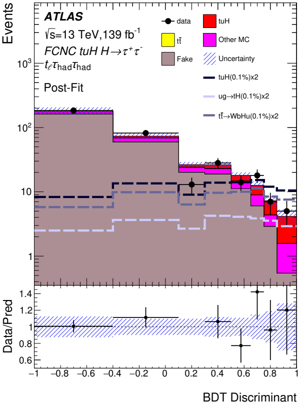
Uncertainty	$\Delta\sigma/\sigma$
$t\bar{t}\gamma$ modelling	±5.6%
Background MC statistics	±3.5%
$t\bar{t}$ modelling	±3.4%
$tq\gamma$ MC statistics	±3.4%
$t\,(\to \ell\nu b\gamma)\,q$ modelling	±1.9%
Additional background uncertainties	±1.9%
$tq\gamma$ modelling	±1.8%
$t\,(\to \ell\nu b\gamma)\,q$ MC statistics	±0.3%
Lepton fakes	±2.2%
$h \to \gamma$ photon fakes	±2.2%
$e \to \gamma$ photon fakes	±0.6%
Luminosity	±2.2%
Pileup	±1.2%
Jets and $E_{\mathrm{T}}^{\mathrm{miss}}$	±4.0%
Photons	±2.5%
Leptons	±0.9%
b-tagging	±0.8%
Total systematic uncertainty	±10.9%

FCNC in tH interactions

arXiv:2208.11415

- FCNC in SM strongly suppressed
- BSM models predict effects at LHC
- $H \to \tau\tau$ with either 2 hadronic τ or 1 leptonic and 1 hadronic τ
- 4 preselections defined wrt. to the decay of the top and the τ
- 7 SRs, 6 CRs and 2 validation regions (VRs) defined
- BDT used for signal to background separation; BDT output used for fit





Result

Slight excess of 2.3σ above SM

$\mathcal{B}(t \to uH) < 6.9 \cdot 10^{-4}$ (95% CL)

$\mathcal{B}(t \to cH) < 9.4 \cdot 10^{-4}$ (95% CL)

$C_{c\phi} < 1.35$ and $C_{u\phi} < 1.16$

FCNC in tH interactions

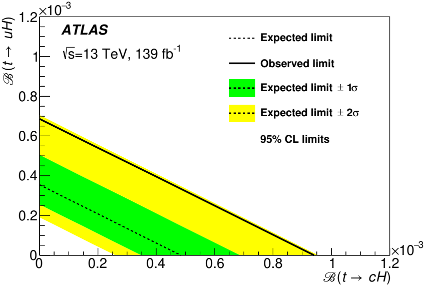
arXiv:2208.11415

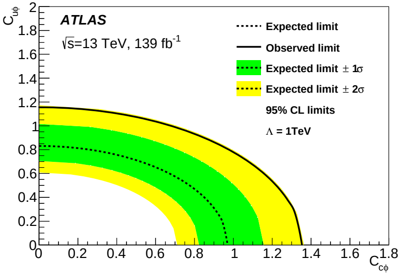
Requirement	Leptonic channels $t_h\tau_{lep}\tau_{had}$	Leptonic channels $t_\ell\tau_{had}\tau_{had}$	Leptonic channels $t_\ell\tau_{had}$	Hadronic channel $t_h\tau_{had}\tau_{had}$
Trigger	single-lepton trigger			di-τ trigger
Leptons	=1 isolated e or μ			=0 isolated e or μ
τ_{had}	=1 τ_{had}	=2 τ_{had}	=1 τ_{had}	=2 τ_{had}
Electric charge (Q)	$Q_\ell \times Q_{\tau_{had1}} = -1$	$Q_{\tau_{had1}} \times Q_{\tau_{had2}} = -1$	$Q_\ell \times Q_{\tau_{had1}} = 1$	$Q_{\tau_{had1}} \times Q_{\tau_{had2}} = -1$
Jets	≥3 jets	≥1 jets	≥2 jets	≥3 jets
b-tagging	=1 b-jets			=1 b-jets

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

FCNC in tH interactions

arXiv:2208.11415





Source of uncertainty	$\Delta\mathscr{B}$ $[10^{-5}]$ $t \to uH$	$\Delta\mathscr{B}$ $[10^{-5}]$ $t \to cH$
Lepton ID	0.6	0.8
$E_{\mathrm{T}}^{\mathrm{miss}}$	0.7	0.7
Fake lepton modeling	1.2	1.7
JES and JER	2.5	3.3
Flavour tagging	2.7	3.7
$t\bar{t}$ modeling	2.6	3.9
Other MC modeling	2.1	3.0
Fake τ modeling	3.3	4.7
Signal modeling including Br($H \to \tau\tau$)	1.8	1.5
τ ID	3.3	4.4
Luminosity and Pileup	1.7	2.4
MC statistics	5.1	7.1
Total systematic uncertainty	10.1	14.1
Data statistical uncertainty	14.9	19.4
Total uncertainties	18	24

cLFV interactions ($\tau\mu tq$)

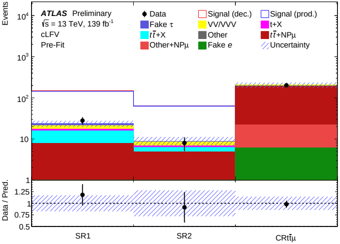
ATLAS-CONF-2022-071

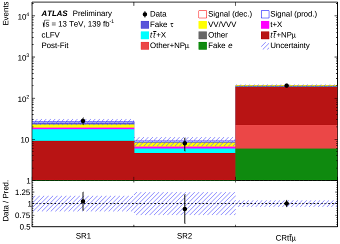
Preselection:	
Number of leptons	$N_\ell = 3,\ p_T > 10$ GeV, $\lvert\eta\rvert < 2.5$
Leading muon / electron p_T	p_T ¿ 27 GeV
Trigger matching	≥ 1 trigger-matched muon / electron
Sum of lepton charges	$\sum q_i = \pm 1$

	SR1	**SR2**	**CRτ**	**CR$tt\mu$**
Lepton flavour	$2\mu 1\tau_{\text{had-vis}}$			$2\mu 1e$ ($\ell_3 = \mu$)
N_{jets}	≥ 2	1	≥ 2	≥ 2
$N_{b-\text{tags}}$	1	1	1	≤ 2
Muon p_T cut	> 15 GeV	> 15 GeV	> 15 GeV	> 10 GeV
Lowest p_T muon selection	*Tight*	*Tight*	*Tight*	*Loose*
Muon charges	SS	SS	OS	-
$\lvert m^{OS}_{\mu\mu} - M_Z\rvert$	-	-	<10 GeV	>10 GeV

	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

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





$t\bar{t}$ @ 13.6 TeV
ATLAS-CONF-2022-070

Selection:

- 2 OS leptons (27 GeV)
- 66 GeV $< m_{ll} <$ 116 GeV in SF regions
- no b-tag requirements, although only events with 1 or 2 b-tags used in fit

Systematics:

- 10% uncertainty on luminosity
- systematics include: PDF/scale variations, background normalisations, conservative uncertainties on ID and flavour tagging efficiencies