Highlights of top quark measurements with the ATLAS experiment

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ATLAS Experiment

- Measurements of processes involving top quarks are of major importance to check predictions of the SM and provide sensitivity to new physics beyond the SM (BSM).
- In the last years, the ATLAS experiment at the LHC performed precise measurements of the top quark properties and measured also "rare" SM processes associated with top quarks.
- Will present some of the most recent and relevant results released by the ATLAS collaboration in 2021 ⇒ full list can be found here.

(I) Measurements of the inclusive and differential production cross sections of a tt pair in association with a Z boson at $\sqrt{s}$ = 13 TeV with the ATLAS detector ➡ ***arXiv:2103.12603***

(II) Measurement of the $tttt$ production cross section in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector ➡ ***arXiv:2106.11683***

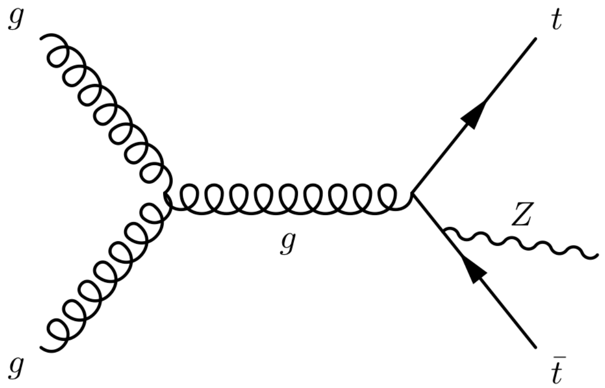
(III) Measurements of differential cross-sections in tt events with a high p_T top quark and limits on BSM contributions to tt production with the ATLAS detector ➡ ***ATLAS-CONF-2021-31***

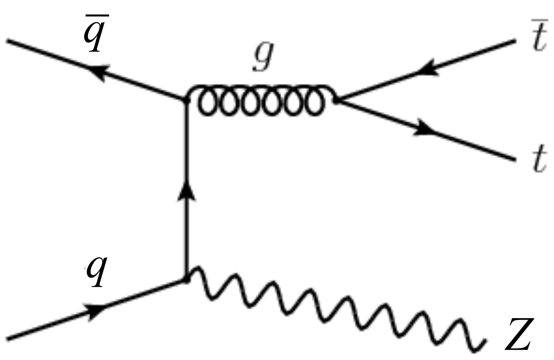
(IV) Measurement of the polarisation of single top quarks/antiquarks produced in the t-channel collected with the ATLAS detector at $\sqrt{s}$ = 13 TeV and bounds on the tWb dipole operator ➡ ***ATLAS-CONF-2021-027***

(I)
Inclusive & differential *ttZ* cross sections

Production of top quark pairs in association with a *Z* boson (*ttZ*):

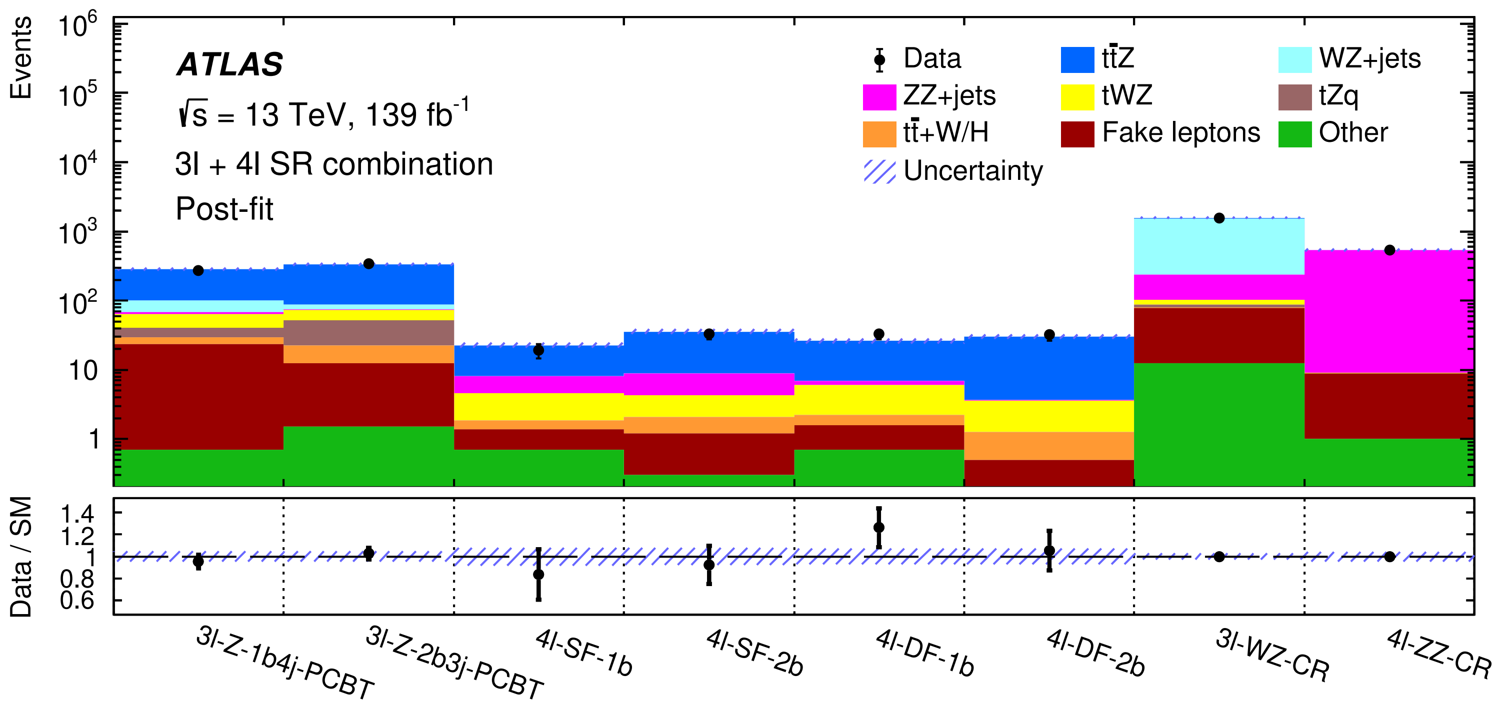
- Rare process in the SM ⇒ around 1000 times smaller than *tt* only.
- Inclusive cross-section measurement was performed by ATLAS in 2019, but without using the full Run II dataset:
  - $\sigma_{ttZ} = 0.95 \pm 0.08$ (stat.) $\pm$ 0.10 (syst.) pb ***Phys. Rev. D 99 (2019) 072009***
- Full Run II dataset (139 fb^{-1}) provides sufficient statistics to measure this process also differentially.
- Provides access to top-*Z* coupling ⇒ interesting in the context of effective field theory (EFT) interpretations.
- Important background for SM searches/measurements.
- Theory predictions exist at NLO+NNLL precision ⇒ see ***JHEP 08 (2019) 039***, ***EPJC 80 (2020) 428***.
- Leptonic and hadronic decay modes of the *Z* boson and *tt* system ⇒ different lepton multiplicities in final states.
  - Analysis regions based on multi-lepton signatures (**3*l***, **4*l***) ⇒ highest sensitivities.





ttZ: Inclusive measurement

- Simultaneous maximum-likelihood fit in $3l/4l$ signal regions (SR) and control regions (CR) for WZ/ZZ+jets to obtain signal-strength parameter: $\mu_{ttZ} = \sigma_{\text{Data}}/\sigma_{\text{SM}}$.
  - Fit performed separately in **$3l$**, **$4l$** and combined **$3l + 4l$** channels ⇒ consistent results.
  - Inclusive ttZ cross section is computed for specific fiducial phase-space, assuming on-shell decay of Z boson: 70 GeV < m_{ll} < 110 GeV.
  - Compatible with previous ATLAS result and latest CMS measurement in same fiducial phase-space ⇒ see ***JHEP 03 (2020) 056***.



Observed/predicted event yields in $3l/4l$ regions

arXiv:2103.12603

Channel	$\mu_{t\bar{t}Z}$
Trilepton	$1.17 \pm 0.07\,(\text{stat.})\,^{+0.12}_{-0.11}\,(\text{syst.})$
Tetralepton	$1.21 \pm 0.15\,(\text{stat.})\,^{+0.11}_{-0.10}\,(\text{syst.})$
Combination ($3\ell + 4\ell$)	$1.19 \pm 0.06\,(\text{stat.}) \pm 0.10\,(\text{syst.})$

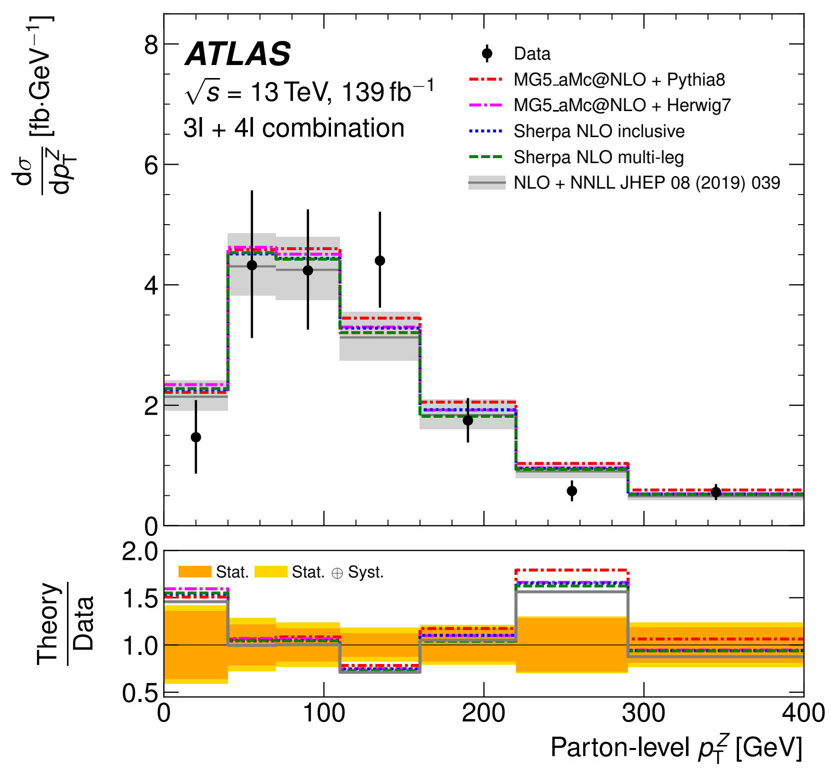
$$\sigma(pp \to t\bar{t}Z) = 0.99 \pm 0.05\,(\text{stat.}) \pm 0.08\,(\text{syst.})\,\text{pb}$$

ttZ: Differential measurements

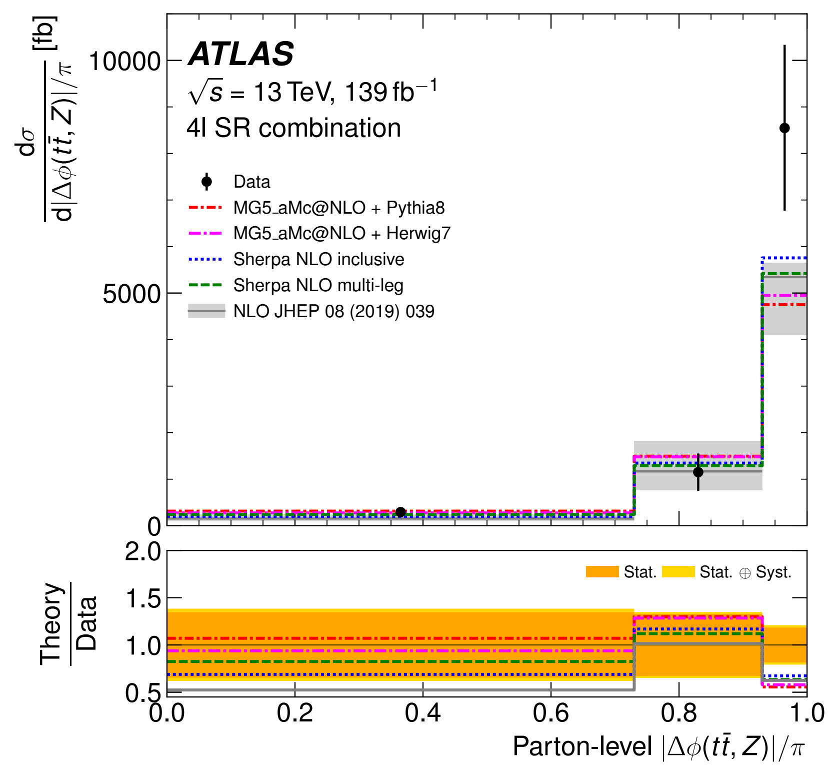
- Differential cross-section measurements performed in nine observables probing the kinematics of the *ttZ* system.
- Absolute and normalised measurements (reduced systematics) ⇒ unfold to particle/parton-level using Iterative Bayesian Unfolding (see here).
- Evaluating compatibility between data and theoretical predictions by computing χ^2/ndf and *p*-values for differential distributions.
  - All *p*-values > 0.05 ⇒ largest tensions in p_T of *Z* boson and Δφ between *Z* boson and *tt* system.

	Variable
$3\ell + 4\ell$	p_T^Z
	$\lvert y^Z \rvert$
3ℓ	N_{jets}
	$p_T^{\ell,\text{non-}Z}$
	$\lvert\Delta\phi(Z, t_{lep})\rvert$
	$\lvert\Delta y(Z, t_{lep})\rvert$
4ℓ	N_{jets}
	$\lvert\Delta\phi(\ell_t^+, \ell_{\bar{t}}^-)\rvert$
	$\lvert\Delta\phi(t\bar{t}, Z)\rvert$
	$p_T^{t\bar{t}}$

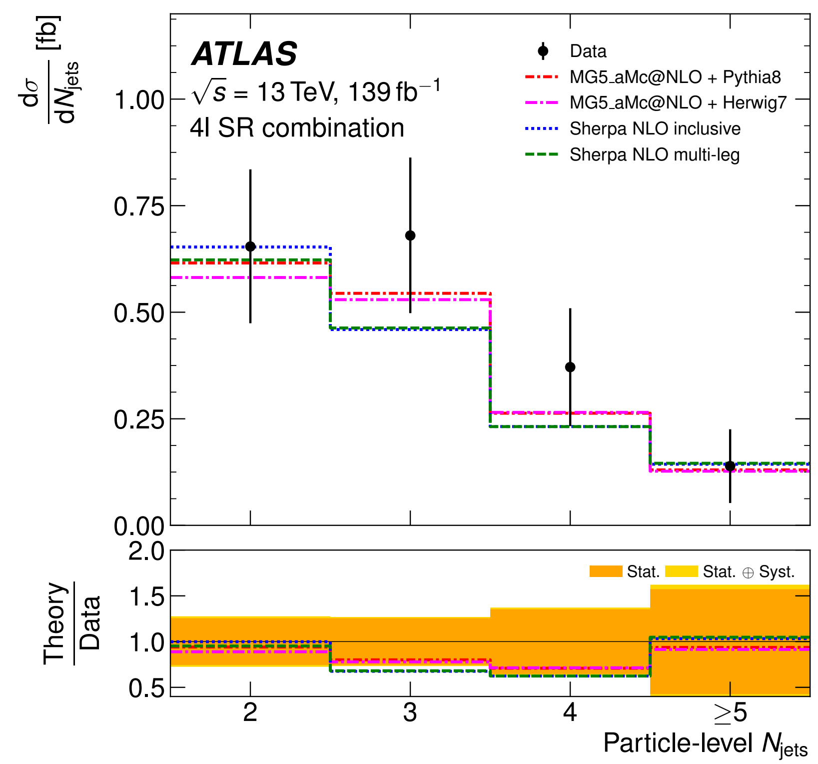
arXiv:2103.12603



$p_T(Z)$: parton



$\lvert\Delta\varphi(Z,tt)\rvert$: parton

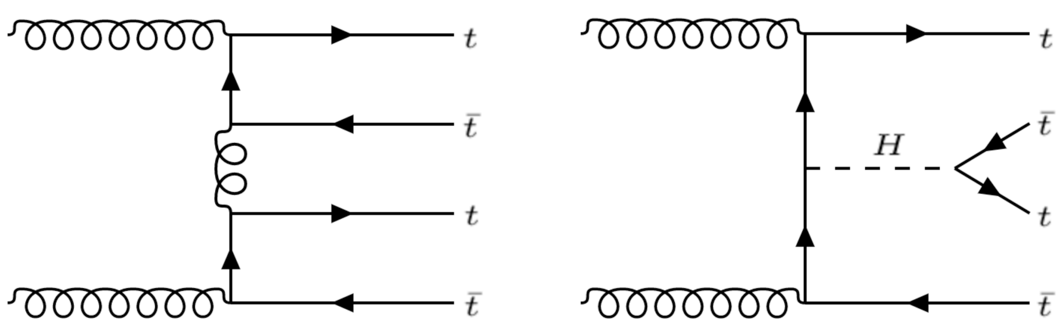


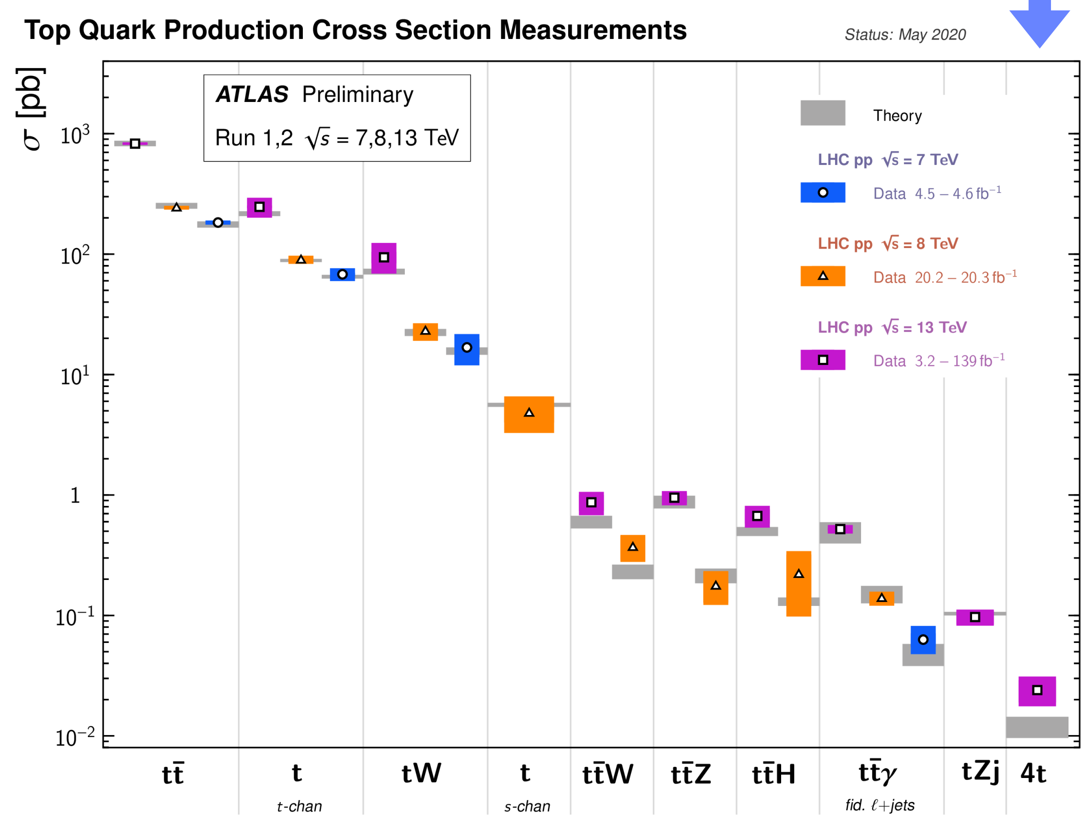
N_{jet}: particle in 4*l*

(II)
Measurement of *tttt* cross section

Production of four top quarks (*tttt*):

- Very small expected cross section: σ_{tttt} = 12 ± 2.4 fb (NLO EW+QCD) ***JHEP 02 (2018) 031***
- Process sensitive to magnitude and CP properties of top-Higgs Yukawa coupling
- Also sensitive to BSM scenarios and EFT operators (e.g. modifying the four-fermion couplings).
- Similarly to *ttZ*, *tttt* events can give rise to various final states covering different lepton multiplicities.
- Earlier published 2*l* (SS), 3*l* results: ***EPJC 80 (2020) 1085*** ⇒ recently combined with the results in the 1*l*, 2*l* (OS) channels.
- Multi-lepton channels have smaller background contaminations but lower branching ratio.
  - BR[2*l* (SS), 3*l*] = 13%, BR[1*l*, 2*l* (OS)] = 57%.



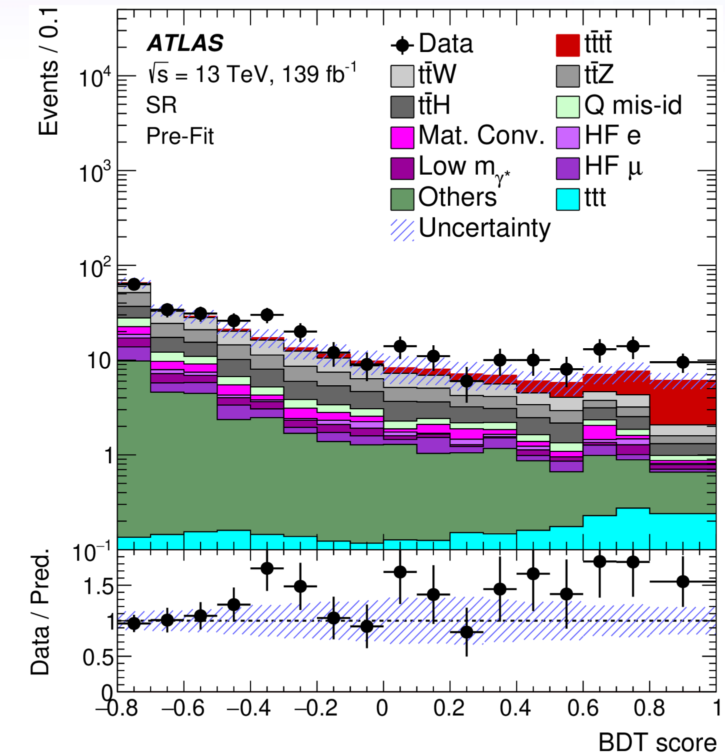


ATLAS-PHYS-PUB-2020-12

EPJC 80 (2020) 1085

$2l$(SS)/$3l$ analysis:

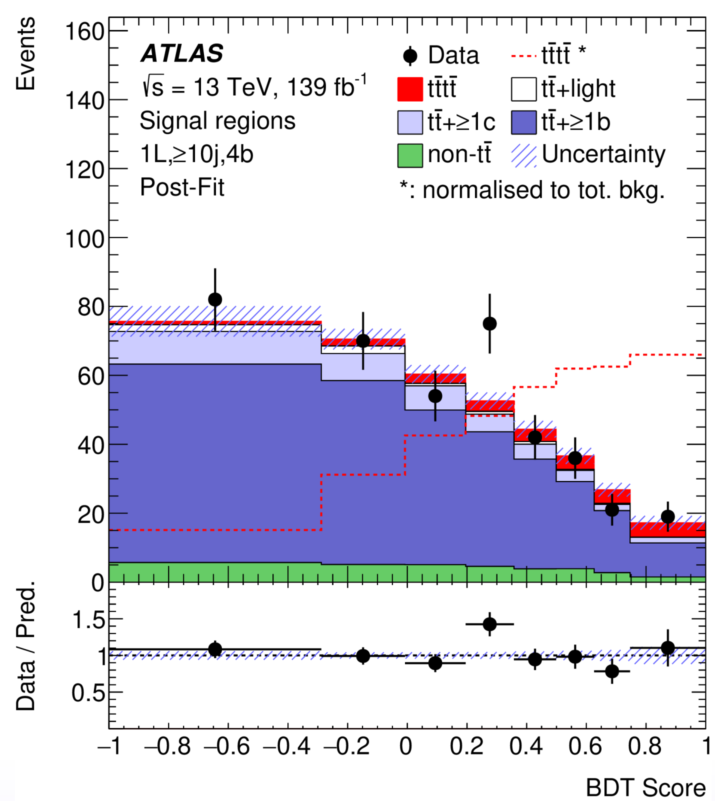
- Select $2l$ (SS) or $3l$ events and train boosted decision tree (BDT) to separate $tttt$ from background.
- Use CRs for ttW and reducible background sources from fake/non-prompt leptons (e.g. heavy-flavour decays, γ-conversions).
- Apply binned maximum-likelihood fit to BDT score to determine μ_{tttt} and inclusive cross section.

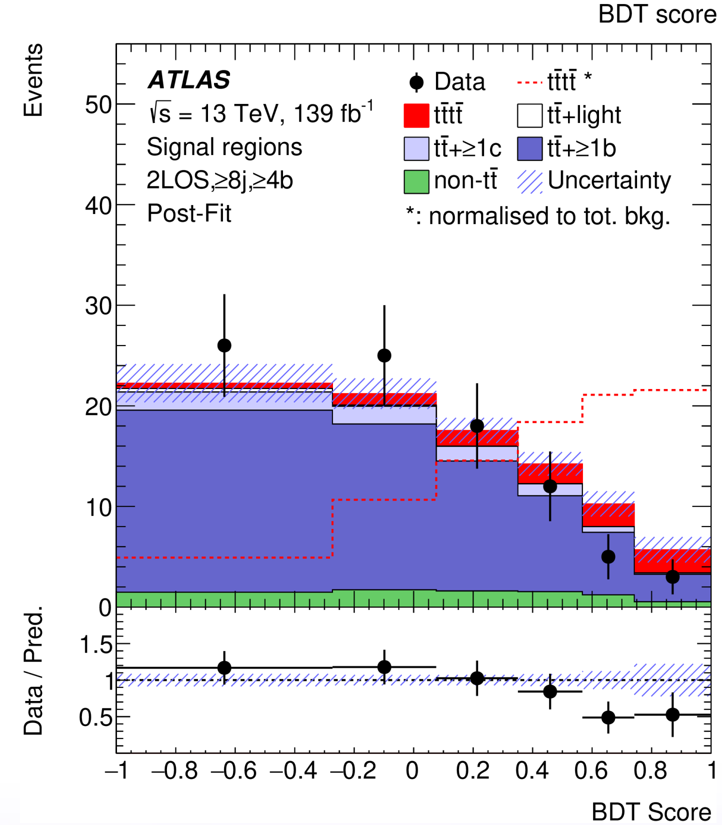


$1l$/$2l$(OS) analysis:

arXiv:2103.12603

- Use different regions with $1l$ or $2l$ (OS) selections, further separated by N_{jets} and $N_{b\text{-jets}}$.
  - Twelve regions in $1l$, nine regions in $2l$ (OS) channel.
- All SRs have $N_{b\text{-jets}} \geq 3$, $N_{\text{jets}} \geq 7$.
- Use binned fit to different variables to extract μ_{tttt}.
  - BDT score in SRs & H_T in CRs.



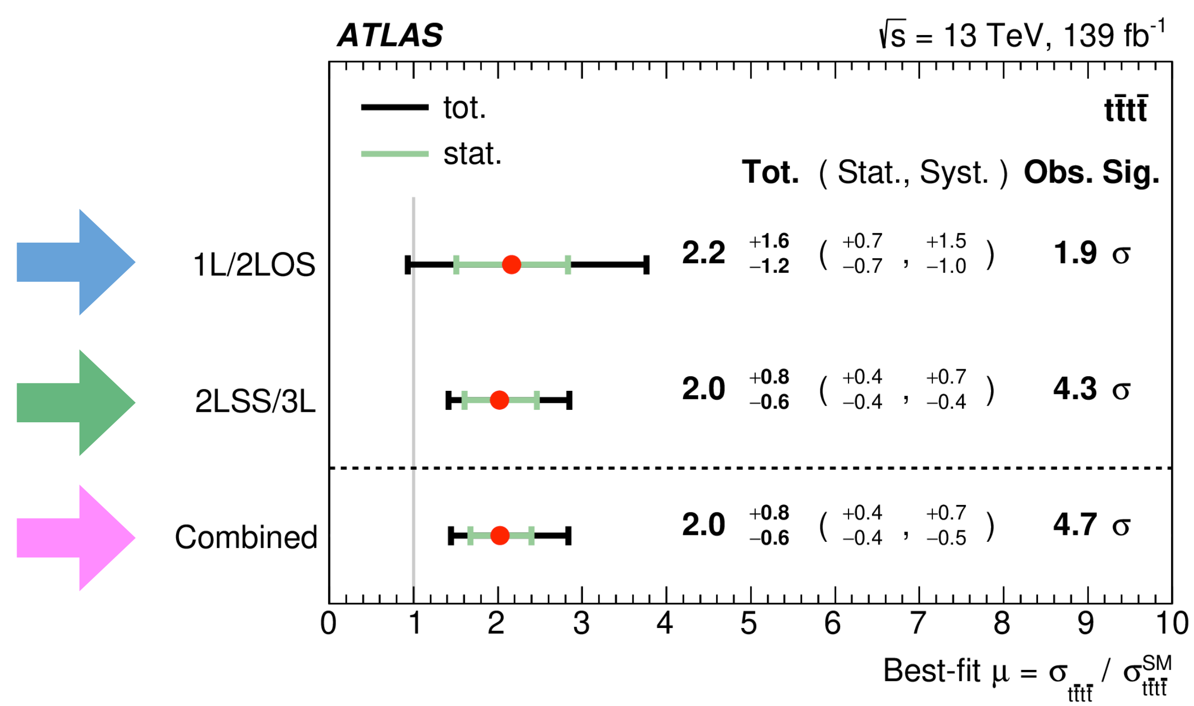


BDT scores in the $2l$(SS)/$3l$, $1l$ and $2l$(OS) channels

- Results of **1*l*/2*l* (OS)** and **2*l* (SS)/3*l*** analyses deliver compatible μ_{tttt} values ⇒ **combination** for the final cross-section measurement:

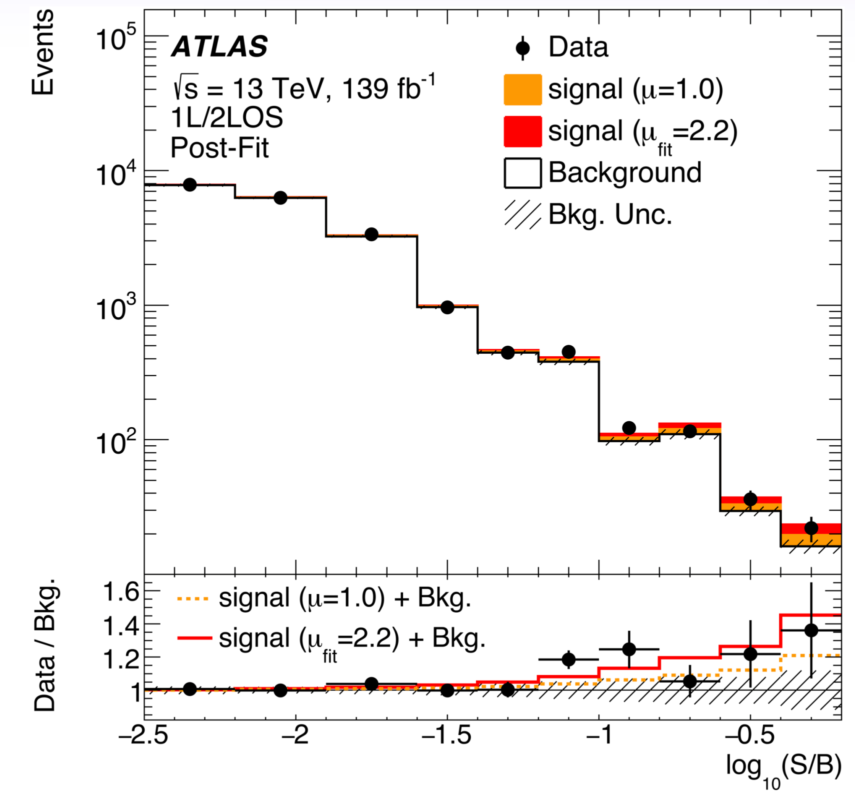
$$\sigma_{t\bar{t}t\bar{t}} = 24 \pm 4\,(\text{stat.})\,^{+5}_{-4}\,(\text{syst.})\text{ fb} = 24\,^{+7}_{-6}\text{ fb}$$

- Most relevant systematics in the two analysis are different ⇒ limited impact of systematics correlations.
- Higher precision in 2*l* (SS)/3*l* ⇒ dominates combined result.

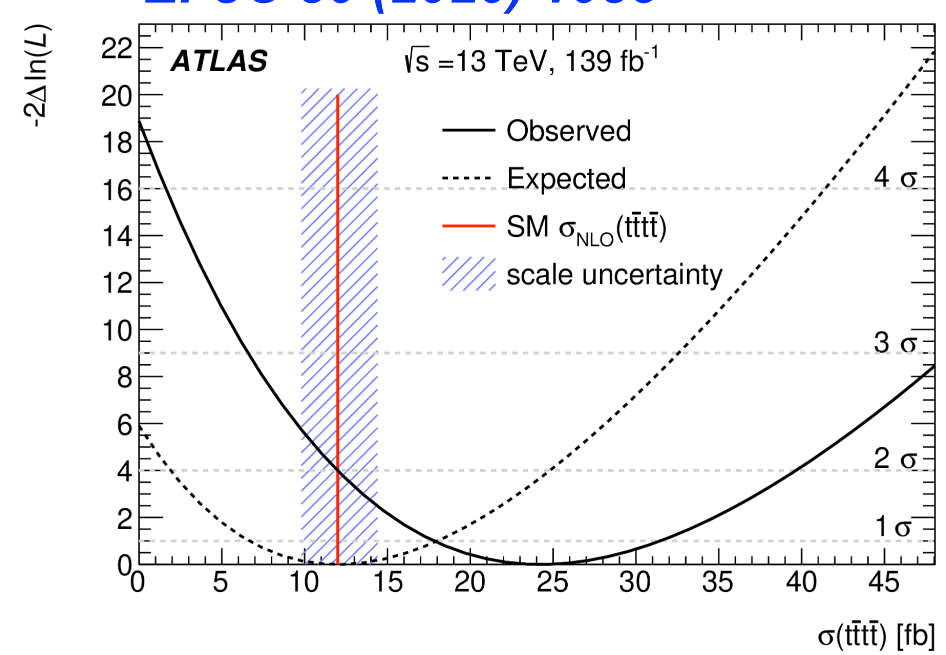


- Cross section ≈ 2 times larger than SM expectation, but within two standard deviations consistent with the latest CMS results ⇒ see ***EPJC 80 (2020) 75***.

arXiv:2103.12603



EPJC 80 (2020) 1085

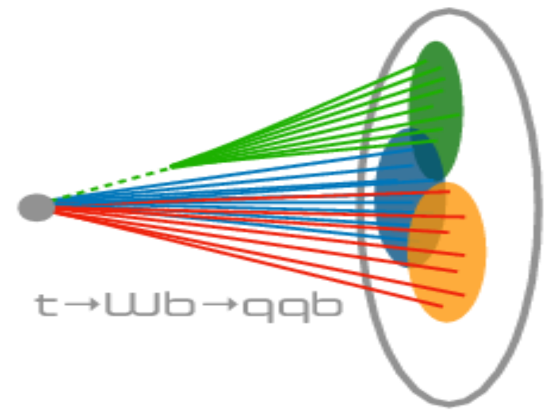


1*l*/2*l*(OS) yields (top) and 2*l*(SS)/3*l* limit (bottom)

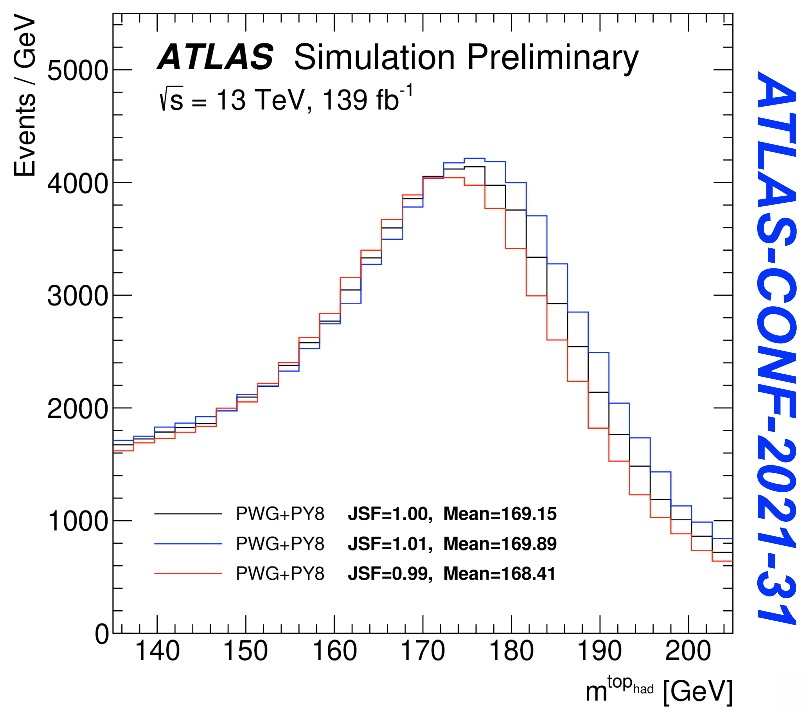
(III)
Differential $t\bar{t}$ cross sections with high top p_T

Boosted *tt* analysis:

- Targeting high p_T ("boosted") semi-leptonic *tt* events ⇒ selecting one lepton (electron/muon) and an hadronically decaying top quark with $p_T > 355$ GeV.
- Some EFT operators and BSM scenarios expect deviations from SM for large p_T or high m_{tt}.
- The *tt* system is fully reconstructed from the final state particles (using also large-*R* jets for unresolved top decays).
- Inclusive/differential cross sections already measured by ATLAS in 2019, but without full Run II data and EFT interpretations ⇒ see ***EPJC 79 (2019) 1028***.



- Background processes (non-*tt*) with at least one real lepton estimated from MC (mostly *tW*). Multi-jet (0*l*) estimated via matrix method (see here).
- Significant impact of jet energy scale uncertainty on results.
  - Reduced by deriving custom jet energy scale factors (JSF) to be applied on top of the standard ATLAS calibration, based on matching between top mass (mass of top-tagged jet) in data and MC.
  - Best data/MC agreement for JSF = 1.0035 ± 0.00087.



m_j^{top} in MC for different JSF values

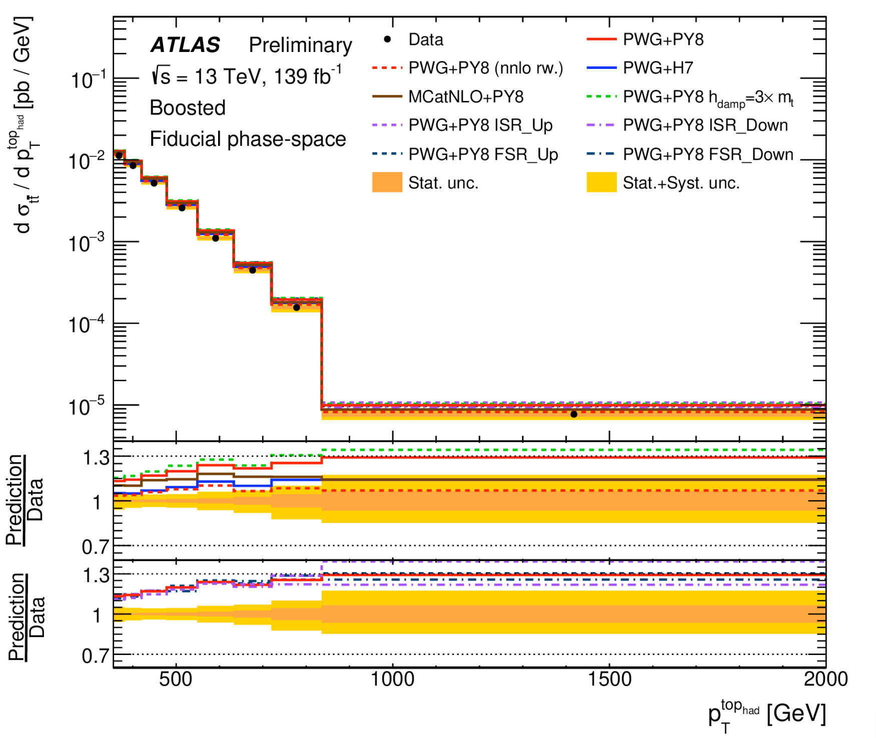
tt-boosted: Differential measurement

- Measure differential cross sections for several observables sensitive to kinematics of top quarks and parton shower/radiation effects.
- Differential distributions unfolded to particle-level via Iterative Bayesian Unfolding (see *ttZ* analysis).
- Check compatibility with data (based on χ^2/ndf) for several parton shower algorithms and FSR/ISR variations in the MC generators.
- Use sum of bins for inclusive fiducial cross section:

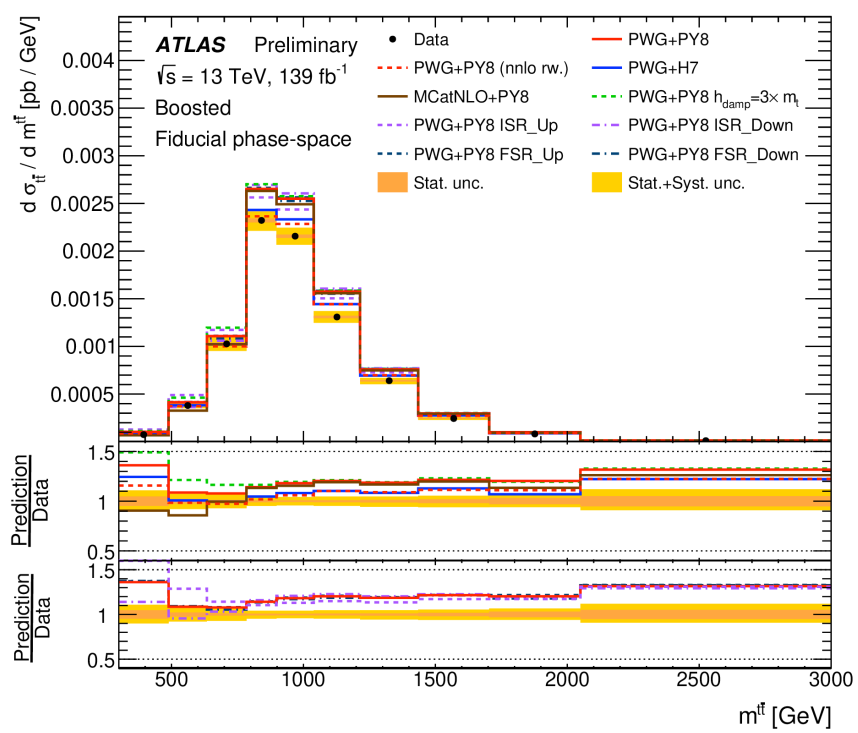
$$\sigma_{tt} = 1.267 \pm 0.005\ (\text{stat.}) \pm 0.053\ (\text{syst.})\ \text{pb}$$

Observables	
$p_T^{\text{top}_\text{had}}$	$N^{extrajets}$
$p_T^{\text{top}_\text{lep}}$	$\Delta\phi(\text{extra}_1, \text{top}_\text{had})$
$p_T^{t\bar{t}}$	$\Delta\phi(\text{extra}_2, \text{top}_\text{had})$
$H_T^{t\bar{t}+\text{jets}}$	$\Delta\phi(b_\text{lep}, \text{top}_\text{had})$
$H_T^{t\bar{t}}$	$\Delta\phi(\text{top}_\text{lep}, \text{top}_\text{had})$
$\lvert y^{\text{top}_\text{had}}\rvert$	$\Delta\phi(\text{extra}_1, \text{extra}_2)$
$\lvert y^{\text{top}_\text{lep}}\rvert$	$m(\text{extra}_1, \text{top}_\text{had})$
$\lvert y^{t\bar{t}}\rvert$	$p_T^{\text{extra}_1}$ vs $N^{extrajets}$
$m^{t\bar{t}}$	$p_T^{\text{extra}_1}$ vs $p_T^{\text{top}_\text{had}}$
$p_T^{\text{extra}_1}$	$\Delta\phi(\text{extra}_1, \text{top}_\text{had})$ vs $p_T^{\text{top}_\text{had}}$
$p_T^{\text{extra}_2}$	$\Delta\phi(\text{extra}_1, \text{top}_\text{had})$ vs $N^{extrajets}$

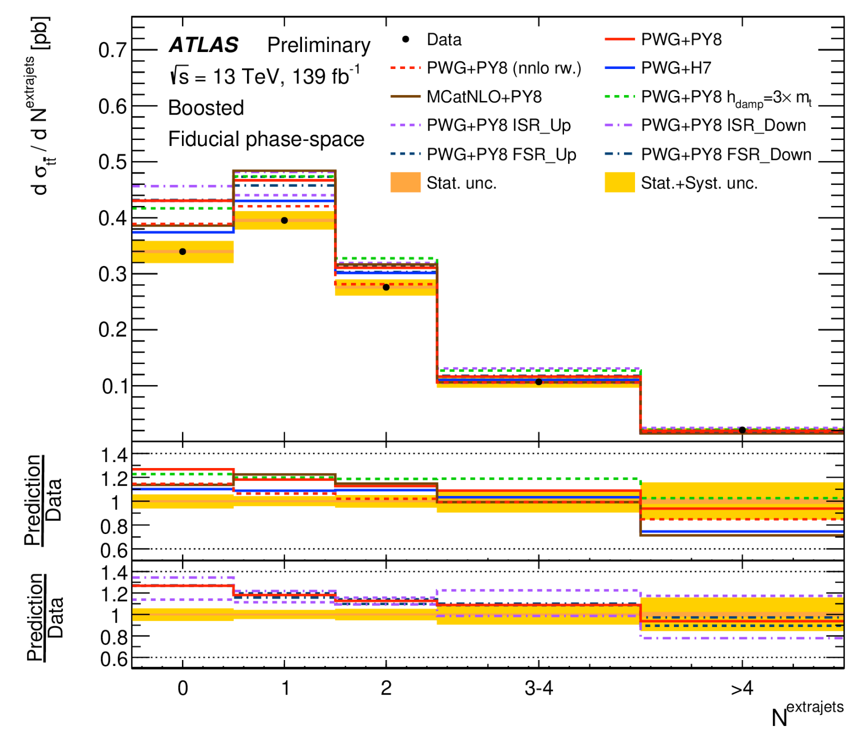
ATLAS-CONF-2021-31



p_T(hadronic-top)

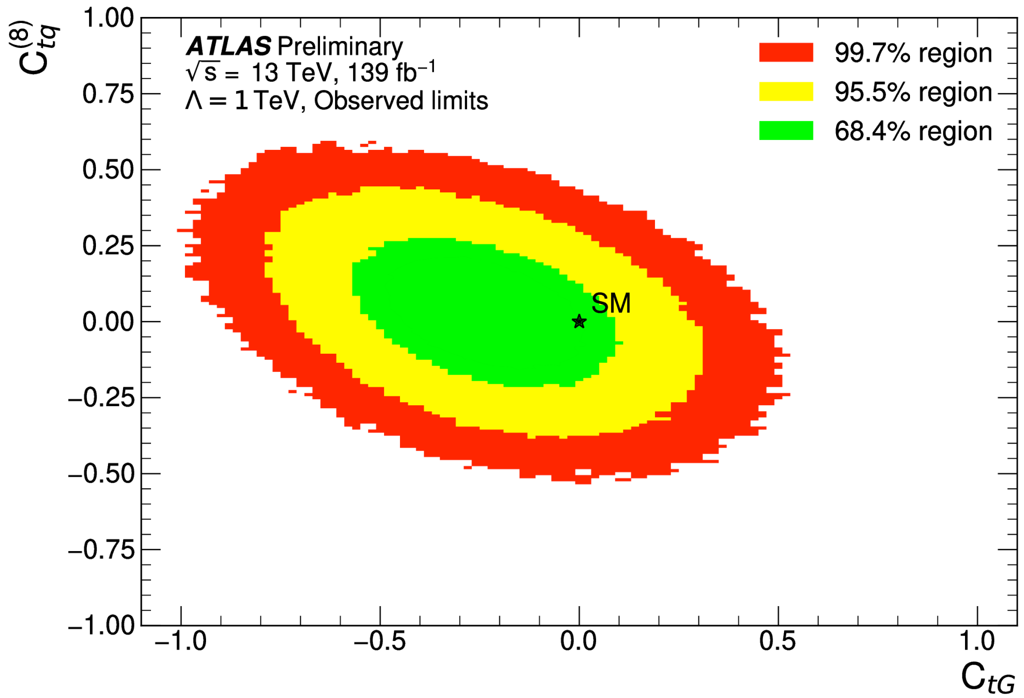


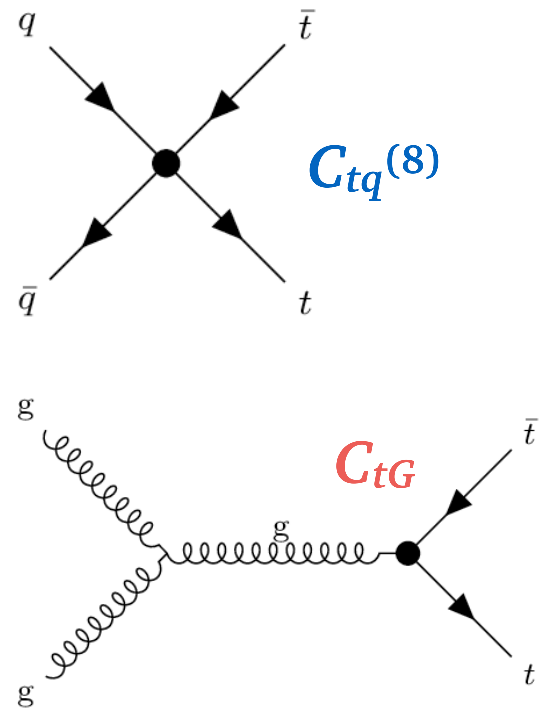
Invariant mass of *tt* system



No. of extra (non *t*-tagged) jets

- Inclusive fiducial cross section shows best agreement with data for MC predictions for POWHEG and MADGRAPH5 with NNLO(QCD)+NLO(EW) reweighing at parton level.
- Using differential distribution of hadronic top quark p_T to derive limits on two Wilson coefficients modifying the top-g and top-q couplings: $C_{tq}^{(8)}$, C_{tG}
- More stringent limits on $C_{tq}^{(8)}$ than latest global SMEFT result ⇒ see ***arXiv:2105.00006***.





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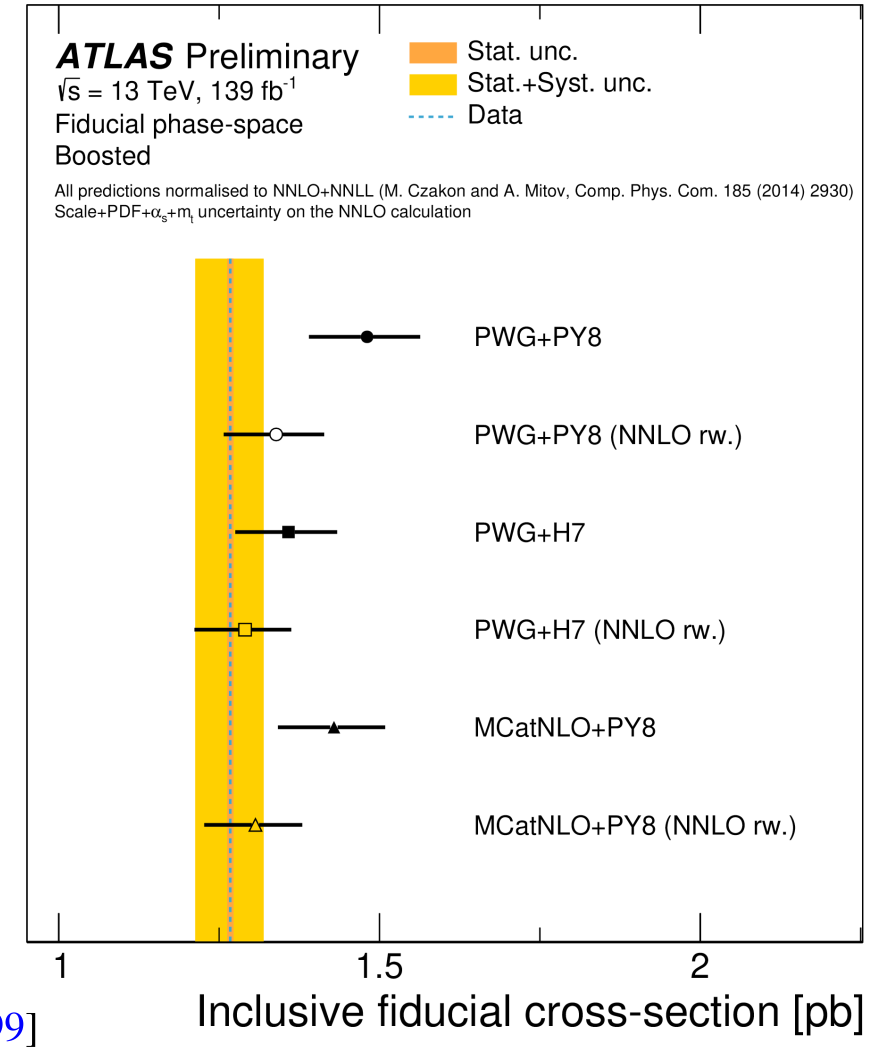


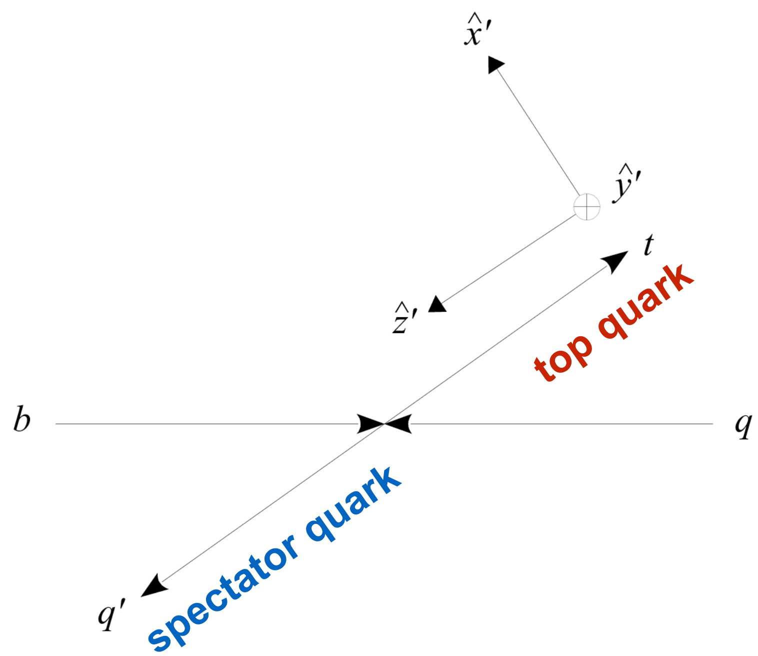
Wilson coefficient	Marginalised 95% intervals		Individual 95% intervals		
	Expected	Observed	Expected	Observed	Global fit [99]
C_{tG}	[-0.44, 0.44]	[-0.68, 0.21]	[-0.41, 0.42]	[-0.63, 0.20]	[0.007, 0.111]
$C_{tq}^{(8)}$	[-0.35, 0.35]	[-0.30, 0.36]	[-0.35, 0.36]	[-0.34, 0.27]	[-0.40, 0.61]

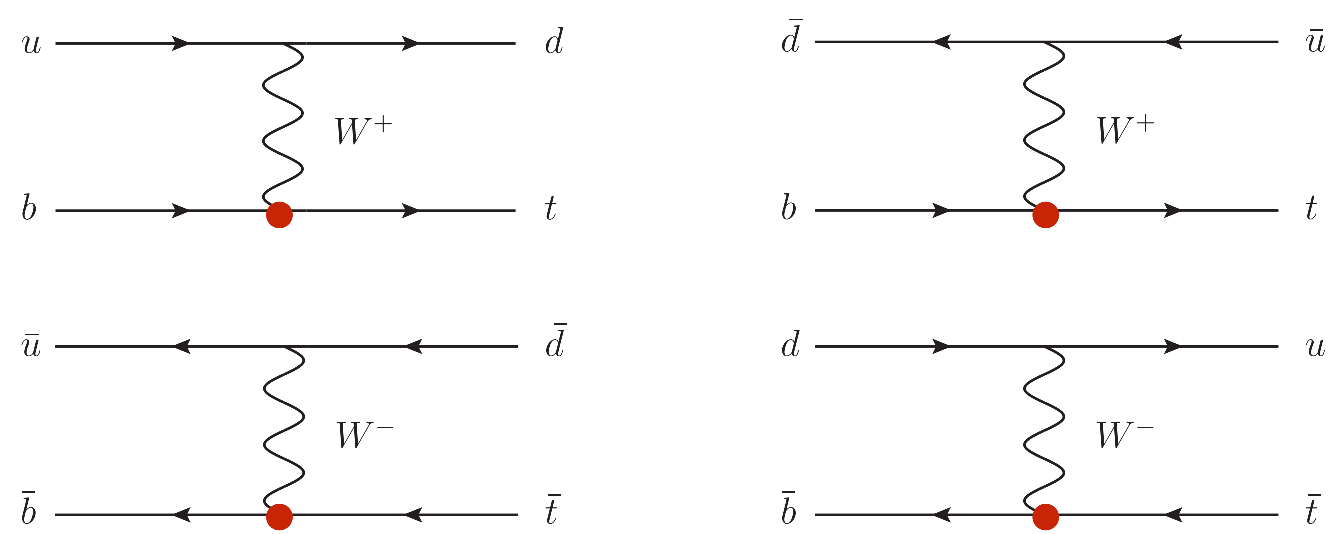
(IV)
Single-top polarisation measurement

Single-top polarisation: Analysis motivation

Top-polarisation measurement in single top:

- Perform first cut-based fiducial measurement of the single top-quark polarisation in with full Run II dataset.
- Focus on single top quarks/antiquark production via exchange of virtual W boson in t-channel $\Rightarrow$ producing a top quark/antiquark and a recoiling light-flavour quark q (“spectator quark”).
- Top quarks/antiquarks are polarised due to vector-axial vector (V-A) form of the tWb vertex $\Rightarrow$ spin aligned to down-type quarks.





- Selecting $1l$ + jets events: top polarisation vector accessible from angular variables of the lepton in the top quark rest frame $\cos\theta_{lx'}$, $\cos\theta_{ly'}$, $\cos\theta_{lz'}$ $\Rightarrow$ see ***Phys. Rev. D. 89 (2014) 114009***.

- Lepton angular variables in top rest frame $\{\cos\theta_{lx'}, \cos\theta_{ly'}, \cos\theta_{lz'}\}$ allow to determine polarisation vector $\boldsymbol{P} = \{P_{x'}, P_{y'}, P_{z'}\}$ of top quark/antiquarks from a likelihood minimisation (after selecting events in SR).
- Differential cross section measurement of angular variables.
  - Unfolded to particle-level and compared to the predictions of different MC generators and parton shower algorithms (e.g. POWHEG+PY8, POWHEG+H7, MADGRAPH5+PY8).

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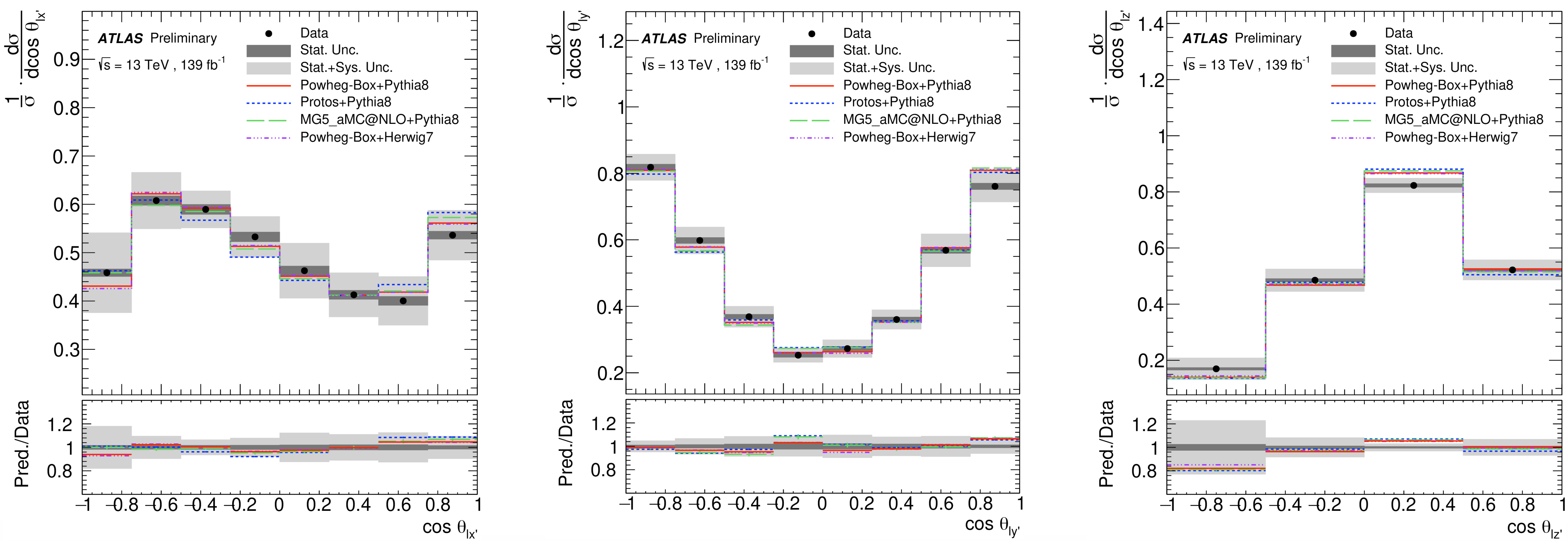

Particle-level distributions of $\cos\theta_{lx'}$ (left), $\cos\theta_{ly'}$ (middle), $\cos\theta_{lz'}$ (right)

- Can set limits (green/yellow) on the $\{P_{x'}, P_{z'}\}$ components of the top/antitop polarisation vector.
  - $P_{x'} = 0.01 \pm 0.18$, $P_{z'} = 0.91 \pm 0.10$ (top).
  - $P_{x'} = -0.02 \pm 0.20$, $P_{z'} = -0.79 \pm 0.16$ (anti top).
  - In agreement with the NLO MC prediction from POWHEG+PYTHIA8 (★).
- Can also constrain two Wilson coefficients which modify the tW coupling: C_{tW}, C_{itW}.
  - Best-fit values are (within 68% CL) in agreement with SM expectation ($C_{tW} = C_{itW} = 0$).
  - So far, most stringent simultaneously derived limits on C_{tW} and C_{itW}.

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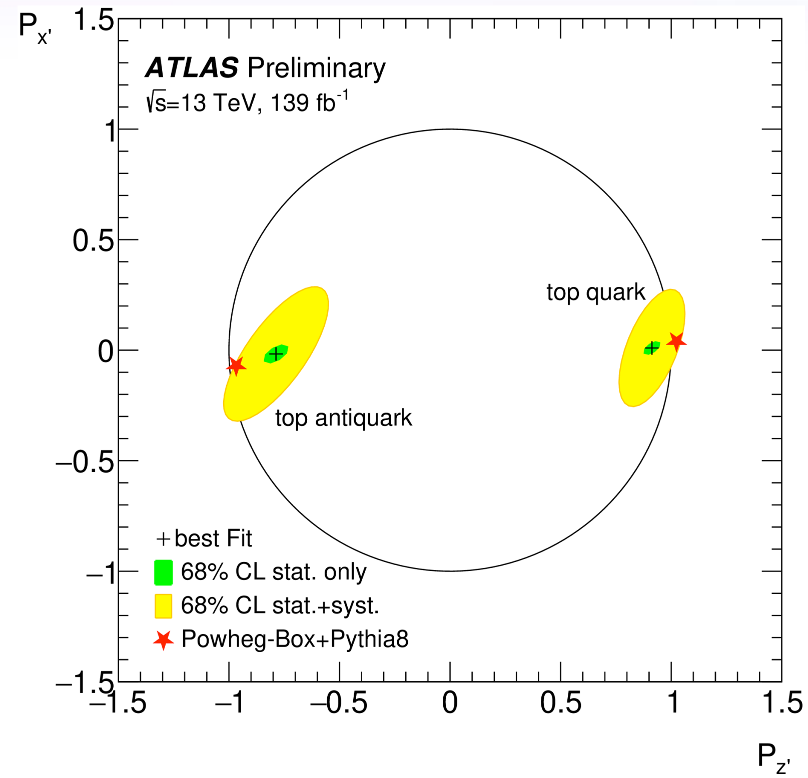
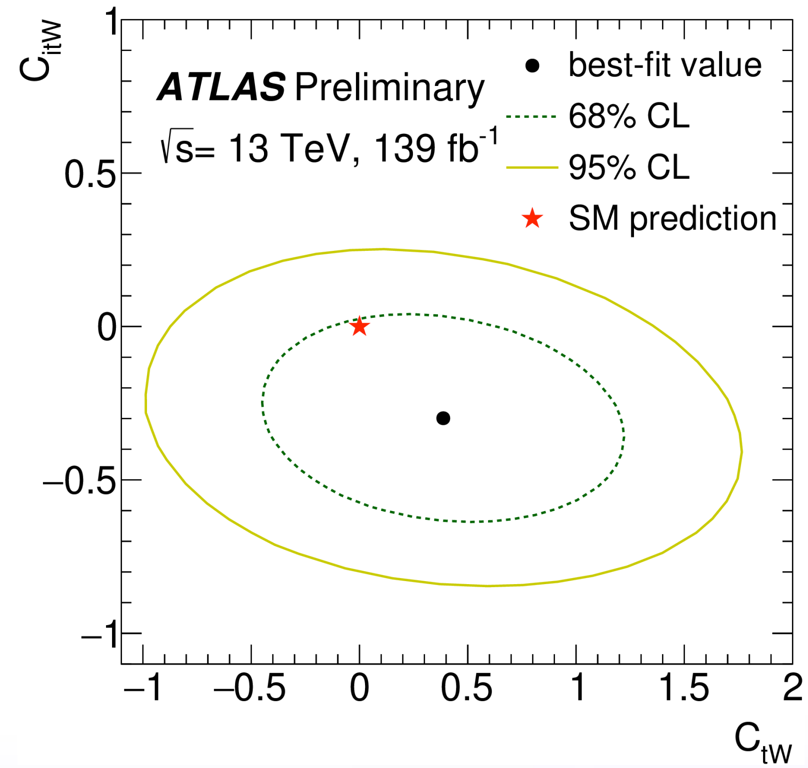
	C_{tW} 68% CL	C_{tW} 95% CL	C_{itW} 68% CL	C_{itW} 95% CL
All terms	[-0.2, 0.9]	[-0.7, 1.5]	[-0.5, -0.1]	[-0.7, 0.2]
Order $1/\Lambda^4$	[-0.2, 0.9]	[-0.7, 1.5]	[-0.5, -0.1]	[-0.7, 0.2]
Order $1/\Lambda^2$	[-0.2, 1.0]	[-0.7, 1.7]	[-0.5, -0.1]	[-0.8, 0.2]





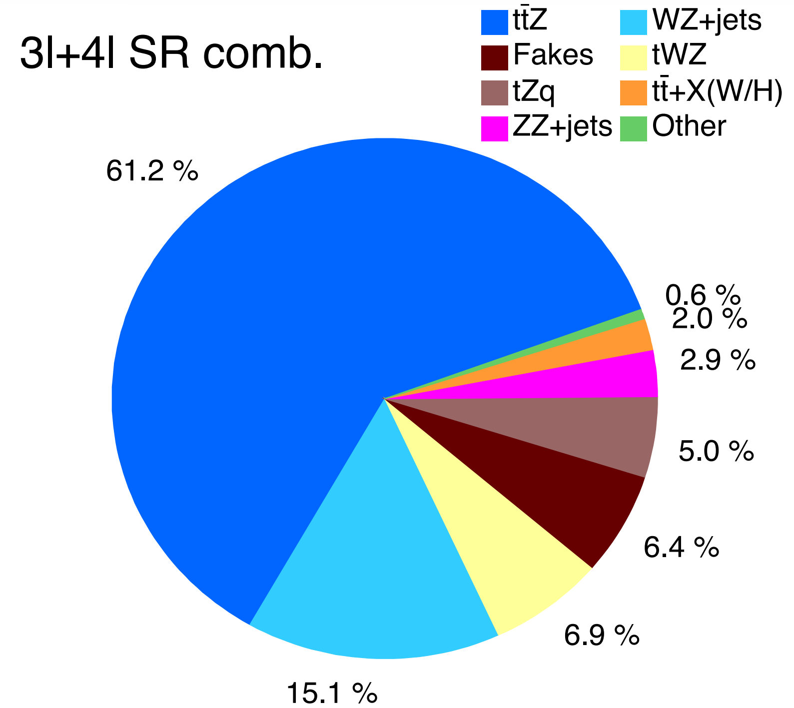
- Presented four of the most recent ATLAS measurements on top quark related processes (most results released in the last 2-3 months).
  - Measurement of inclusive and differential ttZ cross sections in $3l$ and $4l$ final states
    $\Rightarrow$ ***arXiv:2103.12603***.
  - Measurement of the $tttt$ production cross section in $1l/2l$ (OS) and $2l$ (SS)/$3l$ channels
    $\Rightarrow$ ***arXiv:2106.11683***.
  - Differentials and inclusive cross section measurements of tt events with high p_T top quarks
    $\Rightarrow$ ***ATLAS-CONF-2021-31***.
  - Measurement of top quark/antiquark polarisation in single top events
    $\Rightarrow$ ***ATLAS-CONF-2021-027***.

- Further interesting results on top physics in ATLAS can be found on the “Top Public Results” webpage of the ATLAS collaboration (see here).

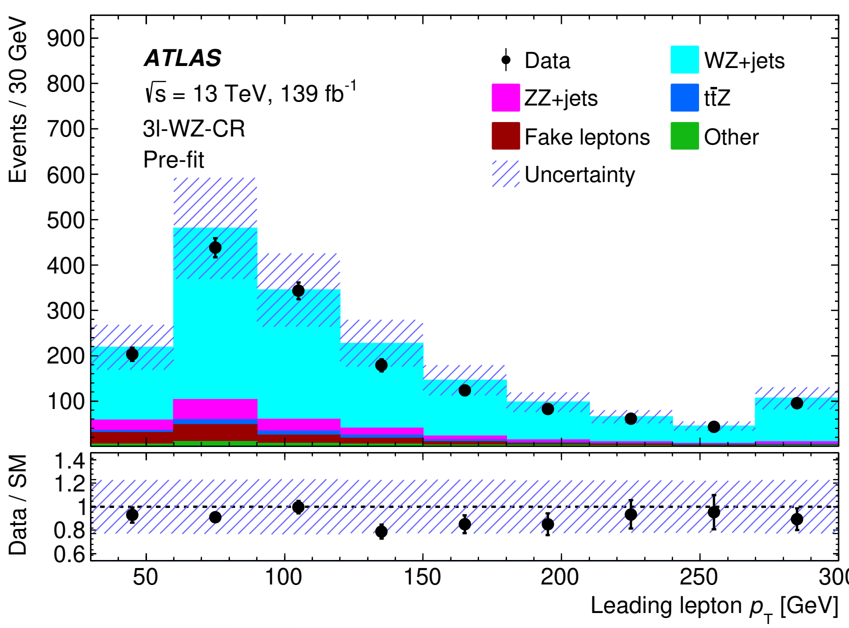
Thanks a lot for your attention!

Backup

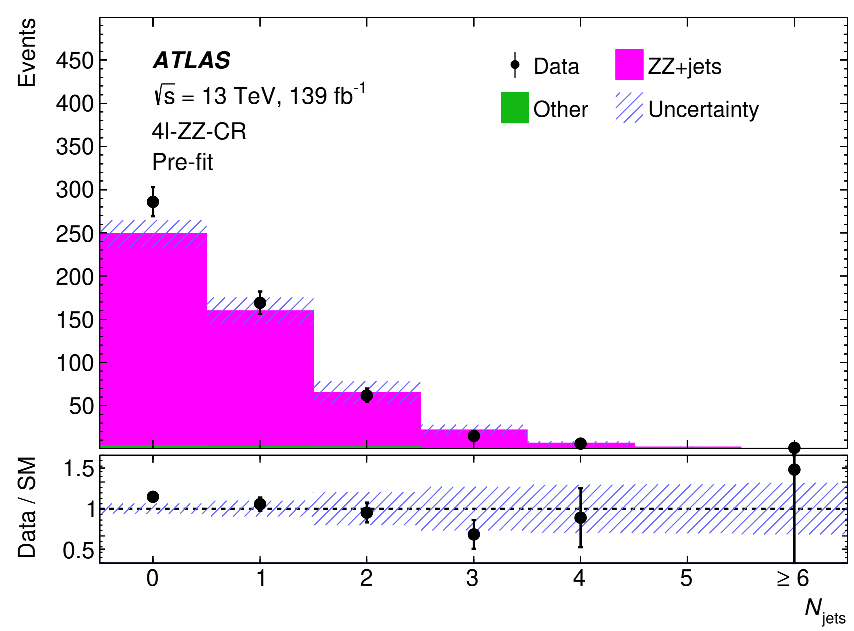
- Dominated by $WZ+\text{jets}$ ($3l$) and $ZZ+\text{jets}$ ($4l$) $\Rightarrow$ using control regions to constrain backgrounds (only light-jet components).
  - Normalisations for WZ/ZZ + light-jets free fit parameters. WZ/ZZ + b/c-jets fixed to MC prediction (but extra unc.).
- Data-driven matrix-method for fake/non-prompt lepton background.
  - Fake-lepton prediction validated in $3l$ region with Z-veto $\Rightarrow$ up to 60% fake leptons.
- Smaller SM backgrounds (e.g. $tt+W/H$, tZq, tWZ) estimated purely from MC (all < 7%).



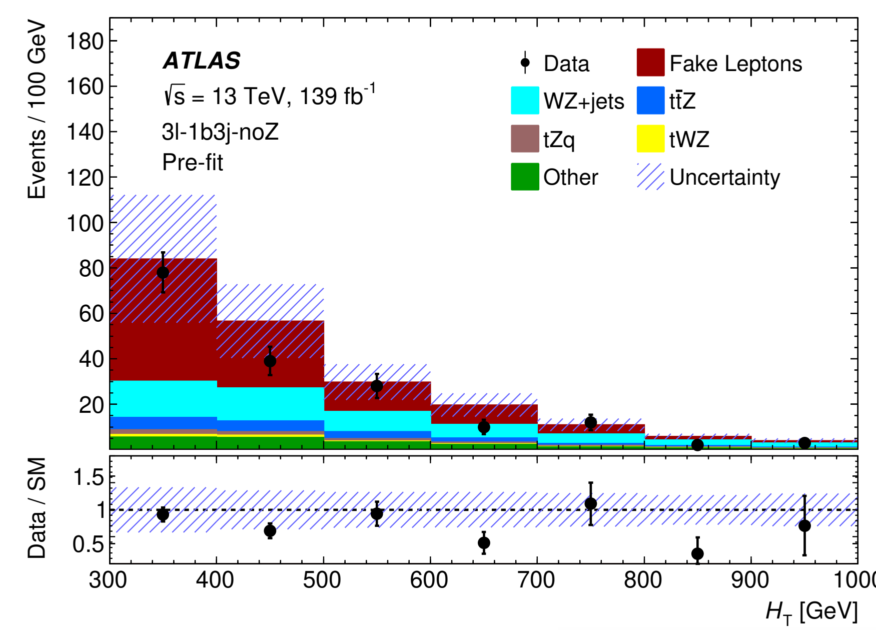
arXiv:2103.12603



CR-$3l$-WZ: 1st lepton p_T



CR-$4l$-ZZ: N_{jet} (p_T > 25 GeV)



VR-$3l$-Fakes: H_T

arXiv:2103.12603

Most relevant systematics:

- All detector-related uncertainties (JES/JER, b-tag, lepton SF etc.) considered.
- *ttZ* parton-shower (& underlying event):
  - Comparison of nominal *ttZ* MC (MadGraph5 + Pythia8) vs. MadGraph5 + Herwig7.
- *tWZ* modelling:
  - Comparison of different diagram removal schemes: DR1 vs. DR2 (see here).
- *WZ/ZZ* + jets modelling:
  - μ_F, μ_R variations & normalisation uncertainties.
  - Extra 50% (30%) for $WZ/ZZ + b(c)$-jet components ⇒ obtained from $Z + b$ events ($2l$).

Uncertainty	$\Delta\sigma_{t\bar{t}Z}/\sigma_{t\bar{t}Z}$ [%]
$t\bar{t}Z$ parton shower	3.1
tWZ modelling	2.9
b-tagging	2.9
WZ/ZZ + jets modelling	2.8
tZq modelling	2.6
Lepton	2.3
Luminosity	2.2
Jets + E_T^{miss}	2.1
Fake leptons	2.1
$t\bar{t}Z$ ISR	1.6
$t\bar{t}Z$ μ_f and μ_r scales	0.9
Other backgrounds	0.7
Pile-up	0.7
$t\bar{t}Z$ PDF	0.2
Total systematic	8.4
Data statistics	5.2
Total	10

ttZ analysis: Compatibility of differential results

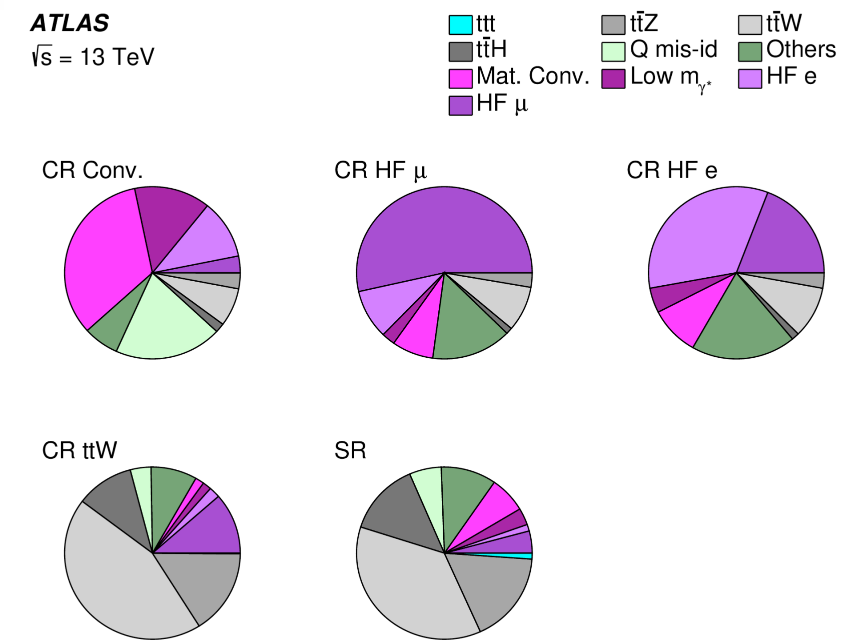
- Can evaluate the compatibility between data and the theoretical predictions by computing χ^2/ndf and p-values for differential distributions.
  - Checked for different *ttZ* generators, as well as hand-made theory calculations at NLO, NLO+NNLL and nNLO precisions ⇒ see ***JHEP 08 (2019) 039***.
  - All p-values > 0.05 ⇒ largest tensions in $p_T(Z)$, $p_T(l^{\text{non-}Z})$, $\Delta\varphi(Z,t_l)$ and $\Delta\varphi(tt,Z)$.
  - NLO+NNLL predictions for $p_T(Z)$ seem to show improved agreement.

arXiv:2103.12603

	Variable	Particle	Parton	Absolute	Normalised	Figure	MG5_aMC@NLO 2.3.3 + Pythia 8		MG5_aMC@NLO 2.3.3 + Herwig 7		Sherpa 2.2.1 NLO multi-leg		Sherpa 2.2.1 NLO inclusive		Additional Theory	
							χ^2/ndf	p-value	χ^2/ndf	p-value	χ^2/ndf	p-value	χ^2/ndf	p-value	χ^2/ndf	p-value
$3\ell+4\ell$	p_T^Z	✓		✓		9(a)	12.8/7	0.08	12.0/7	0.10	11.6/7	0.11	12.1/7	0.10	/	/
	p_T^Z		✓	✓		9(b)	12.8/7	0.08	11.7/7	0.11	11.2/7	0.13	11.3/7	0.13	10.4/7	0.17
	p_T^Z	✓			✓	10(a)	11.0/6	0.09	10.8/6	0.09	10.6/6	0.10	10.7/6	0.10	/	/
	p_T^Z		✓		✓	10(b)	11.0/6	0.09	10.8/6	0.10	10.7/6	0.10	10.6/6	0.10	10.5/6	0.11
	$\|y^Z\|$		✓	✓		11(a)	2.8/8	0.95	2.9/8	0.94	4.0/8	0.85	2.7/8	0.95	2.9/8	0.94
3ℓ	N_{jets}	✓		✓		12(a)	0.8/3	0.85	0.6/3	0.90	0.3/3	0.95	0.5/3	0.92	/	/
	$p_T^{\ell,\text{non-}Z}$		✓	✓		13(a)	7.6/4	0.11	8.8/4	0.07	8.3/4	0.08	8.6/4	0.07	/	/
	$\|\Delta\phi(Z,t_{\text{lep}})\|$		✓	✓		13(b)	5.5/3	0.14	5.8/3	0.12	5.2/3	0.16	6.9/3	0.07	6.6/3	0.09
	$\|\Delta y(Z,t_{\text{lep}})\|$		✓	✓		14(a)	0.9/3	0.82	0.7/3	0.88	0.2/3	0.98	0.5/3	0.92	0.3/3	0.96
4ℓ	N_{jets}	✓		✓		12(b)	1.4/4	0.84	1.7/4	0.79	2.8/4	0.59	2.8/4	0.59	/	/
	$\|\Delta\phi(\ell_t^+,\ell_{\bar{t}}^-)\|$		✓	✓		14(b)	2.1/4	0.72	2.3/4	0.69	2.7/4	0.62	2.6/4	0.63	/	/
	$\|\Delta\phi(t\bar{t},Z)\|$		✓	✓		15(a)	5.2/3	0.16	4.7/3	0.19	3.5/3	0.32	3.4/3	0.33	4.9/3	0.18
	$p_T^{t\bar{t}}$		✓	✓		15(b)	3.5/4	0.47	3.6/4	0.47	3.5/4	0.48	3.5/4	0.47	4.6/4	0.33

- Use CRs for ttW and non-prompt electrons/muons originating from heavy-flavour (HF) decays and electrons from γ-conversions.
- Obtain normalisation factors (NFs) for these background components together with μ_{tttt} from simultaneous fit in all SRs/CRs.
  - Corrected MC is used for SM background prediction in SRs.

Parameter	$\mathrm{NF}_{t\bar{t}W}$	$\mathrm{NF}_{\mathrm{Mat.\ Conv.}}$	$\mathrm{NF}_{\mathrm{Low}\ m_{\gamma^*}}$	$\mathrm{NF}_{\mathrm{HF}\ e}$	$\mathrm{NF}_{\mathrm{HF}\ \mu}$
Value	1.6 ± 0.3	1.6 ± 0.5	0.9 ± 0.4	0.8 ± 0.4	1.0 ± 0.4



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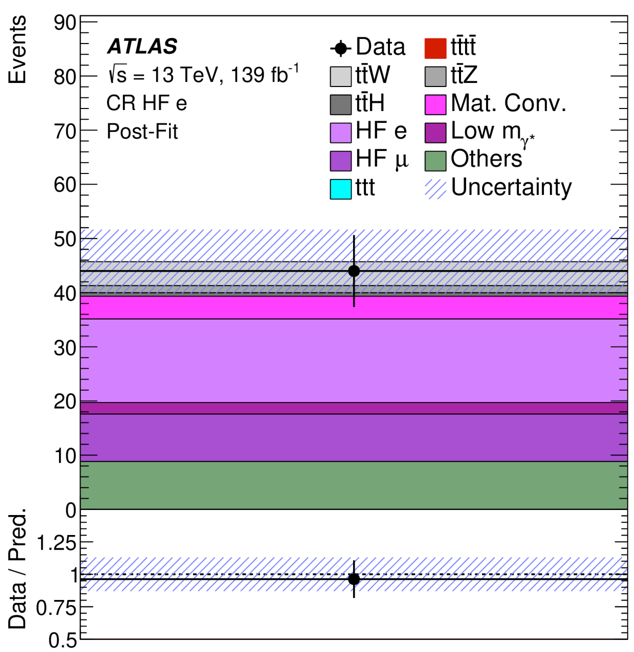
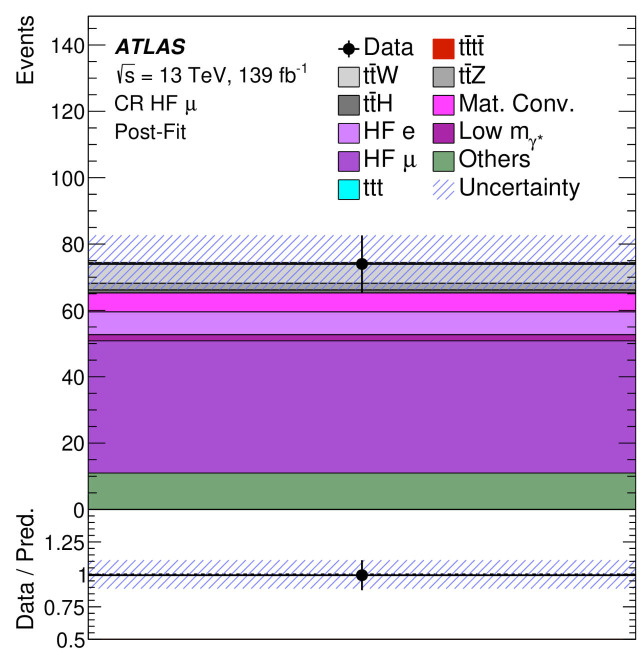
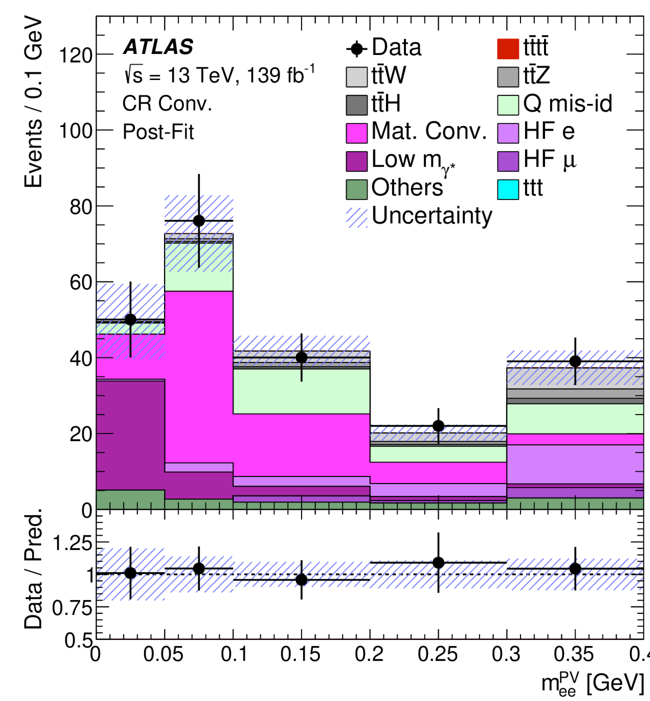


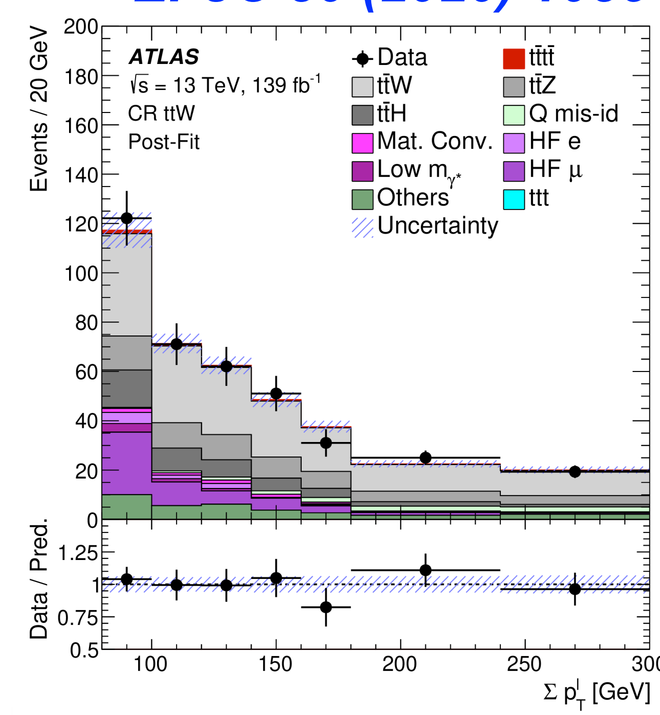
CR for HF electrons



CR for HF muons

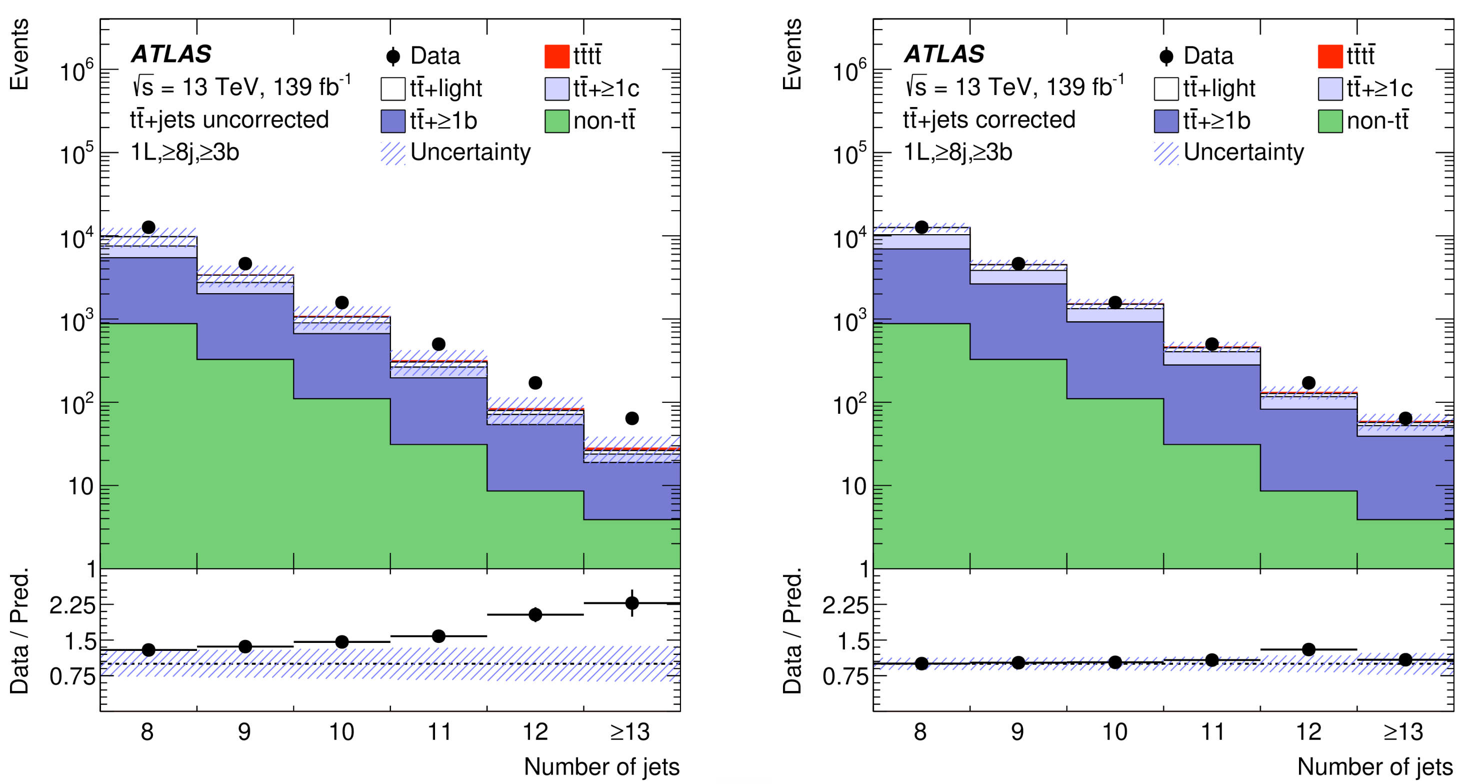


CR for γ-conversions



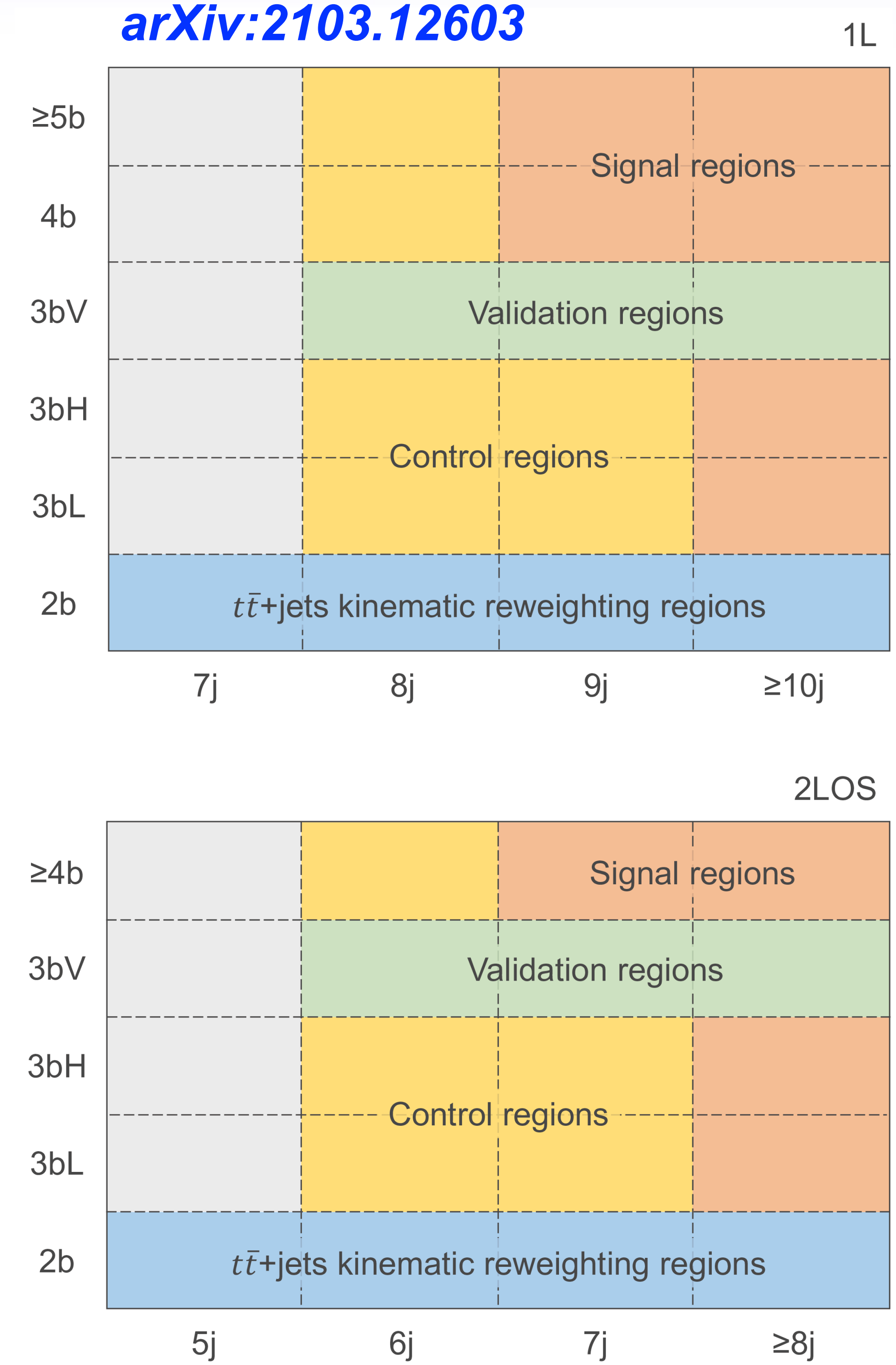
CR for ttW

- Signal and control regions are categorised by N_{jets} and $N_{b\text{-jets}}$ in 1*l* and 2*l* (OS) channels.
  - All SRs have high jet multiplicities and ≥ 3 *b*-jets (■).
  - Regions with = 3 *b*-jets and lower jet multiplicities (■) are used as CRs to fit *tt*+jets, separated by jet-flavour: *tt*+light, *tt*+*b*, *tt*+*c*.
  - Total *tt* is reweighed to data in regions with = 2 *b*-jets (■) as a function of different kinematic variables.



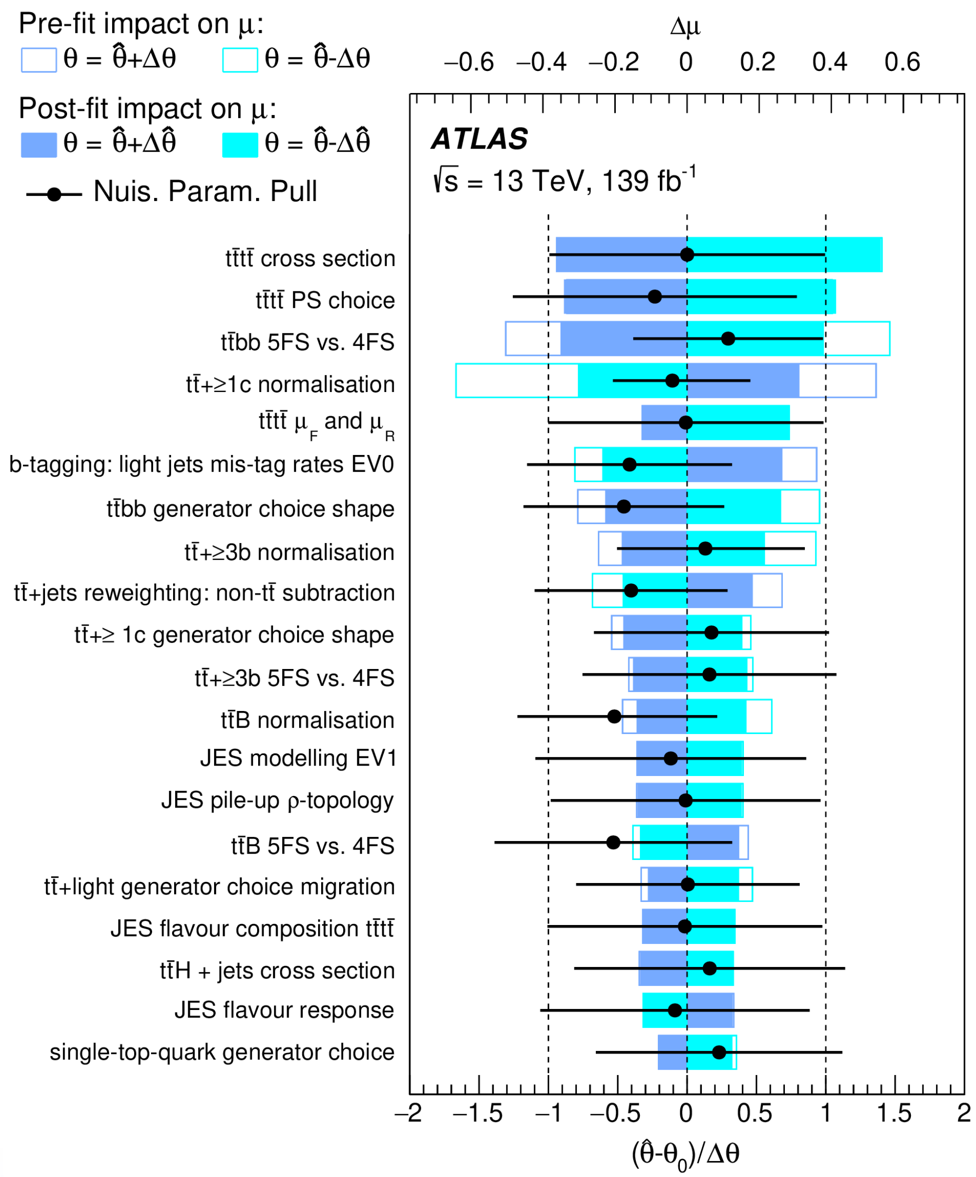
N_{jet} in one of the 3*b* CR: pre-fit (left) and post-fit (right)

arXiv:2103.12603



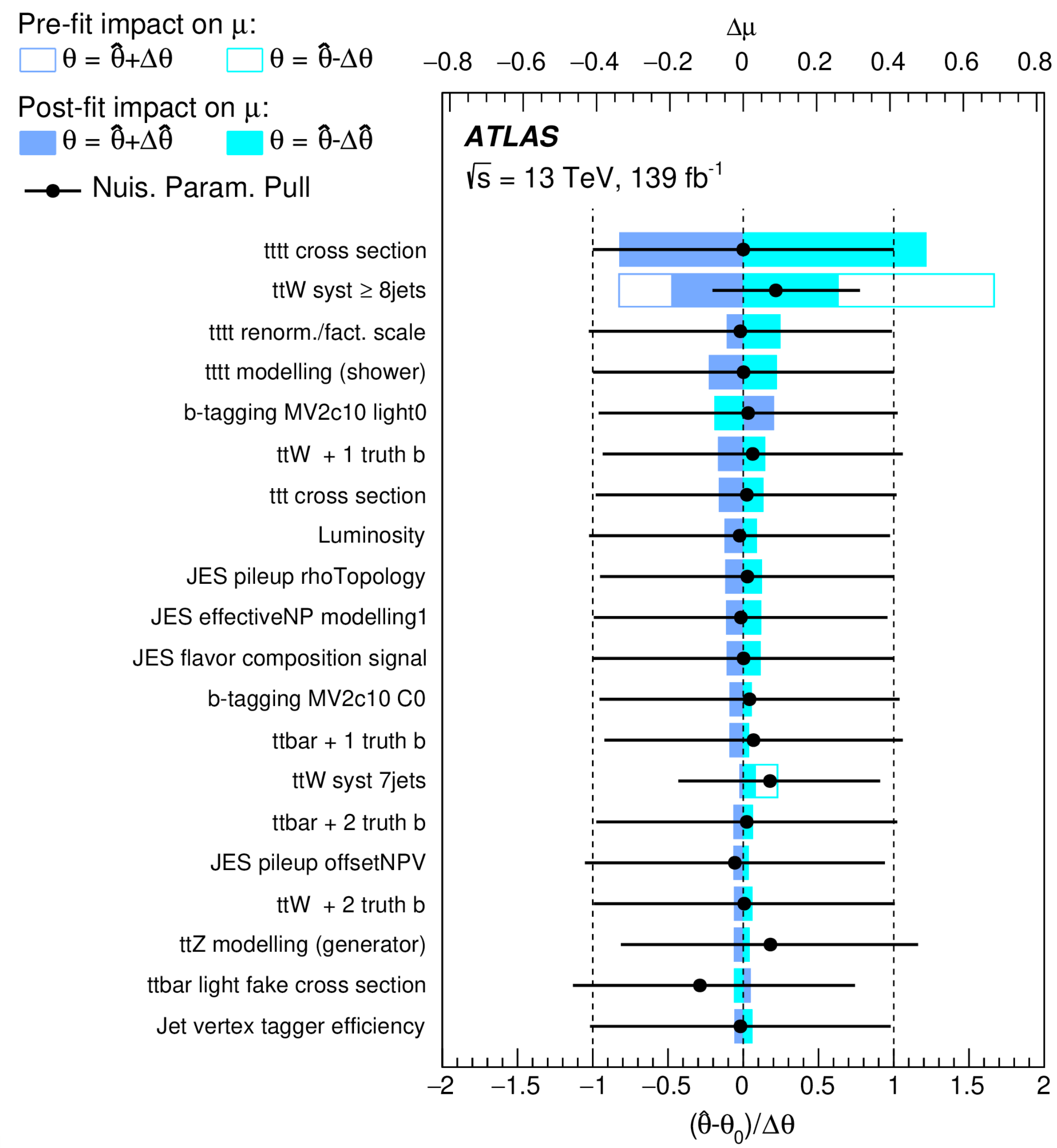
SRs/CRs in 1*l* and 2*l*(OS) channel

- The nuisance parameters ranked according to their post-fit impacts on the best-fit value of μ_{tttt} in the $1l/2l$ (OS) channel (left) and the $2l$ (SS)/$3l$ channel (right).
- Besides the *tttt* cross section uncertainty, different uncertainty sources are dominant for the two channels ⇒ no strong correlations.



arXiv:2103.12603

Fit in $1l/2l$(OS)



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Fit in $2l$(SS)/$3l$

- Summary of ATLAS and CMS measurements of tt+X, X = W, Z, γ (left) and $tttt$ (right) cross sections at $\sqrt{s}$ = 13 TeV.

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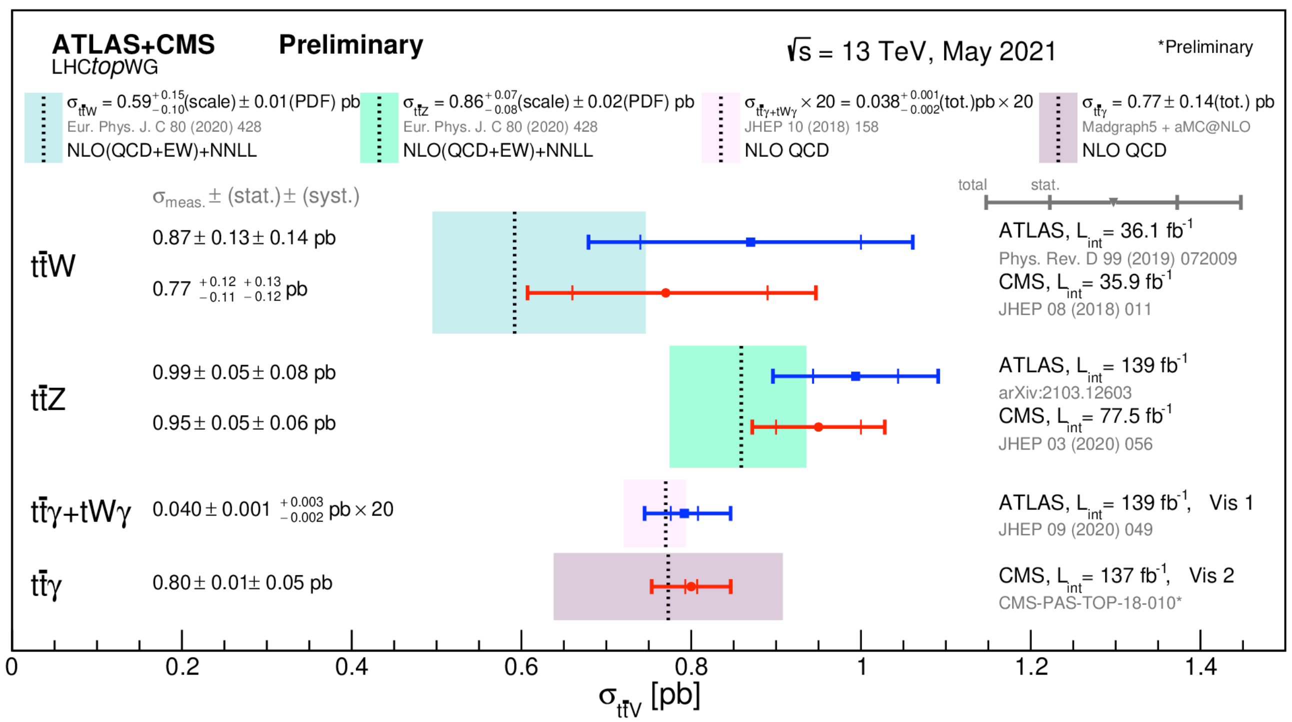

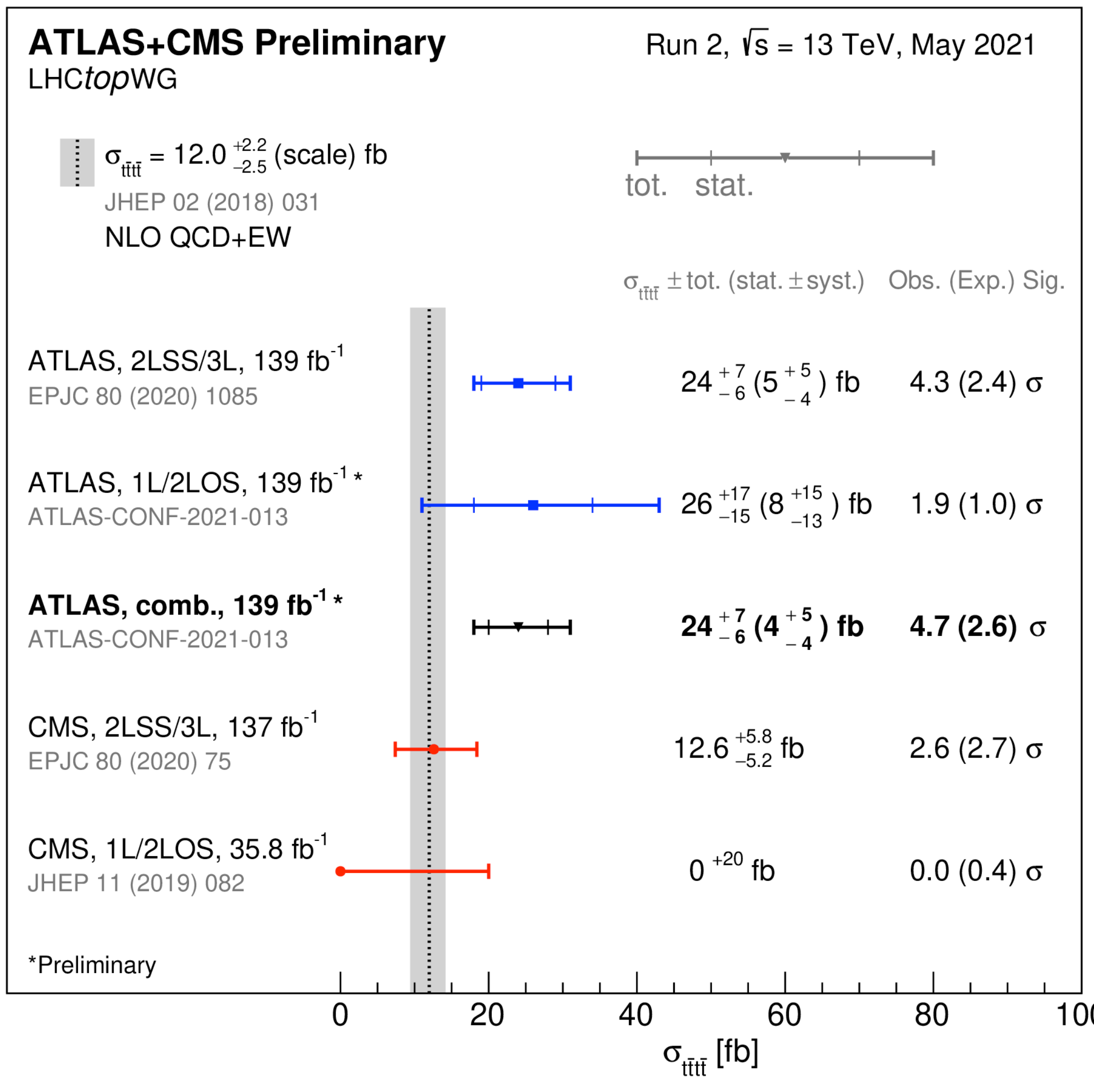

- Custom correction factors to the jet energy scale (JSF) are applied to reduce the default ATLAS JES uncertainties.
  - Left: the distribution of $m_j^{\text{top-tagged}}$ for three example values of the JSF.
  - Middle: the mean of the same distribution as a function of JSF and a linear fit to the simulated samples ⇒ best agreement with data for JSF = 1.0035 ± 0.00087.
  - Right: the m_j distribution observed in data compared to the expected signal and background processes for JSF = 1.

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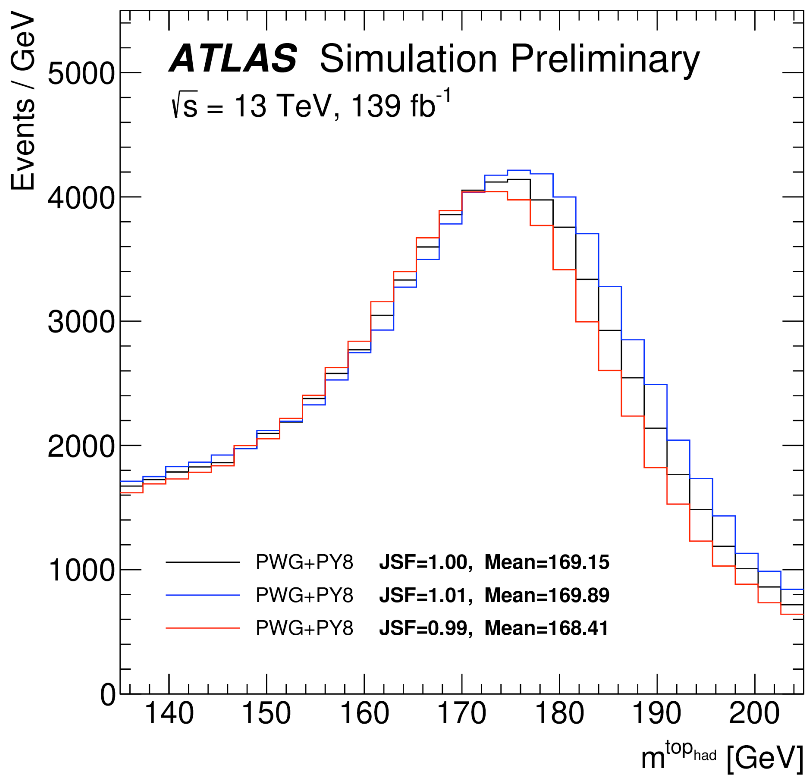

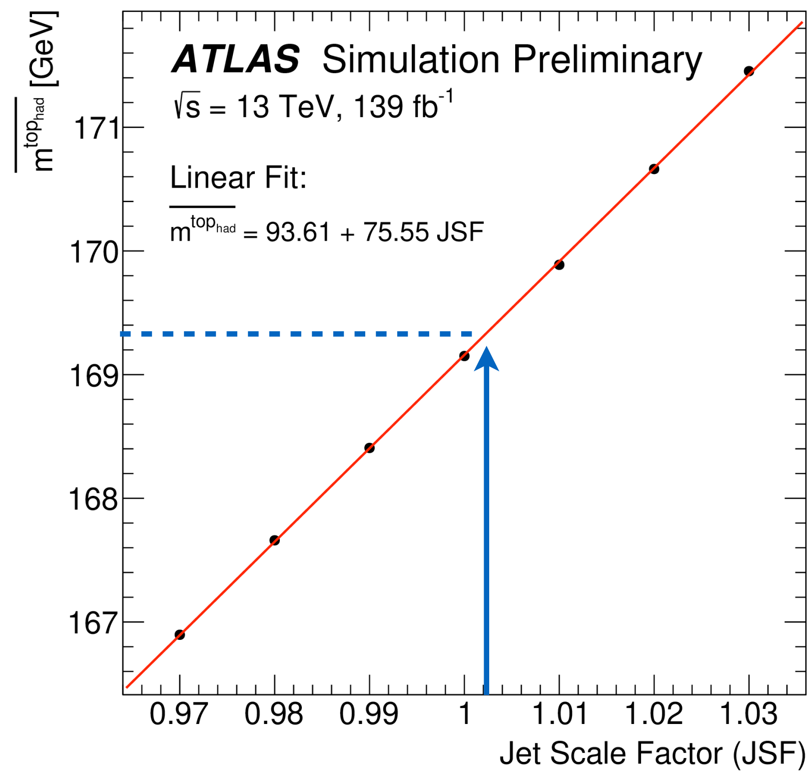

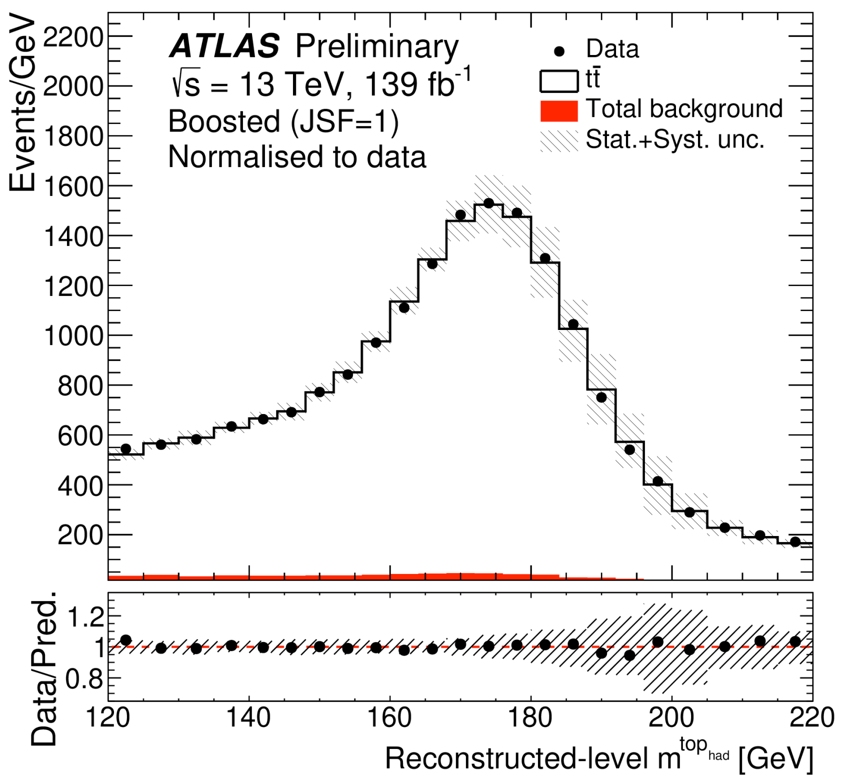

- Breakdown of systematic uncertainties for the inclusive measurement (left) and the differential result, binned in the top quark p_T (top right).
  - Dominant uncertainties: *b*-tagging, hadronisation modelling and luminosity.

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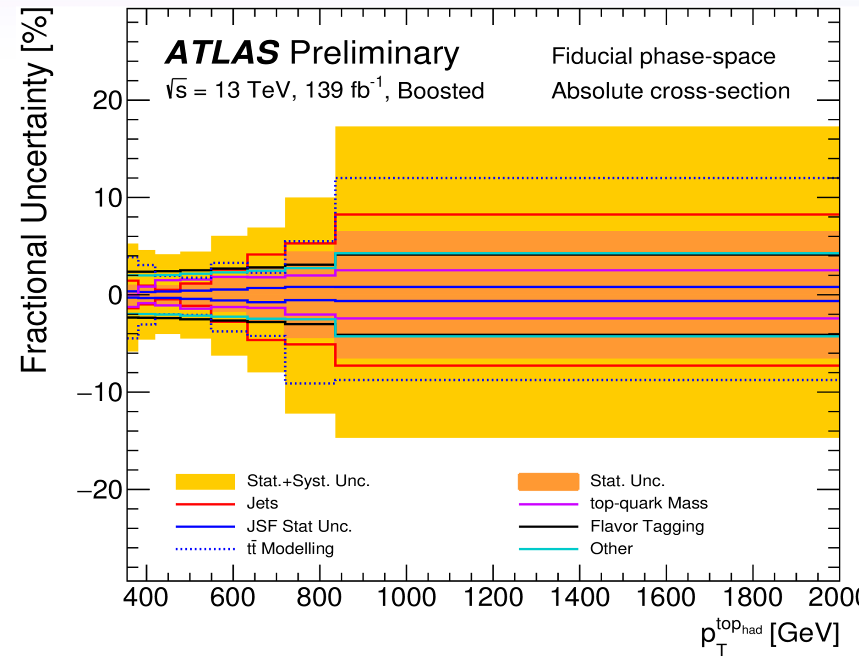
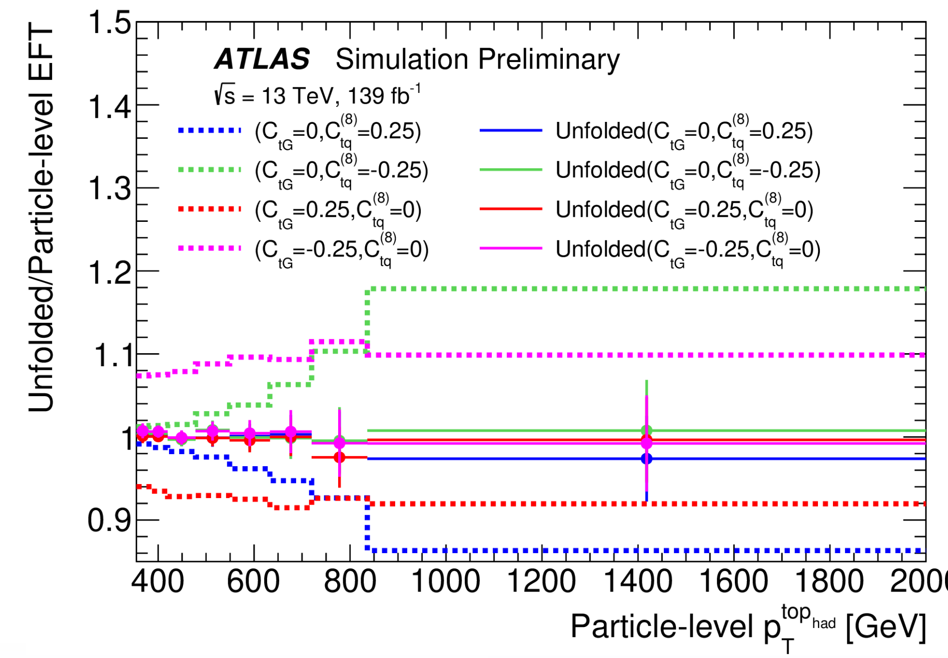
Source	Uncertainty [%]	Uncertainty [%] (no JSF)
Statistical (data)	±0.4	±0.4
JSF statistical (data)	±0.4	—
Statistical (MC)	±0.2	±0.1
Hard scatter	±0.5	±0.8
Hadronisation	±2.0	±1.8
Radiation (IFSR + h_{damp})	+1.0 −1.6	+1.4 −2.3
PDF	±0.1	±0.1
Top-quark mass	+0.8 −1.1	±0.1
Jets	±0.7	±4.2
b-tagging	±2.4	±2.4
Leptons	±0.8	±0.8
E_T^{miss}	±0.1	±0.1
Pileup	±0.4	±0.0
Luminosity	±1.8	±1.8
Backgrounds	±0.7	±0.6
Total systematics	+4.1 −4.3	+5.8 −6.0
Total	+4.1 −4.3	+5.8 −6.0



- Impact of the operators $C_{tq}^{(8)}$, C_{tG} on the particle-level distribution of the top p_T.



- Can evaluate the compatibility between data and the theoretical predictions by computing χ^2/ndf and p-values for differential distributions.
  - Checked for different MC generators setups (variation of parton-shower algorithm and ISR/FSR).
  - Predictions from POWHEG and MADGRAPH5 exist also with extra NNLO(QCD)+NLO(EW) reweighing at parton-level $\Rightarrow$ better agreement with data in most cases.

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Observable	PWG+PY8		PWG+PY8(NNLO WEIGHT)		MC@NLO+PY8		MC@NLO+PY8(NNLO WEIGHT)		PWG+H7		PWG+H7(NNLO WEIGHT)	
	χ^2/NDF	p-value	χ^2/NDF	p-value	χ^2/NDF	p-value	χ^2/NDF	p-value	χ^2/NDF	p-value	χ^2/NDF	p-value
$p_T^{\mathrm{top_{had}}}$	26/8	<0.01	5/8	0.79	18/8	0.03	4/8	0.85	7/8	0.56	3/8	0.94
$p_T^{\mathrm{top_{lep}}}$	78/8	<0.01	28/8	<0.01	144/8	<0.01	10/8	0.27	43/8	<0.01	18/8	0.02
$p_T^{t\bar{t}}$	162/7	<0.01	46/7	<0.01	171/7	<0.01	22/7	<0.01	122/7	<0.01	39/7	<0.01
$H_T^{t\bar{t}+\mathrm{jets}}$	36/7	<0.01	7/7	0.42	17/7	0.02	23/7	<0.01	21/7	<0.01	12/7	0.10
$H_T^{t\bar{t}}$	86/10	<0.01	37/10	<0.01	110/10	<0.01	16/10	0.10	47/10	<0.01	28/10	<0.01
$\lvert y^{\mathrm{top_{had}}}\rvert$	47/17	<0.01	27/17	0.06	37/17	<0.01	23/17	0.15	30/17	0.03	26/17	0.07
$\lvert y^{\mathrm{top_{lep}}}\rvert$	40/14	<0.01	17/14	0.26	29/14	0.01	12/14	0.58	28/14	0.01	19/14	0.16
$\lvert y^{t\bar{t}}\rvert$	30/10	<0.01	8/10	0.58	23/10	0.01	6/10	0.81	14/10	0.19	7/10	0.74
$m^{t\bar{t}}$	52/10	<0.01	24/10	<0.01	81/10	<0.01	7/10	0.74	29/10	<0.01	22/10	0.02
$p_T^{\mathrm{extra_1}}$	115/15	<0.01	38/15	<0.01	413/15	<0.01	194/15	<0.01	143/15	<0.01	69/15	<0.01
$p_T^{\mathrm{extra_2}}$	46/9	<0.01	19/9	0.02	25/9	<0.01	74/9	<0.01	42/9	<0.01	29/9	<0.01
$N^{extrajets}$	32/5	<0.01	12/5	0.03	76/5	<0.01	78/5	<0.01	57/5	<0.01	62/5	<0.01
$\Delta\phi(\mathrm{extra_1}, \mathrm{top_{had}})$	17/9	0.05	8/9	0.53	150/9	<0.01	80/9	<0.01	42/9	<0.01	30/9	<0.01
$\Delta\phi(\mathrm{extra_2}, \mathrm{top_{had}})$	8/9	0.56	5/9	0.84	8/9	0.57	25/9	<0.01	85/9	<0.01	76/9	<0.01
$\Delta\phi(b_{\mathrm{lep}}, \mathrm{top_{had}})$	95/13	<0.01	34/13	<0.01	145/13	<0.01	16/13	0.23	52/13	<0.01	25/13	0.02
$\Delta\phi(\mathrm{top_{lep}}, \mathrm{top_{had}})$	111/5	<0.01	36/5	<0.01	134/5	<0.01	82/5	<0.01	90/5	<0.01	36/5	<0.01
$\Delta\phi(\mathrm{extra_1}, \mathrm{extra_2})$	24/11	0.01	16/11	0.13	31/11	<0.01	69/11	<0.01	237/11	<0.01	215/11	<0.01
$m(\mathrm{extra_1}, \mathrm{top_{had}})$	50/12	<0.01	20/12	0.06	221/12	<0.01	48/12	<0.01	41/12	<0.01	19/12	0.08
$p_T^{\mathrm{extra_1}}$ vs $N^{extrajets}$	355/21	<0.01	205/21	<0.01	633/21	<0.01	316/21	<0.01	263/21	<0.01	159/21	<0.01
$p_T^{\mathrm{extra_1}}$ vs $p_T^{\mathrm{top_{had}}}$	115/17	<0.01	53/17	<0.01	383/17	<0.01	152/17	<0.01	121/17	<0.01	74/17	<0.01
$\Delta\phi(\mathrm{extra_1}, \mathrm{top_{had}})$ vs $p_T^{\mathrm{top_{had}}}$	69/21	<0.01	43/21	<0.01	427/21	<0.01	223/21	<0.01	78/21	<0.01	60/21	<0.01
$\Delta\phi(\mathrm{extra_1}, \mathrm{top_{had}})$ vs $N^{extrajets}$	109/19	<0.01	64/19	<0.01	545/19	<0.01	250/19	<0.01	85/19	<0.01	60/19	<0.01

- Left: extracted values for the different components of the top quark/antiquark polarisation vectors $P = \{P_{x'}, P_{y'}, P_{z'}\}$, together with background normalisations from the CRs.
- Right: statistical and systematic uncertainties (grouped by categories) in the measurement of the polarisation-components for top quarks/antiquarks.

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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)

Uncertainty source	$\Delta P^{t}_{x'}$	$\Delta P^{\bar{t}}_{x'}$	$\Delta P^{t}_{y'}$	$\Delta P^{\bar{t}}_{y'}$	$\Delta P^{t}_{z'}$	$\Delta P^{\bar{t}}_{z'}$
Modelling						
Modelling (t-channel)	±0.037	±0.051	±0.010	±0.015	±0.061	±0.061
Modelling ($t\bar{t}$)	±0.016	±0.021	±0.004	±0.016	±0.003	±0.016
Modelling (other)	±0.013	±0.031	±0.003	±0.006	±0.026	±0.043
Experimental						
Jet energy scale	±0.045	±0.048	±0.005	±0.007	±0.033	±0.025
Jet energy resolution	±0.166	±0.185	±0.021	±0.040	±0.070	±0.130
Jet flavour tagging	±0.004	±0.002	<0.001	±0.001	±0.007	±0.009
Other experimental uncertainties	±0.015	±0.029	±0.002	±0.007	±0.014	±0.026
Multijet estimation	±0.008	±0.021	<0.001	±0.001	±0.008	±0.013
Luminosity	±0.001	±0.001	<0.001	<0.001	<0.001	<0.001
Simulation statistics	±0.020	±0.024	±0.008	±0.015	±0.017	±0.031
Total systematic uncertainty	±0.174	±0.199	±0.025	±0.048	±0.096	±0.153
Total statistical uncertainty	±0.017	±0.025	±0.011	±0.017	±0.022	±0.034

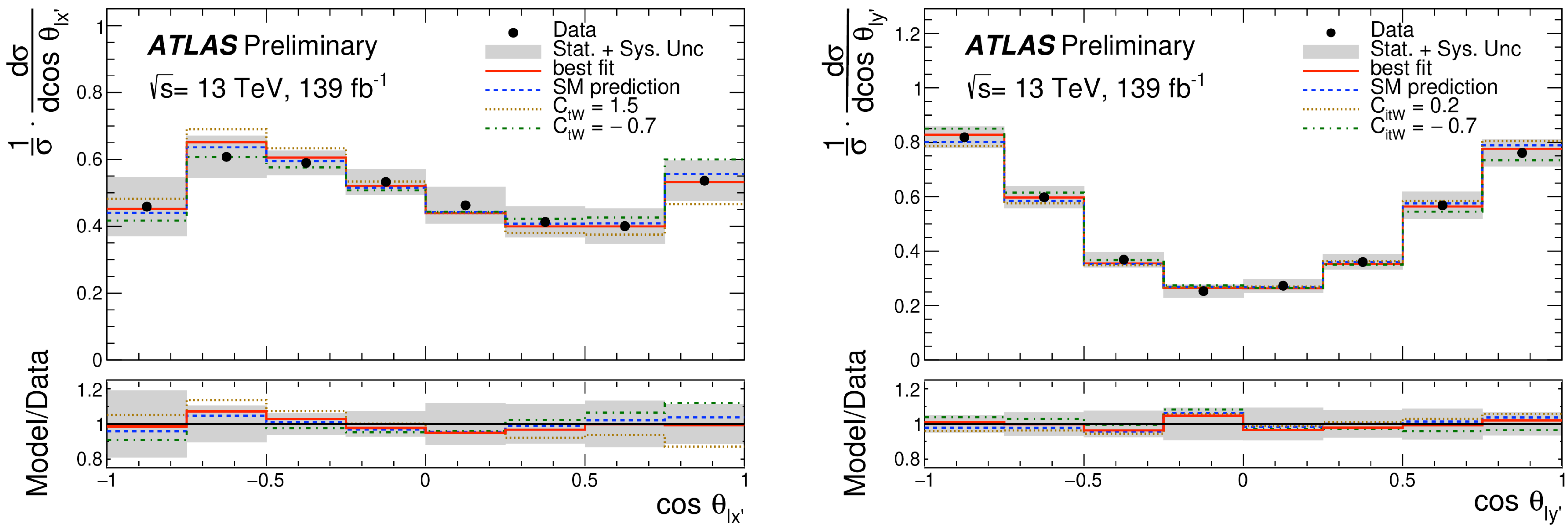
Single-top polarisation: Data-compatibility and EFT impact

- Compatibility between the SM prediction and data for the unfolded differential distributions of $\cos\theta_{lx'}$, $\cos\theta_{ly'}$ and $\cos\theta_{lz'}$ (χ^2/ndf and p-values).

Angular variable	χ^2/NDF	p-value
$\cos\theta_{\ell x'}$	1.53/7	0.98
$\cos\theta_{\ell y'}$	4.25/7	0.75
$\cos\theta_{\ell z'}$	2.98/3	0.39

- Impact of C_{tW} and C_{itW} on the unfolded spectra of $\cos\theta_{lx'}$ and $\cos\theta_{ly'}$ $\Rightarrow$ the particle-level prediction from the SM (■) can be compared to the result from the best-fit values of C_{tW} and C_{itW} (■).

ATLAS-CONF-2021-027



Particle-level distributions of $\cos\theta_{lx'}$ (left) ad $\cos\theta_{ly'}$ (right)