SEARCH FOR TTH IN MULTILEPTON FINAL STATES

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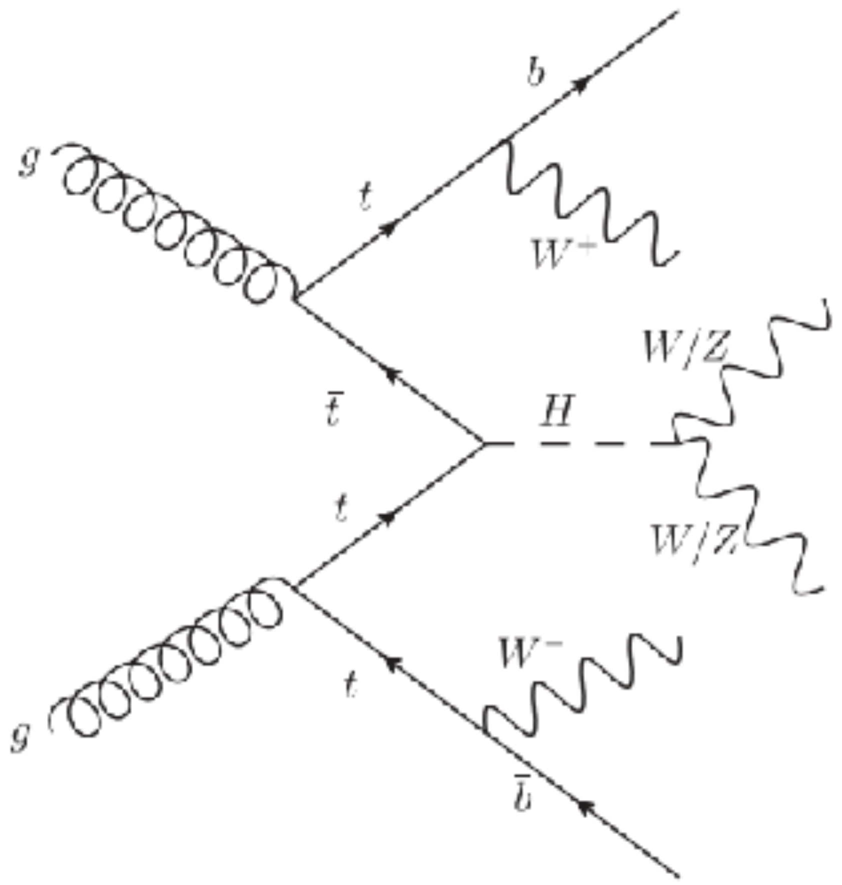
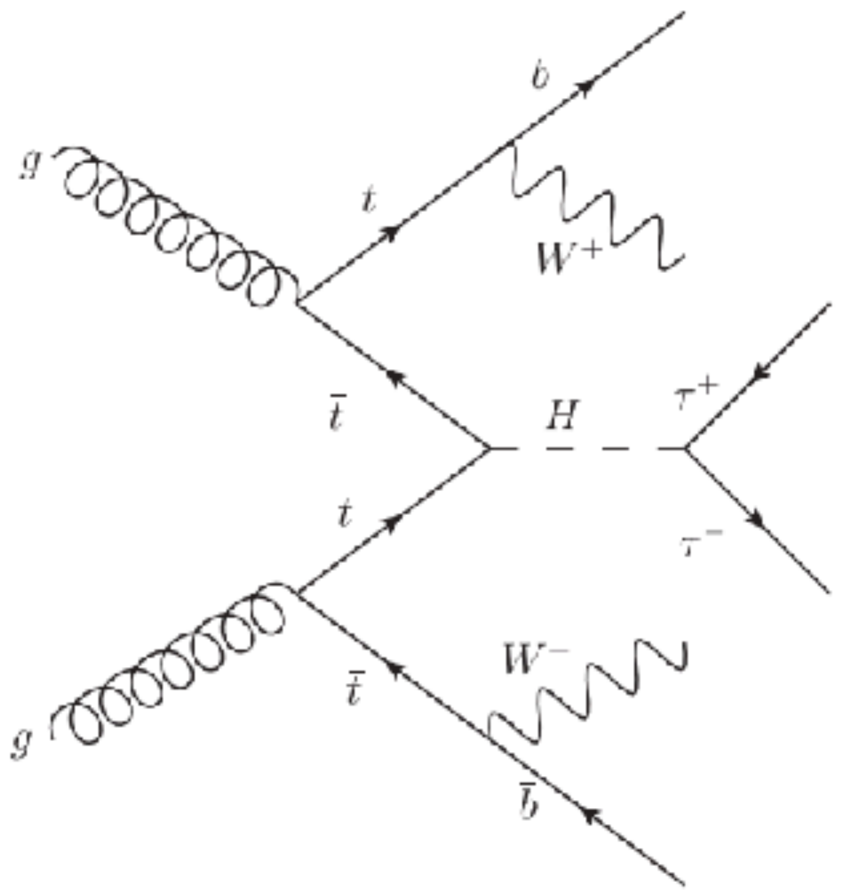
OUTLINE

- ➤*Analysis with 2015+2016 dataset*
- ➤*Status of 2015-17 data analysis*
  - *2 lepton same sign 0τ final state (2lSS) MVA performance*
- ➤*Conclusion*





INTRODUCTION

Top quark Yukawa coupling $\lambda_t = \sqrt{2}\, m_t/v \approx 1$:

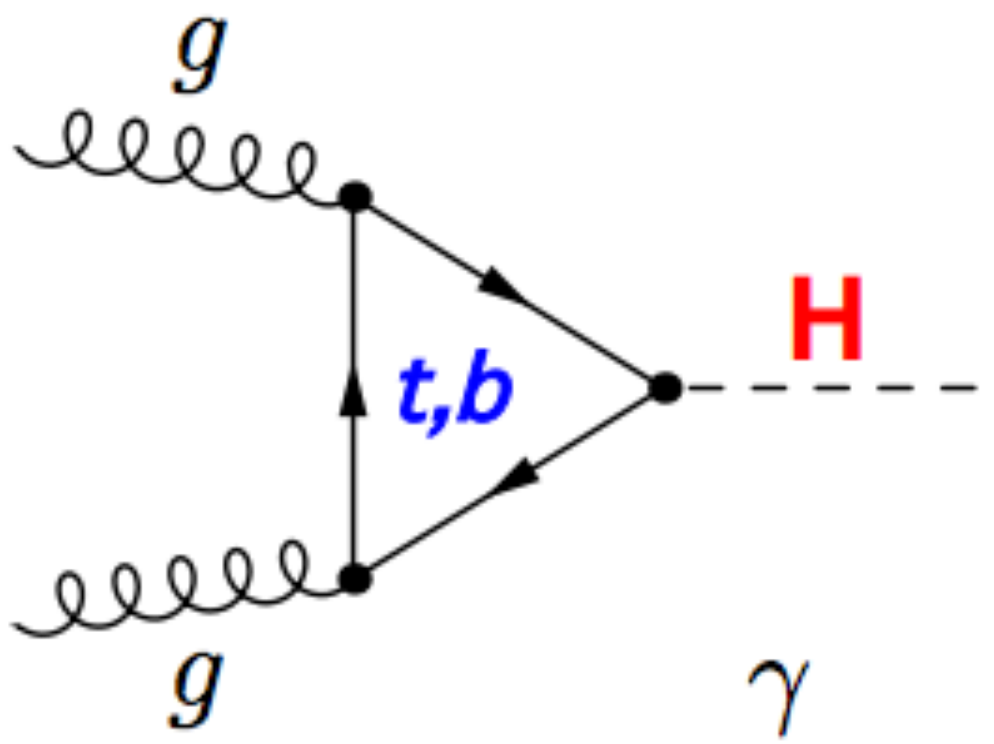
2 complementary measurements of λ_t:

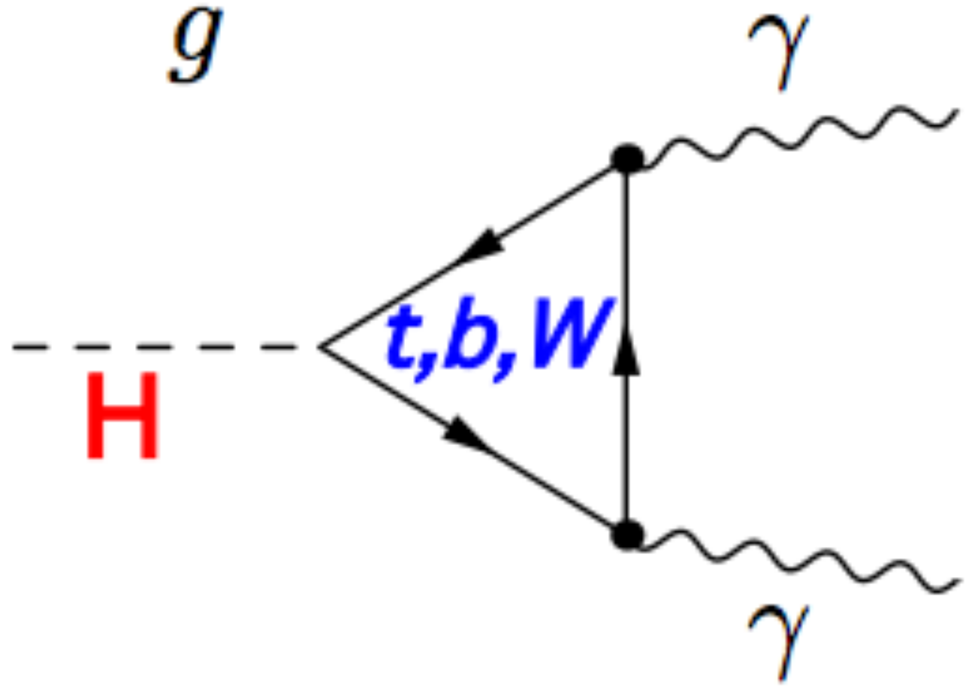
- ➤ *Indirect constraints: ggF, $H \rightarrow \gamma\gamma$ decay*
  - *Contributions enter from top quark loops by λ_t^2.*
  - *Run1 ATLAS+CMS combination measured*

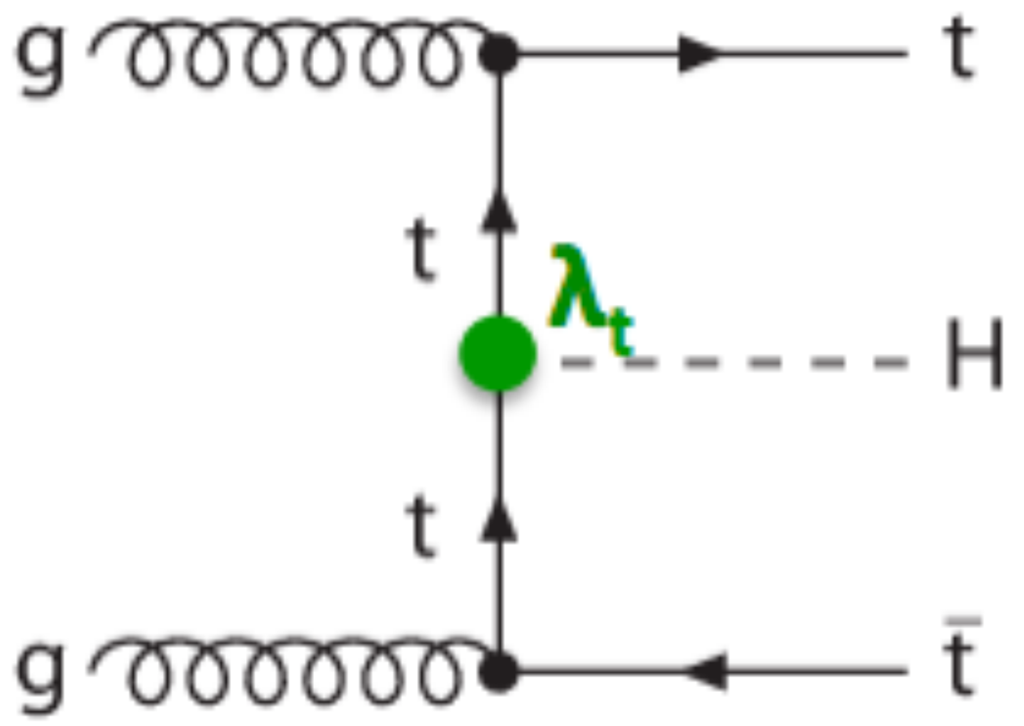
    $\kappa_t = \lambda_t/\lambda_t^{SM} = 0.87 \pm 0.15$
- ➤ *ttH production, best direct way to measure top quark Yukawa coupling:*
  - *Tree-level process, cross-section proportional to λ_t^2.*
  - *Run 1 ATLAS+CMS result on signal strength:*

    $\mu_{ttH} = \sigma_{ttH}/\sigma_{ttH}^{SM} = 2.3^{+0.7}_{-0.6}$,

    Obs. (exp.) significance of 4.4σ (2.0σ)



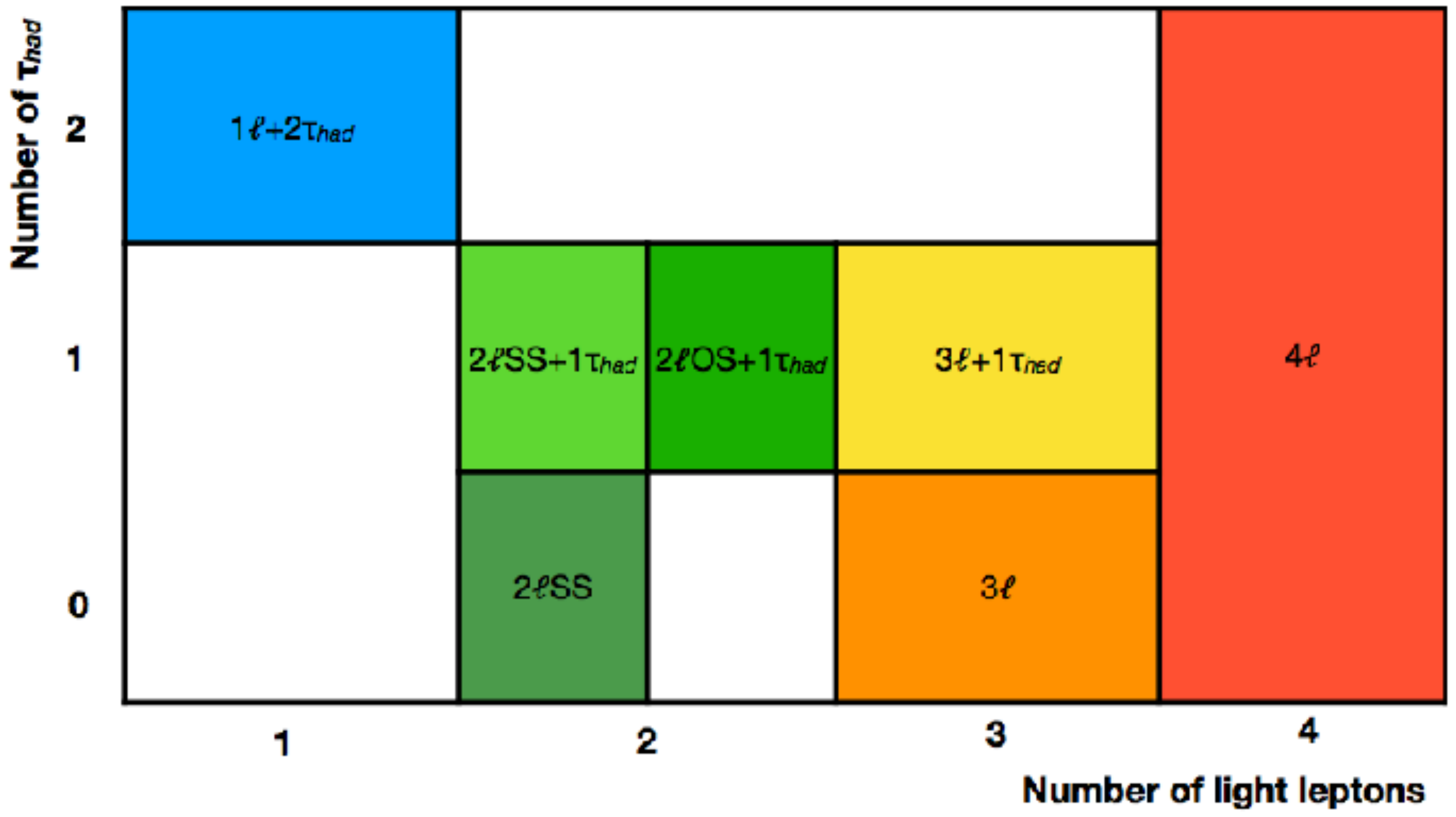




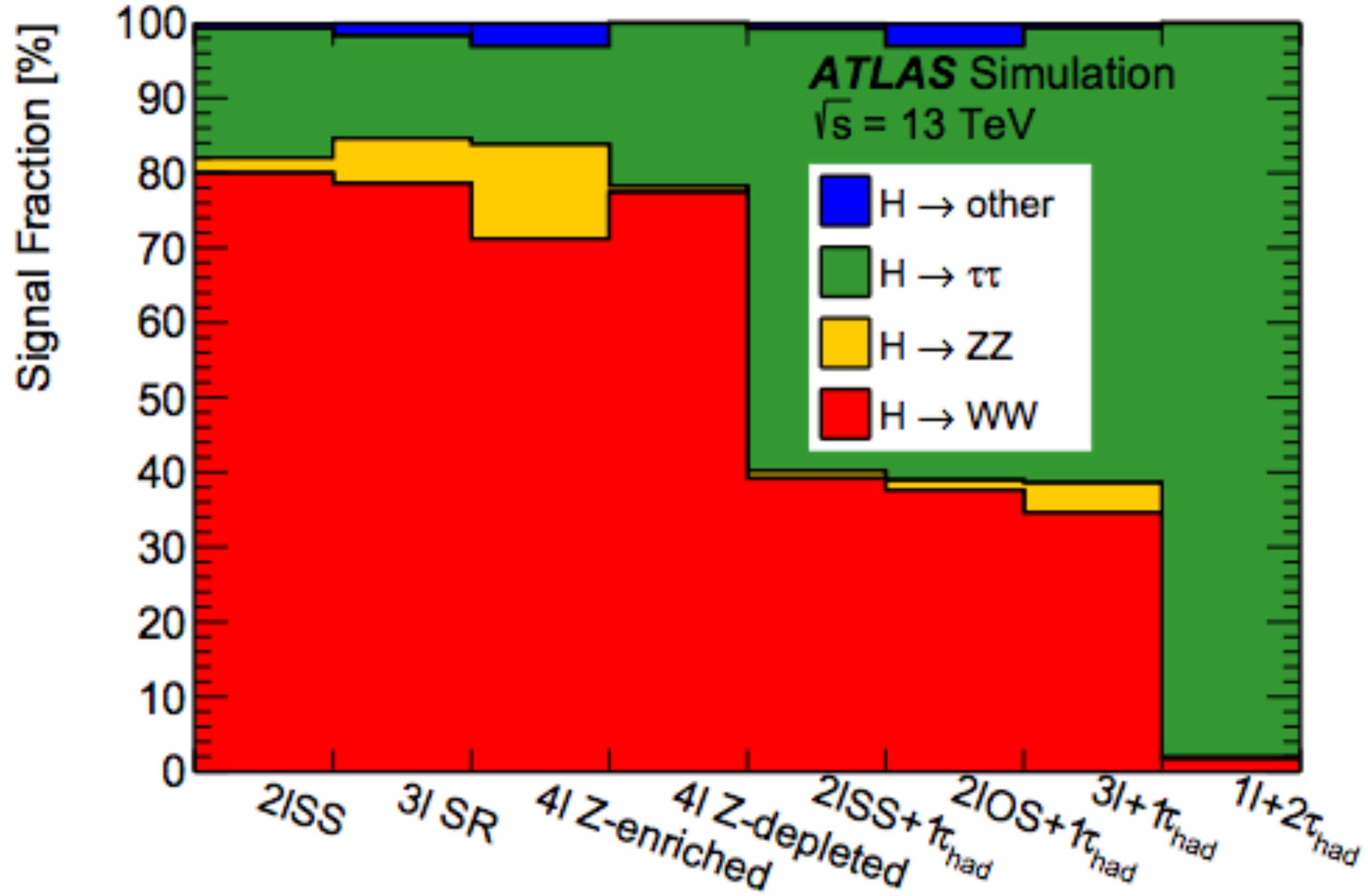
TTH MULTI LEPTON ANALYSIS

- *Use 36.1 fb^{-1} of p-p collision data from ATLAS experiment in 2015-2016.*
- *Analysis targeting at ttH, H→WW, ττ, ZZ with ≥ 2 (1 light) lepton in their final state.*
- *7 Channels orthogonal in light leptons (ℓ=e, μ) and hadronic tau (τ_{had}) multiplicity.*
  - *High lepton multiplicity requirement reduces background.*
  - *Jet requirements: $N_{jet} \geqslant 2$, $N_{b\text{-}tag} \geqslant 1$:*
    - *2lSS, 2lSS+1τ_{had} : $N_{jet} \geqslant 4$*
    - *2lOS+1τ_{had}, 1l+2τ_{had} : $N_{jet} \geqslant 3$*
- *ML+ 0τ: primary sensitive to H→WW.*
- *ML+ ≥1τ: primary sensitive to H→ττ.*

Analysis organized channels:



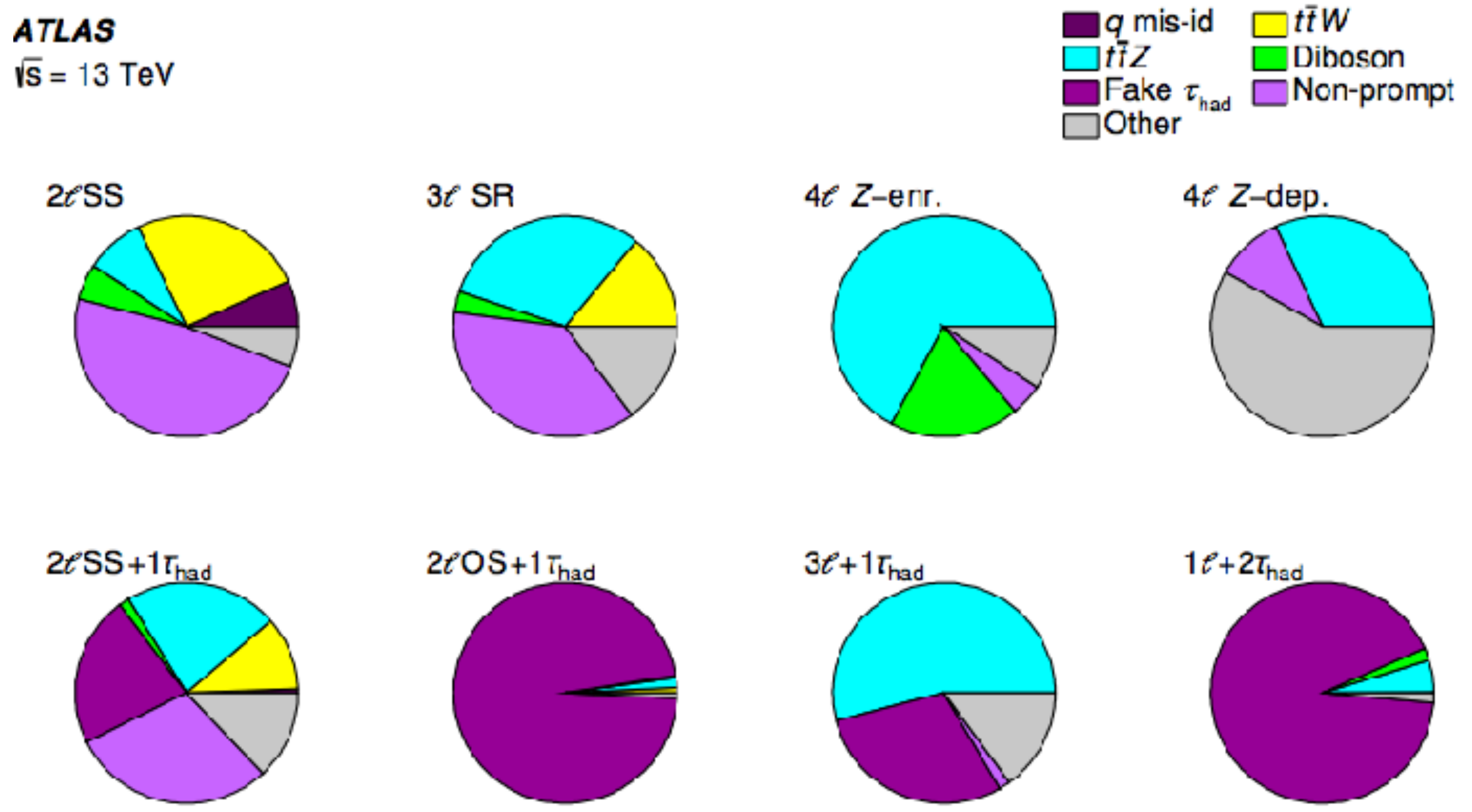
Higgs decay modes:



BACKGROUNDS

Signal region background compositions:

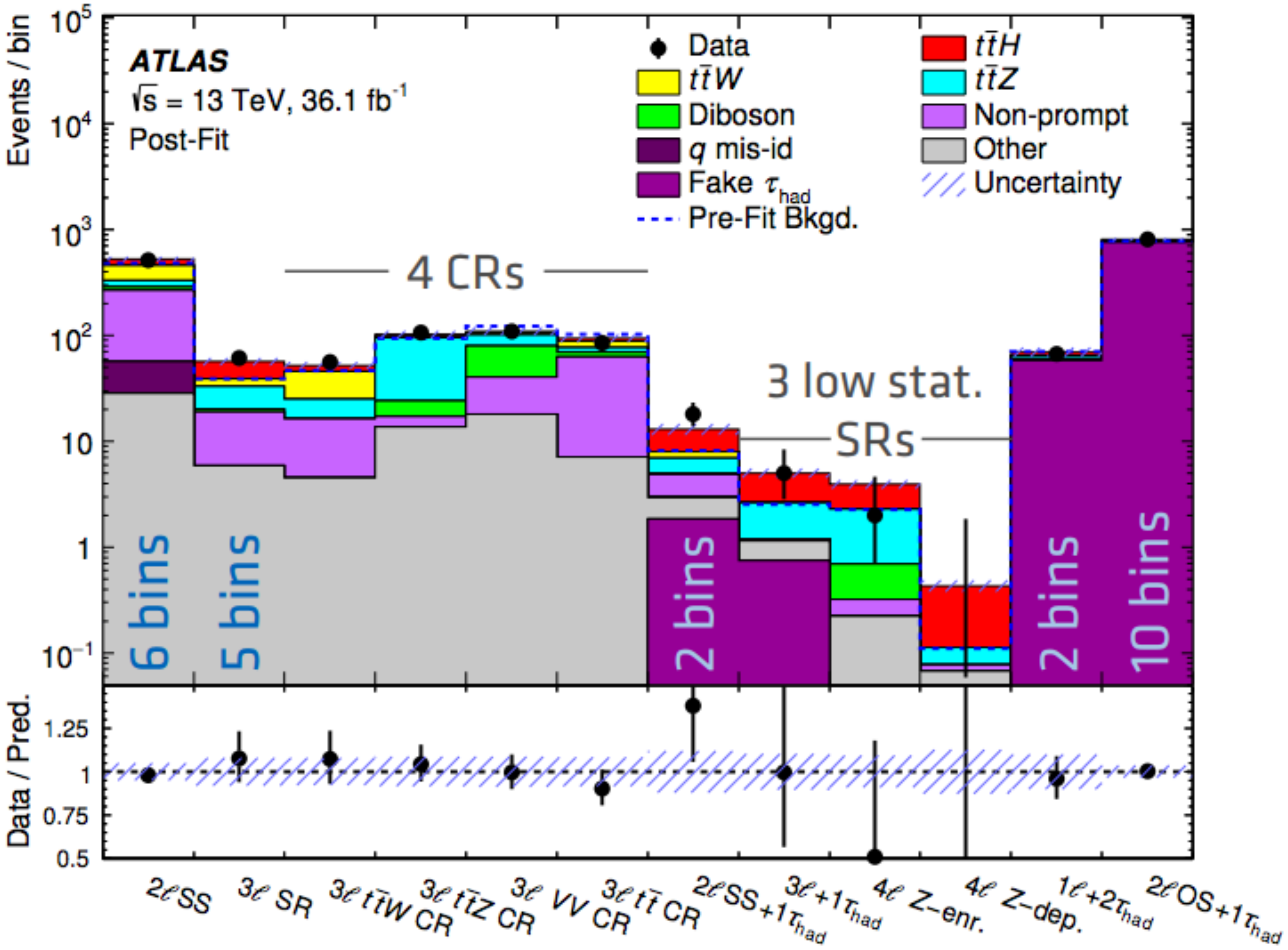
- *Irreducible backgrounds: ttW, ttZ, VV*
  - *Estimated from MC*
  - *Validated in 3ℓ CRs*
- *Reducible backgrounds:*
  - *estimated from data-driven*
  - *Non-prompt light leptons: from b-hadron decays (ttbar) and photon conversions*
  - *Electron charge mis-identification (q mis-id): from 2ℓOS ttbar events*
  - *Fake τ_{had}: from light flavour jets and mis-identified electrons*

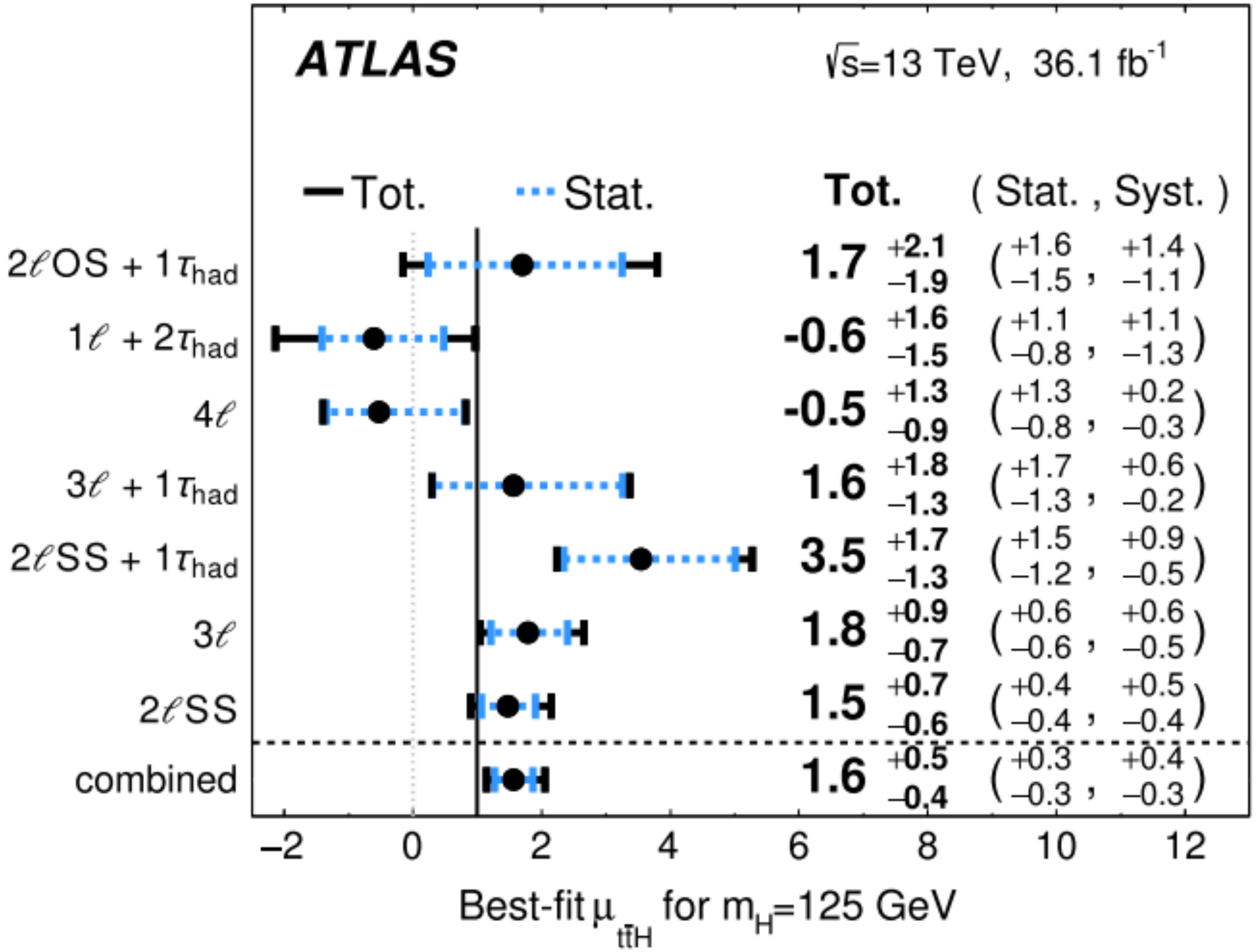


	2ℓSS	3ℓ	4ℓ	1ℓ+2τ_{had}	2ℓSS+1τ_{had}	2ℓOS+1τ_{had}	3ℓ+1τ_{had}
BDT trained against	Fakes and $t\bar{t}V$	$t\bar{t}$, $t\bar{t}W$, $t\bar{t}Z$, VV	$t\bar{t}Z$ / -	$t\bar{t}$	all	$t\bar{t}$	-
Discriminant	2×1D BDT	5D BDT	Event count	BDT	BDT	BDT	Event count
Number of bins	6	5	1 / 1	2	2	10	1
Control regions	-	4	-	-	-	-	-

- *Backgrounds are reduced with cut-and-count and boosted decision trees (BDTs) using lepton isolation and track variables.*
- *Cut-and-count cross checks for 3 most powerful channels (2ℓSS , 3ℓ and 2ℓSS+1τ_{had}) compatible.*

FIT RESULTS

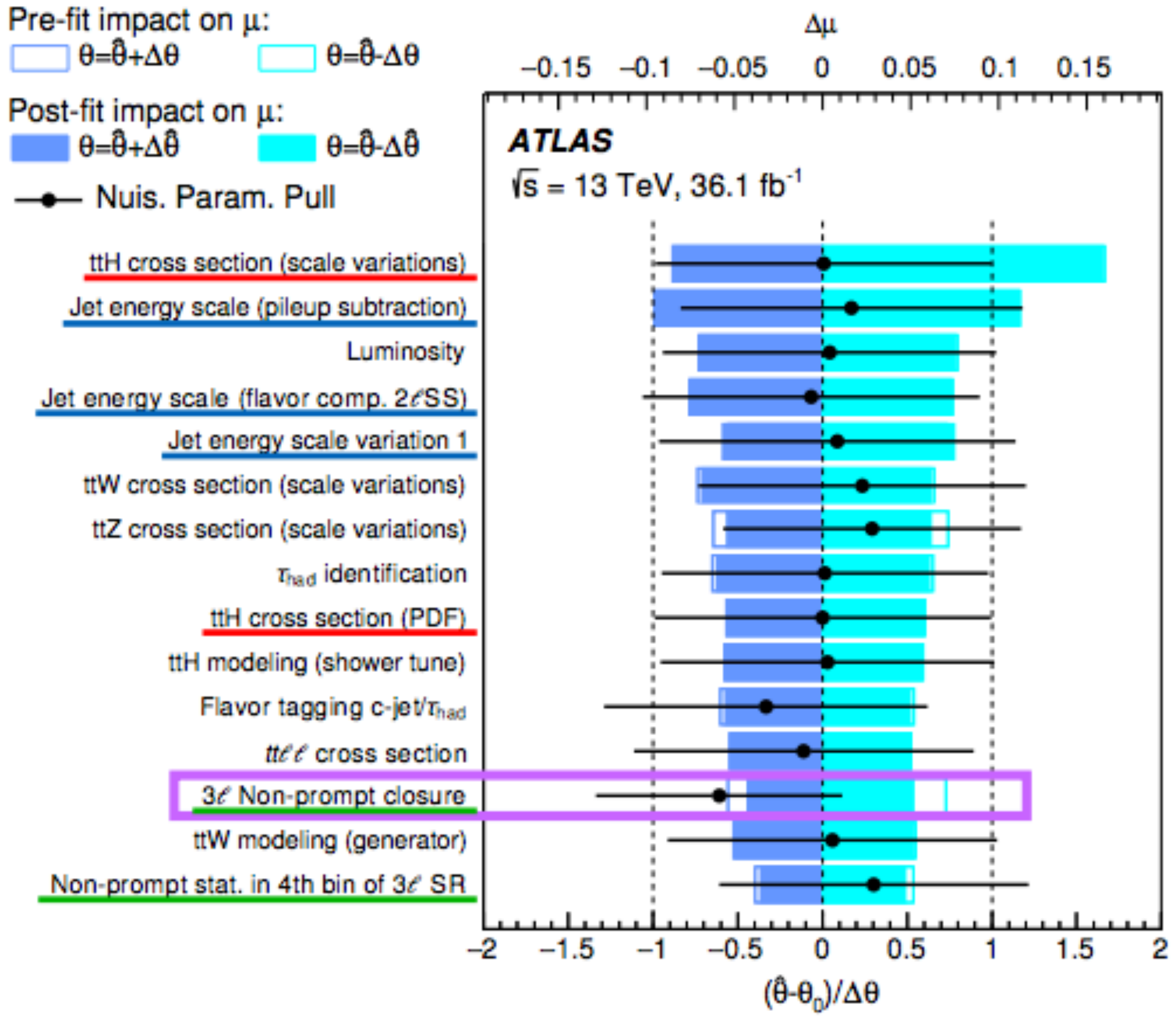




- *Binned maximum-likelihood fit is performed in 8 SRs + 4 CRs simultaneously (32 bins).*
- *Best-fit signal strength $\mu_{ttH} = 1.6^{+0.5}_{-0.4}$, obs. (exp.) significance: 4.1σ (2.8σ).*
- *Cross-section $\sigma_{ttH} = 790^{+230}_{-210}$ fb (expected: 507^{+35}_{-50} fb).*
- *A combination of all channels leading to evidence of ttH productions. (Phys. Rev. D. 97 (2018) 072003)*

UNCERTAINTIES

Uncertainty Source	$\Delta\mu$	
$t\bar{t}H$ modeling (cross section)	+0.20	−0.09
Jet energy scale and resolution	+0.18	−0.15
Non-prompt light-lepton estimates	+0.15	−0.13
Jet flavor tagging and τ_{had} identification	+0.11	−0.09
$t\bar{t}W$ modeling	+0.10	−0.09
$t\bar{t}Z$ modeling	+0.08	−0.07
Other background modeling	+0.08	−0.07
Luminosity	+0.08	−0.06
$t\bar{t}H$ modeling (acceptance)	+0.08	−0.04
Fake τ_{had} estimates	+0.07	−0.07
Other experimental uncertainties	+0.05	−0.04
Simulation sample size	+0.04	−0.04
Charge misassignment	+0.01	−0.01
Total systematic uncertainty	+0.39	−0.30

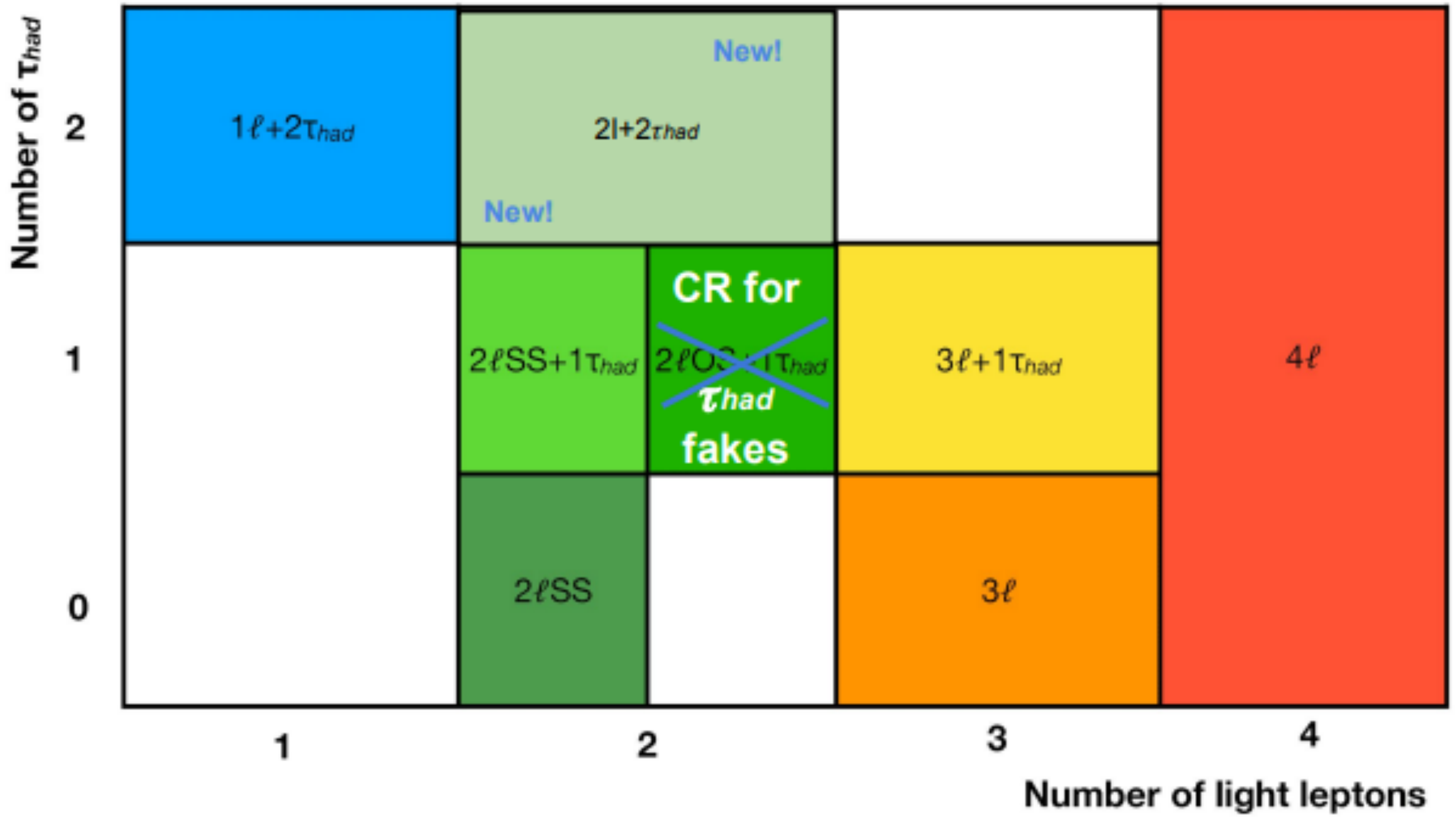


- *Systematics model with 315 nuisance parameters.*
- *Systematic uncertainties with largest impact on errors on μ_{ttH} are:*
  - *ttH cross section uncertainty → theory.*
  - *Jet energy scale and resolution.*
  - *Non-prompt light lepton estimates → large contribution of CR statistics.*
- *Largest pull: 3l Non-prompt estimate closure uncertainty → deficit in 3l ttbar CR.*
- *All uncertainties well controlled.*

TTH MULTILEPTON STRATEGY

- *Use 80 fb^{-1} of p-p collision data from ATLAS experiment in 2015-2017*
- *7 orthogonal signal regions (1 new, 1 moved to CR)*
- *New trigger strategy in 2lSS (Di-Lepton Trigger Only)*
  - *Response from closure test*
  - *Negligible effects on fit results*
- *New tight lepton definition:*
  - *newly optimized work point on:*
    - *Non-prompt lepton MVA*
    - *Charge Mis-Id Killer*
  - *better ttbar rejection*
- *Better TauID performance and modeling*

Analysis organized channels:



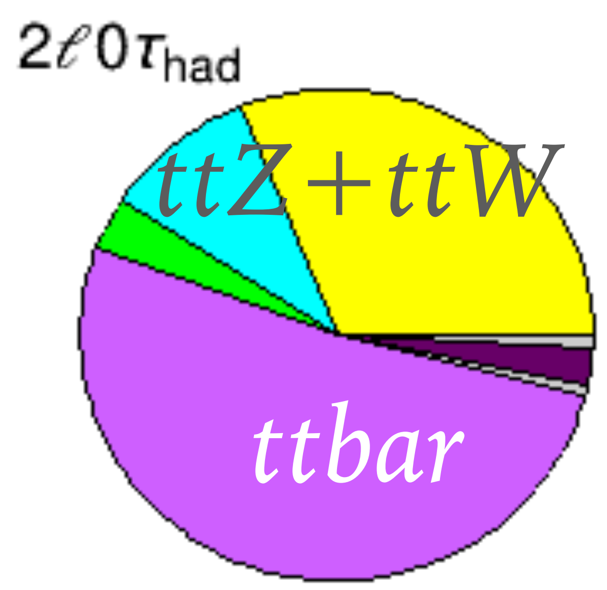
New tight lepton definition:

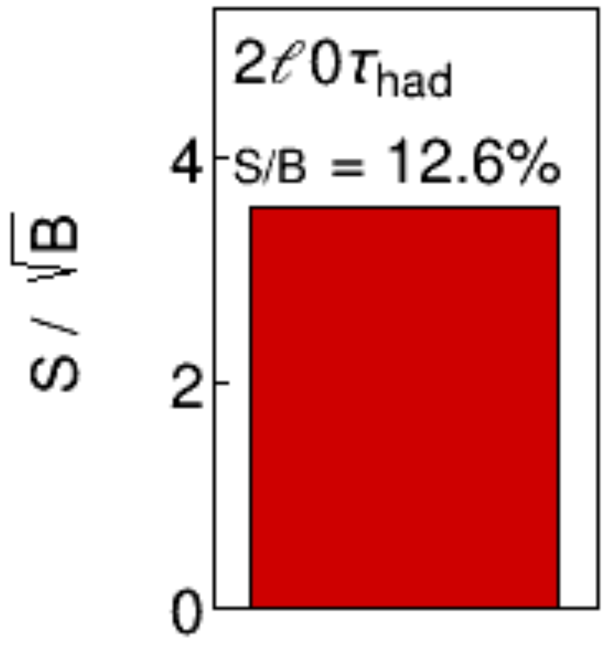
	electron	muon
ID	TightLH && ambiguityType == 0	Loose
Isolation	FixedCutLoose && PromptLeptonVeto < -0.7	FixedCutLoose && PromptLeptonVeto < -0.5
QMisIDMVA	QMisIDMVA > 0.7	-
Impact Parameters	|d0|/σ(d0) < 5 && z0sinθ < 0.5mm	|d0|/σ(d0) < 3 && z0sinθ < 0.5mm

MVA 2LSS-0TAU

2×1D event MVA:

- *Trained versus 2 main backgrounds*
  - *ttH vs ttV (ttZ+ttW)*
  - *ttH vs ttbar (data-driven: non-prompt lepton bkg+electron charge flip bkg)*
  - *Neglecting all other smaller backgrounds such as dibosons*
- *9 Input Variables:*
  - *Max|η|*, Pt_{l_1}, $M_{l_0 l_1}$, $\Delta R_{l_0 j}$, $\Delta R_{l_1 j}$, E_T^{miss}, N_{jets},, $N_{b\text{-}jets}$, *lep_flavour*
- *BDT Algorithm:*
  - *Gradient boosting algorithm (BDTG)*
  - *Final BDT Discriminant:*
    - *BDTG = (BDTG ttbar+BDTG ttV)/2*
    - *Using 6 bins with auto-binning (flat signal)*

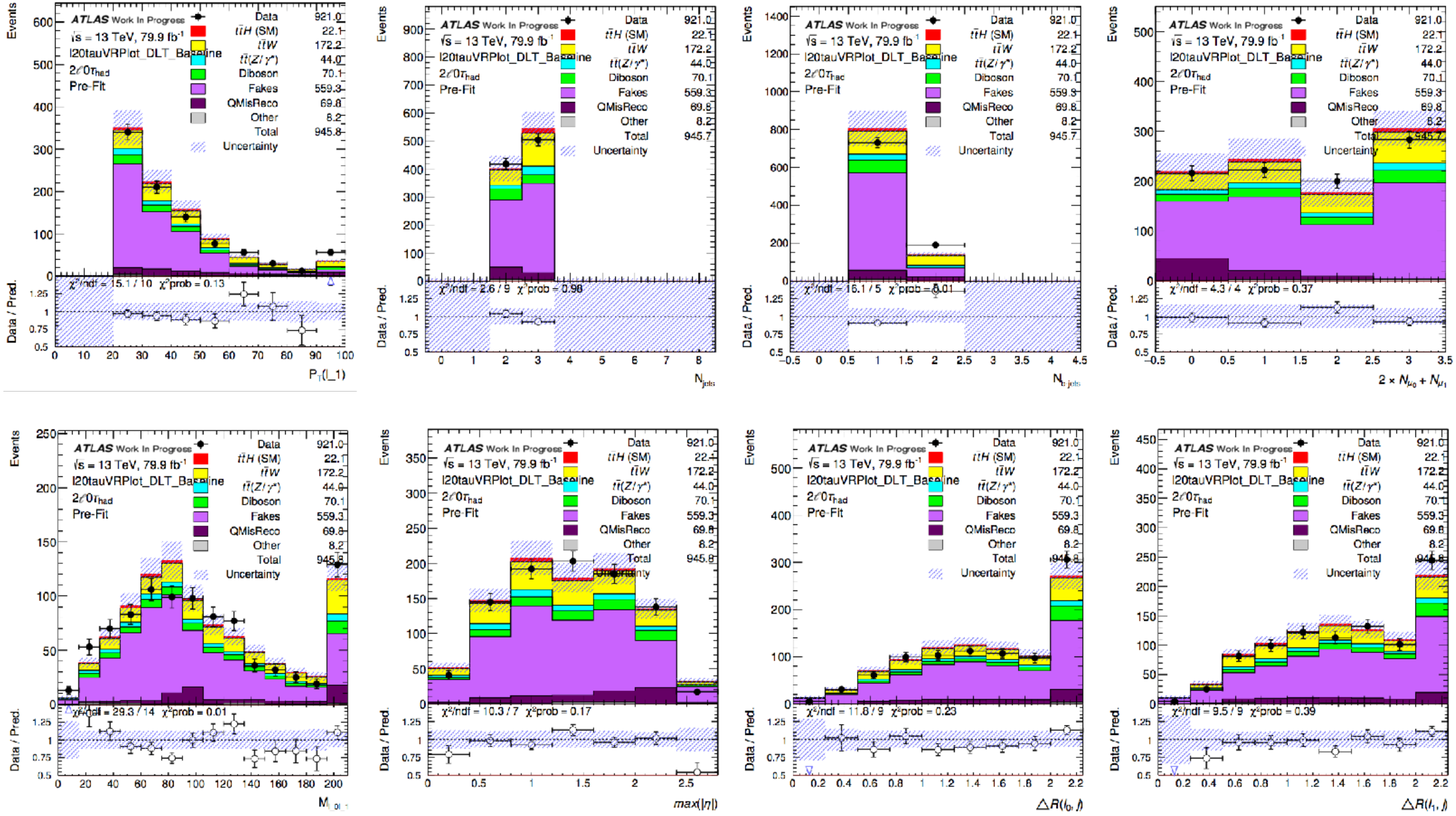




Pre-MVA selection

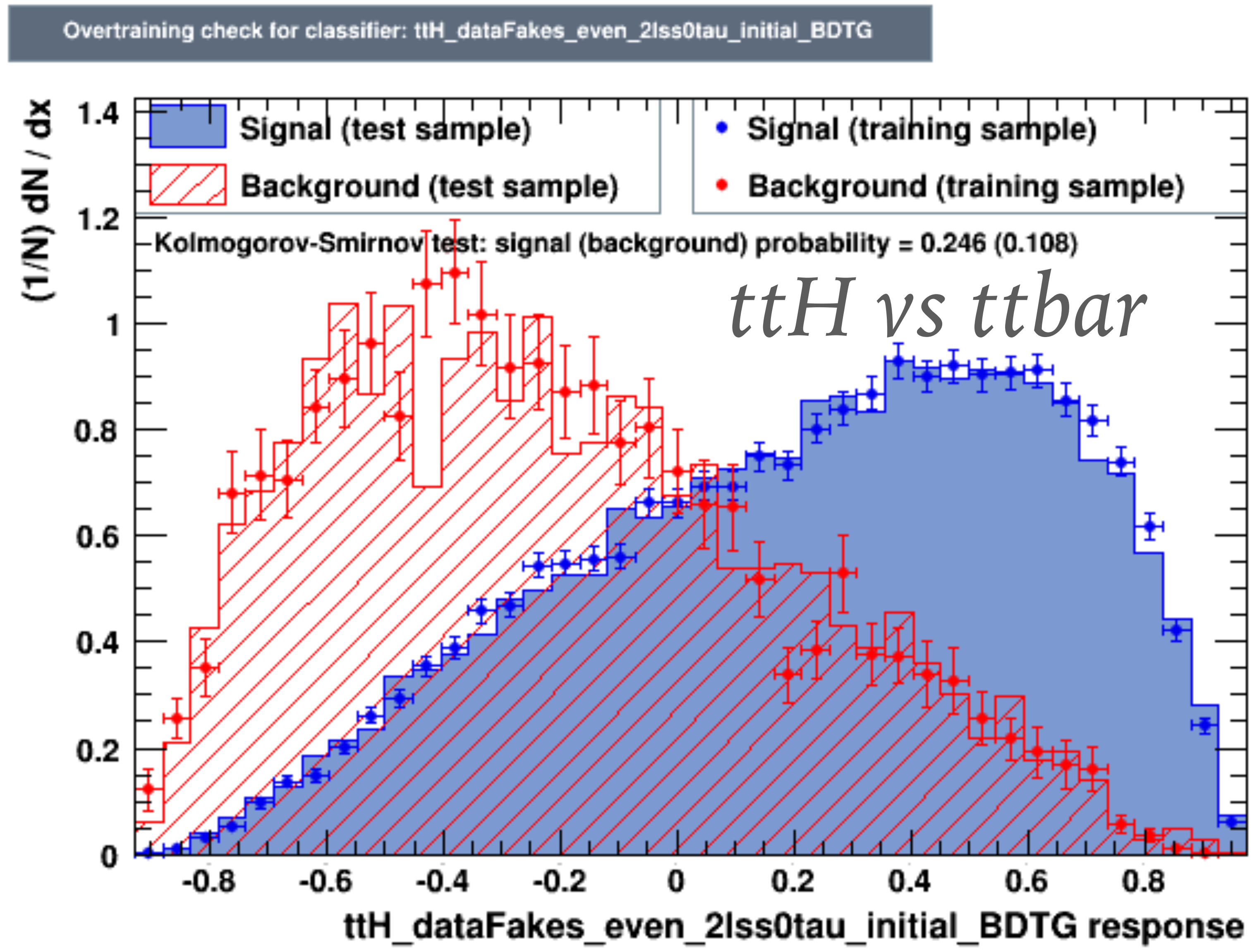
Channel	Selection criteria
Common	$N_{jets} \geq 2$ and $N_{b-jets} \geq 1$
$2\ell SS$	Two very tight light leptons with $p_T > 20$ GeV Same charge light leptons Zero medium τ_{had} candidates $N_{jets} \geq 4$; $N_{b-jets} < 3$

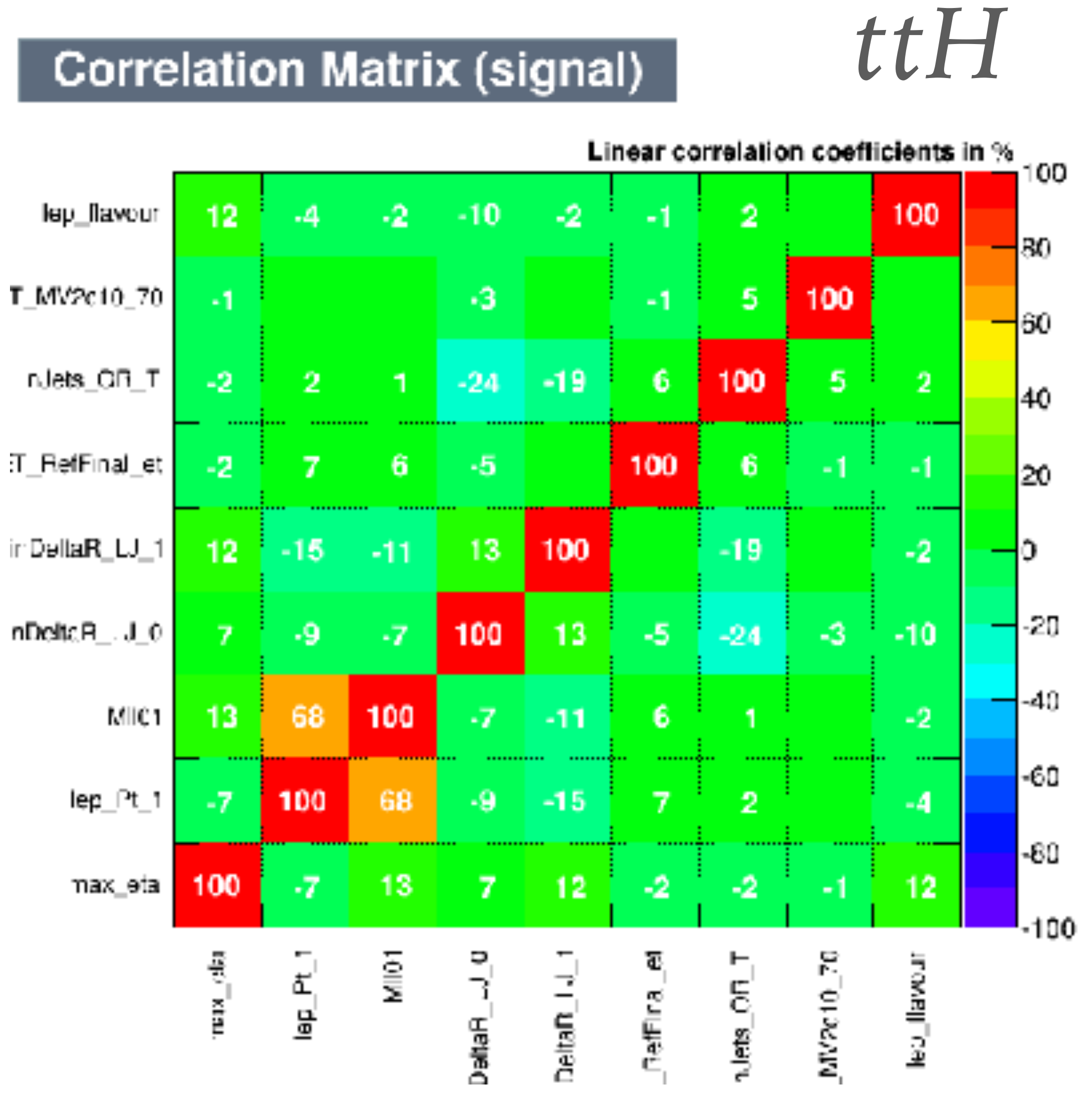
DATA/MC AGREEMENT IN 2LSS VALIDATION REGION

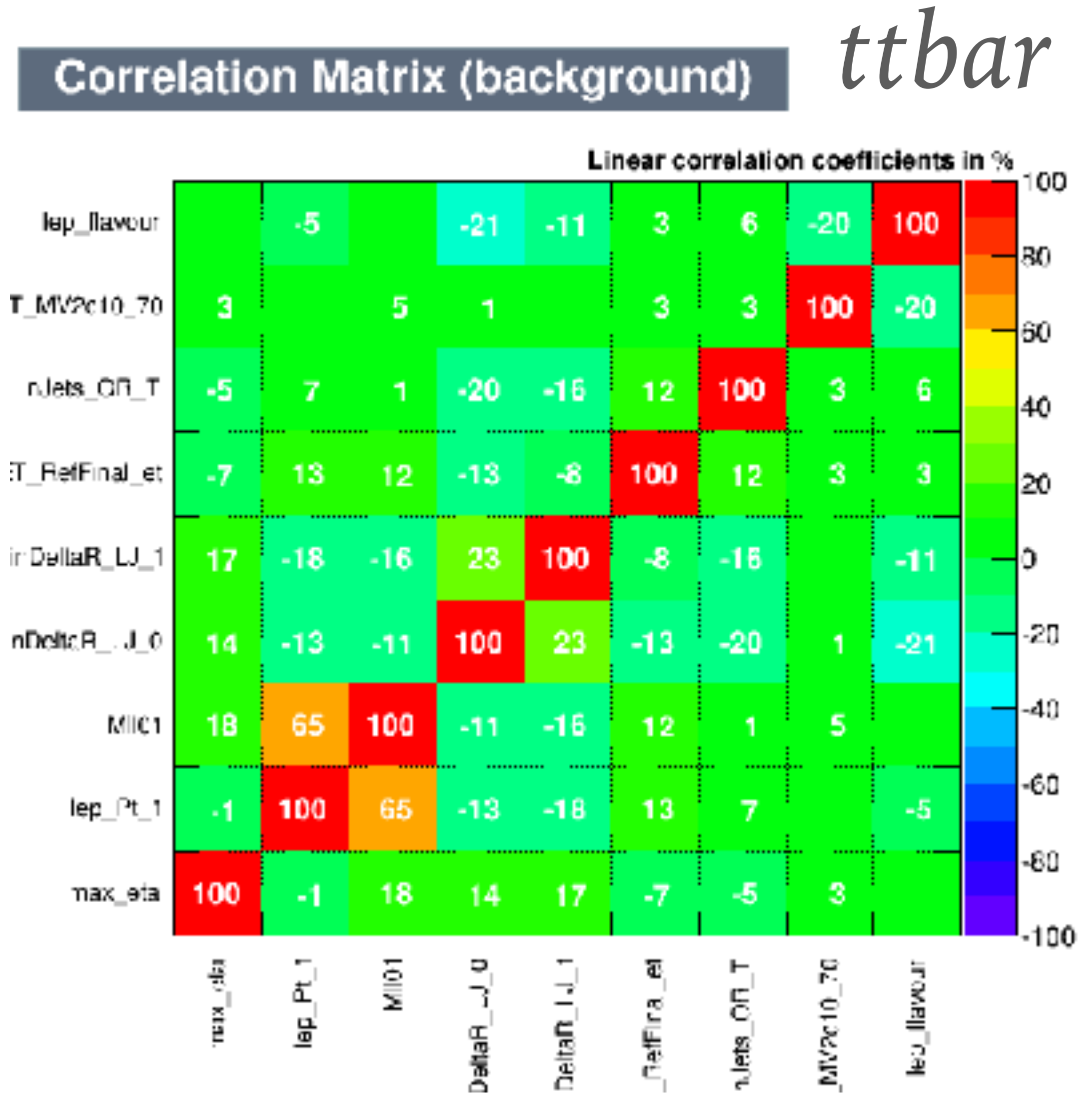


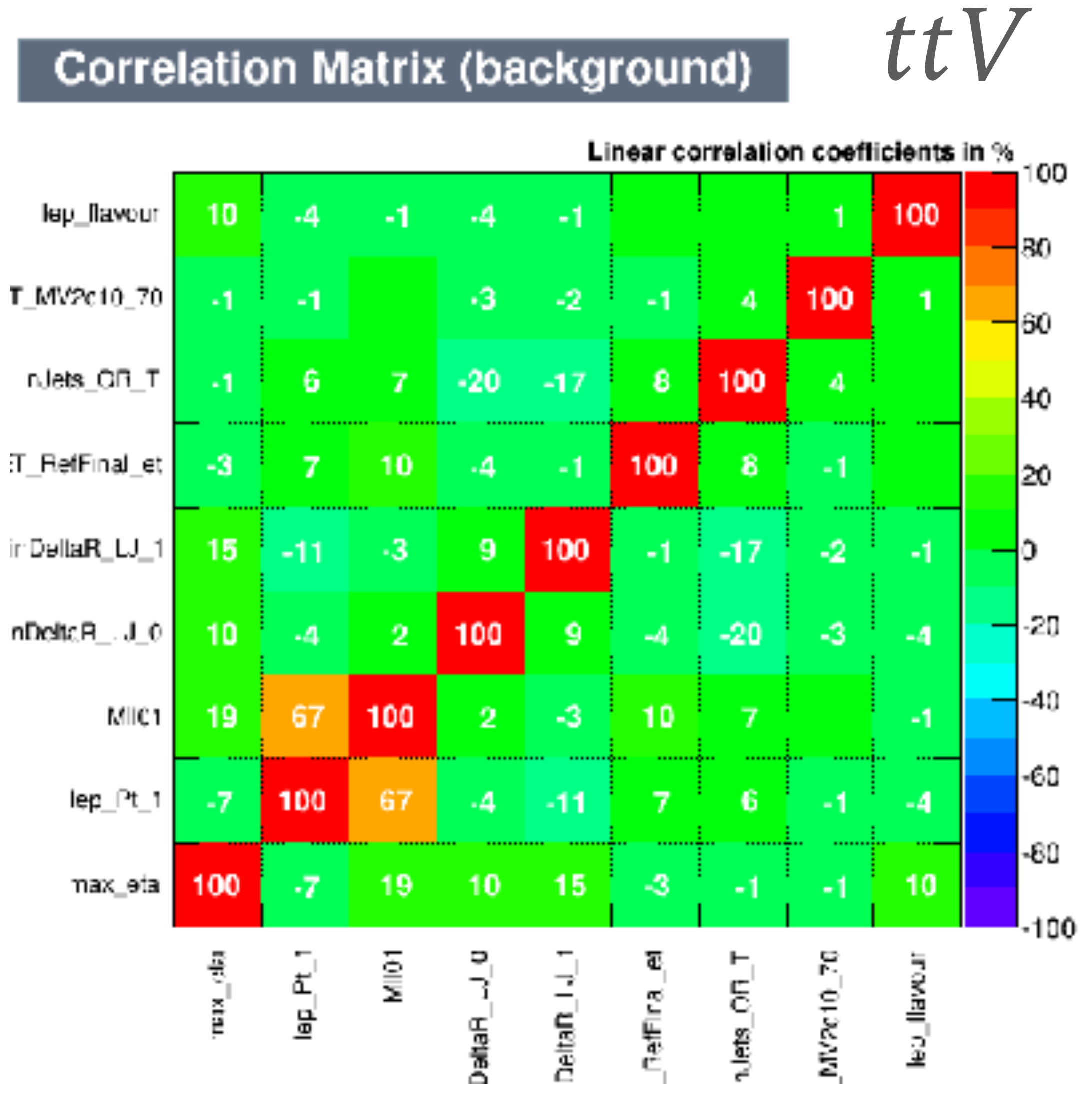
The validation region is defined by reversing the N_{jets} requirement. ($2 \leq N_{jets} \leq 3$)

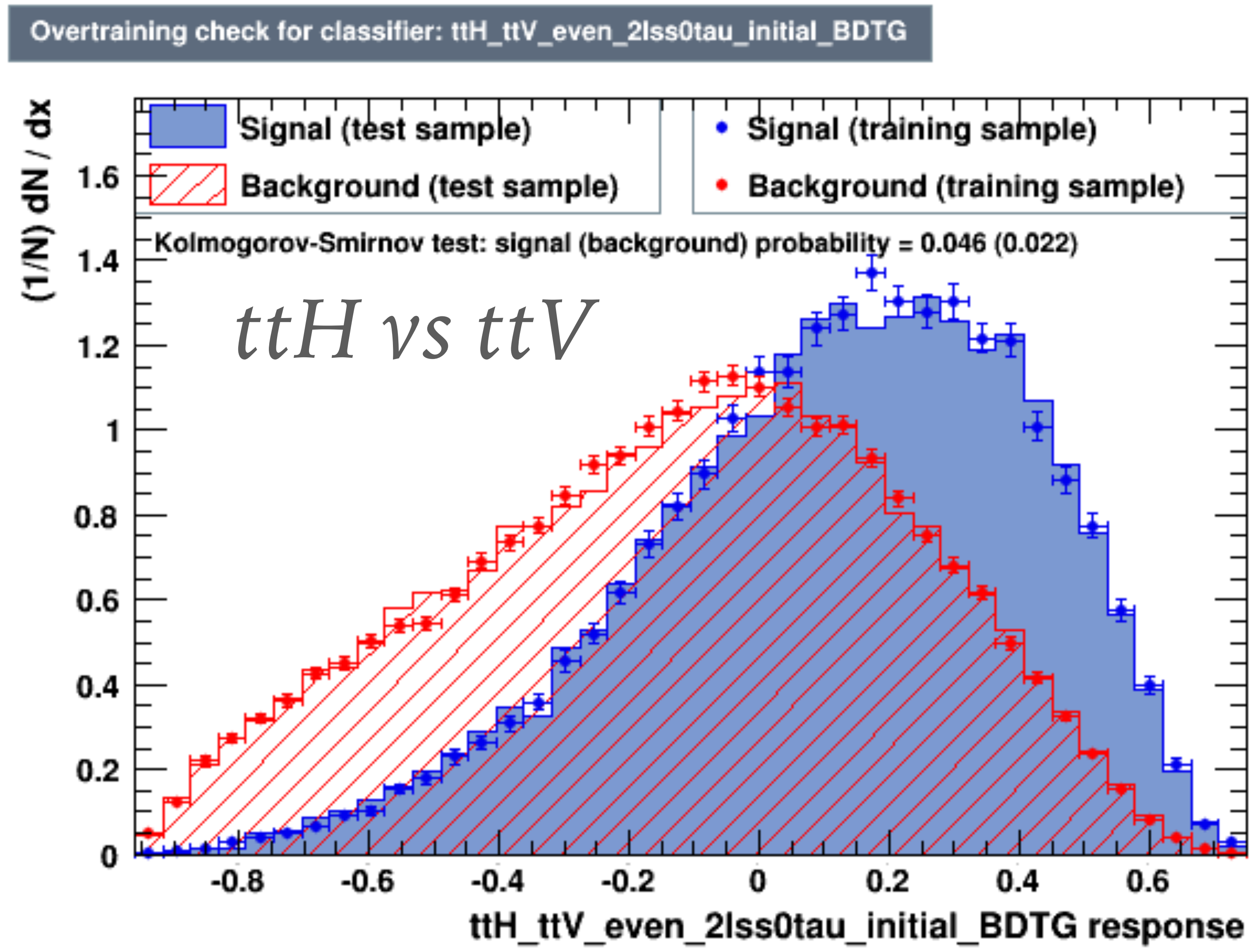
MVA TRAINING

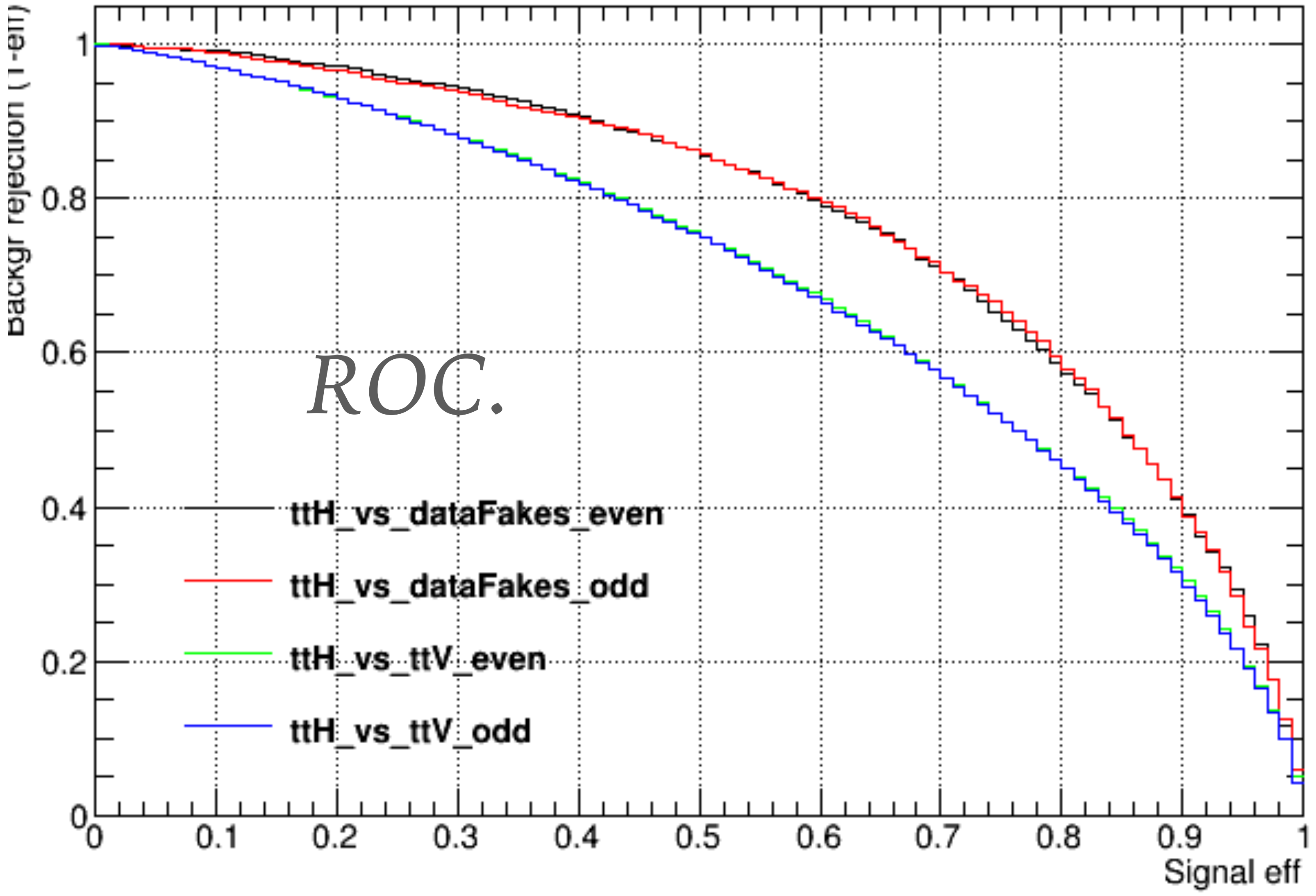


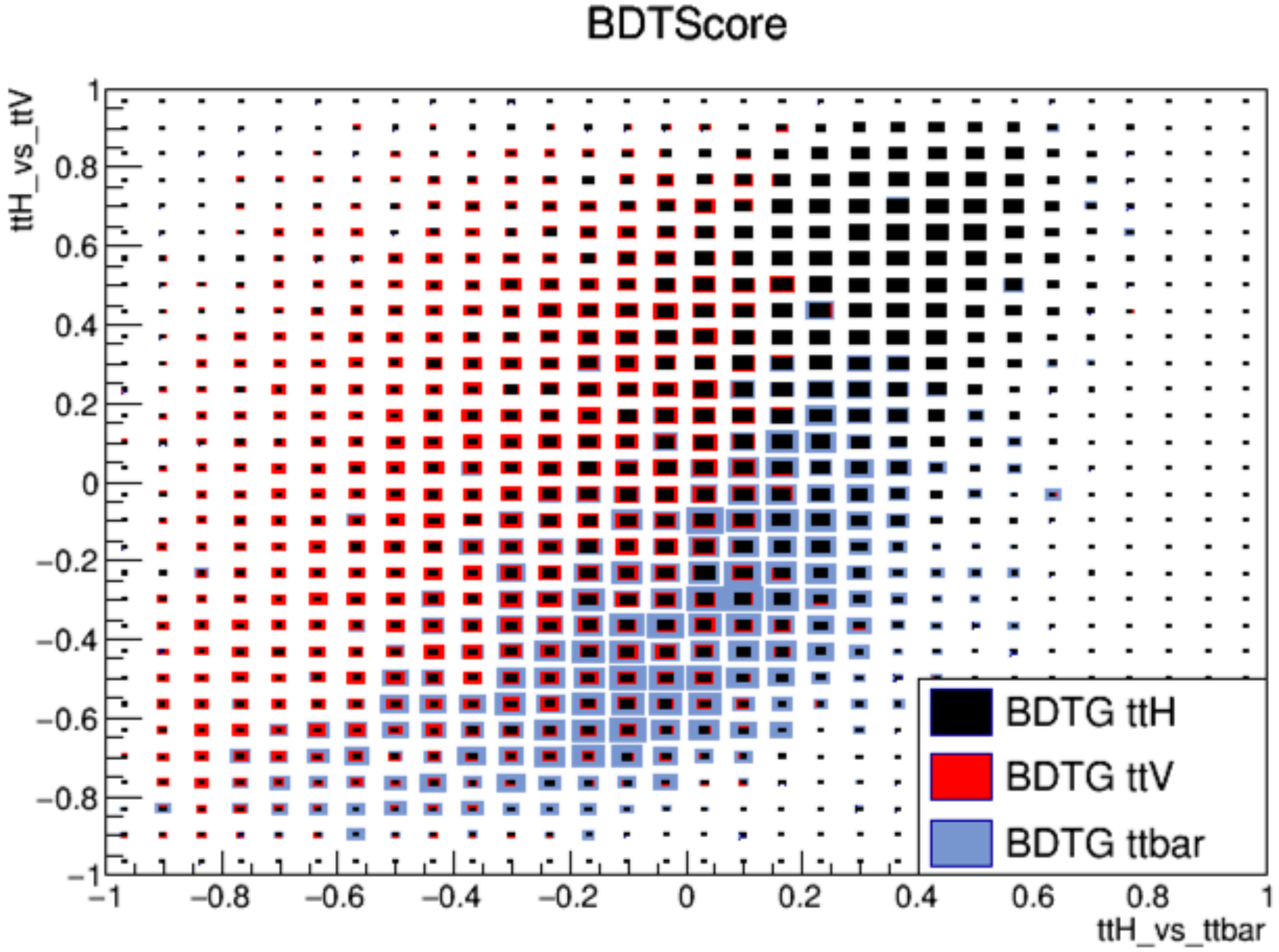






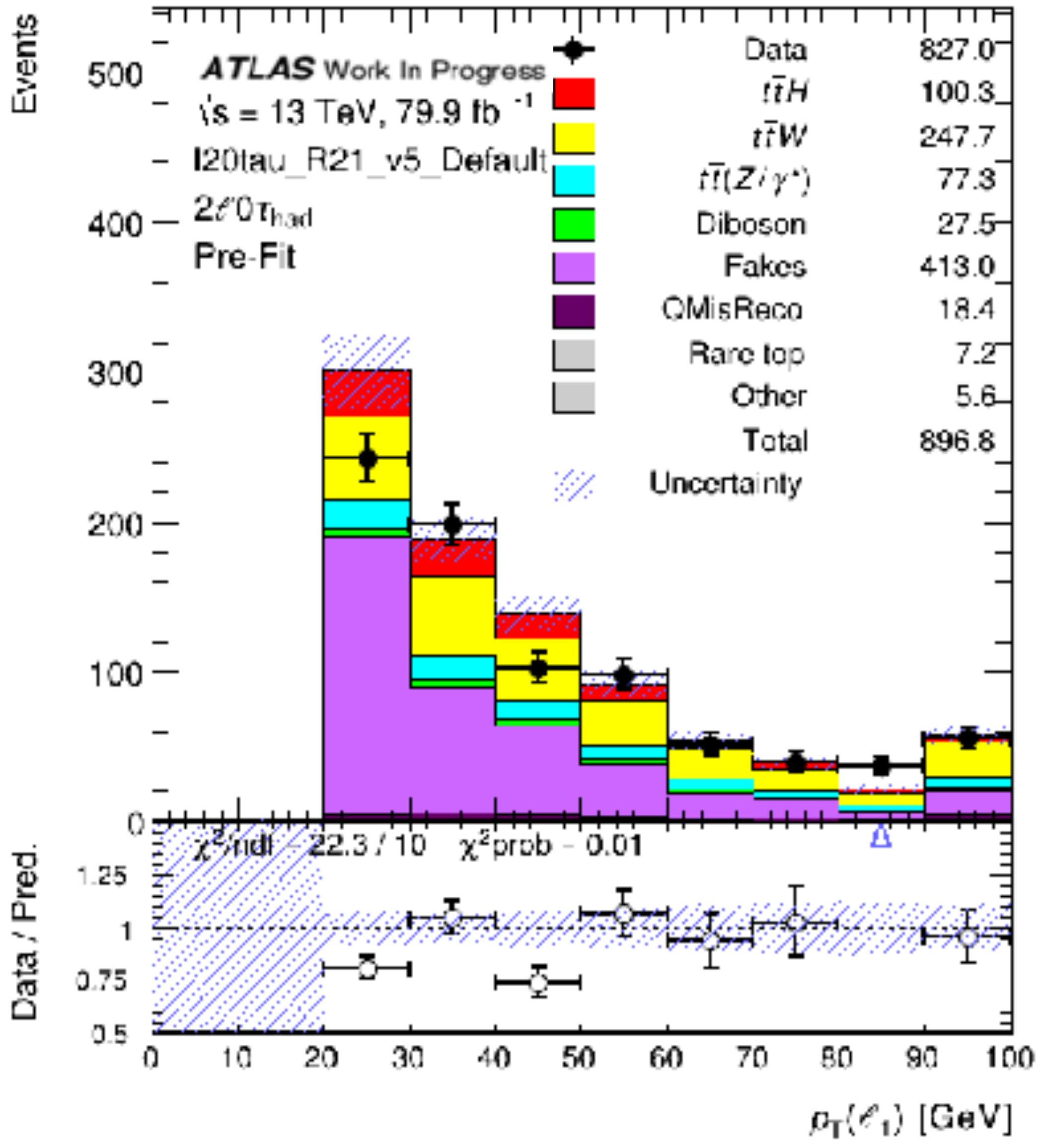


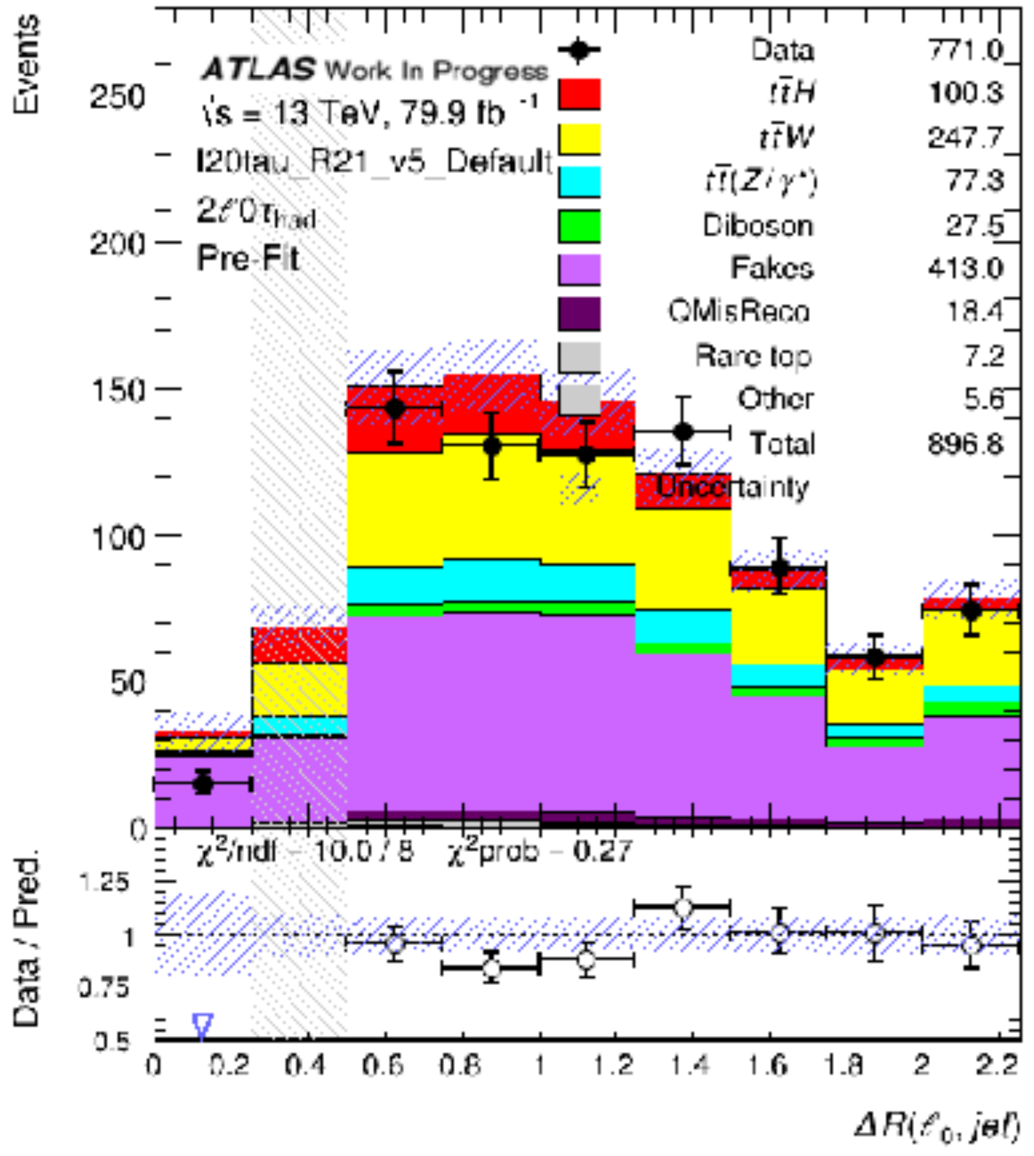


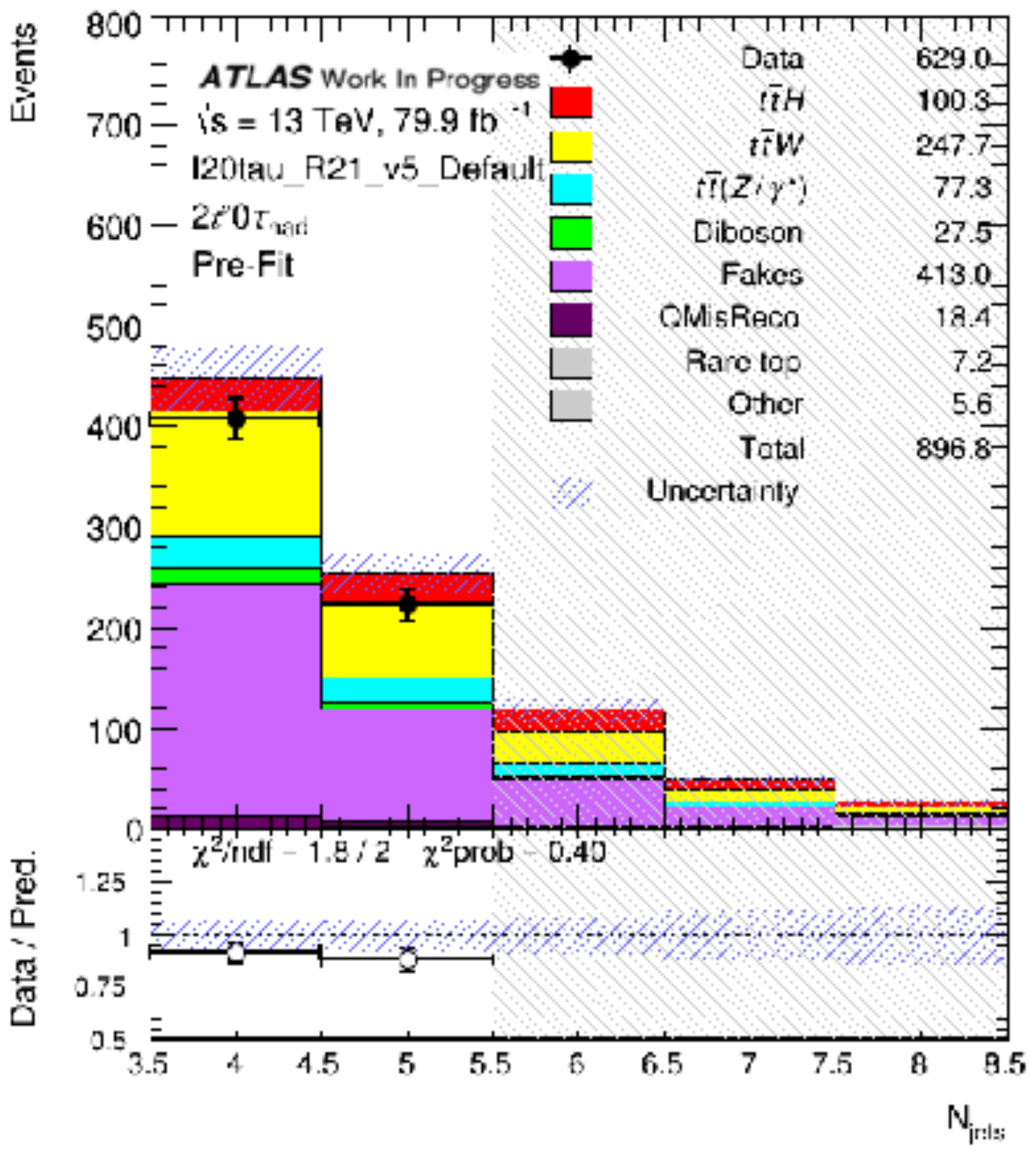


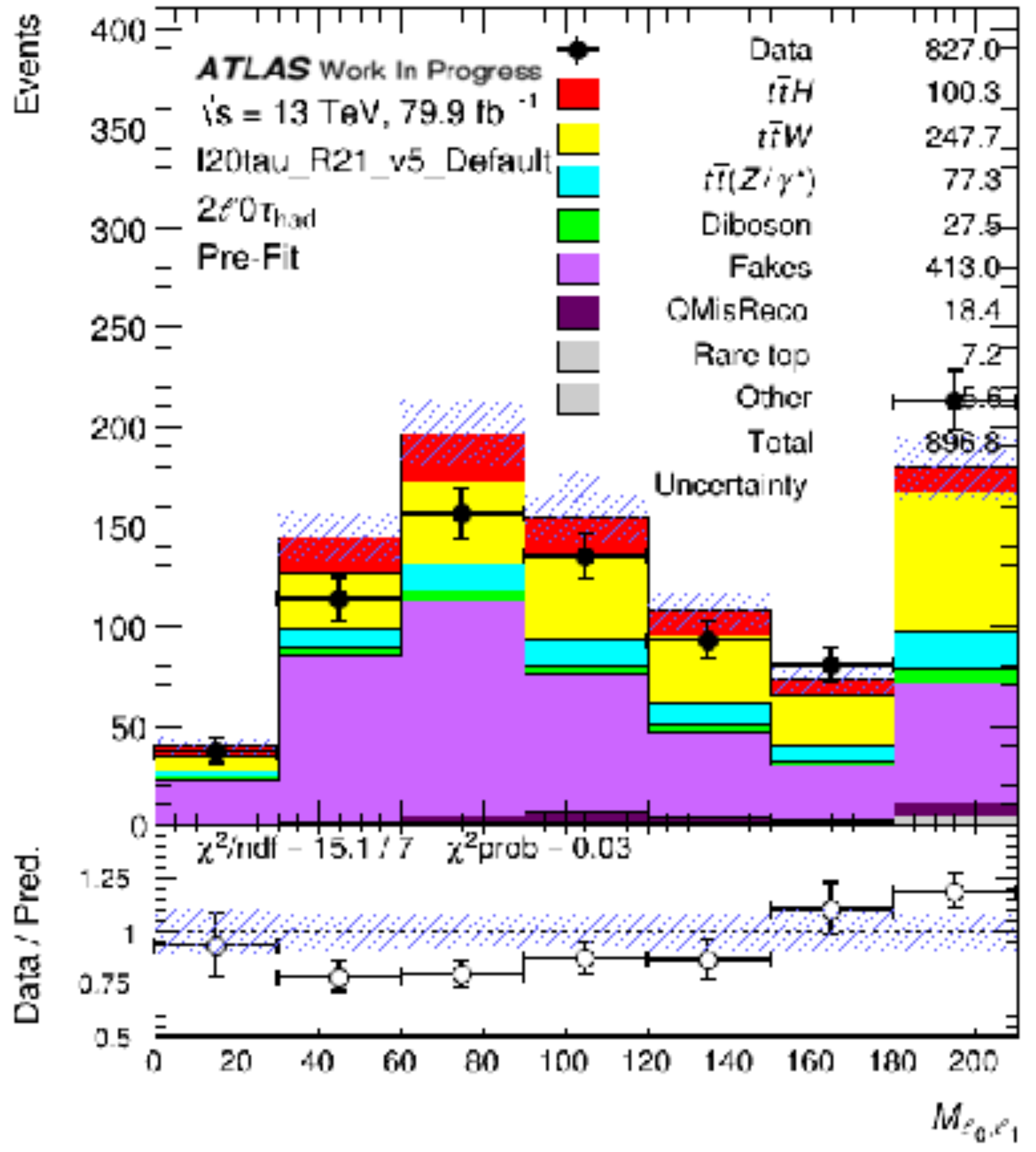
MODELING CHECKING IN SR

Blinding threshold: S/B > 15%









- *These results are still very preliminary, in particular with not final fake estimates and systematic uncertainties!*
- *MVA training is stable and no overtraining observed.*
- *Only one large correlation observed (between Pt_{l_1} and M_{lol_1}).*
- *Data/MC are in good agreements on the distribution of most MVA input variables.*

CONCLUSION

- *Evidence of ttH production with 36 fb^{-1} 13 Tev 2015-2016 data.*

  Paper published (Phys. Rev. D. 97 (2018) 072003)

- *Currently studying 80 fb^{-1} of 2015-2017 data*

- *Expecting discovery of ttH production at 13TeV with Run2 data*

Thank you for your attention!

2e event with 3 b-tagged & 6 non-b-tagged jets (ATLAS-CONF-2016-058)

BACK UP

SIGNAL AND BKG YIELDS, PRE/POST-FIT

Category	Non-prompt	Fake τ_{had}	q mis-id	$t\bar{t}W$	$t\bar{t}Z$	Diboson	Other	Total Bkgd.	$t\bar{t}H$	Observed
					Pre-fit yields					
2ℓSS	233 ± 39	–	33 ± 11	123 ± 18	41.4 ± 5.6	25 ± 15	28.4 ± 5.9	484 ± 38	42.6 ± 4.2	514
3ℓ SR	14.5 ± 4.3	–	–	5.5 ± 1.2	12.0 ± 1.8	1.2 ± 1.2	5.8 ± 1.4	39.1 ± 5.2	11.2 ± 1.6	61
3ℓ $t\bar{t}W$ CR	13.3 ± 4.3	–	–	19.9 ± 3.1	8.7 ± 1.1	< 0.2	4.53 ± 0.92	46.5 ± 5.4	4.18 ± 0.46	56
3ℓ $t\bar{t}Z$ CR	3.9 ± 2.5	–	–	2.71 ± 0.56	66 ± 11	8.4 ± 5.3	12.9 ± 4.2	93 ± 13	3.17 ± 0.41	107
3ℓ VV CR	27.7 ± 8.7	–	–	4.9 ± 1.0	21.3 ± 3.4	51 ± 30	17.9 ± 6.1	123 ± 32	1.67 ± 0.25	109
3ℓ $t\bar{t}$ CR	70 ± 17	–	–	10.5 ± 1.5	7.9 ± 1.1	7.2 ± 4.8	7.3 ± 1.9	103 ± 17	4.00 ± 0.49	85
4ℓ Z-enr.	0.11 ± 0.07	–	–	< 0.01	1.52 ± 0.23	0.43 ± 0.23	0.21 ± 0.09	2.26 ± 0.34	1.06 ± 0.14	2
4ℓ Z-dep.	0.01 ± 0.01	–	–	< 0.01	0.04 ± 0.02	< 0.01	0.06 ± 0.03	0.11 ± 0.03	0.20 ± 0.03	0
1ℓ+$2\tau_{\text{had}}$	–	65 ± 21	–	0.09 ± 0.09	3.3 ± 1.0	1.3 ± 1.0	0.98 ± 0.35	71 ± 21	4.3 ± 1.0	67
2ℓSS+$1\tau_{\text{had}}$	2.4 ± 1.4	1.80 ± 0.30	0.05 ± 0.02	0.88 ± 0.24	1.83 ± 0.37	0.12 ± 0.18	1.06 ± 0.24	8.2 ± 1.6	3.09 ± 0.46	18
2ℓOS+$1\tau_{\text{had}}$	–	756 ± 80	–	6.5 ± 1.3	11.4 ± 1.9	2.0 ± 1.3	5.8 ± 1.5	782 ± 81	14.2 ± 2.0	807
3ℓ+$1\tau_{\text{had}}$	–	0.75 ± 0.15	–	0.04 ± 0.04	1.38 ± 0.24	0.002 ± 0.002	0.38 ± 0.10	2.55 ± 0.32	1.51 ± 0.23	5
					Post-fit yields					
2ℓSS	211 ± 26	–	28.3 ± 9.4	127 ± 18	42.9 ± 5.4	20.0 ± 6.3	28.5 ± 5.7	459 ± 24	67 ± 18	514
3ℓ SR	13.2 ± 3.1	–	–	5.8 ± 1.2	12.9 ± 1.6	1.2 ± 1.1	5.9 ± 1.3	39.0 ± 4.0	17.7 ± 4.9	61
3ℓ $t\bar{t}W$ CR	11.7 ± 3.0	–	–	20.4 ± 3.0	8.9 ± 1.0	< 0.2	4.54 ± 0.88	45.6 ± 4.0	6.6 ± 1.9	56
3ℓ $t\bar{t}Z$ CR	3.5 ± 2.1	–	–	2.82 ± 0.56	70.4 ± 8.6	7.1 ± 3.0	13.6 ± 4.2	97.4 ± 8.6	5.1 ± 1.4	107
3ℓ VV CR	22.4 ± 5.7	–	–	5.05 ± 0.94	22.0 ± 3.0	39 ± 11	18.1 ± 5.9	106.8 ± 9.4	2.61 ± 0.82	109
3ℓ $t\bar{t}$ CR	56.0 ± 8.1	–	–	10.7 ± 1.4	8.1 ± 1.0	5.9 ± 2.7	7.1 ± 1.8	87.8 ± 7.9	6.3 ± 1.8	85
4ℓ Z-enr.	0.10 ± 0.07	–	–	< 0.01	1.60 ± 0.22	0.37 ± 0.15	0.22 ± 0.10	2.29 ± 0.28	1.65 ± 0.47	2
4ℓ Z-dep.	0.01 ± 0.01	–	–	< 0.01	0.04 ± 0.02	< 0.01	0.07 ± 0.03	0.11 ± 0.03	0.32 ± 0.09	0
1ℓ+$2\tau_{\text{had}}$	–	58.0 ± 6.8	–	0.11 ± 0.11	3.31 ± 0.90	0.98 ± 0.75	0.98 ± 0.33	63.4 ± 6.7	6.5 ± 2.0	67
2ℓSS+$1\tau_{\text{had}}$	1.86 ± 0.91	1.86 ± 0.27	0.05 ± 0.02	0.97 ± 0.26	1.96 ± 0.37	0.15 ± 0.20	1.09 ± 0.24	7.9 ± 1.2	5.1 ± 1.3	18
2ℓOS+$1\tau_{\text{had}}$	–	756 ± 28	–	6.6 ± 1.3	11.5 ± 1.7	1.64 ± 0.92	6.1 ± 1.5	782 ± 27	21.7 ± 5.9	807
3ℓ+$1\tau_{\text{had}}$	–	0.75 ± 0.14	–	0.04 ± 0.04	1.42 ± 0.22	0.002 ± 0.002	0.40 ± 0.10	2.61 ± 0.30	2.41 ± 0.68	5

EPS RESULTS

Channel	Best fit $\mu_{t\bar{t}H}$ (observed)	Best fit $\mu_{t\bar{t}H}$ (expected)	Observed (expected) significance
2ℓOS+1τ_{had}	$1.7\ ^{+1.6}_{-1.5}$ (stat.) $^{+1.4}_{-1.1}$ (syst.)	$1.0\ ^{+1.5}_{-1.4}$ (stat.) $^{+1.2}_{-1.1}$ (syst.)	0.9σ (0.5σ)
1ℓ+2τ_{had}	$-0.6\ ^{+1.1}_{-0.8}$ (stat.) $^{+1.1}_{-1.3}$ (syst.)	$1.0\ ^{+1.1}_{-0.9}$ (stat.) $^{+1.2}_{-1.1}$ (syst.)	- (0.6σ)
4ℓ	$-0.5\ ^{+1.3}_{-0.8}$ (stat.) $^{+0.2}_{-0.3}$ (syst.)	$1.0\ ^{+1.7}_{-1.2}$ (stat.) $^{+0.4}_{-0.2}$ (syst.)	- (0.8σ)
3ℓ+1τ_{had}	$1.6\ ^{+1.7}_{-1.3}$ (stat.) $^{+0.6}_{-0.2}$ (syst.)	$1.0\ ^{+1.5}_{-1.1}$ (stat.) $^{+0.4}_{-0.2}$ (syst.)	1.3σ (0.9σ)
2ℓSS+1τ_{had}	$3.5\ ^{+1.5}_{-1.2}$ (stat.) $^{+0.9}_{-0.5}$ (syst.)	$1.0\ ^{+1.1}_{-0.8}$ (stat.) $^{+0.5}_{-0.3}$ (syst.)	3.4σ (1.1σ)
3ℓ	$1.8\ ^{+0.6}_{-0.6}$ (stat.) $^{+0.6}_{-0.5}$ (syst.)	$1.0\ ^{+0.6}_{-0.5}$ (stat.) $^{+0.5}_{-0.4}$ (syst.)	2.4σ (1.5σ)
2ℓSS	$1.5\ ^{+0.4}_{-0.4}$ (stat.) $^{+0.5}_{-0.4}$ (syst.)	$1.0\ ^{+0.4}_{-0.4}$ (stat.) $^{+0.4}_{-0.4}$ (syst.)	2.6σ (1.9σ)
Combined	$1.6\ ^{+0.3}_{-0.3}$ (stat.) $^{+0.4}_{-0.3}$ (syst.)	$1.0\ ^{+0.3}_{-0.3}$ (stat.) $^{+0.3}_{-0.3}$ (syst.)	4.1σ (2.8σ)

CUTFLOW FOR 2L2τ CHANNEL

	ttH	top+X	ttγ	rare	VV	ttW	ttZ (NLO)	Z+jets	Sum bkg
Input	3.69 ± 0.27	31.05 ± 2.97	0.55 ± 0.20	0.13 ± 0.03	50.45 ± 1.17	0.30 ± 0.07	4.17 ± 0.19	527.93 ± 98.79	614.57 ± 98.84
CutBlind	3.69 ± 0.27	31.05 ± 2.97	0.55 ± 0.20	0.13 ± 0.03	50.45 ± 1.17	0.30 ± 0.07	4.17 ± 0.19	527.93 ± 98.79	614.57 ± 98.84
CutEventClean	3.69 ± 0.27	31.05 ± 2.97	0.55 ± 0.20	0.13 ± 0.03	50.45 ± 1.17	0.30 ± 0.07	4.17 ± 0.19	527.93 ± 98.79	614.57 ± 98.84
CutTrigger	3.40 ± 0.27	27.20 ± 2.82	0.47 ± 0.19	0.13 ± 0.03	46.49 ± 1.15	0.29 ± 0.07	3.89 ± 0.19	490.64 ± 95.77	569.10 ± 95.82
CutNLep2	3.36 ± 0.27	27.20 ± 2.82	0.47 ± 0.19	0.13 ± 0.03	46.12 ± 1.15	0.28 ± 0.07	3.79 ± 0.19	490.64 ± 95.77	568.62 ± 95.82
CutLep0Pt	3.32 ± 0.27	25.98 ± 2.75	0.47 ± 0.19	0.13 ± 0.03	45.41 ± 1.15	0.27 ± 0.07	3.78 ± 0.19	502.18 ± 95.26	578.22 ± 95.31
CutLep1Pt	2.73 ± 0.20	20.37 ± 2.40	0.34 ± 0.18	0.11 ± 0.03	41.79 ± 1.09	0.24 ± 0.06	3.38 ± 0.18	480.16 ± 92.96	546.40 ± 92.99
CutTrigMatch	2.66 ± 0.20	18.58 ± 2.31	0.33 ± 0.18	0.11 ± 0.03	40.86 ± 1.09	0.24 ± 0.06	3.29 ± 0.17	489.77 ± 92.41	553.18 ± 92.44
CutTauBTagVeto	2.43 ± 0.19	9.69 ± 1.74	0.24 ± 0.17	0.09 ± 0.02	38.90 ± 1.08	0.16 ± 0.06	2.96 ± 0.17	485.36 ± 92.39	537.40 ± 92.42
CutNTau2	2.43 ± 0.19	9.69 ± 1.74	0.24 ± 0.17	0.09 ± 0.02	38.86 ± 1.08	0.16 ± 0.06	2.95 ± 0.17	485.36 ± 92.39	537.35 ± 92.42
CutZVeto	2.24 ± 0.18	9.53 ± 1.74	0.24 ± 0.17	0.08 ± 0.02	7.35 ± 0.87	0.14 ± 0.05	2.11 ± 0.15	84.79 ± 53.64	104.24 ± 53.67
CutNJet_ge2	1.97 ± 0.18	4.76 ± 1.35	0.00 ± 0.00	0.08 ± 0.02	1.91 ± 0.11	0.07 ± 0.04	1.87 ± 0.14	4.17 ± 1.10	12.85 ± 1.75
CutNBJet_ge1	1.68 ± 0.18	4.29 ± 1.39	0.00 ± 0.00	0.06 ± 0.02	0.13 ± 0.03	0.06 ± 0.04	1.51 ± 0.13	0.22 ± 0.15	6.28 ± 1.41
CutNTauTight_ge1	1.68 ± 0.18	4.29 ± 1.39	0.00 ± 0.00	0.06 ± 0.02	0.13 ± 0.03	0.06 ± 0.04	1.51 ± 0.13	0.22 ± 0.15	6.28 ± 1.41
CutMtt01	1.52 ± 0.18	3.48 ± 1.32	0.00 ± 0.00	0.04 ± 0.02	0.08 ± 0.02	0.06 ± 0.03	1.13 ± 0.11	0.10 ± 0.09	4.90 ± 1.33

let's talk about fakes... (in 2LSS & 3L)

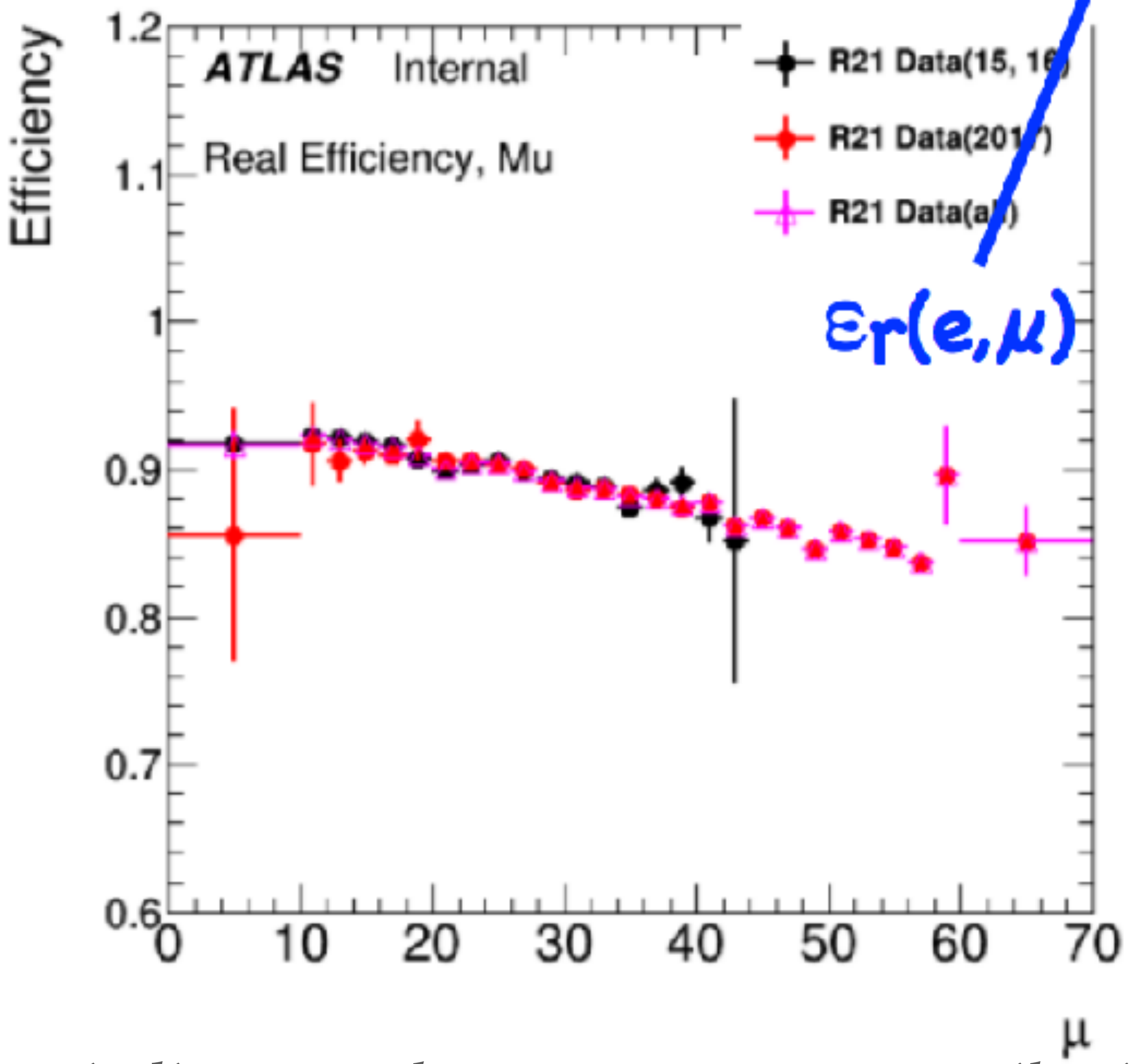
measurement from data after SR selections using leptons passing/failing tight ID

measurement from control regions

$$
\begin{pmatrix} N^{TT} \\ N^{T\not{T}} \\ N^{\not{T}T} \\ N^{\not{T}\not{T}} \end{pmatrix} = \begin{pmatrix} \varepsilon_{r,1}\varepsilon_{r,2} & \varepsilon_{r,1}\varepsilon_{f,2} & \varepsilon_{f,1}\varepsilon_{r,2} & \varepsilon_{f,1}\varepsilon_{f,2} \\ \varepsilon_{r,1}\not{\varepsilon}_{r,2} & \varepsilon_{r,1}\not{\varepsilon}_{f,2} & \varepsilon_{f,1}\not{\varepsilon}_{r,2} & \varepsilon_{f,1}\not{\varepsilon}_{f,2} \\ \not{\varepsilon}_{r,1}\varepsilon_{r,2} & \not{\varepsilon}_{r,1}\varepsilon_{f,2} & \not{\varepsilon}_{f,1}\varepsilon_{r,2} & \not{\varepsilon}_{f,1}\varepsilon_{f,2} \\ \not{\varepsilon}_{r,1}\not{\varepsilon}_{r,2} & \not{\varepsilon}_{r,1}\not{\varepsilon}_{f,2} & \not{\varepsilon}_{f,1}\not{\varepsilon}_{r,2} & \not{\varepsilon}_{f,1}\not{\varepsilon}_{f,2} \end{pmatrix} \begin{pmatrix} N^{rr} \\ N^{rf} \\ N^{fr} \\ N^{ff} \end{pmatrix}
$$

what we want

$\not{\varepsilon} = 1 - \varepsilon$



- CR to measure efficiency of reconstructing a real electron as "tight":
  - $e^{+-}\mu^{-+}$ ttbar enriched, close to our SR
  - tag and probe used
    - ~10% dependency on pile up observed
- Electron fake efficiencies measured in CRs, corrected with the HF/Conv fraction in CR/SR from MC

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https://indico.cern.ch/event/727984/contributions/2997879/attachments/1646281/2631240/PLV_Fakes_080518.pdf

PROMPT LEPTON MVA

PLI:

Variable	Description
N_{track} in track jet	Number of tracks collected by the track jet
IP2 $\log(P_b/P_{light})$	Log-likelihood ratio between the b and light jet hypotheses with the IP2D algorithm
IP3 $\log(P_b/P_{light})$	Log-likelihood ratio between the b and light jet hypotheses with the IP3D algorithm
$N_{TrkAtVtx}$ SV + JF	Number of tracks used in the secondary vertex found by the SV1 algorithm in addition to the number of tracks from secondary vertices found by the JetFitter algorithm with at least two tracks
$p_T^{lepton}/p_T^{track\ jet}$	The ratio of the lepton p_T and the track jet p_T
ΔR(lepton, track jet)	ΔR between the lepton and the track jet axis
p_T VarCone30/p_T	Lepton track isolation, with track collecting radius of $\Delta R < 0.3$
E_T TopoCone30/p_T	Lepton calorimeter isolation, with topological cluster collecting radius of $\Delta R < 0.3$

Table 6: A table of the variables used in the training of `PromptLeptonIso`.

The `PromptLeptonIso` distributions for electrons and muons are shown in Figure 1.

PLV:

Variable	Description
N_{track} in track jet	Number of tracks collected by the track jet
rnnip	Recurrent Neural Network with additional impact parameter information of tracks inside the track-jet
DL1mu	DL1 (deep learning tagger) extended with Soft Muon Tagging information
p_T^{rel}	lepton p_T projected on the track jet direction
$p_T^{track\ lepton}/p_T^{track\ jet}$	The ratio of the track lepton p_T and the track jet p_T
ΔR(lepton, track jet)	ΔR between the lepton and the track jet axis
p_T VarCone30/p_T	Lepton track isolation, with track collecting radius of $\Delta R < 0.3$
E_T TopoCone30/p_T	Lepton calorimeter isolation, with topological cluster collecting radius of $\Delta R < 0.3$

Table 6: A table of the variables used in the training of `PromptLeptonVeto`.

Variable	PromptLeptonIso	PromptLeptonVeto
N_{track} in track jet	✓	✓
sv1_jf_ntrkv	✓	✗
$IP2\log(P_b/P_{light})$	✓	✗
$IP3\log(P_b/P_{light})$	✓	✗
$p_T(lepton)/p_T(track\ jet)$	✓	✗
$\Delta R(lepton, track\ jet)$	✓	✓
$\Sigma E_T(\Delta R < 0.3)/p_T$	✓	✓
$\Sigma p_T(\Delta R < 0.3)/p_T$	✓	✓
rnnip	✗	✓
DL1mu	✗	✓
p_T^{rel}	✗	✓
Track $p_T(lepton)/p_T(track\ jet)$	✗	✓

Figure 1: Comparison of the input variables included in the `PromptLeptonIso` and `PromptLeptonVeto` MVAs.

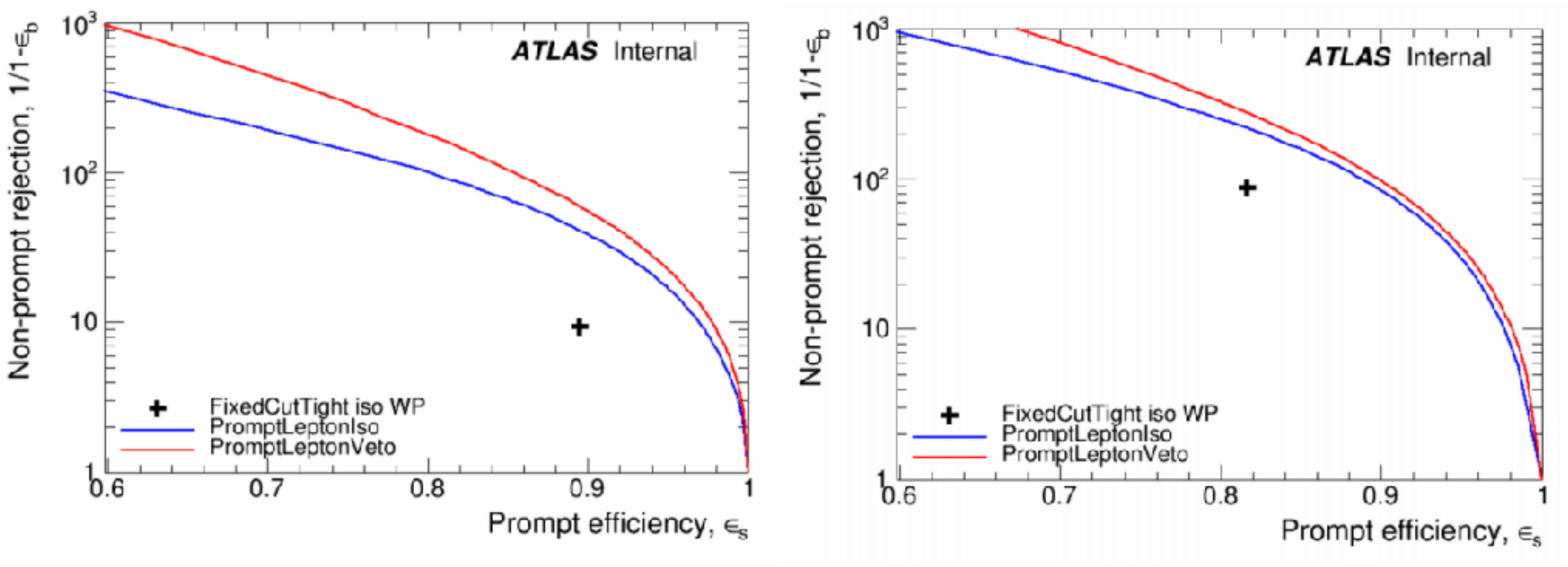

Figure 2: ROC curves from `PromptLeptonVeto` and `PromptLeptonIso`, as well as the performance of FixedCut-Tight working point, for electrons (left) and muons (right).

A lepton MVA has been developed to better reject non-prompt leptons than standard cut based selections based upon impact parameter, isolation and PID.

Prompt lepton veto (PLV) is a successor of PLI and uses more advanced bTagging algorithms as input