



New results on ttW and 4-top production with the ATLAS experiment

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On behalf of ATLAS Collaboration

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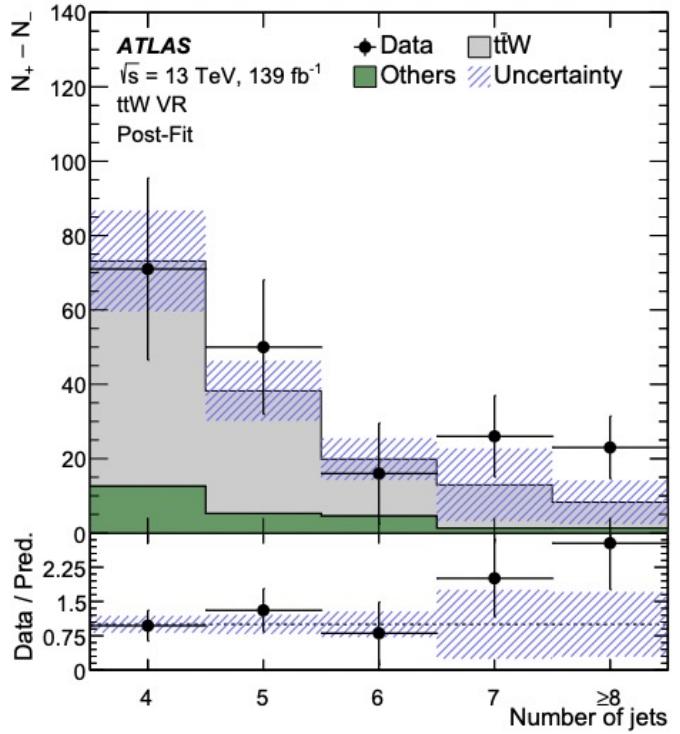
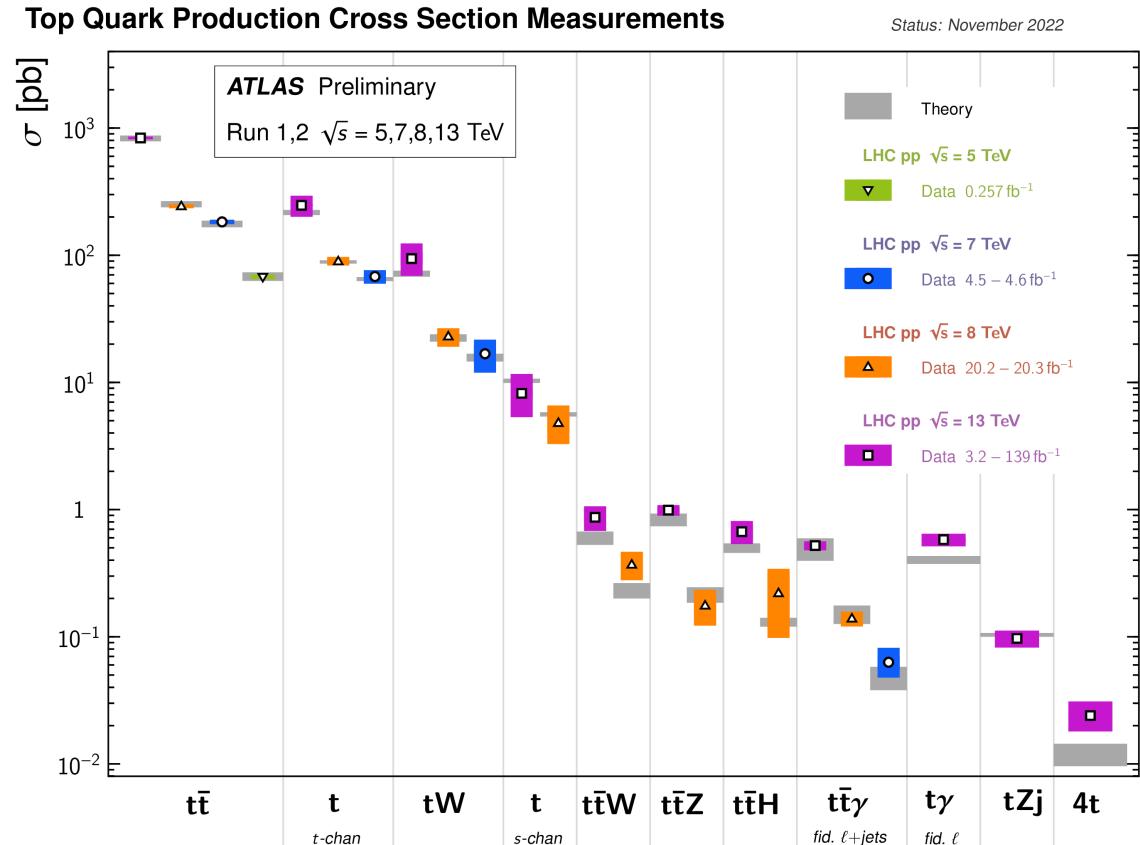


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Rare Top Quark Production Process

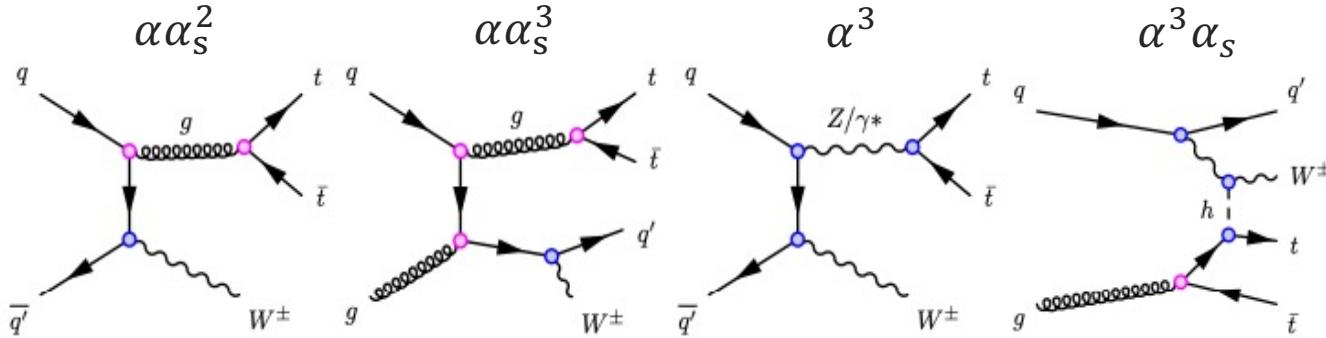
- Rare top quark production is a good approach to finding new physics: like 4 top and ttH production process
- Inside ttW can be the dominant background for these precise measurements of these rare process
- In the previous tttt analysis, ttW modeling has been a large source of uncertainty



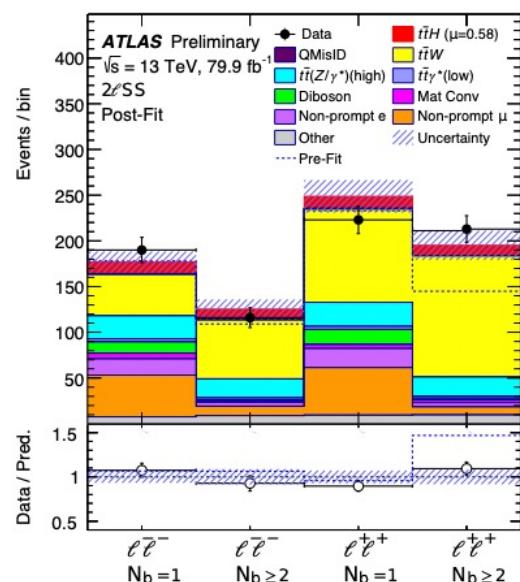
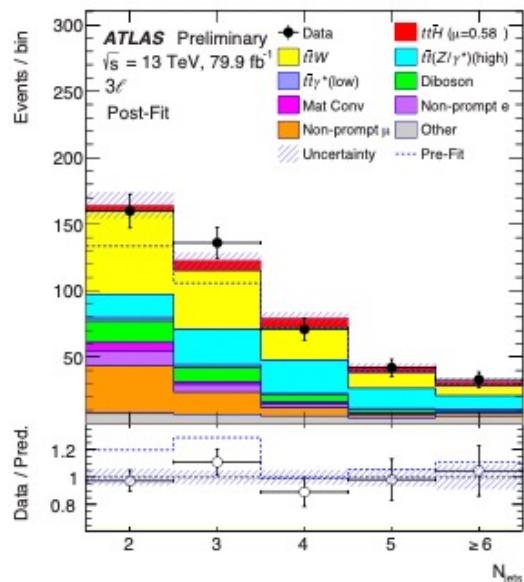


ttW Production

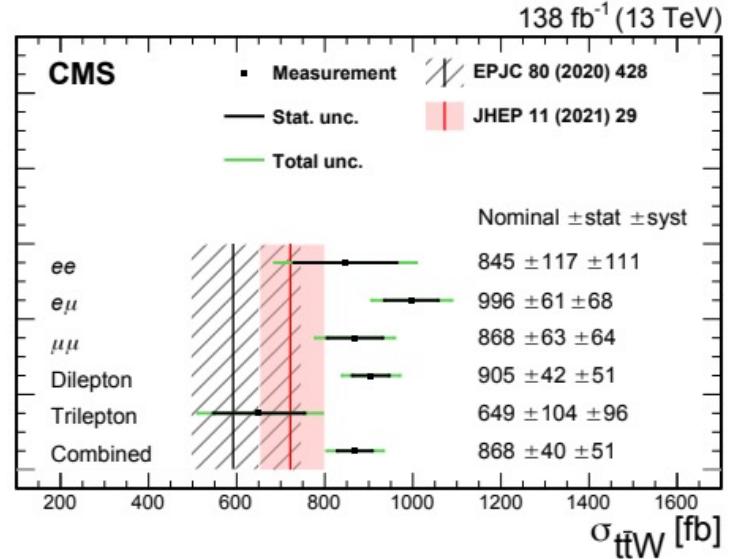
- Theoretical modeling: many production mechanics:
 - Charge-asymmetric production from PDF
 - Complex NLO QCD and EW corrections
- Theory Predictions:
 - NLO + NNL : 606 fb \pm 7% [[JHEP 08\(2019\)039](#)]
 - NLO + FxFx : 722 fb \pm 10% [[JHEP 11 \(2021\) 029](#)]
- ATLAS and CMS both get 20%- 50% higher cross section than SM predictions



[ATLAS_CONF-2019-045](#)



[arXiv: 2208.06485](#)





Measurement of the ttW XS with Full Run 2 Data

Measure inclusive, fiducial, and differential cross sections of ttW in multi-lepton final state with full Run2 data

Multilepton channel:

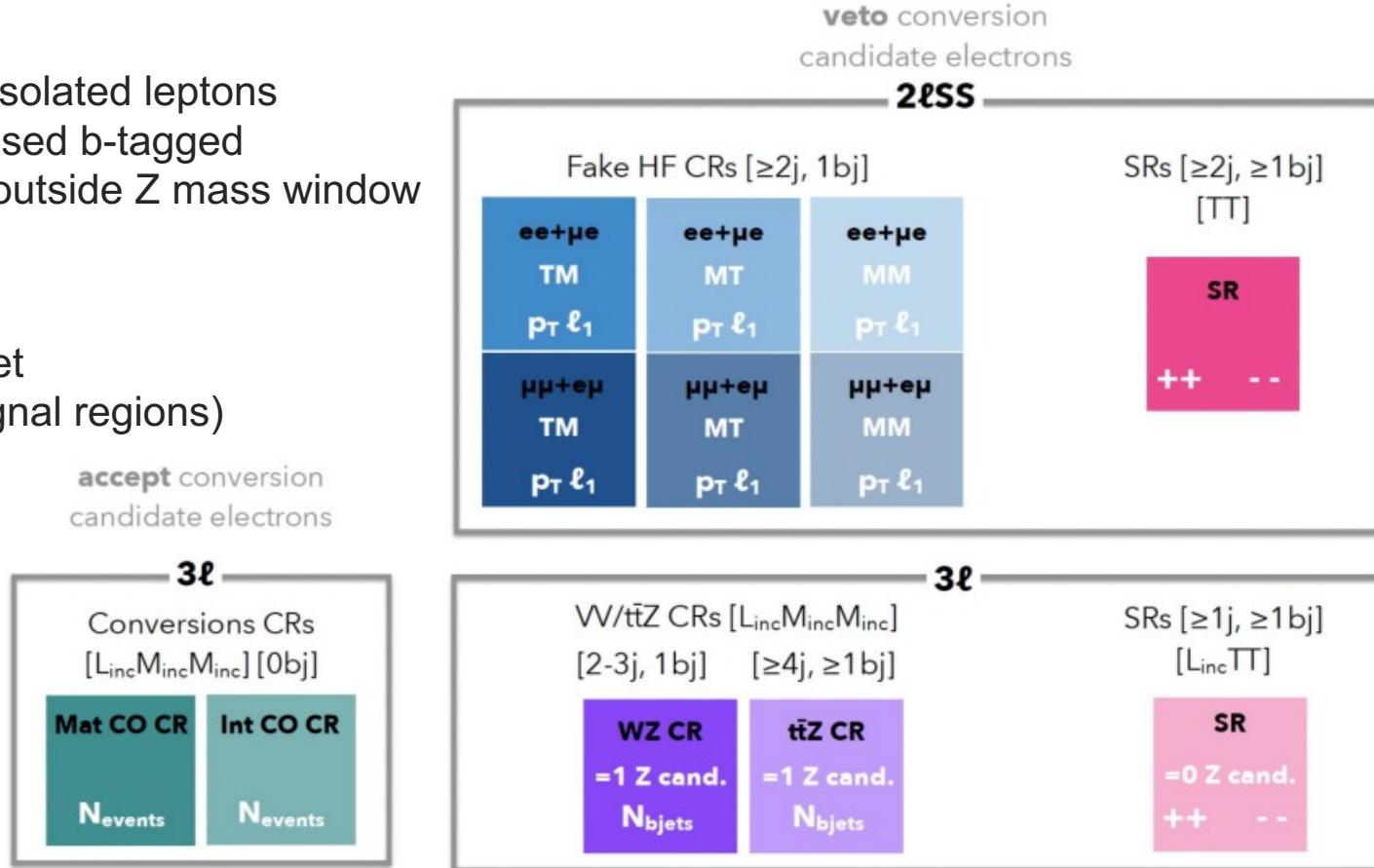
- 2 isolated leptons with same charge or at least 3 isolated leptons
- At least 2 jets, one is tight b-tagged or two are loosed b-tagged
- 3L channel: dilepton or trilepton invariance mass outside Z mass window

Signal region:

- split by lepton charges, lepton flavors, jet, and b-jet multiplicities: 56 signal regions (48 2 ℓ SS + 8 3 ℓ signal regions)

Main backgrounds:

- Physical background: ttZ, diboson(WZ)
- Instrumental backgrounds:
 - Charge misidentified electron
 - Events with non-prompt or fake leptons





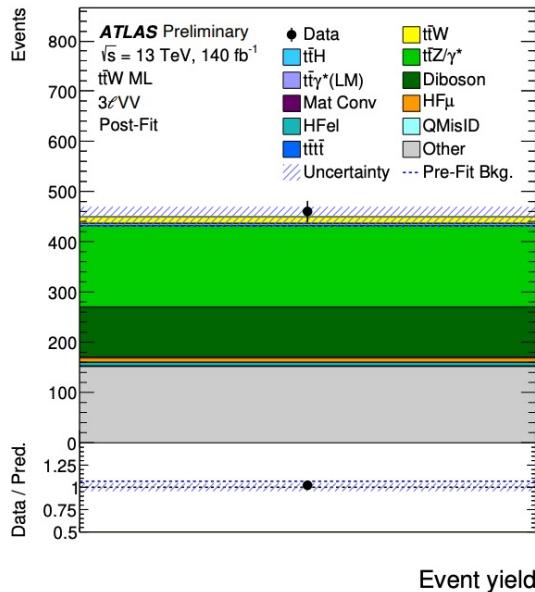
Backgrounds Estimation in ttW Measurement

ttZ and diboson backgrounds

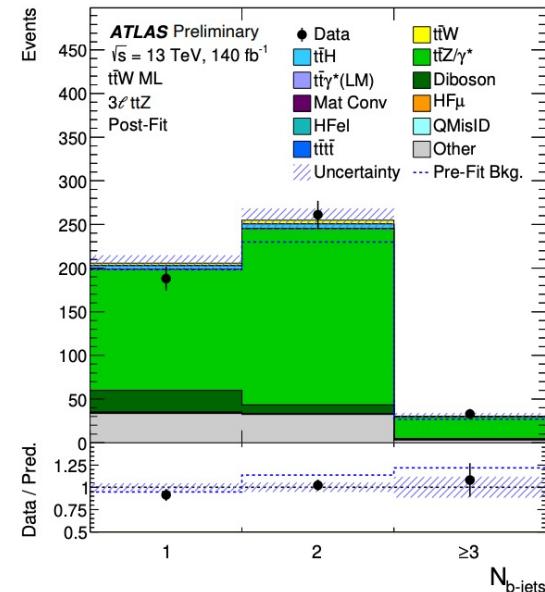
Two control regions with

- Different jet multiplicity
- Invariant mass with the same flavour dilepton pair near the Z peak

$$NF_{VV} = 0.87 \pm 0.33$$



$$NF_{t\bar{t}Z} = 1.16 \pm 0.15$$



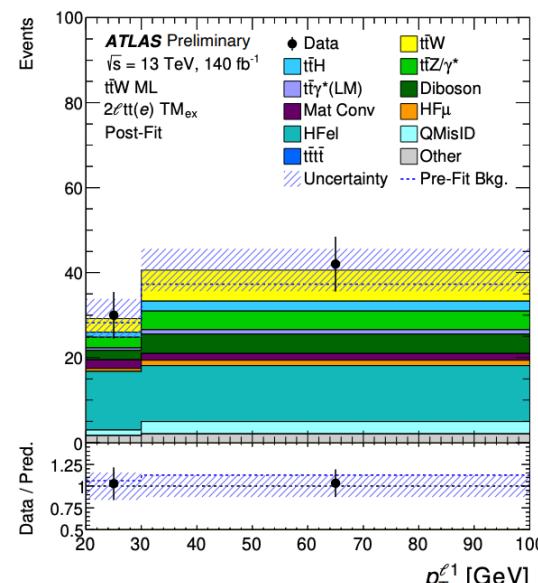
Fake and non-prompt backgrounds

- Control regions for conversions: use electron track reconstructed displaced vertex to split internal/material conversions
- Control regions for heavy flavour non-prompt leptons: based on exclusive medium lepton ID requirements

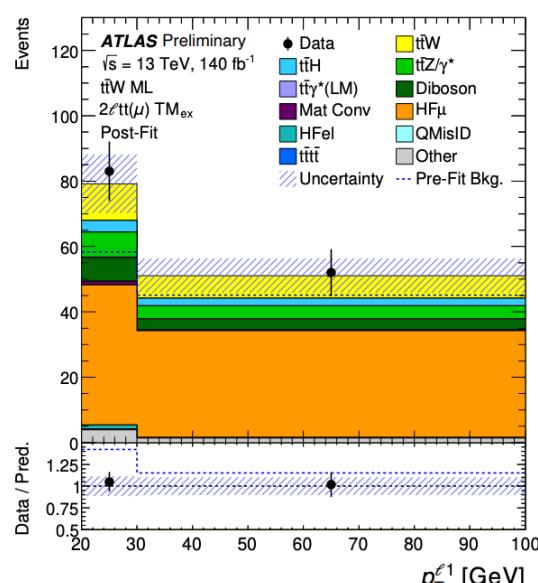
$$NF_{low~m\gamma^*} = 1.07 \pm 0.24$$

$$NF_{Mat.ConV.} = 1.15 \pm 0.31$$

$$NF_{HFe} = 0.83 \pm 0.31$$



$$NF_{HF\mu} = 0.83 \pm 0.31$$





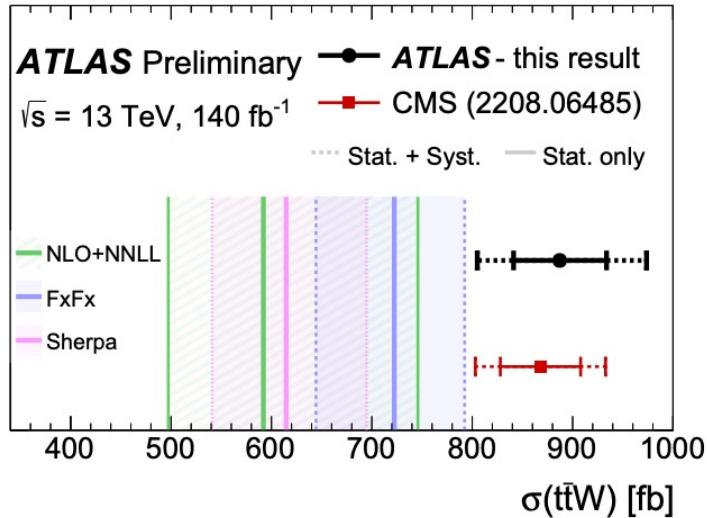
Inclusive ttW Cross Sections

- Simultaneous profile likelihood fit to data using event yields in 56 SRs and 10 CRs

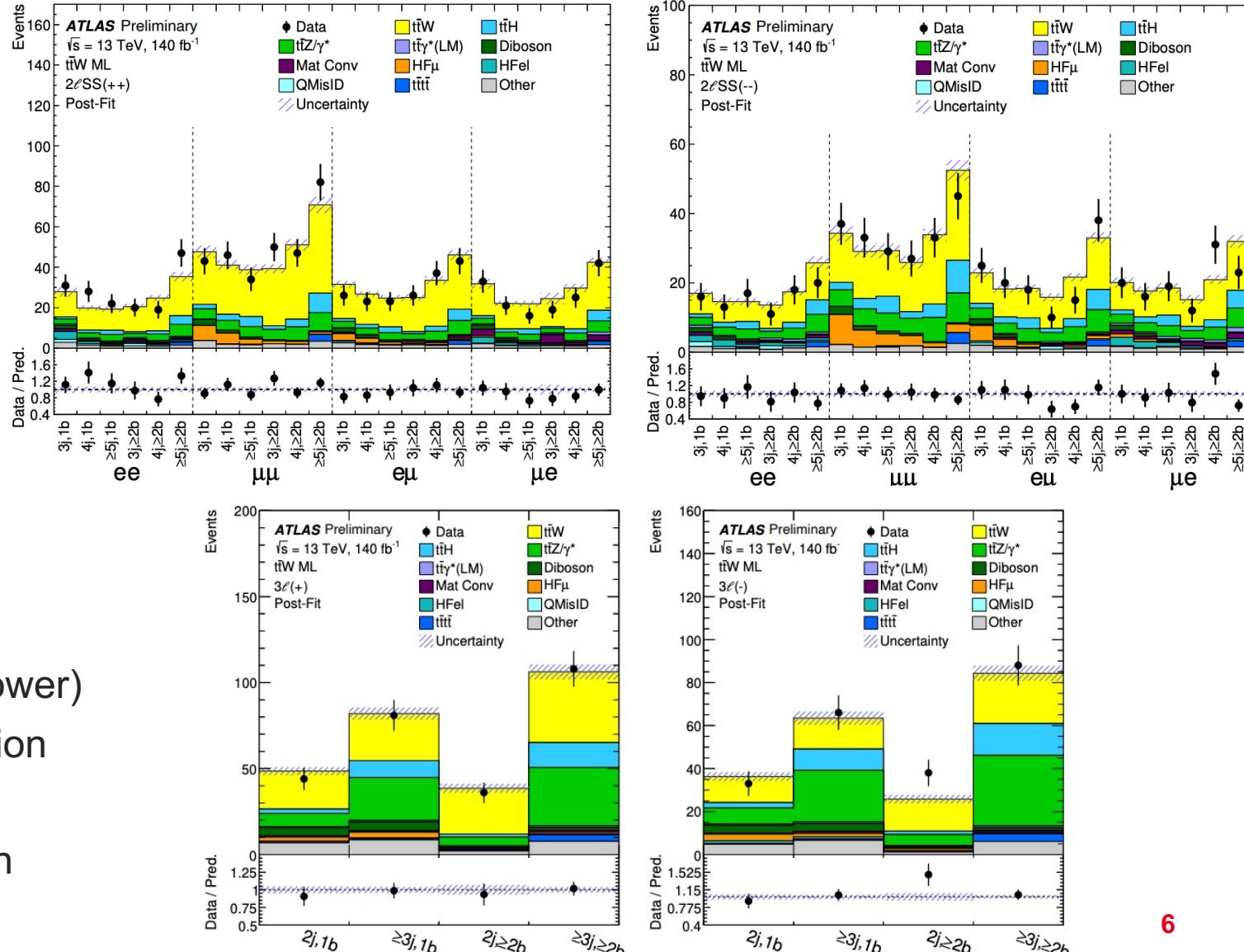
[ATLAS-CONF-2023-019](#)

$$\sigma(t\bar{t}W) = 890 \pm 50(\text{stat}) \pm 70(\text{syst}) \text{ fb}$$

consistent at 1.5σ of the theory ($722 \text{ fb} \pm 10\%$)



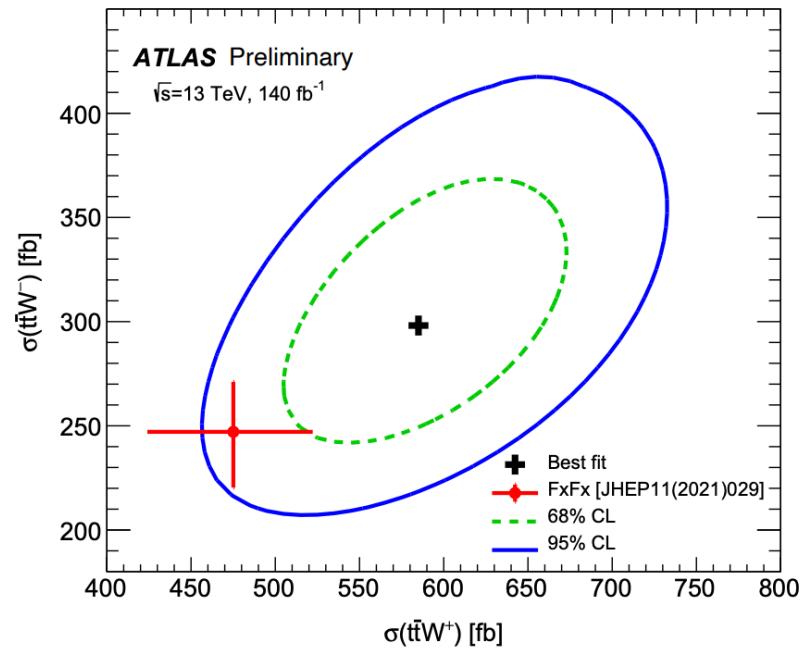
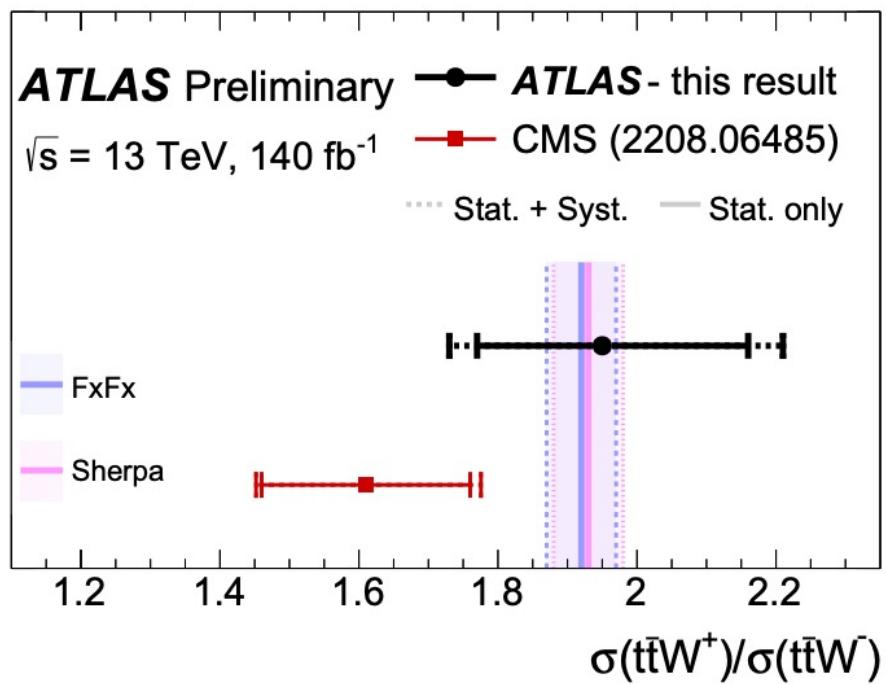
- Main systematic uncertainties:
 - ttW modeling (generator, parton shower)
 - ttH, four-top background normalization
 - b-tagging
 - non-prompt isolation BDT calibration





Cross Section Ratio and Charge Asymmetry

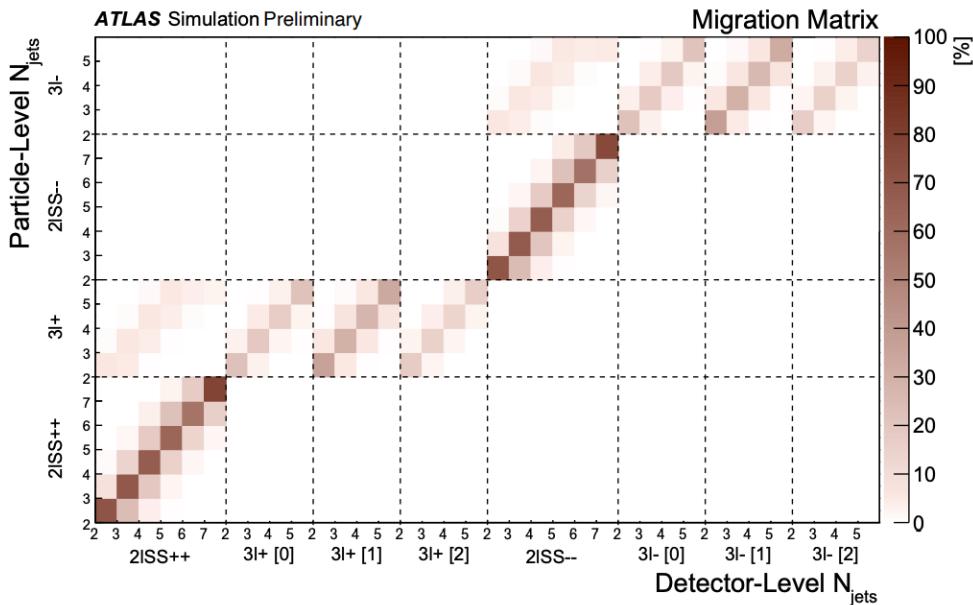
- Ratio of $t\bar{t}W^+$ and $t\bar{t}W^-$ production rate: $\frac{\sigma(t\bar{t}W^+)}{\sigma(t\bar{t}W^-)} = 1.95^{+0.26}_{-0.22}$ (stat + syst) , consistent with the MC prediction
- The measured value of relative charge asymmetry: $A_C^{\text{rel}} = \frac{\sigma(t\bar{t}W^+) - \sigma(t\bar{t}W^-)}{\sigma(t\bar{t}W^-) + \sigma(t\bar{t}W^+)} = 0.32 \pm 0.06$ (tot), is in good agreement with the theory prediction (Sherpa, 0.322 ± 0.003 (scale) ± 0.007 (PDF))



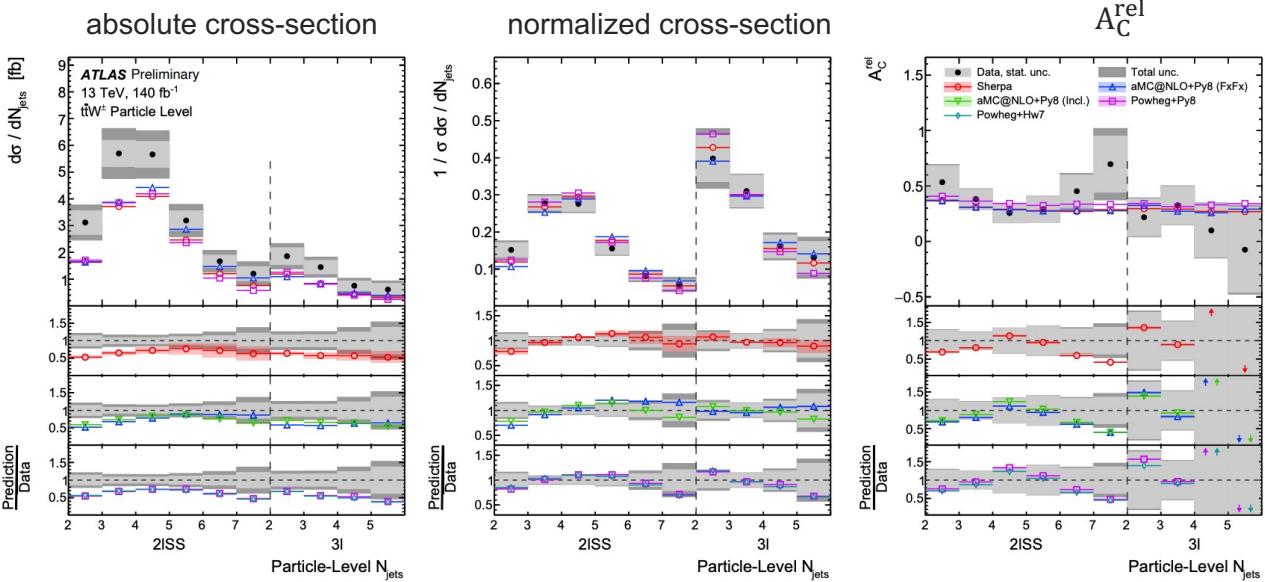


ttW Differential XS Measurement

- Profile likelihood unfolding to measure differential cross-sections at particle level in the fiducial phase-space for one observable at a time
- Same background model and CRs included in the fit
- Good agreement of unfolded data with all MC setups

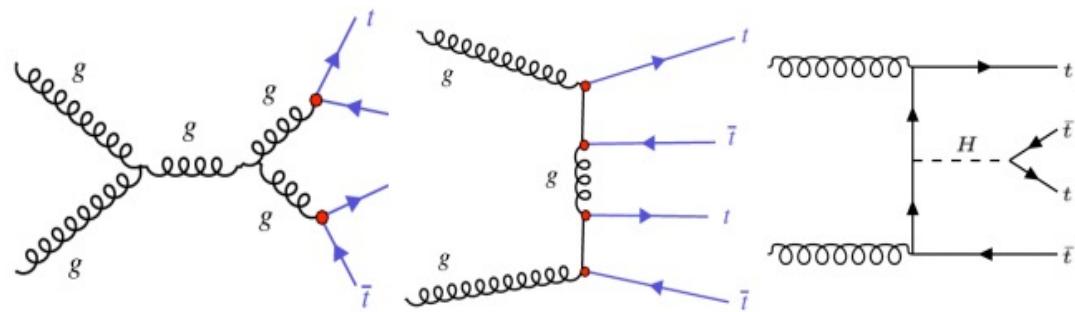


Variable	Definition
N_{jets}	Number of selected jets with $p_T > 25 \text{ GeV}$ and $ \eta < 2.5$
H_T, jets	Scalar sum of the transverse momenta of selected jets with $p_T > 25 \text{ GeV}$ and $ \eta < 2.5$
H_T, lep	Scalar sum of the transverse momenta of selected leptons
$\Delta R_{\text{lb}, \text{lead}}$	Angular distance between the leading lepton and the leading b -tagged jet
$ \Delta\phi_{\text{ll}, \text{ss}} $	Absolute azimuthal separation between the two leptons of the same-sign pair
$ \Delta\eta_{\text{ll}, \text{ss}} $	Absolute pseudo-rapidity separation between the two leptons of the same-sign pair
$M_{\text{jj}, \text{lead}}$	Invariant mass of the two leading jets with $p_T > 25 \text{ GeV}$ and $ \eta < 2.5$

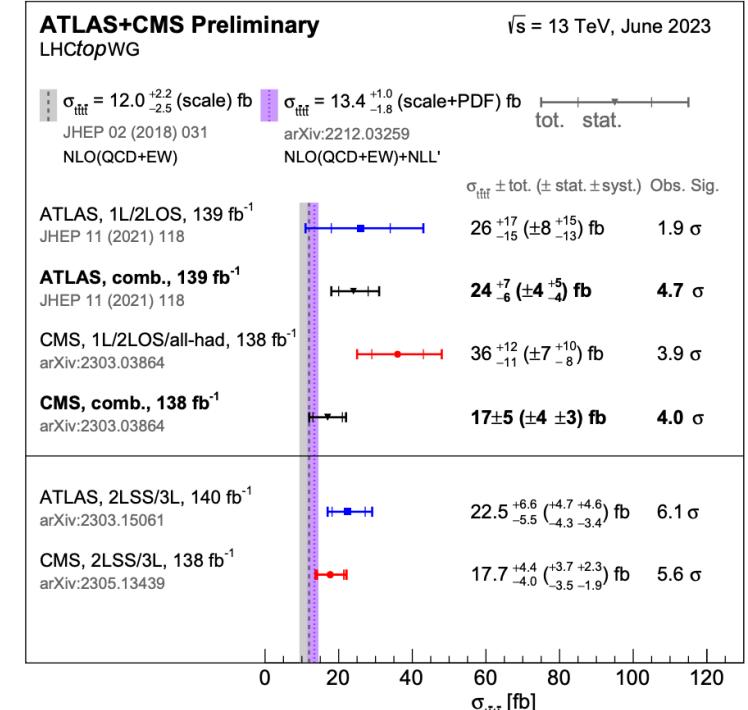
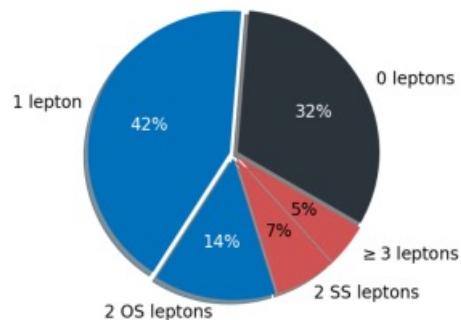


Four Top Quark Production

- $t\bar{t}t\bar{t}$ production is a rare top quark process predicted in the SM. It is one of the heaviest final states accessible at LHC
 - NLO (QCD+EWK): $\sigma(t\bar{t}t\bar{t}) = 12 \text{ fb} \pm 20\%$ [JHEP 02 (2018) 031]
 - NLO+NLL: $\sigma(t\bar{t}t\bar{t}) = 13.4 \text{ fb} \pm 11\%$ [arXiv:2212.03259]



- $t\bar{t}t\bar{t}$ cross section is sensitive to anomalous top Yukawa coupling and Higgs CP properties
- A sensitive probe for new physics, such as EFT, 2HDM model

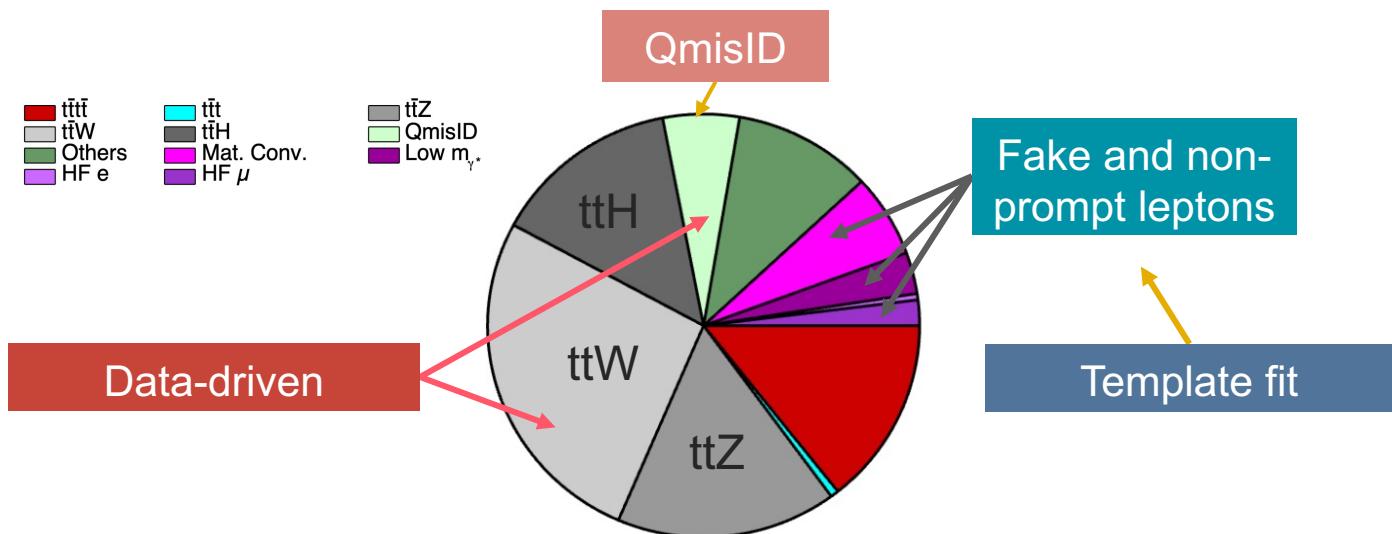
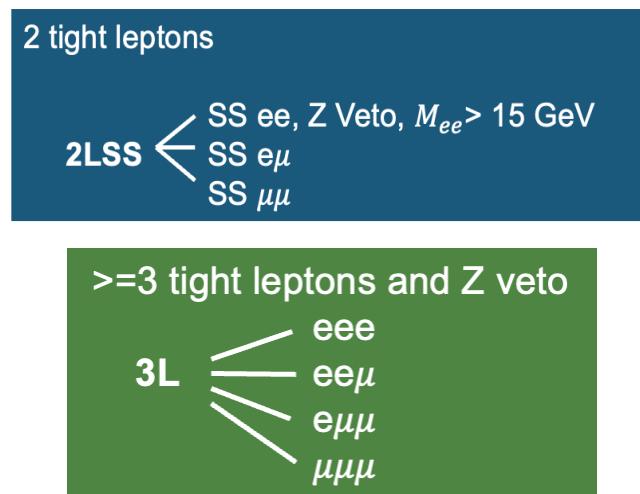


- $t\bar{t}t\bar{t}$ will decay into $W+W-W+W-b\bar{b}b\bar{b}$. Depending on the decay mode of the W bosons, it could lead to the following final states:
 - 2 lepton same-sign / 3 leptons (2LSS / 3L)
 - 1 lepton only / 2 lepton opposite sign (1L / 2LOS)



Four Top Process Signatures and Backgrounds

- Multi-lepton channel: the most sensitive channel with small backgrounds
 - High jet and b-jet multiplicity
 - Small branching ratio (~12%)
- Signal region selection:
 - ≥ 6 jets ≥ 2 b-jets
 - $HT = \sum pT(\text{lepton}) + \sum pT(\text{jets}) \geq 500$ GeV





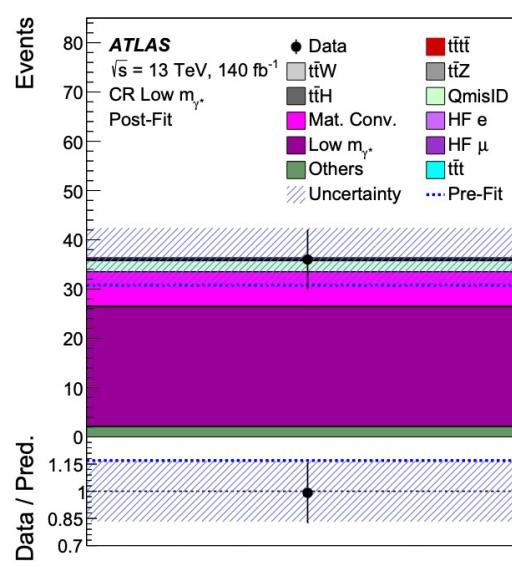
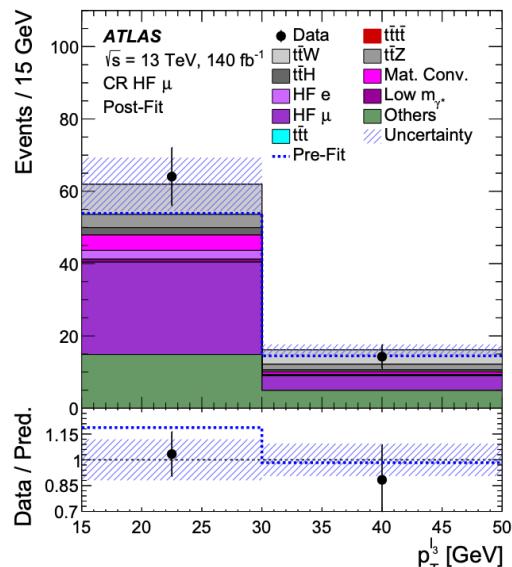
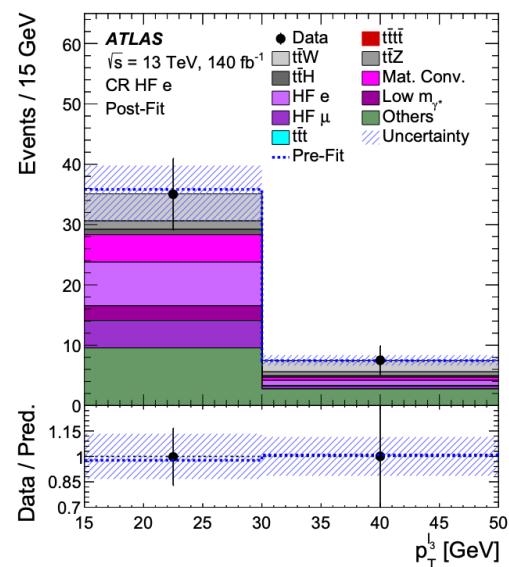
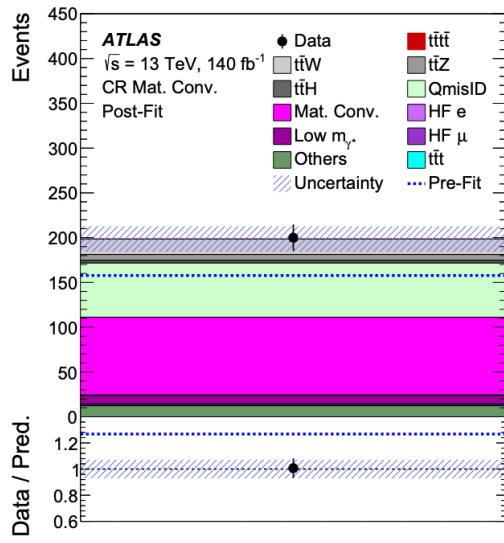
Fake/non-prompt and QmisID Backgrounds

Fake/non-prompt backgrounds

- Define regions enriched in the following background processes to estimate normalization factors
 - Heavy flavor electron and heavy flavor muon
 - Material conversions
 - Virtual photon conversion

Charge misidentification backgrounds

- Applying charge flip rate from data



	NF _{Mat. Conv.}	NF _{Low m_{γ^*}}	NF _{HF e}	NF _{HF μ}
	$1.80^{+0.47}_{-0.41}$	$1.08^{+0.37}_{-0.31}$	$0.66^{+0.75}_{-0.46}$	$1.27^{+0.53}_{-0.46}$



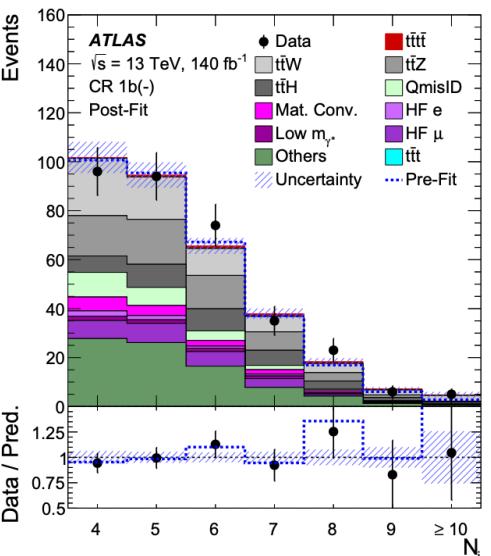
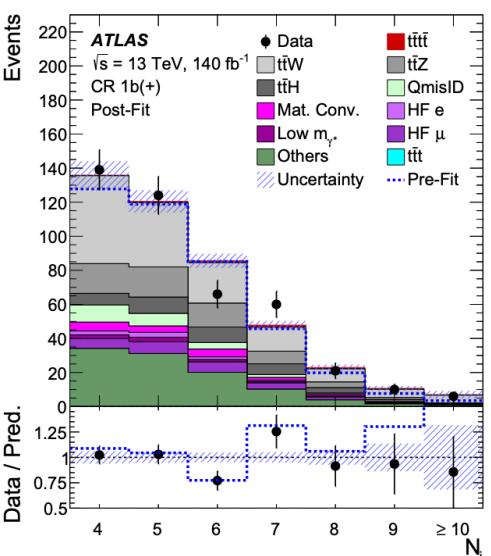
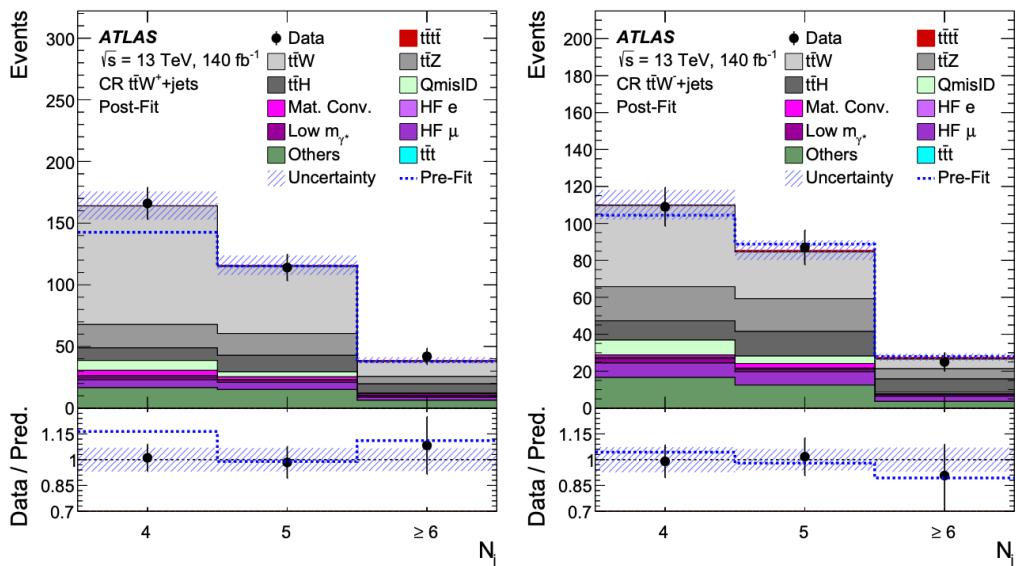
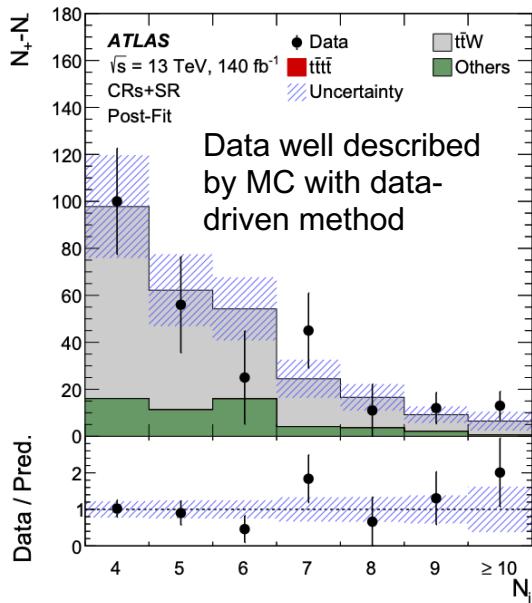
ttW background: Data-Driven Method

- ttW contribution per jet bin parameterized as:

$$NF_{\bar{t}W@n_j} = NF_{\bar{t}W^+@4j} \times \prod_{n'=4}^{n'=n-1} [a_0 + \frac{a_1}{1 + (n' - 4)}] + NF_{\bar{t}W^-@4j} \times \prod_{n'=4}^{n'=n-1} [a_0 + \frac{a_1}{1 + (n' - 4)}].$$

- Derive the free parameters from ttW and 1b control regions with charge split
- Fitted ttW in tttt is compatible with the measurement in the previous pages

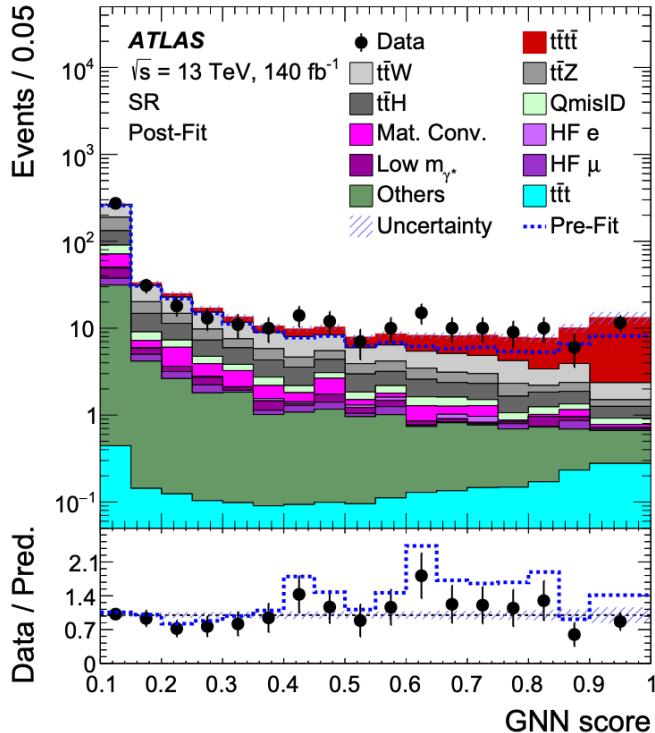
$t\bar{t}W$ background	a_0	a_1	$NF_{t\bar{t}W^+(4jet)}$	$NF_{t\bar{t}W^-(4jet)}$
Value	0.51 ± 0.10	$0.22^{+0.25}_{-0.22}$	$1.27^{+0.25}_{-0.22}$	$1.11^{+0.31}_{-0.28}$





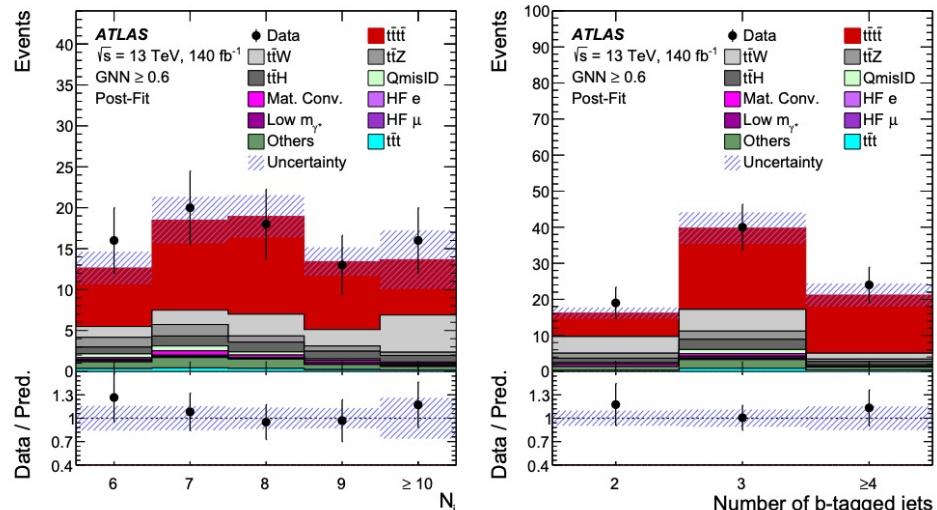
Four Top Cross Section Results

- Use Graph neural network (GNN) to separate signal from backgrounds
- Perform a maximum-likelihood fit to the GNN score distribution in SR and distributions in 8 CRs
- The observed significance is **6.1** sigma: **the first observation of 4top production!**



$$\mu = 1.9 \pm 0.4(\text{stat})^{+0.7}_{-0.4}(\text{syst}) = 1.9^{+0.8}_{-0.5}$$

$$\sigma_{t\bar{t}t\bar{t}} = 22.5^{+4.7}_{-4.3}(\text{stat})^{+4.6}_{-3.4}(\text{syst}) \text{ fb} = 22.5^{+6.6}_{-5.5} \text{ fb}$$



Setups	Significance(σ)	
	Realistic	Observed
Realistic	4.3 (12fb)/ 4.7(13fb)	6.1
Realistic (evidence)	2.69	
Data obs (evidence)		4.3

- The largest uncertainties come from 4top modeling and the data-driven ttW parameters
- Good agreement in high GNN regions with data and MC

The improvements (from 4.7σ to 6.1σ) come from:

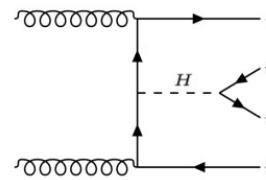
- Updated lepton and jet selections
- Use of the GNN discriminant
- Better modeling of the ttt backgrounds



New Physics Interpretations

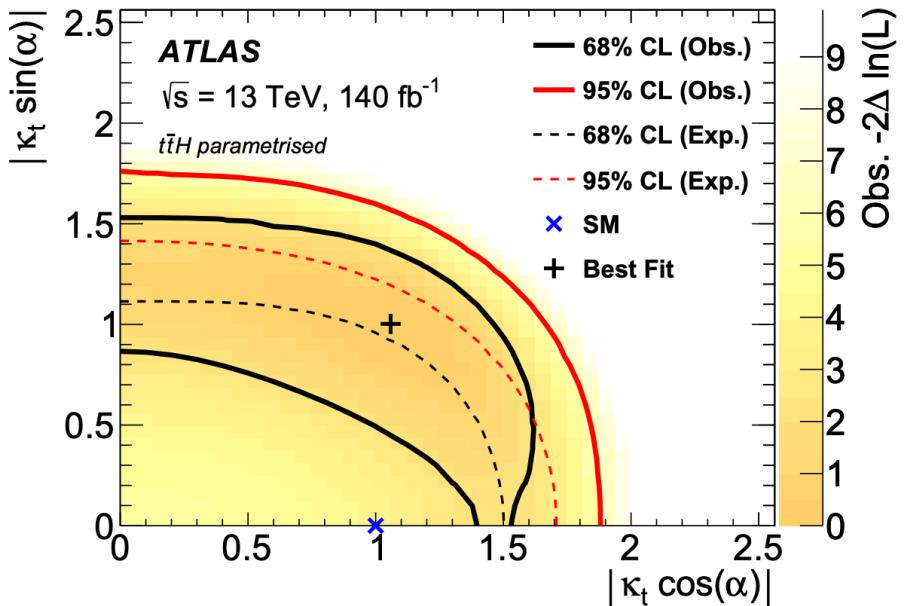
Top Youkawa Coupling

- Four top production is sensitive to measure the top-Higgs Yukawa coupling and its XS can be enhanced by the CP-odd coupling parameters
- CP even: obs (exp) $|\kappa_t| < 1.8(1.6)$ ($t\bar{t}H$ parameterised with k_t)
- CP even: obs (exp) $|\kappa_t| < 2.2(1.8)$ ($t\bar{t}H$ free floated)



$$\mathcal{L} = -\frac{1}{\sqrt{2}} \kappa_t \bar{t} (\cos(\alpha) + i \sin(\alpha) \gamma_5) t h$$

CP even CP odd



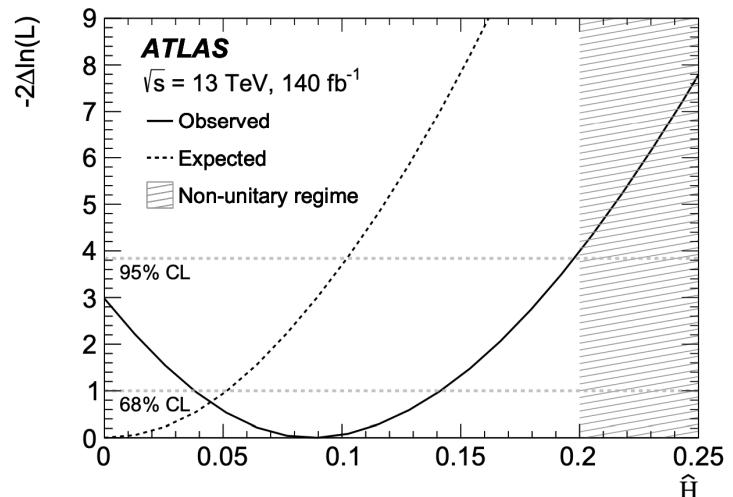
EFT parameters:

- Four top production is sensitive to heavy flavor fermion operators in EFT framework
- It also is sensitive to self-energy correction of the Higgs boson \hat{H} that affects off-shell Higgs interaction ($\hat{H}=0$ in the SM)

Limits on EFT operators sensitive to four top production (one operator at a time)

Operators	Expected C_i/Λ^2 [TeV $^{-2}$]	Observed C_i/Λ^2 [TeV $^{-2}$]
$O_{Q\bar{Q}}^1$	[-2.4, 3.0]	[-3.5, 4.1]
O_{Qt}^1	[-2.5, 2.0]	[-3.5, 3.0]
O_{tt}^1	[-1.1, 1.3]	[-1.7, 1.9]
$O_{Q\bar{t}}^8$	[-4.2, 4.8]	[-6.2, 6.9]

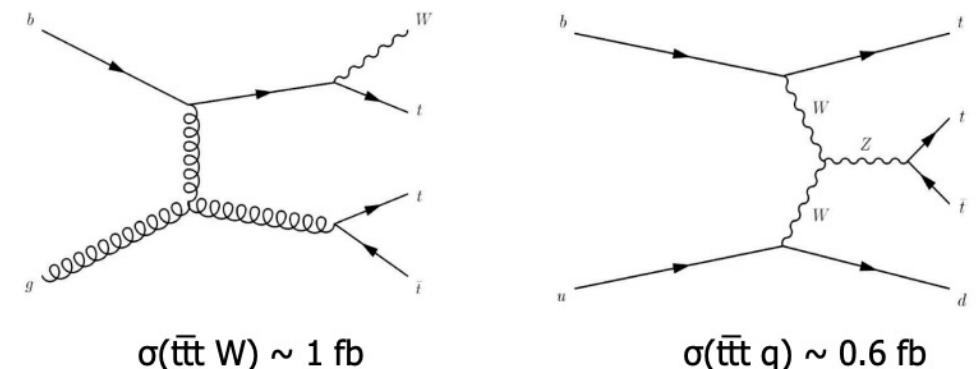
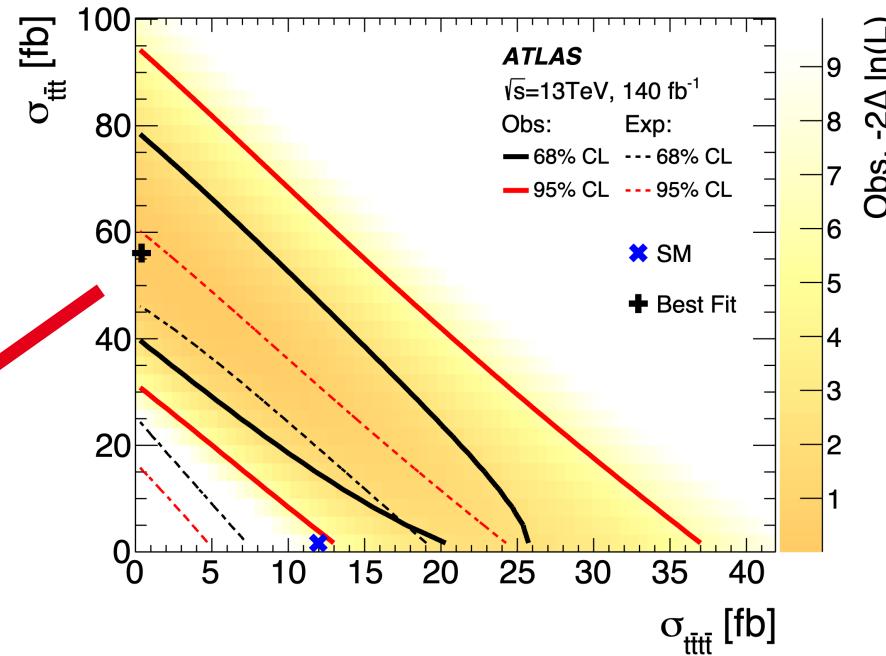
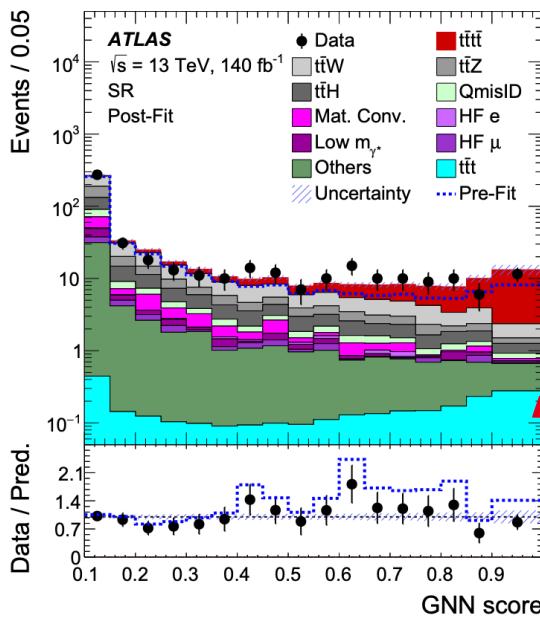
Limit on Higgs oblique parameter \hat{H}





Interpretations-Three Top Cross Section

- SM three top production is even rarer than 4 top and is not discovered yet.
- Three top final state is very similar to four top: large contribution in high GNN region
- We tried also to constrain the 3top production
- The correlation between 4top and 3top is very large (-93%) after free-floating both cross sections



Limit on 3top production

Processes	95% CL cross section interval [fb] $\mu_{t\bar{t}t\bar{t}} = 1$	95% CL cross section interval [fb] $\mu_{t\bar{t}t\bar{t}} = 1.9$
$t\bar{t}t\bar{t}$	[4.7, 60]	[0, 41]
$t\bar{t}W$	[3.1, 43]	[0, 30]
$t\bar{t}q$	[0, 144]	[0, 100]



Summary

- Two new ATLAS results with full Run 2 data in multilepton final state were presented
- Inclusive, fiducial and the first differential cross section measurement of ttW
 - The inclusive cross section is found to be higher than the theoretical prediction and consistent at 1.5σ level
 - Normalized differential distributions agree with data
- Re-analyzing of tttt with full Run2 data in the multilepton channel in ATLAS
 - **The first observation of 4top:** the observed (expected) significance of 4top reaches 6.1 (4.3) σ
 - Many interpretations also included: top-Higgs Yukawa coupling, EFT, Higgs oblique, 3 top cross-section



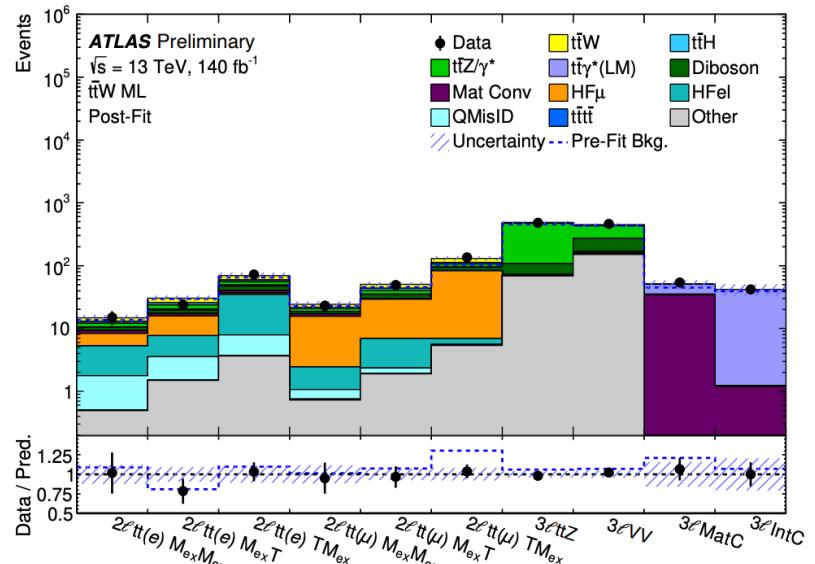
Backups



ttW SRs/CRs Definition

Signal region preselection	$2\ell\text{SS}$	3ℓ
Lepton definition	TT	LTT
Lepton p_T [GeV]	(20, 20)	(10, 20, 20)
N_{jets}		≥ 2
$N_{b-\text{jets}}$		$\geq 1 b^{60\%} \text{ or } \geq 2 b^{77\%}$
$m_{\ell^+\ell^\pm}^{\text{SF}} \text{ or } m_{\ell^+\ell^-}^{\text{SF}}$ [GeV]		> 12
$ m_{\ell^+\ell^-}^{\text{SF}} - m_Z $ [GeV]	-	> 10
$ m_{\ell\ell\ell\ell} - m_Z $ [GeV]	-	> 10
Inclusive cross section measurement		
Lepton charge split	$(\ell^+\ell^+, \ell^-\ell^-)$	$(\ell^+\ell^-\ell^-, \ell^-\ell^+\ell^+)$
Lepton flavour split	$(\mu\mu, e\mu, \mu e, ee)$	-
Jet multiplicity split	$(3, 4, \geq 5)$	$(2, \geq 3)$
b -jet multiplicity split		$(1, \geq 2)$
Total inclusive SRs	48	8
Differential cross section measurement		
Lepton charge split	$(\ell^+\ell^+, \ell^-\ell^-)$	$(\ell^+\ell^-\ell^-, \ell^-\ell^+\ell^+)$
Number of OS-SF pairs split	-	$(0, 1, 2)$
Total differential SRs	2	6

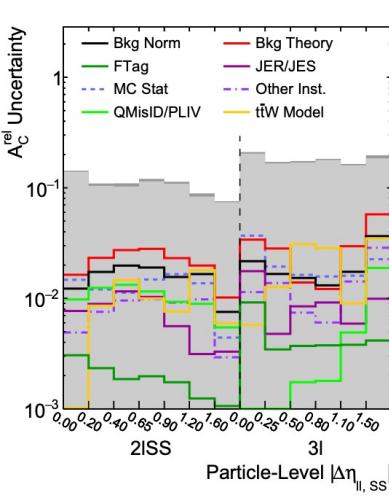
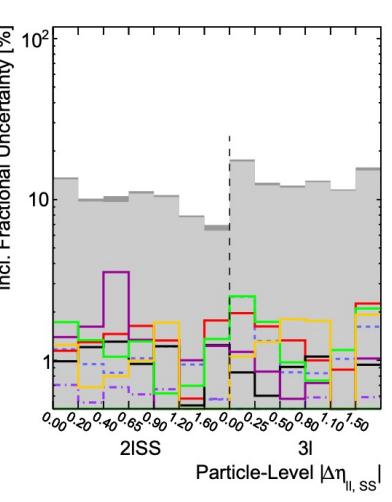
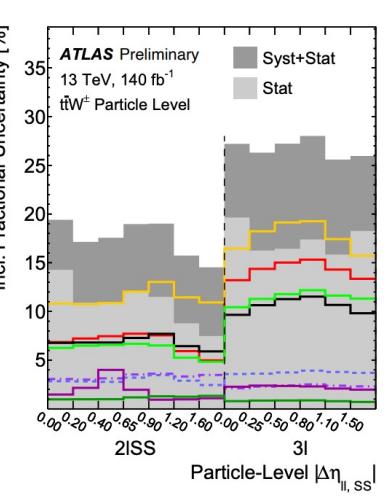
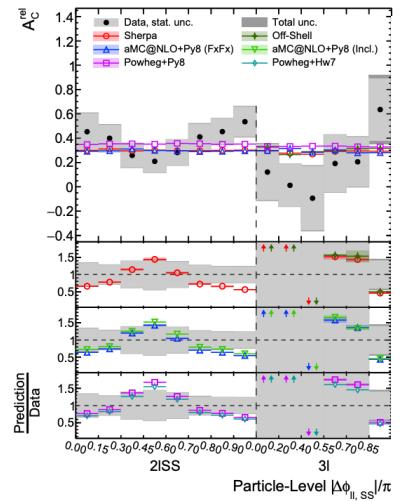
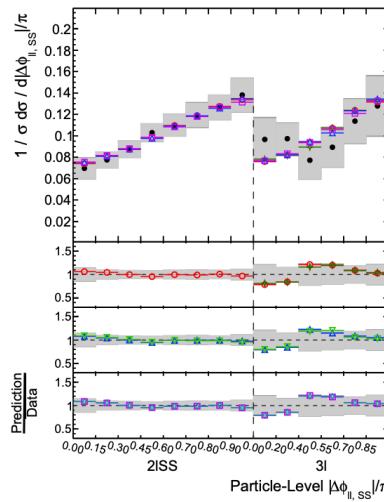
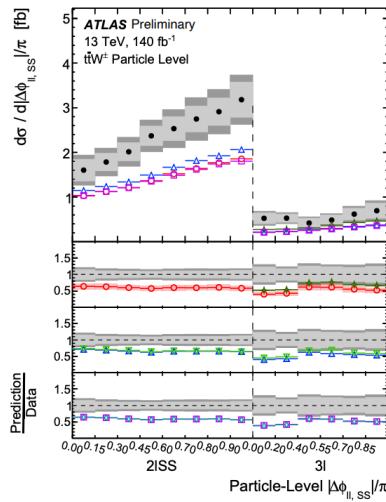
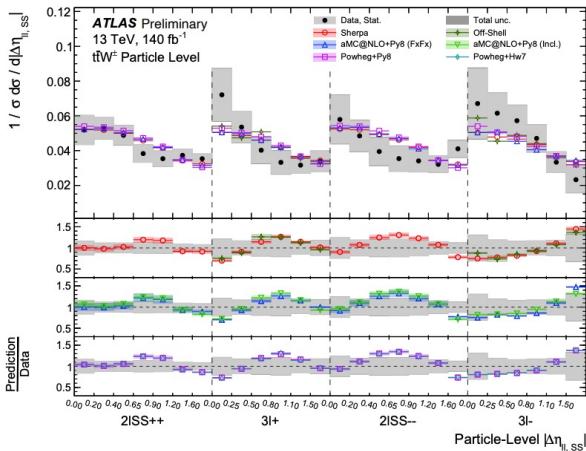
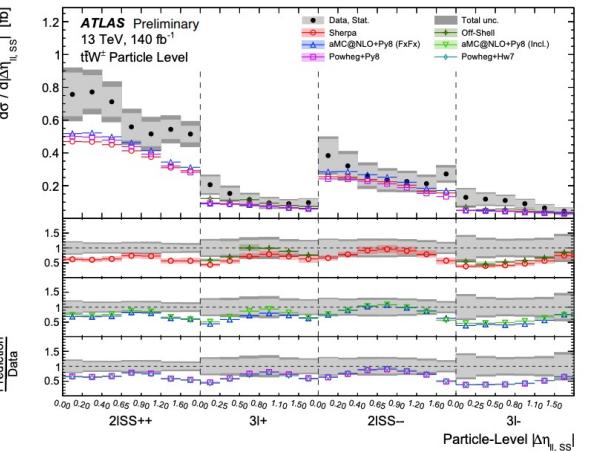
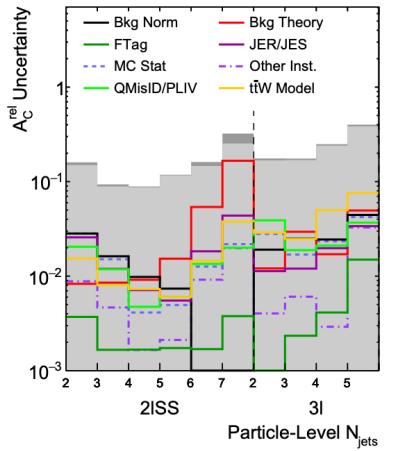
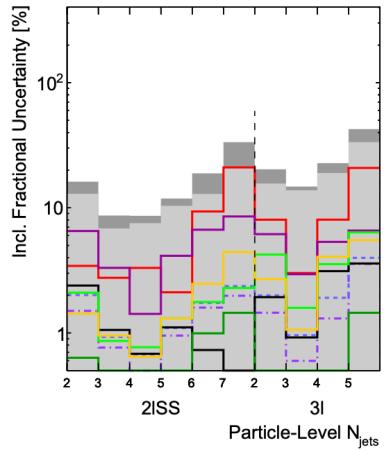
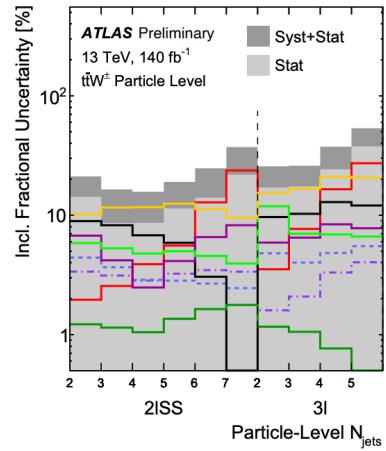
Control regions for:	Diboson	$t\bar{t}Z$	Conversions	HF non-prompt
N_{jets}	2 or 3	≥ 4	≥ 0	≥ 2
$N_{b-\text{jets}}$	$1 b^{60\%}$	$\geq 1 b^{60\%} \text{ or } \geq 2 b^{77\%}$	$0 b^{77\%}$	$1 b^{77\%}$
Lepton requirement		3ℓ	$\mu\mu e^*$	$2\ell\text{SS}$
Lepton definition		(L, M, M)		$(T, M_{\text{ex}}) \parallel (M_{\text{ex}}, T) \parallel (M_{\text{ex}}, M_{\text{ex}})$
Lepton p_T [GeV]		(10, 20, 20)		(20, 20)
$m_{\ell^+\ell^-}^{\text{SF}}$ [GeV]	> 12		> 12	-
$ m_{\ell^+\ell^-}^{\text{SF}} - m_Z $ [GeV]	< 10		> 10	-
$ m_{\ell\ell\ell\ell} - m_Z $ [GeV]	-		< 10	-
$m_T(\ell_0, E_T^{\text{miss}})$ [GeV]		-		< 250 for $T M_{\text{ex}}$ and $M_{\text{ex}} T$ pairs
Region split	-	-	internal / material	subleading $e/\mu \times (T M_{\text{ex}}, M_{\text{ex}} T, M_{\text{ex}} M_{\text{ex}})$
Region naming	$3\ell\text{VV}$	$3\ell t\bar{t}Z$	$3\ell\text{IntC}$	$2\ell t\bar{t}(e)_{T M_{\text{ex}}}, 2\ell t\bar{t}(e)_{M_{\text{ex}} T}, 2\ell t\bar{t}(e)_{M_{\text{ex}} M_{\text{ex}}}$
			$3\ell\text{MatC}$	$2\ell t\bar{t}(\mu)_{T M_{\text{ex}}}, 2\ell t\bar{t}(\mu)_{M_{\text{ex}} T}, 2\ell t\bar{t}(\mu)_{M_{\text{ex}} M_{\text{ex}}}$





ttW Uncertainties

	$\frac{\Delta\sigma(t\bar{t}W)}{\sigma(t\bar{t}W)} [\%]$	$\frac{\Delta\sigma_{\text{fid}}(t\bar{t}W)}{\sigma_{\text{fid}}} [\%]$	$\frac{\Delta R(t\bar{t}W)}{R(t\bar{t}W)} [\%]$	$\frac{\Delta A_C^{\text{rel}}}{A_C^{\text{rel}}} [\%]$
<i>t</i> <i>t</i> W ME and PS modelling	6.0	7.0	6.0	8.0
Prompt lepton bkg. norm.	2.6	2.5	1.6	2.2
Lepton isolation BDT	2.3	2.3	1.0	1.2
Fakes/VV/ <i>t</i> <i>t</i> Z norm. (free-floated)	2.3	2.7	1.8	2.5
Non-prompt lepton bkg. modelling	1.9	1.7	2.3	3.1
Trigger	1.9	1.8	0.5	0.7
MC statistics	1.5	1.6	1.9	2.5
<i>t</i> <i>t</i> W PDF	1.5	1.4	2.1	2.8
Jet energy scale	1.4	1.9	0.8	1.1
Prompt lepton bkg. modelling	1.3	1.3	1.3	1.9
Luminosity	1.0	1.0	0.08	0.13
Charge Mis-ID	0.7	0.7	0.4	0.5
Jet energy resolution	0.5	0.6	0.7	0.31
Flavour tagging	0.28	0.33	0.5	1.0
<i>t</i> <i>t</i> W Scale	0.21	0.9	1.4	1.9
Electron/photon reco.	0.15	0.2	0.12	0.3
MET	<0.10	<0.10	0.17	0.4
Muon	<0.10	<0.10	<0.10	0.4
Pile-up	<0.10	0.25	<0.10	0.3
Total syst.	8	10	8	10
Data statistics	5	5	10	16
Total	9	11	13	19





ttW Differential XS Result

Table 10: χ^2 and p -values calculated for unfolded normalised cross-section distributions in the 2ℓ SS region.

Observable	NDF	Sherpa 2.2.10		MG5aMC+Py8 FxFx		MG5aMC+Py8 Incl.		Powheg+Pythia8		Powheg+Herwig7	
		χ^2	p -value	χ^2	p -value	χ^2	p -value	χ^2	p -value	χ^2	p -value
N_{jets}	5	2.4	0.79	4.2	0.52	2.8	0.73	2.9	0.72	2.6	0.76
$H_{\text{T},\text{jets}}$	5	0.7	0.98	1.1	0.95	0.8	0.98	1.5	0.91	2.0	0.85
$H_{\text{T},\text{lep}}$	7	3.6	0.82	3.8	0.80	3.4	0.84	3.4	0.85	3.5	0.84
$\Delta R_{\text{lb, lead}}$	7	2.0	0.96	2.4	0.93	2.6	0.92	2.6	0.92	2.5	0.93
$ \Delta \phi_{\text{ll, SS}} $	7	0.6	1.00	0.7	1.00	0.9	1.00	0.8	1.00	0.9	1.00
$ \Delta \eta_{\text{ll, SS}} $	6	6.5	0.37	7.3	0.29	11.4	0.08	9.5	0.15	9.4	0.15
$M_{\text{jj, lead}}$	6	4.9	0.56	2.7	0.84	7.2	0.30	9.0	0.17	10.9	0.09

Table 11: χ^2 and p -values calculated for unfolded normalised cross-section distributions in the 3ℓ region.

Observable	NDF	Sherpa 2.2.10		Off-Shell		MG5aMC+Py8 FxFx		MG5aMC+Py8 Incl.		Powheg+Py8		Powheg+H7	
		χ^2	p -value	χ^2	p -value	χ^2	p -value	χ^2	p -value	χ^2	p -value	χ^2	p -value
N_{jets}	3	0.2	0.98	-	-	0.2	0.98	0.3	0.97	1.0	0.80	1.1	0.79
$H_{\text{T},\text{jets}}$	4	1.4	0.84	-	-	0.9	0.92	1.9	0.75	2.4	0.66	3.3	0.51
$H_{\text{T},\text{lep}}$	5	1.0	0.96	3.4	0.64	1.3	0.94	1.7	0.88	1.5	0.91	1.4	0.93
$\Delta R_{\text{lb, lead}}$	5	4.0	0.55	3.5	0.63	5.0	0.42	3.7	0.59	3.7	0.60	3.8	0.58
$ \Delta \phi_{\text{ll, SS}} $	5	2.7	0.75	2.2	0.81	2.6	0.76	2.2	0.82	2.4	0.79	2.3	0.80
$ \Delta \eta_{\text{ll, SS}} $	5	2.6	0.77	5.6	0.35	2.9	0.72	2.3	0.80	2.0	0.84	2.1	0.83
$M_{\text{jj, lead}}$	5	0.1	1.00	-	-	0.2	1.00	0.4	0.99	0.7	0.98	1.0	0.96

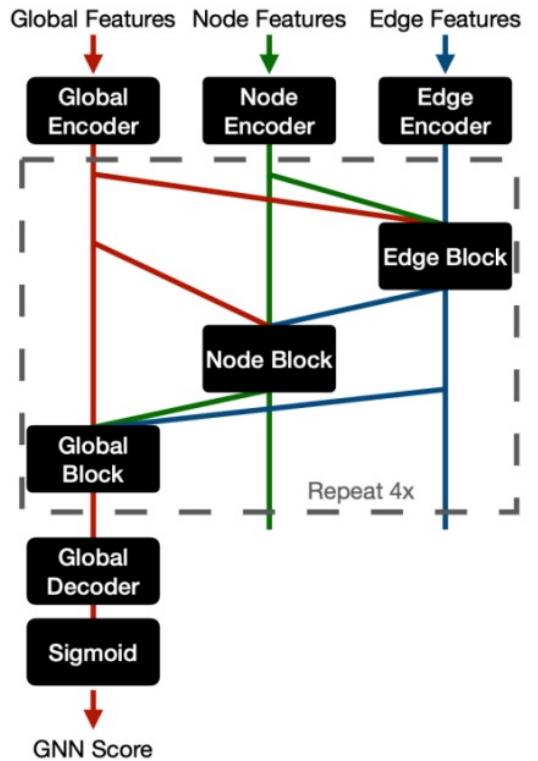
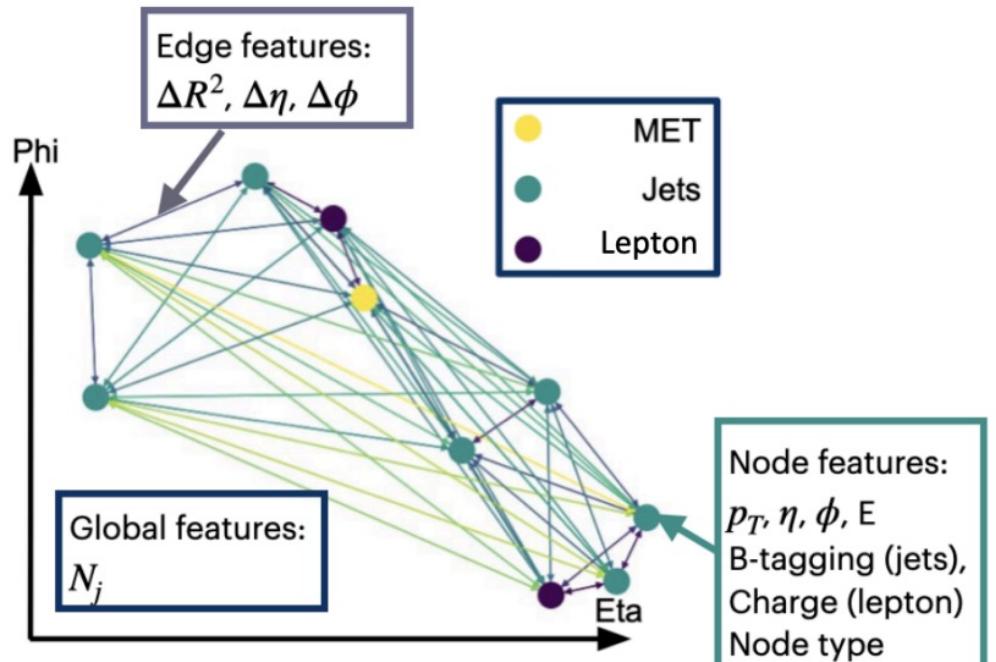


Regions Four Top

Region	Channel	N_j	N_b	Other selection	Fitted variable
CR Low m_{γ^*}	SS, ee or e μ	$4 \leq N_j < 6$	≥ 1	ℓ_1 or ℓ_2 is from virtual photon (γ^*) decay ℓ_1 and ℓ_2 are not from photon conversion	event yield
CR Mat. Conv.	SS, ee or e μ	$4 \leq N_j < 6$	≥ 1	ℓ_1 or ℓ_2 is from photon conversion	event yield
CR HF μ	e $\mu\mu$ or $\mu\mu\mu$	≥ 1	$= 1$	$100 < H_T < 300$ GeV $E_T^{\text{miss}} > 50$ GeV total charge = ± 1	$p_T^{\ell_3}$
CR HF e	eee or ee μ	≥ 1	$= 1$	$100 < H_T < 275$ GeV $E_T^{\text{miss}} > 35$ GeV total charge = ± 1	$p_T^{\ell_3}$
CR $t\bar{t}W^+$ +jets	SS, e μ or $\mu\mu$	≥ 4	≥ 2	$ \eta(e) < 1.5$ when $N_b = 2$: $H_T < 500$ GeV or $N_j < 6$ when $N_b \geq 3$: $H_T < 500$ GeV total charge > 0	N_j
CR $t\bar{t}W^-$ +jets	SS, e μ or $\mu\mu$	≥ 4	≥ 2	$ \eta(e) < 1.5$ when $N_b = 2$: $H_T < 500$ GeV or $N_j < 6$ when $N_b \geq 3$: $H_T < 500$ GeV total charge < 0	N_j
CR 1b(+)	2LSS+3L	≥ 4	$= 1$	ℓ_1 and ℓ_2 are not from photon conversion $H_T > 500$ GeV total charge > 0	N_j
CR 1b(-)	2LSS+3L	≥ 4	$= 1$	ℓ_1 and ℓ_2 are not from photon conversion $H_T > 500$ GeV total charge < 0	N_j
SR	2LSS+3L	≥ 6	≥ 2	$H_T > 500$ GeV	GNN score



GNN Method





Detailed Uncertainties - $t\bar{t}t\bar{t}$

Uncertainty source	$\Delta\sigma$ [fb]	$\Delta\sigma/\sigma[\%]$
Signal modelling		
$t\bar{t}t\bar{t}$ generator choice	+3.7	-2.7 +17 -12
$t\bar{t}t\bar{t}$ parton shower model	+1.6	-1.0 +7 -4
Other $t\bar{t}t\bar{t}$ modelling	+0.8	-0.5 +4 -2
Background modelling		
$t\bar{t}H$ +jets modelling	+0.9	-0.7 +4 -3
$t\bar{t}W$ +jets modelling	+0.8	-0.8 +4 -3
$t\bar{t}Z$ +jets modelling	+0.5	-0.4 +2 -2
Other background modelling	+0.5	-0.4 +2 -2
Non-prompt leptons modelling	+0.4	-0.3 +2 -2
$t\bar{t}t$ modelling	+0.3	-0.2 +1 -1
Charge misassignment	+0.1	-0.1 +0 -0
Instrumental		
Jet flavour tagging (b -jets)	+1.1	-0.8 +5 -4
Jet uncertainties	+1.1	-0.7 +5 -3
Jet flavour tagging (light-flavour jets)	+0.9	-0.6 +4 -3
Jet flavour tagging (c -jets)	+0.5	-0.4 +2 -2
Simulation sample size	+0.4	-0.3 +2 -1
Other experimental uncertainties	+0.4	-0.3 +2 -1
Luminosity	+0.2	-0.2 +1 -1
Total systematic uncertainty	+4.6	-3.4 +20 -16
Statistical		
Intrinsic statistical uncertainty	+4.2	-3.9 +19 -17
$t\bar{t}W$ +jets normalisation and scaling factors	+1.2	-1.1 +6 -5
Non-prompt leptons normalisation (HF, Mat. Conv., Low m_{γ^*})	+0.4	-0.3 +2 -1
Total statistical uncertainty	+4.7	-4.3 +21 -19
Total uncertainty	+6.6	-5.5 +29 -25