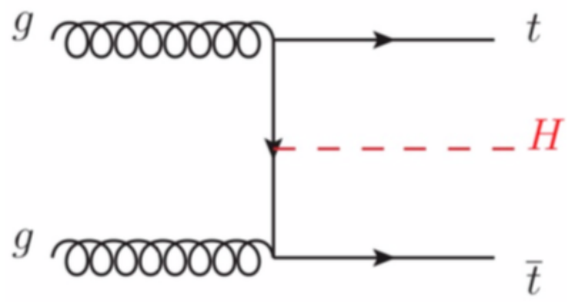
Analysis of $t\bar{t}H$ and $t\bar{t}W$ production in multilepton final state with the ATLAS detector.

Rohin Narayan for ATLAS collaboration
Southern Methodist University, Dallas

ATLAS-CONF-2019-045

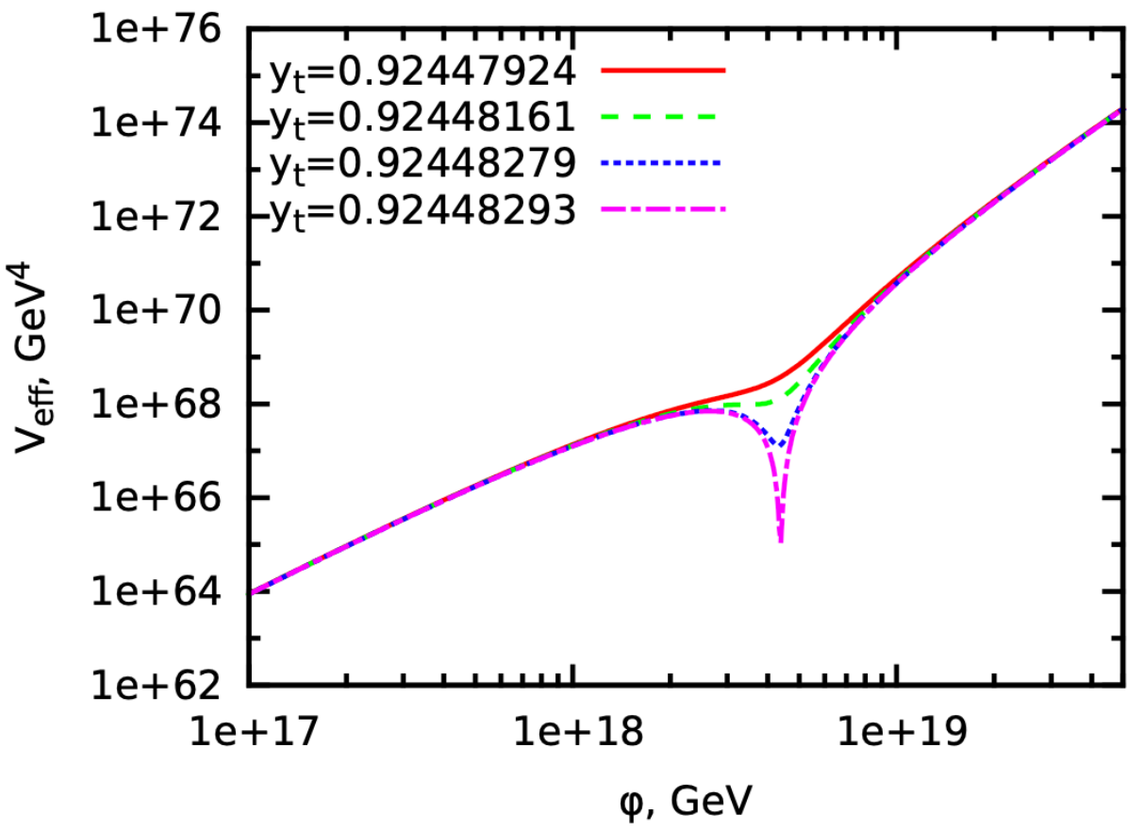
Why do we measure $t\bar{t}H$?

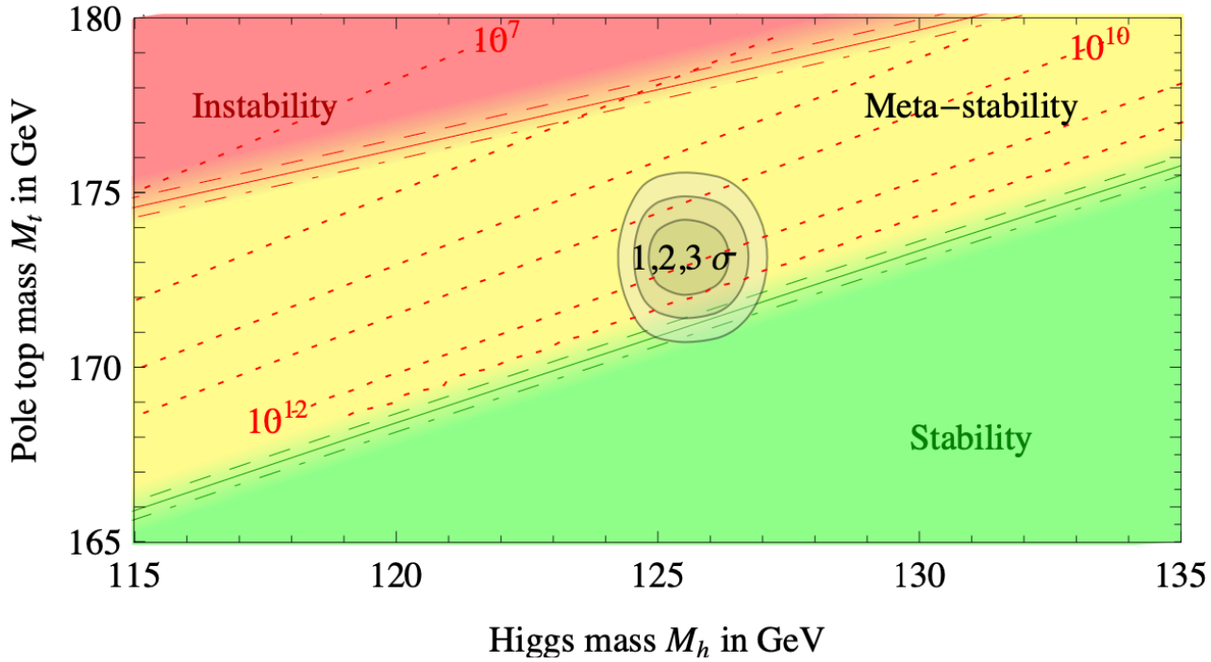


- Top quarks: Large Yukawa coupling to Higgs (y_t)
- ttH/tH production cross-section measurement is the only direct way to measure y_t

Are we in a stable universe?

- Measured Higgs boson and Top quark masses suggest we are close to the metastability region.

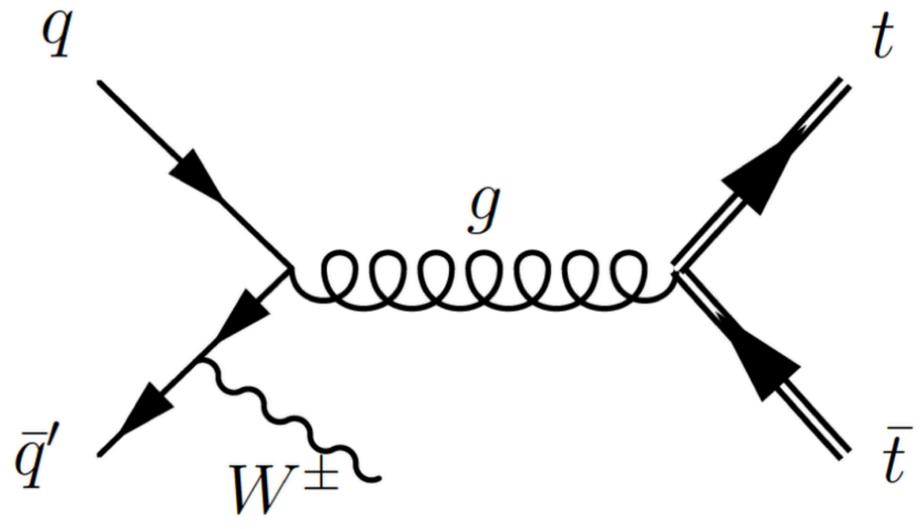




- Assuming Standard model is true up to GUT scale:
  - top Yukawa coupling sensitive to additional minima in the effective Higgs potential.

arXiv:1205.6497v2
arXiv:1411.1923v2

Why do we measure $t\bar{t}W$?



arxiv:1406.3262

- At LO $t\bar{t}W$ is a $q\bar{q}'$ initiated process with a $W^{\pm}$ emitted from the initial state.
- $q\bar{q}'$ initial state results in an asymmetry
  - As high as 12% in leptons from top quark legs
- Emission of W results in highly polarized $t\bar{t}$ system.

- Sensitive to physics beyond standard model
  - Eg: Axigluons
- Background to measurements with multiple leptonic signature.

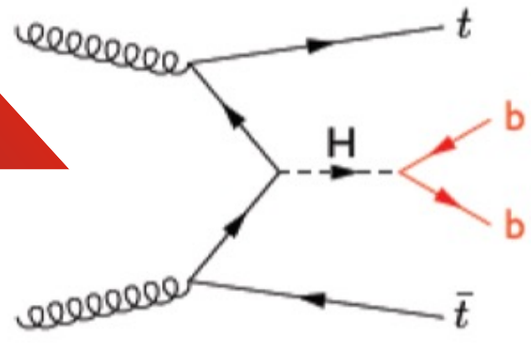
Multilepton measurement for $t\bar{t}H$

- $t\bar{t}W$ is an irreducible background in $t\bar{t}H$ multileptons analysis.

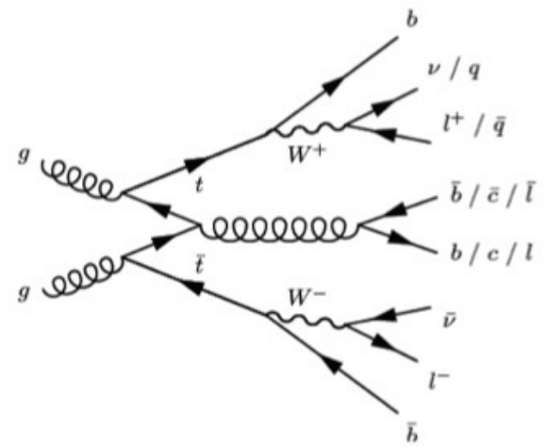
Signal

Backgrounds

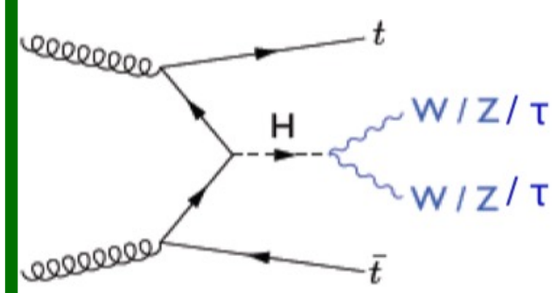
Higgs Branching ratio



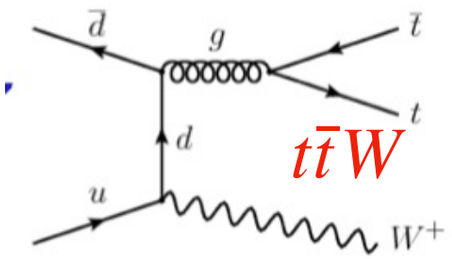
$t\bar{t}H(b\bar{b})$



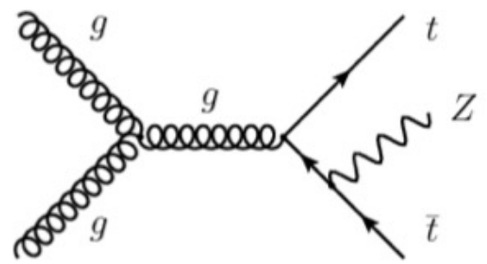
$t\bar{t}$+(HF) jets



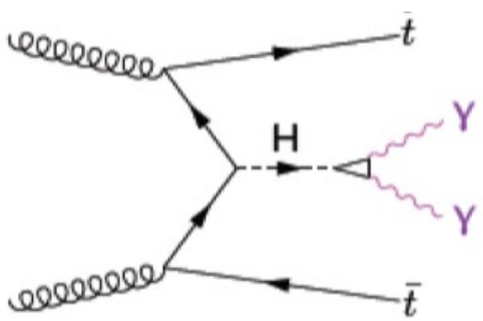
$t\bar{t}H$-multileptons



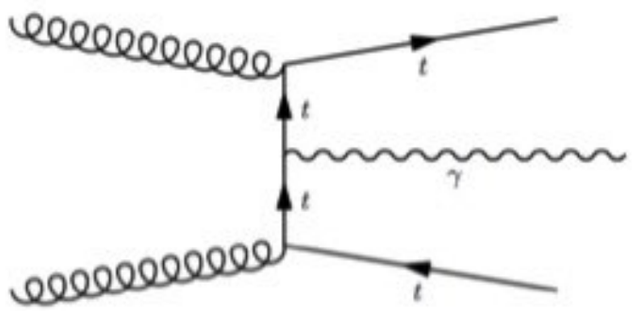
$t\bar{t}W$



$t\bar{t}Z$



$t\bar{t}H(\gamma\gamma)$

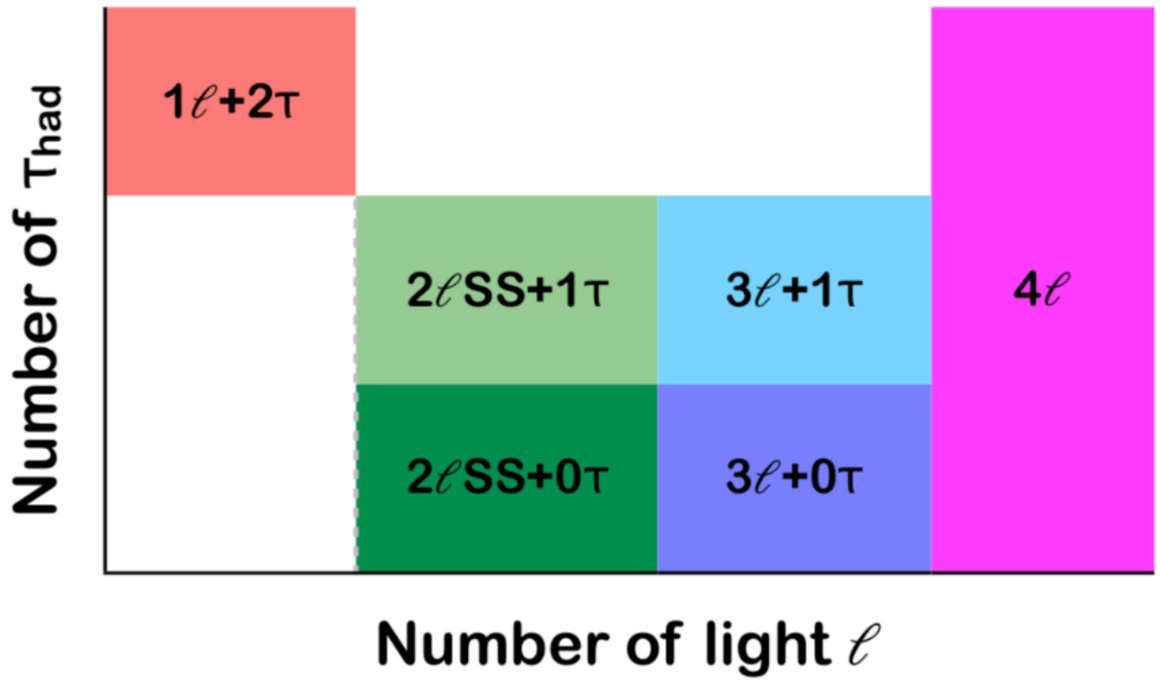


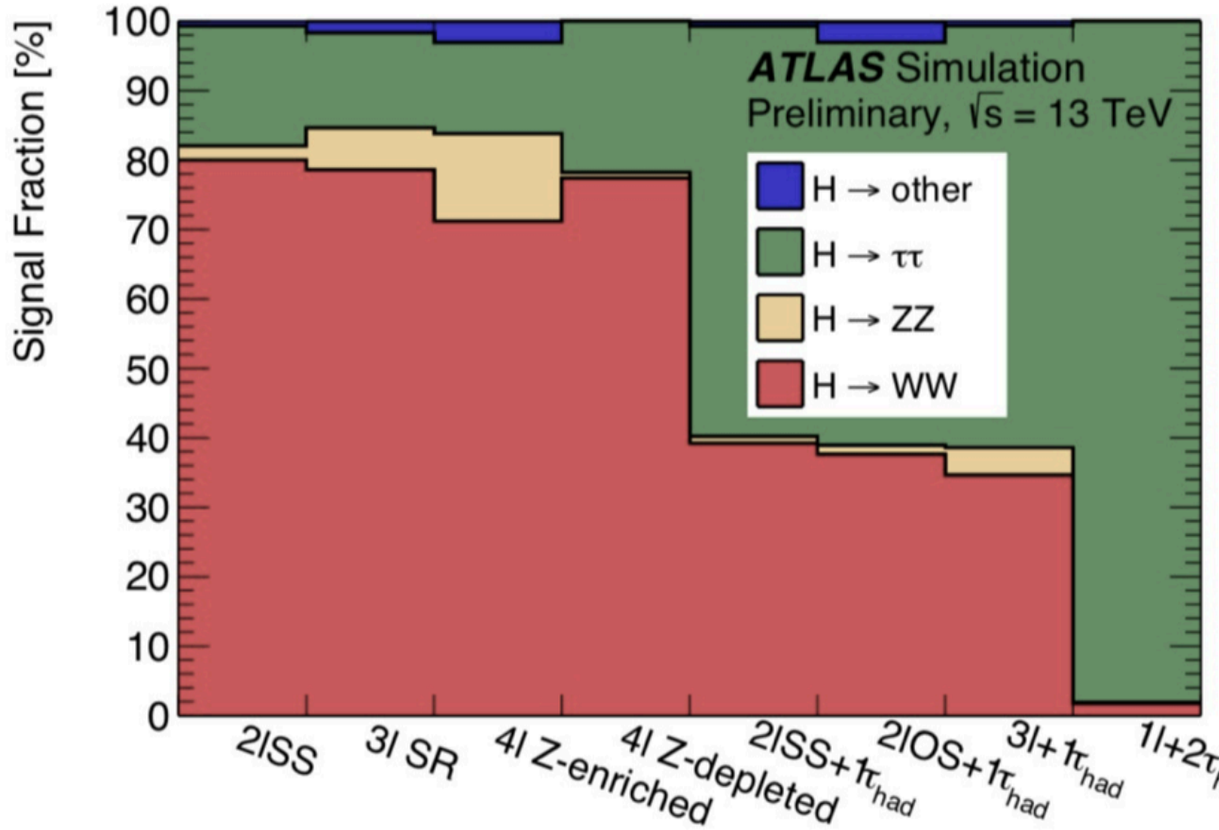
$t\bar{t}\gamma$

Analysis strategy

- Events categorized based on number of light leptons and hadronic taus ($\tau \rightarrow$ had)
- Common jet selection $N_{\text{jet}} \geq 2$ and $N_{\text{bjet}} \geq 1$

Higgs decay modes in sub channels

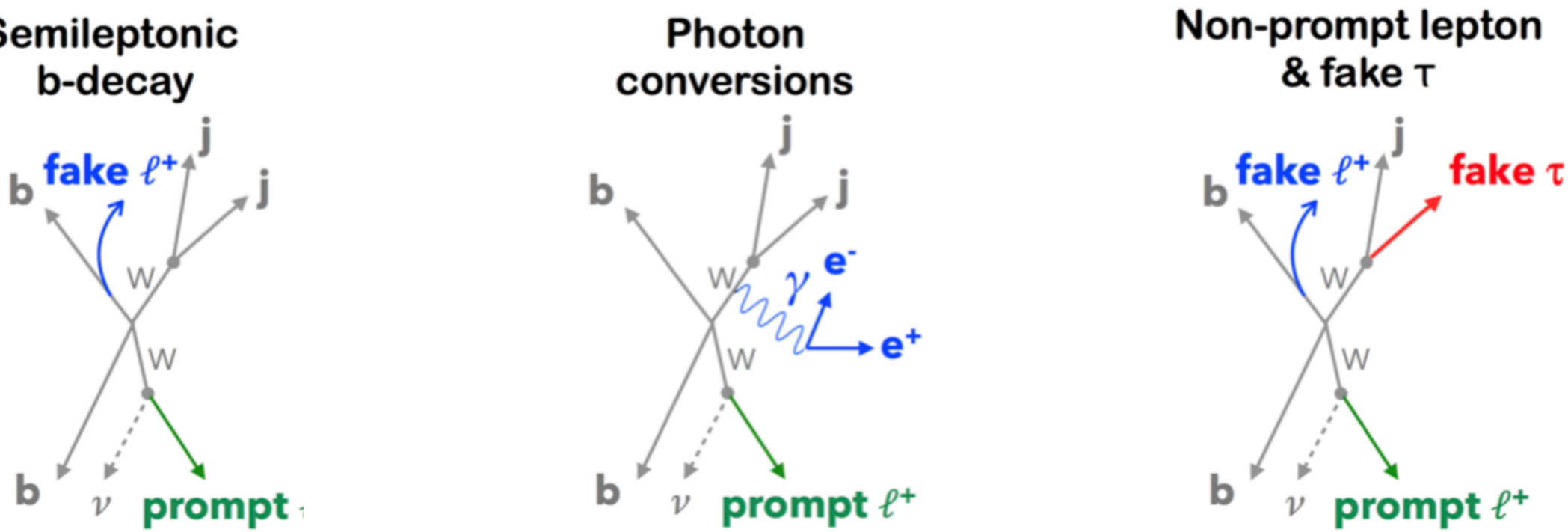




- Leptons ordered in p_T in $2\ell SS0\tau$ channel
- In $3l0\tau$ channel: 1 opposite sign and 2 same sign lepton

Backgrounds

- **Irreducible background** from prompt-leptons and hadronic taus
  - Mainly $t\bar{t}W, t\bar{t}Z, VV$: Estimated using Montecarlo.
- **Non-prompt lepton backgrounds**:

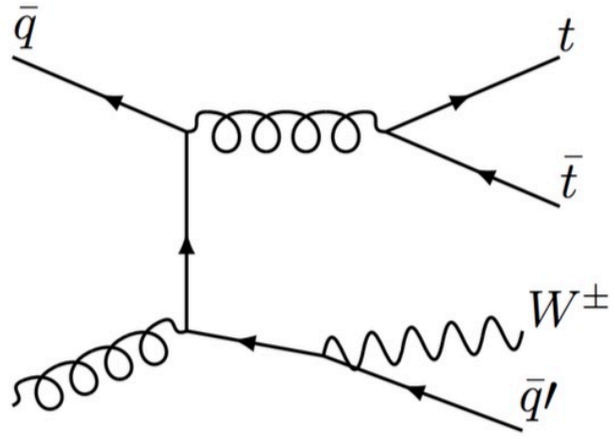


- Data-driven and semi data-driven techniques to estimate fakes.

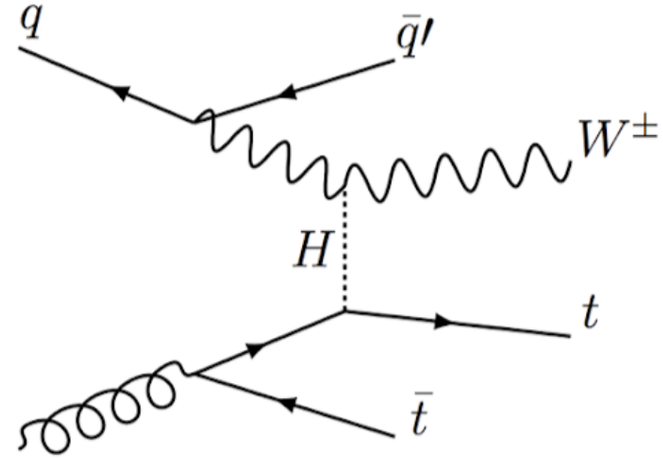
$t\bar{t}W$ Modeling

- There are two known cross section corrections which were not available in any MC generators.

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



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

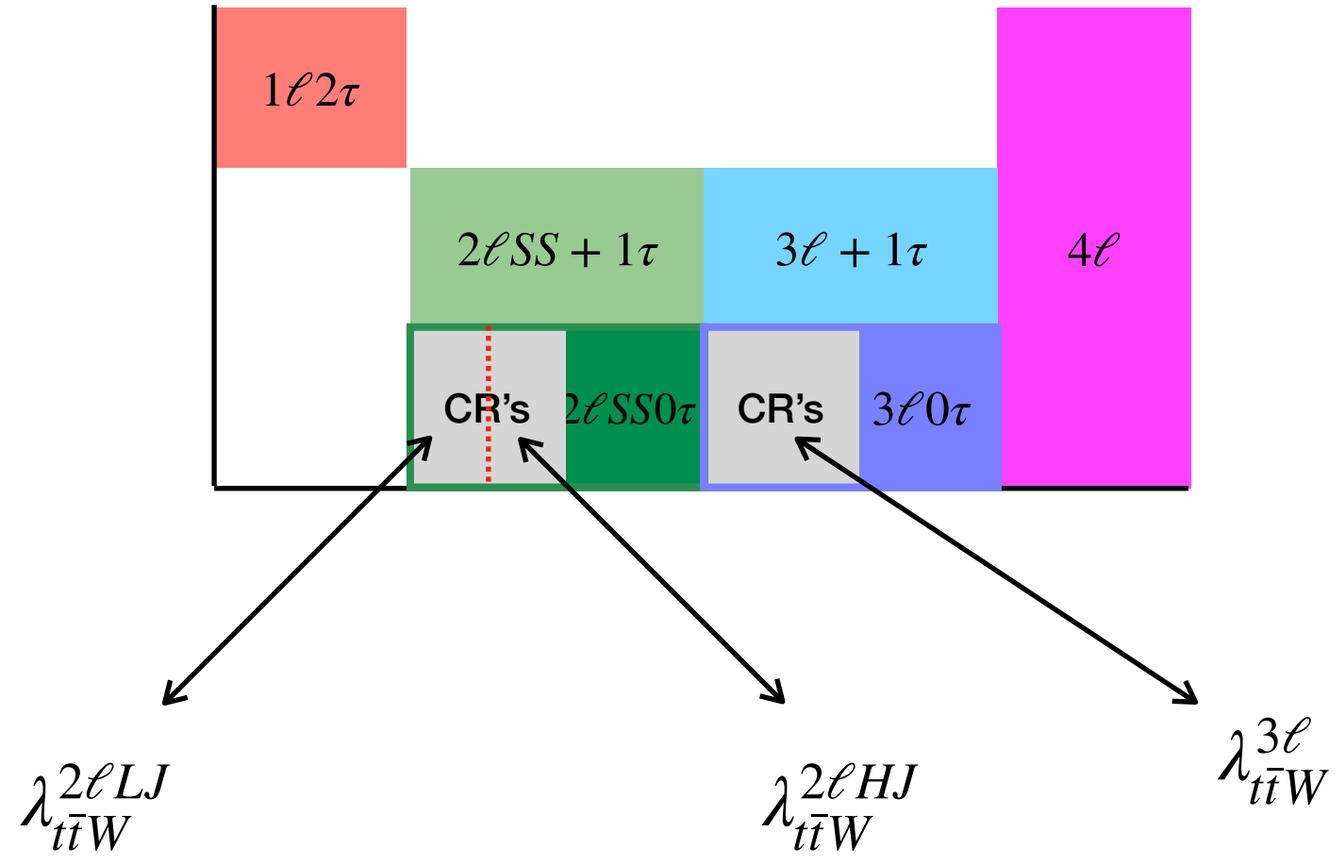


- Total of **1.2** k-factor applied for $t\bar{t}W$
  - Updated $t\bar{t}W$ cross-section [601 ± 76 fb $\longrightarrow$ 727 ± 92 fb]

$t\bar{t}W$ Modeling

Normalization factors

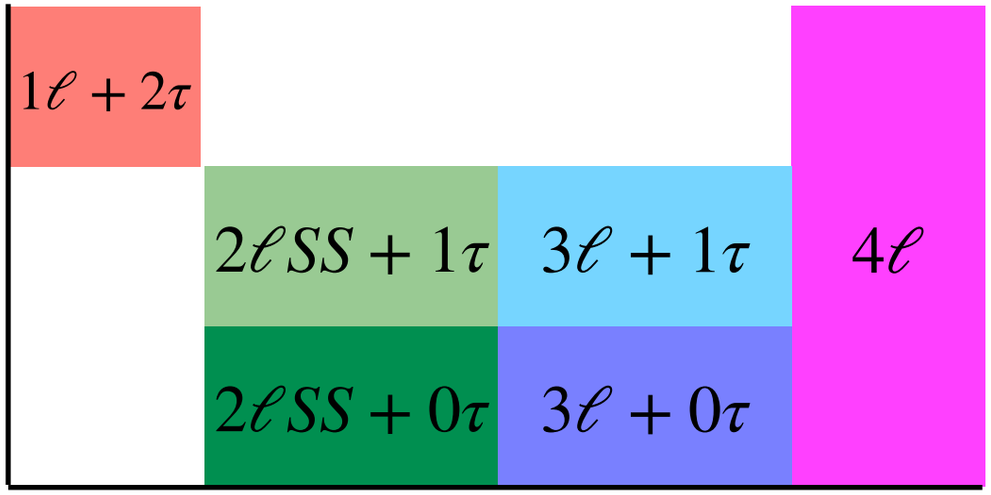
- 3 $t\bar{t}W$ normalization factors (across jet multiplicities and channels)
  - $\lambda_{t\bar{t}W}^{2\ell LJ}$ in $2\ell SS0\tau$ channel 2-3 jets regions
  - $\lambda_{t\bar{t}W}^{2\ell HJ}$ in $2\ell SS0\tau$ channel 4 jets and beyond
  - $\lambda_{t\bar{t}W}^{3\ell}$ in $3\ell 0\tau$ channel



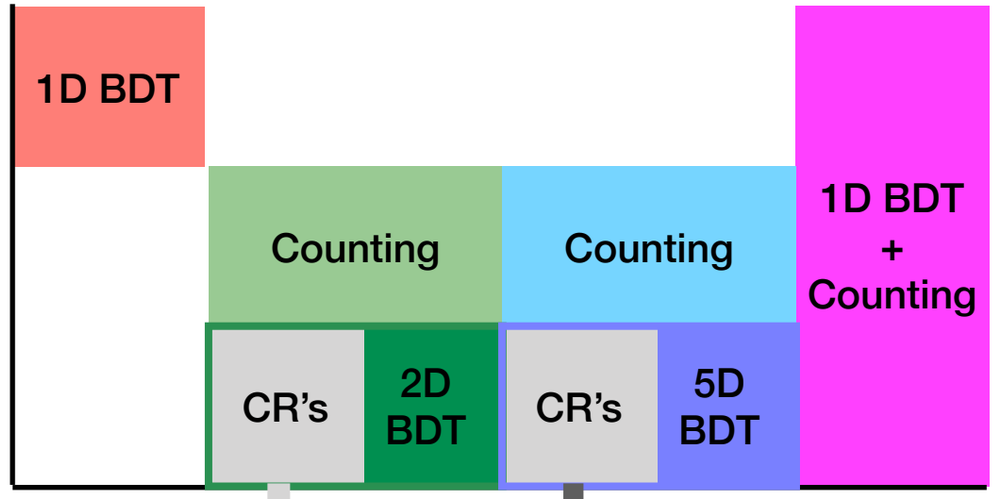
- These factors are determined by the fit

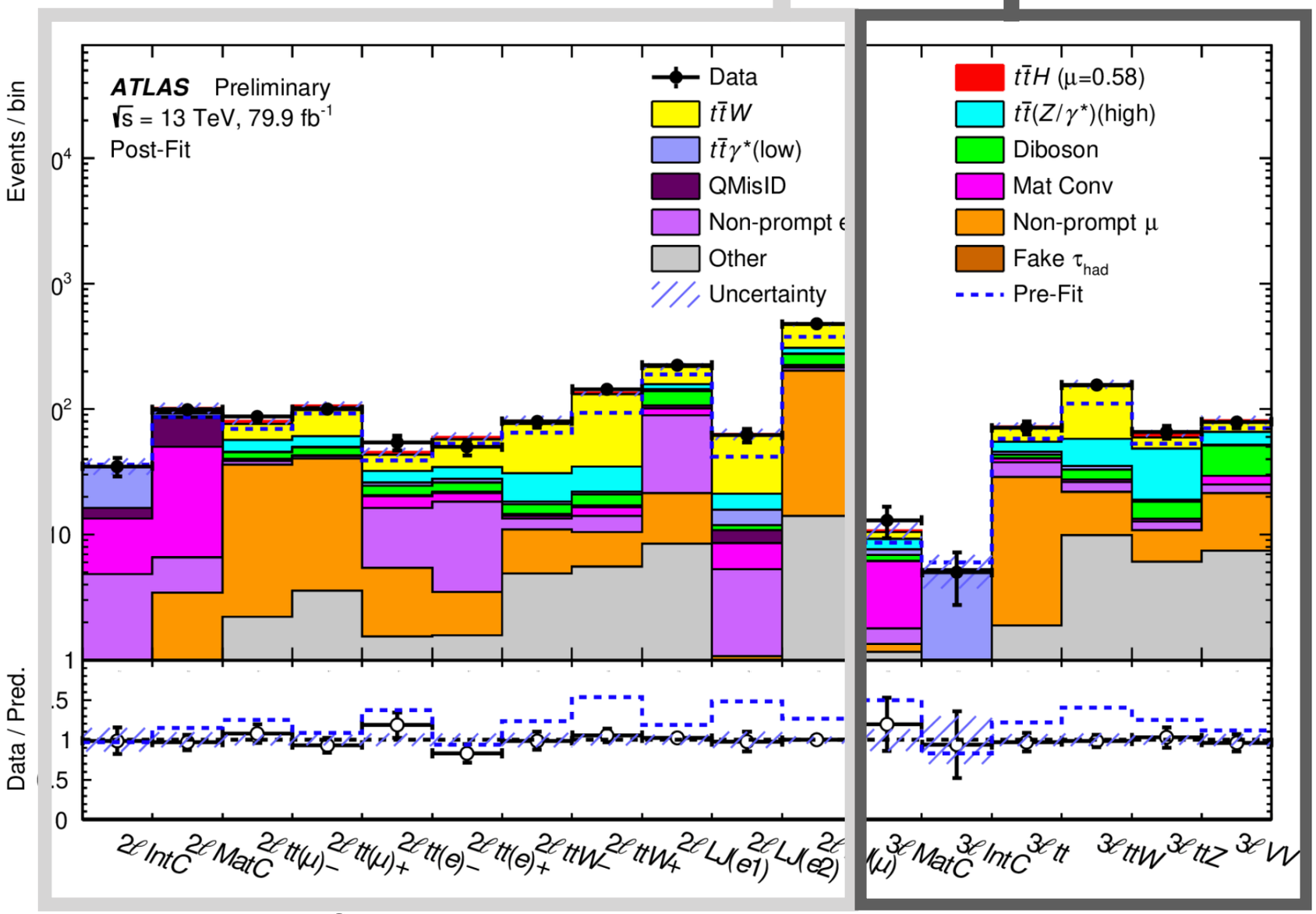
Fit Model

- In total 17 control regions + 8 signal regions.



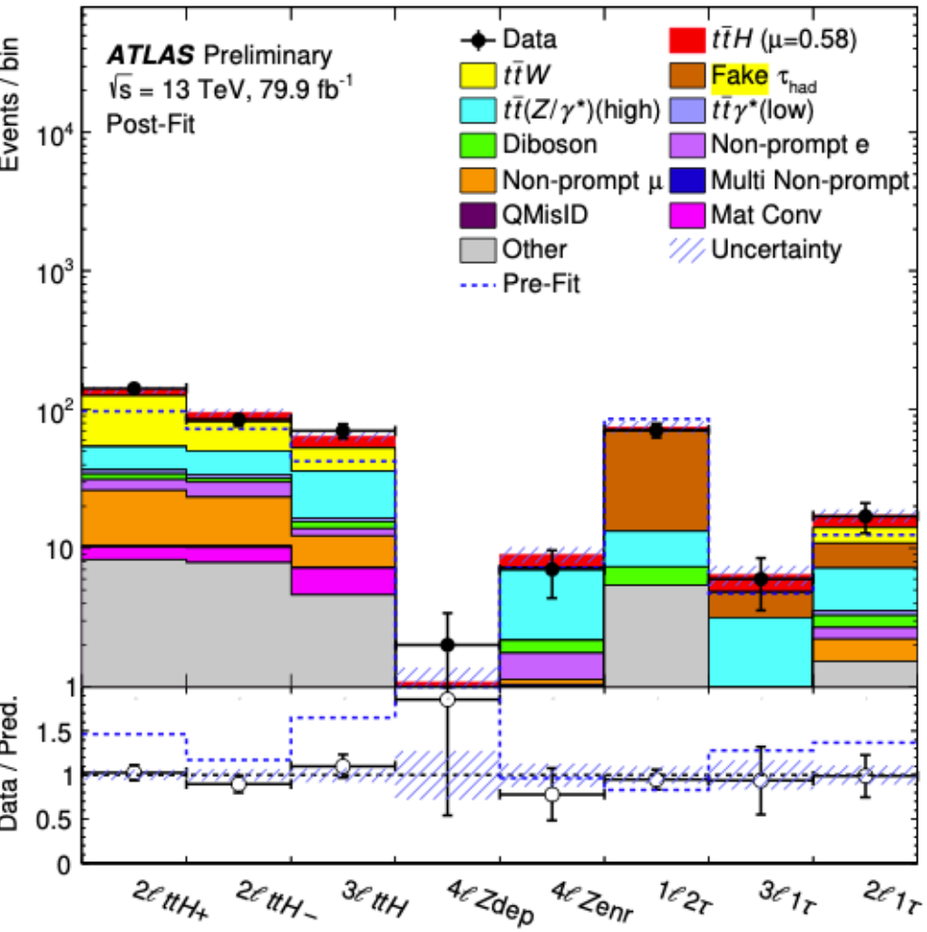
Optimizations in each Channel



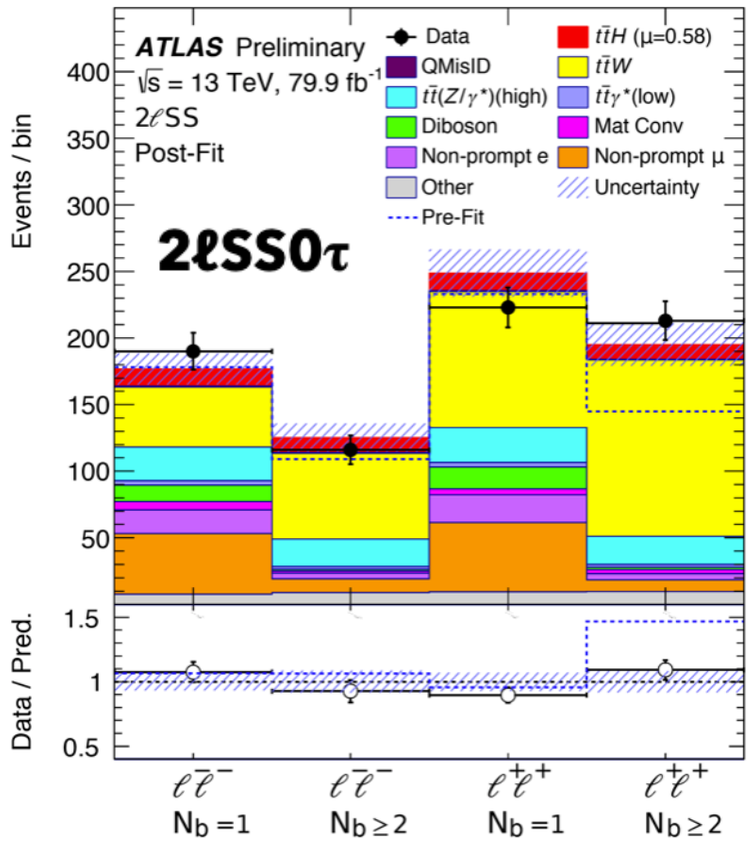


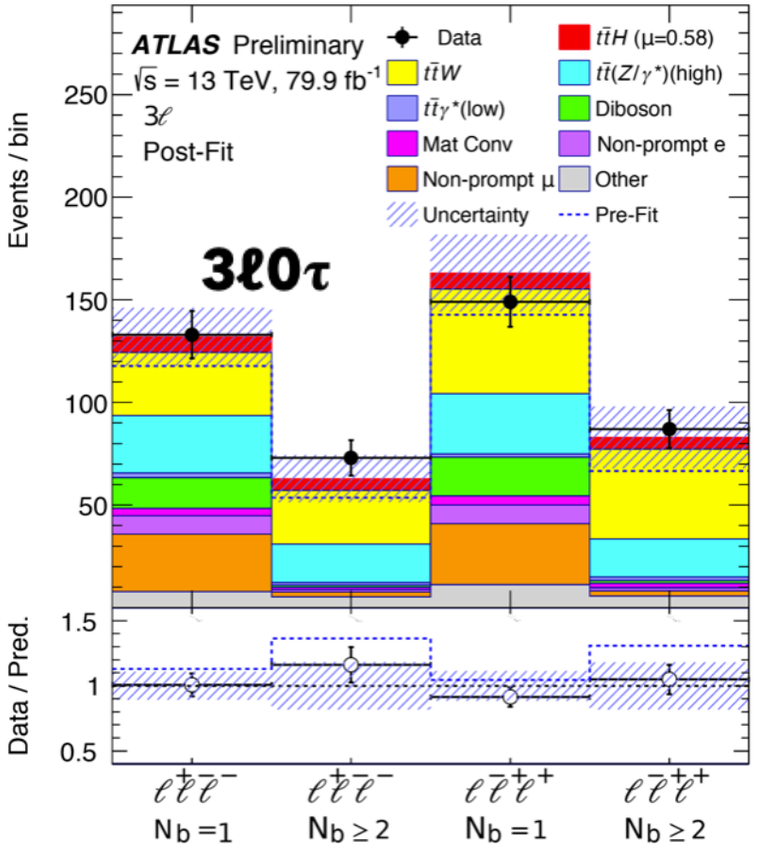
Fit Results:

$t\bar{t}H$ signal regions



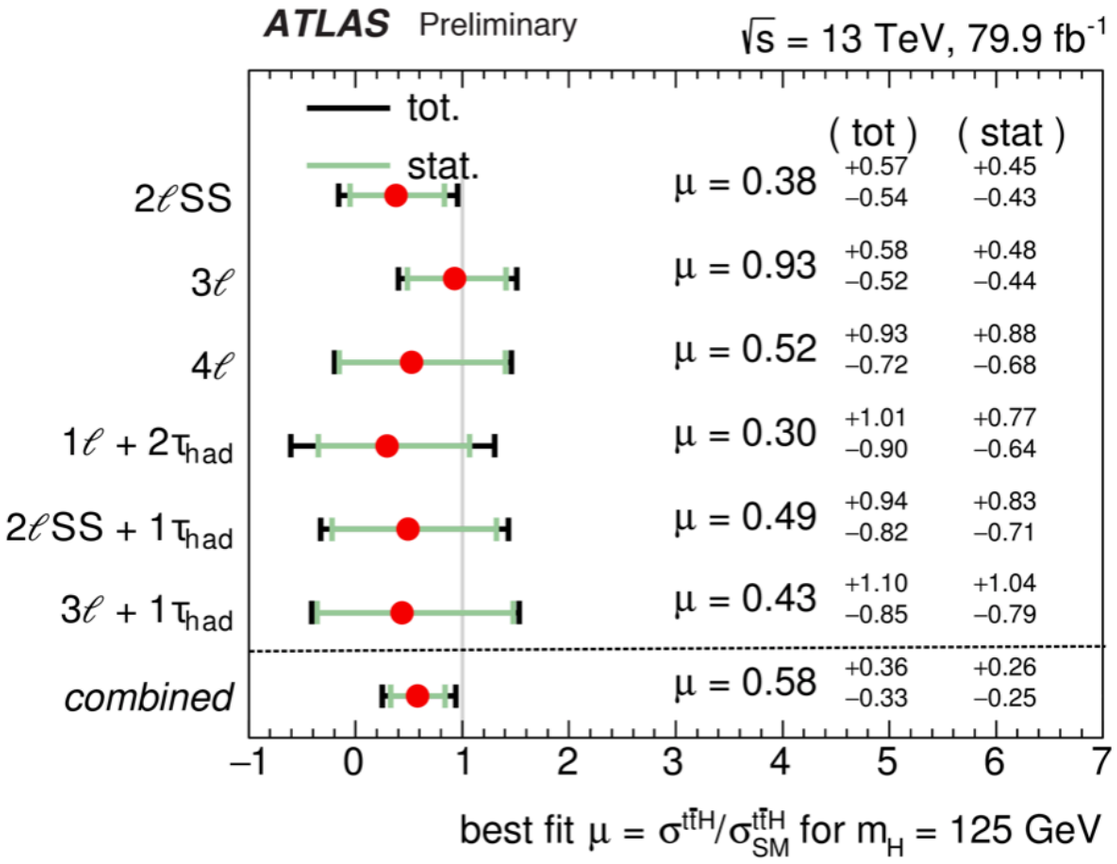
Total Charge & N_b–jets

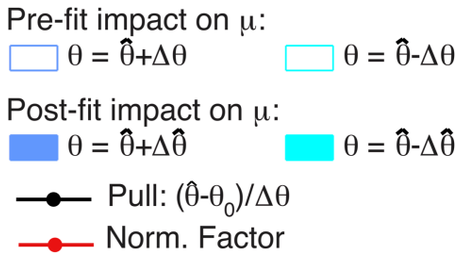


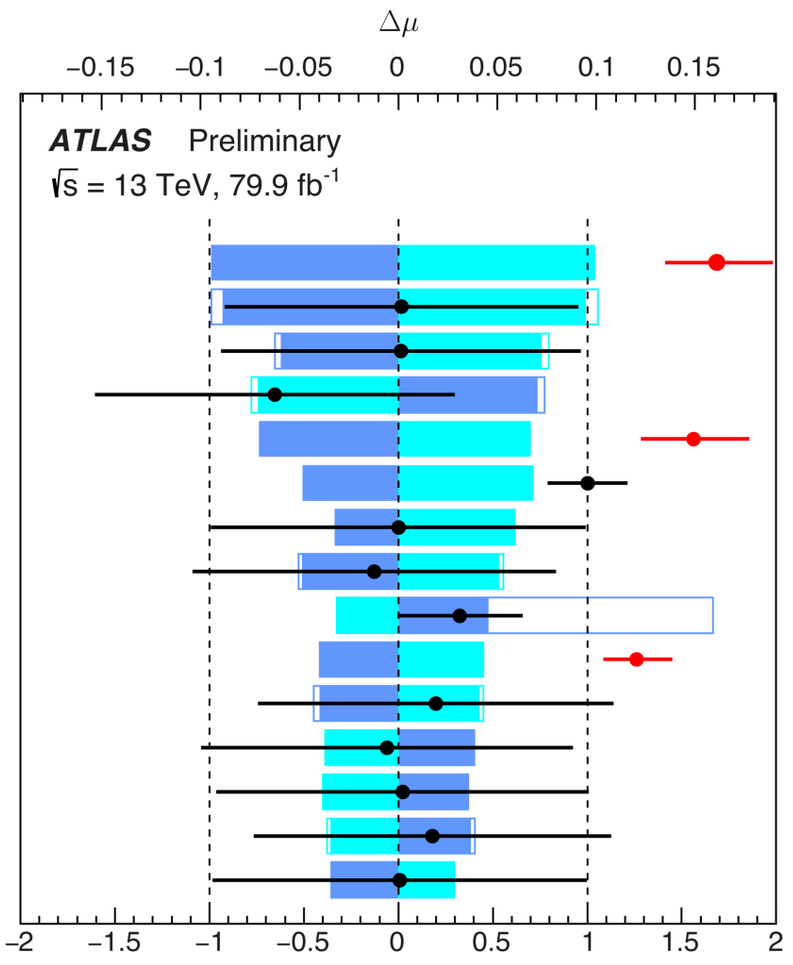


- Pre-fit mis-modeling in $t\bar{t}W$ dominated signal regions
- Mis-modeling depends on
  - Total charge
  - Number of b-tag jets.

Fit Results:







- Leading experimental systematics jet energy scale and resolution
- $t\bar{t}H$ Cross-section 294^{+182}_{-162} fb
- $t\bar{t}W$ 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 measurement 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.

- Fit to data prefers $t\bar{t}W$ background scaled between 1.3 and 1.7 wrt to standard model.

- Improved description of $t\bar{t}W$ process is needed to reach greater precision in $t\bar{t}H$ multileptons analysis

Backup

Analysis: Event and object selection

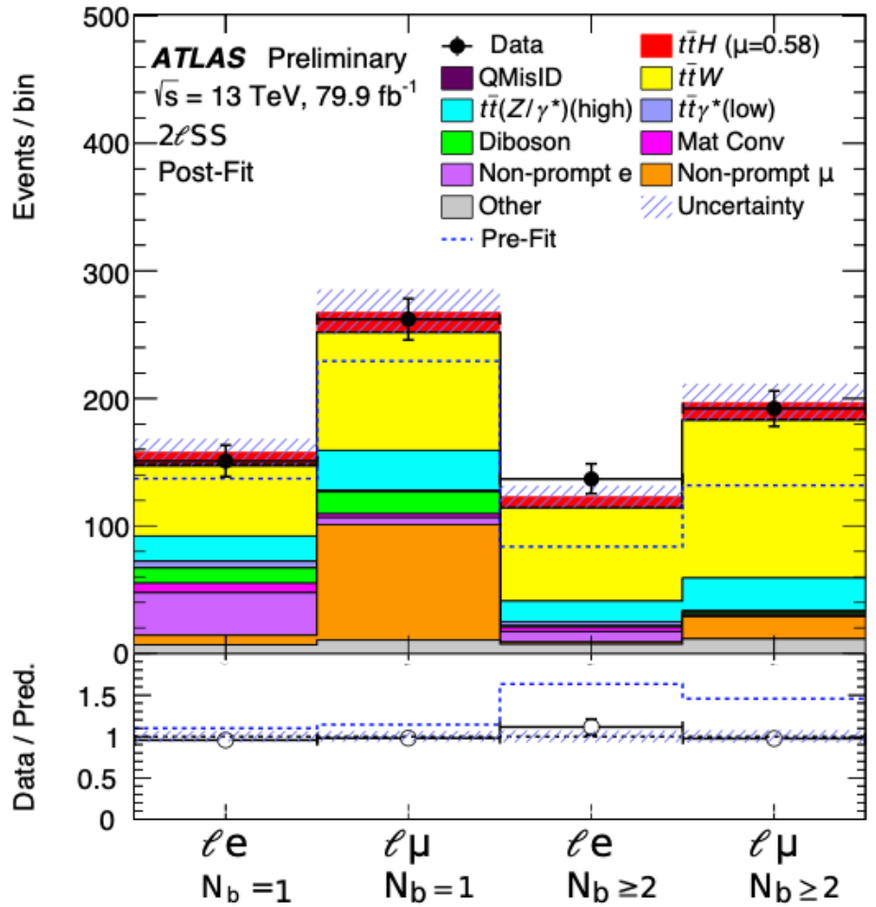
- Events are required to pass di-lepton trigger or single lepton trigger.

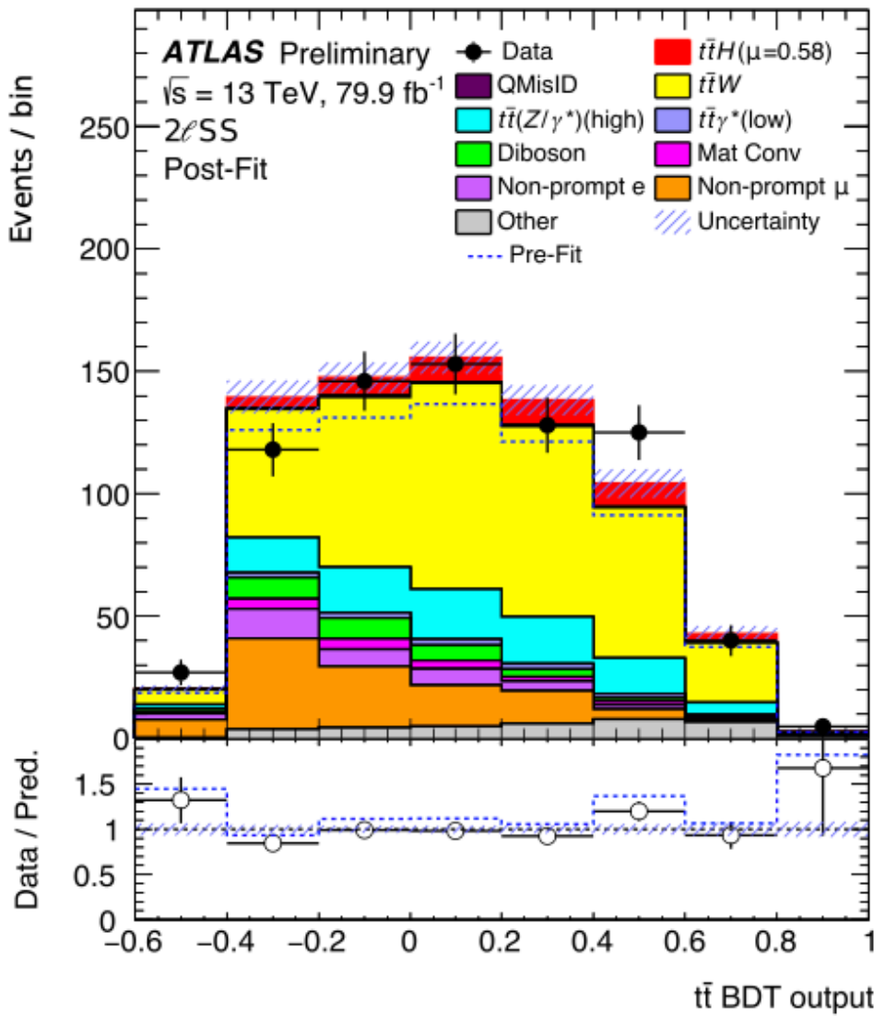
- Jets are reconstructed using anti-kT algorithm (R=0.4)
  - $p_T >$ 25 GeV, $|\eta| \leq 2.5$

- B-tagged jets are identified using a BDT algorithm(uses calorimeter and tracking information)
- Light leptons (e, μ) : At least 15 GeV p_T, $|\eta| \leq 2.5$, (“Crack removal” for electrons)
- τ_{had} reconstructed using calo and tracking information.
  - Identification enriched using a BDT algorithm
  - $p_T > 25$ GeV $|\eta| \leq 2.5$

Fit: Modeling of Non-prompt leptons

- Checking flavor dependance of non-prompt lepton modeling.
- Pre-fit mis-modeling is not related to non-prompt mis-modeling.

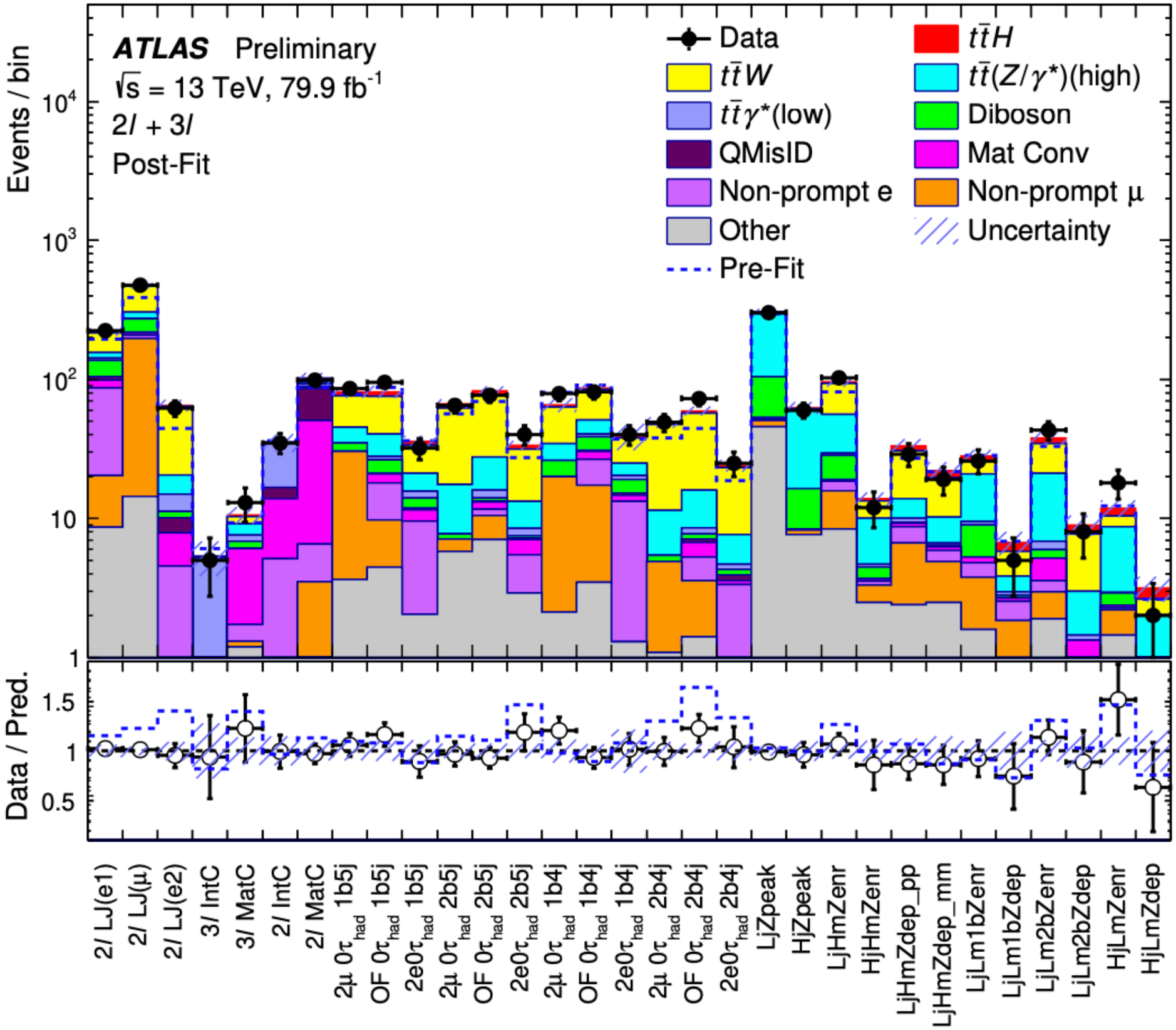




- Checking $t\bar{t}$ vs $t\bar{t}W$ BDT from $2lSS0\tau$ channel.
- No mis-modeling observed in $t\bar{t}$ enriched Non-prompt lepton dominated regions

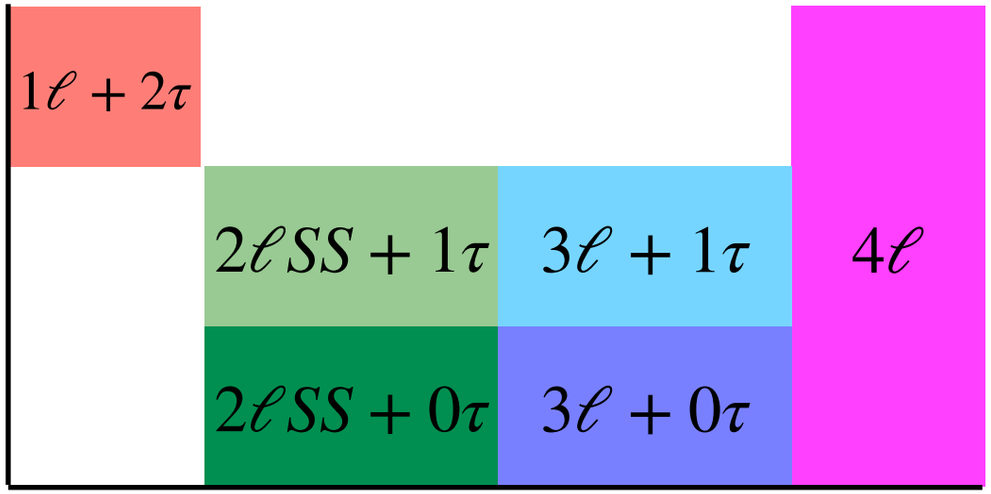
Cross-checks

Cut & Count

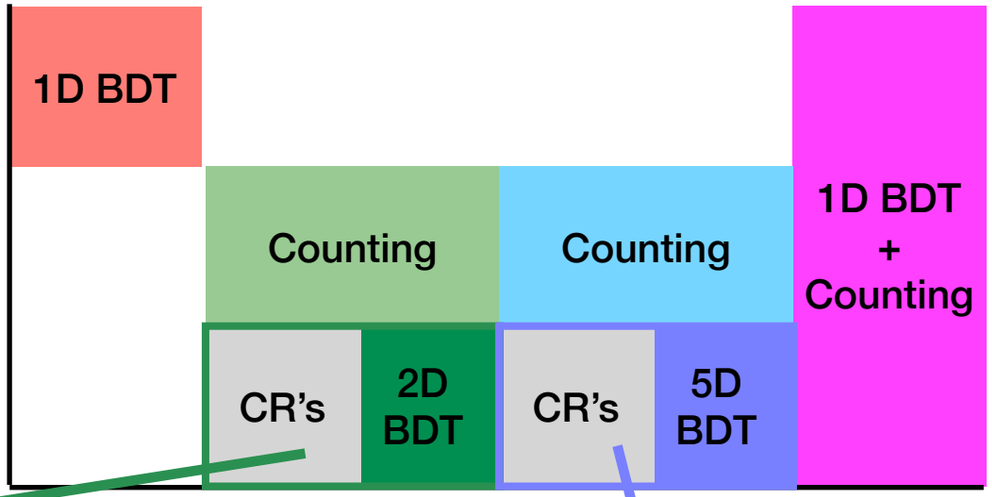


R . Narayan

Fit Model



Optimizations in each Channel



2ℓSS0τ [2-3j, ≥1bj]

ee+μe 1b	ee+μe 2b	μμ+eμ
$dR(\ell\ell)$	HT_{lep}	HT_{lep}

2ℓSS0τ [≥2j, ≥1bj]

Ext CO CR	Int CO CR
counting	counting

3ℓ0τ [≥2j, ≥1bj]

Ext CO CR	Int CO CR
counting	counting

2ℓSS0τ [≥4j, ≥1bj]

$t\bar{t}$ ee+μe CR	$t\bar{t}$ μμ+eμ CR
++ --	++ --
SR $BDT_{t\bar{t}V}$	$t\bar{t}W$ CR
++ --	++ --

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

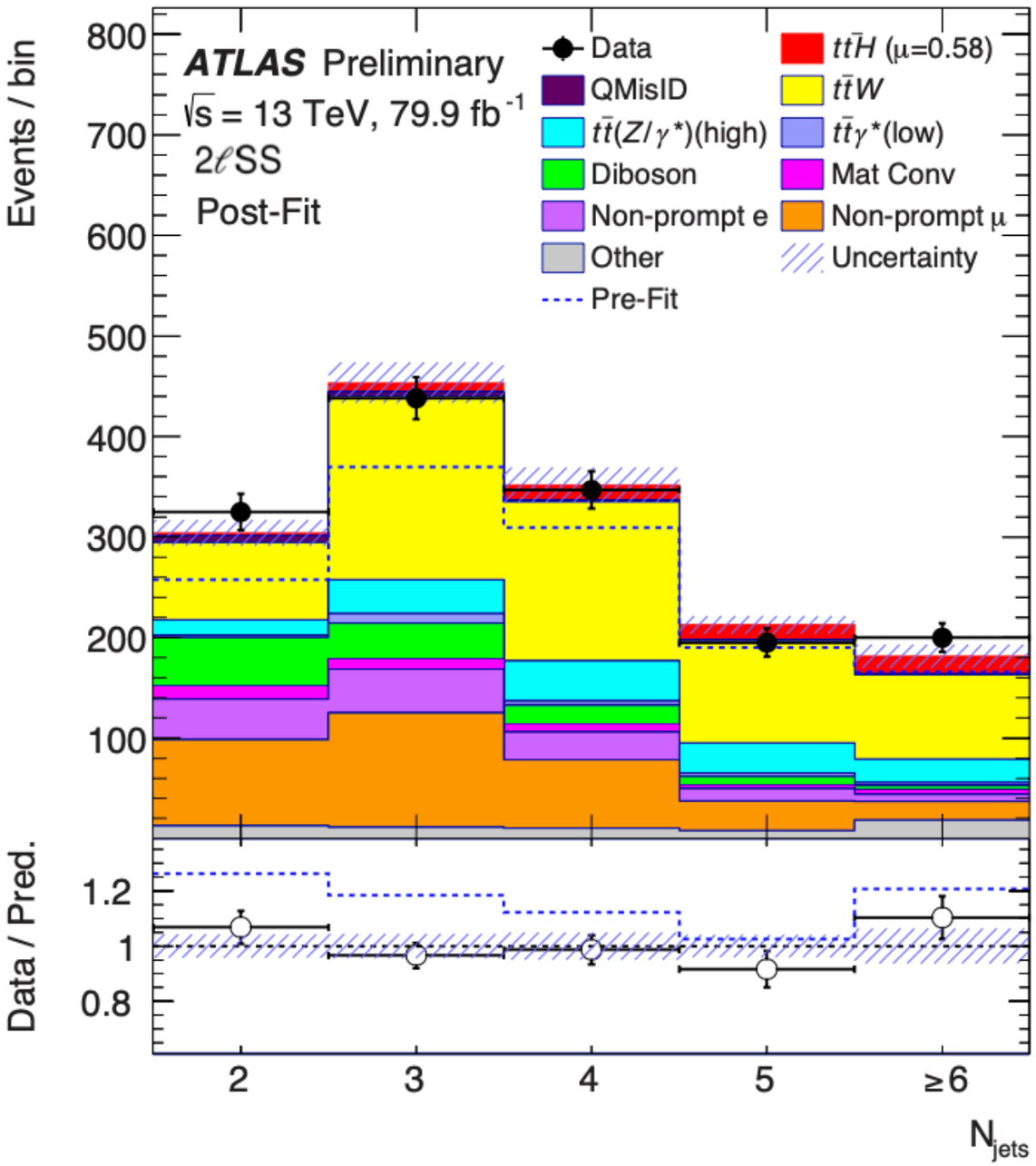
$t\bar{t}Z$ CR	$t\bar{t}W$ CR	VV CR	$t\bar{t}$ CR
counting			BDT

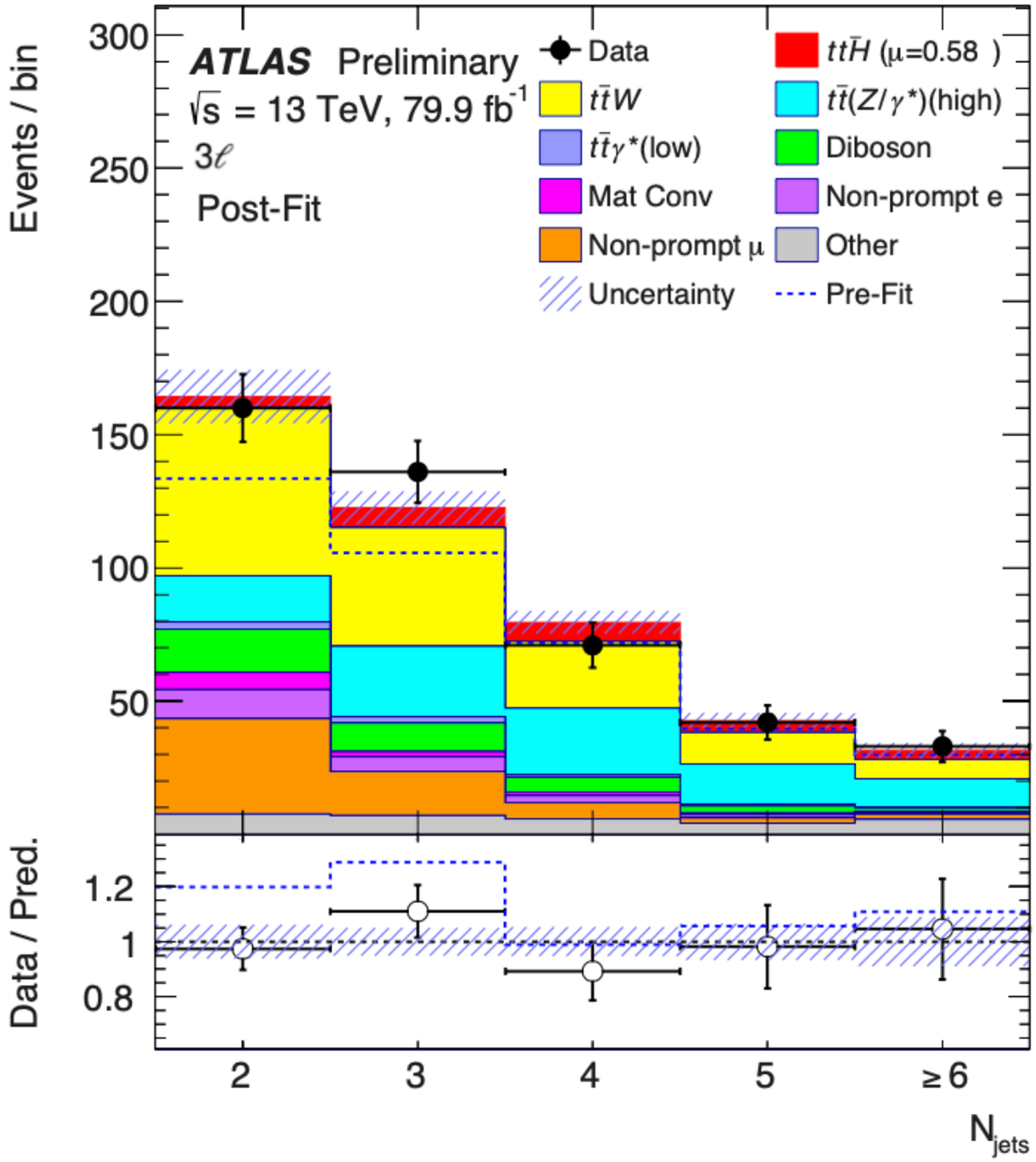
SR
BDT

$t\bar{t}W$ Model

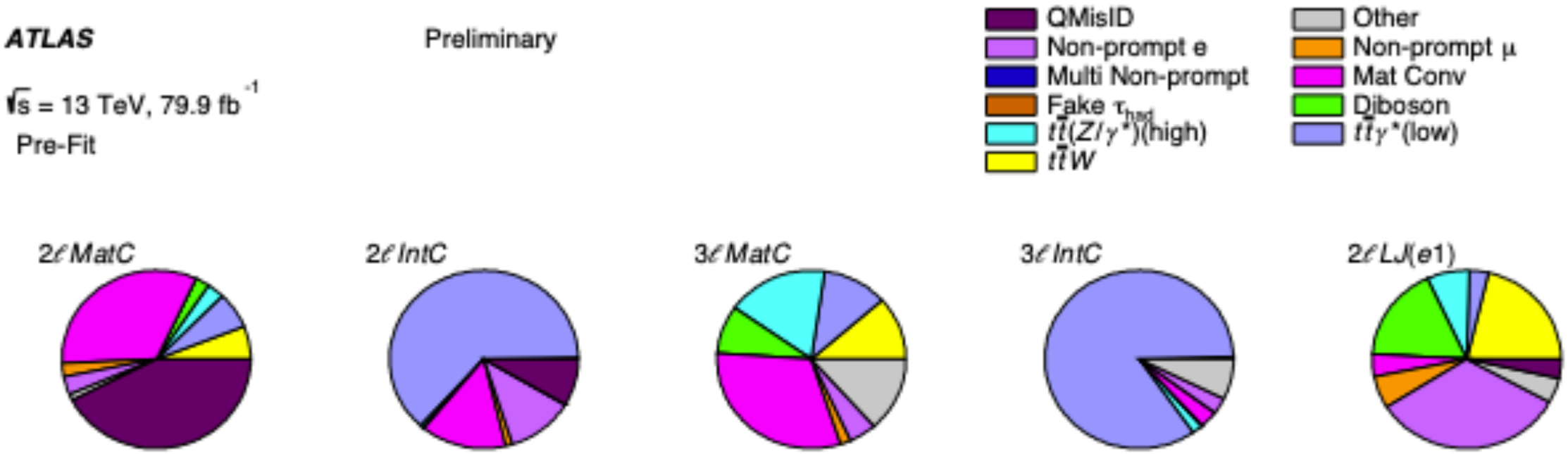
Process	Generator	ME order	Parton shower	PDF	Tune
$t\bar{t}H$	POWHEG-BOX [23, 24]	NLO	PYTHIA 8	NNPDF3.0 NLO [25]/ NNPDF2.3 LO [48]	A14
	(POWHEG-BOX)	(NLO)	(HERWIG7)	(NNPDF3.0 NLO/ MMHT2014 LO [49])	(H7-UE-MMHT)
$tHqb$	MG5_aMC	LO	PYTHIA 8	CT10 [50]	A14
tHW	MG5_aMC	NLO	HERWIG++	CT10/ CTEQ6L1 [51, 52]	UE-EE-5
$t\bar{t}W$	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

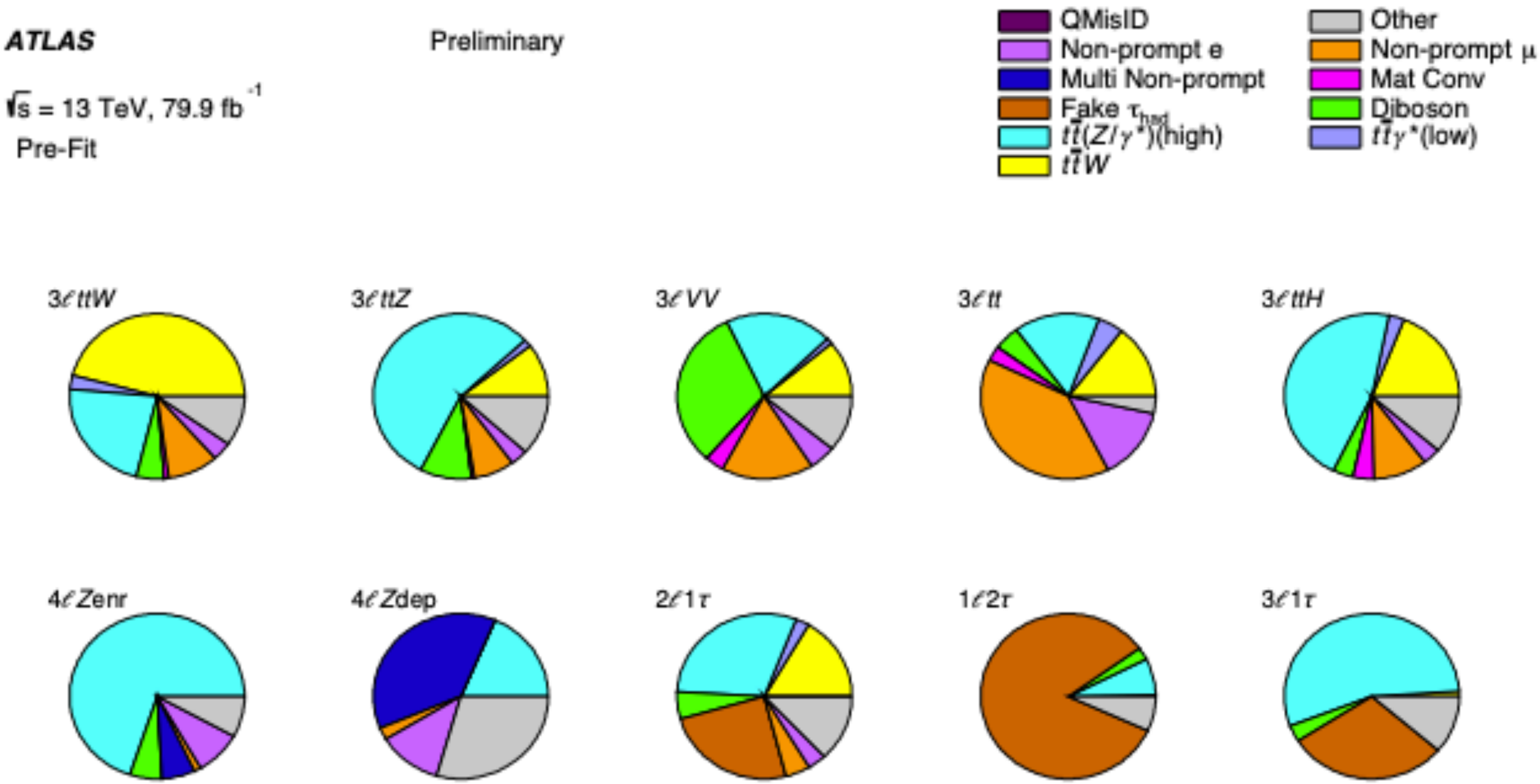




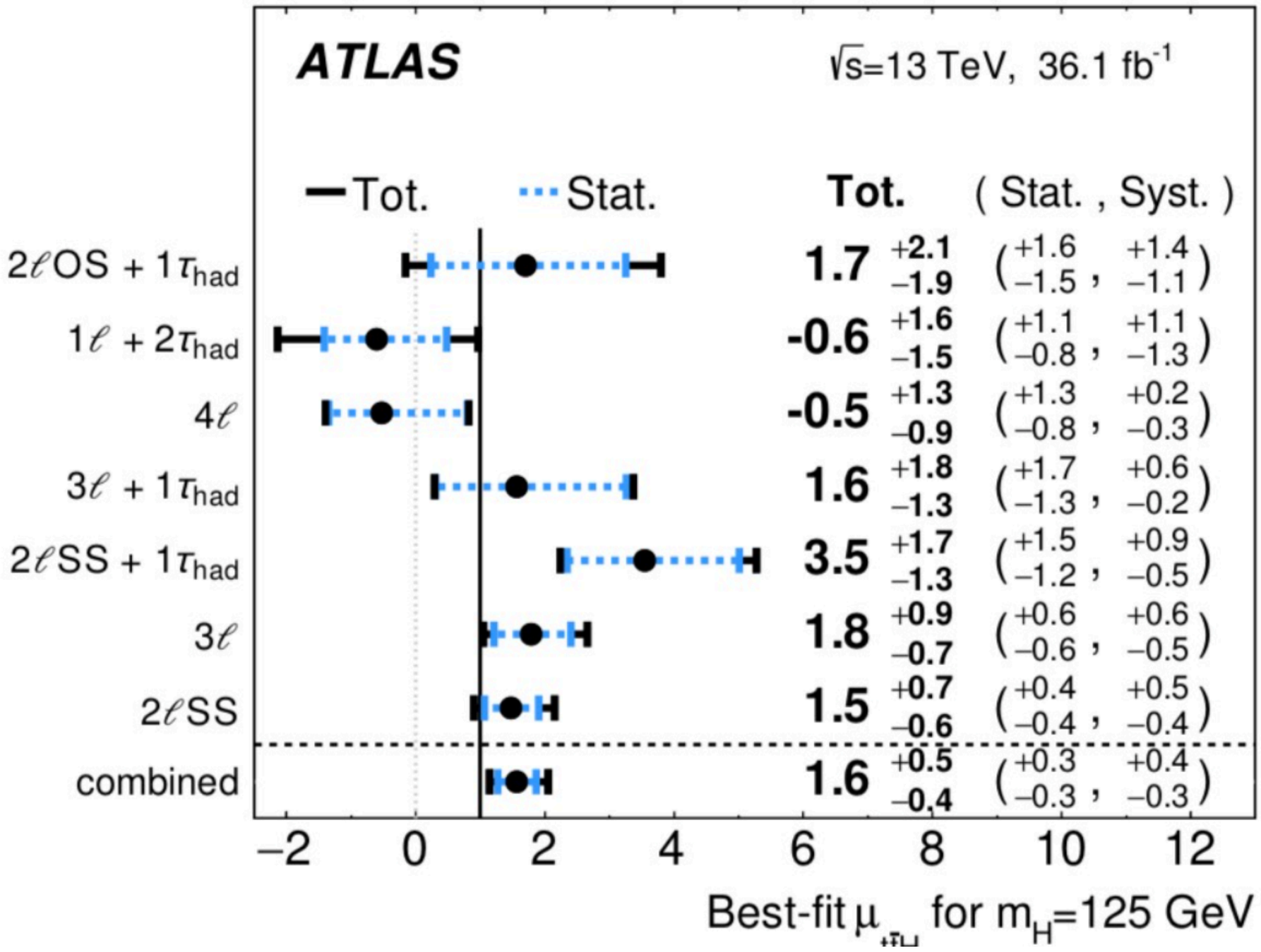
Background composition



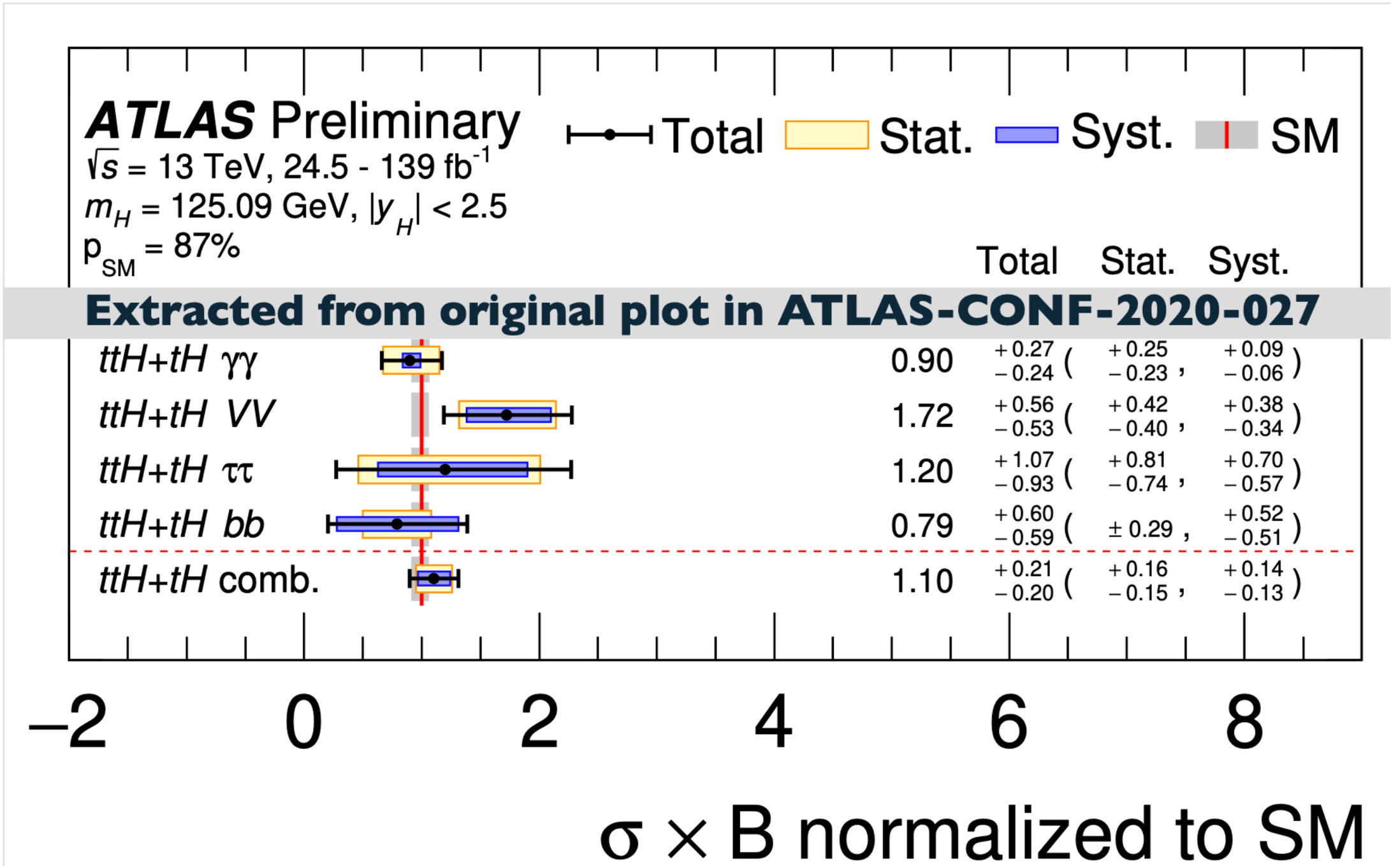
Background composition



Previous results



ATLAS $t\bar{t}H$ combinations



R . Narayan