# Measurement of the cross-sections of ttW production at 13 TeV with the ATLAS detector

Chenliang WANG

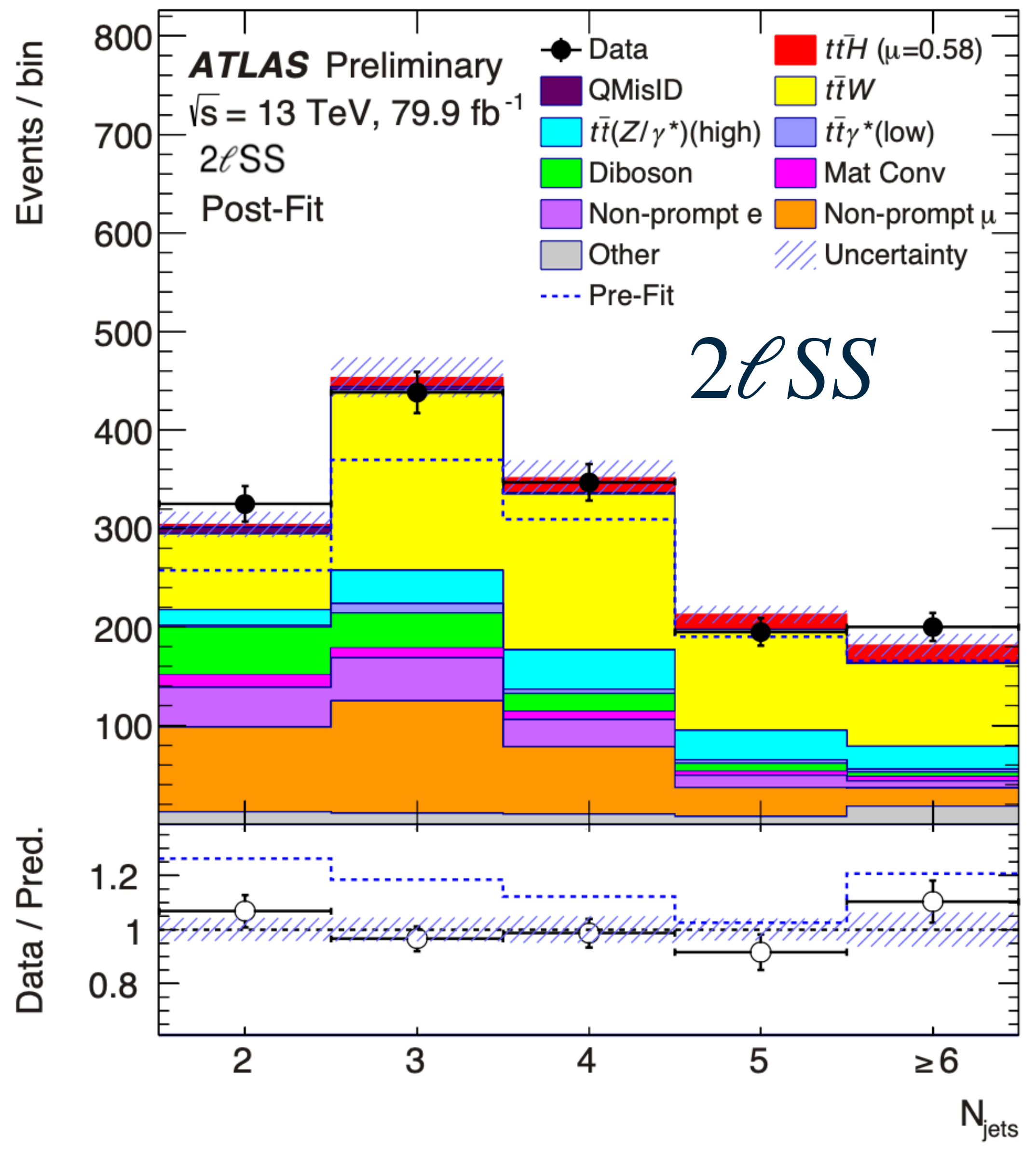
2022, November 24 @ CLHCP

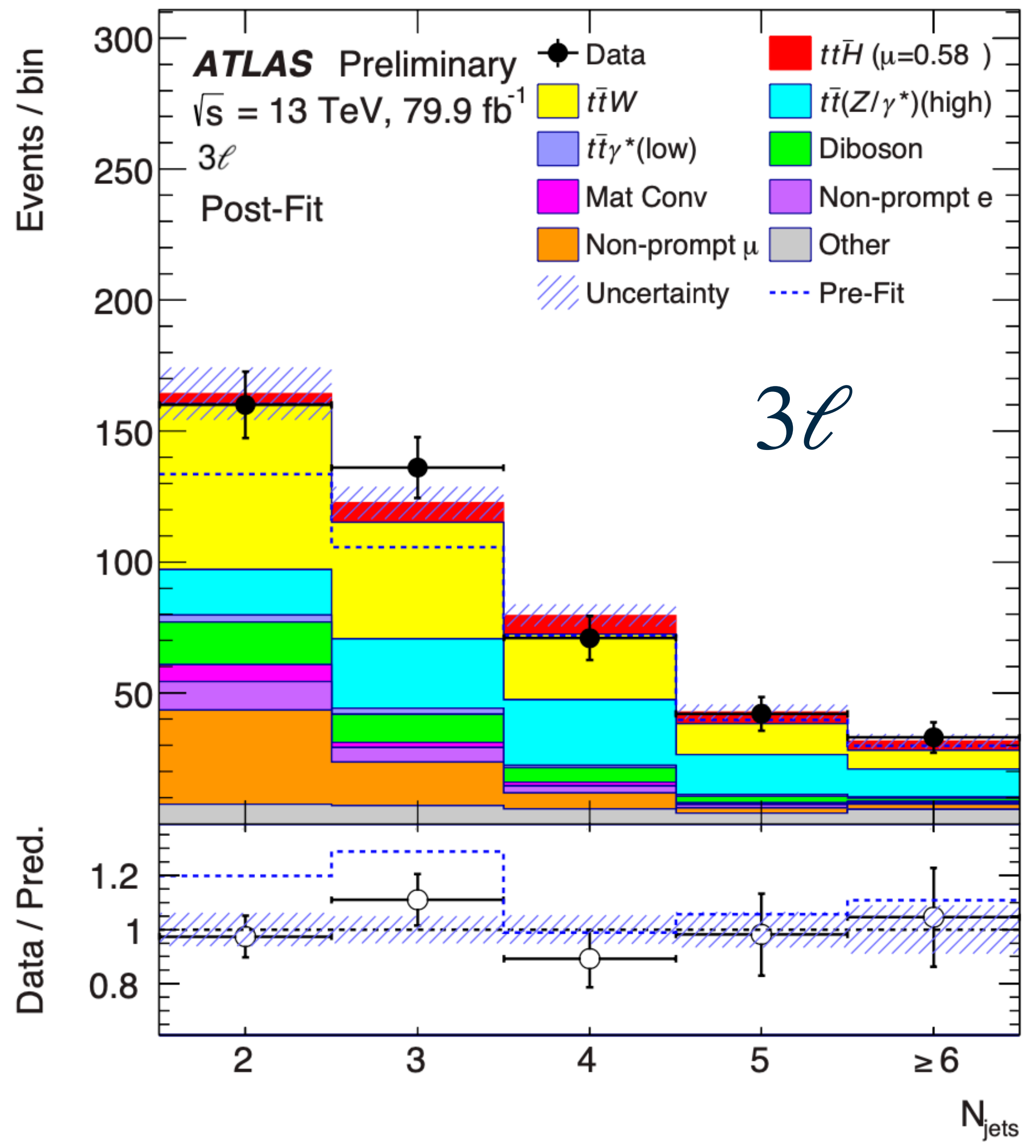
上海交通大學
SHANGHAI JIAO TONG UNIVERSITY

ATLAS EXPERIMENT
"YOU ARE WELCOME HERE!"

# Motivation

- ttW process is the dominant background in many measurements with MultiLepton final states.
- Significant mis-modelling observed 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 **ttH-ML CMS** analysis
- A two-step analysis strategy was decided for the **full Run 2 ttH-ML analysis:**
    - The first step is to **measure inclusive and differential cross-sections of ttW production in $2\ell SS$ and $3\ell$ channels**
    - Following on ttW measurements, measure the **cross-section of ttH production**

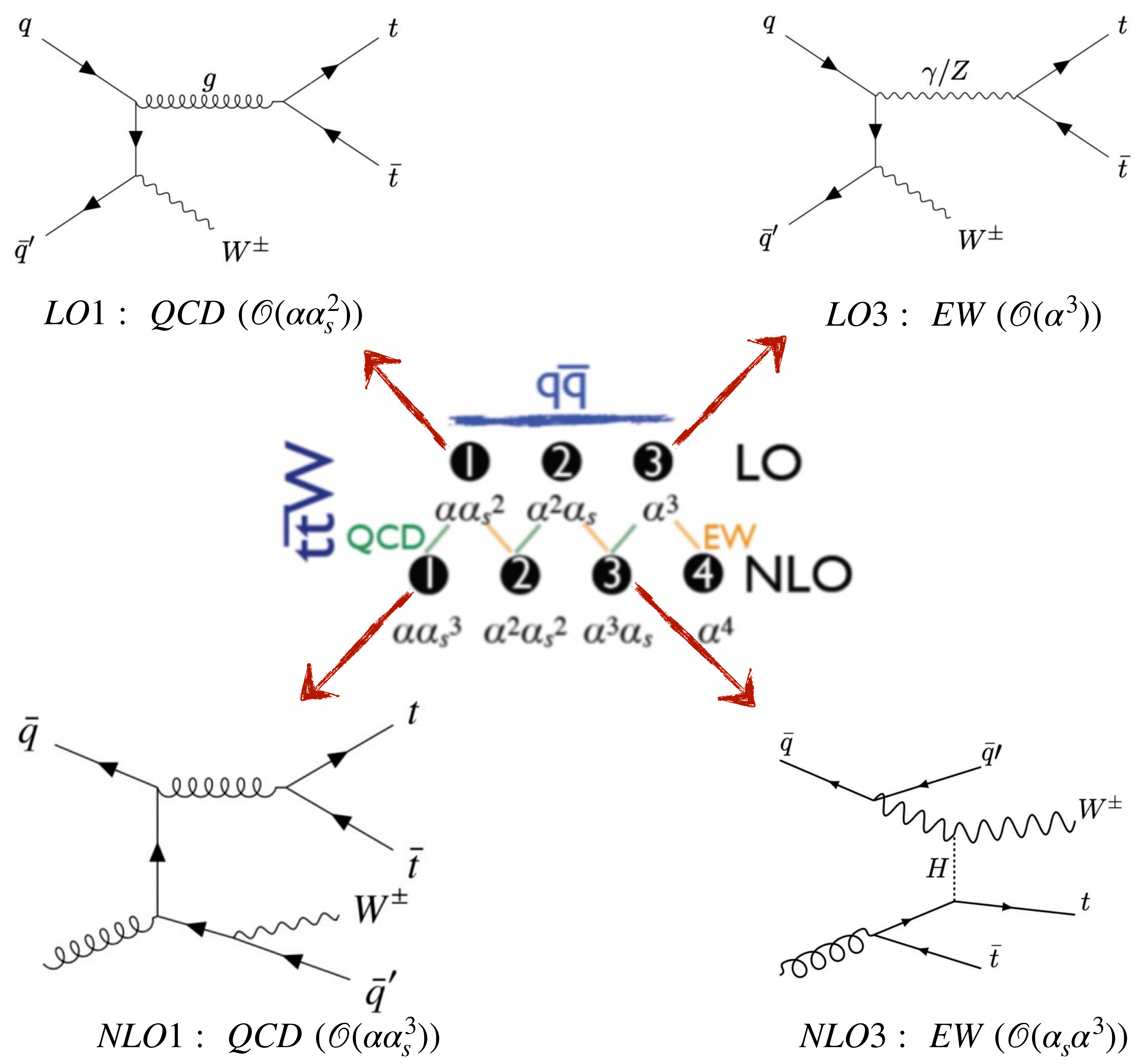



ATLAS-CONF-2019-045

# Signal Modeling

- Nominal ttW MC sample is Sherpa 2.2.10
  - **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)
- Alternative ttW samples used for uncertainties
  - **MG5_aMC@NLO FxFx:** account for Matrix Element (**ME**) and Parton Shower (**PS**) uncertainty
  - **Powheg+Pythia8/Herwig7:** give **additional PS** uncertainty as the difference
  - Separated to QCD and EW, normalized to Sherpa cross-sections



# Object and event selection

## Pre-Selection

- Applying lowest $p_T$ un-prescaled 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 JVT, pT>25 GeV
  - Tag b-jets with DL1r tagger

## Overlap removal

- e/μ: if $\Delta R(e, \mu) < 0.01$,
  remove μ if calo-tagged, else remove e
- e/j: if $\Delta R(\text{jet}, e) < 0.2$,
  remove jet if not b-tagged
- μ/j: if $\Delta R(\text{jet}, \mu) < 0.4$,
  remove jet if not b-tagged, < 3 tracks

## Event Selection ($2\ell SS$ and $3\ell$)

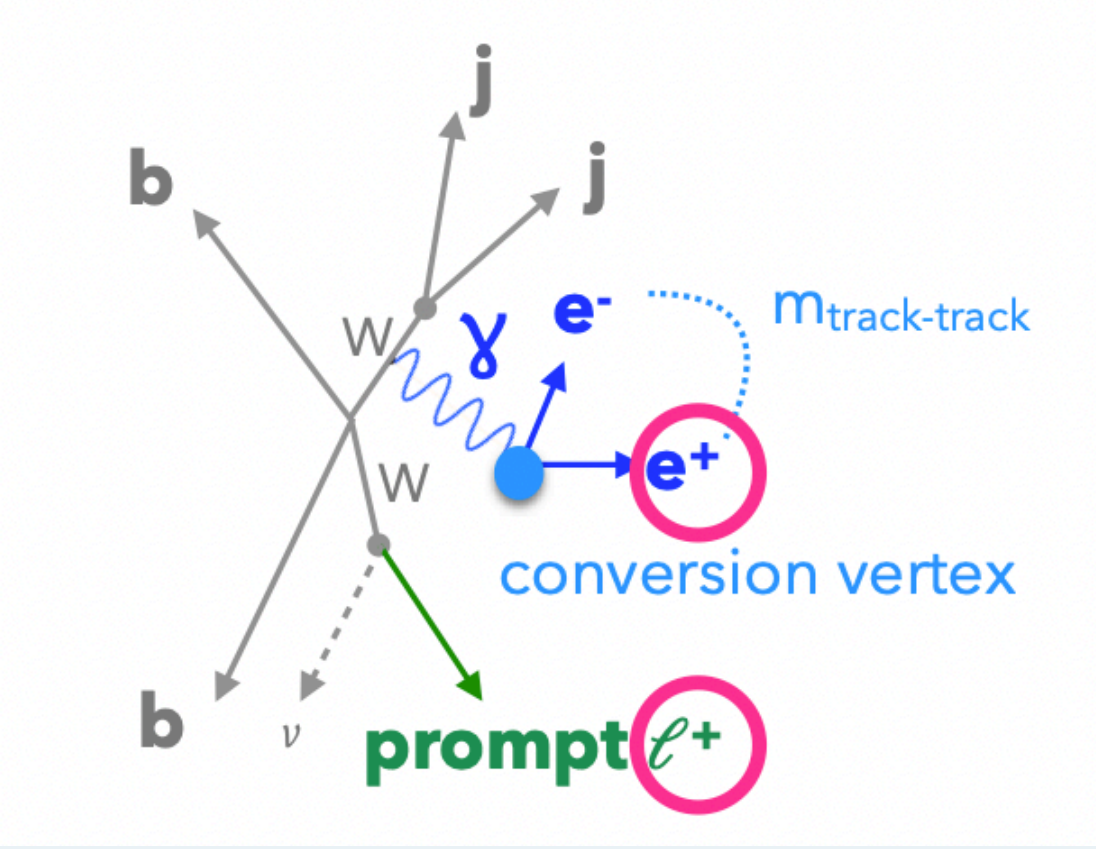
- Njet≥2, Nb-jet≥1
  - ≥ 1b (hybrid WP, =1b @ 60% or ≥ 2 @ 77%)
- $M_{\ell\ell}$>12 GeV in $2\ell SS$
- $M_{\ell\ell}$>12 GeV, $|M_{\ell\ell} - M_Z| > 10$ GeV (SFOS),$|M_{3\ell} - M_Z|$ > 10 GeV, in $3\ell$

# Background Estimation

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

- **Charge mis-identification (Q-MisID)**
  - Wrongly associate a track to an electron or measure the electron track-curvature
  - Estimated through a Data-Driven approach in the $2\ell SS$ channel
  - Suppressed with an MVA method

- **Internal and Material Conversion (CO)**
  - Suppressed with track invariant masses and conversion radius cuts

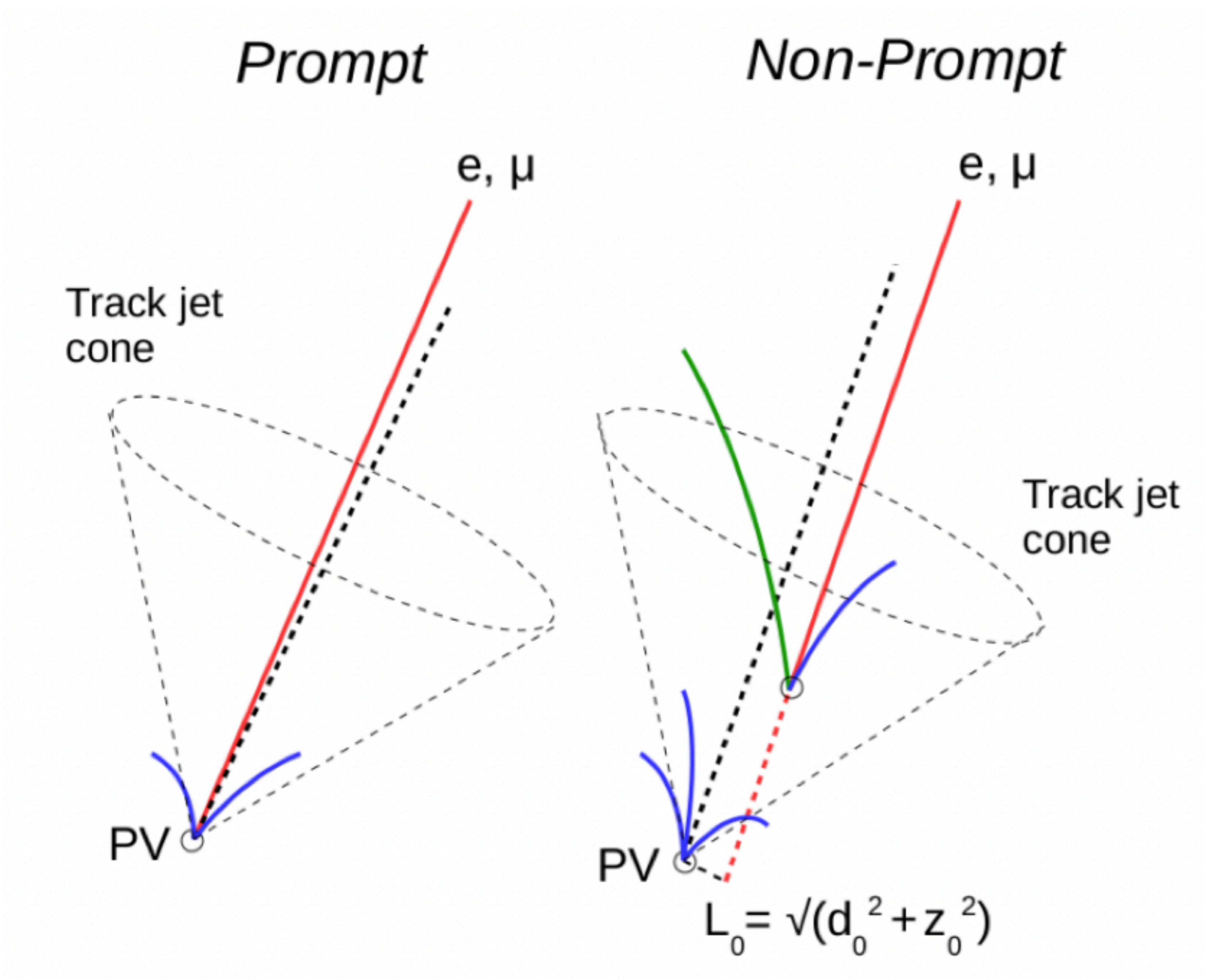


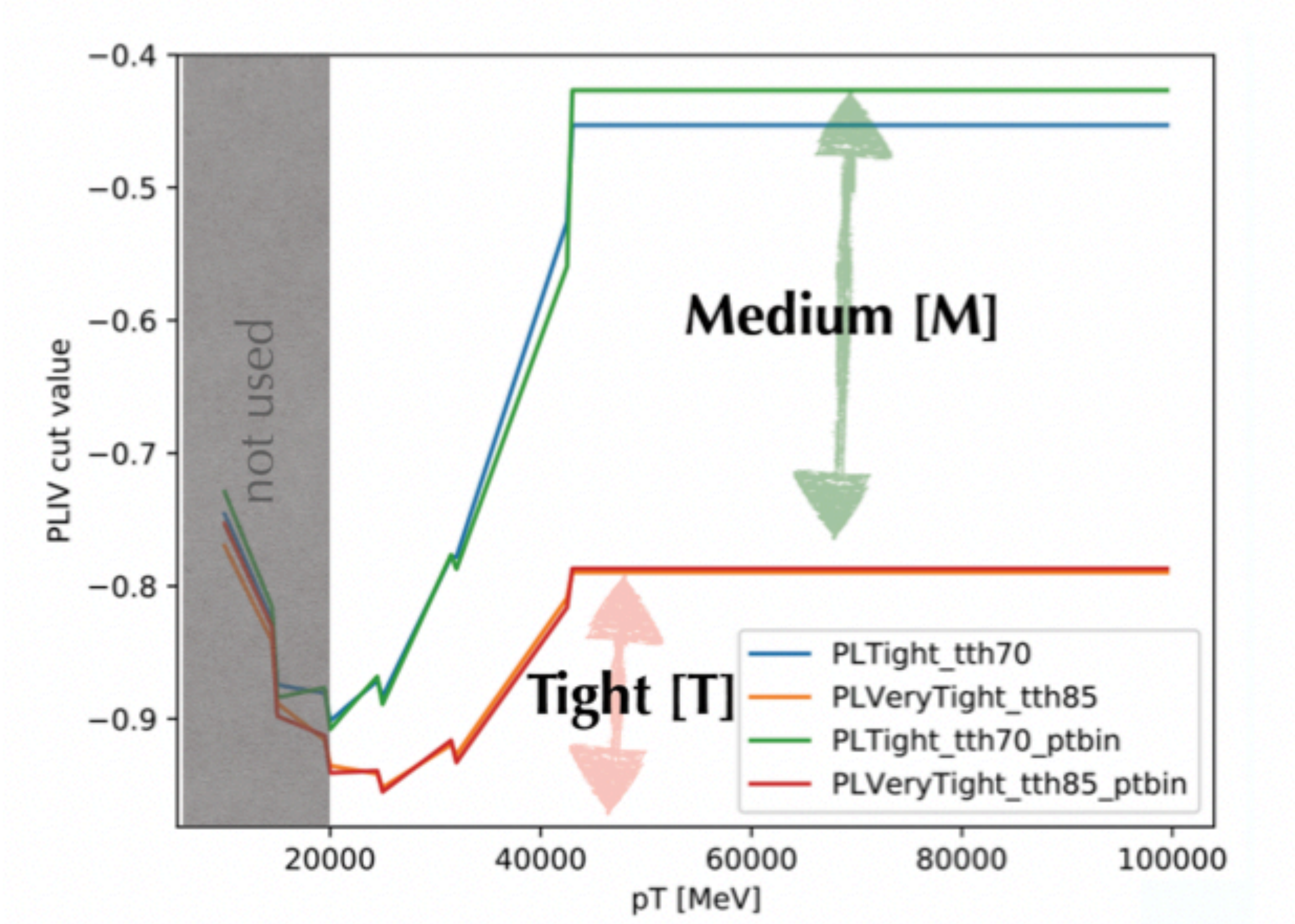

| electron CO selection | CO radius | $m_{track\text{-}track}$ |
|---|---|---|
| γ (1) material CO | > 20 mm | < 100 MeV (wrt. CV) |
| γ* (2) internal CO | not (1) | < 100 MeV (wrt. PV) |
| (3) very tight | not (1) and not (2) | |

*(beam pipe @ 24 mm)*

# Background Estimation

- **Reducible background:**
  - **Non-prompt leptons from Heavy Flavor (HF) decay**
    - Rejected with Multivariate lepton isolation, called **PromptLeptonImprovedVeto** (**PLIV**) tagger
    - Defined lepton pT- dependent working points (WPs): **VeryTight** and **Tight**



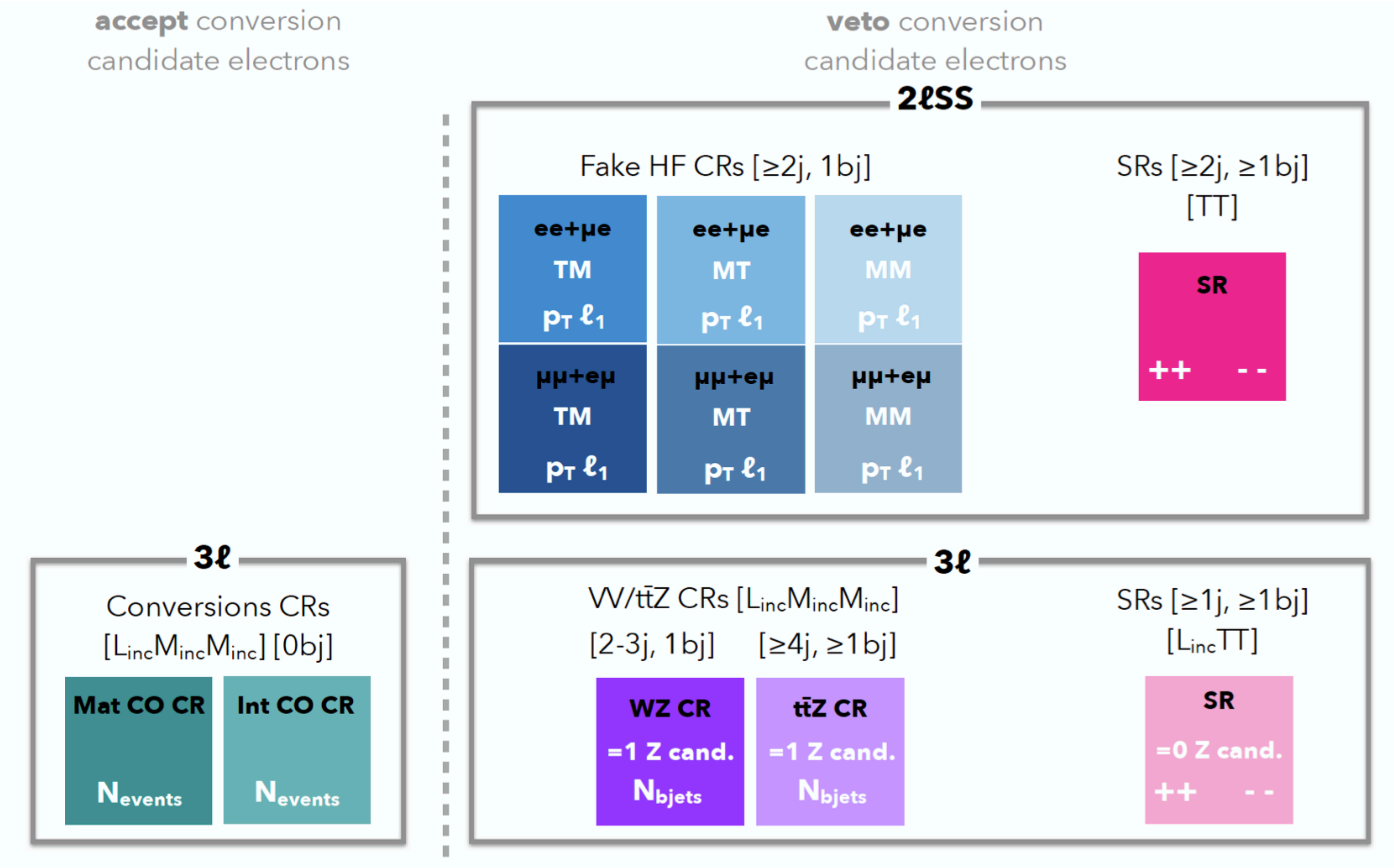

- **Use custom PLIV WPs to build CRs enriched in non-prompt HF leptons and to enhance ttW**
  - Tight [T]: VeryTight PLIV WP
  - Medium [Mexcl]: Tight-not-VeryTight PLIV WP

# 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 custom PLIV WPs to define CR

- **6 fit normalisation factors:** HFe + HFu + internalCO + materialCO + VV + $t\bar{t}Z$

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

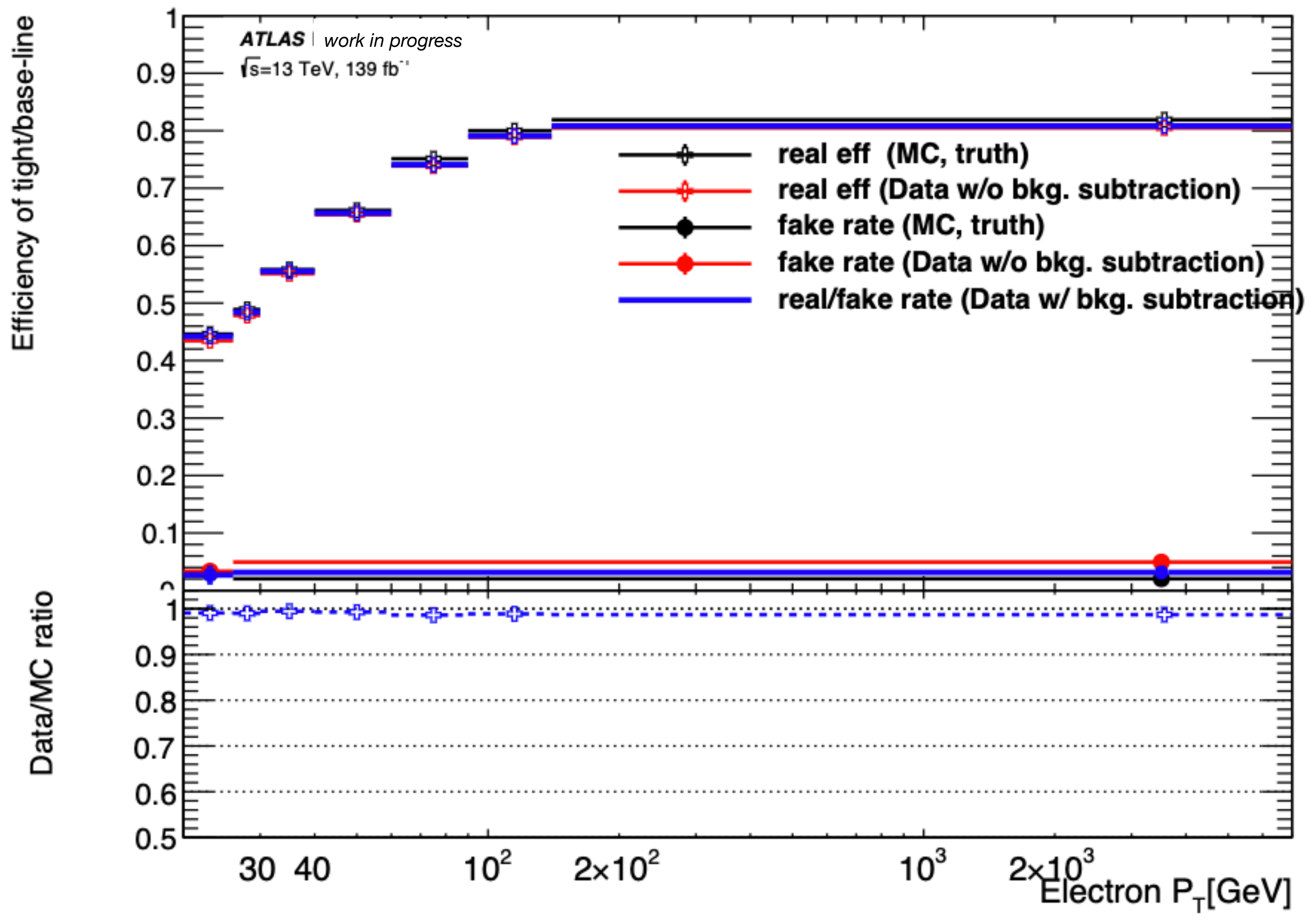


# Fake Estimation (Alternative): Matrix Method

- Estimate the non-prompt lepton background 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:
- Apply the efficiencies in the SR to calculate the total number of fake events (where at least one of the leptons is fake)

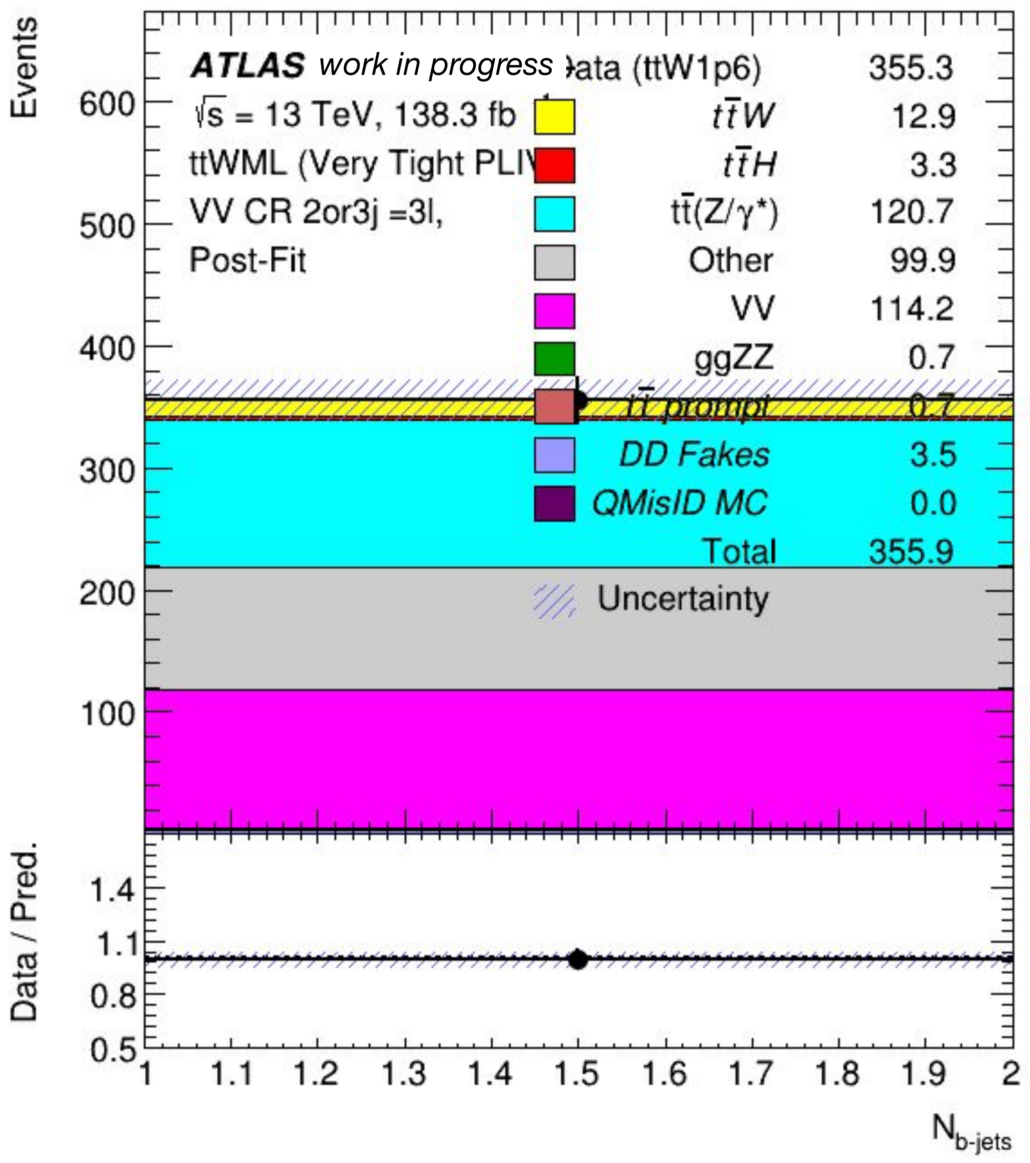
$$\begin{pmatrix} N^{TT} \\ N^{T\bar{T}} \\ N^{\bar{T}T} \\ N^{\bar{T}\bar{T}} \end{pmatrix} = \begin{pmatrix} \epsilon_{r,1}\epsilon_{r,2} & \epsilon_{r,1}\epsilon_{f,2} & \epsilon_{f,1}\epsilon_{r,2} & \epsilon_{f,1}\epsilon_{f,2} \\ \epsilon_{r,1}\bar{\epsilon}_{r,2} & \epsilon_{r,1}\bar{\epsilon}_{f,2}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

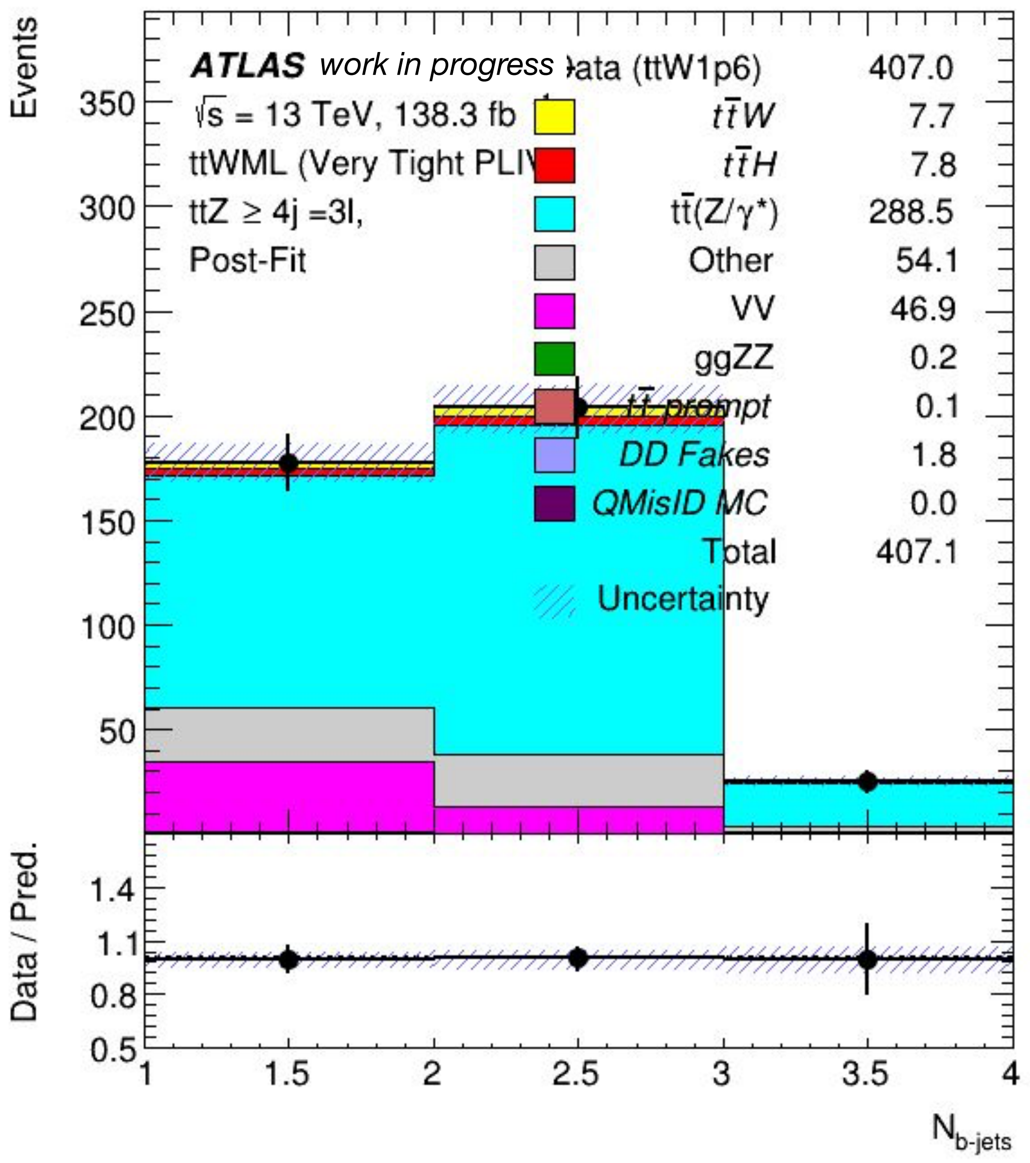
$$N^{f}_{TT} = N^{rf}_{TT} + N^{fr}_{TT} + N^{ff}_{TT} = \epsilon_{r,1}\epsilon_{f,2}N^{rf} + \epsilon_{r,2}\epsilon_{f,1}N^{fr} + \epsilon_{f,1}\epsilon_{f,2}N^{ff}$$



# Matrix Method:

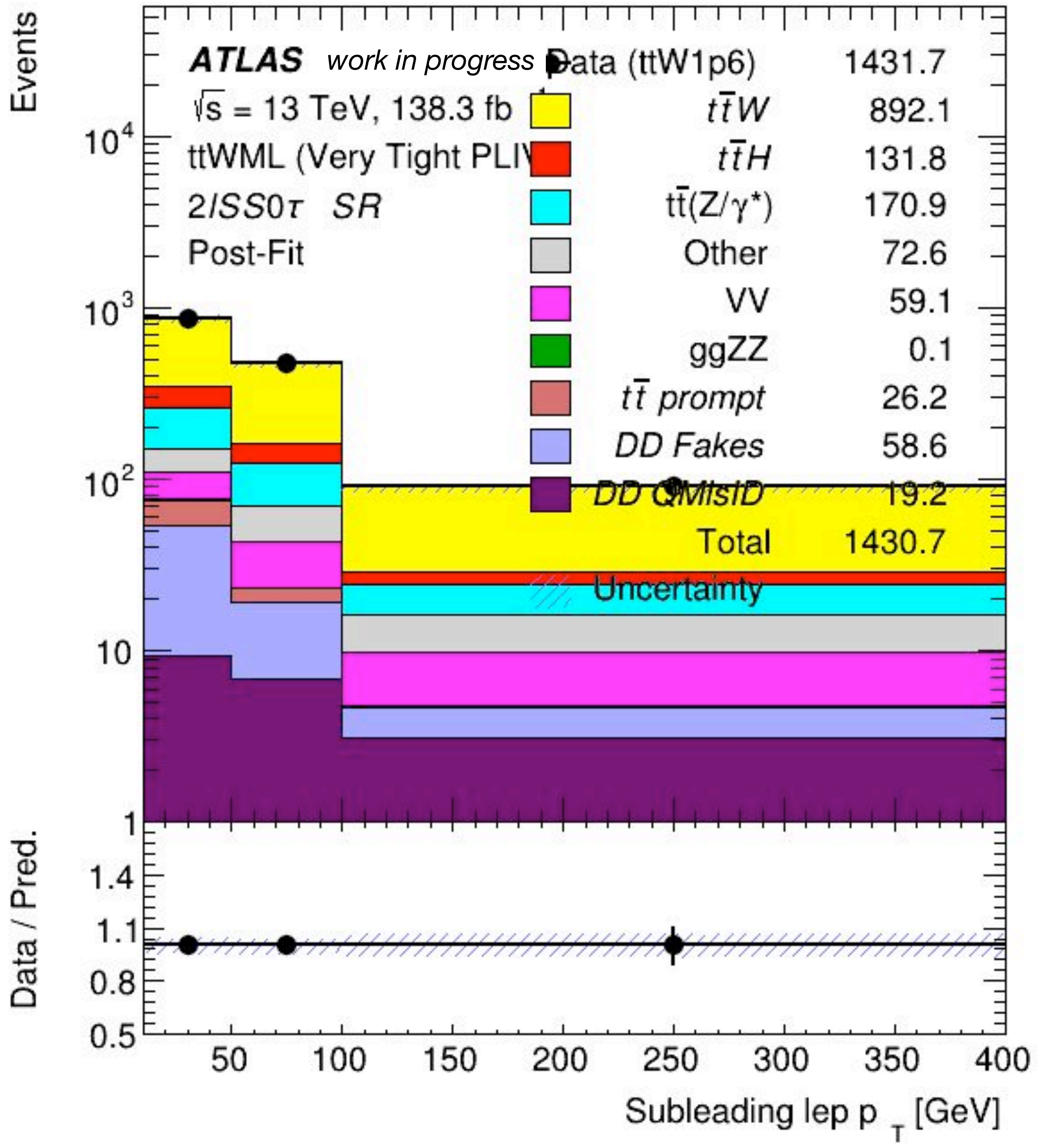
- Defined 5 regions for fit test, injected $\mu_{ttW} = 1.7$:
  - 2lSS: subleading lepton Pt in CR and SR,
  - 3l: 3rd leading lepton Pt SR,  VV CR and ttZ CR

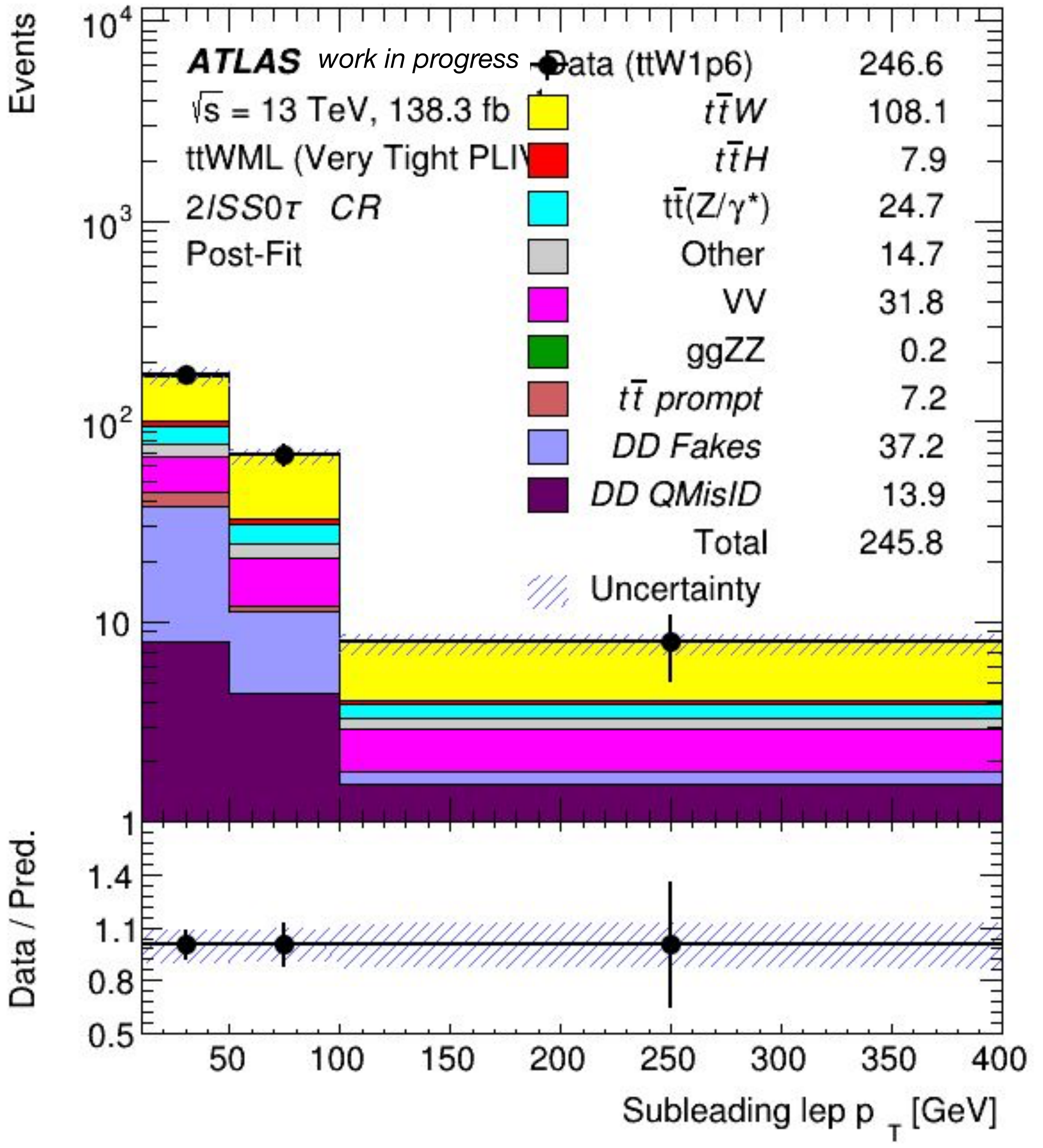


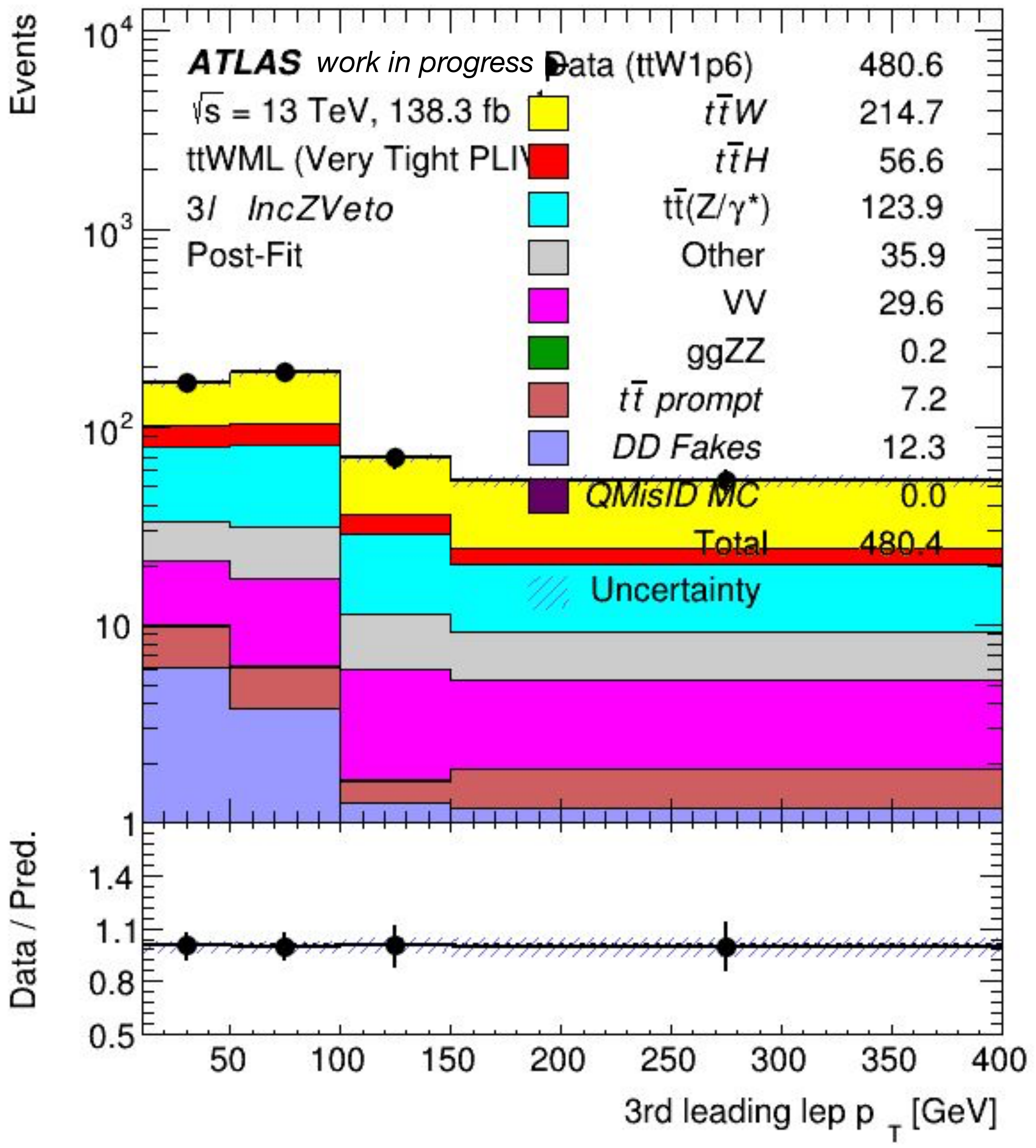




$3\ell$, $N_{b-jets}$ / $P_{T,subleading\ lep}$

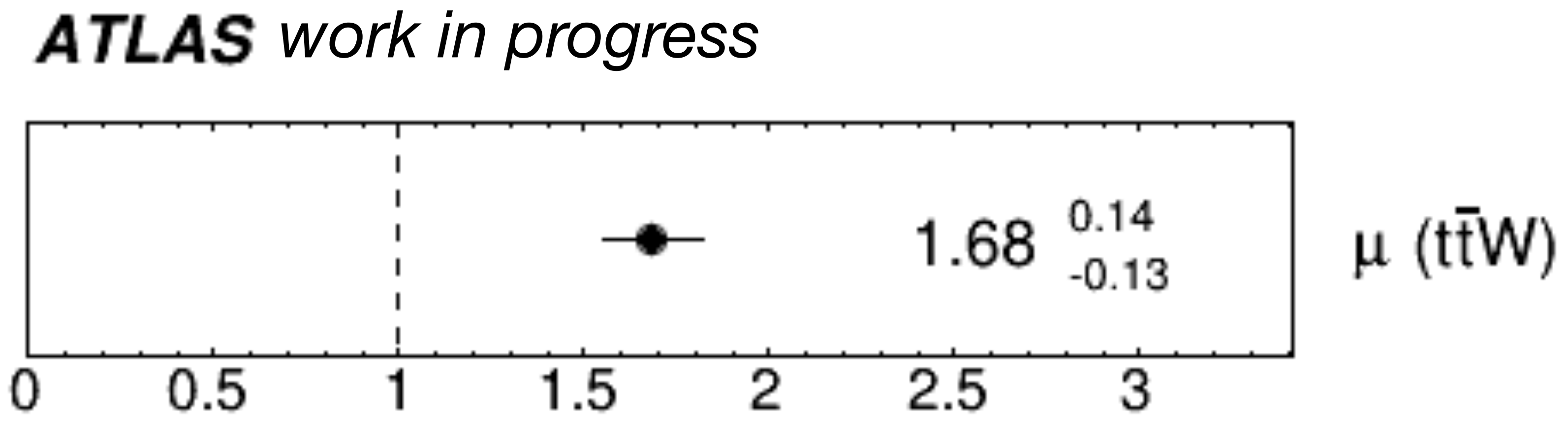
$2\ell SS$, $P_{T,subleading\ lep}$

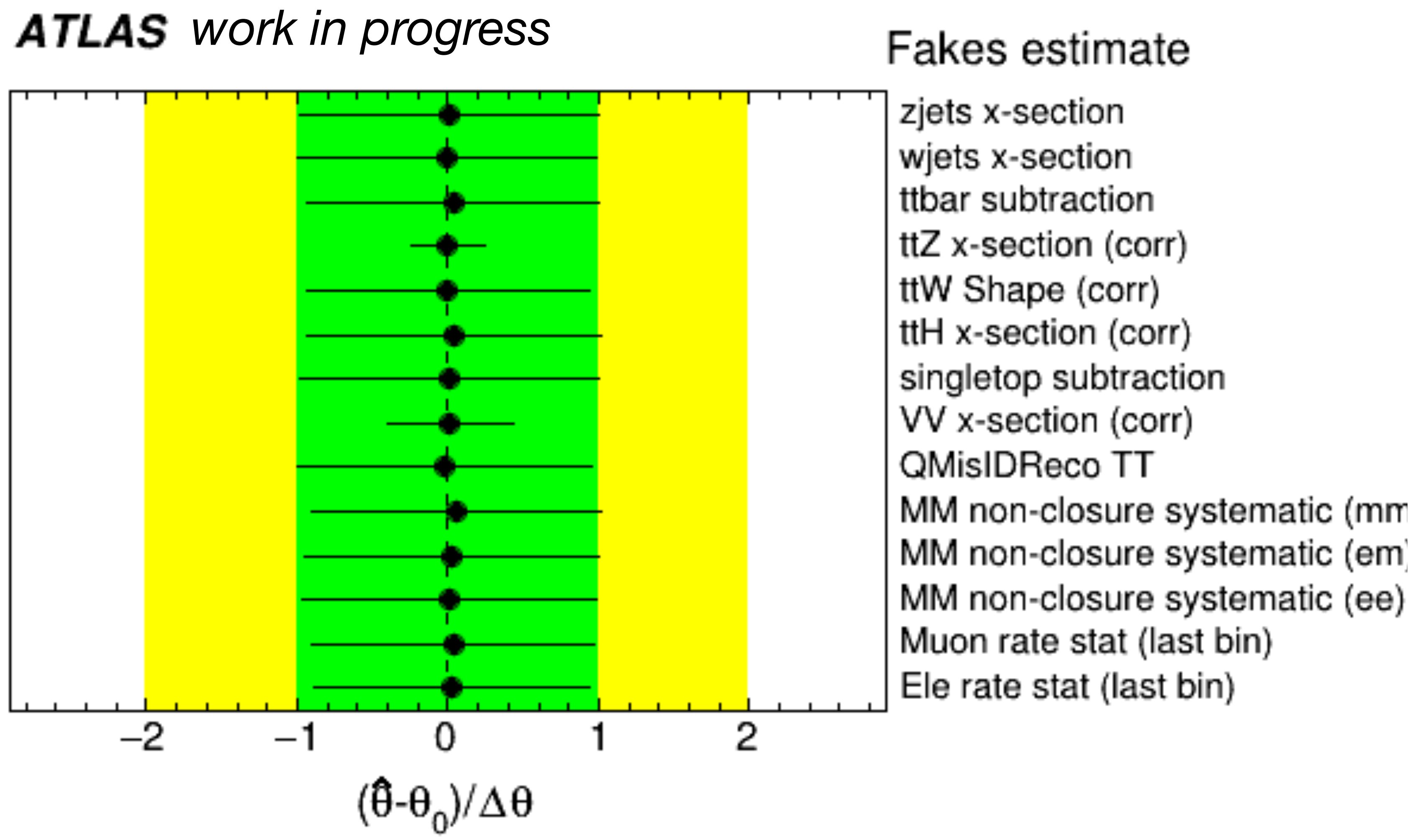


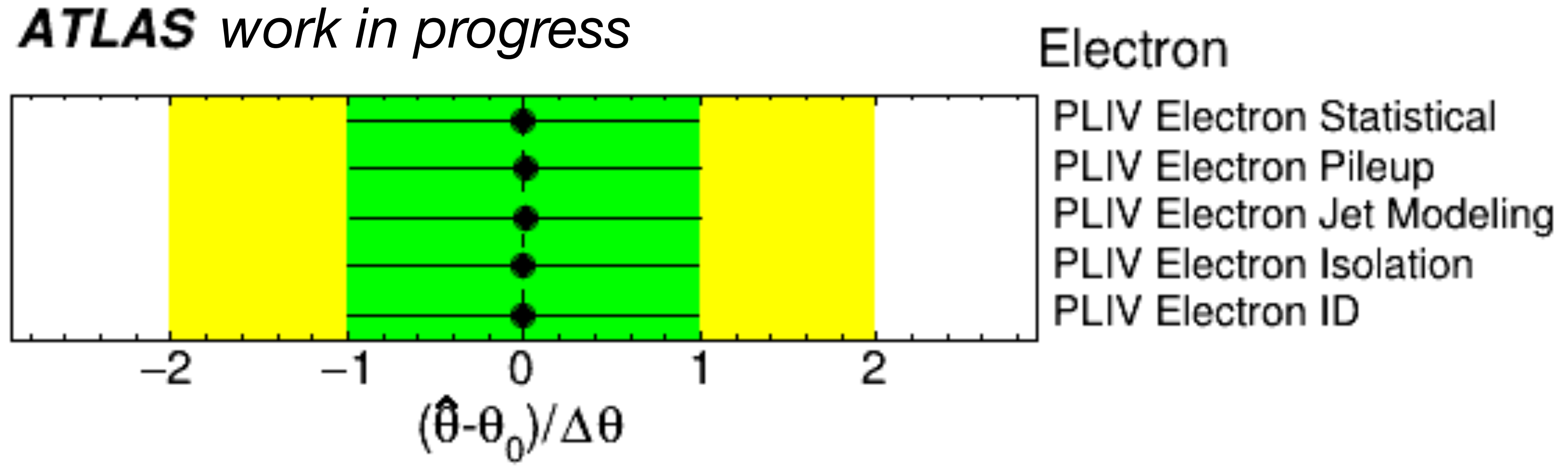



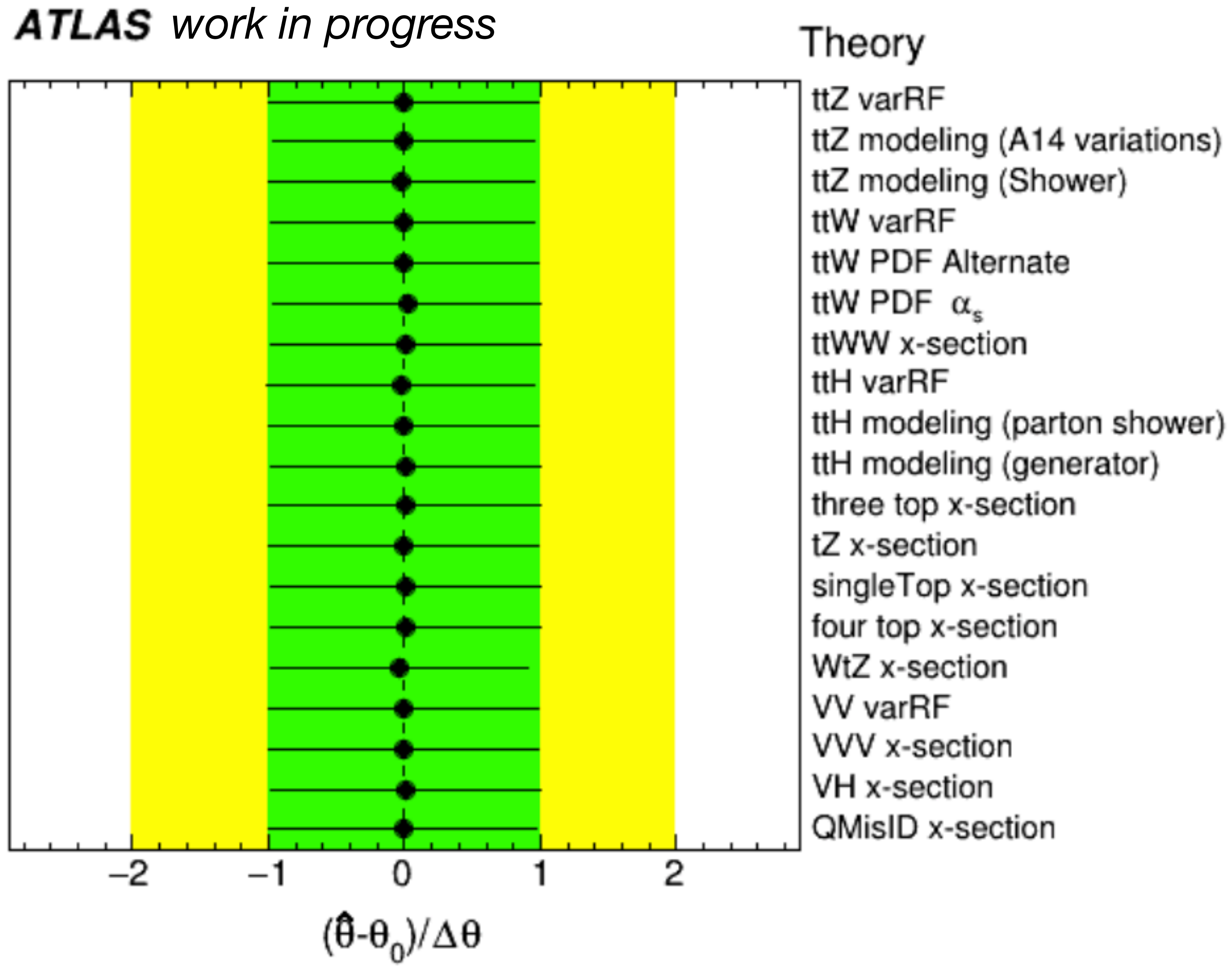



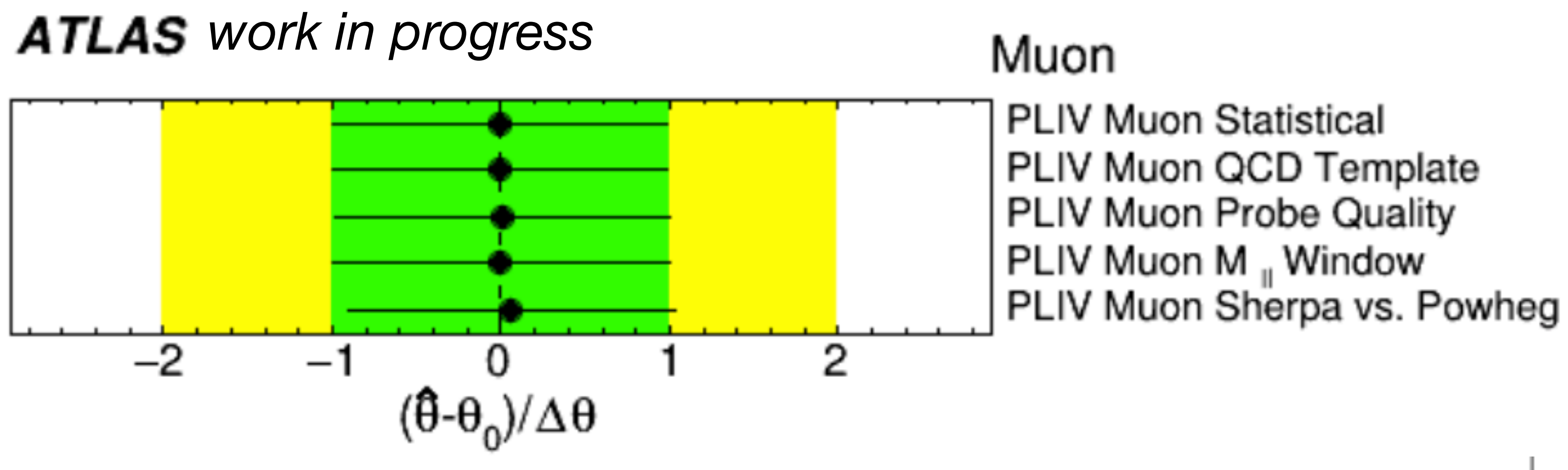
# Fake Estimation (Alternative): Matrix Method

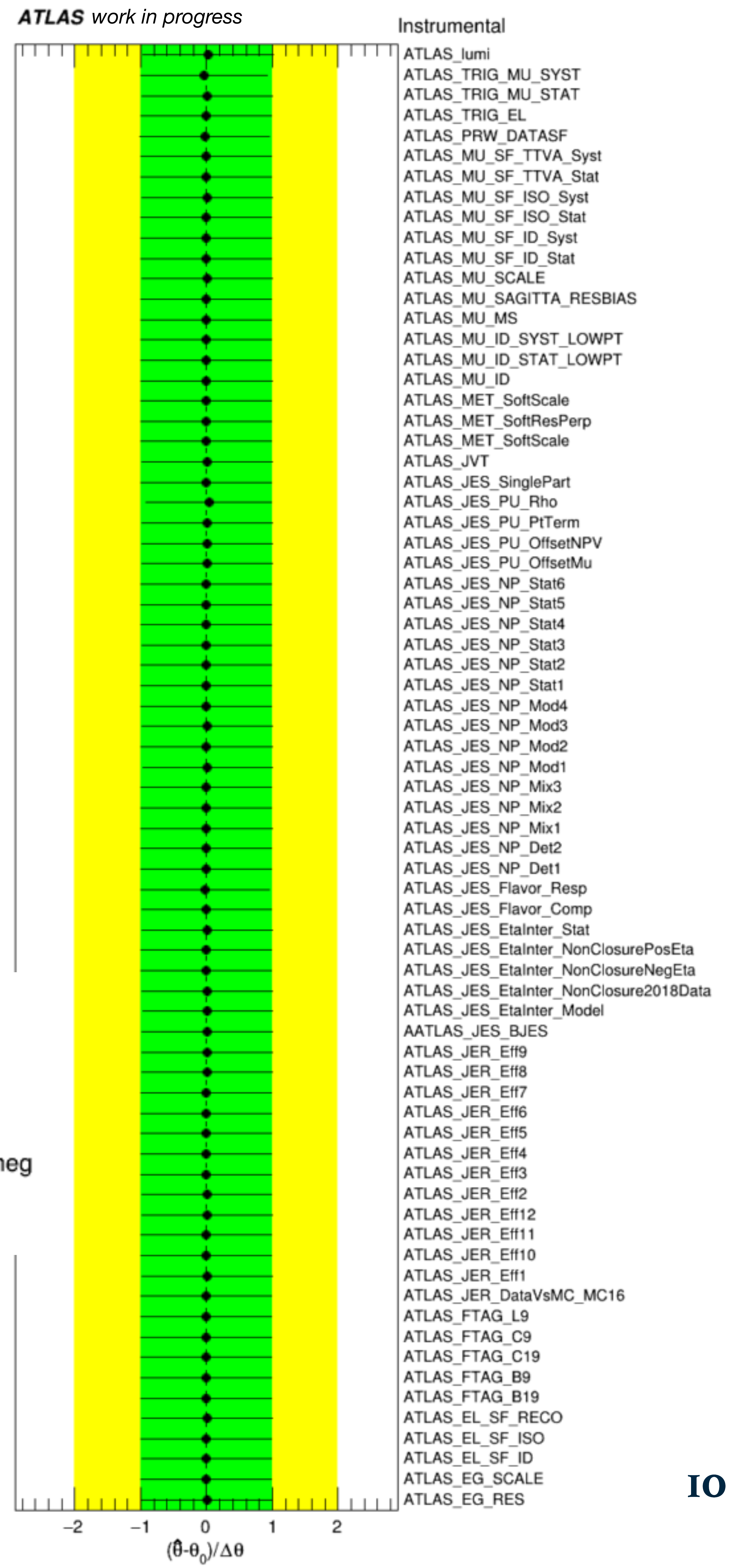


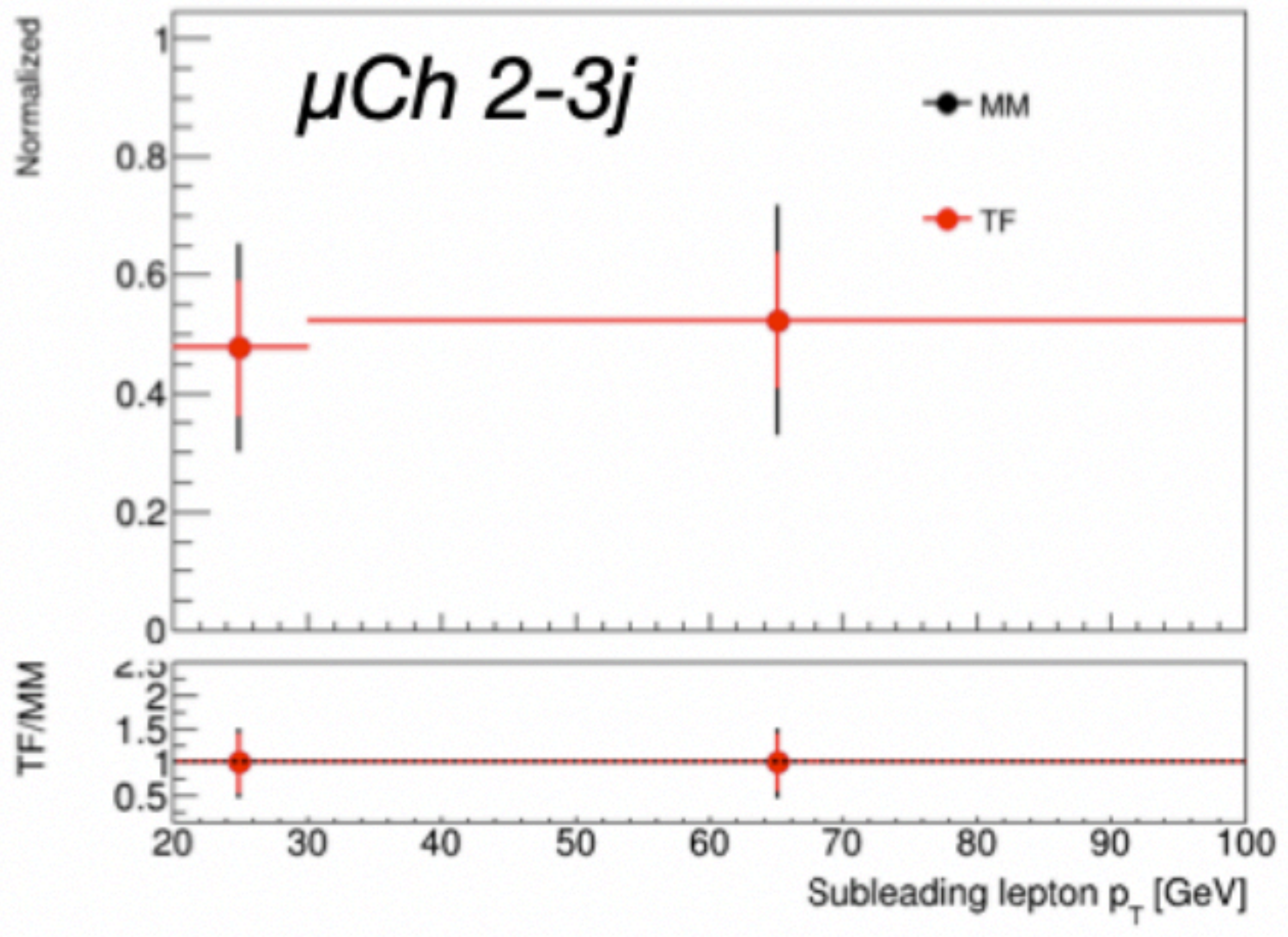



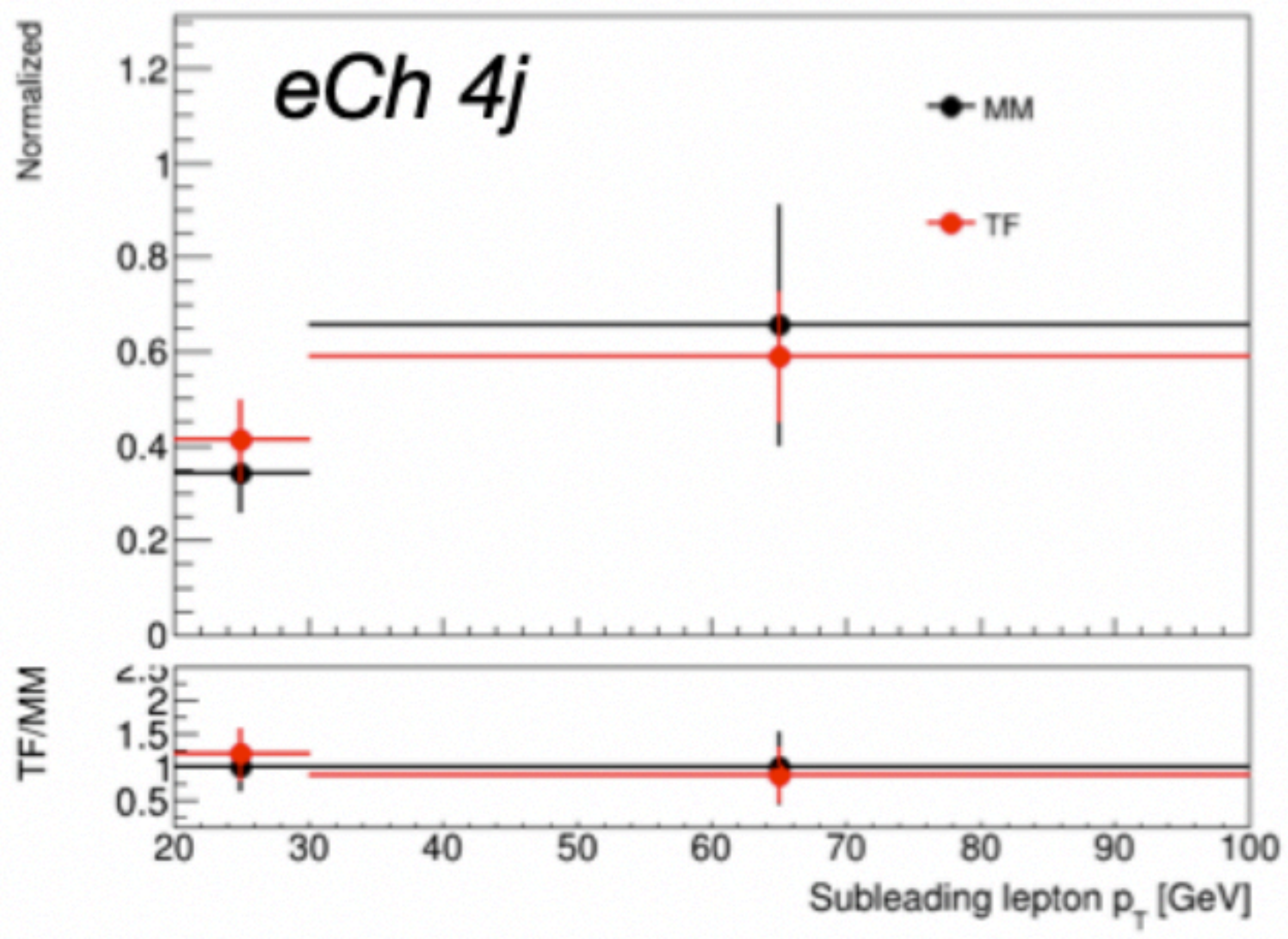




- ttZ Xsec and VV Xsec are constrained.
- No significant pull is observed.

# Fake Estimation Comparison: TF vs MM

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



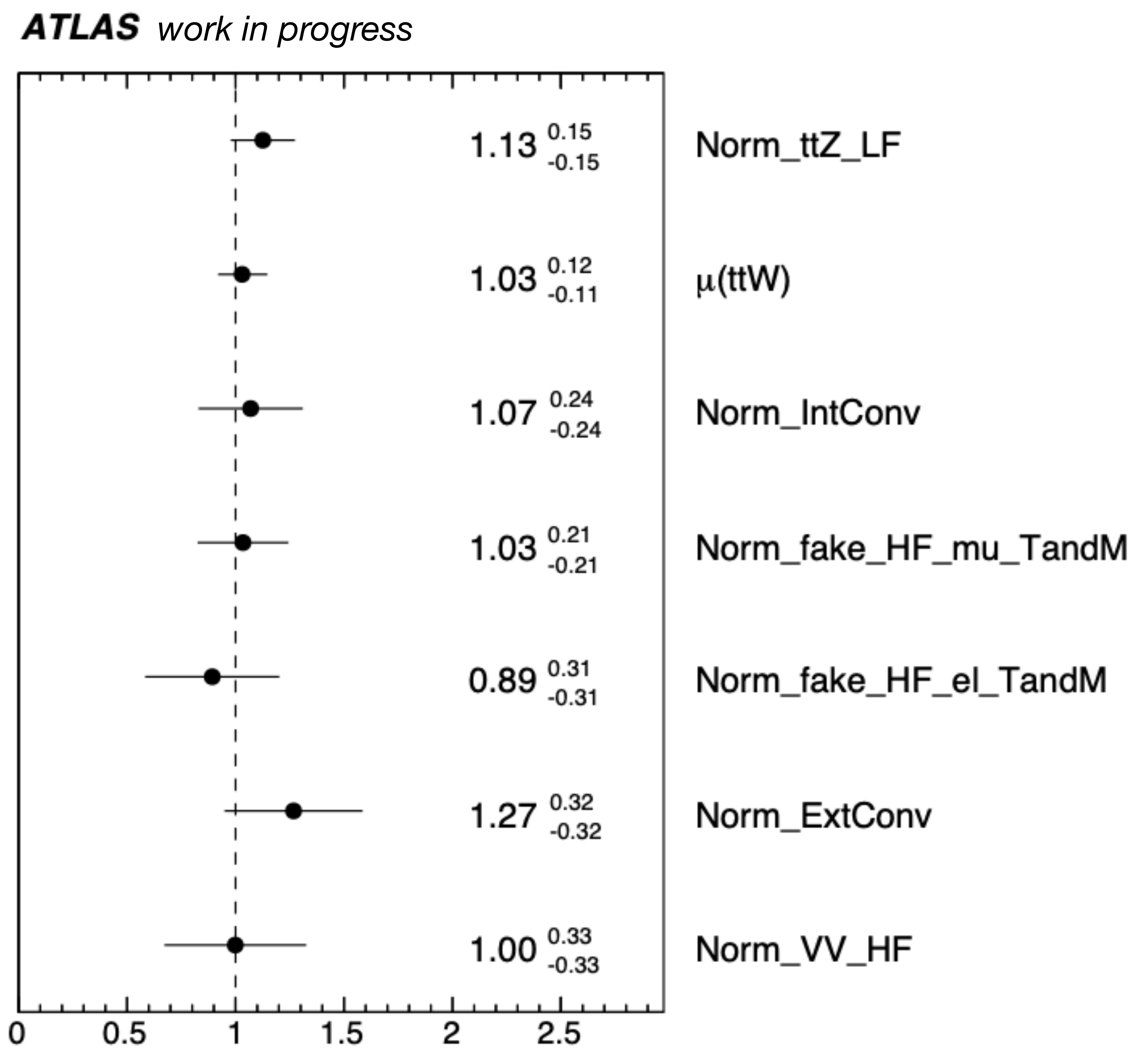

- MM seems to be predicting a higher estimate than the TF (1.6 to 2 times higher)

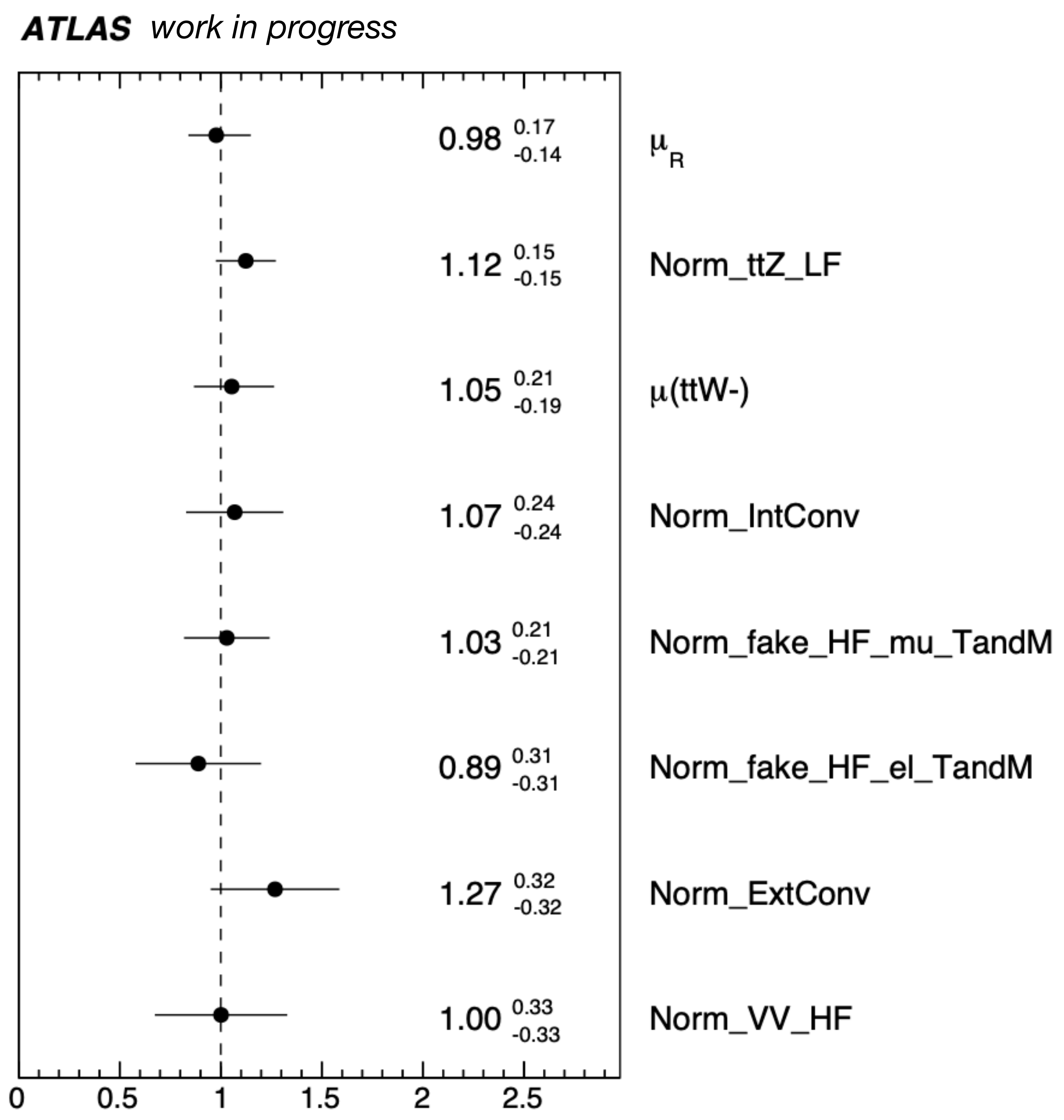
# Inclusive Fit studies

- Measures both inclusive and differential cross-sections based on the template fit method
- Inclusive and fiducial cross section measurements:
  - Inclusive fit: hybrid fit, Asimov data in SR and real data in CR
  - Charge ratio fit: $R_+ = \frac{\sigma_{ttW-}}{\sigma_{ttW+}}$, $R_- = \frac{\sigma_{ttW+}}{\sigma_{ttW-}}$
  - Fiducial fit uses the same fiducial phase space in the differential fit
- Granted approval for unblinding, reviewing the fit results with data!

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

# Conclusion

- The ttW analysis has been significantly developed with the full Run 2 dataset
  - Estimated the challenging fake lepton background
  - Measured the inclusive and differential cross-sections
  - Reviewing the unblinded results.
  - Planning the publication end of this year.
- In the meantime, measurement of the cross-section of ttH production began this spring.

Thank you for your attention!

# Backup