Measurement of the Cross-section of $t\bar{t}W$ Production with ATLAS Detector

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2023, November 7 @ 14th FCPPL

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ATLAS EXPERIMENT
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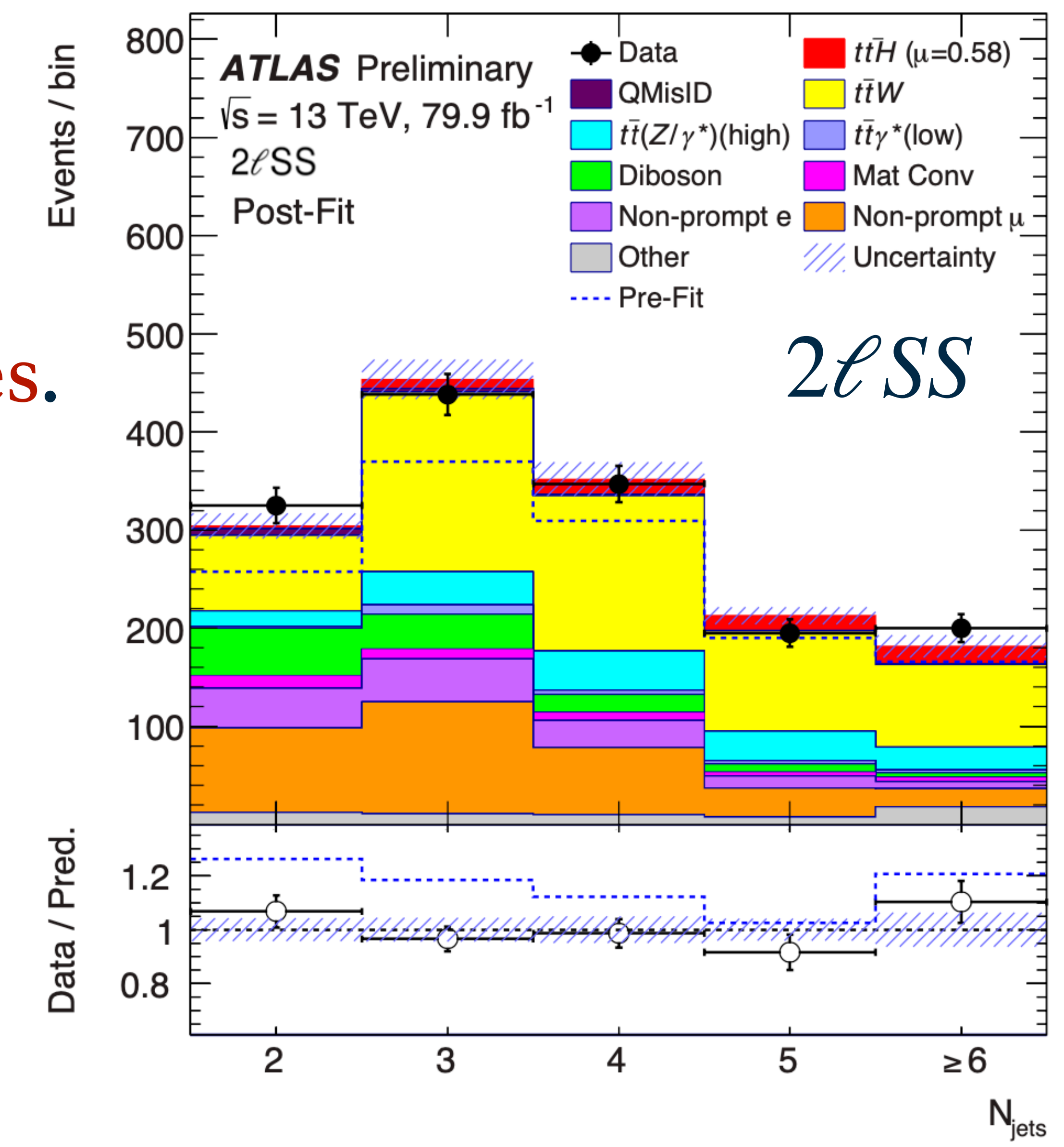
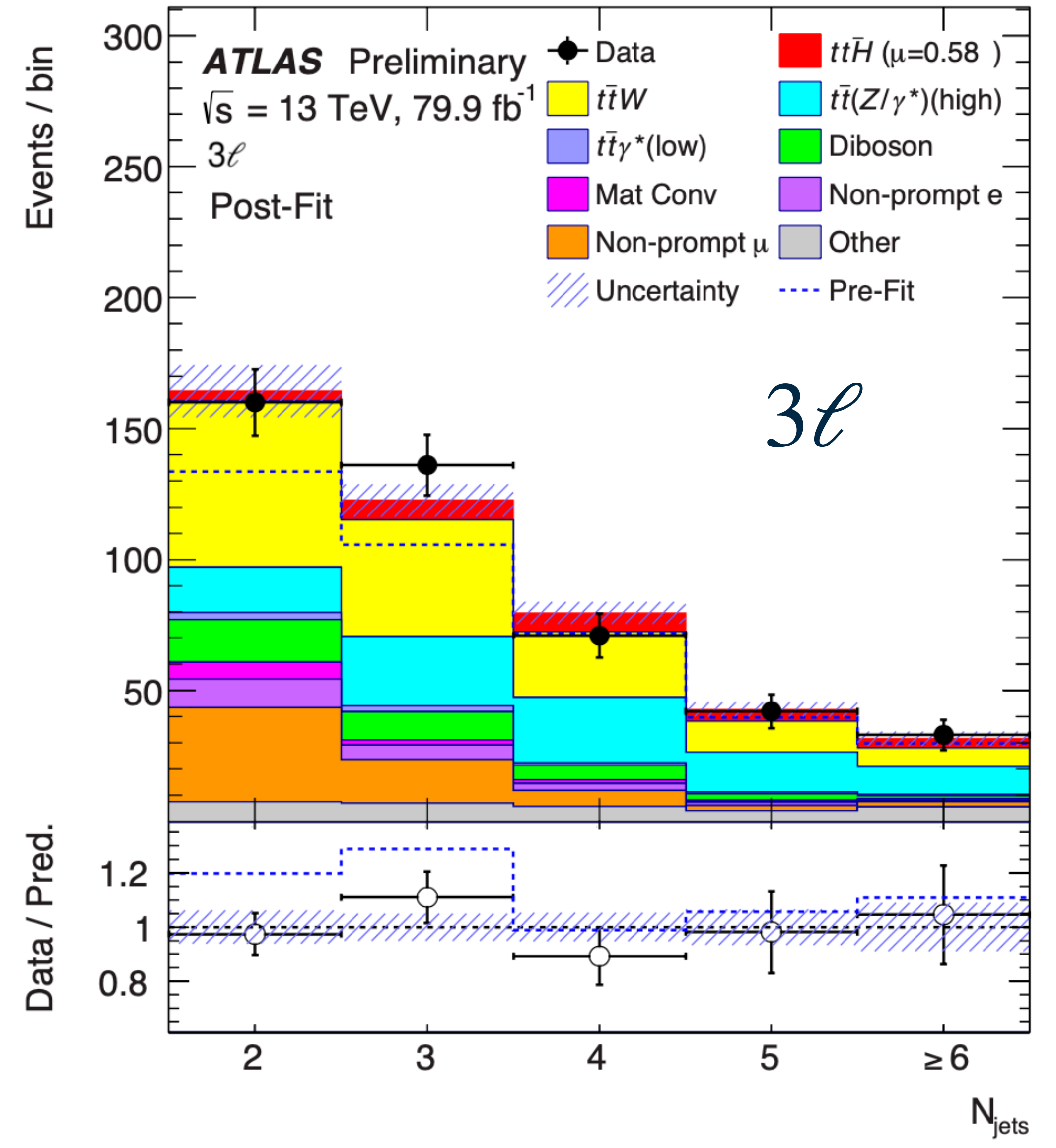
Motivation

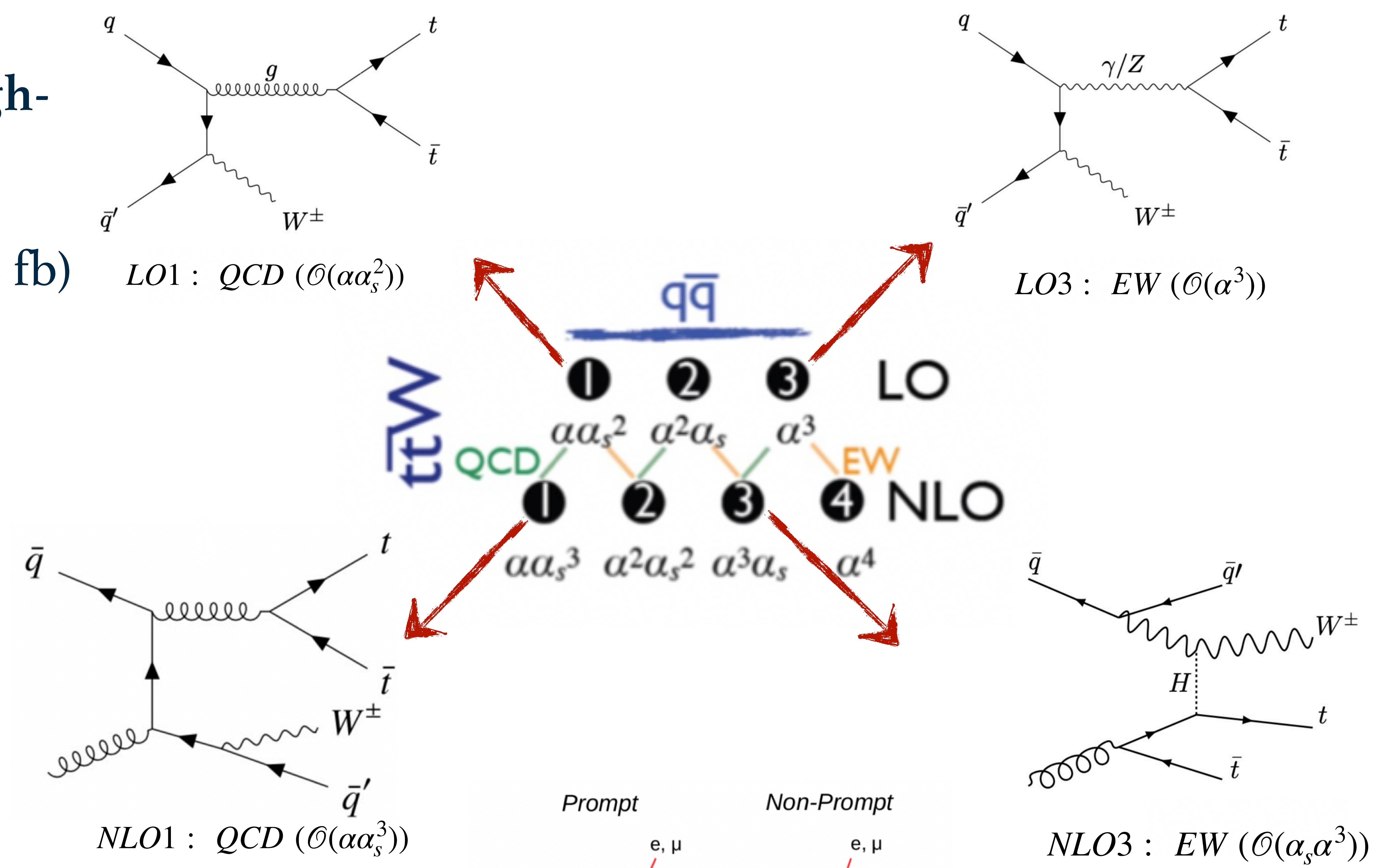
- $t\bar{t}W$ process is the dominant background in many measurements with multi-lepton final states.
  - Provides irreducible source of same-sign dilepton pairs
- Significant mis-modelling observed (excess) in the **80 fb⁻¹ ttH-ML** analysis:
  - Normalisation factors above the theoretical prediction
    - $\lambda^{2lLJ} = 1.56 \pm 0.29,\ \lambda^{2lHJ} = 1.26 \pm 0.19\ and\ \lambda^{3l} = 1.68 \pm 0.29$
  - Similar excesses, $\lambda^{CMS} = 1.43$, observed in **CMS ttH-ML** analysis
- A two-step analysis strategy was decided for the **full Run 2 ttH-ML analysis:**
  - The first step is to **measure cross-sections of ttW production in $2\ell SS$ and 3ℓ channels**
  - Following on ttW measurements, measure the **cross-section of ttH production**



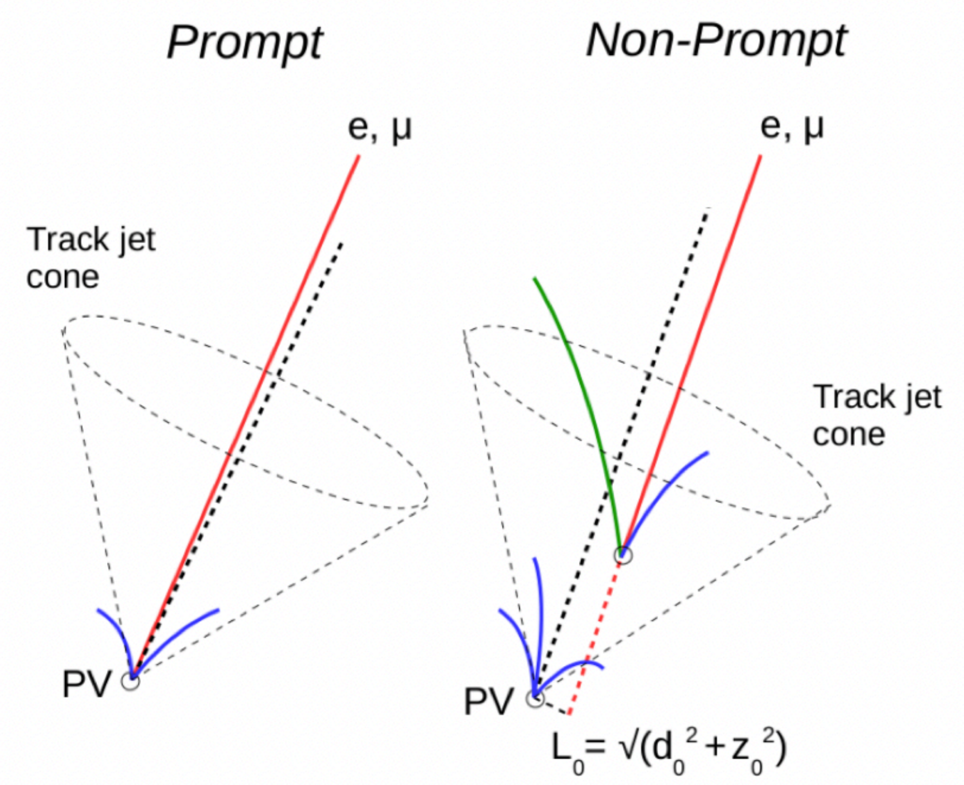


Signal Modeling and Background Estimation

- Challenging to simulate because of the high-order EW and QCD corrections.
  - **QCD sample**: LO1+NLO1 (597 fb → 573.68 fb)
    - Include -3.9% interference effect from LO3+NLO2 EW diagrams
  - **EW sample**: NLO3 diagram (42.1 fb)



- Reducible background:
  - Charge mis-identification (**Q-MisID**)
  - Internal and Material Conversion (**CO**)
  - Non-prompt leptons from Heavy Flavor (**HF**) decay



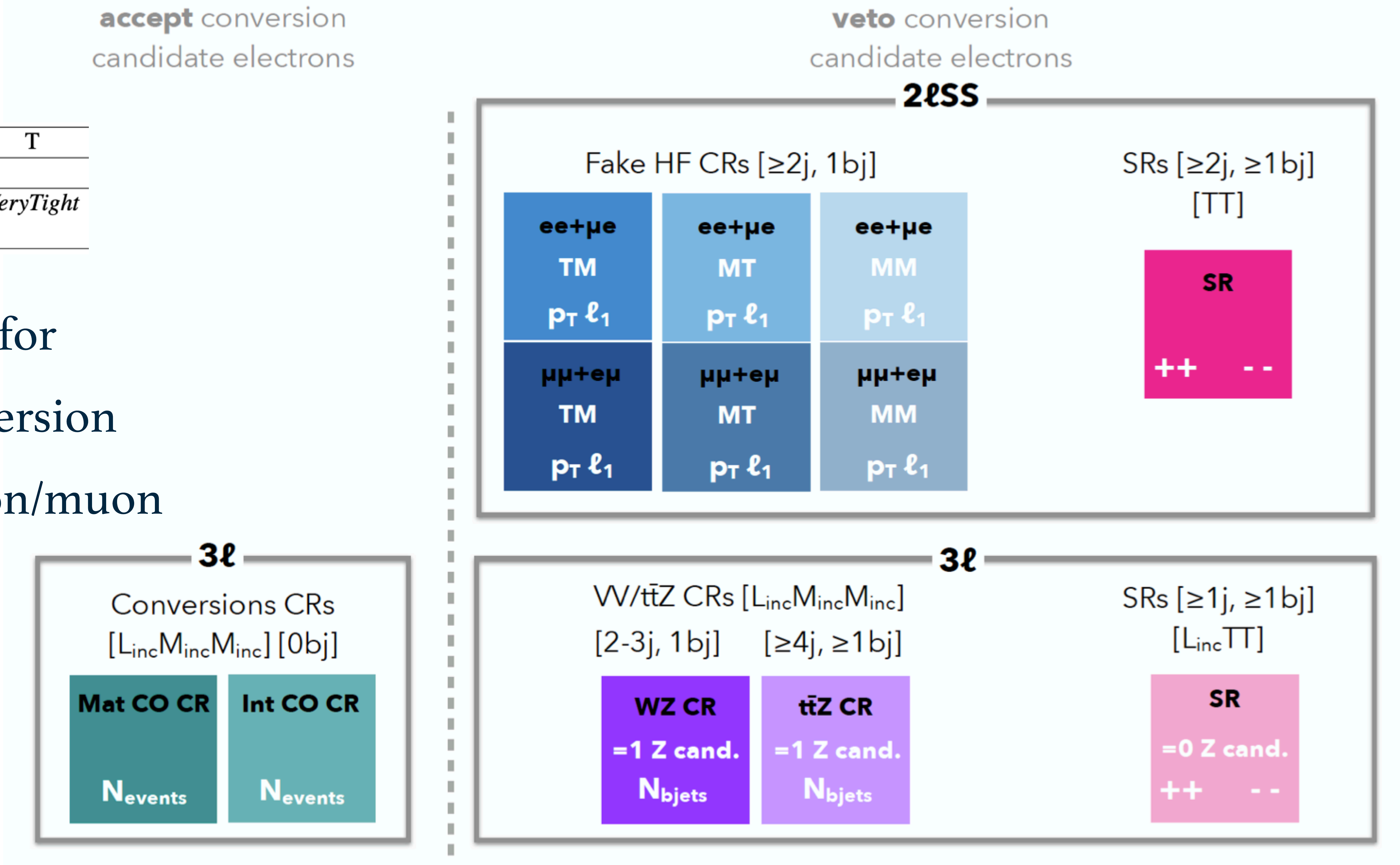
- Irreducible background:
  - ttZ ,VV samples: estimated with dedicated CR and free floated when fitting

Non-prompt/Fake leptons Estimation: Template Fit

- 10 control regions: 6 for **HF fakes**, 1 for **VV**, 1 for **$t\bar{t}Z$** and 2 for **internal** and **material CO**
  - Use PLIV WPs to define CR

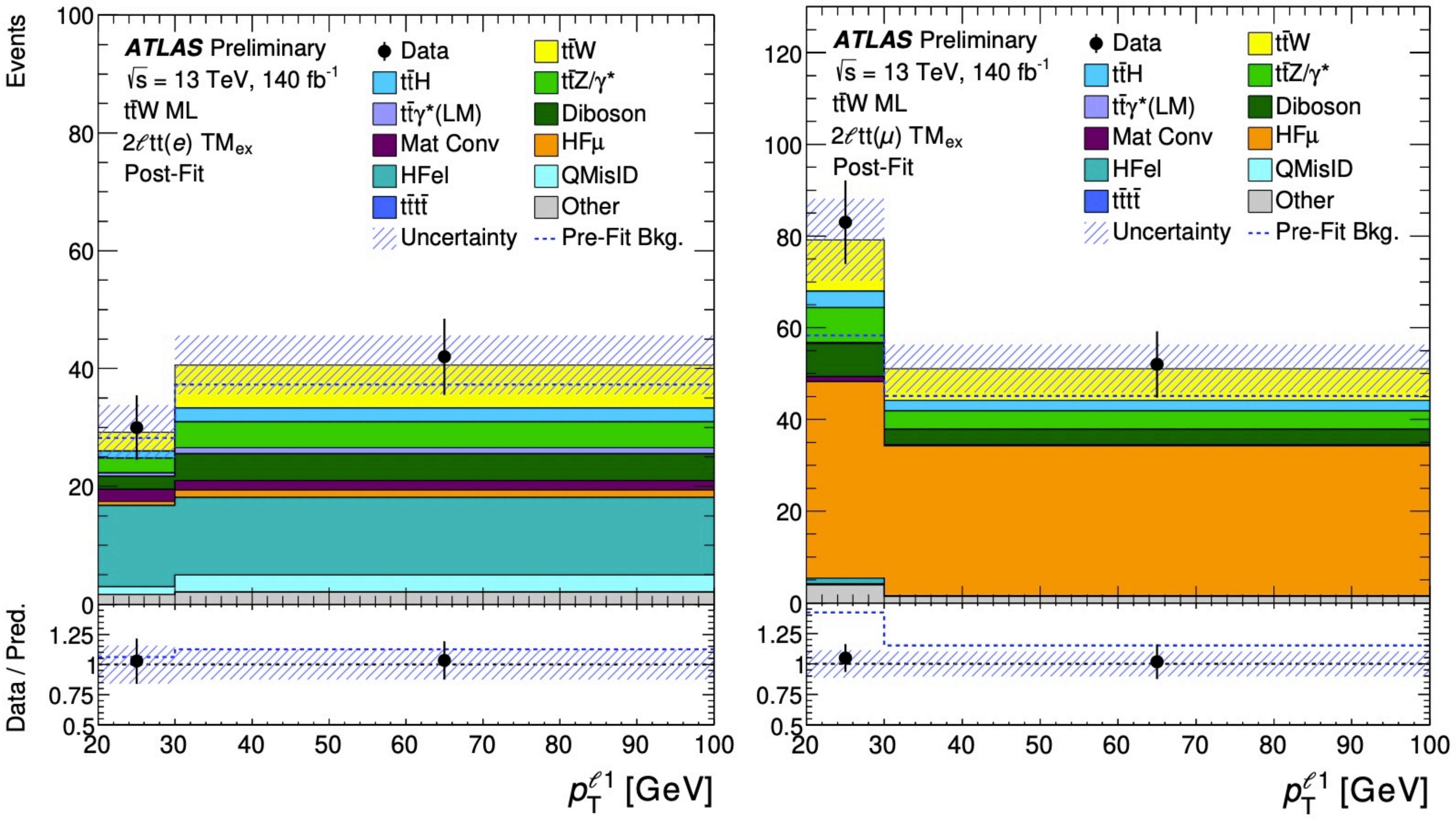
	Linc	L	Minc	M	T
FCLoose isolation			Yes		
Non-prompt lepton BDT (PLIV)	No	PLIV < 0 and *not-Tight*	*Tight*	*Tight-not-VeryTight*	*VeryTight*

- Uses 6 free floating normalisation factors for
  - internal conversion and external conversion
  - heavy flavour with non-prompt electron/muon
  - $t\bar{t}Z$ and diboson backgrounds

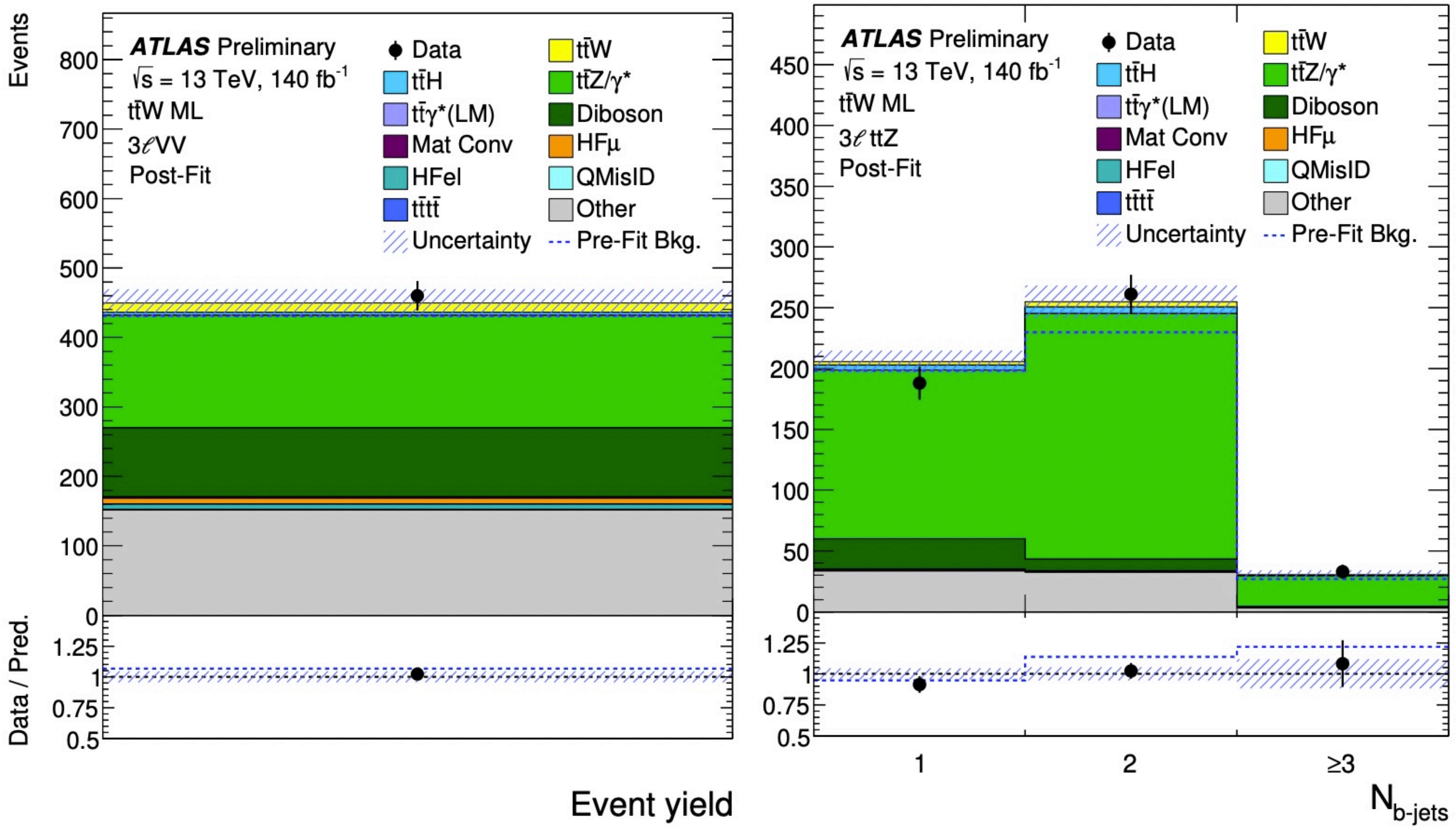


Template Fit: Data Fits in CRs

$2\ell SS,\ P_{T,subleading\ lep}$



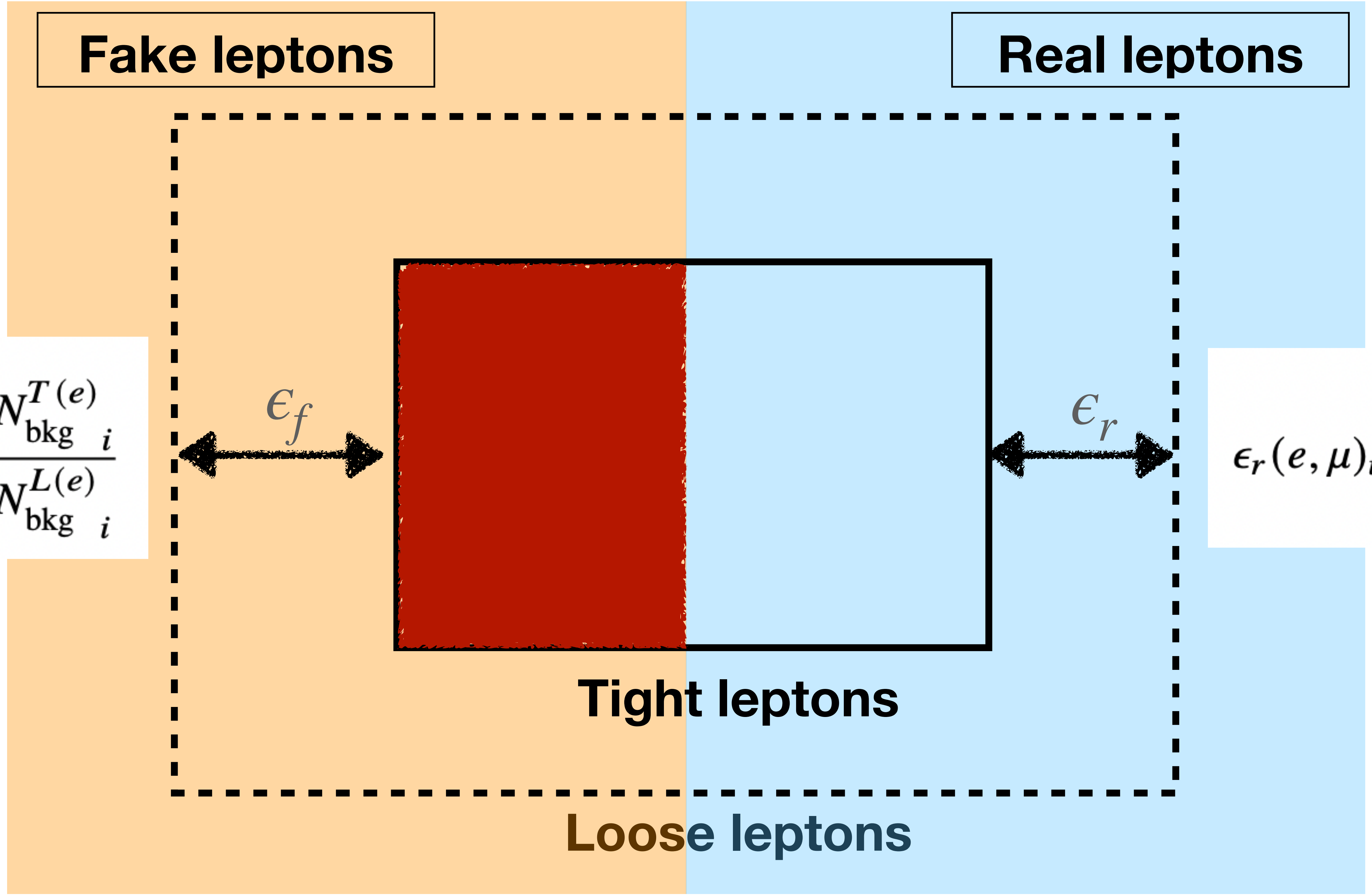
3ℓ



Fake estimation with Matrix Method

- Estimate the fakes with the matrix method (data-driven)
- Define CR, in which measure the efficiencies for the real and fake leptons from Loose selection to Tight selection, using Tag&Probe method
- Apply the efficiencies in the SR to calculate the total number of fake events (where at least one of the leptons is fake)

$$\epsilon_f(e)_i = \frac{N_i^{T(e)} - N_{\text{bkg}\,i}^{T(e)}}{N_i^{L(e)} - N_{\text{bkg}\,i}^{L(e)}}$$



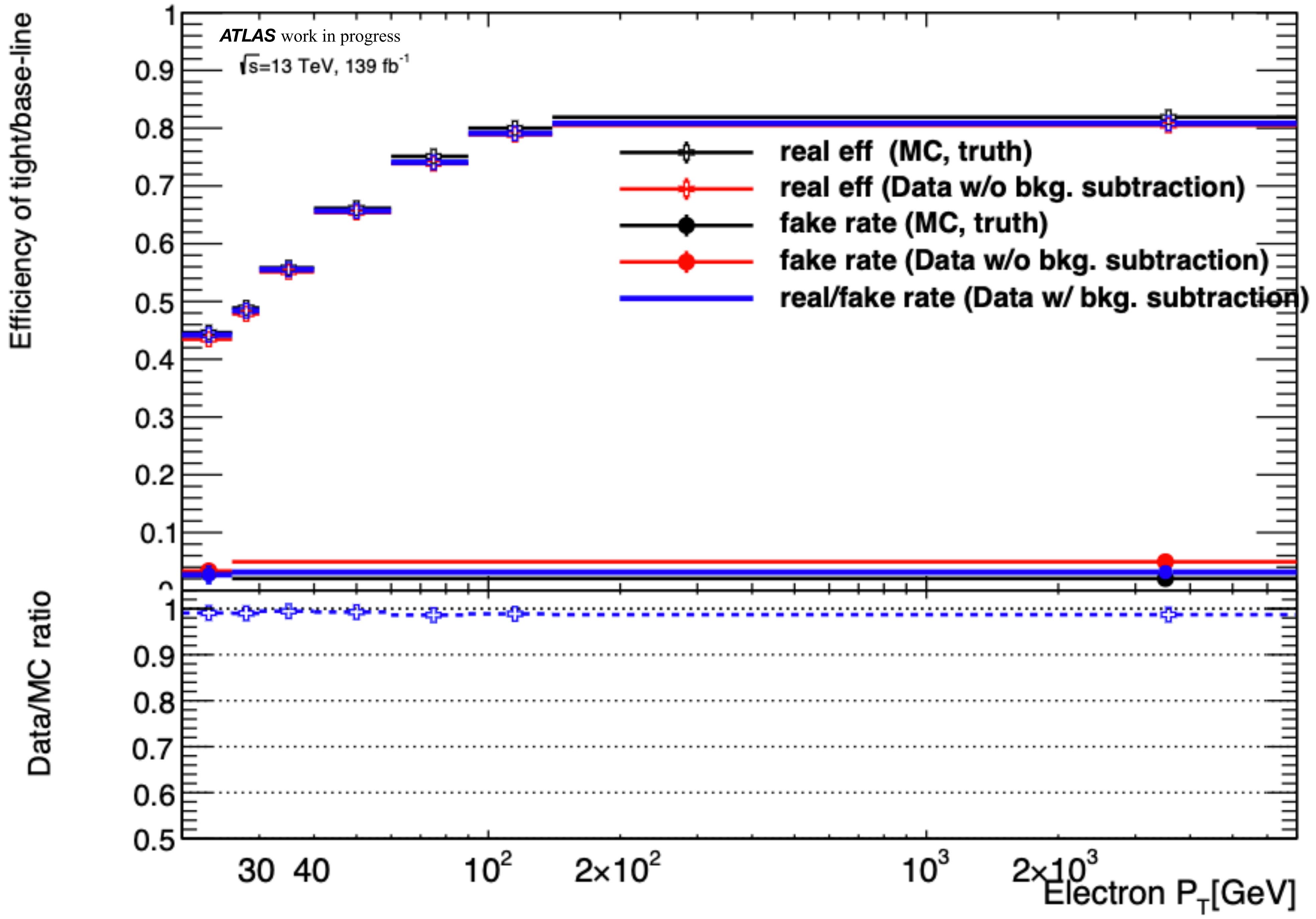
$$\epsilon_r(e,\mu)_i = \frac{N_i^{T(e,\mu)} - N_{\text{bkg}\,i}^{T(e,\mu)}}{N_i^{L(e,\mu)} - N_{\text{bkg}\,i}^{L(e,\mu)}}$$

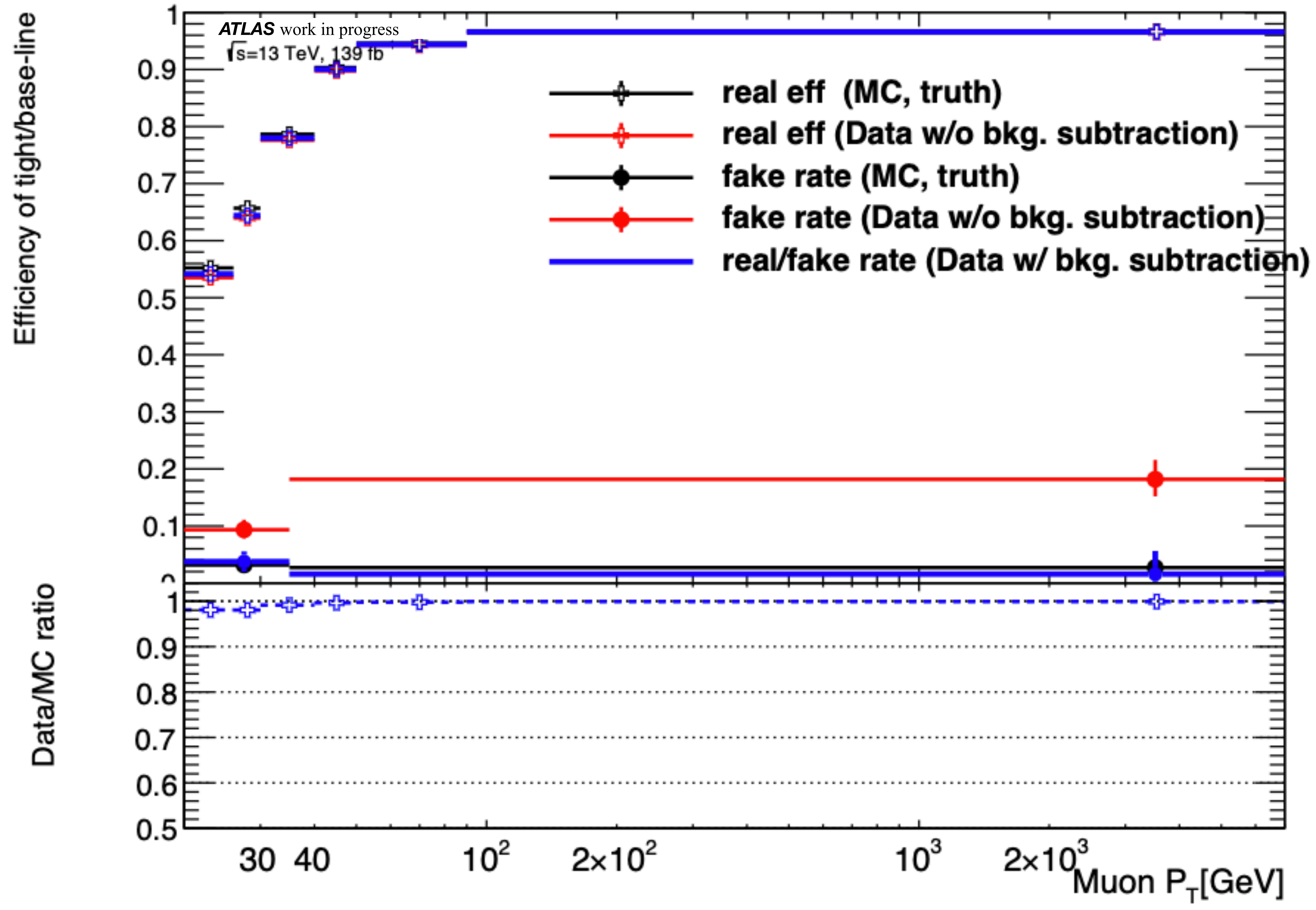
$$\begin{pmatrix} N^{TT} \\ N^{T\bar{T}} \\ N^{\bar{T}T} \\ N^{\bar{T}\bar{T}} \end{pmatrix} = \begin{pmatrix} \epsilon_{r,1}\epsilon_{r,2} & \epsilon_{r,1}\epsilon_{f,2} & \epsilon_{f,1}\epsilon_{r,2} & \epsilon_{f,1}\epsilon_{f,2} \\ \epsilon_{r,1}\bar{\epsilon}_{r,2} & \epsilon_{r,1}\bar{\epsilon}_{f,2} & \epsilon_{f,1}\bar{\epsilon}_{r,2} & \epsilon_{f,1}\bar{\epsilon}_{f,2} \\ \bar{\epsilon}_{r,1}\epsilon_{r,2} & \bar{\epsilon}_{r,1}\epsilon_{f,2} & \bar{\epsilon}_{f,1}\epsilon_{r,2} & \bar{\epsilon}_{f,1}\epsilon_{f,2} \\ \bar{\epsilon}_{r,1}\bar{\epsilon}_{r,2} & \bar{\epsilon}_{r,1}\bar{\epsilon}_{f,2} & \bar{\epsilon}_{f,1}\bar{\epsilon}_{r,2} & \bar{\epsilon}_{f,1}\bar{\epsilon}_{f,2} \end{pmatrix} \begin{pmatrix} N^{rr} \\ N^{rf} \\ N^{fr} \\ N^{ff} \end{pmatrix}$$

$$N_{TT}^{f} = N_{TT}^{rf} + N_{TT}^{fr} + N_{TT}^{ff} = \epsilon_{r,1}\epsilon_{f,2}N^{rf} + \epsilon_{r,2}\epsilon_{f,1}N^{fr} + \epsilon_{f,1}\epsilon_{f,2}N^{ff}$$

Fake estimation with Matrix Method

- Estimate the fakes with the matrix method (data-driven)
- Define CR, in which measure the efficiencies for the real and fake leptons from Loose selection to Tight selection, using Tag&Probe method
- Apply the efficiencies in the SR to calculate the total number of fake events (where at least one of the leptons is fake)

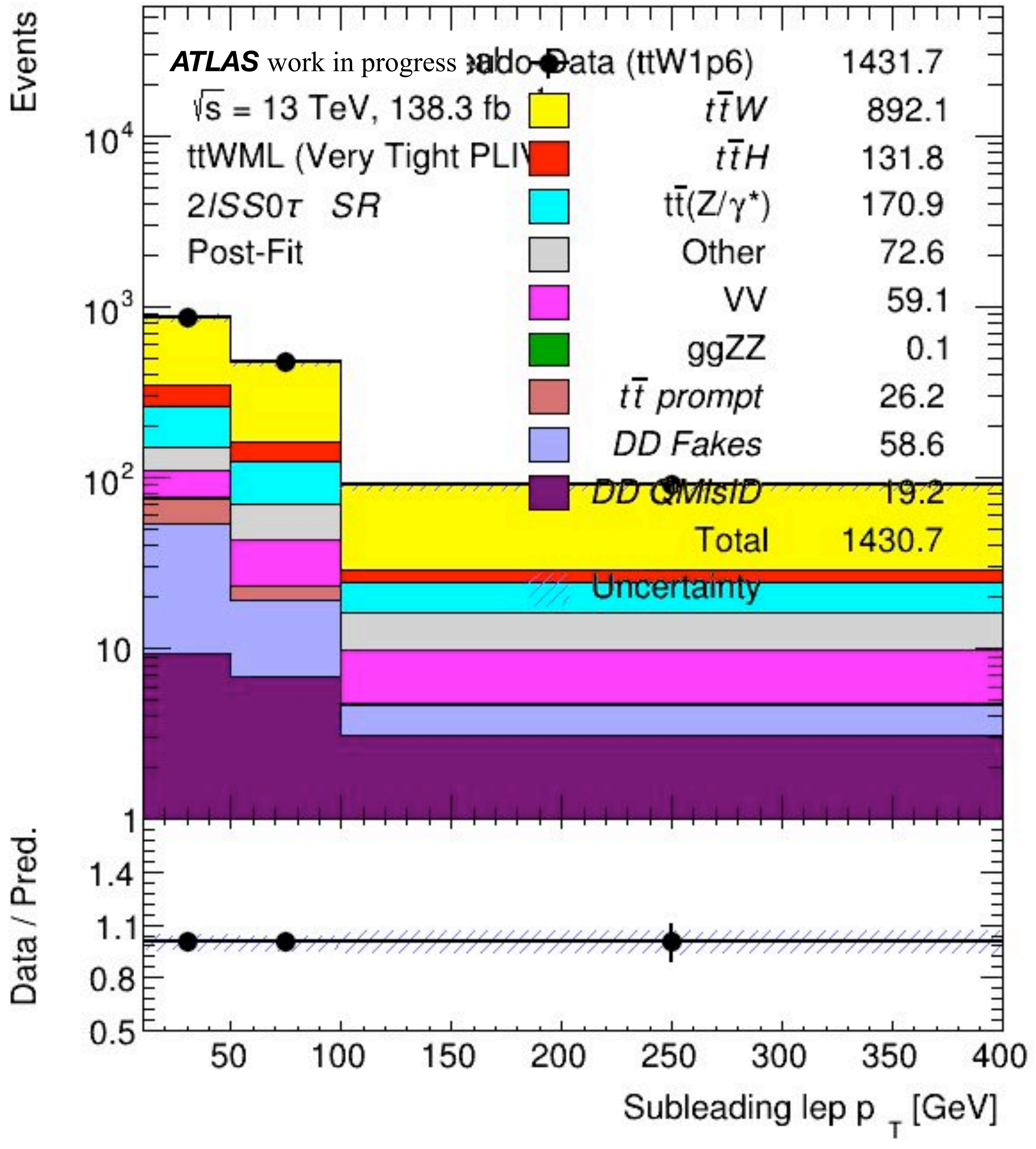


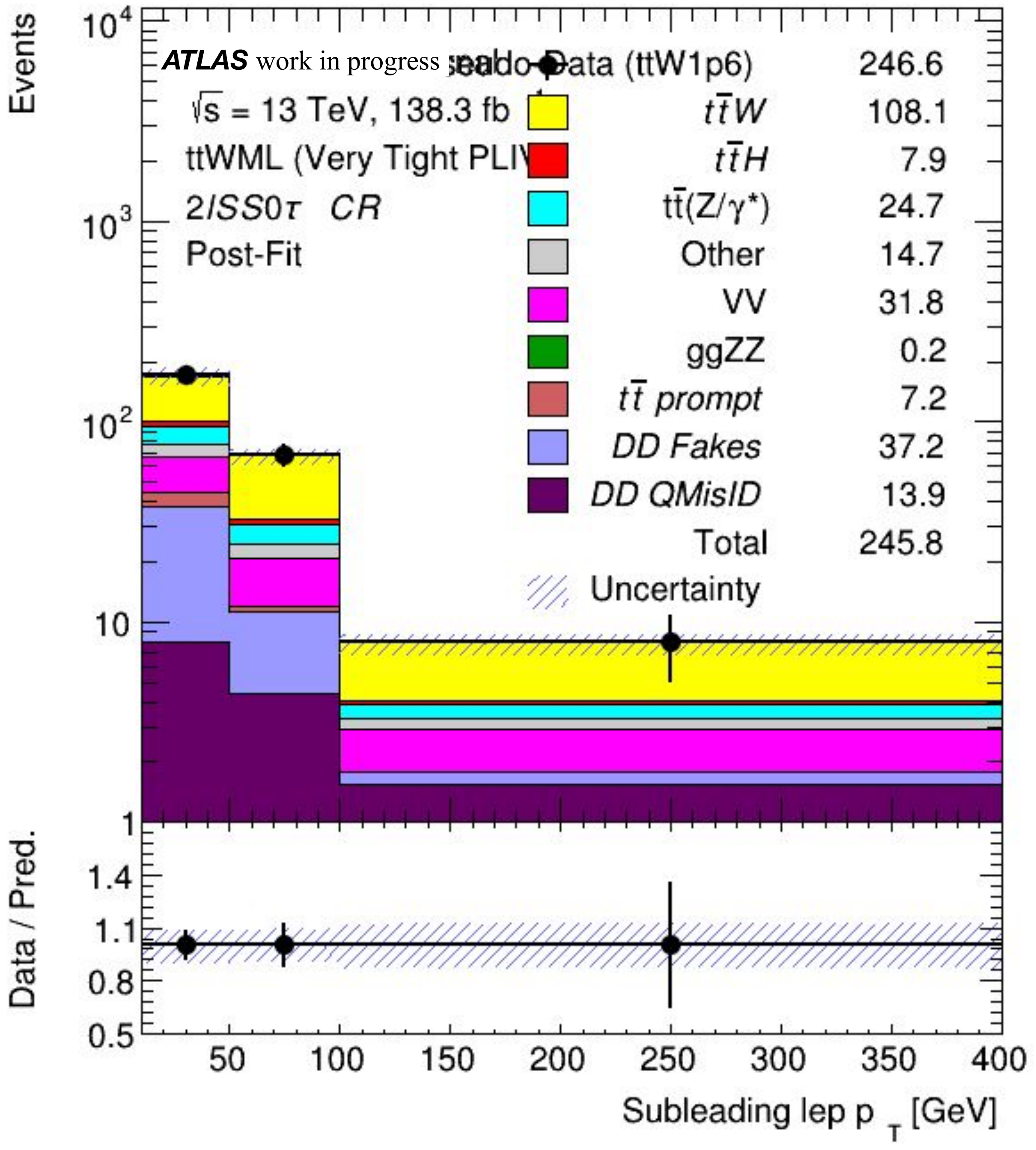


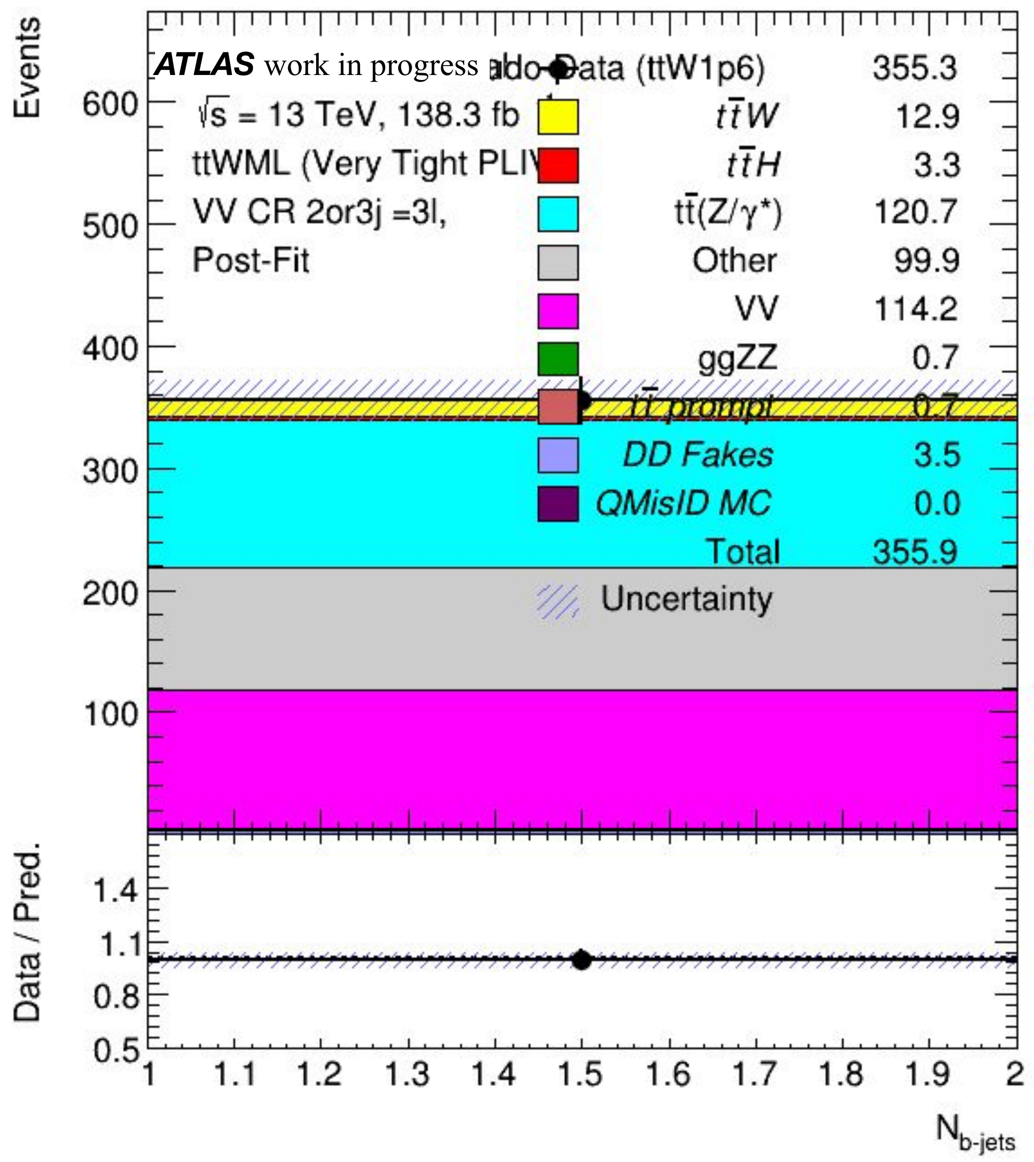
Matrix Method fit test:

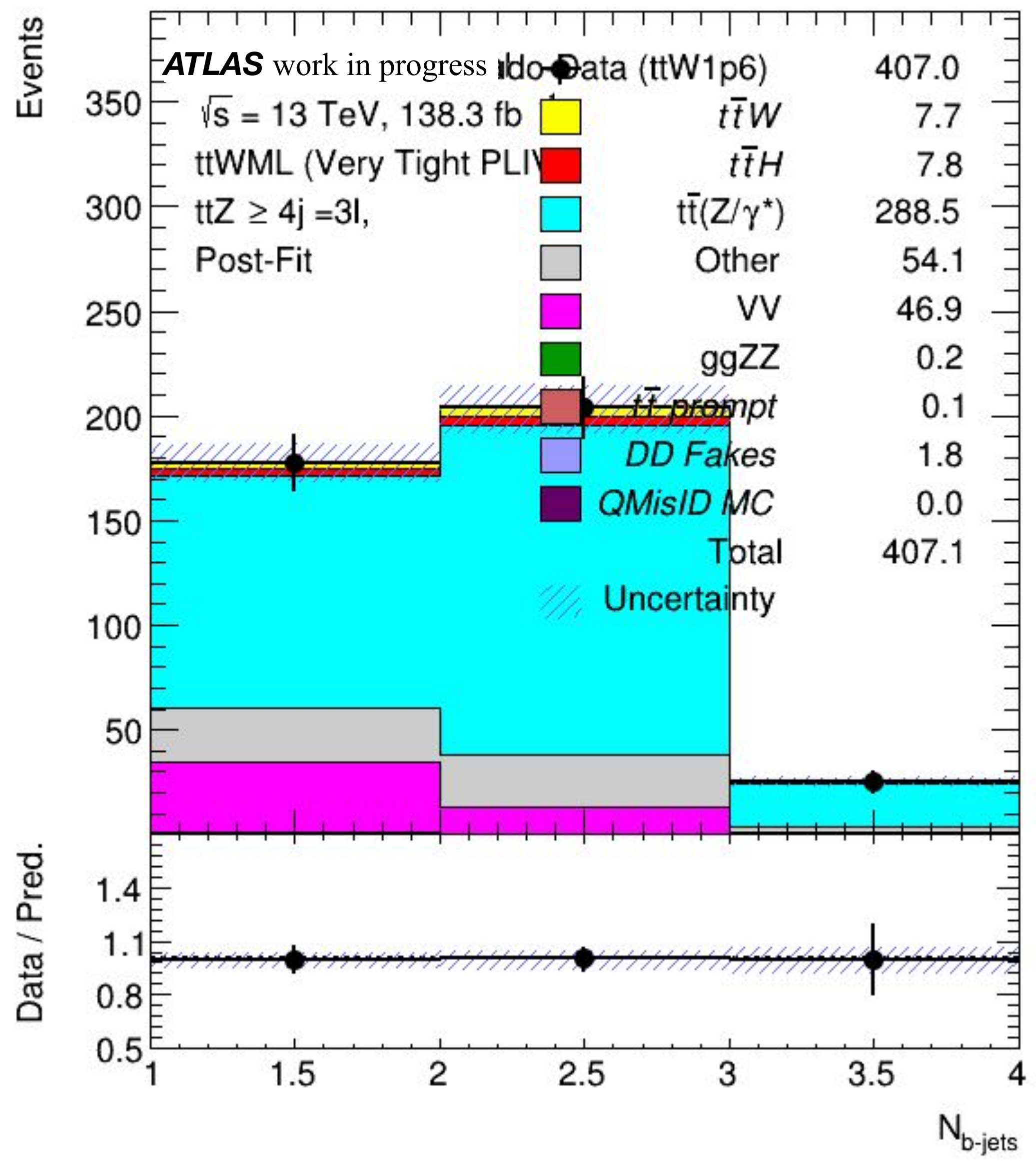
- Defined 5 regions for fit test:
  - 2lSS: subleading lepton Pt in CR and SR,
  - 3l: 3rd leading lepton Pt SR, VV CR and ttZ CR
- Performed statistical fit test via TReXFitter, njected $\mu_{ttW} = 1.7$

$2\ell SS,\ P_{T,subleading\ lep}$

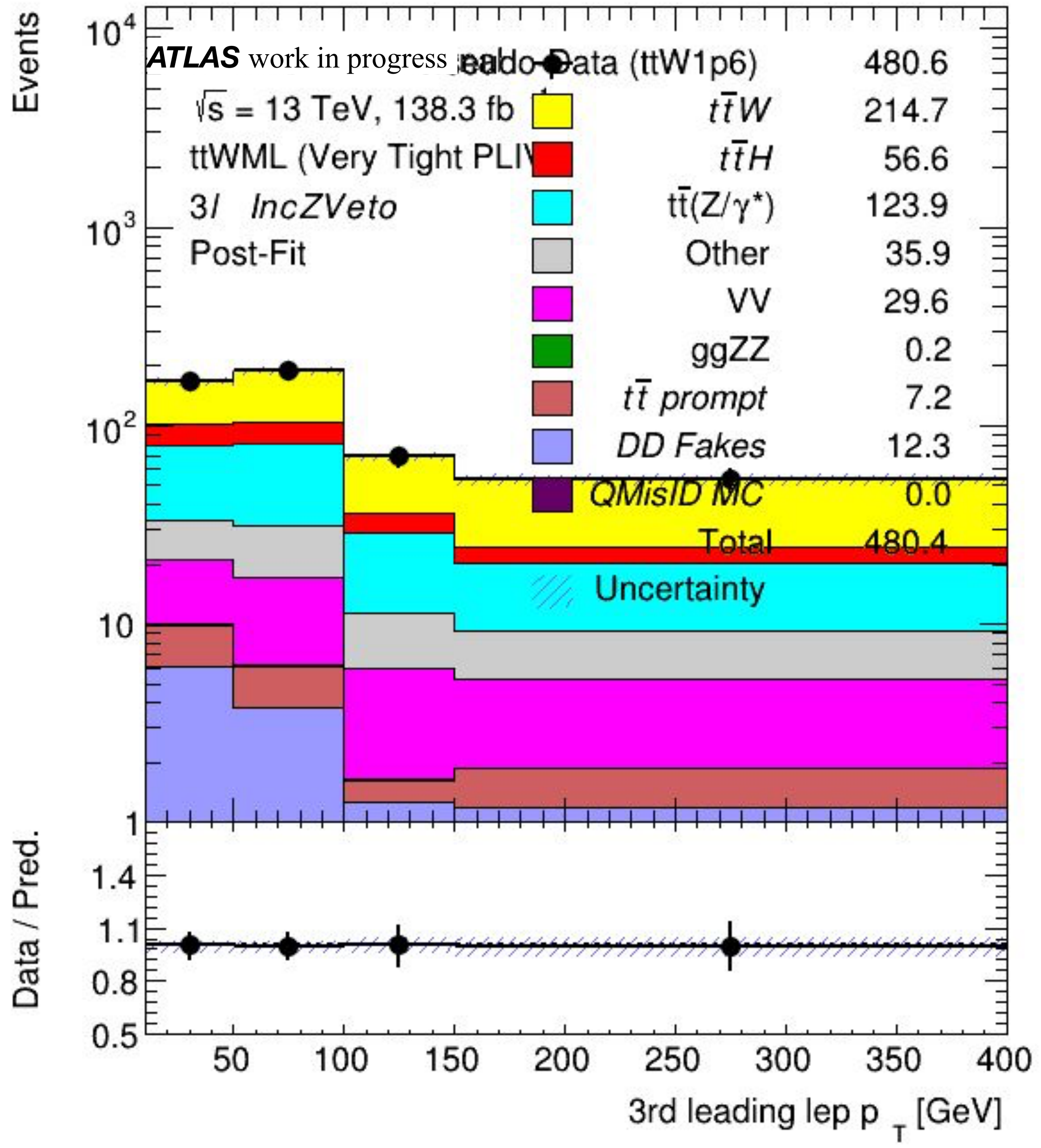








$3\ell,\ N_{b-jets}$ / $P_{T,subleading\ lep}$



Inclusive cross-section measurement

- Utilizing an inclusive measurement strategy resembling the one adopted in the previous 36 fb−1 measurement
- Use a total of 56 SRs within 2lSS and 3l channels
  - The observable used for fitting is the yields per region.

2ℓSS (48 regions)

Split by: Charge (++,--)
Flavour (ee, $e\mu$, μe, $\mu\mu$)
N_{jets} ($= 3$, $= 4$, ≥ 5)
$N_{b-\text{jets}}$ ($= 1$, ≥ 2)

3ℓ (8 regions)

Split by: Charge (+,-)
N_{jets} ($= 2$, ≥ 3)
$N_{b-\text{jets}}$ ($= 1$, ≥ 2)

- Estimate non-prompt lepton background using template fit method
- In addition to the signal strength, also measure charge ratio and relative charge asymmetry in inclusive fit

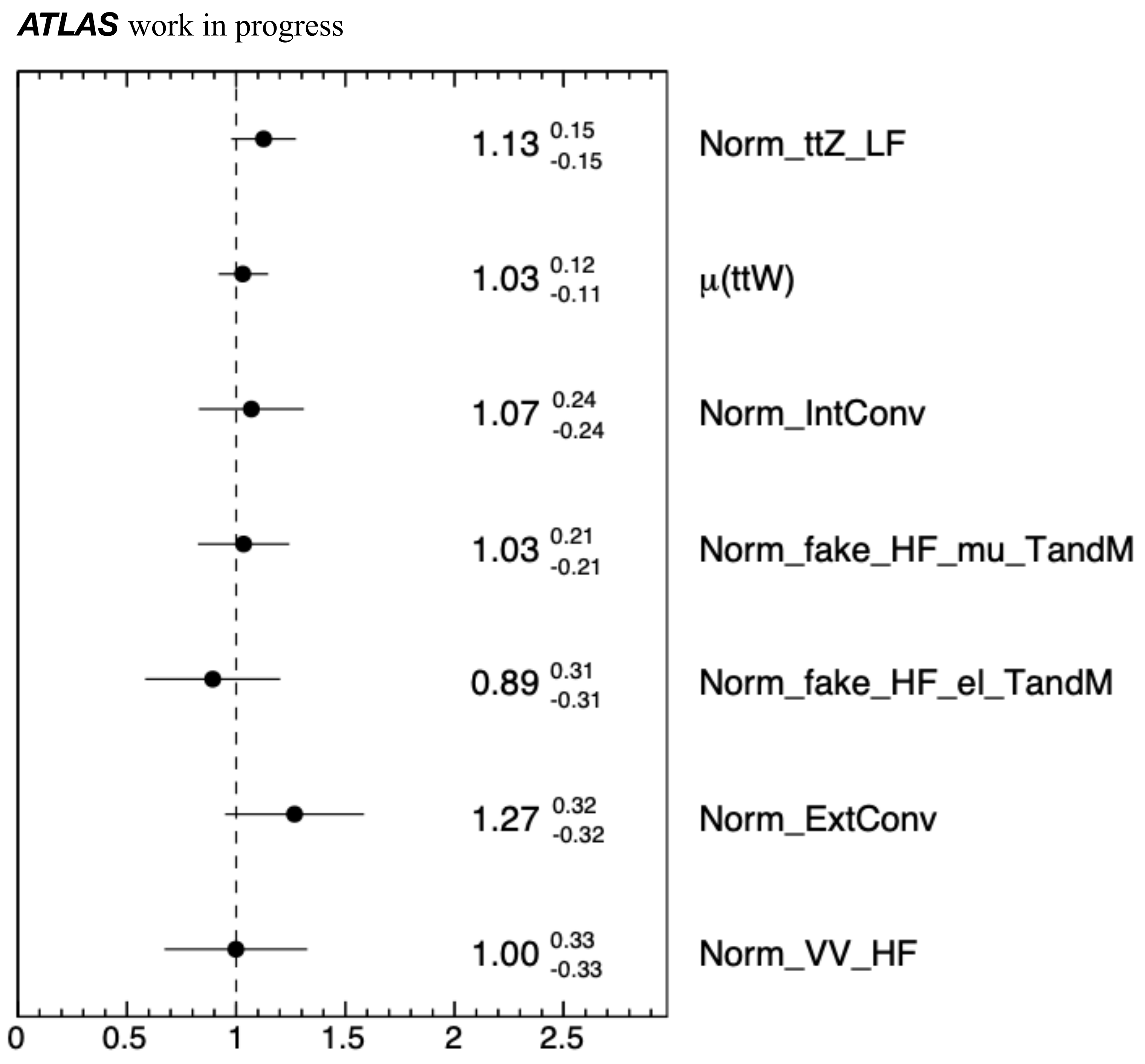
$$R = \frac{\sigma(t\bar{t}W^+)}{\sigma(t\bar{t}W^-)} \qquad A_C^R = \frac{\sigma(t\bar{t}W^+) - \sigma(t\bar{t}W^-)}{\sigma(t\bar{t}W^+) + \sigma(t\bar{t}W^-)}$$

Asimov Fit studies

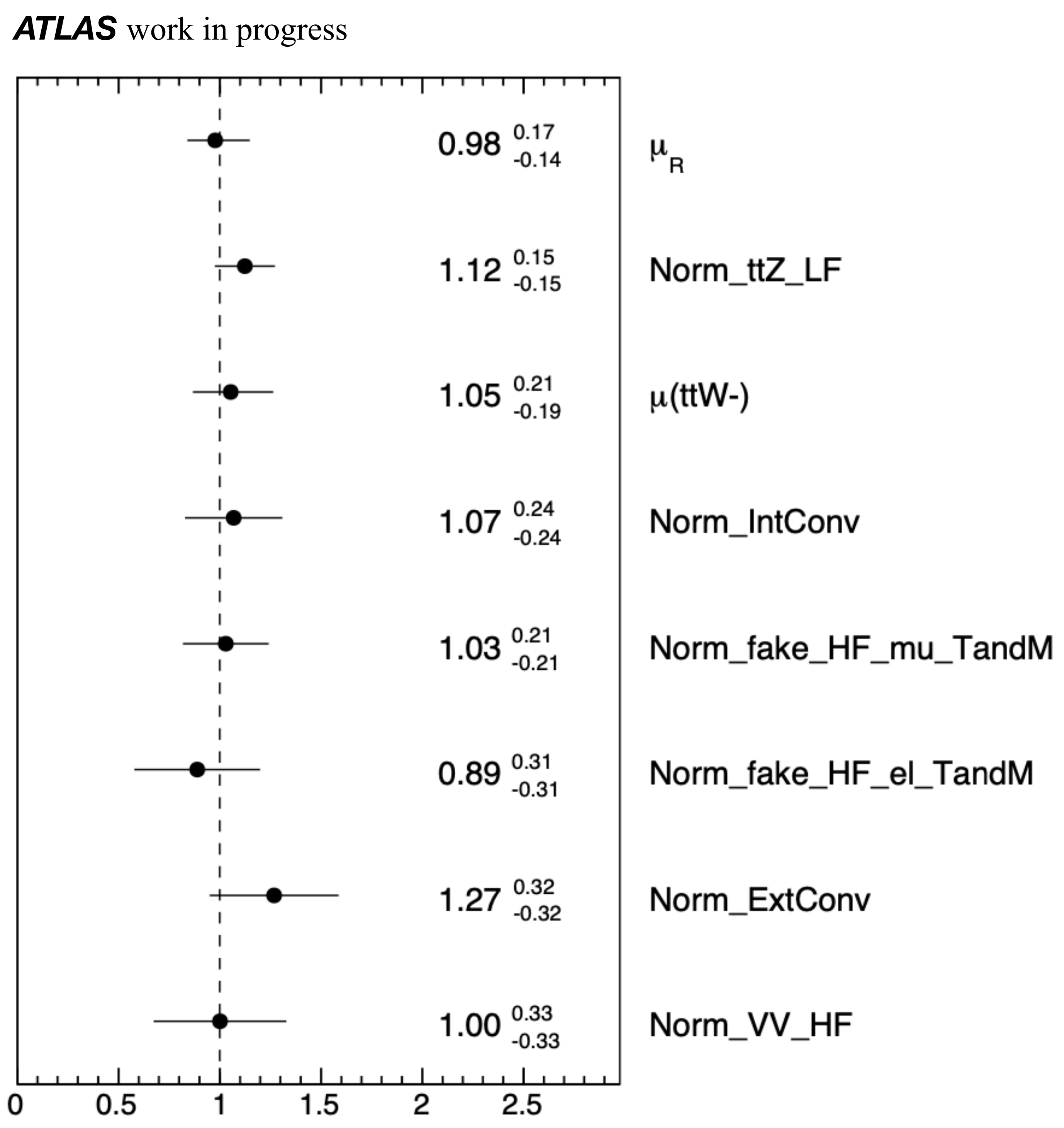
- Inclusive fit: hybrid fit, Asimov data in SR and real data in CR
- Charge ratio fit: $R = \frac{\sigma_{ttW+}}{\sigma_{ttW-}}$
- Real data fit with u(ttW) blind

mu_ttW split into the stat and syst components

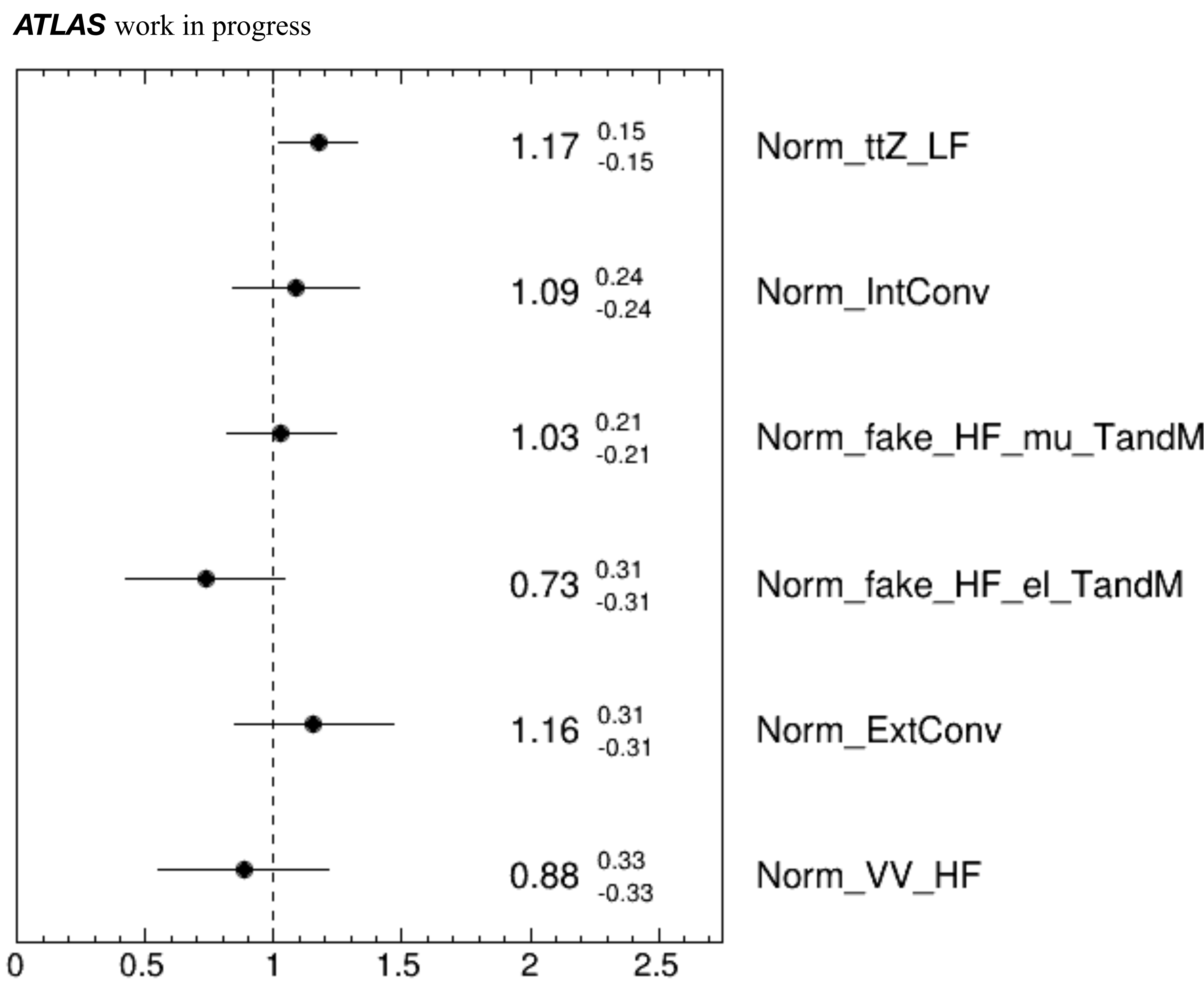
$$\mu(ttW) = 1.03^{+0.07}_{-0.07}(Stat.)^{+0.10}_{-0.08}(Syst.)$$



- Inclusive fit



- Ratio fit



- Data fit

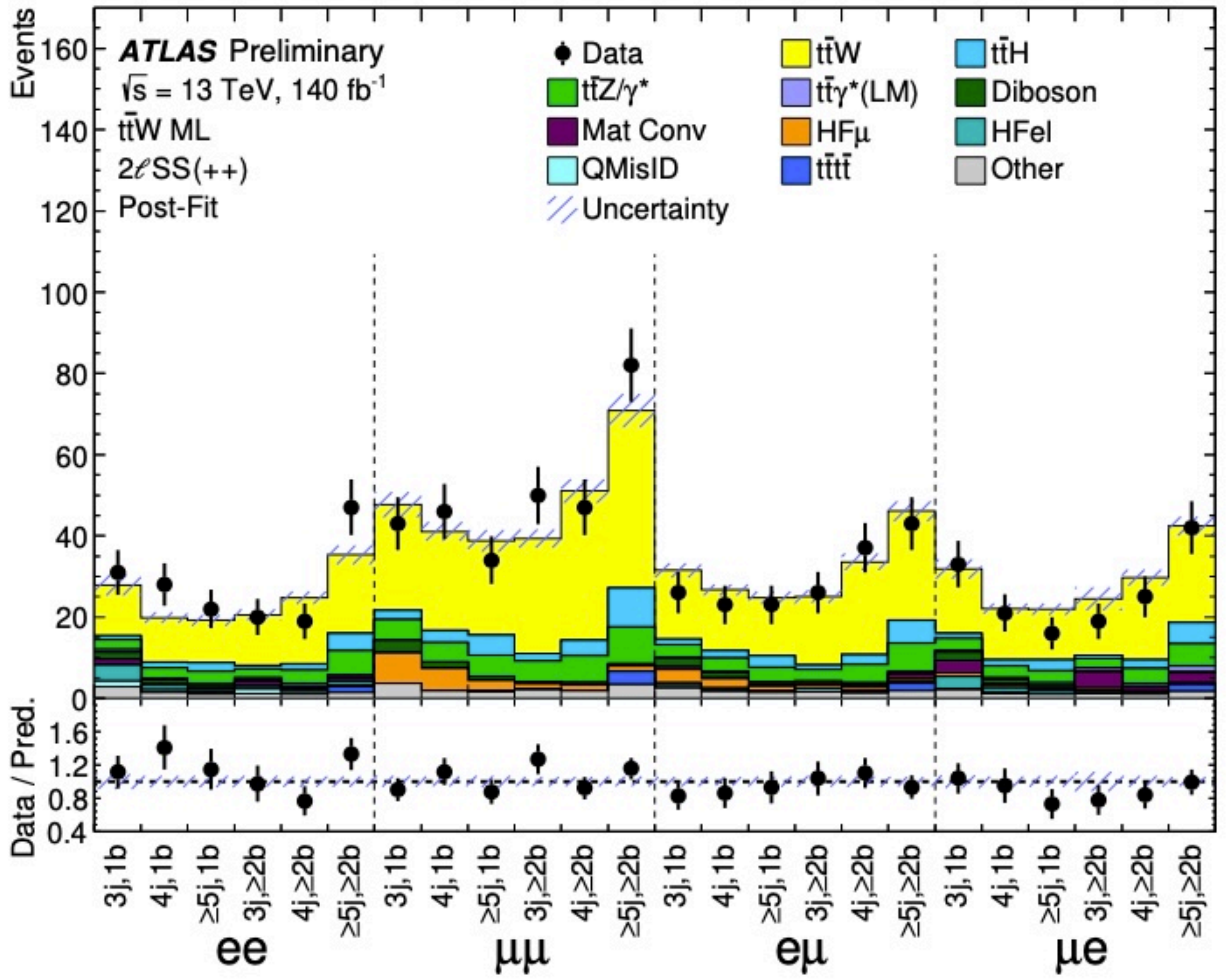
Inclusive measurement

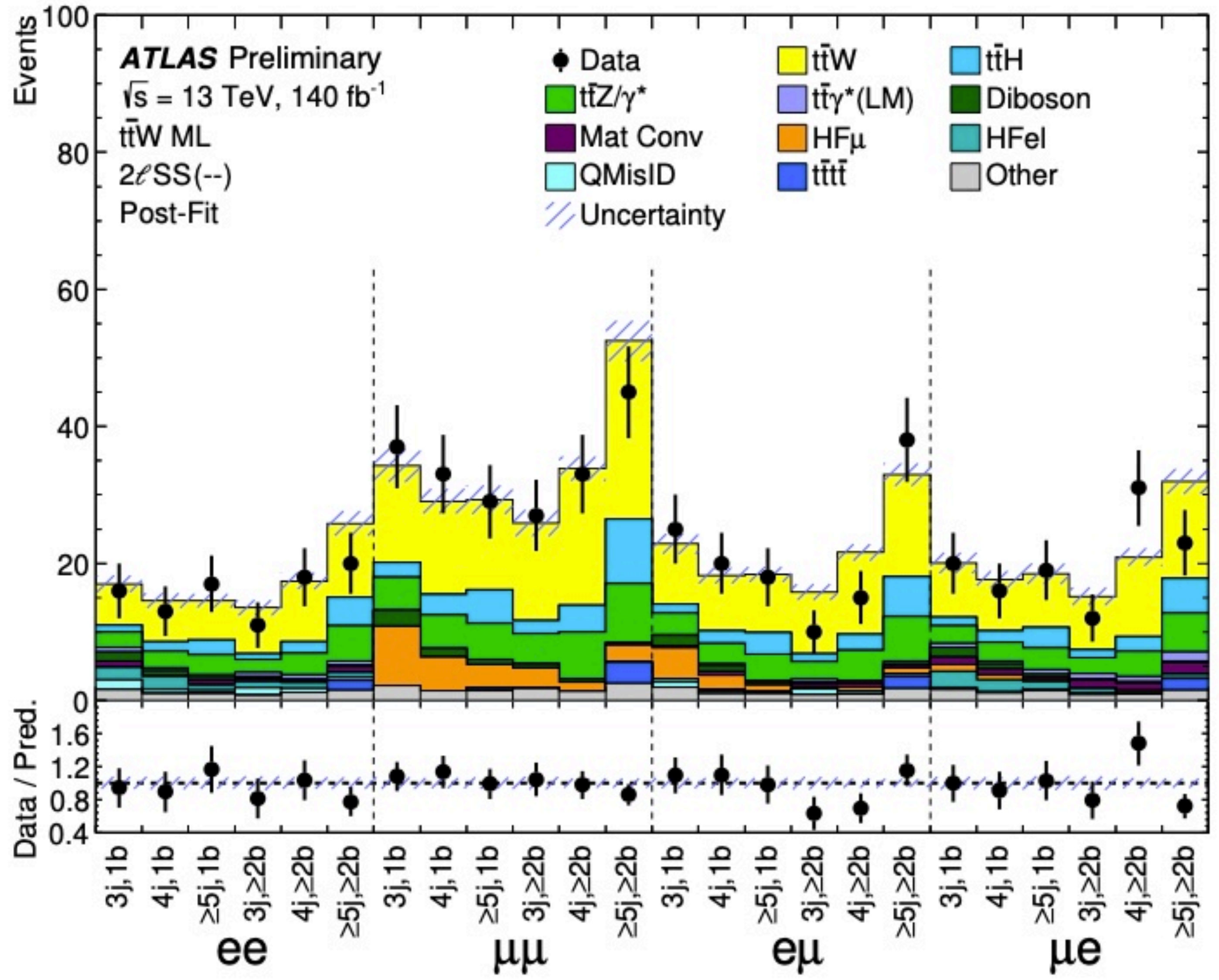
Post-fit

- Use a total of 56 SRs within 2lSS and 3l channels
- Template fit for background estimation in parallel

2ℓSS (48 regions)

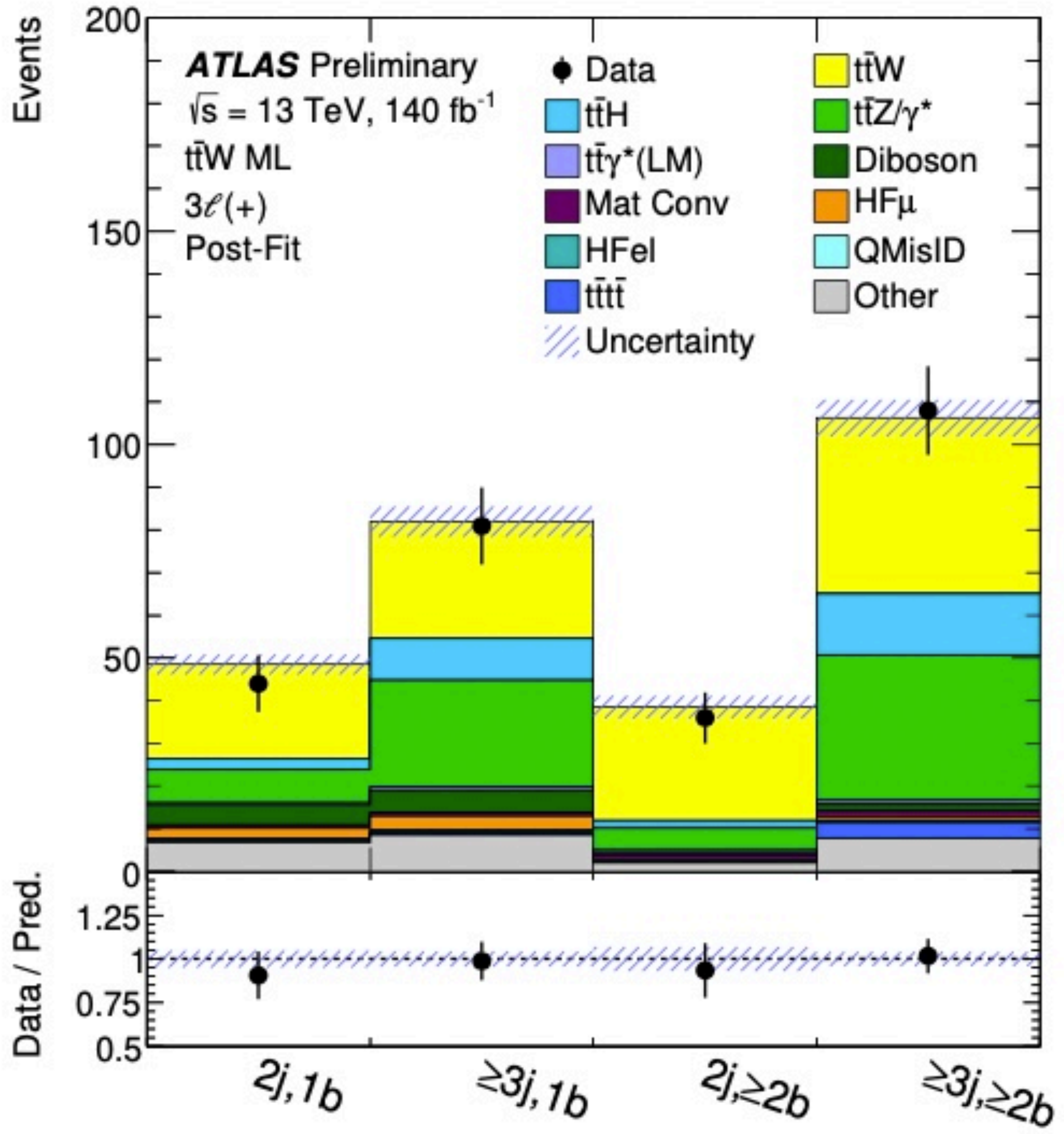
Split by: Charge (++,--)
Flavour (ee, $e\mu$, μe, $\mu\mu$)
N_{jets} ($= 3$, $= 4$, ≥ 5)
$N_{b-\text{jets}}$ ($= 1$, ≥ 2)

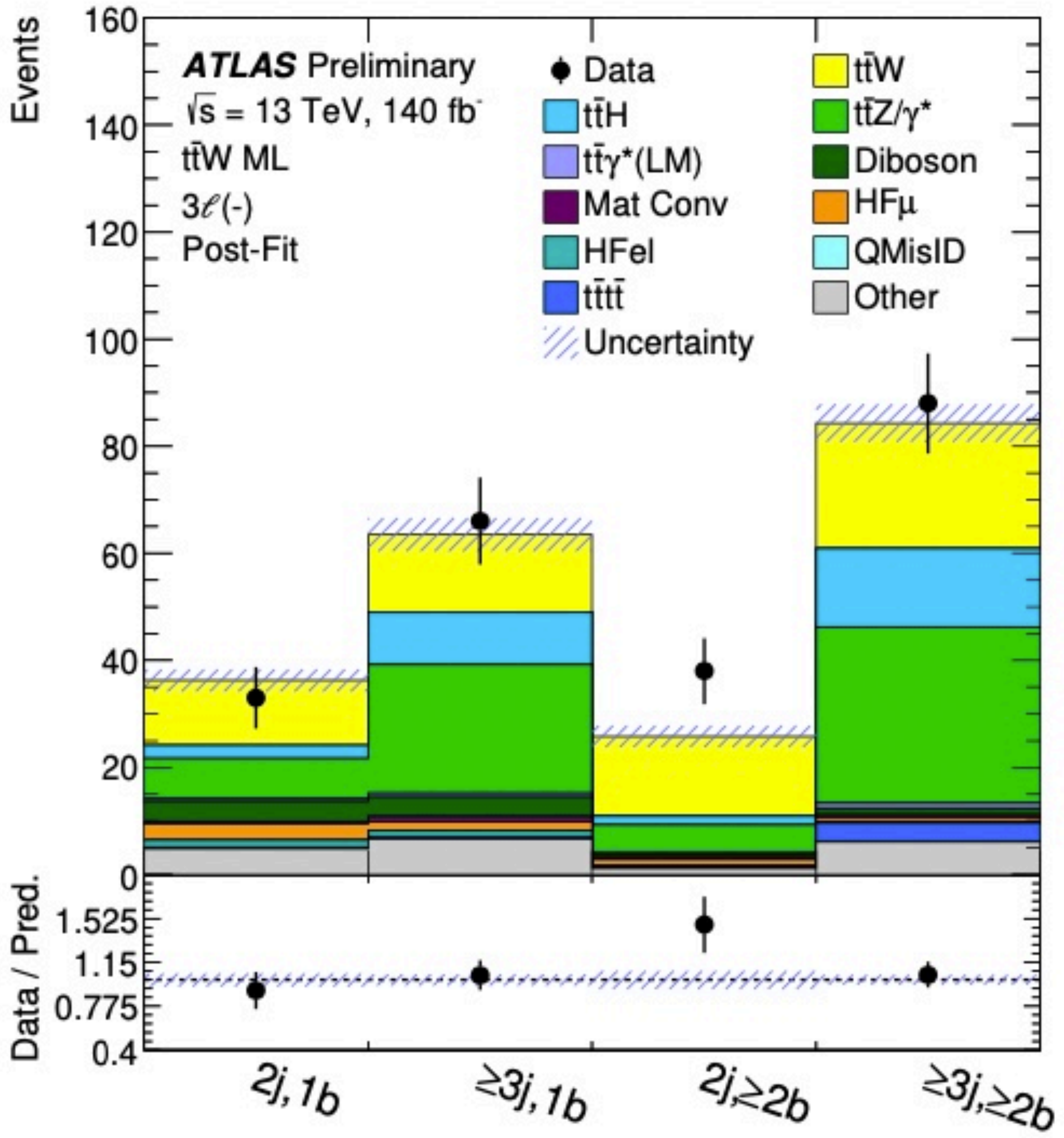




3ℓ (8 regions)

Split by: Charge (+,-)
N_{jets} ($= 2$, ≥ 3)
$N_{b-\text{jets}}$ ($= 1$, ≥ 2)



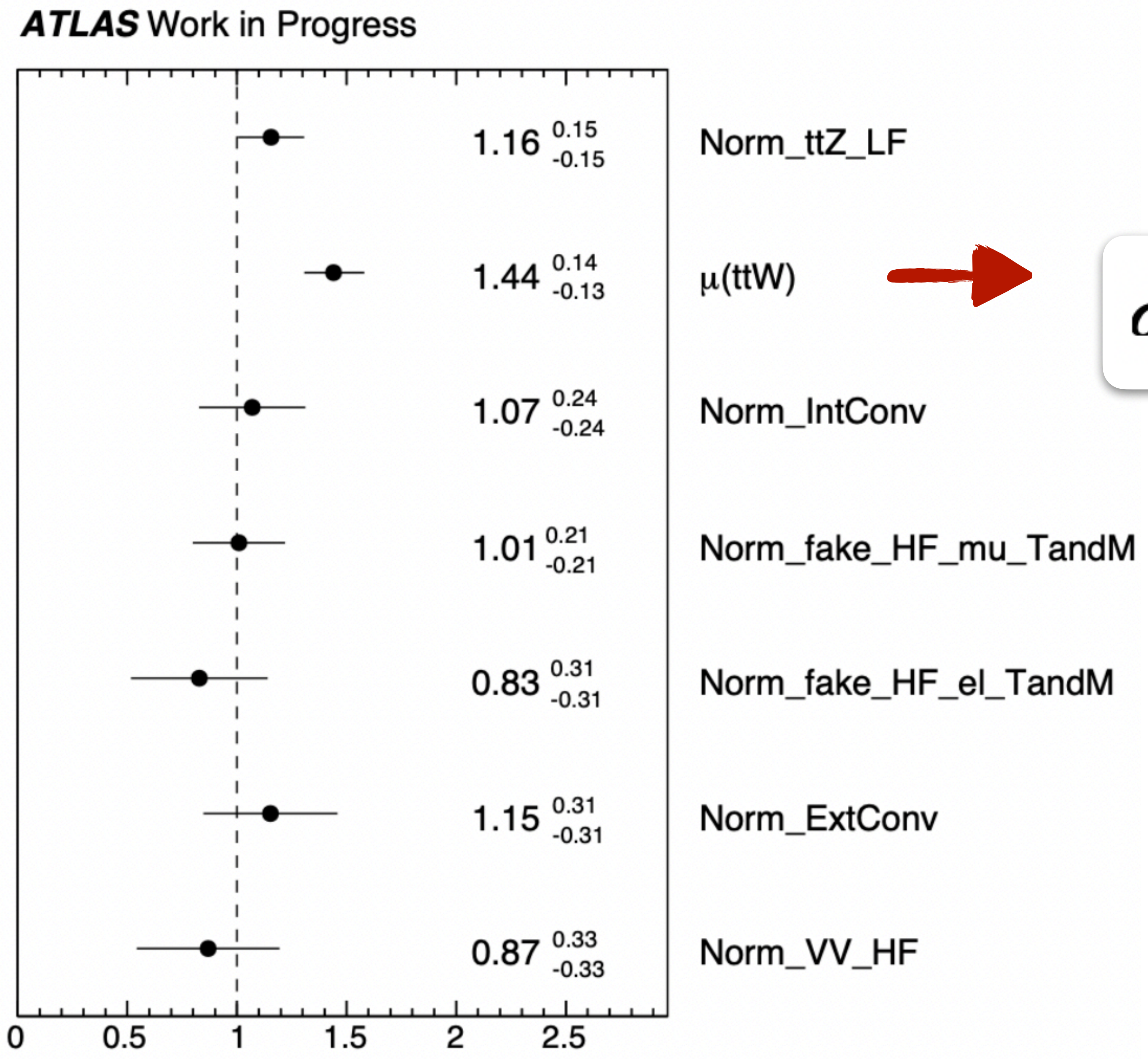


Inclusive cross-section

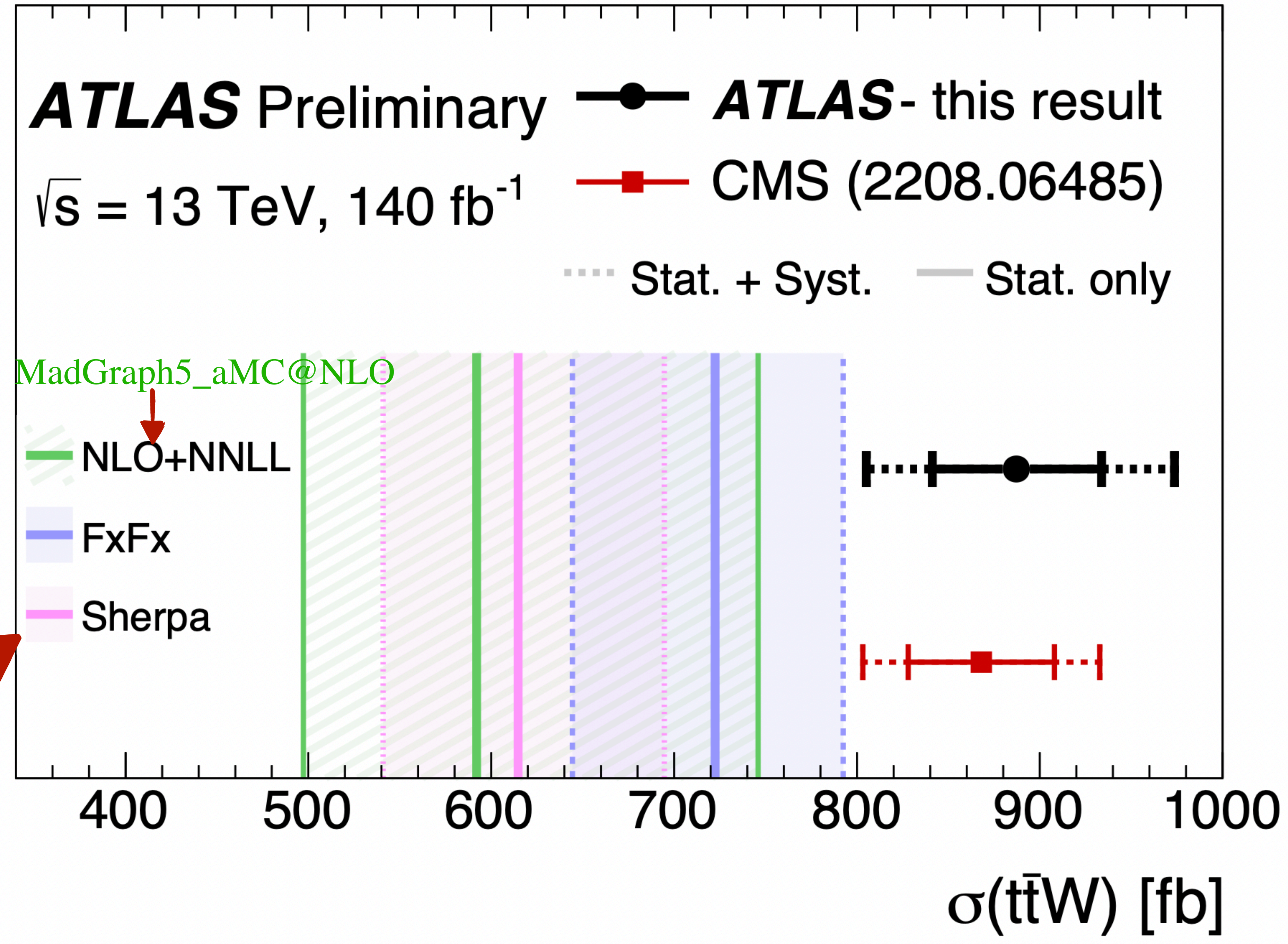
- Measured cross-section:

$$\sigma(t\bar{t}W) = 890 \,^{+50}_{-50}\,(\text{stat.})\,^{+70}_{-70}\,(\text{syst.}) = 890\,^{+90}_{-80}\,(\text{tot.})\text{ fb}$$

- Compatible with the measurement from CMS

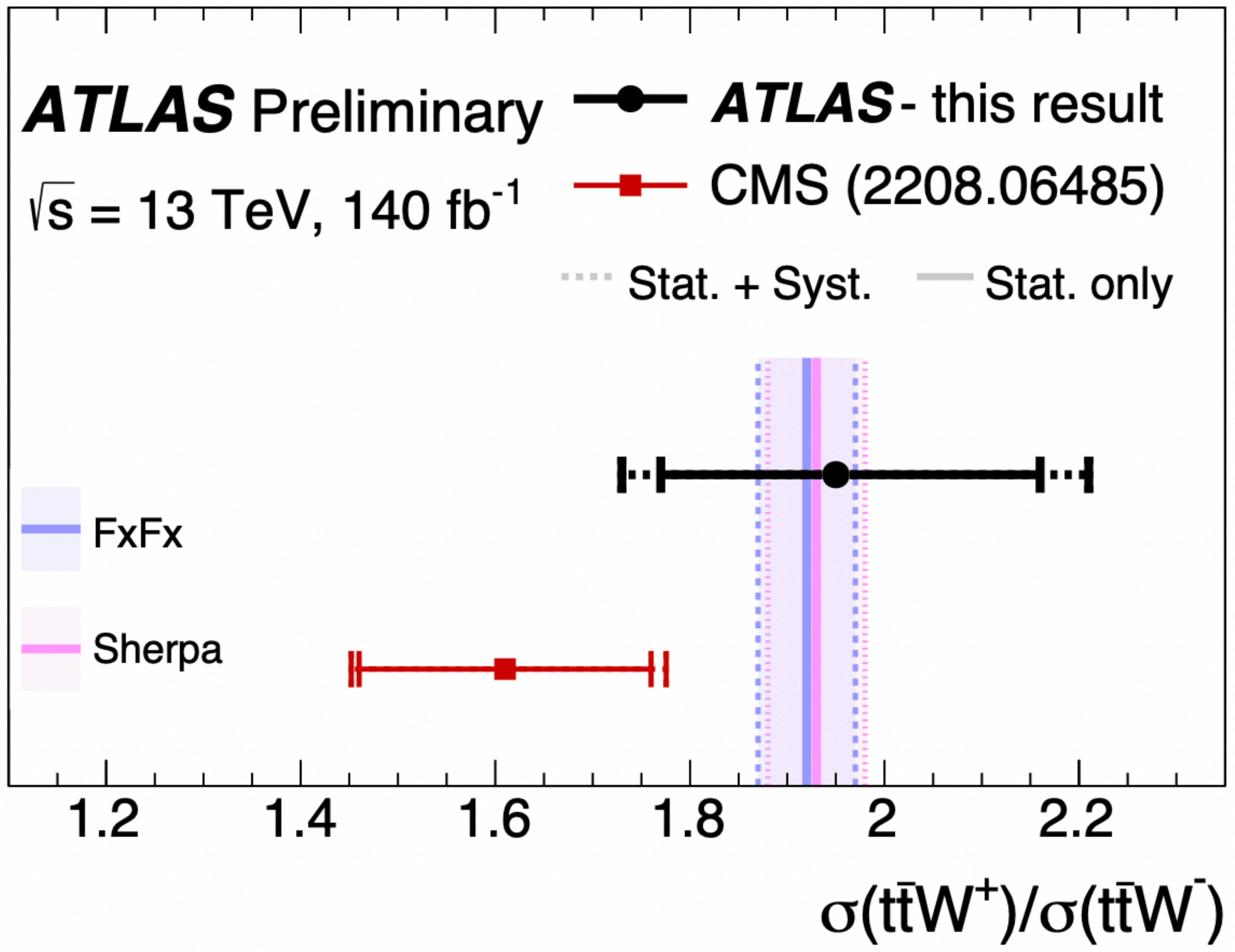


$$\sigma^{ref} = 615.8 \text{ fb}$$



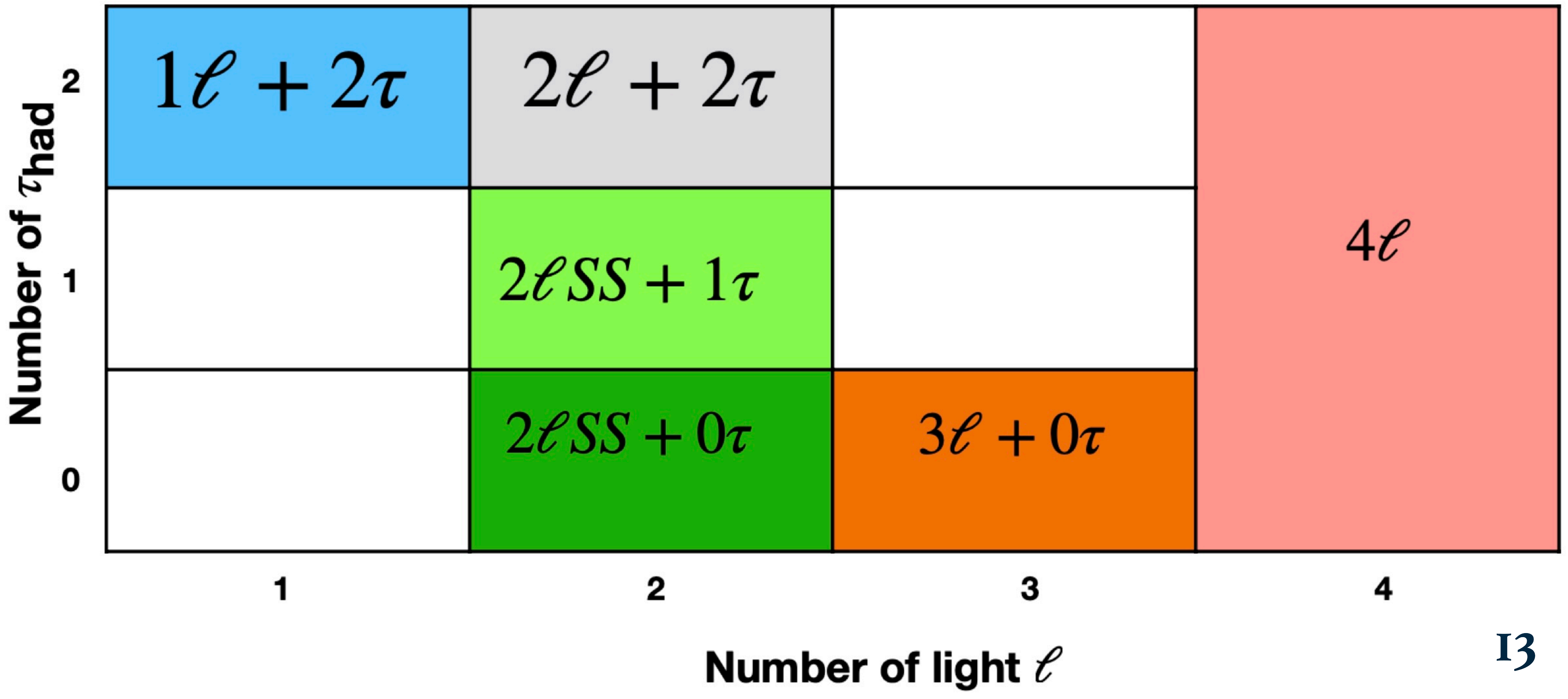
- Charge ratio measurement

$$R(t\bar{t}W) = 1.95^{+0.21}_{-0.18}\,(\text{stat.})^{+0.16}_{-0.13}\,(\text{syst.}) = 1.95^{+0.26}_{-0.22}\,(\text{tot.})$$



Conclusion

- The ttW analysis has been significantly developed with the full Run 2 dataset
  - Estimated the challenging fake lepton background and measured the inclusive cross-section
  - The measured cross-section is 40% over the MC prediction, compatible with measurement from CMS
  - A CONF Note was published in March of this year and the analysis paper is being reviewed by the collaboration.
- Run 2 ttH-ML analysis is ongoing, making use of improved understanding of fakes and ttW modelling
  - Measure the inclusive cross-section of ttH production
  - Simplified template cross sections (STXS) measurement



Thank you for your attention!

Backup

Object and event selection

Pre-Selection

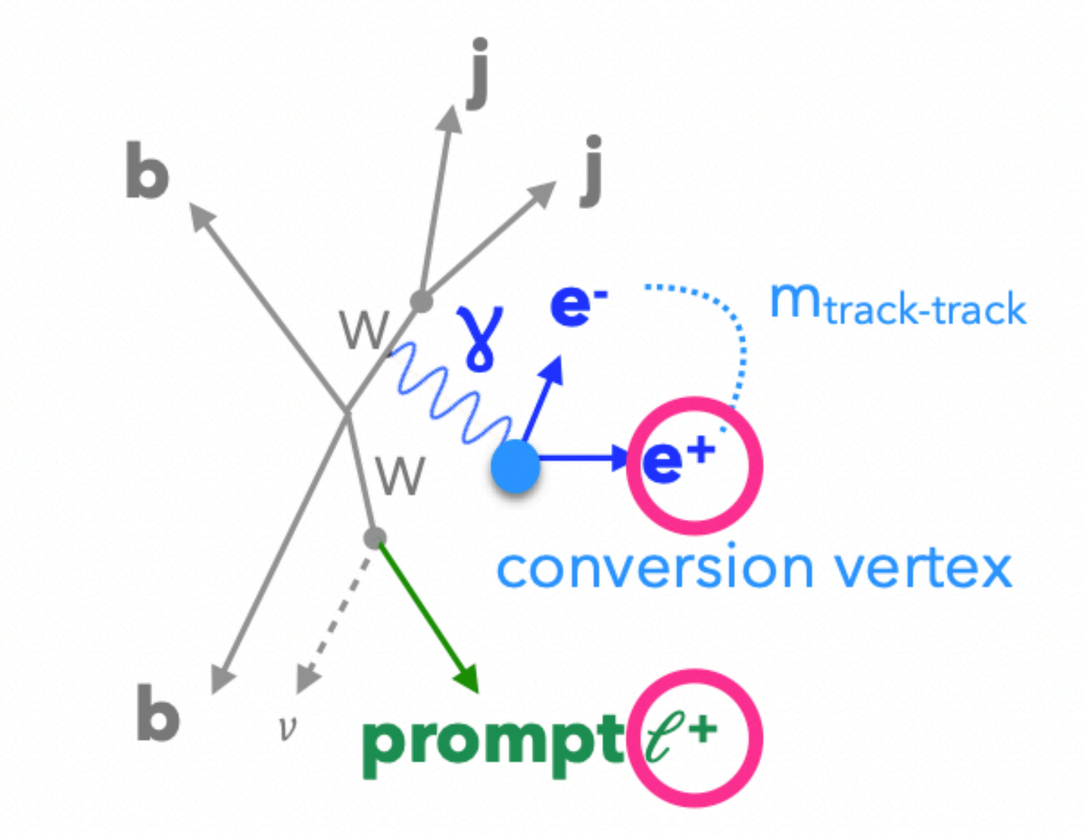
- Applying Di-lepton triggers
- Leptons:
  - pT>10 GeV, $|\eta_e| < 2.47$, $|\eta_\mu| < 2.5$
  - veto electrons in LAr crack region
  - FCLoose isolation, Loose/ LooseLH ID for μ/e
- Jets:
  - Reconstruct with Anti-Kt PFlow w/ R=0.4
  - Pass Jet Vertex Tagger
  - pT>25 GeV
  - Tag b-jets with DL1r tagger

Event Selection ($2\ell SS$ and 3ℓ)

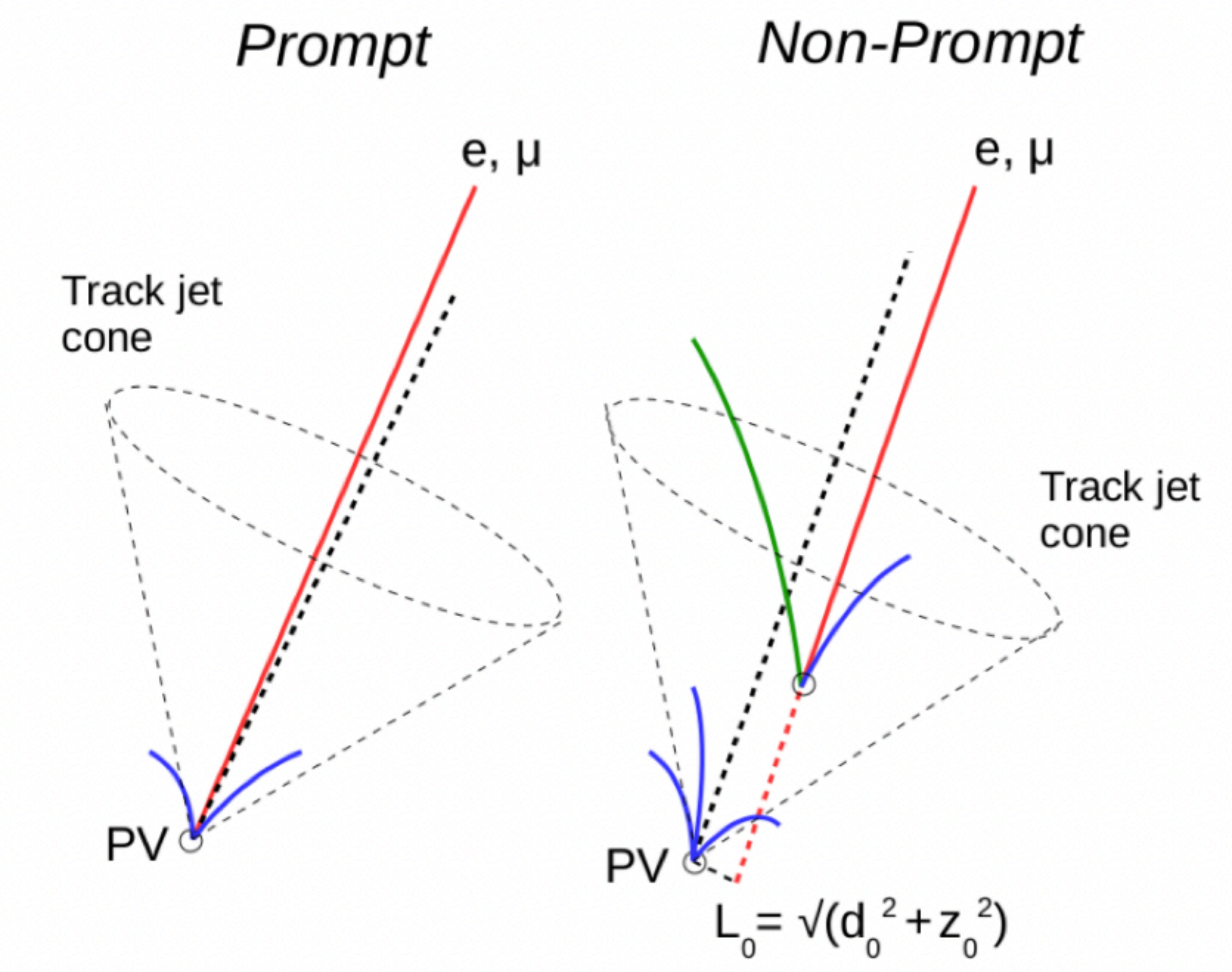
- Njet≥2, Nb-jet≥1
  - ≥ 1b (hybrid WP, =1b @ 60% or ≥ 2 @ 77%)
- $M_{\ell\ell}$>12 GeV in $2\ell SS$
- $M_{\ell\ell}$>12 GeV, $|M_{\ell\ell} - M_Z| > 10$ GeV (SFOS),$| M_{3\ell} - M_Z | > 10$ GeV, in 3ℓ

Background Estimation

- **Irreducible background:**
  - ttZ ,VV samples: estimated with dedicated CR and free floated when fitting



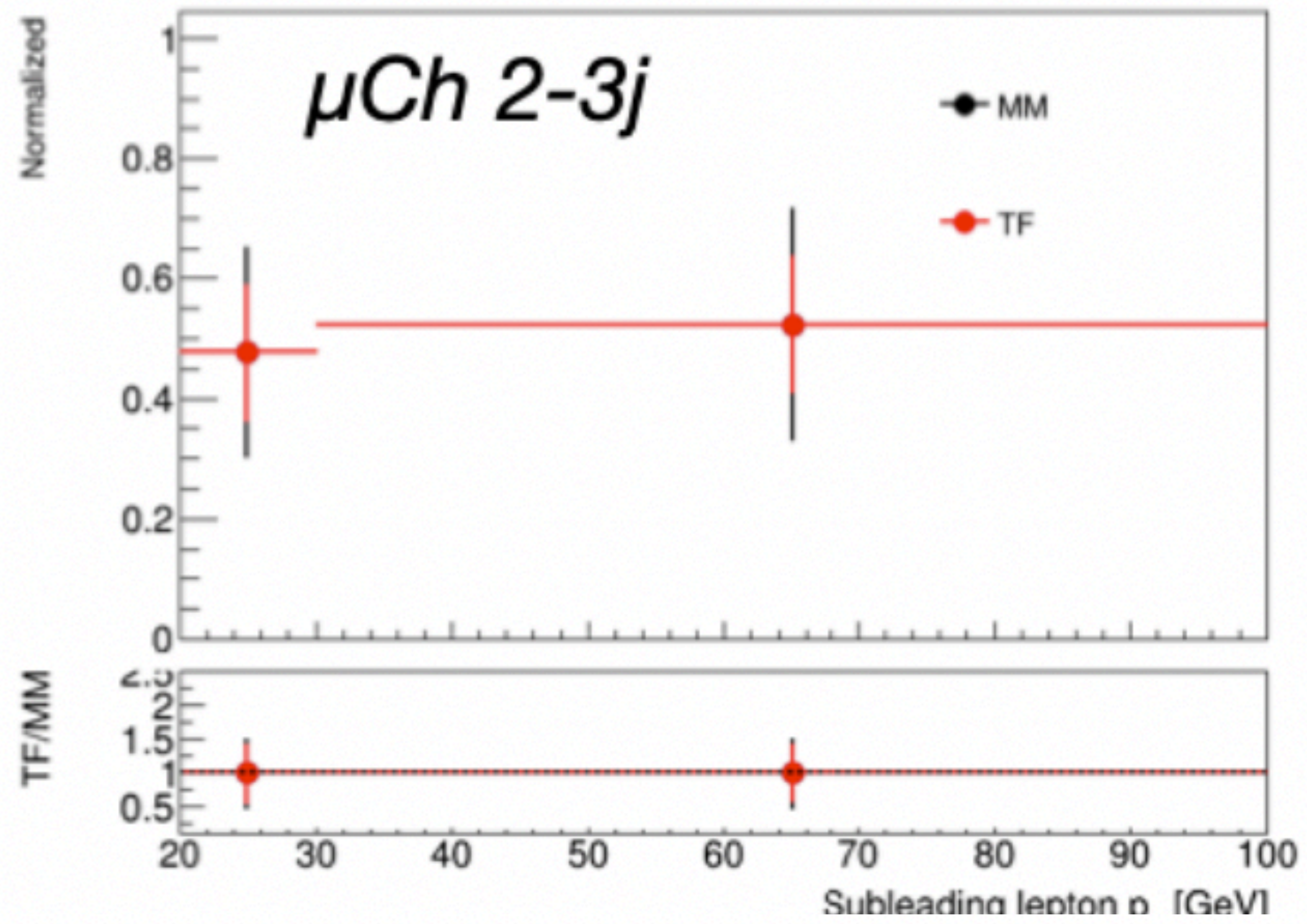
- **Reducible background:**
  - **Charge mis-identification (Q-MisID)**
  - **Internal and Material Conversion (CO)**
  - **Non-prompt leptons from Heavy Flavor (HF) decay**
    - Rejected with Multivariate lepton isolation, called PromptLeptonImprovedVeto (**PLIV**) tagger



Fake Estimation Comparison: TF vs MM

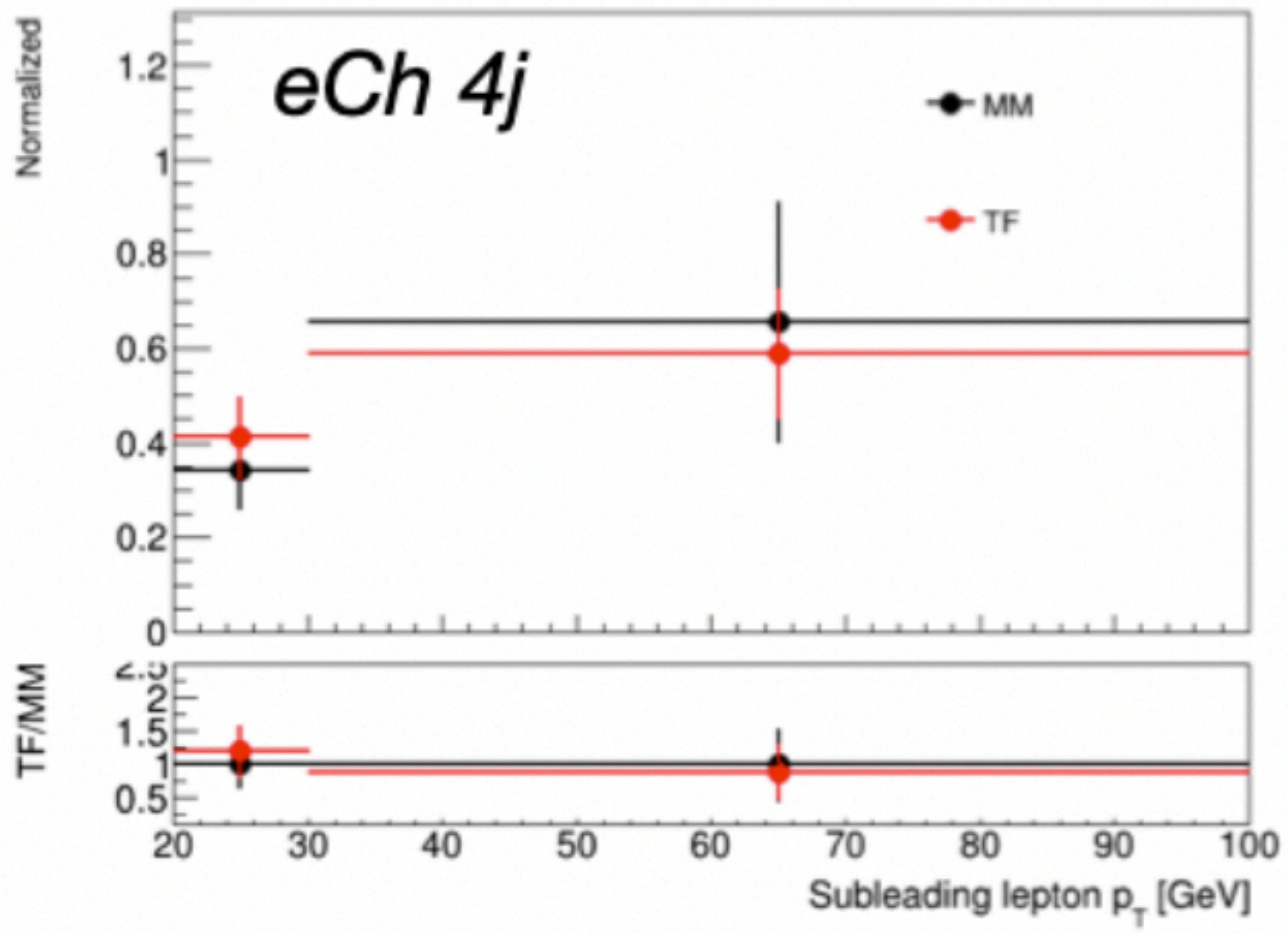
- Dedicate validation regions are defined to perform the comparisons

Region label	elCh 2-3j	elCh 4jincl	muCh 2-3j	muCh 4jincl
channel flavour	$ee+\mu e$		$\mu\mu+e\mu$	
jets multiplicity	2 or 3	≥ 4	2 or 3	≥ 4
leptons definition (lep1 lep2)	Tight Tight			
b-jets multiplicity	== 1 @ 60% WP or $\geq$ 2 @ 77% WP			
additional cuts	$H_T^{had} < 200$ GeV and E_T^{miss}<85 GeV for 2-3j regions			



- MM seems to be predicting a higher estimate than the TF (1.6 to 2 times higher)

Region	Template Fit (TF)	Matrix Method (MM)	MM/TF
elCh 2-3j	30.9±8.3	66.1 ± 25.4	2.1
elCh 4jinc	33.9 ± 7.8	54.6 ± 19.8	1.6
muCh 2-3j	41.4 ± 11.1	68.9 ±27.2	1.7
muCh 4jincl	41.9 ± 10.7	68.3 ± 27.6	1.6

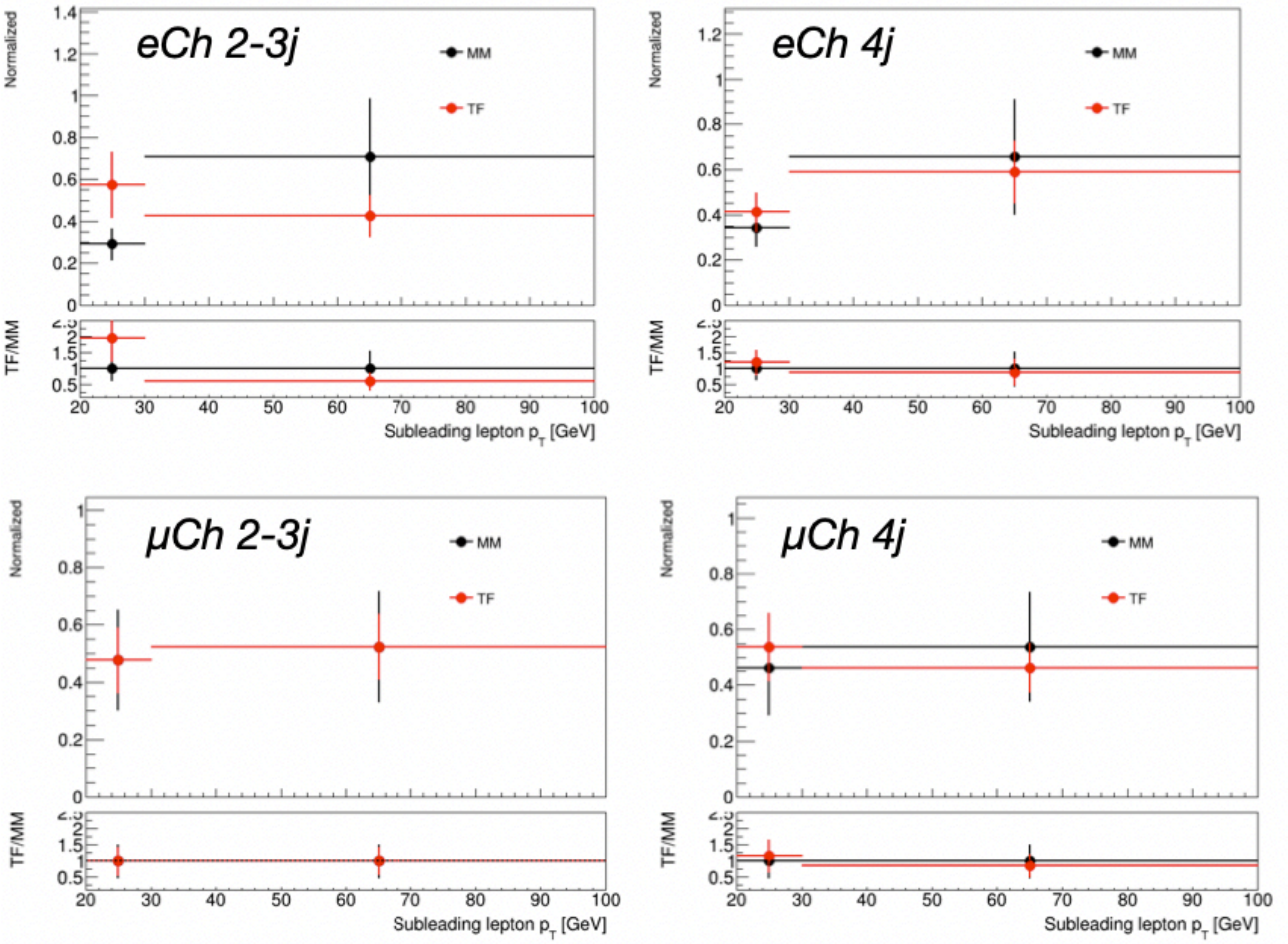


- The shapes agree quite well between the two estimates within their uncertainties

Fake Estimation Comparison: TF vs MM

- Overall, the shapes agree quite well between the two estimates within their uncertainties

- MM seems to be predicting a higher estimate than the TF (1.6 to 2 times higher)



Non-prompt/Fake leptons Estimation

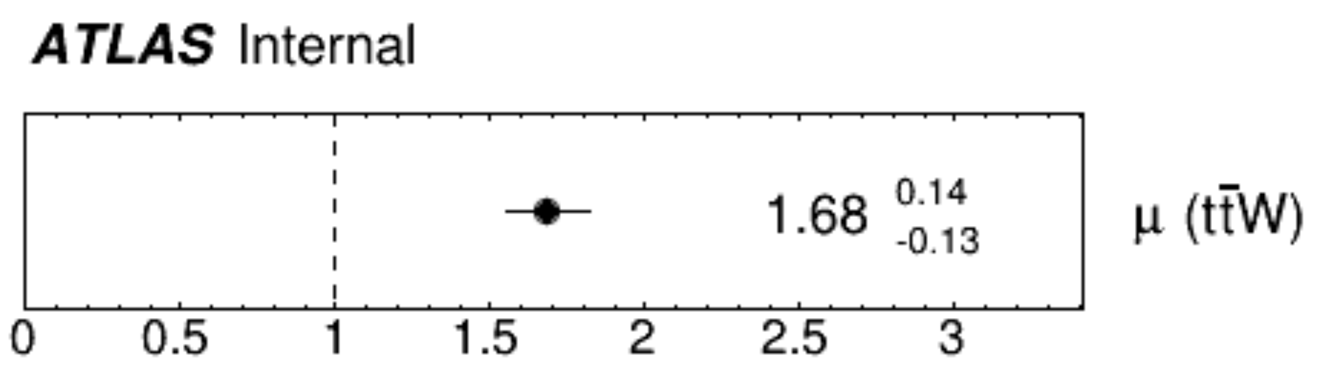
- **Matrix Method**
  - A data-driven technique for estimating the contamination of fake leptons.
  - Define loose and tight CRs, measure the efficiencies of the real and fake lepton, and estimate the fakes in SR

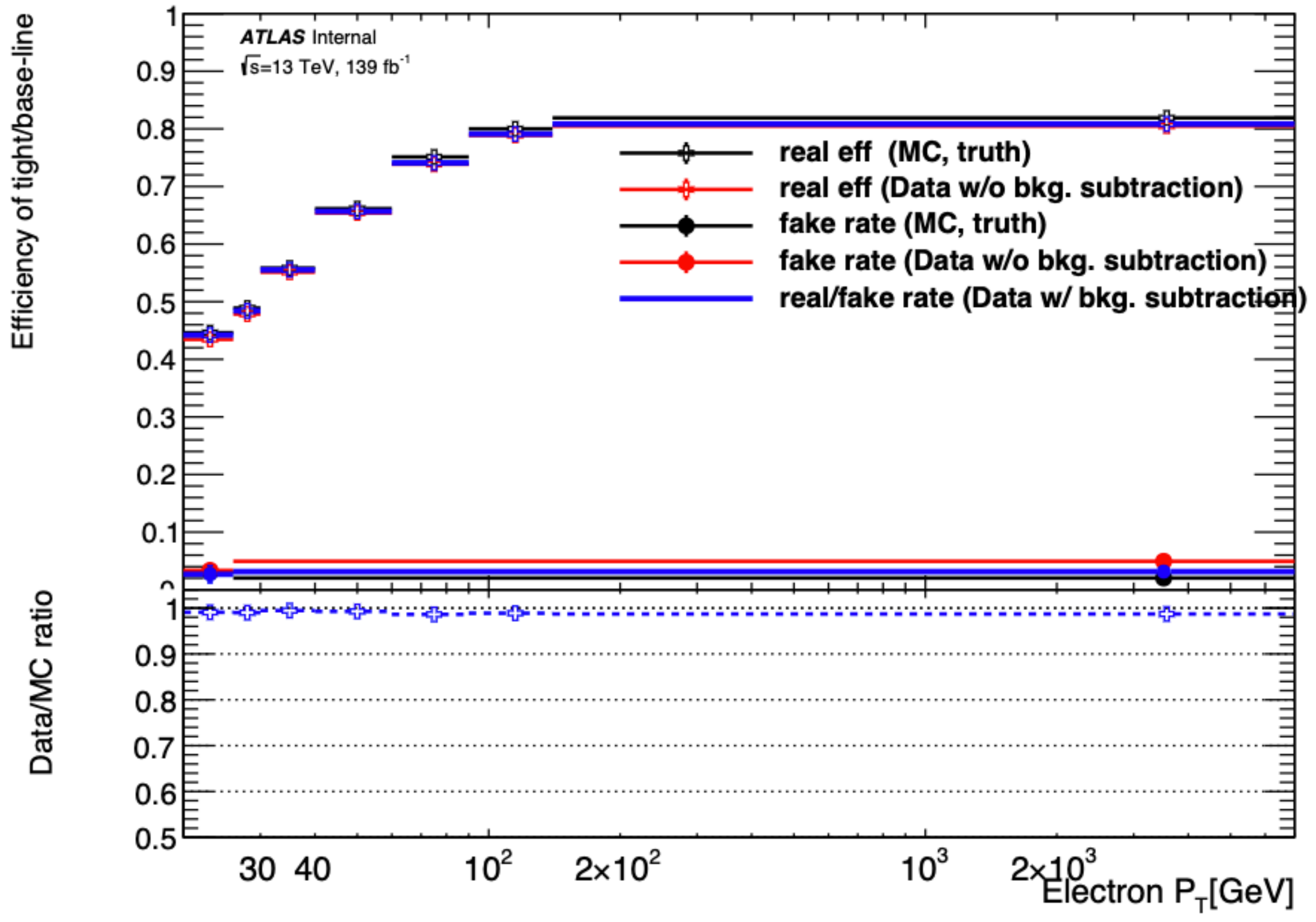
$$\begin{pmatrix} N^{TT} \\ N^{T\bar{T}} \\ N^{\bar{T}T} \\ N^{\bar{T}\bar{T}} \end{pmatrix} = \begin{pmatrix} \epsilon_{r,1}\epsilon_{r,2} & \epsilon_{r,1}\epsilon_{f,2} & \epsilon_{f,1}\epsilon_{r,2} & \epsilon_{f,1}\epsilon_{f,2} \\ \epsilon_{r,1}\bar{\epsilon}_{r,2} & \epsilon_{r,1}\bar{\epsilon}_{f,2} & \epsilon_{f,1}\bar{\epsilon}_{r,2} & \epsilon_{f,1}\bar{\epsilon}_{f,2} \\ \bar{\epsilon}_{r,1}\epsilon_{r,2} & \bar{\epsilon}_{r,1}\epsilon_{f,2} & \bar{\epsilon}_{f,1}\epsilon_{r,2} & \bar{\epsilon}_{f,1}\epsilon_{f,2} \\ \bar{\epsilon}_{r,1}\bar{\epsilon}_{r,2} & \bar{\epsilon}_{r,1}\bar{\epsilon}_{f,2} & \bar{\epsilon}_{f,1}\bar{\epsilon}_{r,2} & \bar{\epsilon}_{f,1}\bar{\epsilon}_{f,2} \end{pmatrix} \begin{pmatrix} N^{rr} \\ N^{rf} \\ N^{fr} \\ N^{ff} \end{pmatrix}$$

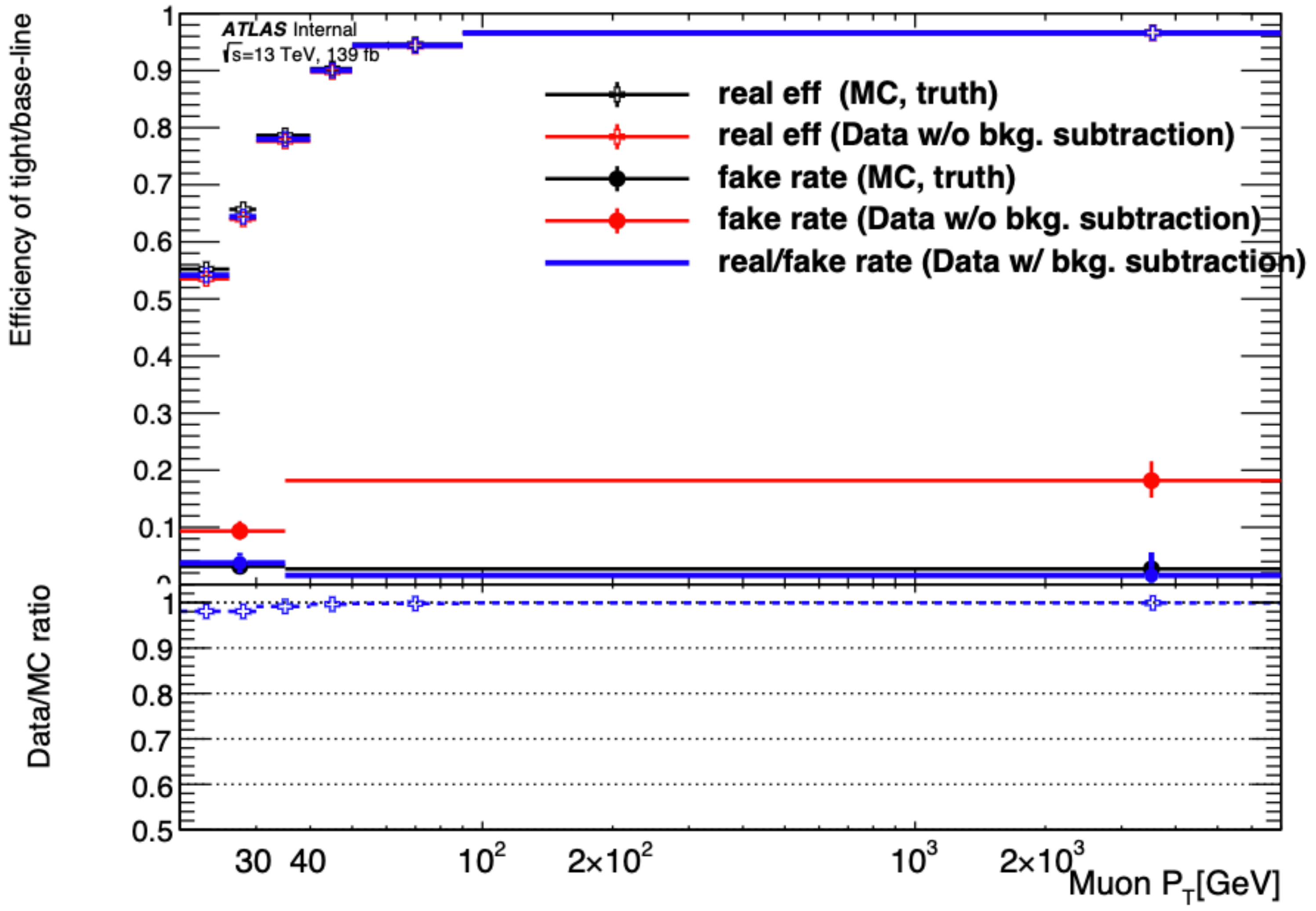
$$N^{f}_{TT} = N^{rf}_{TT} + N^{fr}_{TT} + N^{ff}_{TT} = \epsilon_{r,1}\epsilon_{f,2}N^{rf} + \epsilon_{r,2}\epsilon_{f,1}N^{fr} + \epsilon_{f,1}\epsilon_{f,2}N^{ff}$$

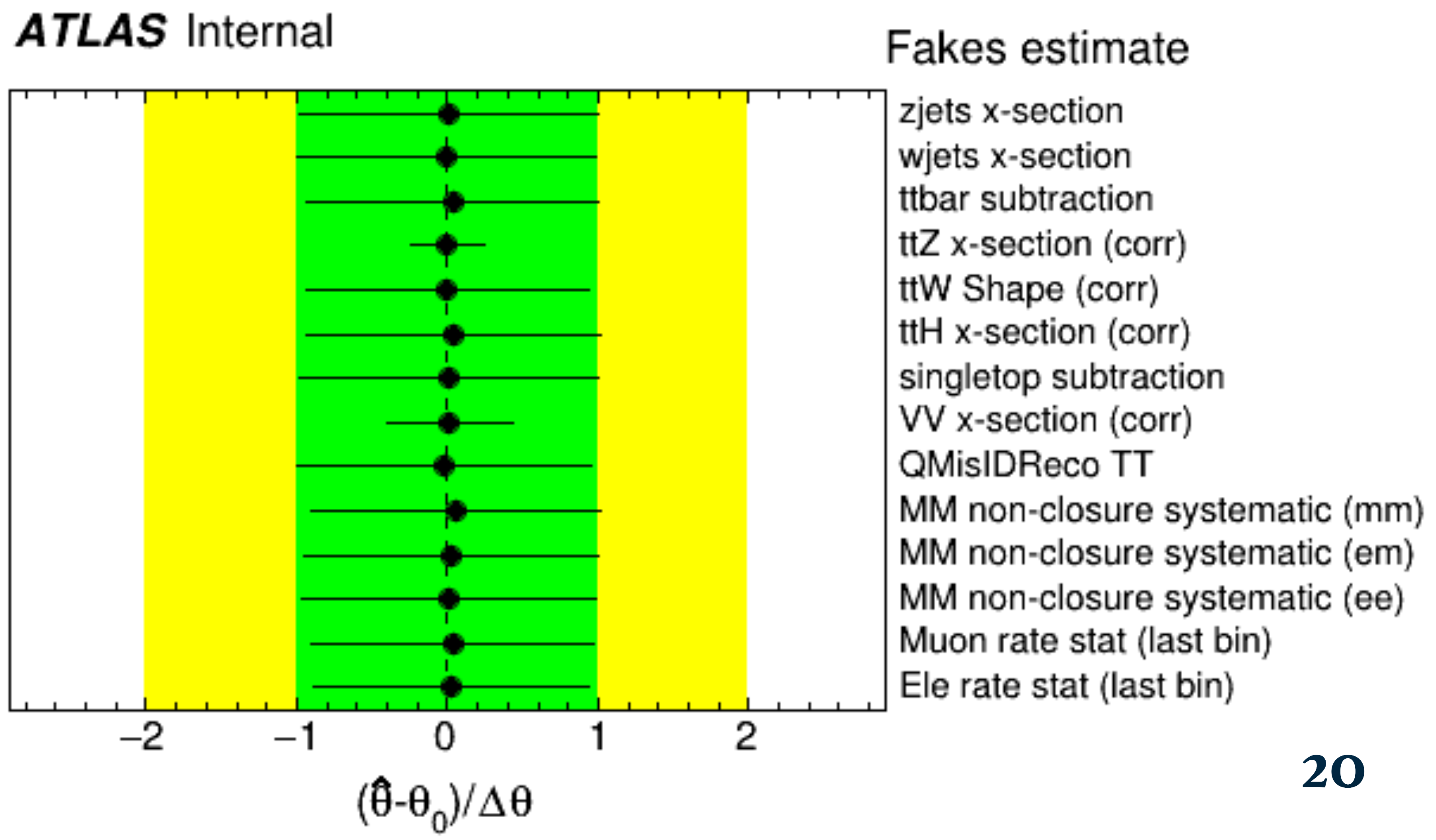
- **Reducible background:**
  - Charge mis-identification (Q-MisID)
  - Internal & Material conversion (CO)
  - Heavy Flavor decay

- Customized Asimov fit with $\mu_{ttW} = 1.7$



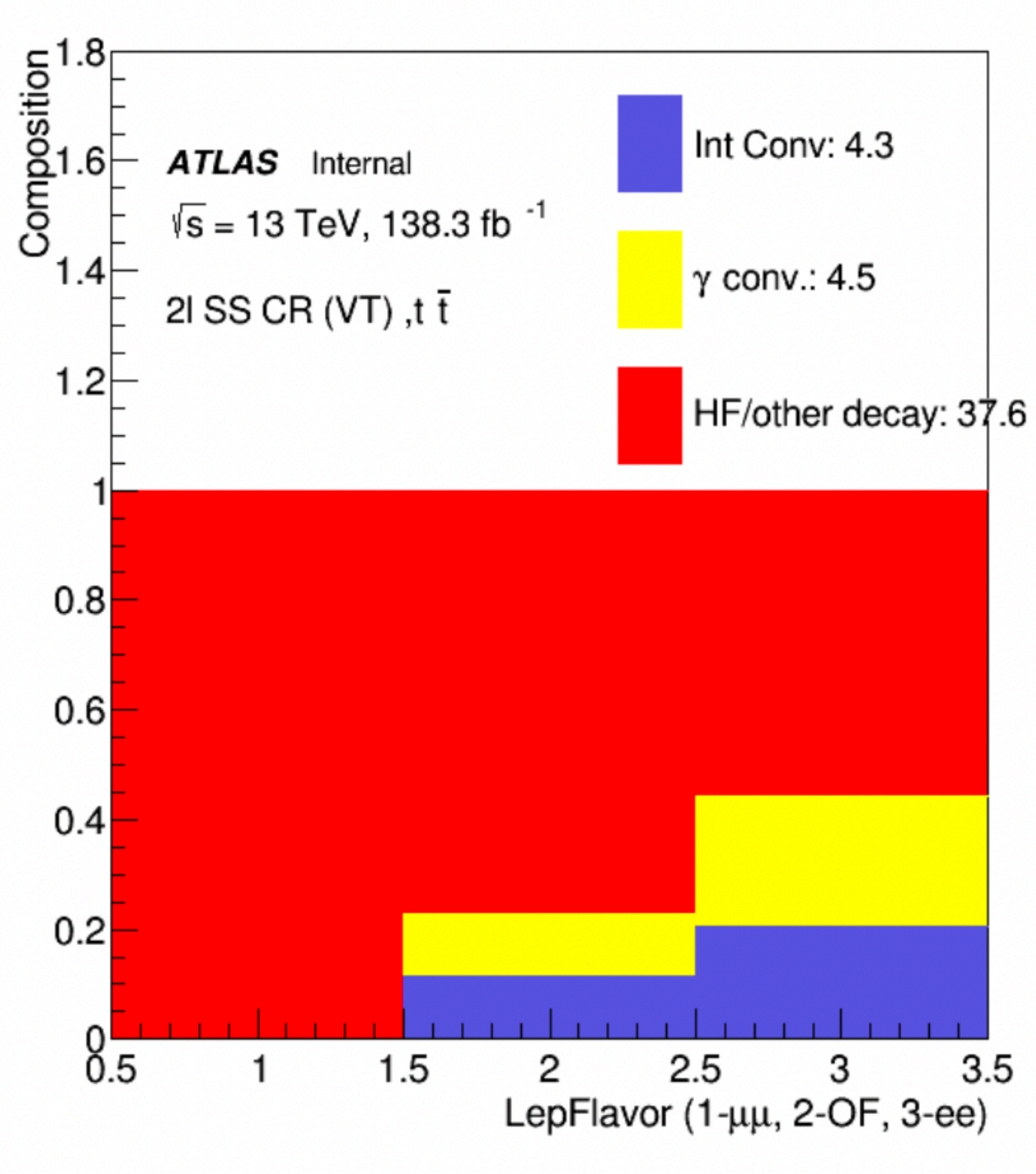




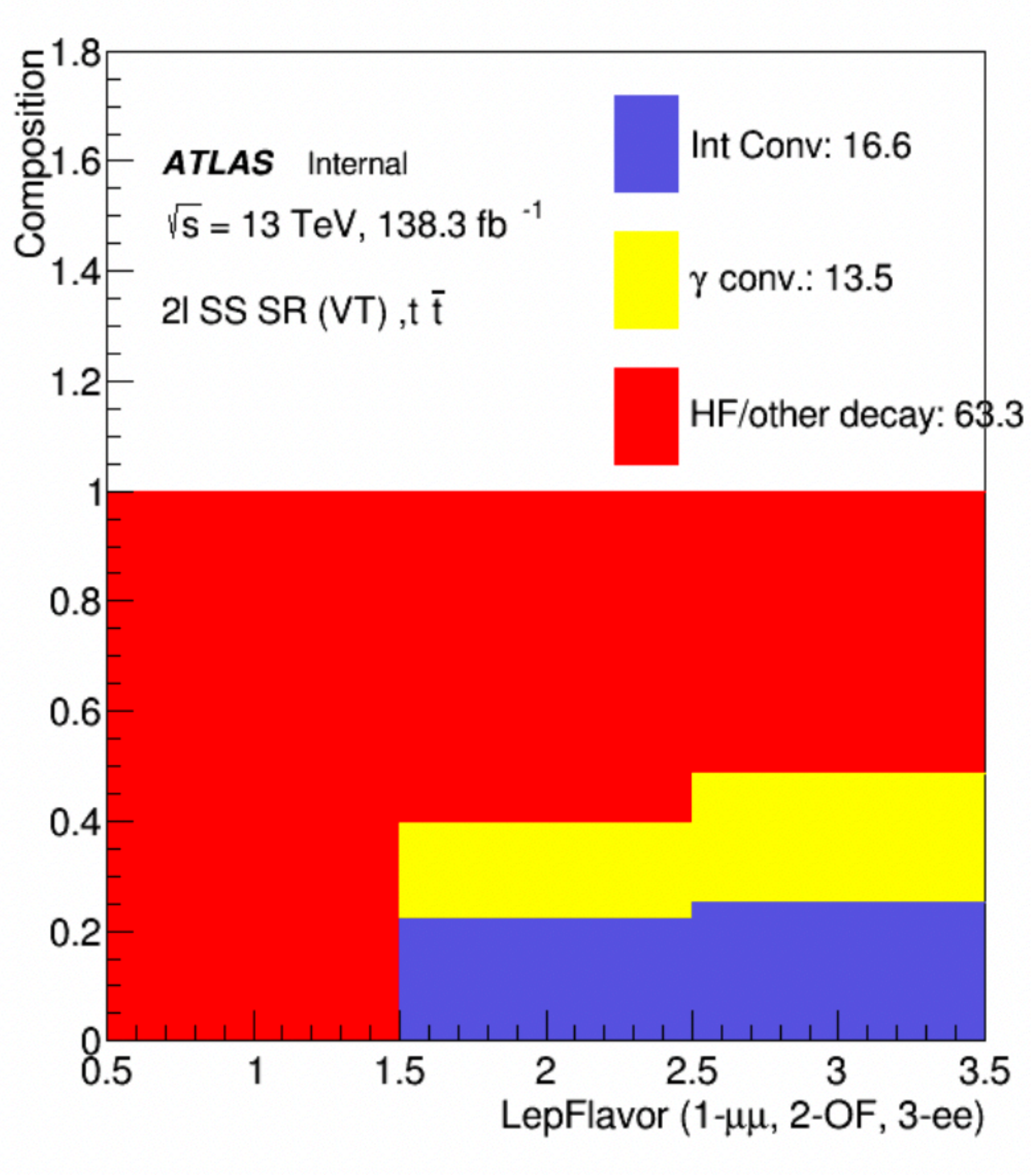


Fake estimation with Matrix Method

- Fake subleading lepton origin fractions in semileptonic $t\bar{t}$ events in the MM CR and SR



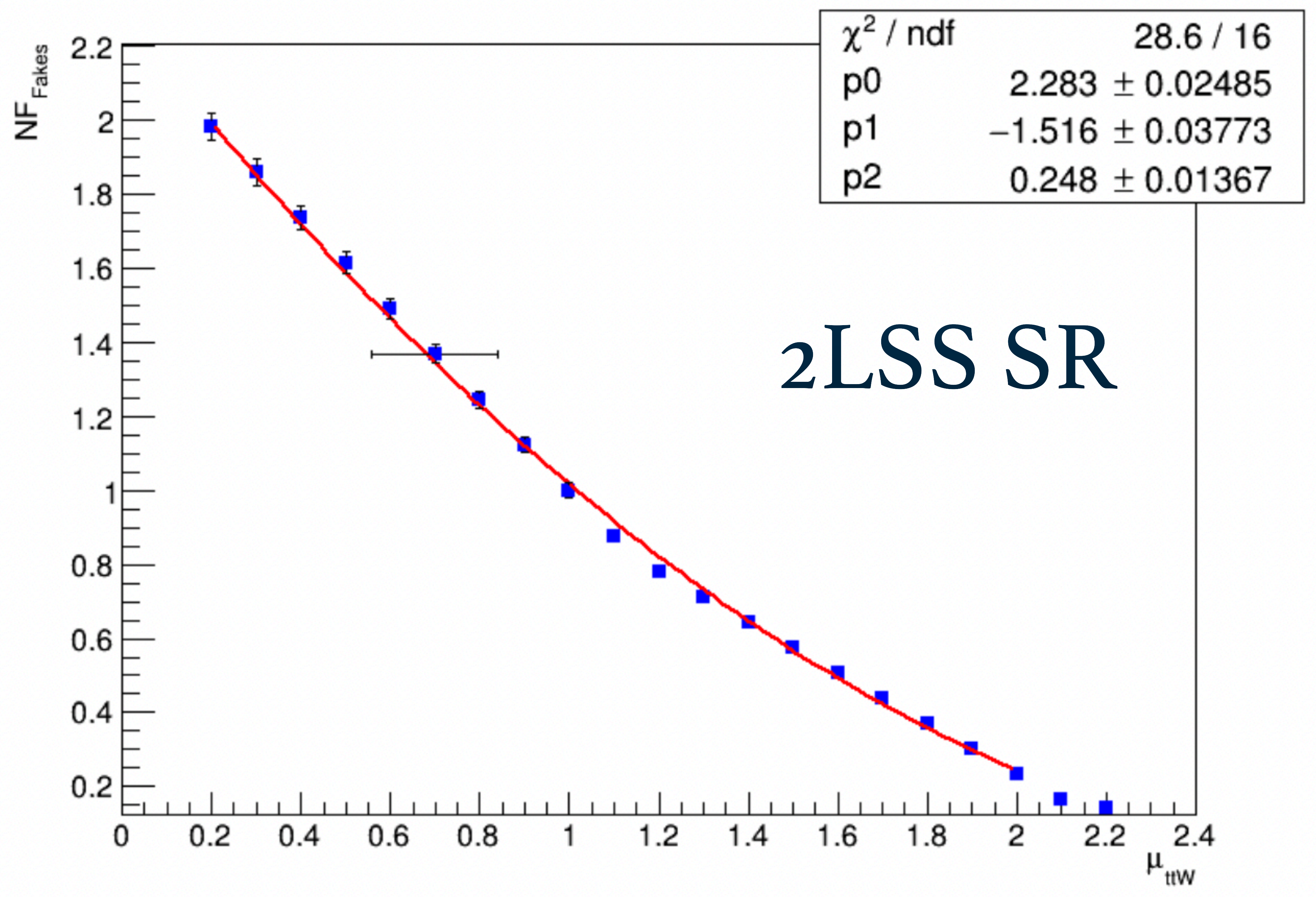
CR

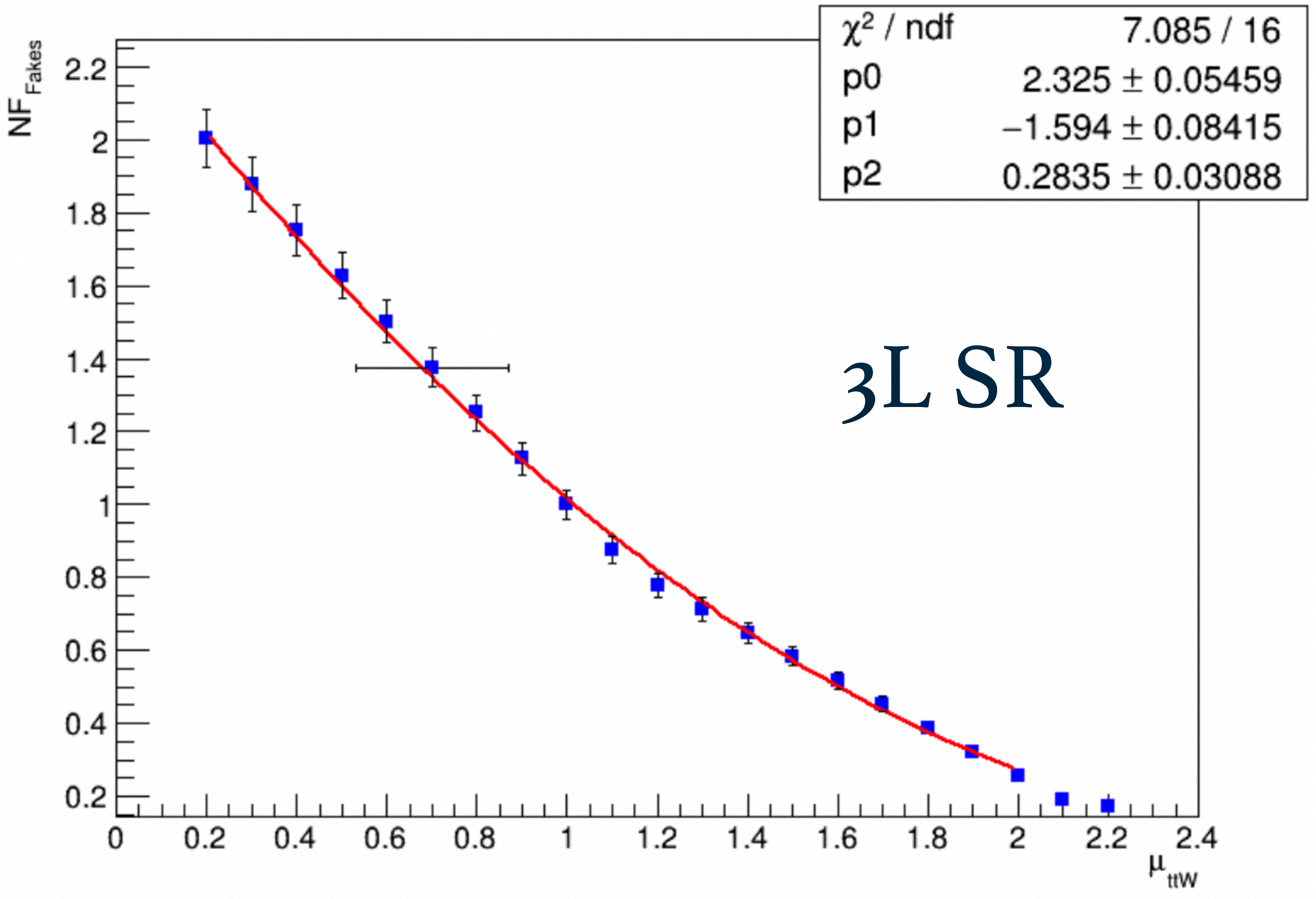


SR

Matrix Method Limitations

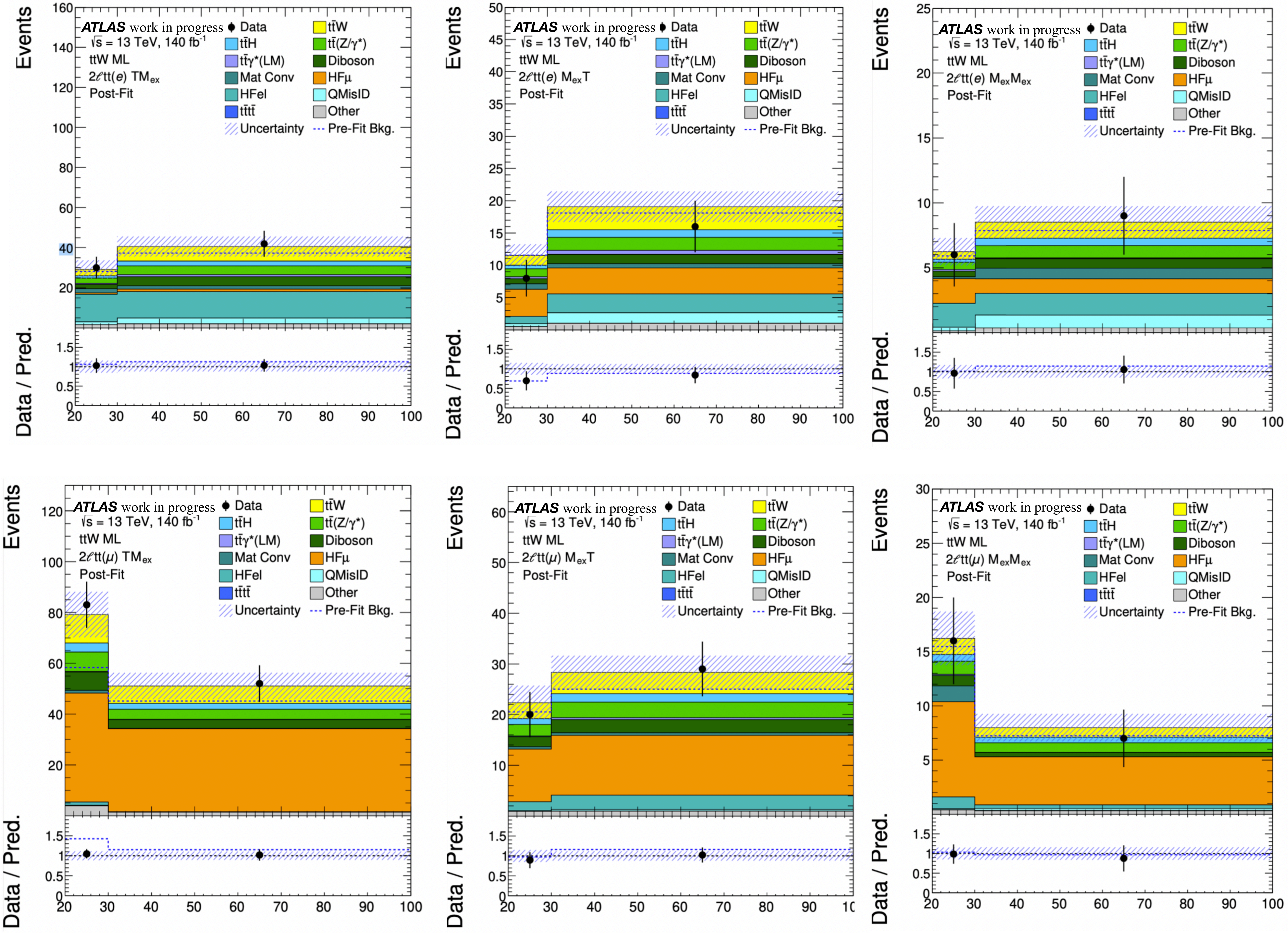
- The applying of VeryTight PLIV WP results a relatively large ttW contamination (~ 30%) in CR.
- The measured fakes rates, and subsequently the fakes estimate depends on the ttW.
- MM fakes estimate is parametrised as a function of μ_ttW, to account for the possible mis-modeling of the ttW and avoid any bias of the fakes estimate towards the SM prediction of ttW.
- D A second degree polynomial function is used to derive a continuous parametrisation of NF_fakes vs μ_ttW



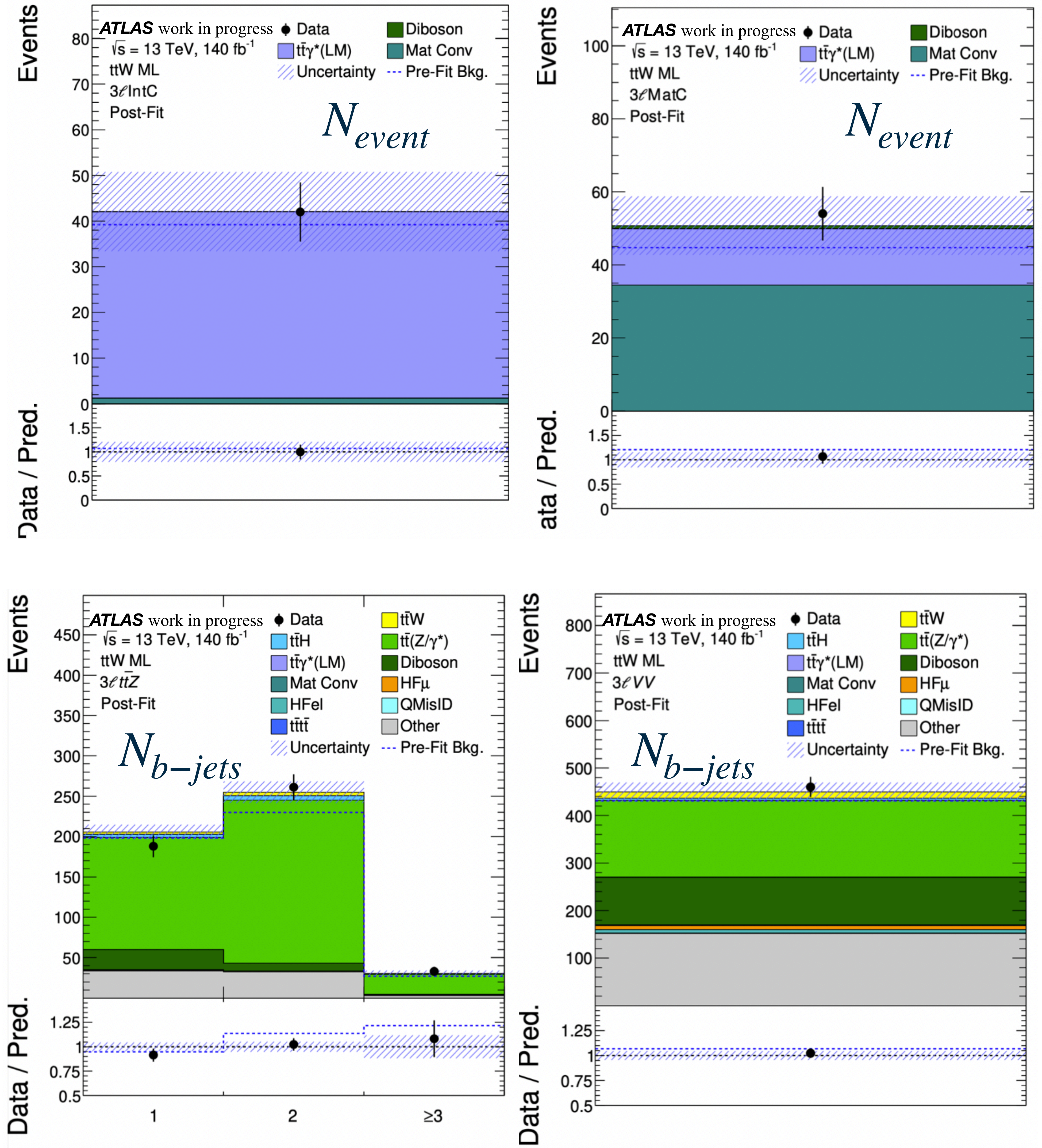


Template Fit: Data Fits in CRs

$2\ell SS$, $P_{T,subleading\ lep}$

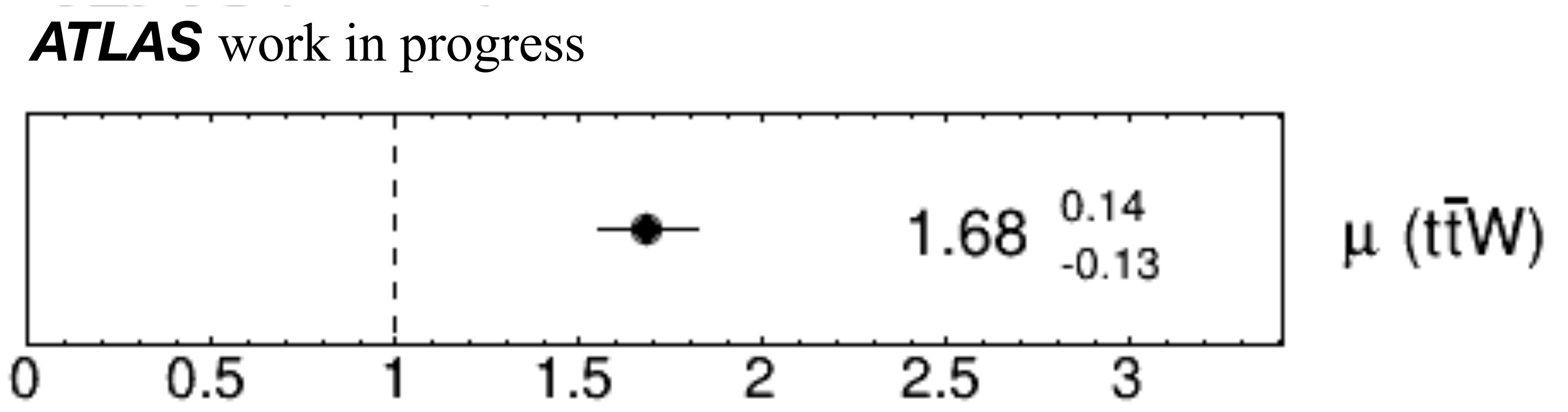


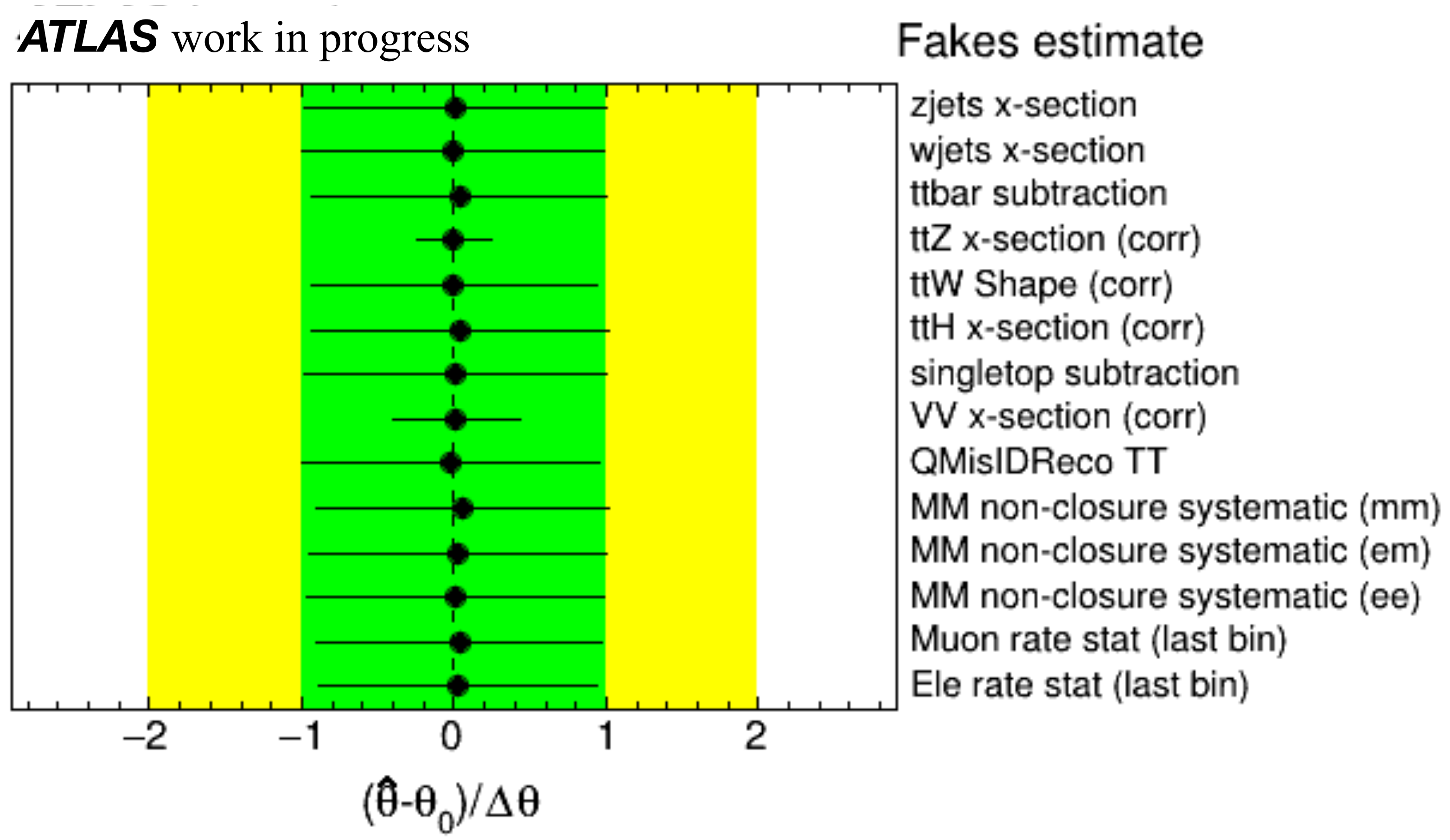
3ℓ

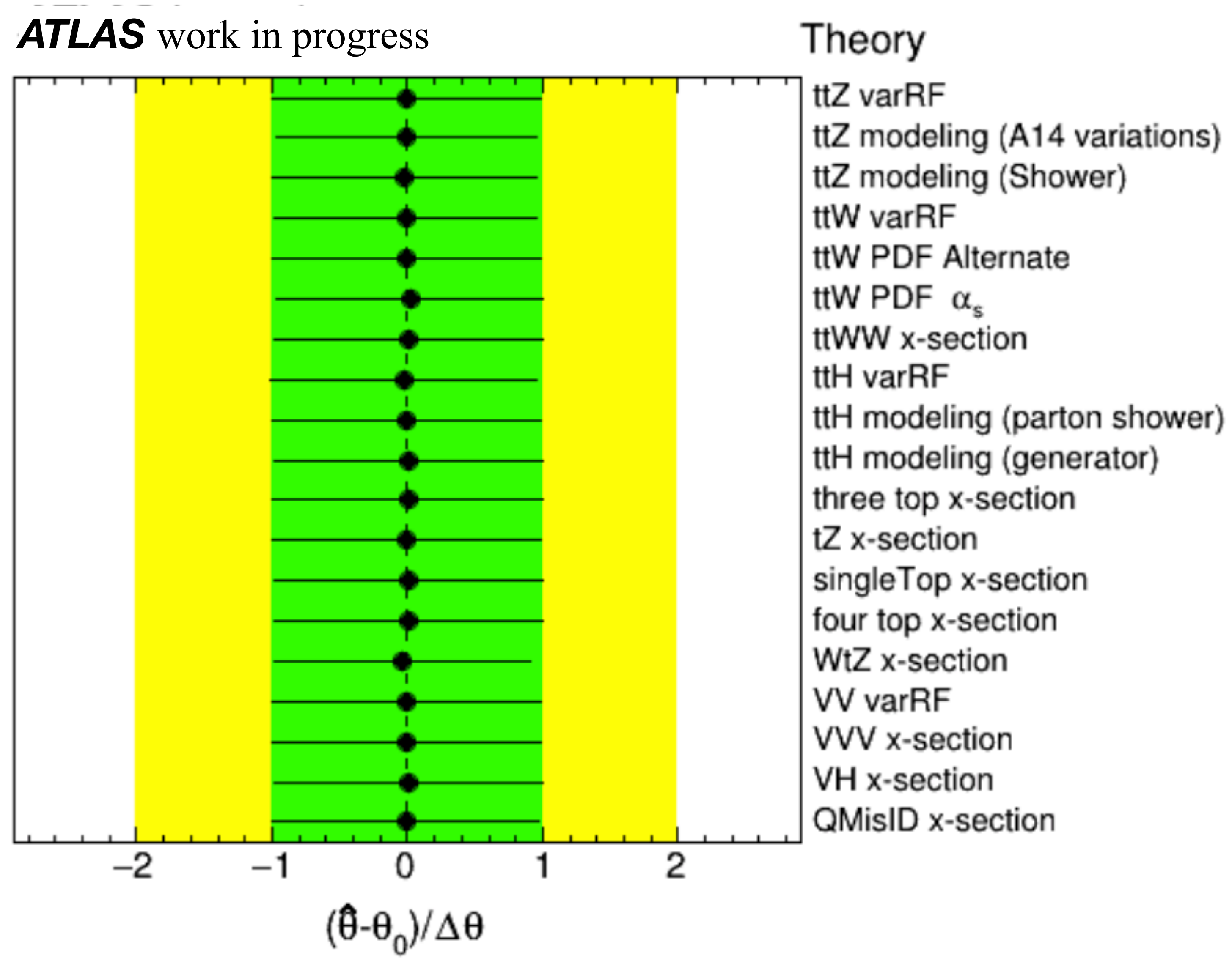


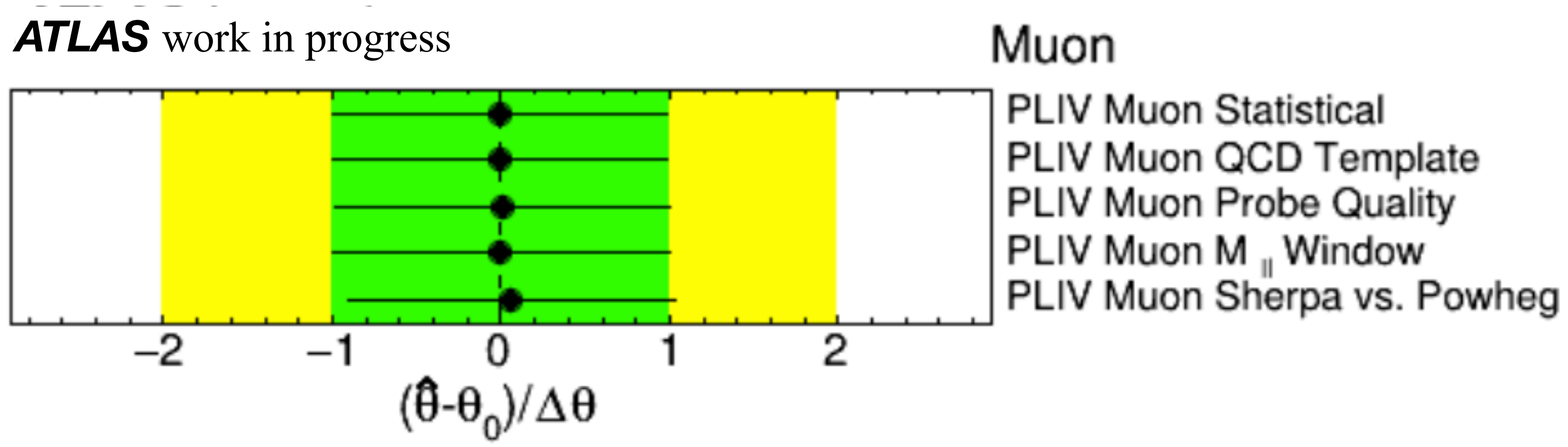
Fake Estimation (Alternative): Matrix Method

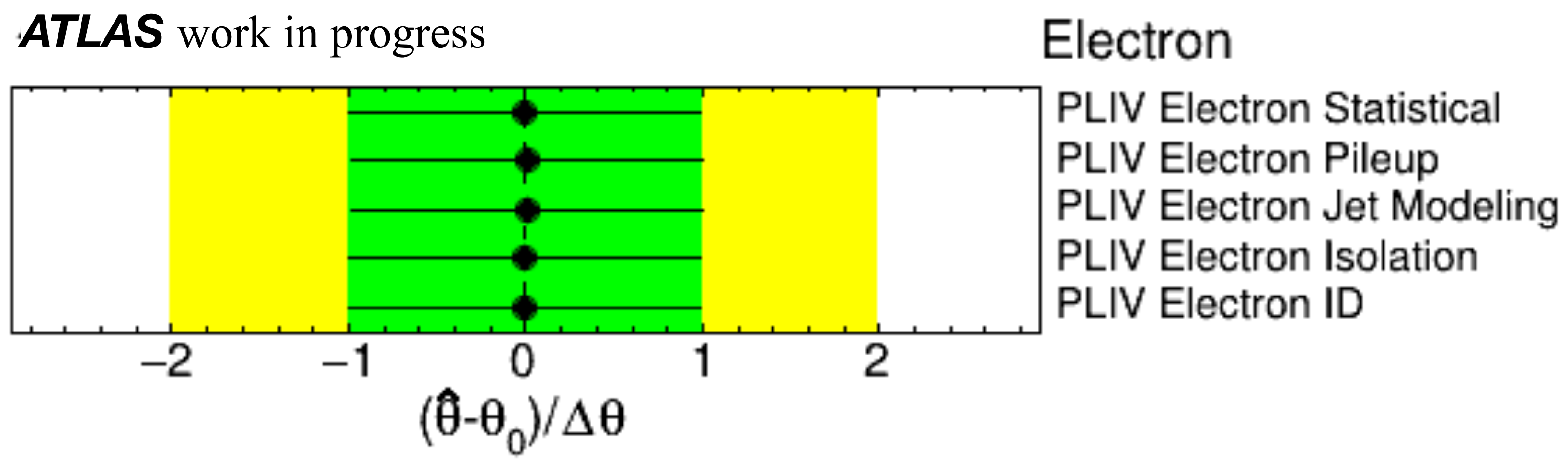
- Customized Asimov data with $\mu_{ttW} = 1.7$

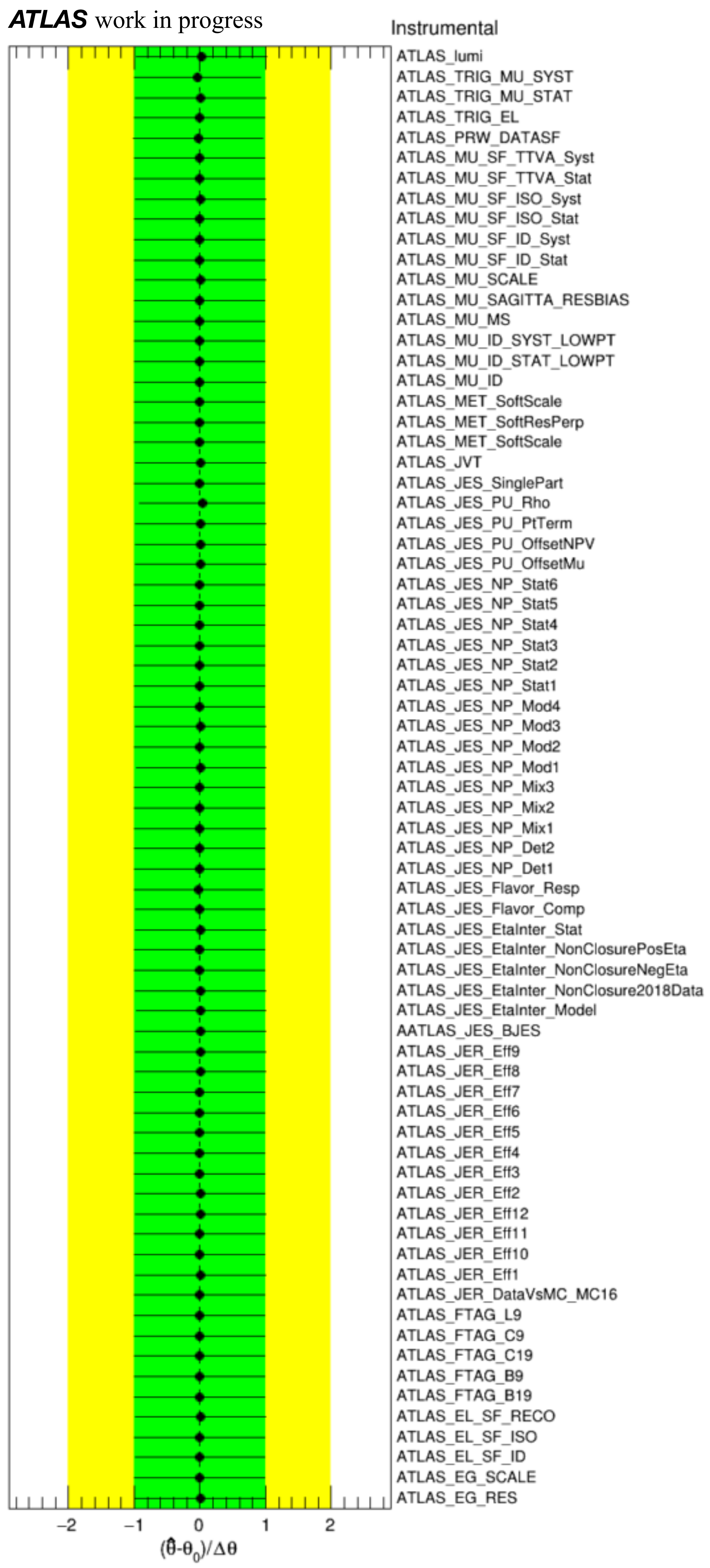










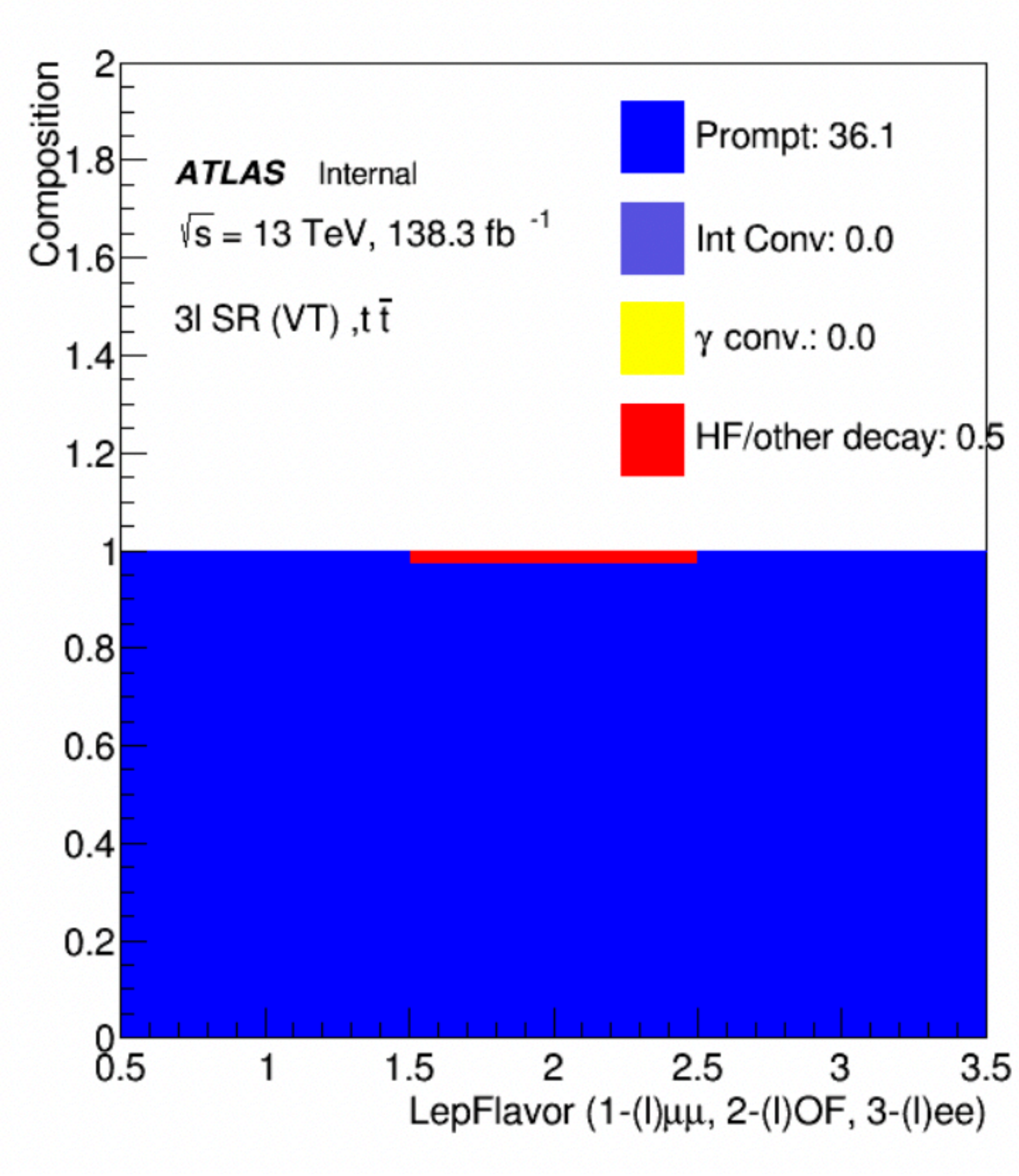


- No significant pull is observed.
- ttZ Xsec and VV Xsec are constrained.

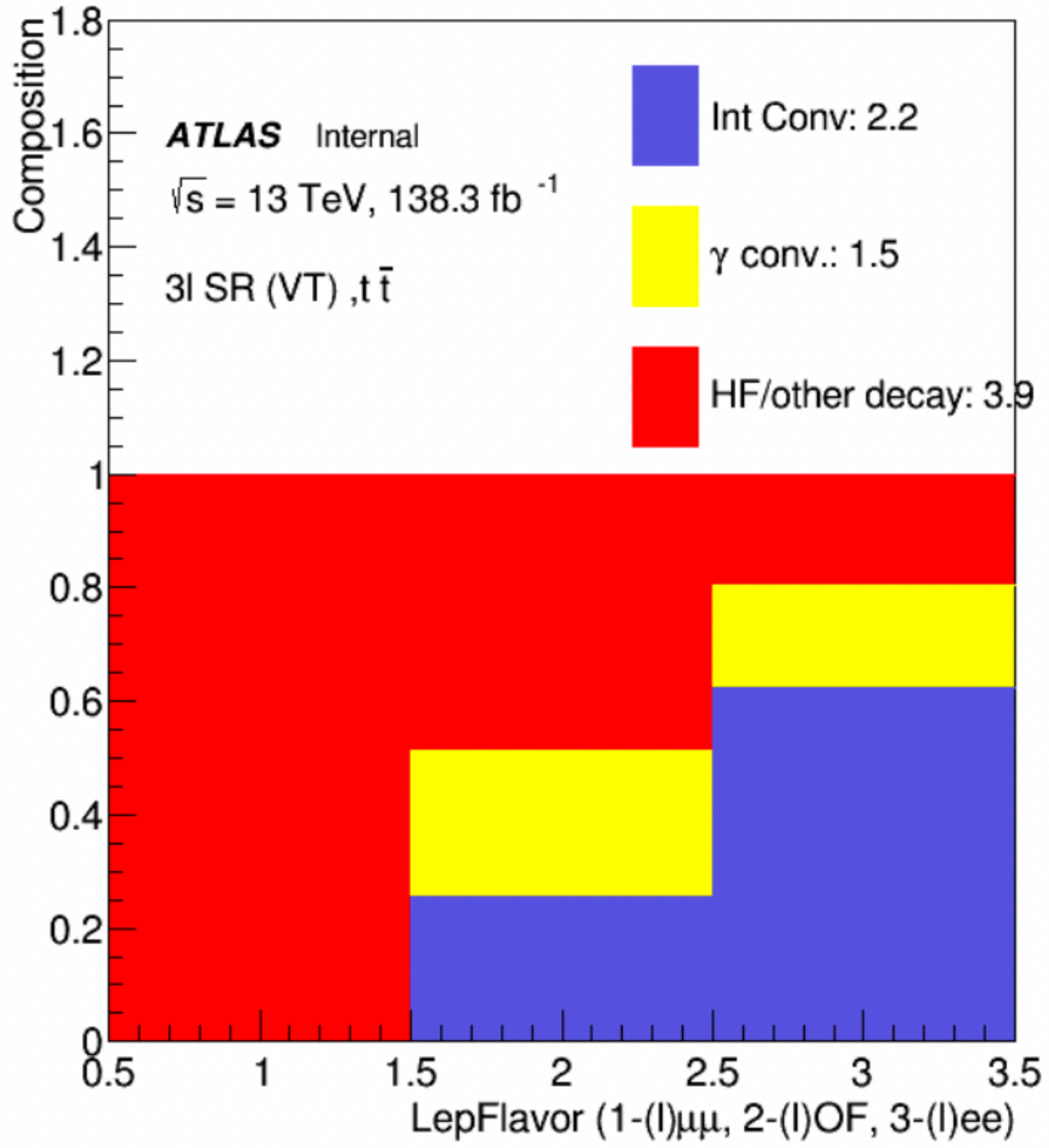
Fake Estimation (Alternative): Matrix Method

- Lepton origin fractions

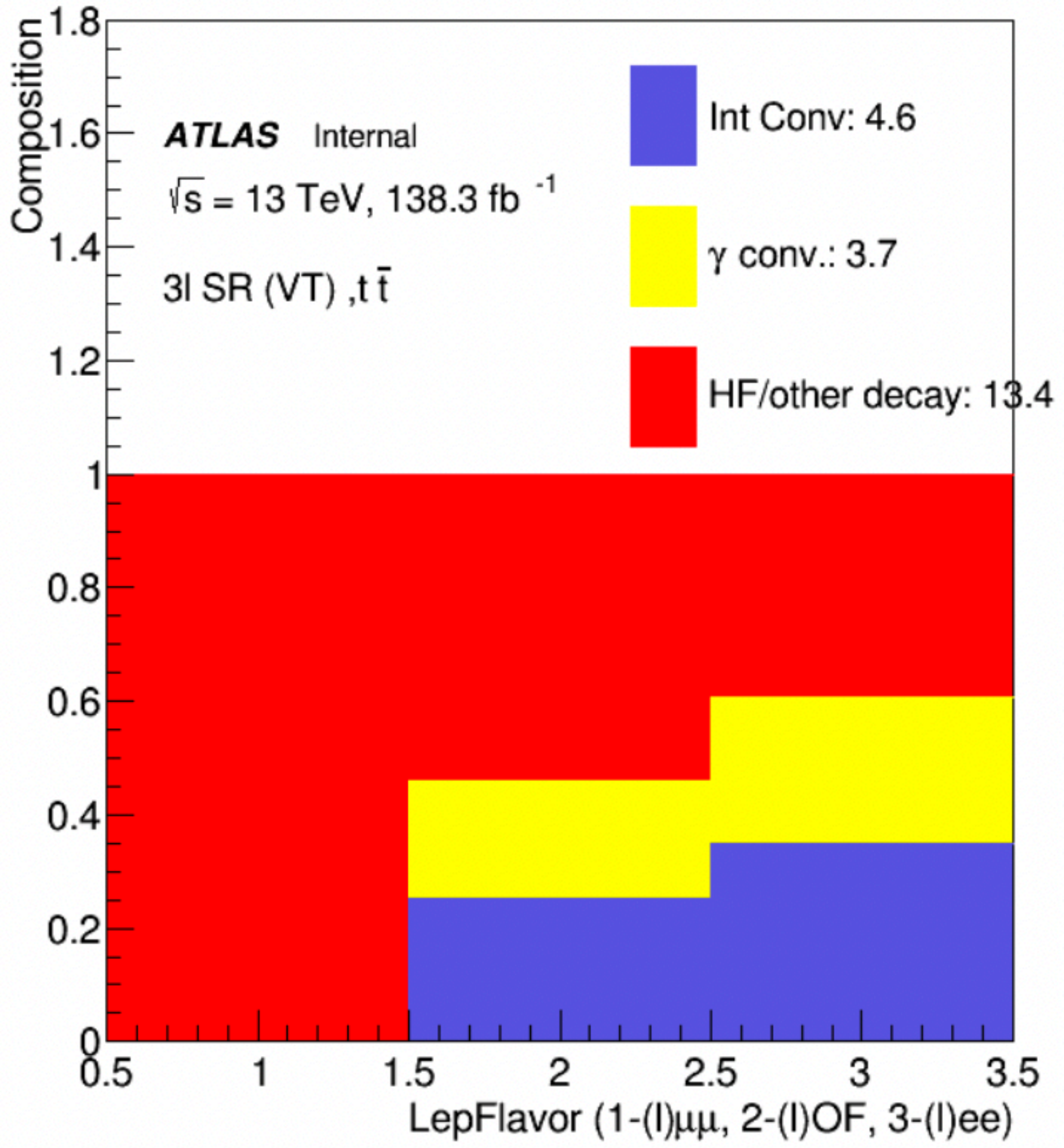
- Leading



- Subleading



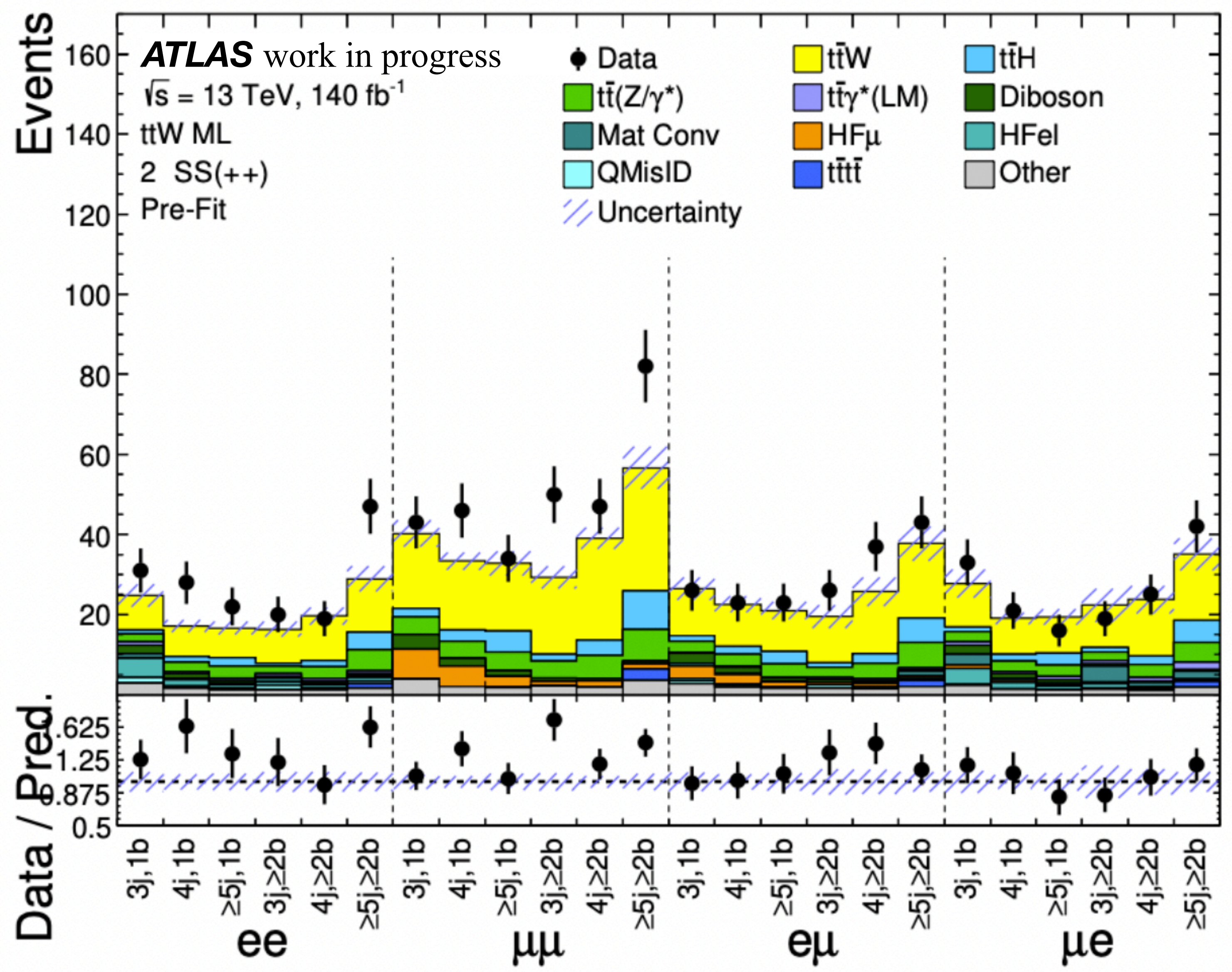
- Second leading

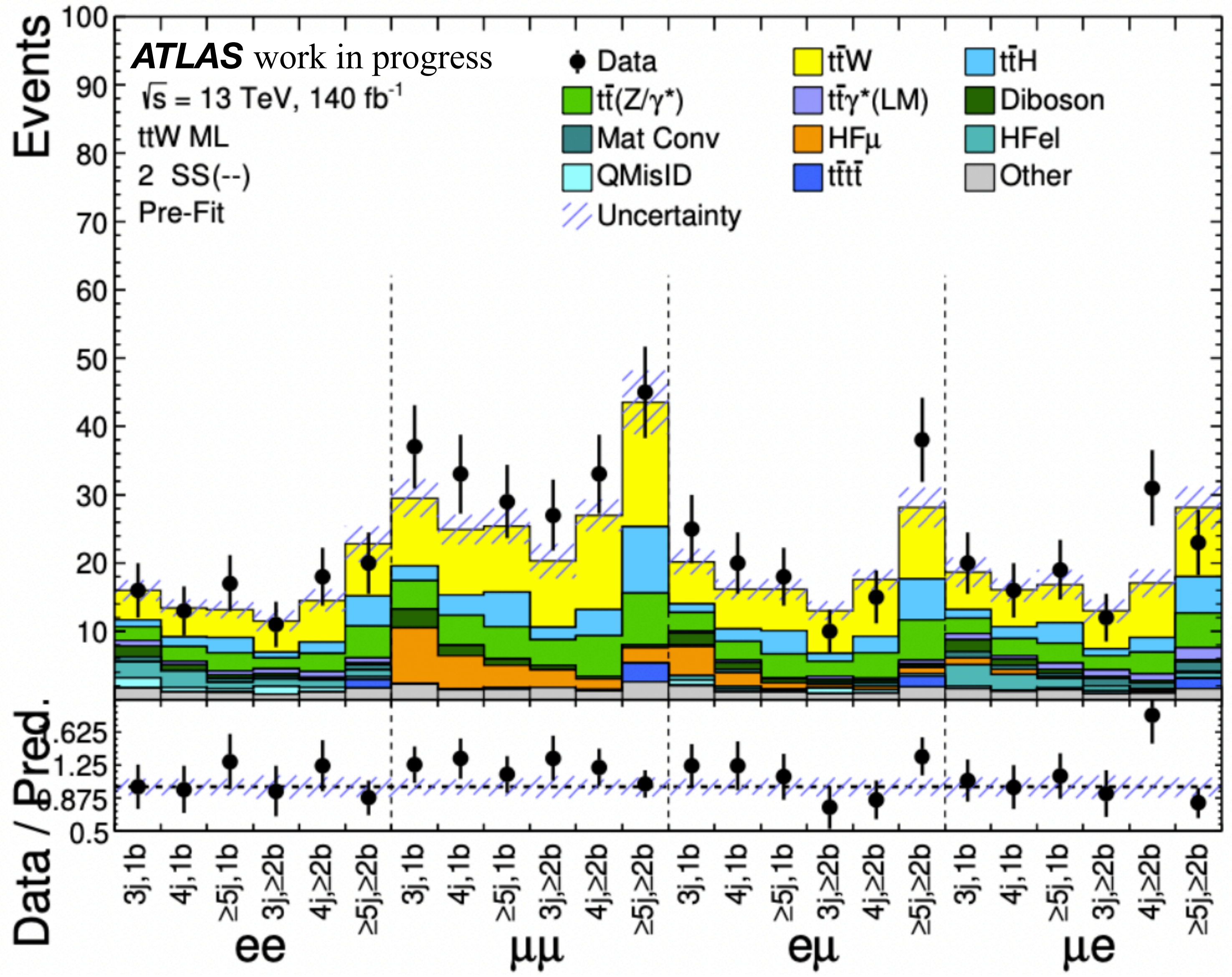


Inclusive measurement

Pre-fit

- Use a total of 56 SRs within 2lSS and 3l channels
- Template fit for background estimation in parallel



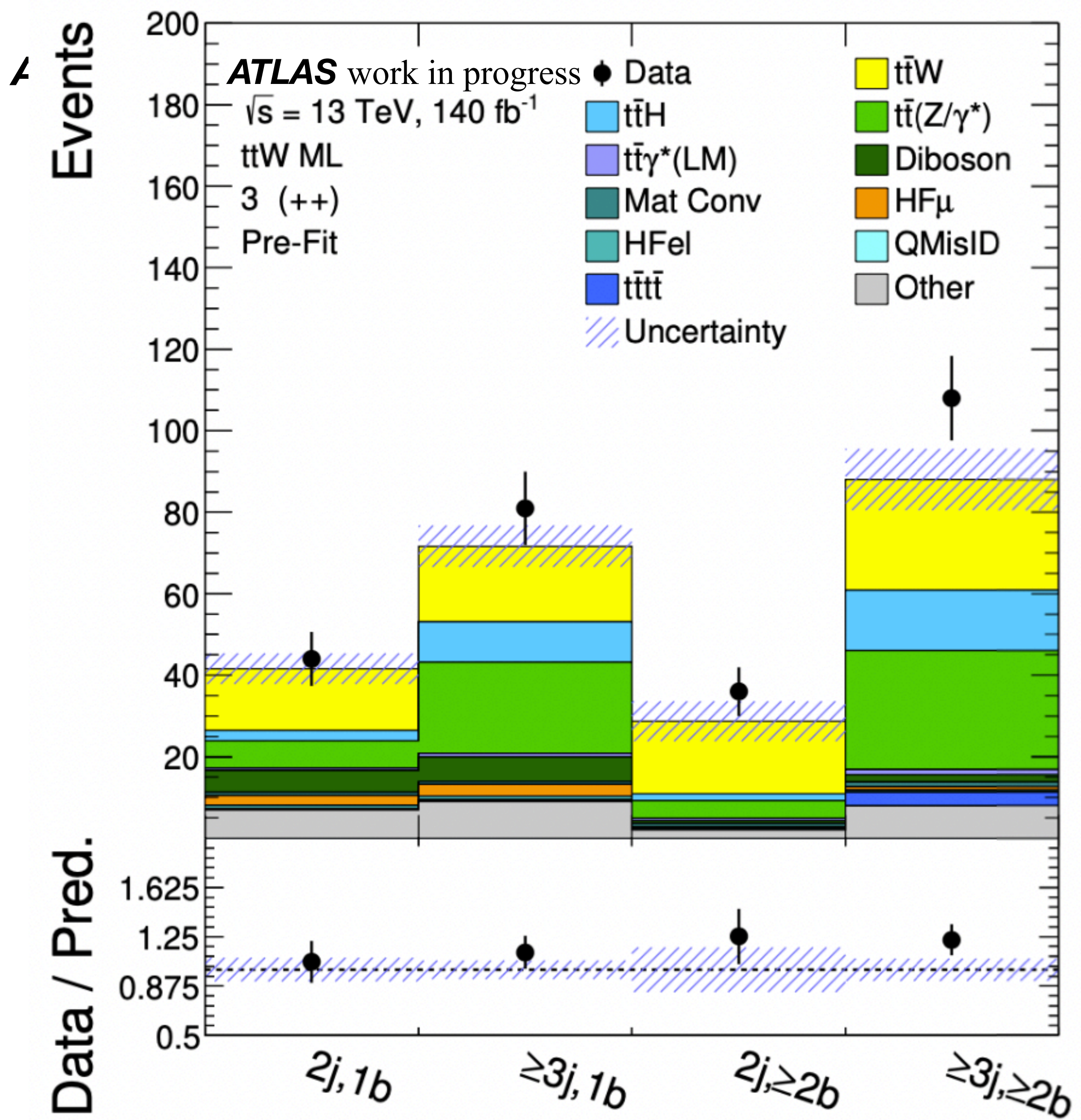


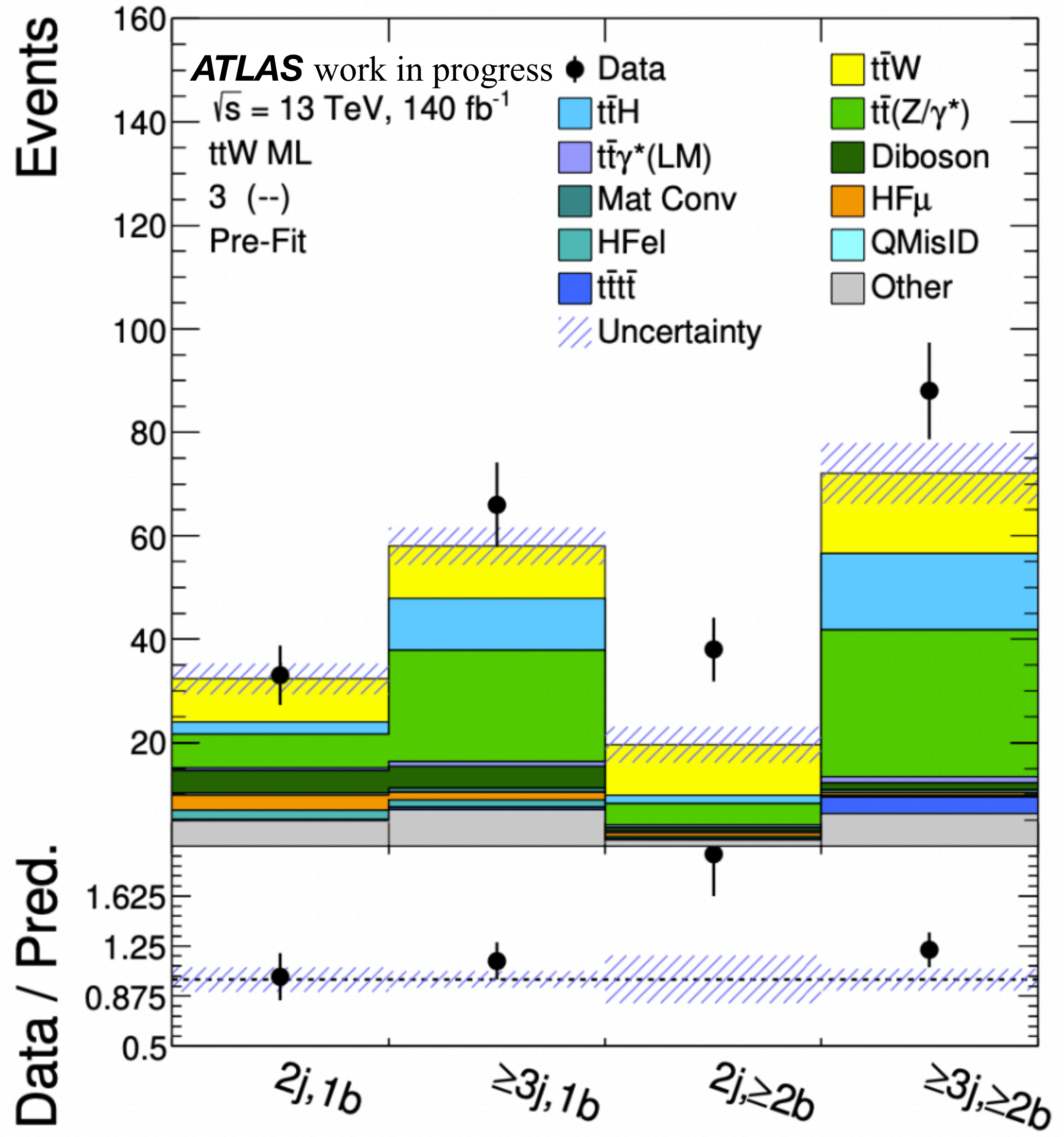
2ℓSS (48 regions)

Split by: Charge (++,--)
Flavour (ee, $e\mu$, μe, $\mu\mu$)
N_{jets} $(=3, =4, \geq 5)$
$N_{b-\text{jets}}$ $(=1, \geq 2)$

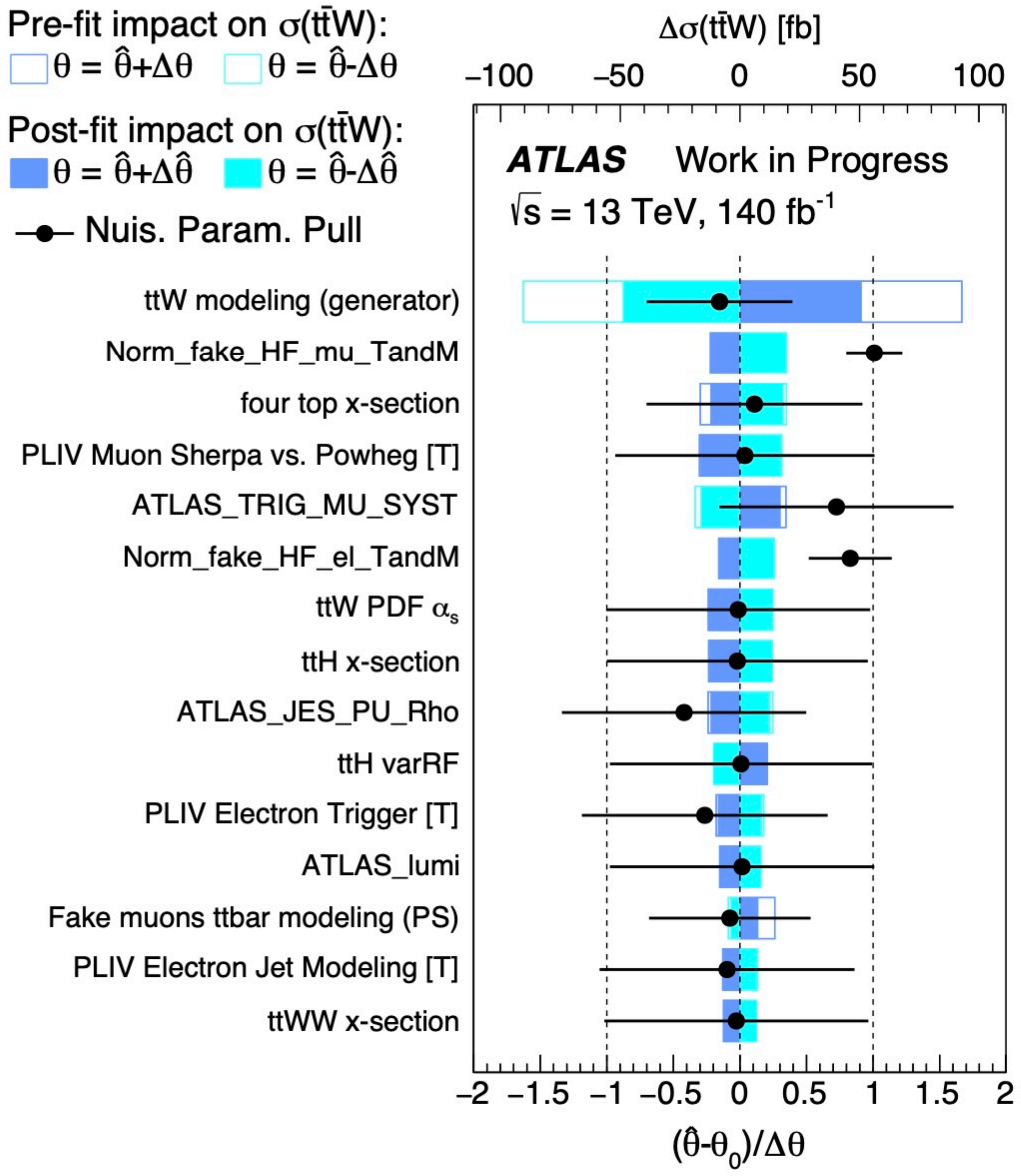
3ℓ (8 regions)

Split by: Charge (+,-)
N_{jets} $(=2, \geq 3)$
$N_{b-\text{jets}}$ $(=1, \geq 2)$



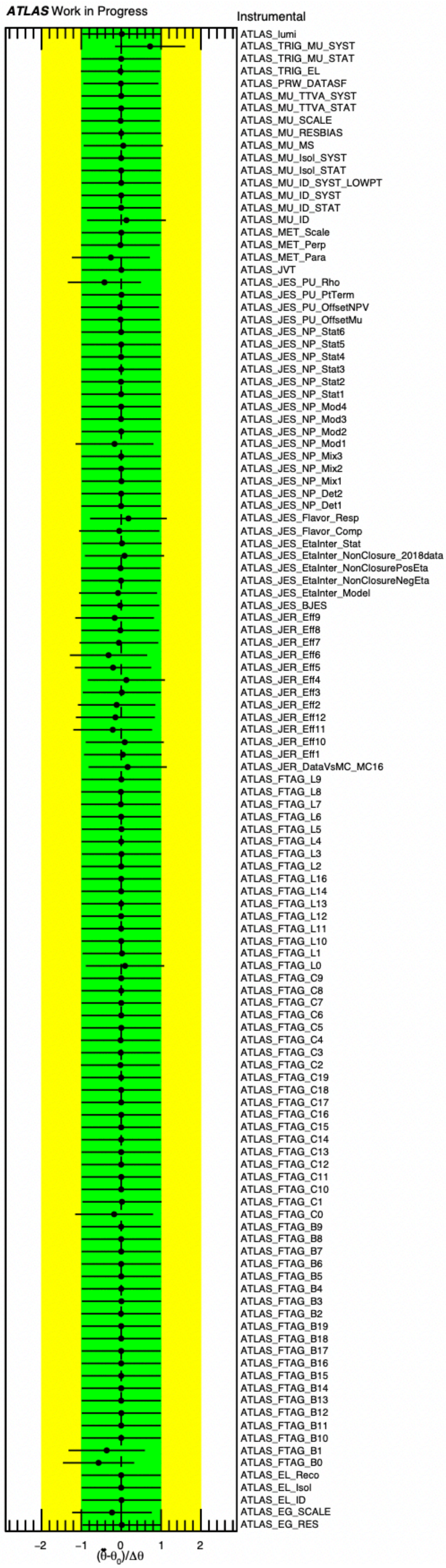


Inclusive fit



Suggestion to split ME+PS, will add when fits converge

	$\frac{\Delta\sigma(t\bar{t}W)}{\sigma(t\bar{t}W)}$ [%]	$\frac{\Delta\sigma_{\text{fid}}(t\bar{t}W)}{\sigma_{\text{fid}}}$ [%]	$\frac{\Delta R(t\bar{t}W)}{R(t\bar{t}W)}$ [%]	$\frac{\Delta A_{\text{Crel}}}{A_{\text{Crel}}}$ [%]
$t\bar{t}W$ 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/ttZ 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
$t\bar{t}W$ 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
$t\bar{t}W$ 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.	8.0	10.0	8.0	10.0
Data statistics	5.0	5.0	10.0	16.0
Total	9.0	11.0	13.0	19.0


ATLAS Work in Progress
Instrumental
ATLAS_lumi
ATLAS_TRIG_MU_SYST
ATLAS_TRIG_MU_STAT
ATLAS_TRIG_EL
ATLAS_PRW_DATASF
ATLAS_MU_TTVA_SYST
ATLAS_MU_TTVA_STAT
ATLAS_MU_SCALE
ATLAS_MU_RESBIAS
ATLAS_MU_MS
ATLAS_MU_Isol_SYST
ATLAS_MU_Isol_STAT
ATLAS_MU_ID_SYST_LOWPT
ATLAS_MU_ID_SYST
ATLAS_MU_ID_STAT
ATLAS_MU_ID
ATLAS_MET_Scale
ATLAS_MET_Perp
ATLAS_MET_Para
ATLAS_JVT
ATLAS_JES_PU_Rho
ATLAS_JES_PU_PtTerm
ATLAS_JES_PU_OffsetNPV
ATLAS_JES_PU_OffsetMu
ATLAS_JES_NP_Stat6
ATLAS_JES_NP_Stat5
ATLAS_JES_NP_Stat4
ATLAS_JES_NP_Stat3
ATLAS_JES_NP_Stat2
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ATLAS_JES_NP_Mod1
ATLAS_JES_NP_Mix3
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ATLAS_JES_NP_Det1
ATLAS_JES_Flavor_Resp
ATLAS_JES_Flavor_Comp
ATLAS_JES_EtaInter_Stat
ATLAS_JES_EtaInter_NonClosure_2018data
ATLAS_JES_EtaInter_NonClosurePosEta
ATLAS_JES_EtaInter_NonClosureNegEta
ATLAS_JES_EtaInter_Model
ATLAS_JES_BJES
ATLAS_JER_Eff9
ATLAS_JER_Eff8
ATLAS_JER_Eff7
ATLAS_JER_Eff6
ATLAS_JER_Eff5
ATLAS_JER_Eff4
ATLAS_JER_Eff3
ATLAS_JER_Eff2
ATLAS_JER_Eff12
ATLAS_JER_Eff11
ATLAS_JER_Eff10
ATLAS_JER_Eff1
ATLAS_JER_DataVsMC_MC16
ATLAS_FTAG_L9
ATLAS_FTAG_L8
ATLAS_FTAG_L7
ATLAS_FTAG_L6
ATLAS_FTAG_L5
ATLAS_FTAG_L4
ATLAS_FTAG_L3
ATLAS_FTAG_L2
ATLAS_FTAG_L16
ATLAS_FTAG_L14
ATLAS_FTAG_L13
ATLAS_FTAG_L12
ATLAS_FTAG_L11
ATLAS_FTAG_L10
ATLAS_FTAG_L1
ATLAS_FTAG_L0
ATLAS_FTAG_C9
ATLAS_FTAG_C8
ATLAS_FTAG_C7
ATLAS_FTAG_C6
ATLAS_FTAG_C5
ATLAS_FTAG_C4
ATLAS_FTAG_C3
ATLAS_FTAG_C2
ATLAS_FTAG_C19
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ATLAS_FTAG_C10
ATLAS_FTAG_C1
ATLAS_FTAG_C0
ATLAS_FTAG_B9
ATLAS_FTAG_B8
ATLAS_FTAG_B7
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ATLAS_FTAG_B5
ATLAS_FTAG_B4
ATLAS_FTAG_B3
ATLAS_FTAG_B2
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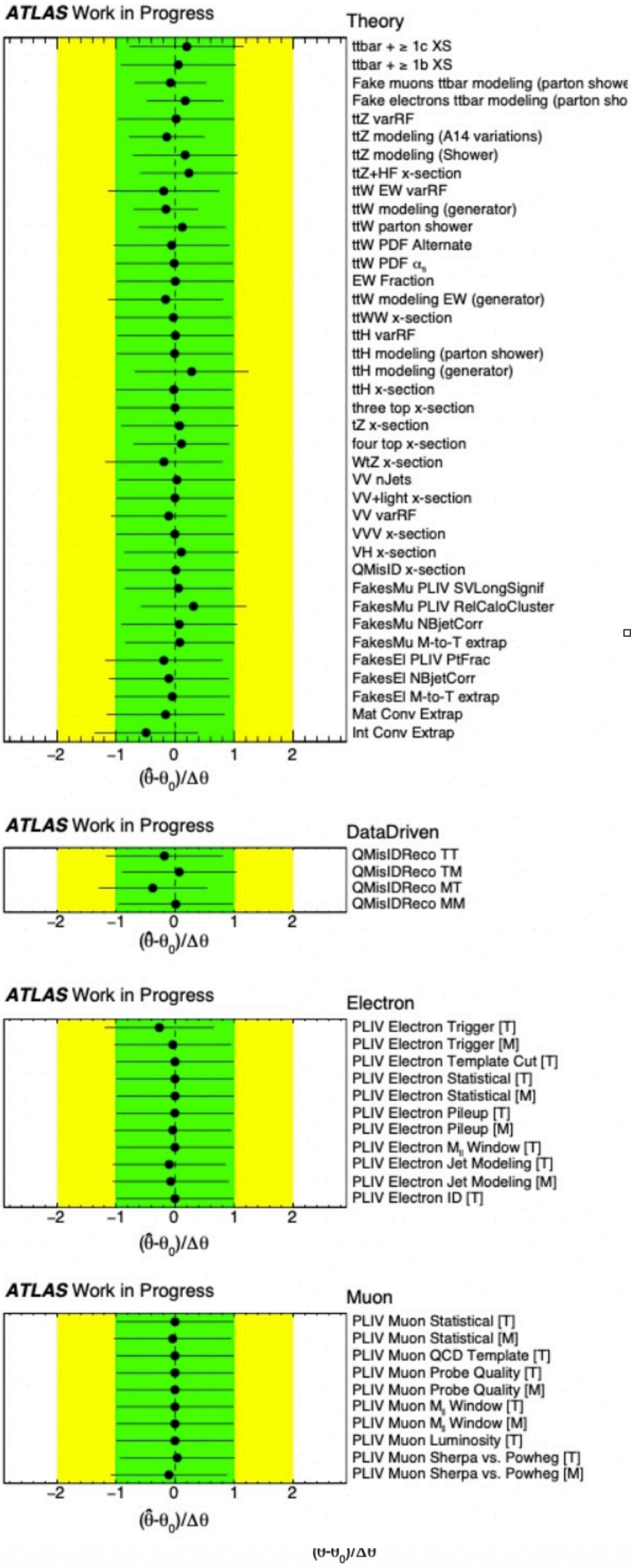
ATLAS_FTAG_B15
ATLAS_FTAG_B14
ATLAS_FTAG_B13
ATLAS_FTAG_B12
ATLAS_FTAG_B11
ATLAS_FTAG_B10
ATLAS_FTAG_B1
ATLAS_FTAG_B0
ATLAS_EL_Reco
ATLAS_EL_Isol
ATLAS_EL_ID
ATLAS_EG_SCALE
ATLAS_EG_RES
−2
−1
0
1
2
$(\hat{\theta}-\theta_0)/\Delta\theta$


ATLAS Work in Progress
Theory
ttbar + ≥ 1c XS
ttbar + ≥ 1b XS
Fake muons ttbar modeling (parton showe
Fake electrons ttbar modeling (parton sho
ttZ varRF
ttZ modeling (A14 variations)
ttZ modeling (Shower)
ttZ+HF x-section
ttW EW varRF
ttW modeling (generator)
ttW parton shower
ttW PDF Alternate
ttW PDF α_s
EW Fraction
ttW modeling EW (generator)
ttWW x-section
ttH varRF
ttH modeling (parton shower)
ttH modeling (generator)
ttH x-section
three top x-section
tZ x-section
four top x-section
WtZ x-section
VV nJets
VV+light x-section
VV varRF
VVV x-section
VH x-section
QMisID x-section
FakesMu PLIV SVLongSignif
FakesMu PLIV RelCaloCluster
FakesMu NBjetCorr
FakesMu M-to-T extrap
FakesEl PLIV PtFrac
FakesEl NBjetCorr
FakesEl M-to-T extrap
Mat Conv Extrap
Int Conv Extrap
−2
−1
0
1
2
$(\hat{\theta}-\theta_0)/\Delta\theta$
ATLAS Work in Progress
DataDriven
QMisIDReco TT
QMisIDReco TM
QMisIDReco MT
QMisIDReco MM
−2
−1
0
1
2
$(\hat{\theta}-\theta_0)/\Delta\theta$
ATLAS Work in Progress
Electron
PLIV Electron Trigger [T]
PLIV Electron Trigger [M]
PLIV Electron Template Cut [T]
PLIV Electron Statistical [T]
PLIV Electron Statistical [M]
PLIV Electron Pileup [T]
PLIV Electron Pileup [M]
PLIV Electron M_{ll} Window [T]
PLIV Electron Jet Modeling [T]
PLIV Electron Jet Modeling [M]
PLIV Electron ID [T]
−2
−1
0
1
2
$(\hat{\theta}-\theta_0)/\Delta\theta$
ATLAS Work in Progress
Muon
PLIV Muon Statistical [T]
PLIV Muon Statistical [M]
PLIV Muon QCD Template [T]
PLIV Muon Probe Quality [T]
PLIV Muon Probe Quality [M]
PLIV Muon M_{ll} Window [T]
PLIV Muon M_{ll} Window [M]
PLIV Muon Luminosity [T]
PLIV Muon Sherpa vs. Powheg [T]
PLIV Muon Sherpa vs. Powheg [M]
−2
−1
0
1
2
$(\hat{\theta}-\theta_0)/\Delta\theta$

Fake Estimation Comparison: TF vs MM

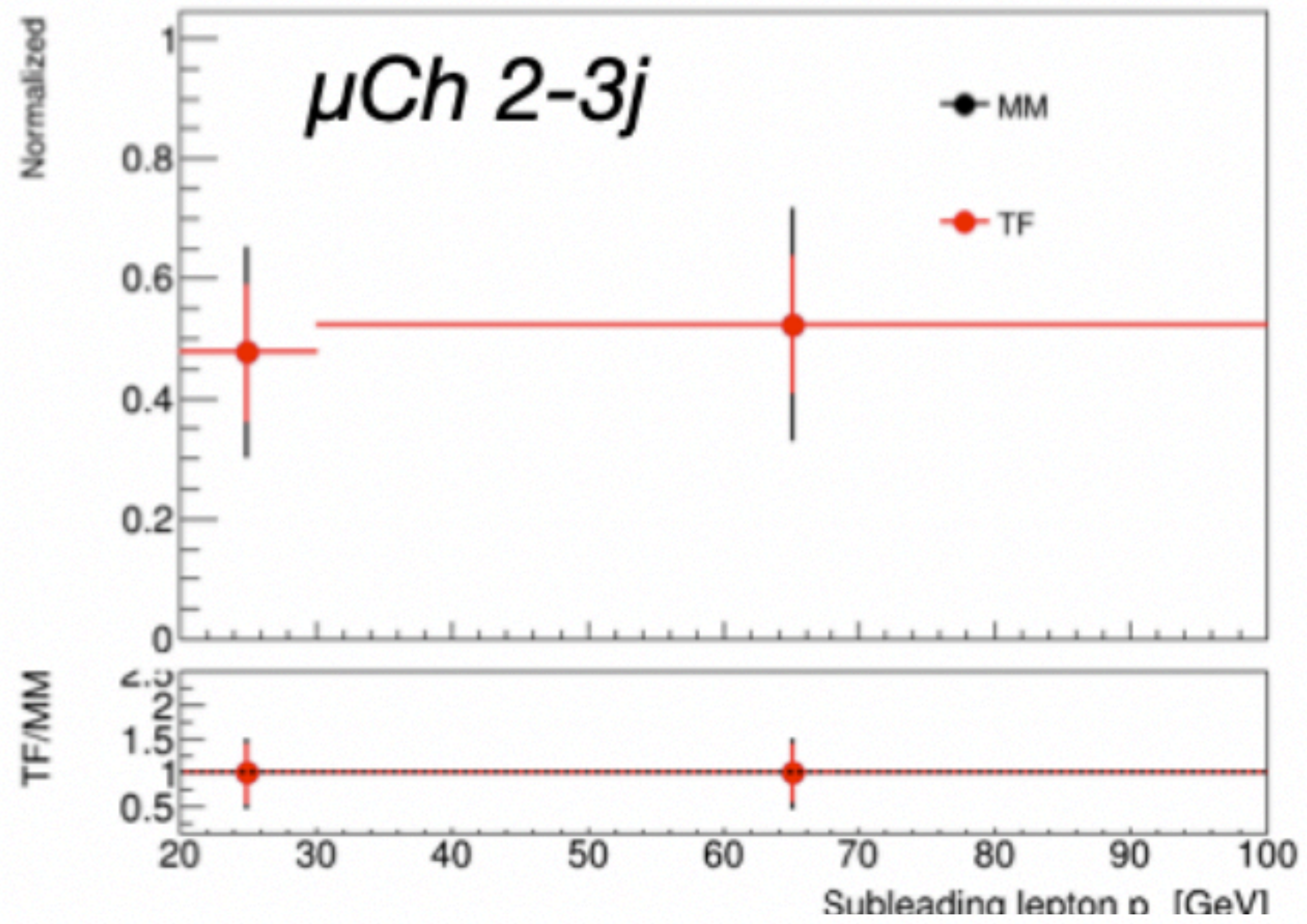
- Dedicate validation regions are defined to perform the comparisons

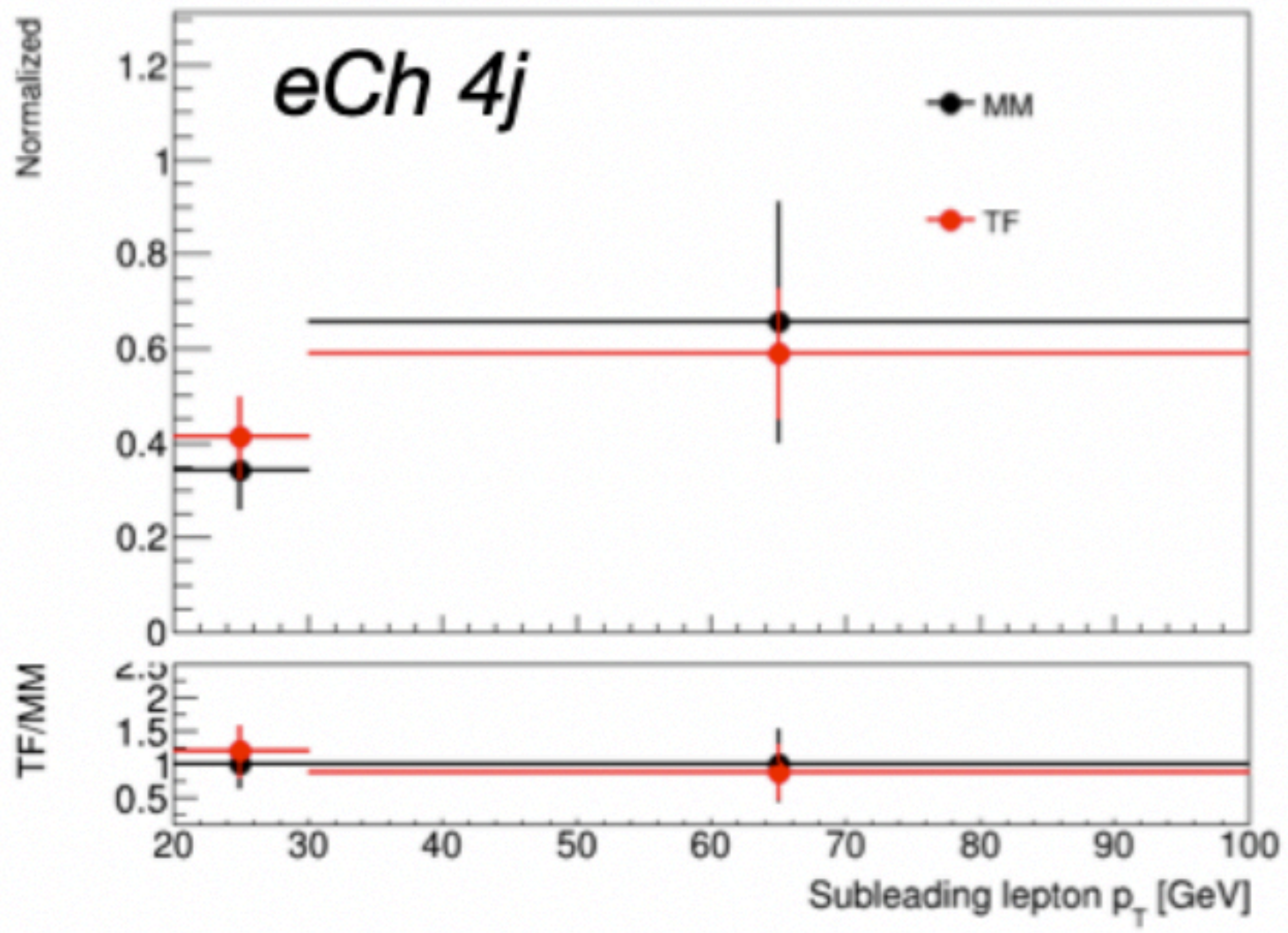
Region label	elCh 2-3j	elCh 4jincl	muCh 2-3j	muCh 4jincl
channel flavour	ee+μe		$\mu\mu$+eμ	
jets multiplicity	2 or 3	≥ 4	2 or 3	≥ 4
leptons definition (lep1 lep2)	Tight Tight			
b-jets multiplicity	== 1 @ 60% WP or $\geq$ 2 @ 77% WP			
additional cuts	$H_T^{had} < 200$ GeV and E_T^{miss}<85 GeV for 2-3j regions			

- MM seems to be predicting a higher estimate than the TF (1.6 to 2 times higher)

Region	Template Fit (TF)	Matrix Method (MM)	MM/TF
elCh 2-3j	30.9±8.3	66.1 ± 25.4	2.1
elCh 4jinc	33.9 ± 7.8	54.6 ± 19.8	1.6
muCh 2-3j	41.4 ± 11.1	68.9 ±27.2	1.7
muCh 4jincl	41.9 ± 10.7	68.3 ± 27.6	1.6

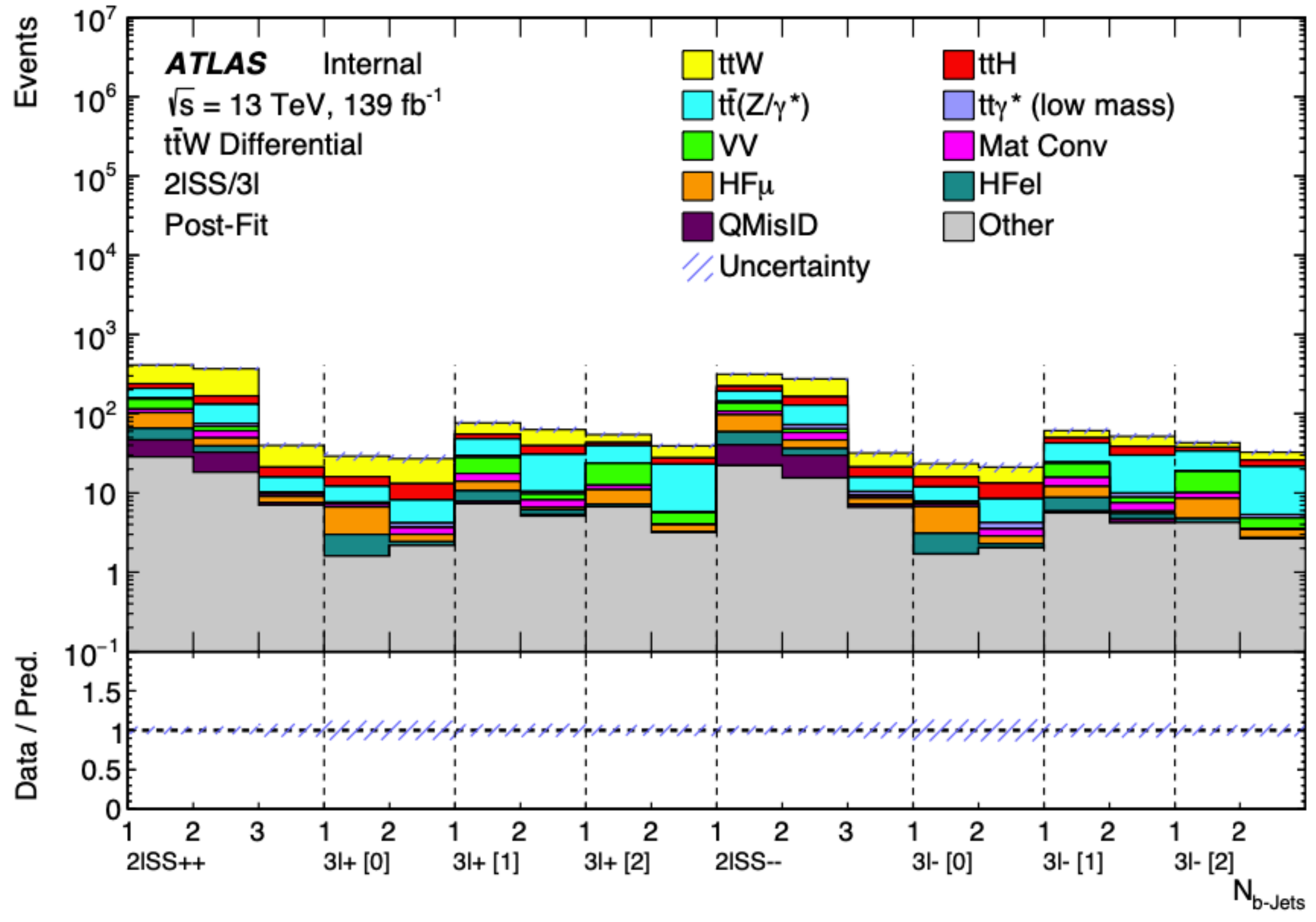
- The shapes agree quite well between the two estimates within their uncertainties





Differential measurement

- Producing hybrid Asimov fits for ten observables with the combined TF + unfolding setup
- 2 different parameterizations -->
  - 2lSS++, 2lSS--, 3l+ and 3l- separately
  - a charge-inclusive treatment of 2lSS and 3l + the ttW+/ttW- asymmetry
- Preparing the differential results in standard parametrisation and asymmetry parametrisation (Calculate relative charge asymmetry)
- The inclusive and inclusive asymmetry parameterizations allow for a direct comparison between unfolded observables in terms of inclusive fiducial cross sections and asymmetries.

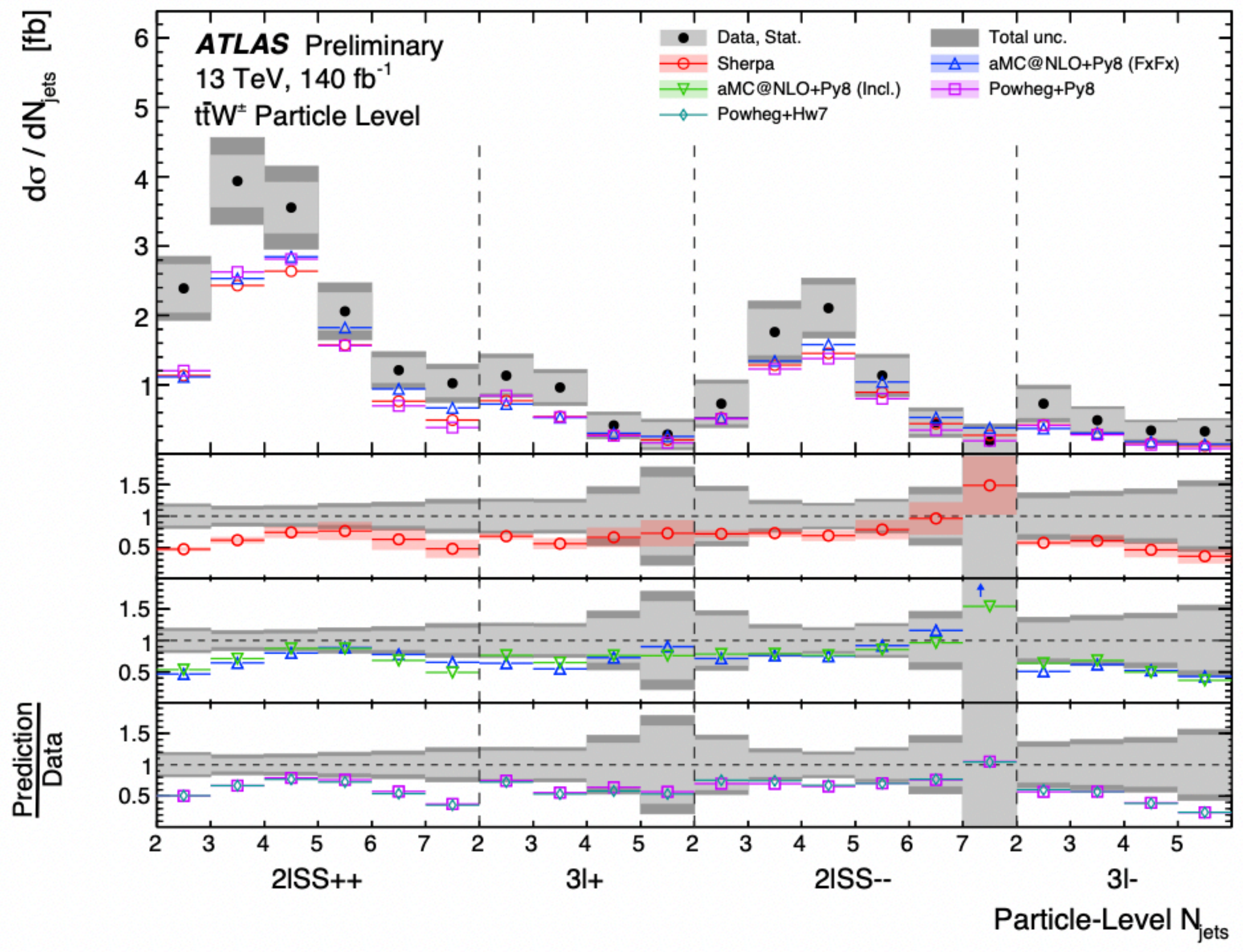


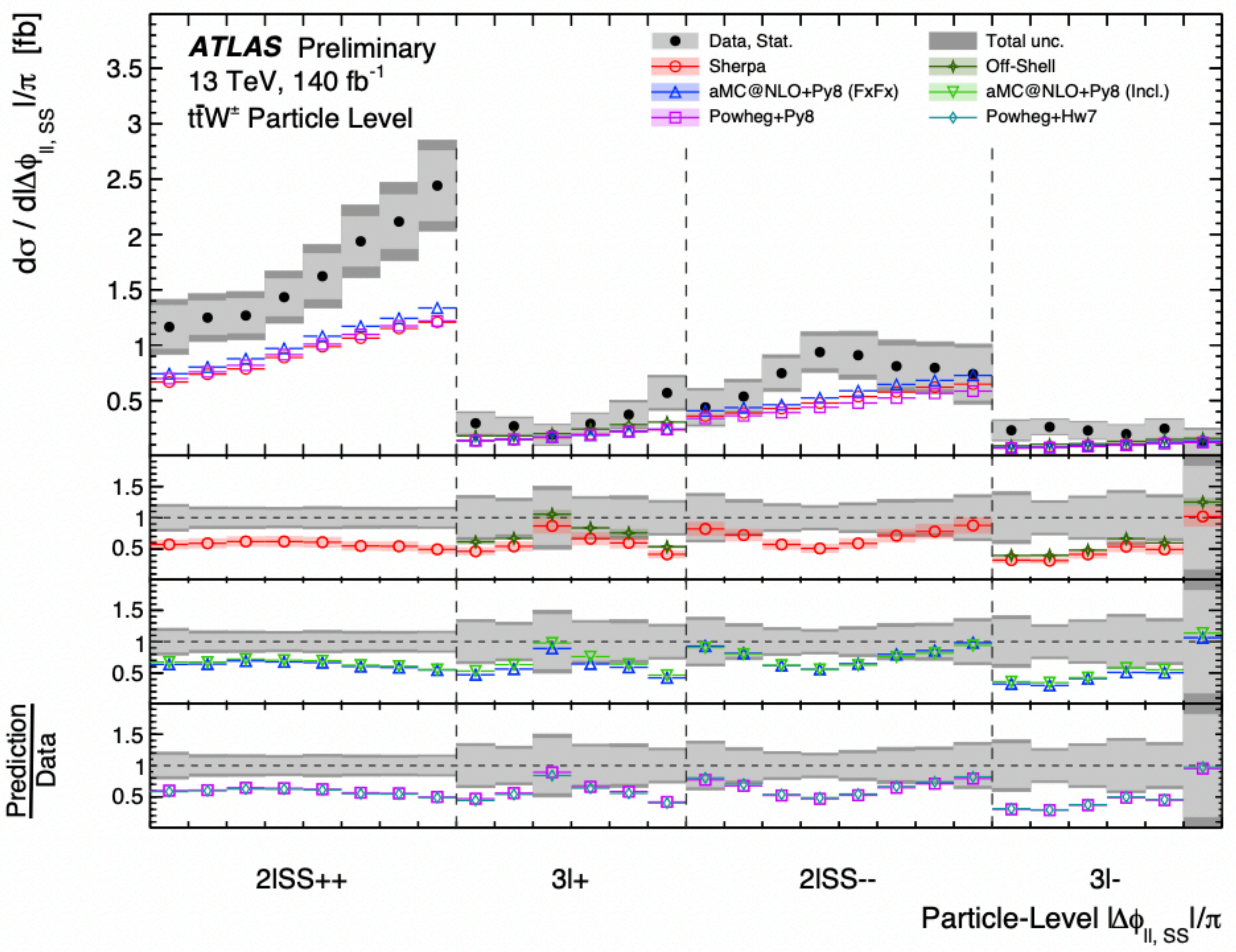
$$A_C^R = \frac{N^+ - N^-}{N^+ + N^-} = \frac{\sigma(t\bar{t}W^+) - \sigma(t\bar{t}W^-)}{\sigma(t\bar{t}W^+) + \sigma(t\bar{t}W^-)}$$

Differential	Differential Asymmetry	Inclusive	Inclusive Asymmetry
$\{\mu_i^{2\ell SS++}\}_{i=1}^m, \{\mu_i^{2\ell SS++}\}_{i=1}^m, \{\mu_i^{3\ell+}\}_{i=1}^m, \{\mu_i^{3\ell-}\}_{i=1}^m$	$\{\mu_i^{2\ell SS}\}_{i=1}^m, \{A_{C,i}^{R,2\ell SS}\}_{i=1}^m, \{\mu_i^{3\ell}\}_{i=1}^m, \{A_{C,i}^{R,3\ell}\}_{i=1}^m$	$\mu^{2\ell SS++}, \mu^{2\ell SS--}, \mu^{3\ell+}, \mu^{3\ell-}$	$\mu^{2\ell SS}, A_C^{R,2\ell SS}, \mu^{3\ell}, A_C^{R,3\ell}$
Standard parameterization	$\mu_i^- = \frac{1}{2}\mu_i\left(1 - \frac{N_i^+}{N_i^-}\right)(1 - A_{C,i}^R)$ $\mu_i^+ = \frac{1}{2}\mu_i\left(1 - \frac{N_i^-}{N_i^+}\right)(1 + A_{C,i}^R)$	$\mu_1 = \frac{1}{N_1}\left(\mu N - \sum_{i=2}^m \mu_i N_i\right)$	$\mu_1^- = \frac{1}{2N_1^-}\left[\mu N(1 - A_C^R) - \sum_{i=2}^m \mu_i N_i(1 - A_{C,i}^R)\right]$ $\mu_1^+ = \frac{1}{2N_1^+}\left[\mu N(1 + A_C^R) - \sum_{i=2}^m \mu_i N_i(1 + A_{C,i}^R)\right]$

Differential results

- Predicts slightly higher in the absolute cross-section measurements, consistent with the inclusive measurement result.





Differential results

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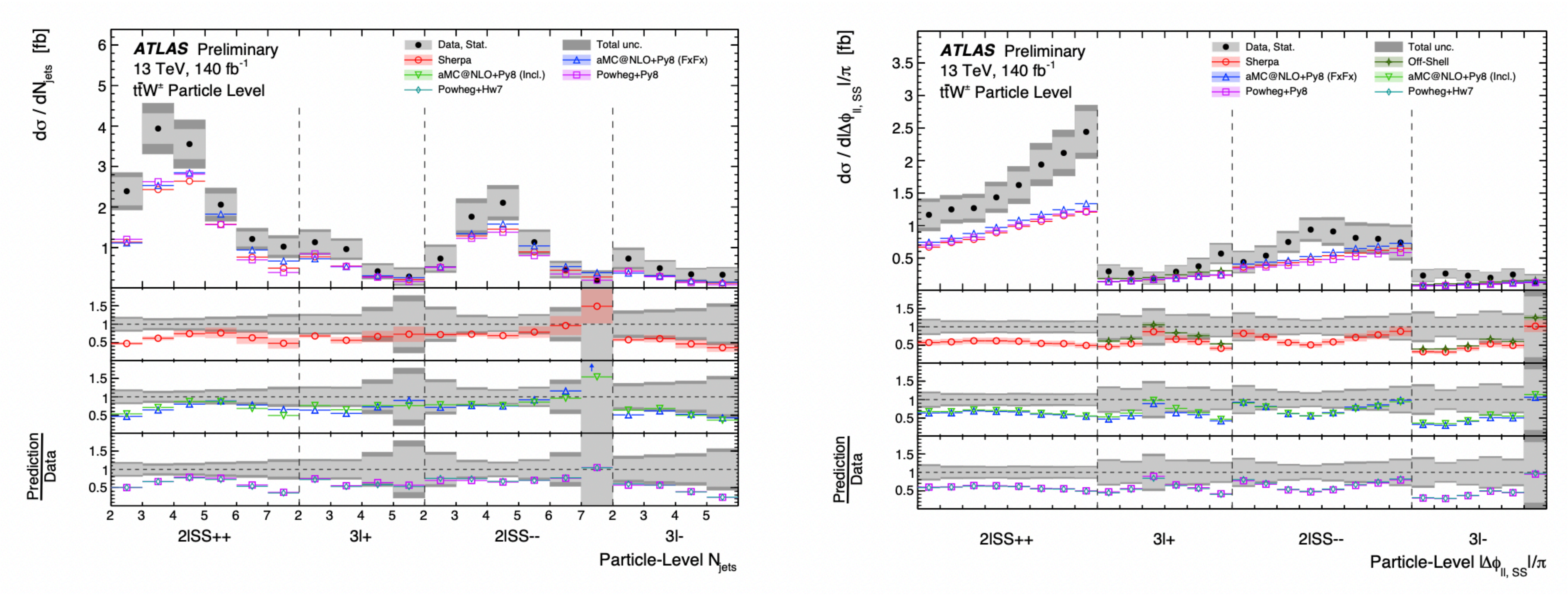


Differential results

- Good agreement between data and MC from different MC generators
- $\chi 2$ *p*-values are calculated to test the agreement of the normalised cross-section measurement

▷ 2LSS

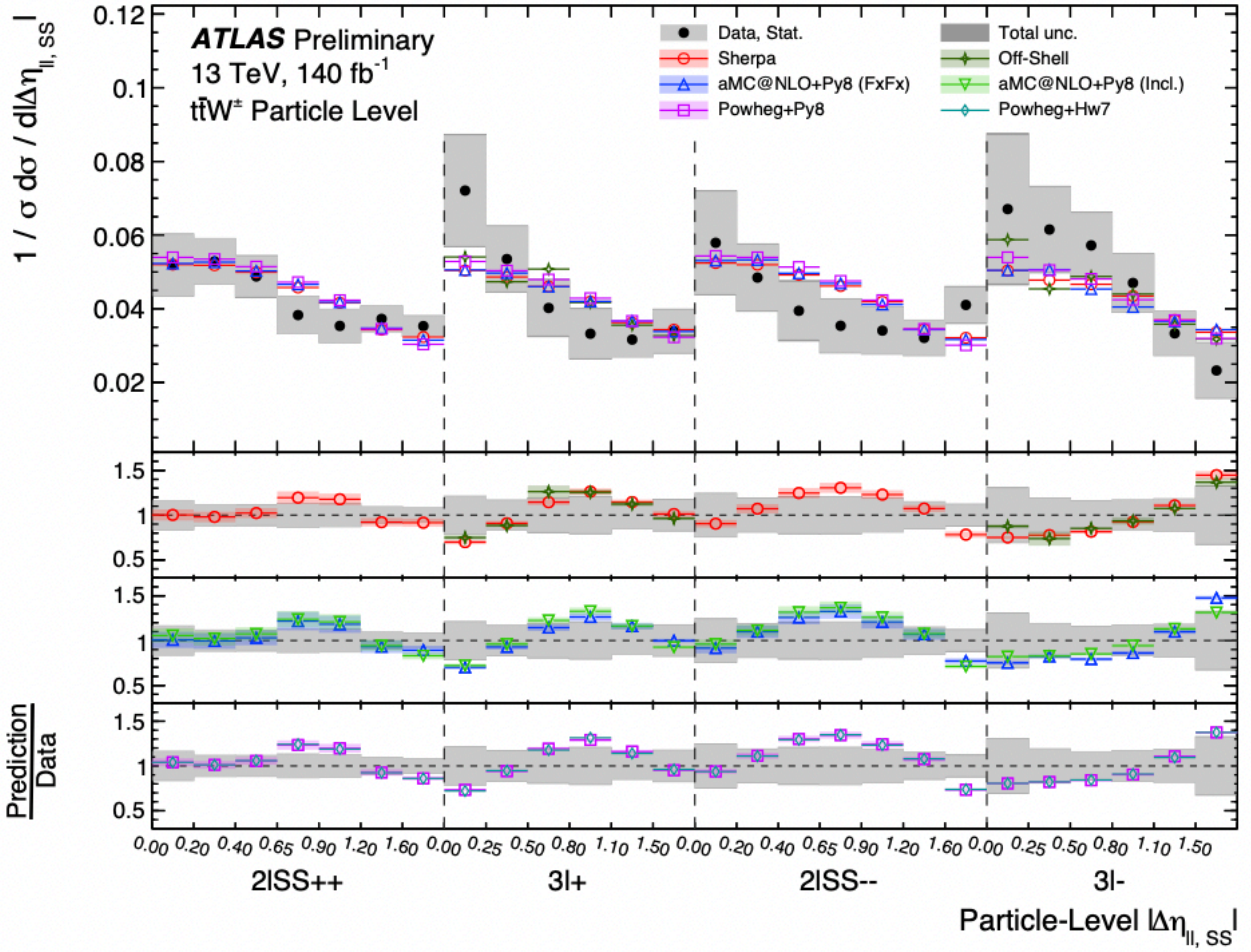
Observable	NDF	Sherpa 2.2.10		MG5aMC+Py8 FxFx		MG5aMC+Py8 Incl.		Powheg+Pythia8		Powheg+Herwig7	
		χ^2	p-value	χ^2	p-value	χ^2	p-value	χ^2	p-value	χ^2	p-value
N_{jets}	5	2.4	0.79	4.2	0.52	2.8	0.73	2.9	0.72	2.6	0.76
$H_{\text{T,jets}}$	5	0.7	0.98	1.1	0.95	0.8	0.98	1.5	0.91	2.0	0.85
$H_{\text{T,lep}}$	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

▷ 3L

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
$H_{\text{T,jets}}$	4	1.4	0.84	-	-	0.9	0.92	1.9	0.75	2.4	0.66	3.3	0.51
$H_{\text{T,lep}}$	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

Differential results

- Small tension shows in Δη between two leptons, the *χ2 p*-value for the normalised cross section measurement is 0.37

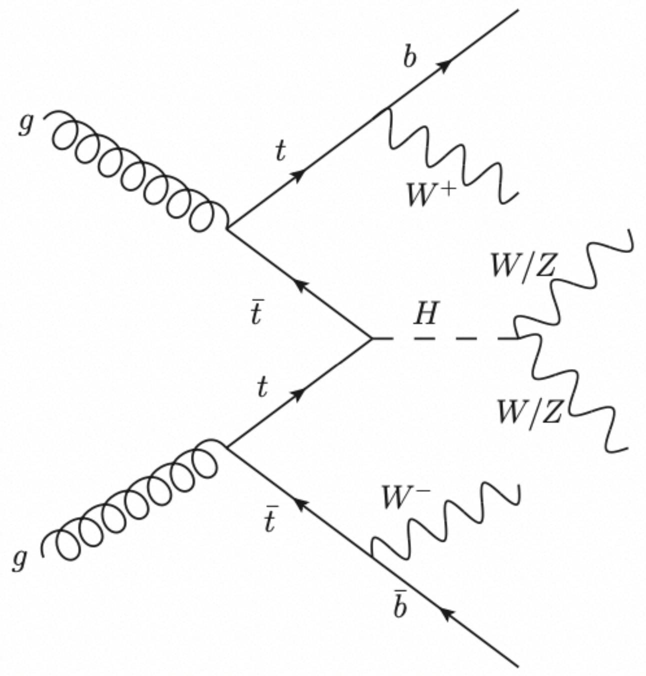


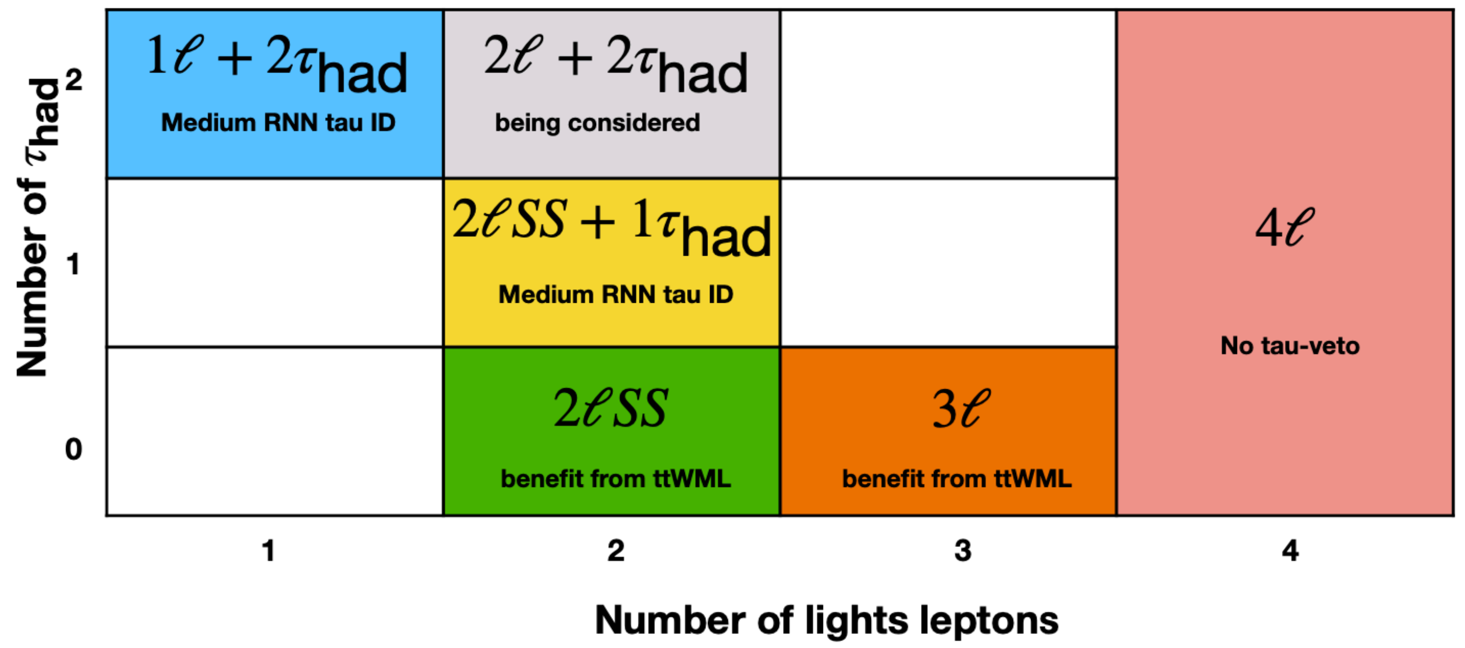
- 2LSS

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
$H_{\text{T,jets}}$	5	0.7	0.98	1.1	0.95	0.8	0.98	1.5	0.91	2.0	0.85
$H_{\text{T,lep}}$	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
$\lvert\Delta\phi_{\text{ll, SS}}\rvert$	7	0.6	1.00	0.7	1.00	0.9	1.00	0.8	1.00	0.9	1.00
$\lvert\Delta\eta_{\text{ll, SS}}\rvert$	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

ttH-ML analysis

- Following on ttW production cross-section measurements, the analysis team targets the ttH measurement with the full Run 2 dataset
  - Measure the inclusive cross-section of ttH production
  - ttH-ML simplified template cross sections (STXS) measurement (p_T^H : [0,200] & [200,∞])
  - Higgs decay to WW/ZZ/$\tau\tau$ channels with multilepton final states





- Adopted the object definition and event selection from $t\bar{t}W$ analysis for non-tau channels. For tau channel, dedicated tau ID optimization studies were required:
  - New RNN Medium WP was chosen to identify tau candidates, compared with previous BDT-based approach