$t\bar{t}W$ and $t\bar{t}H$ measurements in multilepton final state at ATLAS experiment with $80\ fb^{-1}$ data.

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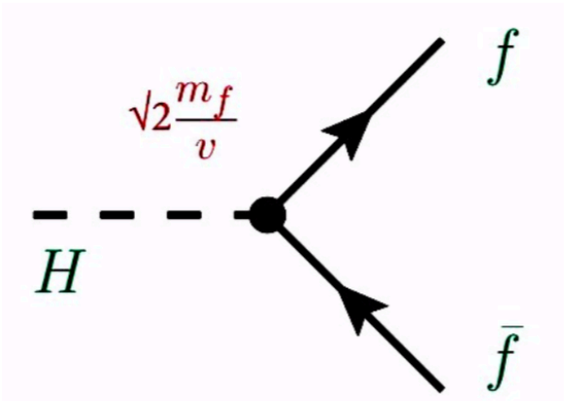
ATLAS-CONF-2019-045

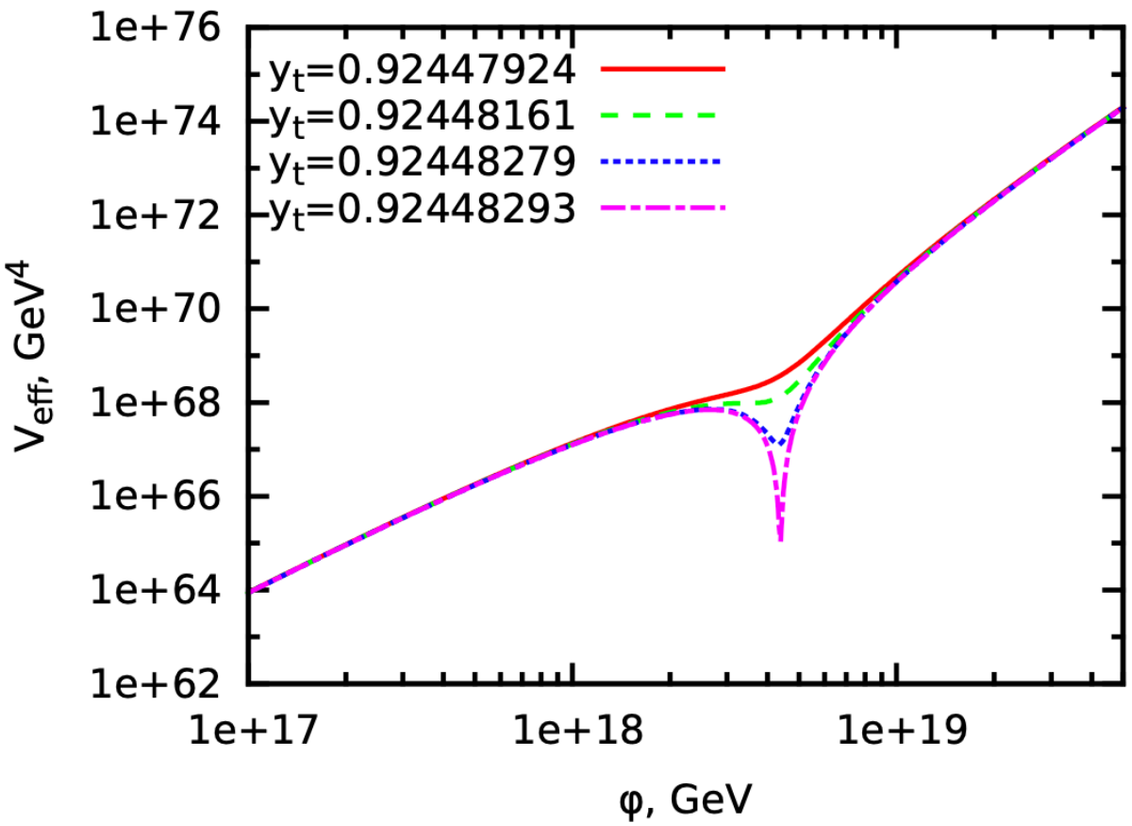
Motivation

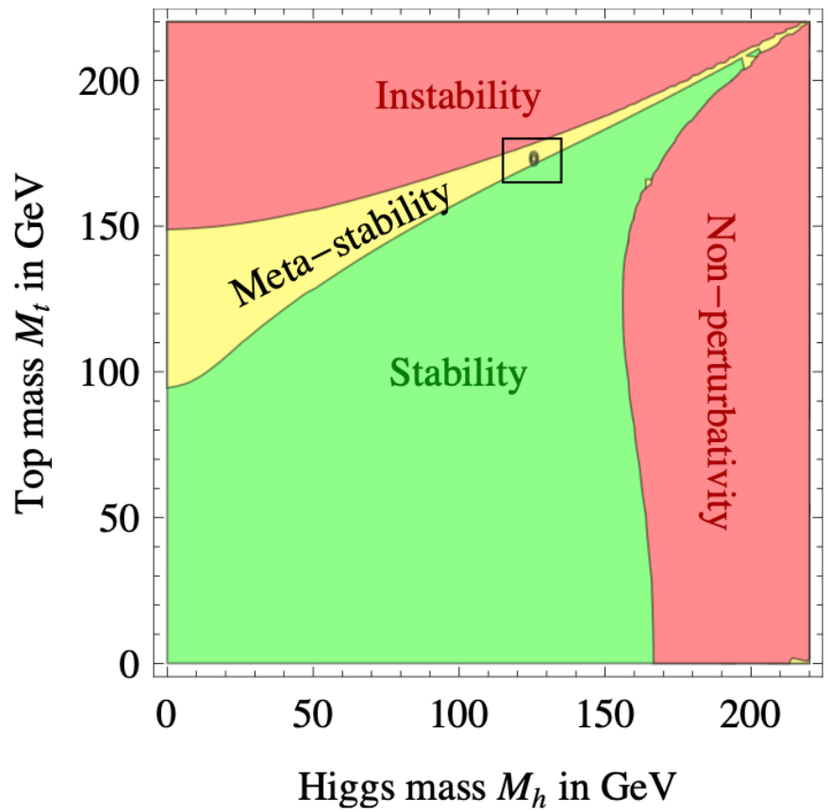


- Fermion masses are generated through Yukawa interaction
- Heaviest SM particle (top) expected to have largest Yukawa coupling (y_t) to the Higgs field.

Why should we care about top-Yukawa ? Are we in a stable universe?

arXiv:1205.6497v2
arXiv:1411.1923v2





- $t\bar{t}H$ or tH production measurement is the only direct way to measure y_t
- Both ATLAS and CMS have observed $t\bar{t}H$ production.

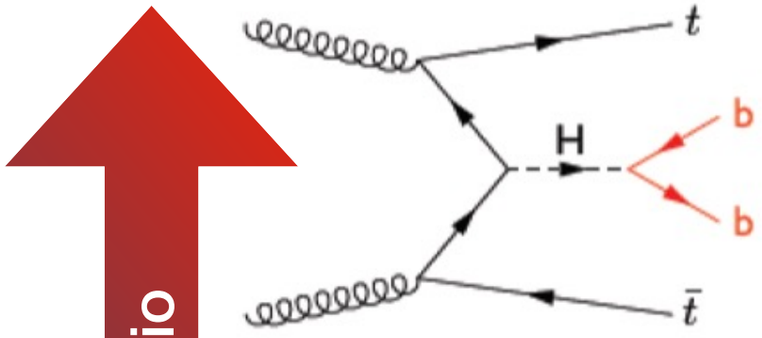
Experimental challenges

- Standard Model production cross section: ~507 fb: About 1% of total Higgs cross-section.
  - Many final states
  - Tiny signal and large backgrounds

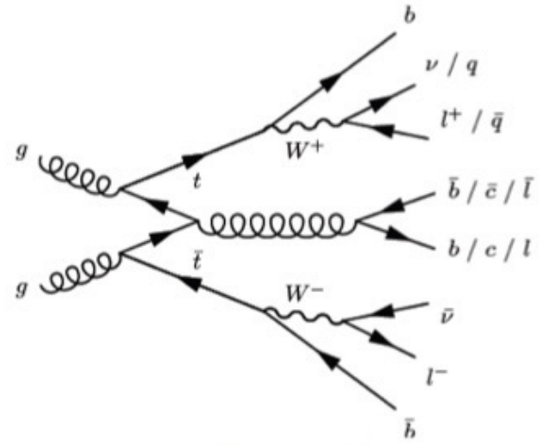
Signal

Background

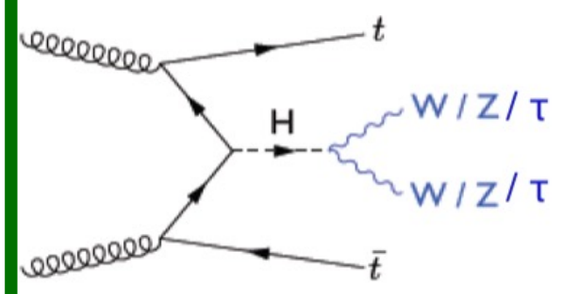
Higgs Branching ratio



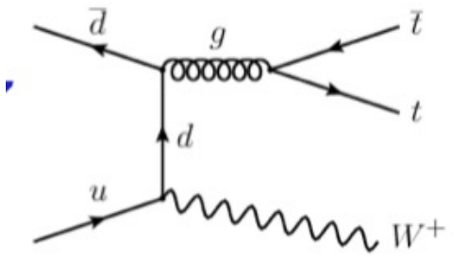
ttH(bb)

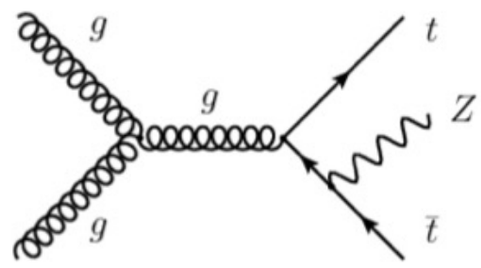


tt+(HF) jets (irreducible)

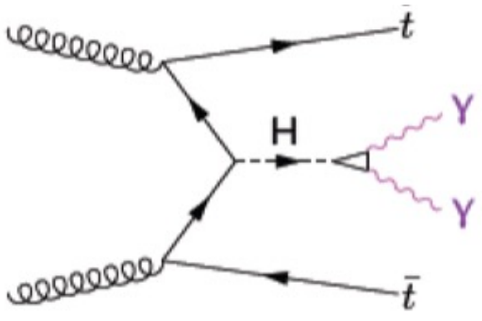


ttH-multileptons

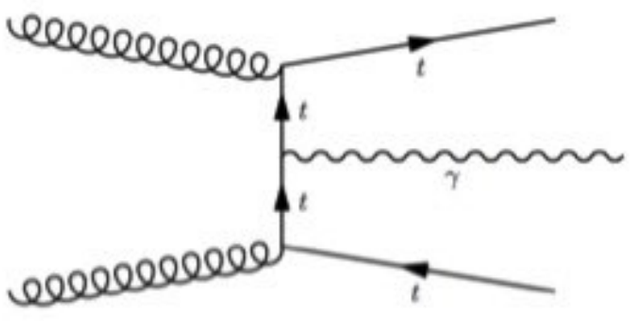




ttV



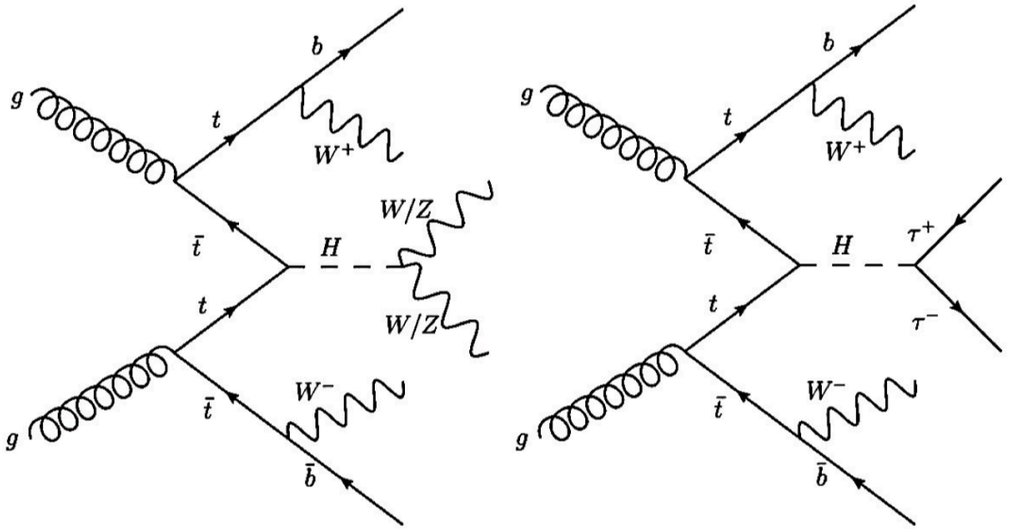
ttH(γγ)



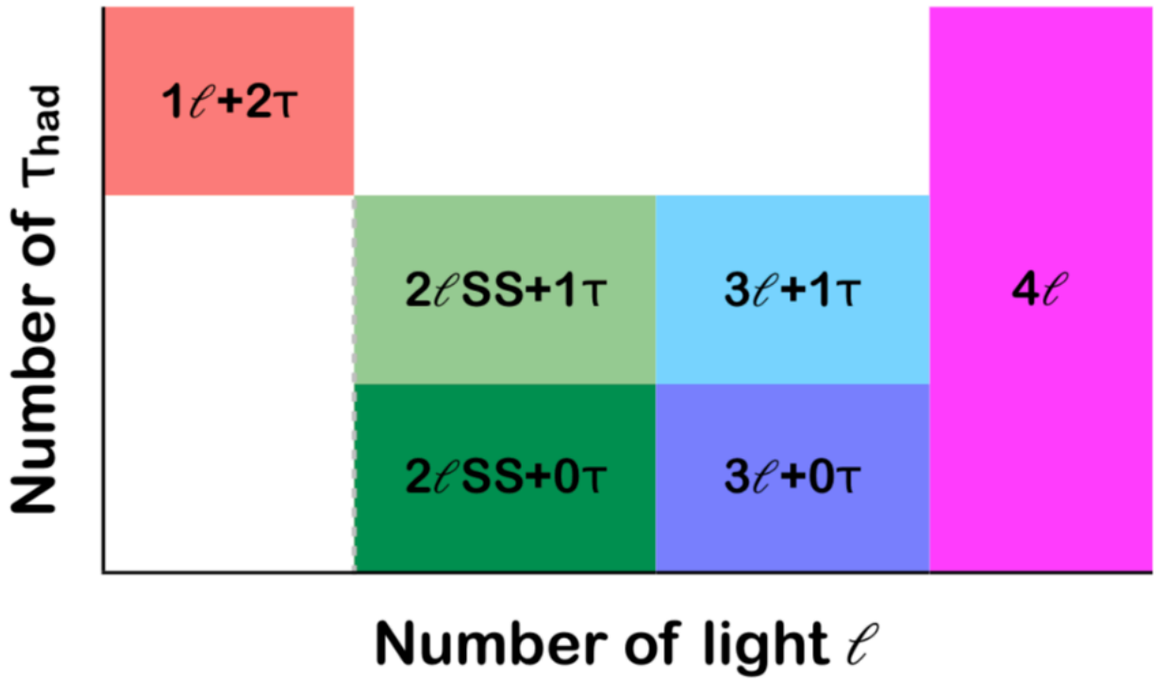
ttγ

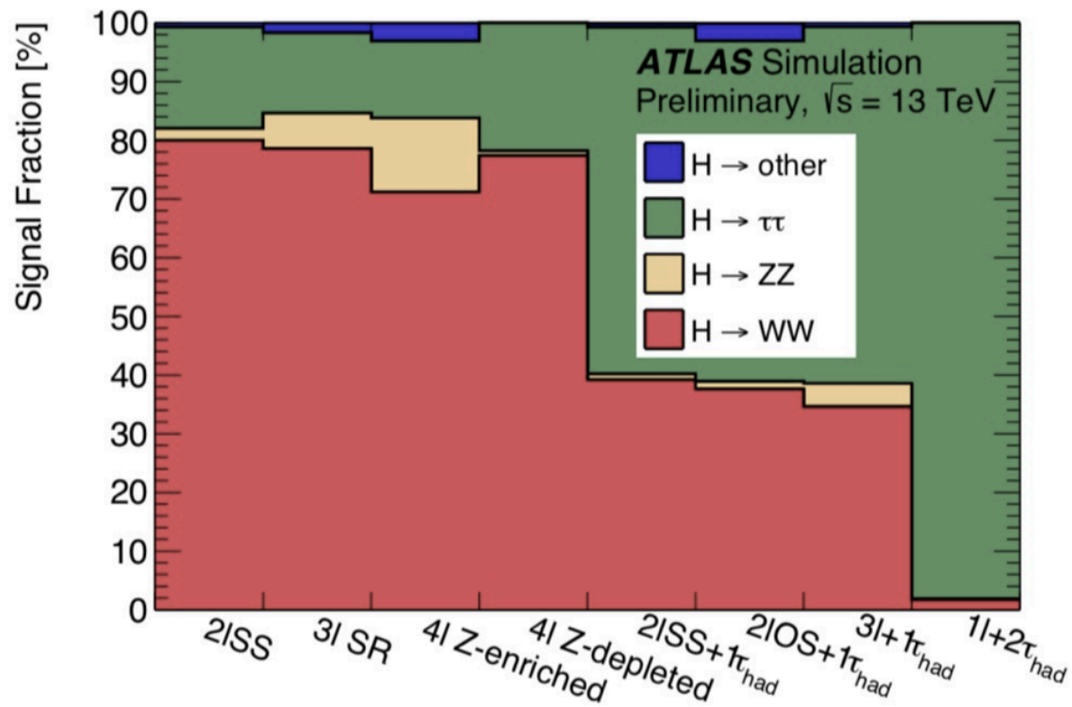
Analysis strategy

- Targets $H \to ZZ^*, H \to WW^*, H \to \tau^+\tau^-$
- Events categorized based on number of light leptons and hadronic taus.



Decay modes in sub channels





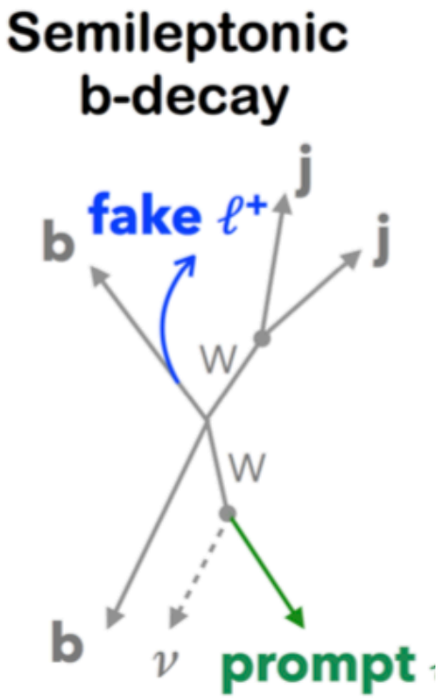
- Common jet selection $N_{\text{jet}} \geq 2$ and $N_{\text{bjet}} \geq 1$
- Optimized lepton selection in each category

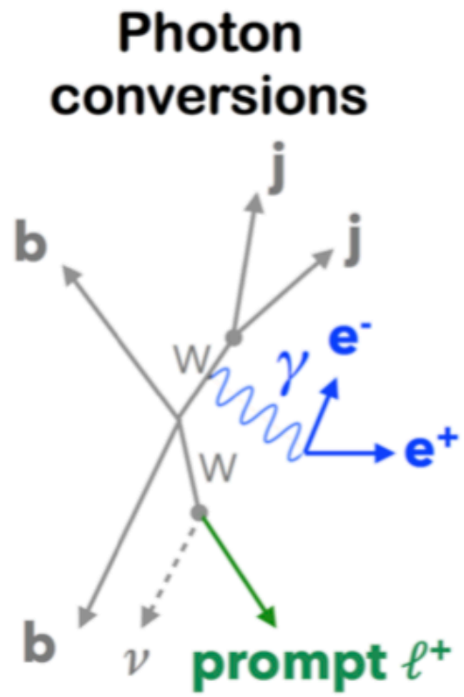
- Light leptons channels dominated by $H \to WW^*$
- Tau channels dominated by $H \to \tau^+\tau^-$

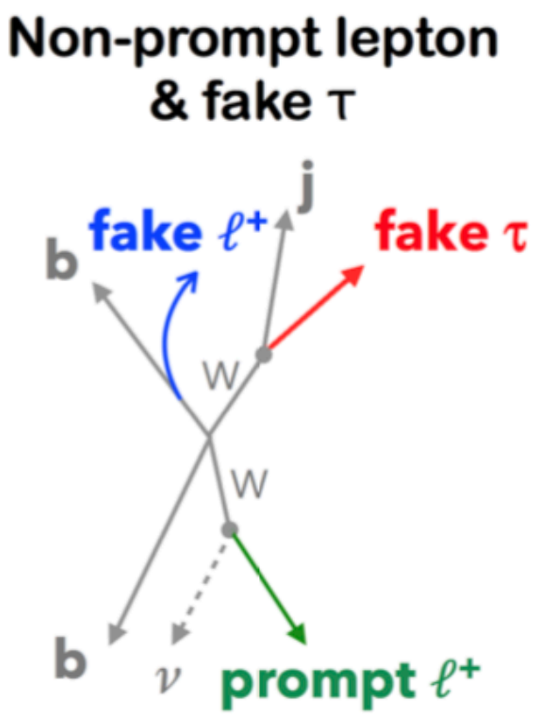
Background

- Irreducible background from prompt-leptons and hadronic taus
  - Estimated with MonteCarlo
  - Mainly $t\bar{t}W, t\bar{t}Z, VV$
- Electron charge mis-identification for 2ISS and 2ISS+1τ-had
  - Suppressed using a BDT algorithm
  - Datadriven estimation: Charge-misid rates in $Z \to e^+e^-/\mu^+\mu^-$
- Light-lepton and non-prompt lepton fakes
  - Source: Semileptonic b-decay, photon conversions
  - Heavy flavor leptons suppressed using a BDT algorithm
- Hadronic-tau fakes
  - Source: light flavor jets and mis-reconstructed electrons.
- Data-driven, semi data-driven and template fit to estimate fakes.

Illustration in tt-bar system

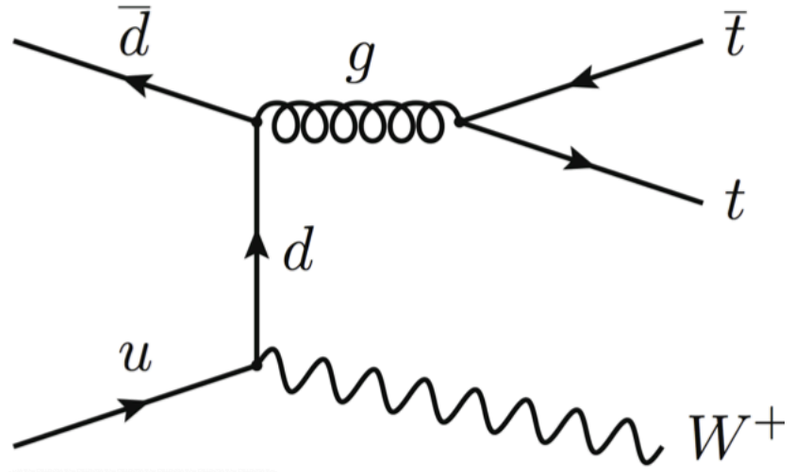




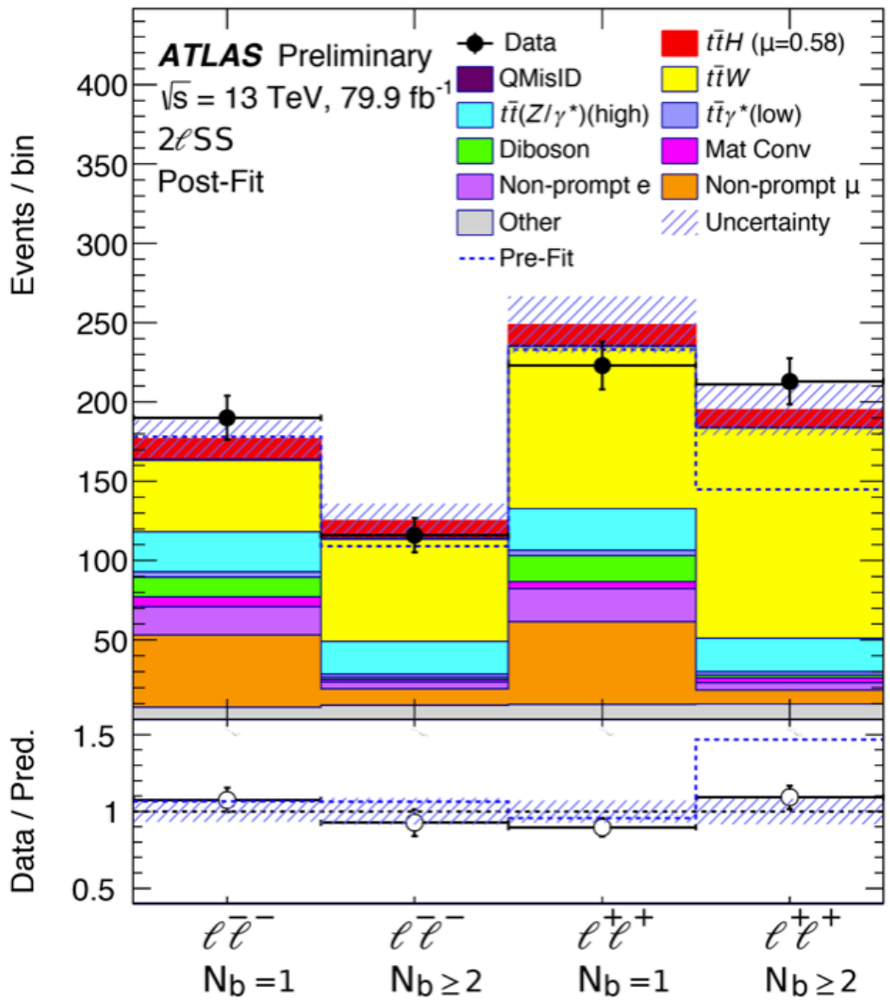


$t\bar{t}W$ Modeling

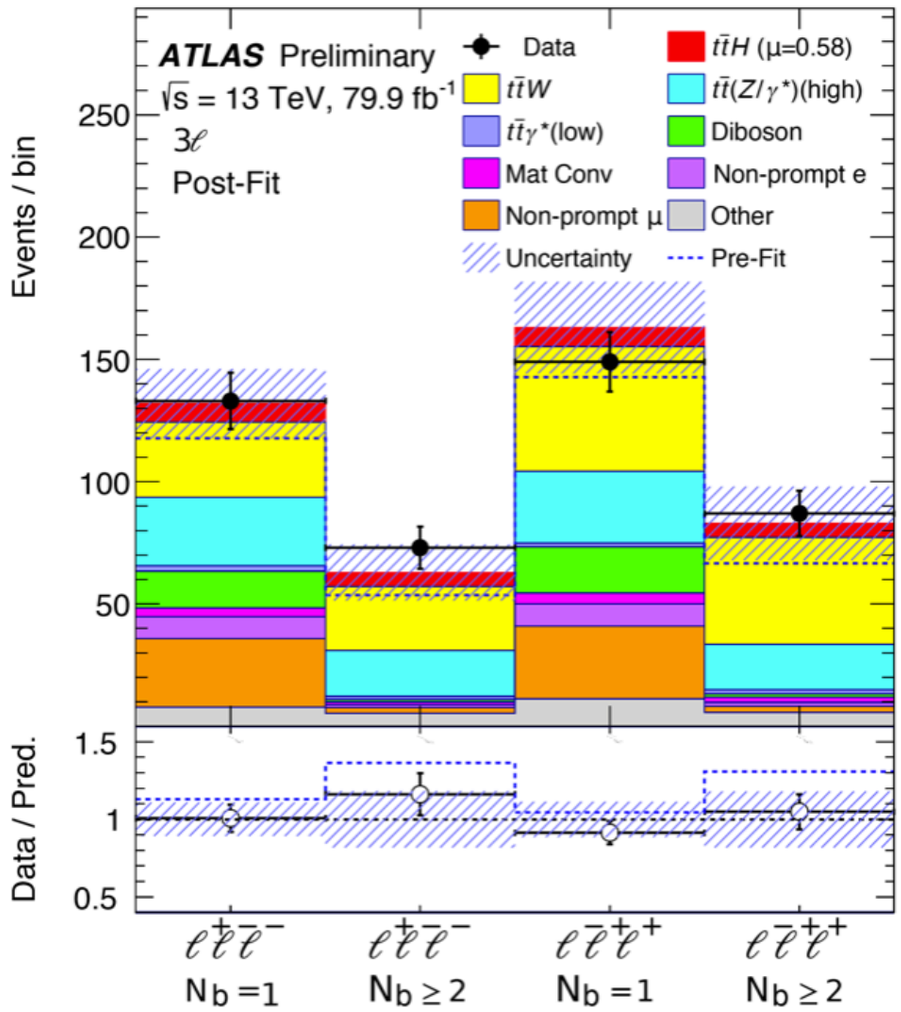
- $t\bar{t}W$ background is difficult to model.
  - We apply a k-factor of 1.2 inferred from [arXiv:1405.0301v2 and arXiv:1711.02116v2]
  - 3 Normalization factors [across jet multiplicity regions, channels]



2ℓSS0τ

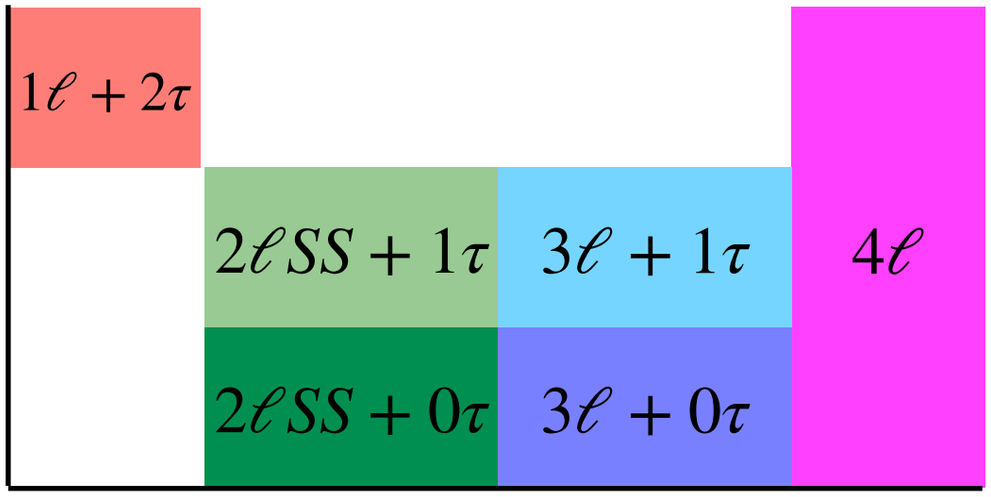


3ℓ0τ

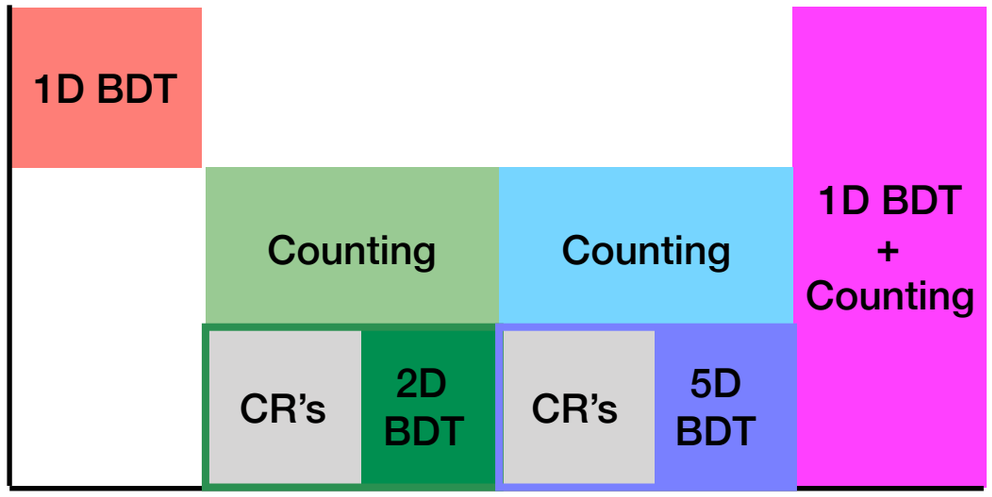


- High b-jet multiplicity region shows modeling difficulties in both 2l and 3l preselection regions.

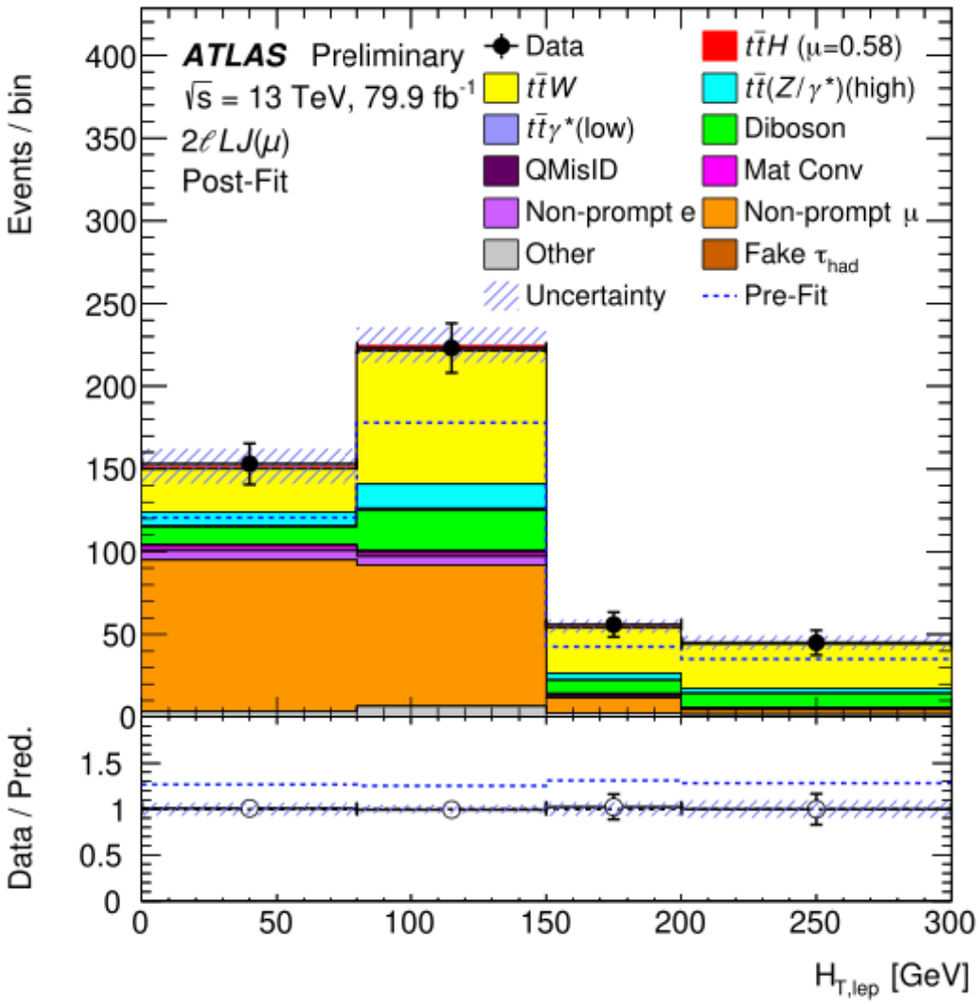
Fit Model



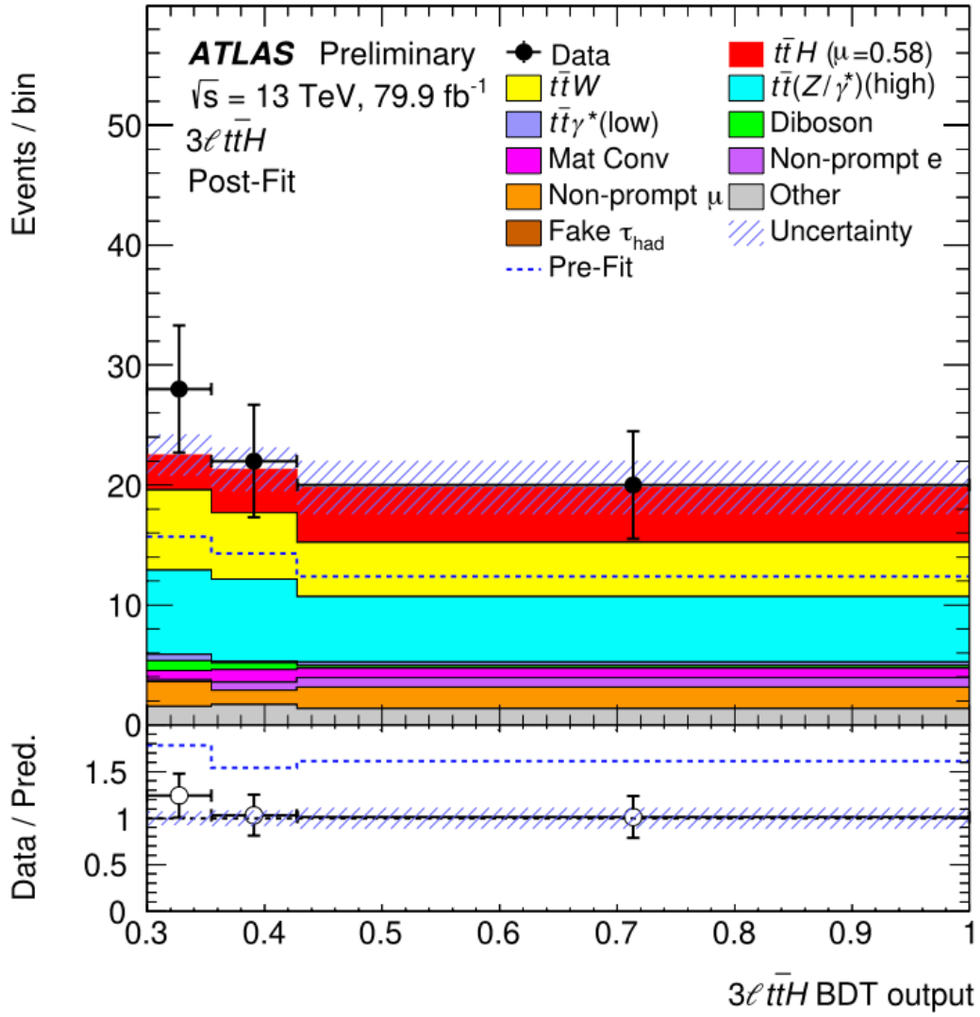
Optimizations in each Channel



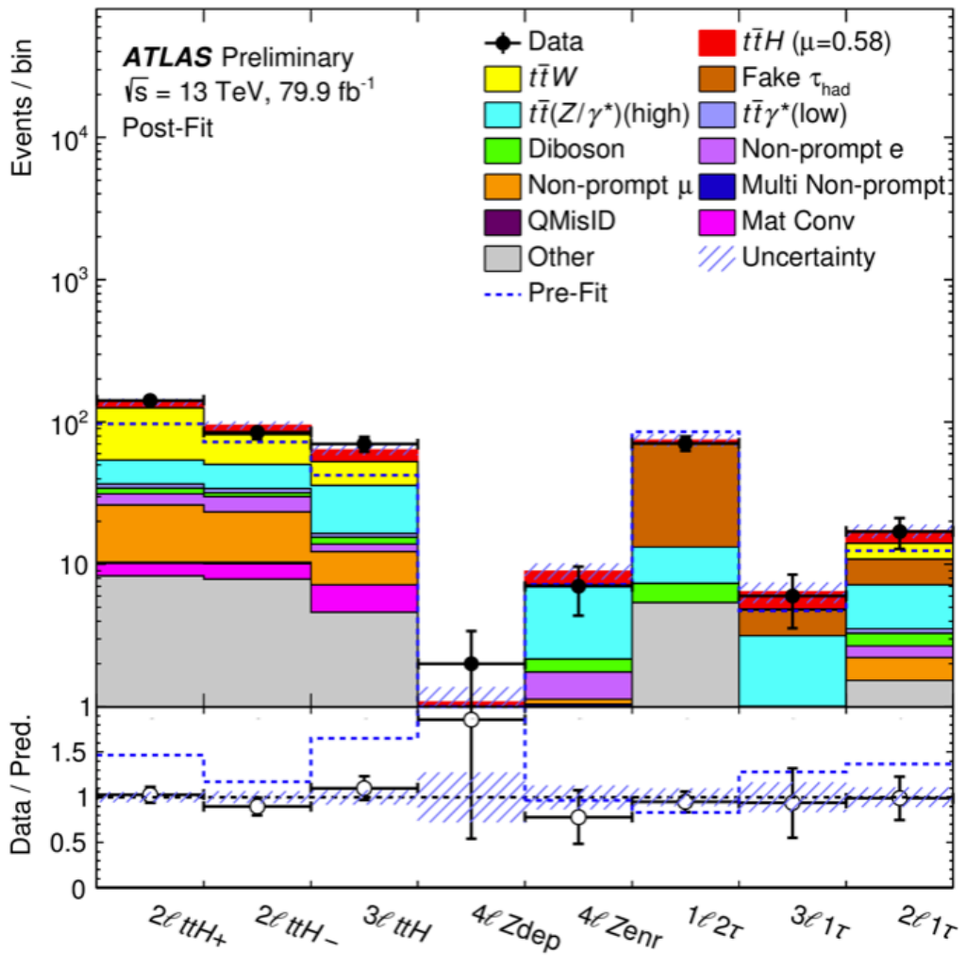
- Dedicated $t\bar{t}W$ Control regions

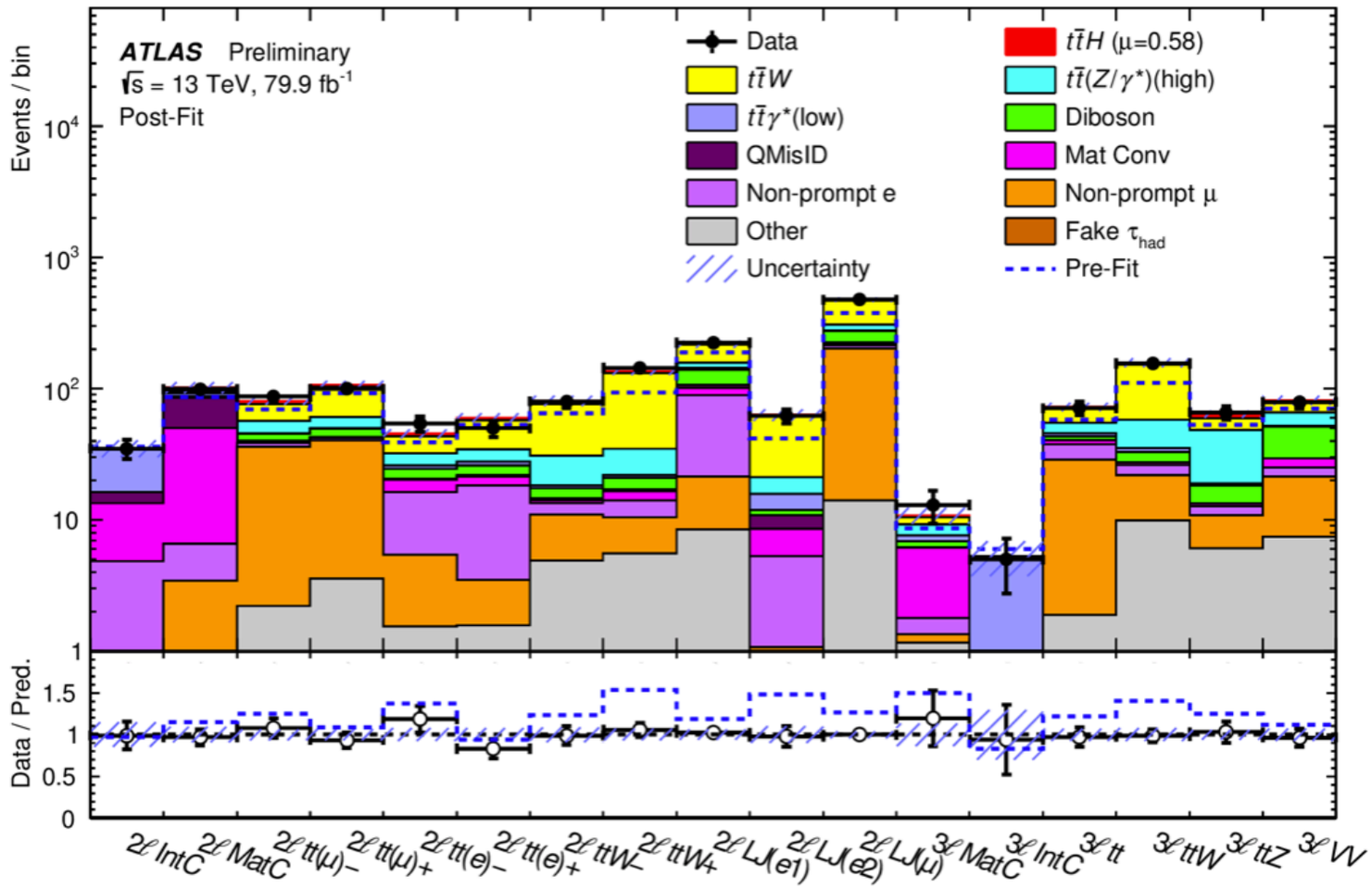


- Good post-fit agreement in $t\bar{t}H$ regions



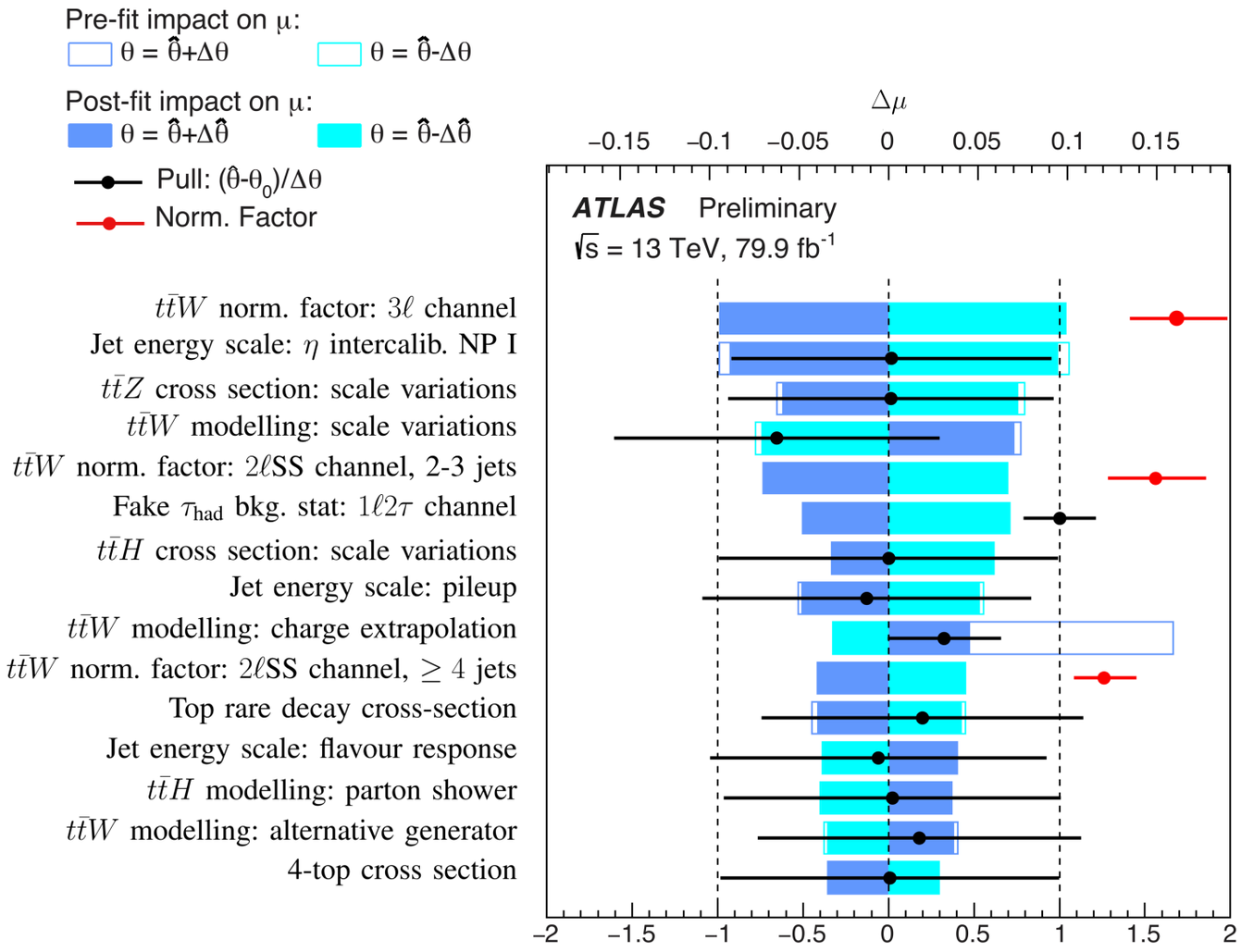
Fit Results:

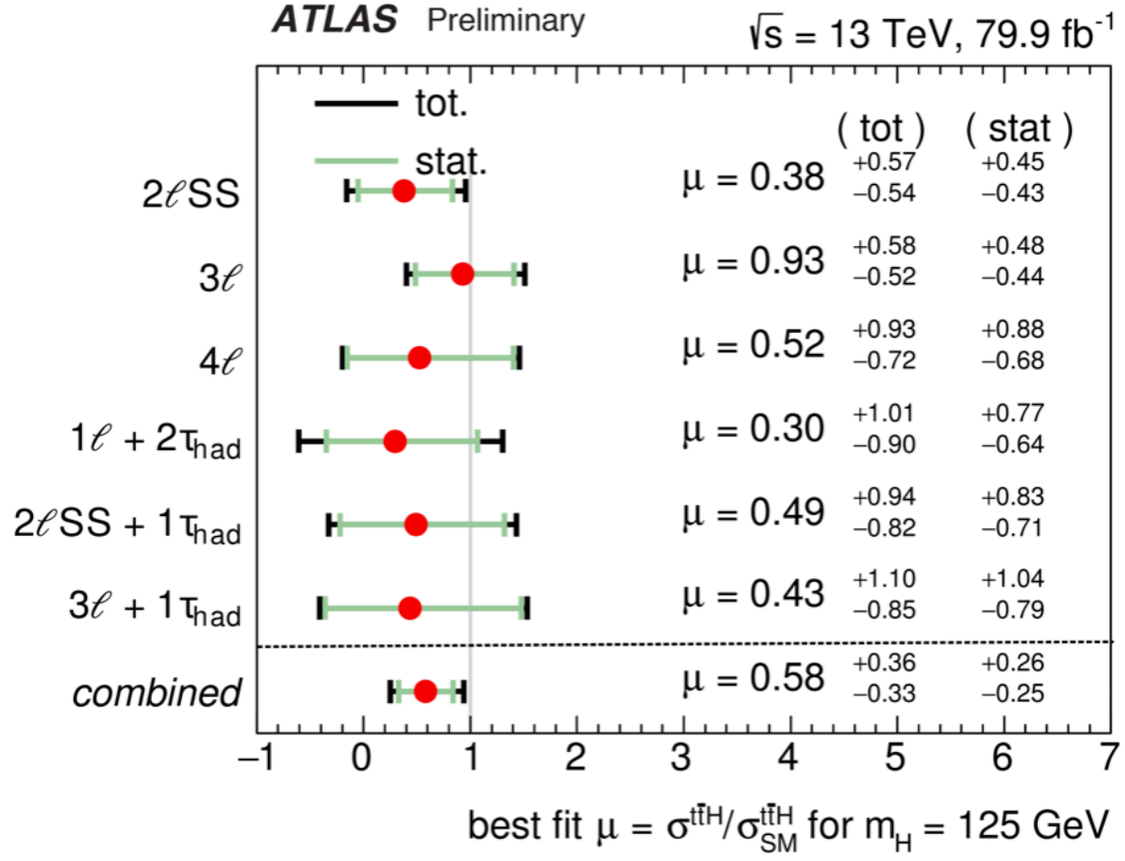




- In total 25 signal+control regions
- Pre-fit mis-modeling in $t\bar{t}W$ dominated regions can be clearly seen.

Fit Results:





- Leading experimental systematics jet energy scale and resolution
- $t\bar{t}H$ Cross-section 294^{+182}_{-162}
- $t\bar{t}W$ normalization factors are high

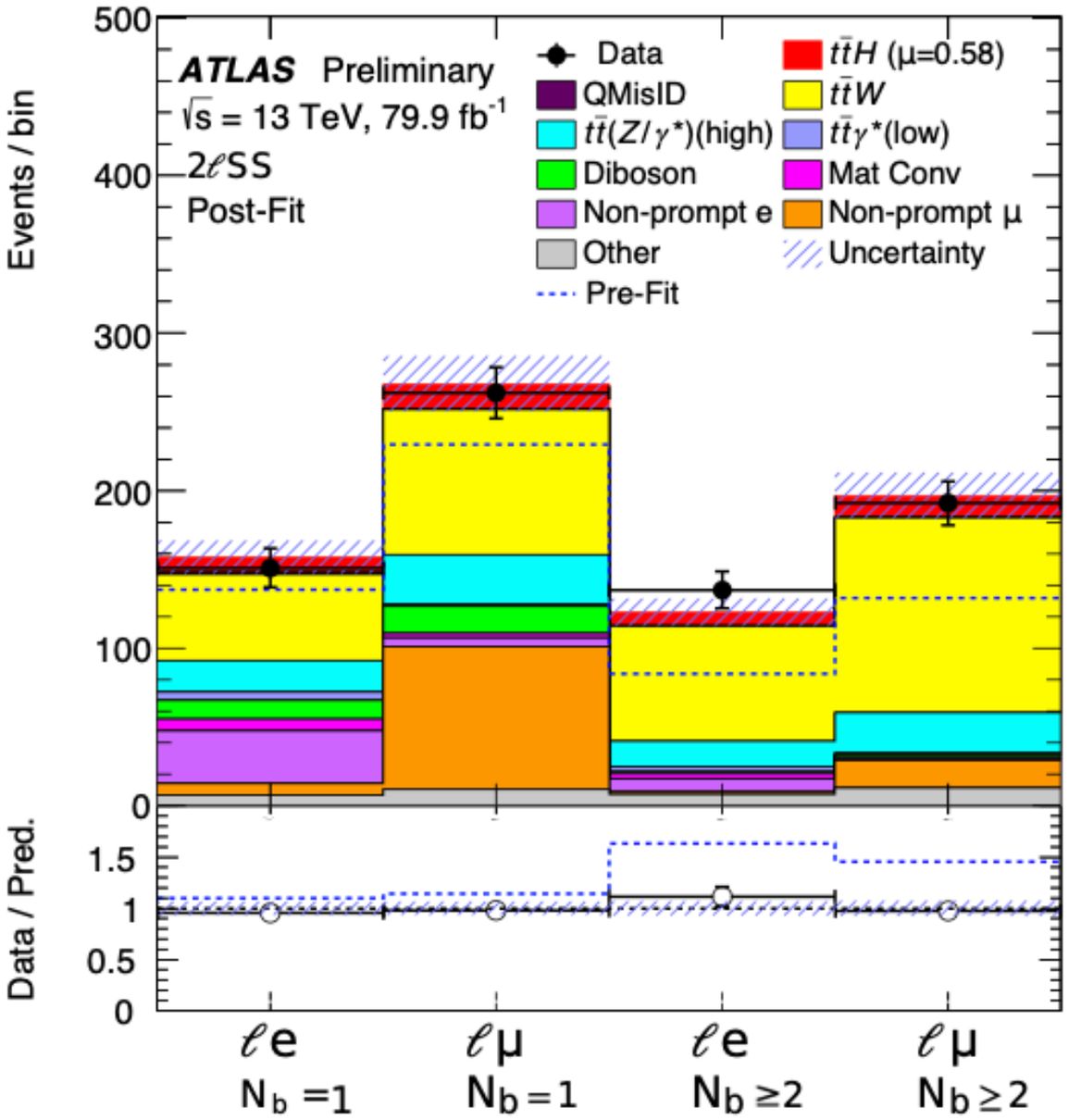
Region	$\lambda_{t\bar{t}W}$
2lSS (2-3 jets)	$1.56^{+0.30}_{-0.28}$
2lSS(>= 4jets)	$1.26^{+0.19}_{0.18}$
3l	$1.68^{+0.30}_{-0.28}$

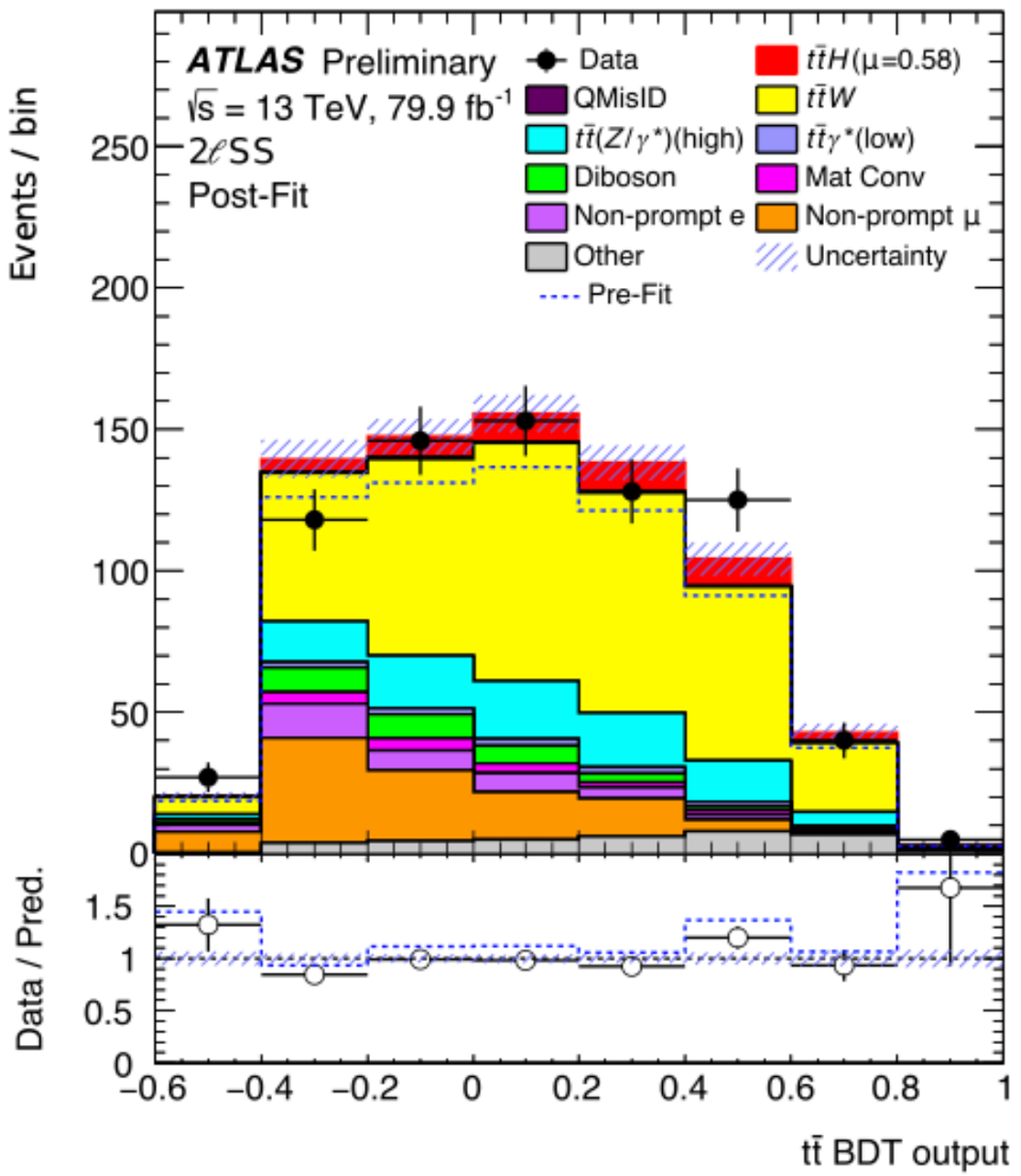
Conclusion

- A search for $t\bar{t}H$ production in six multi lepton final states using $80\ fb^{-1}$data has been presented
- Observed production cross-section is 294^{+182}_{-162} fb consistent with the standard model prediction of 507^{+35}_{-50} fb.
- The normalization factors obtained for $t\bar{t}W$ background is in the range 1.3-1.7 even above the updated theory prediction.
- Modeling issues have been observed in regions dominated by $t\bar{t}W$.
  - Even in a non-BDT cut and count cross-check analysis.
- Improved description of $t\bar{t}W$ is needed to reach greater precision in the future.

Backup

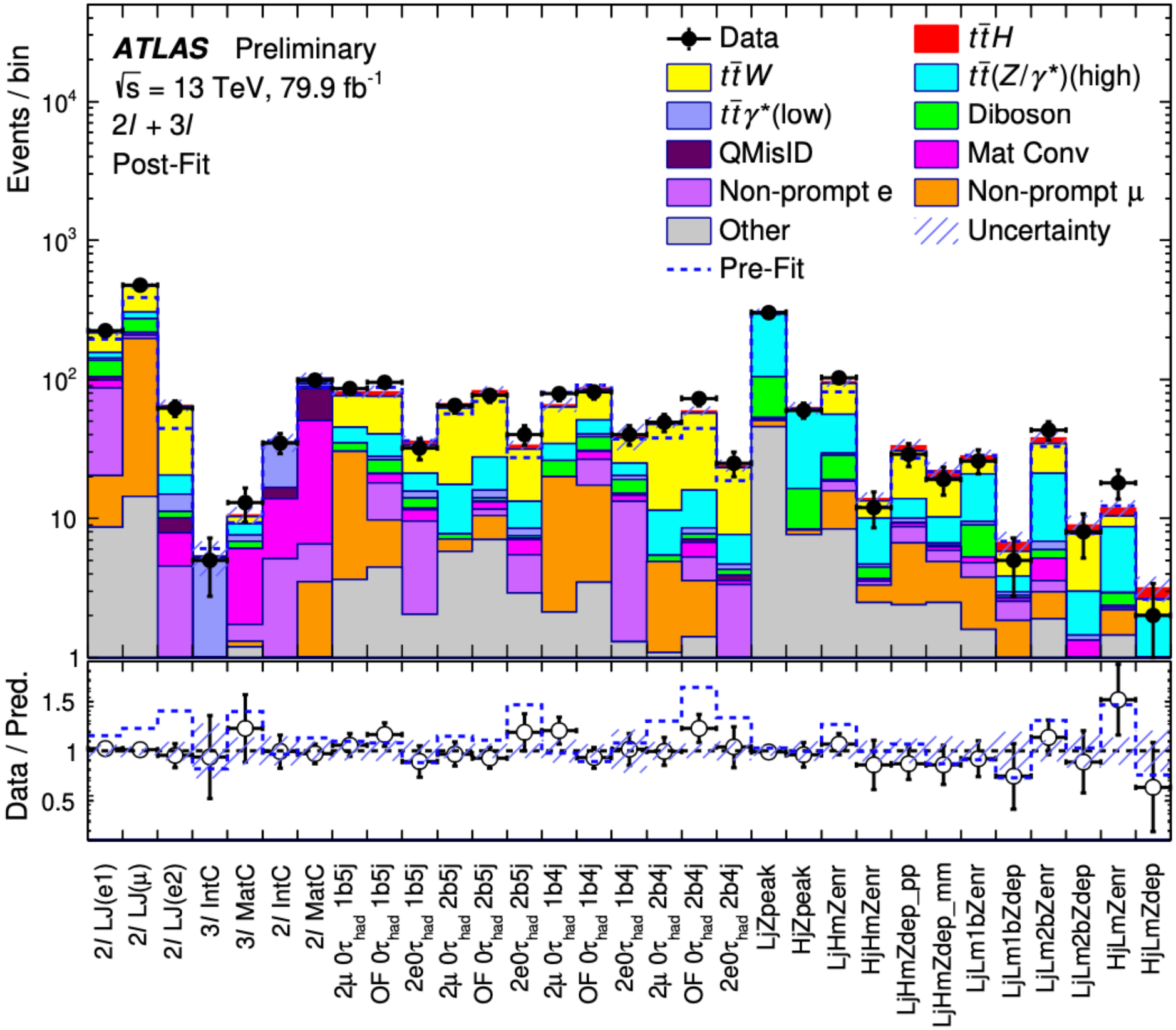
Cross-checks



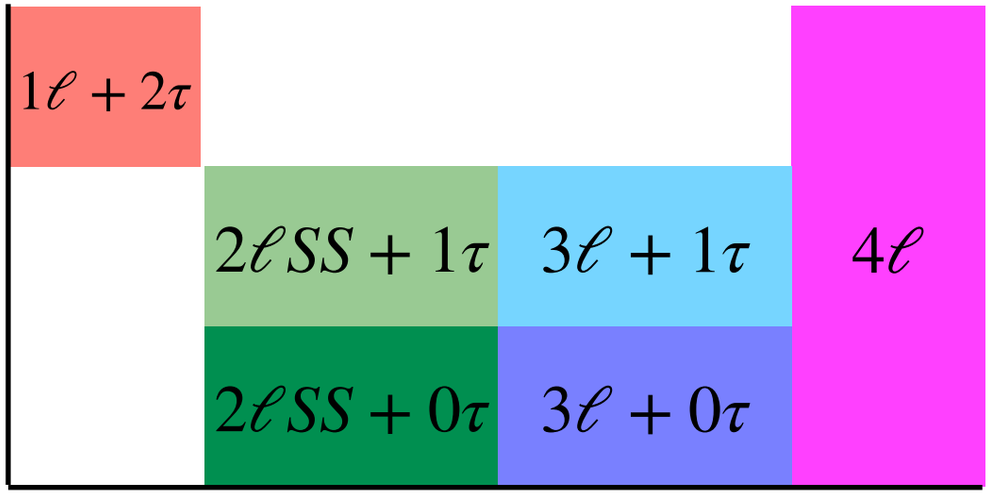


Cross-checks

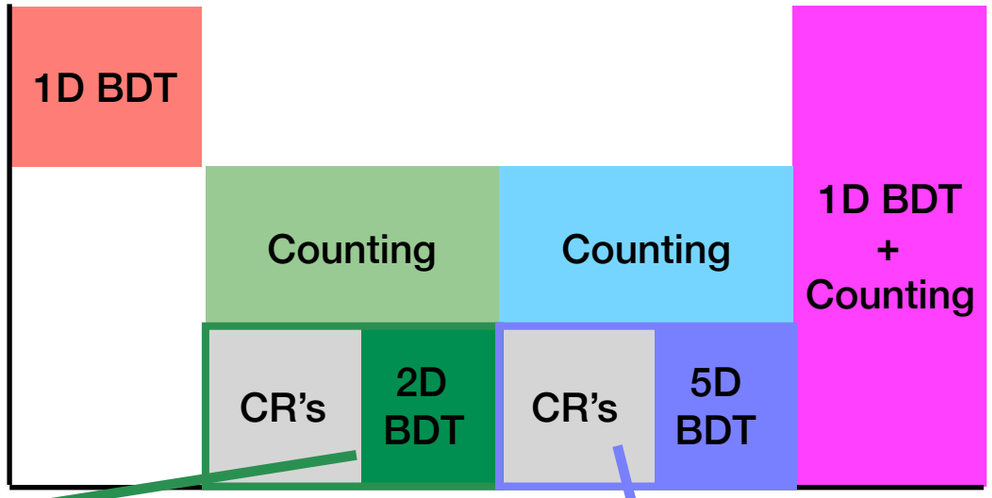
Cut & Count



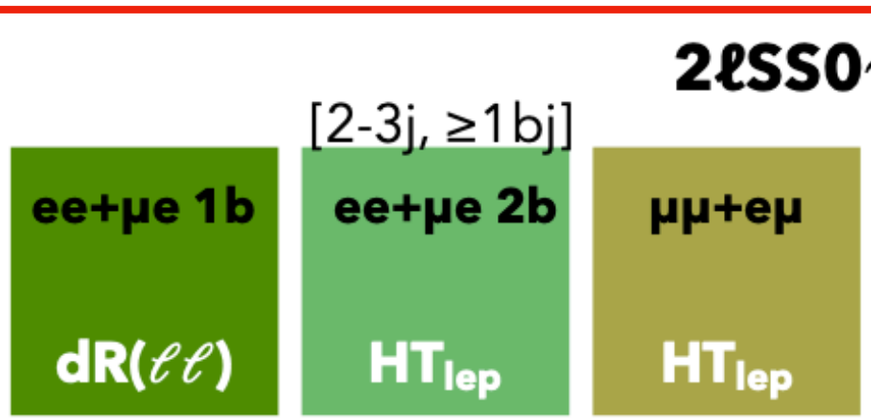
Fit Model



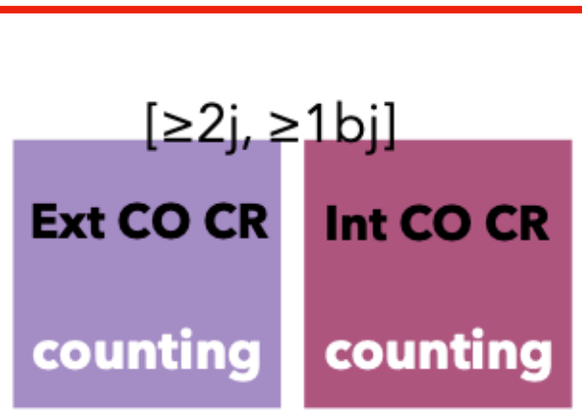
Optimizations in each Channel



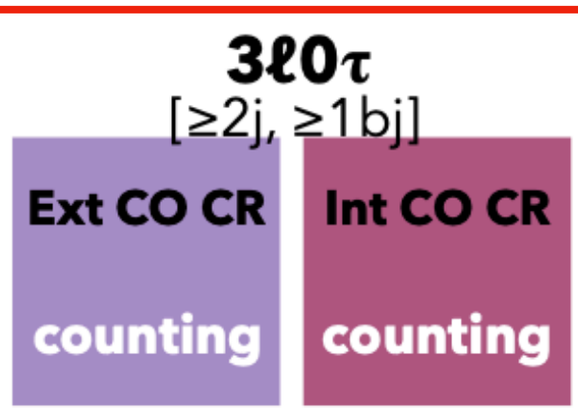
2ℓSS0τ [2-3j, ≥1bj]



2ℓSS0τ [≥2j, ≥1bj]

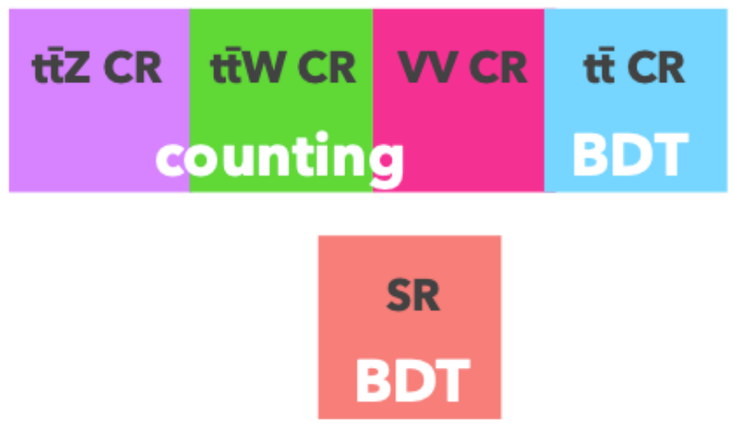


3ℓ0τ [≥2j, ≥1bj]



2ℓSS0τ [≥4j, ≥1bj]

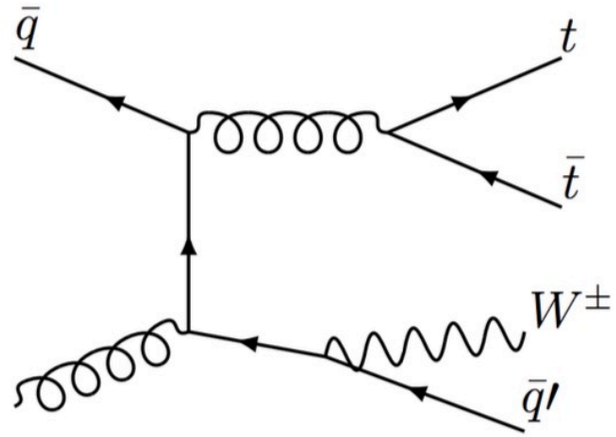
- Dedicated $t\bar{t}W$ Control regions
- Control regions for Conversion fakes



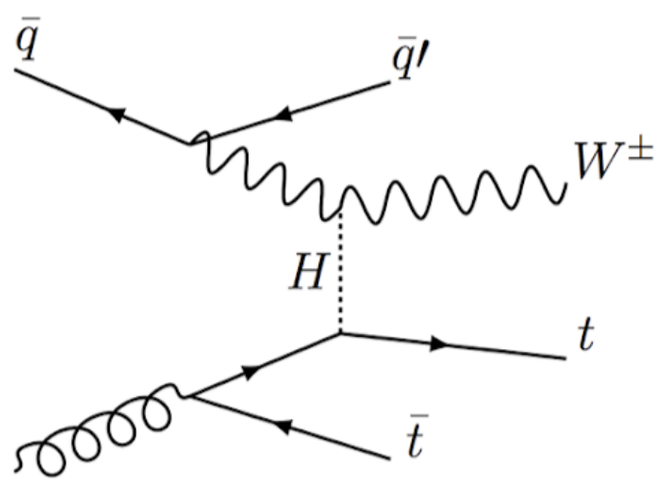
$t\bar{t}W$ Modeling

- We float this background in our fit model with 3 normalization factors and extrapolation uncertainties for the charge asymmetry.
- There are two known corrections which are missing in YR4 recommendation. We apply these corrections.

- QCD corrections: [1405.0301]
  - qg initiated $t\bar{t}W$ diagrams have only LO accuracy
  - Correction factor 1.11



- NLO3 Electroweak corrections: [1711.02116]
  - t-channel higgs diagrams are missing in the calculations
  - Correction factor 1.09

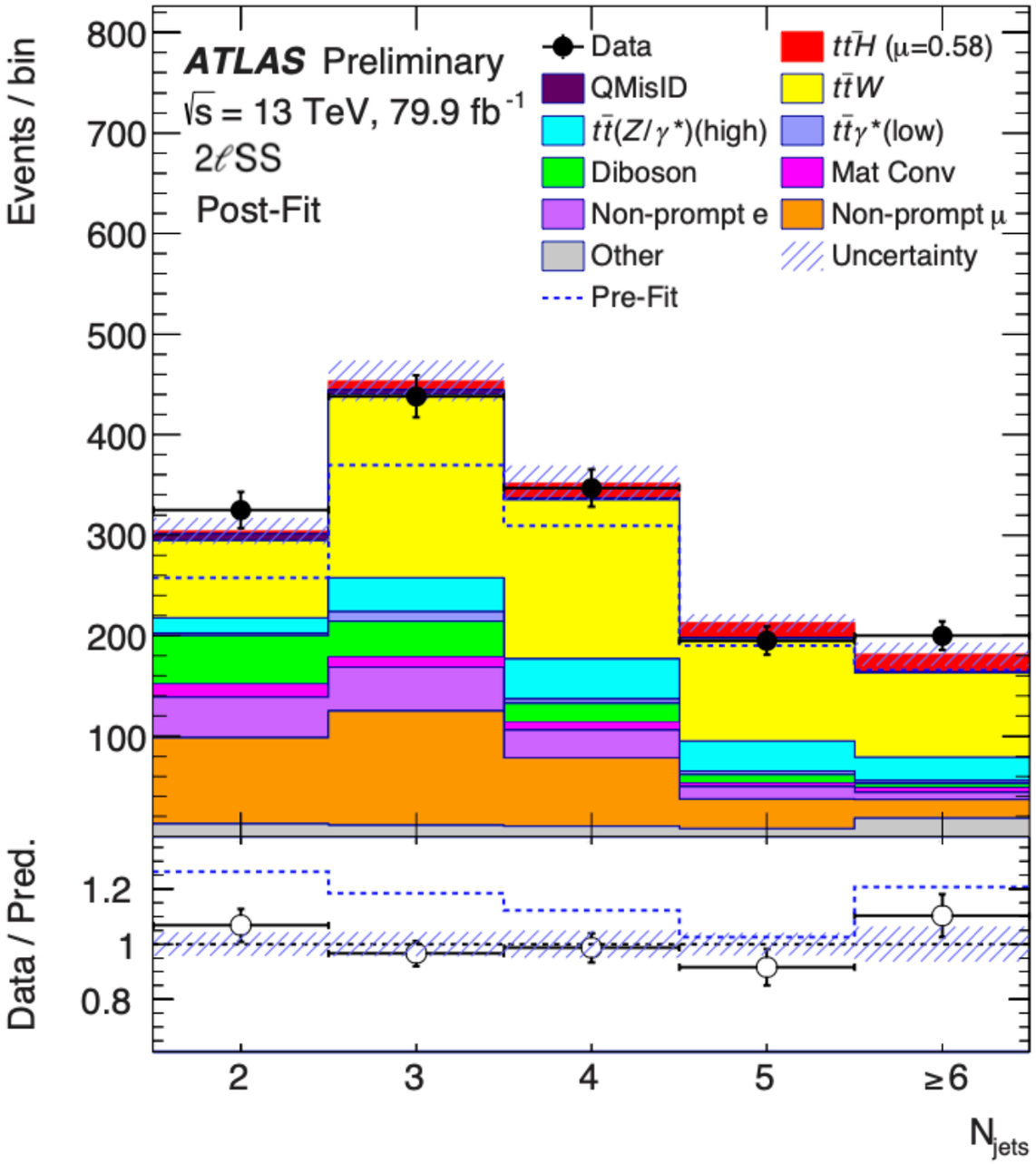


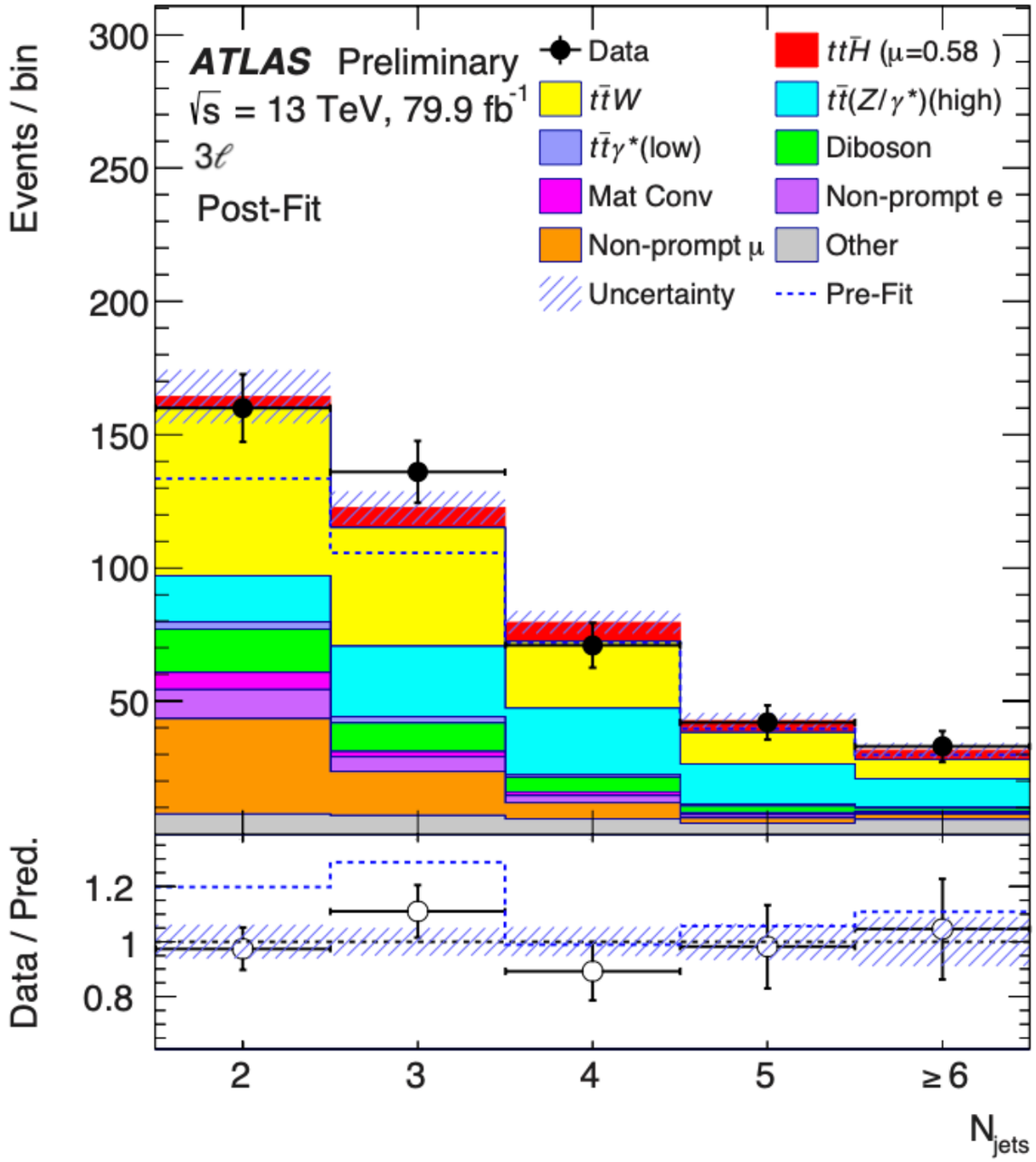
- Total of 1.2 k-factor applied for $t\bar{t}W$
- Updated $t\bar{t}W$ cross-section [601 ± 76 fb $\longrightarrow$ 727 ± 92 fb]

$t\bar{t}W$ Model

Process	Generator	ME order	Parton shower	PDF	Tune
$t\bar{t}H$	POWHEG-BOX [23, 24]	NLO	PYTHIA 8	NNPDF3.0 NLO [25]/ NNPDF2.3 LO [48]	A14
	(POWHEG-BOX)	(NLO)	(HERWIG7)	(NNPDF3.0 NLO/ MMHT2014 LO [49])	(H7-UE-MMHT)
$tHqb$	MG5_aMC	LO	PYTHIA 8	CT10 [50]	A14
tHW	MG5_aMC	NLO	HERWIG++	CT10/ CTEQ6L1 [51, 52]	UE-EE-5
$t\bar{t}W$	SHERPA 2.2.1 (MG5_aMC)	MEPS@NLO (NLO)	SHERPA (PYTHIA 8)	NNPDF3.0 NNLO (NNPDF3.0 NLO/ NNPDF2.3 LO)	SHERPA default (A14)
$t\bar{t}(Z/\gamma^*)$	MG5_aMC	NLO	PYTHIA 8	NNPDF3.0 NLO/ NNPDF2.3 LO	A14
	(SHERPA 2.2.0)	(LO multileg)	(SHERPA)	(NNPDF3.0 NLO)	(SHERPA default)
$t\bar{t} \to W^+bW^-\bar{b}l^+l^-$	MG5_aMC	LO	PYTHIA 8	NNPDF3.0 LO	A14
tZ	MG5_aMC	LO	PYTHIA 6	CTEQ6L1	Perugia2012
tWZ	MG5_aMC	NLO	PYTHIA 8	NNPDF2.3 LO	A14
$t\bar{t}t$, $t\bar{t}t\bar{t}$	MG5_aMC	LO	PYTHIA 8	NNPDF2.3 LO	A14
$t\bar{t}W^+W^-$	MG5_aMC	LO	PYTHIA 8	NNPDF2.3 LO	A14
$t\bar{t}$	POWHEG-BOX	NLO	PYTHIA 8	NNPDF3.0 NLO/ NNPDF2.3 LO	A14
Single top (t-, Wt-, s-channel)	POWHEG-BOX [53–55]	NLO	PYTHIA 8	NNPDF3.0 NLO/ NNPDF2.3 LO	A14
VV, $qqVV$, VVV	SHERPA 2.2.2	MEPS@NLO	SHERPA	NNPDF3.0 NNLO	SHERPA default
$Z \to l^+l^-$	SHERPA 2.2.1	MEPS@NLO	SHERPA	NNPDF3.0 NLO	SHERPA default

$t\bar{t}W$ Model: Kinematic details





Previous results