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Background estimate for a $t\bar{t}W$ Cross-Section Measurement

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GEFÖRDERT VOM

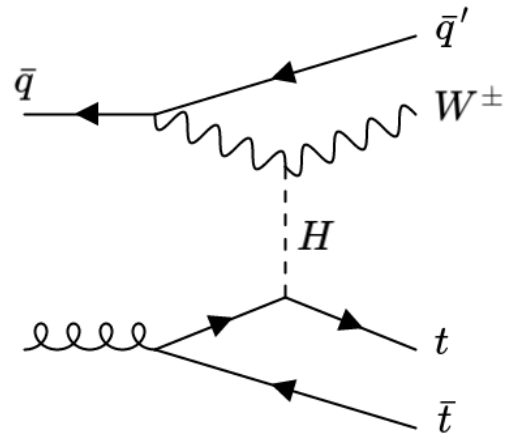
Bundesministerium
für Bildung
und Forschung

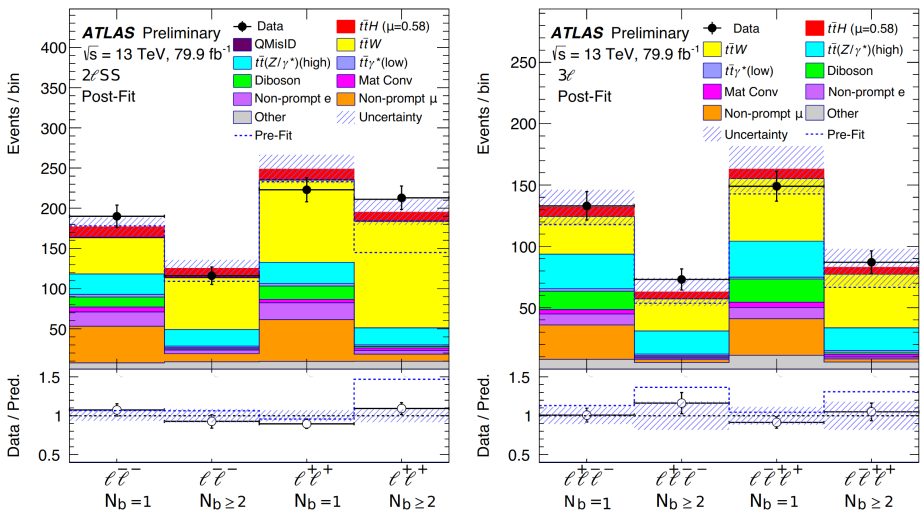
BMBF-ErUM-Forschungsschwerpunkt
ATLAS-EXPERIMENT
Ausbau von ATLAS am LHC: Physik mit dem ATLAS-Experiment

ErUM-FSP T02
ATLAS

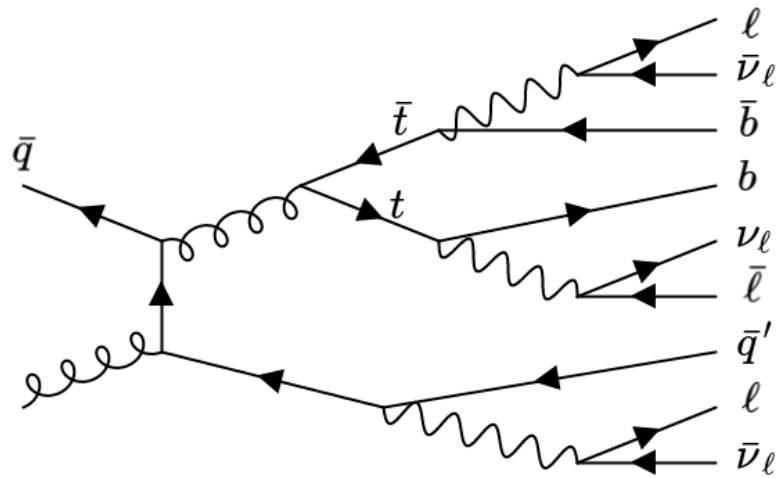
The $t\bar{t}W$ Measurement

- Measure differential $t\bar{t}W$ cross-section in multi-lepton (ML) final state with full Run-II dataset
- Process needs to be better understood
- Difficult to model due to higher order electroweak corrections
- Important background for $t\bar{t}H$, where large excess has been found (also in 4-tops)



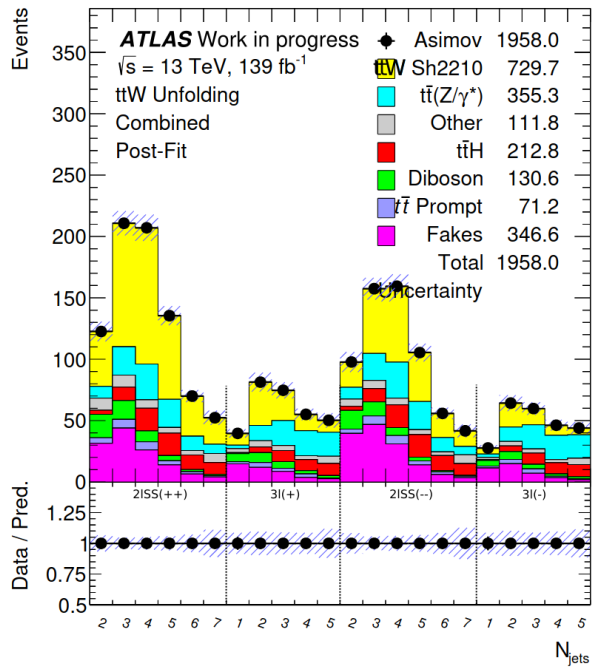


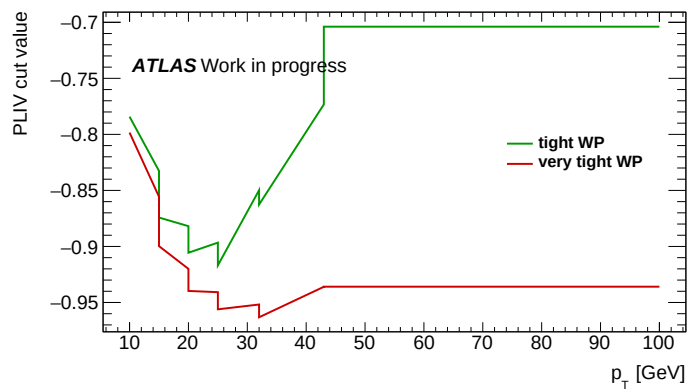
From ATLAS-CONF-2019-045



Motivation

- Difficult to measure experimentally
- Fake background is significant for $t\bar{t}W$ and the follow-up $t\bar{t}H$ analysis
- Use a prompt lepton veto (PLV), to distinguish between prompt and non-prompt leptons
- Tags prompt leptons (next slide)
- PLV has been used in previous $t\bar{t}H$ analysis to select leptons
- An improved version of the prompt lepton veto (PLIV) is available
- Used for background estimation by template fit
- Other significant backgrounds: $t\bar{t}Z$, diboson





Prompt Lepton Veto (PLV)

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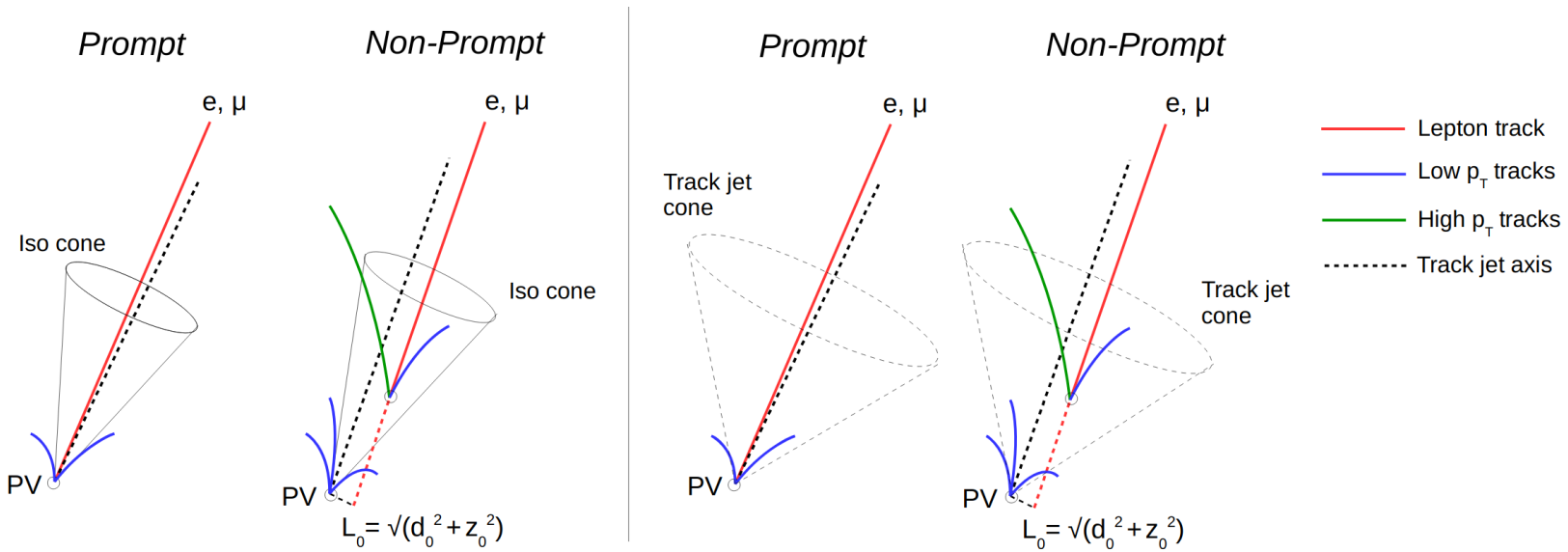
- Leptons from W or Z decays originate from the primary vertex (prompt)
- Non-prompt leptons are from b or c hadron decays
- Lifetimes of these hadrons can be detected
- Typically simple cuts on impact parameter and isolation
- PLV based on a boosted decision tree (BDT)
- Uses track jets matched to the lepton to determine lifetime



Prompt Lepton Improved Veto (PLIV)

- Developed for Run-II analyses
- Uses more powerful isolation variables
- New secondary vertex reconstruction algorithm
- Improved BDT algorithm
  - Separate training for barrel/end-cap electrons
  - Include p_T bin number for p_T dependent cuts
- Observed better performance (non-prompt rejection) than PLV, especially for muons and end-cap electrons
- BDT score is used to define WPs, i.e. tight and very tight
- Non-prompt lepton rejection increased up to a factor of 2

WPs @ $p_T = 32$ GeV	$\text{tight}_{\text{barrel}}$	$\text{tight}_{\text{endcap}}$	$\text{very tight}_{\text{barrel}}$	$\text{very tight}_{\text{endcap}}$
prompt efficiency	0.86	0.8	0.69	0.71
non-prompt efficiency	0.037	0.031	0.02	0.025

Template Fit Method I

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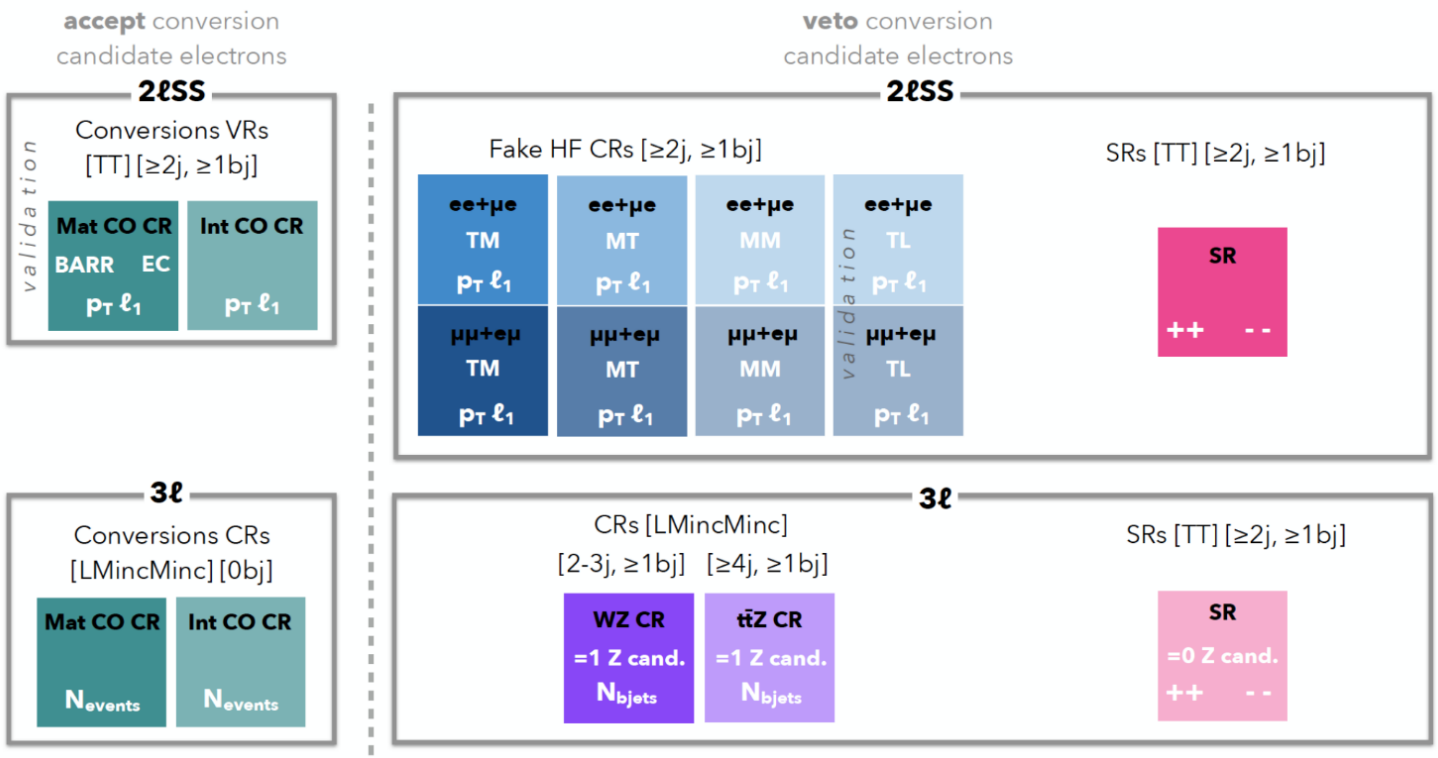
- Estimate fake lepton background using a template fit method
- Semi-data driven/relies on MC truth
- Flexible method to deal with multi-source fake background
- Similar approach has been used by the previous $t\bar{t}H$ analysis
- Here, an exclusive PLIV WP will be used to give a more precise fake estimate
- Uses free floating normalisation factors for
  - internal conversion ($\gamma* \rightarrow \ell^+\ell^-$, mostly electrons)
  - external conversion ($\gamma \rightarrow \ell^+\ell^-$, only in material, mostly electrons)
  - heavy flavour with non-prompt electron (mostly B decay)
  - heavy flavour with non-prompt muon (mostly B decay)

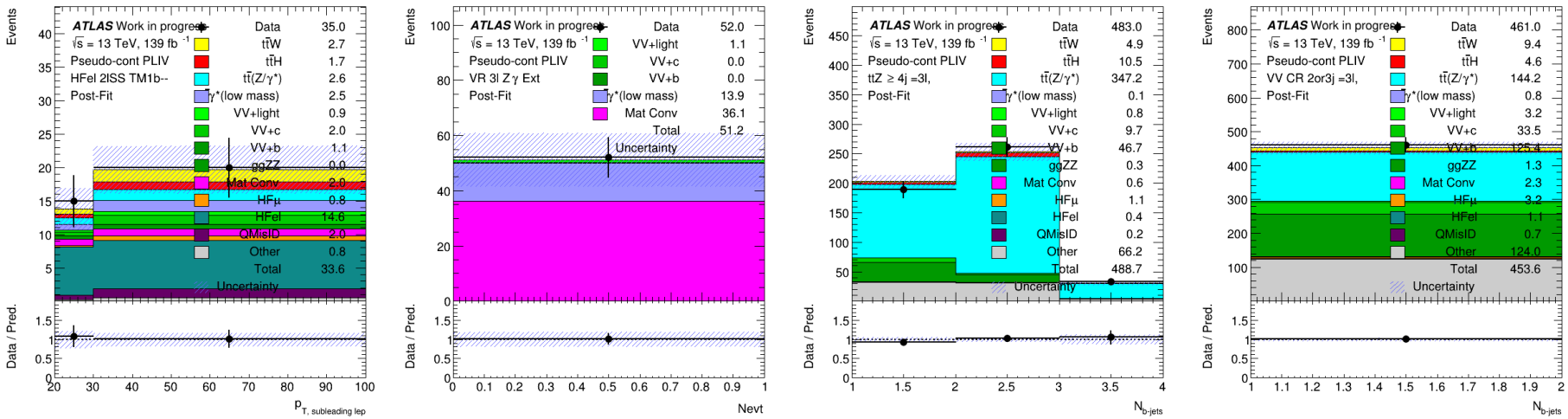
Template Fit Method II

- Analysis performed in 2ℓSS and 3ℓ channel
- The fit uses a total of 12 CRs; 8 in 2ℓSS and 4 in 3ℓ
- 8 regions enriched in non-prompt ℓ, 1 for each of internal conversion, material conversion, $t\bar{t}Z$, diboson
- Several validation regions to assess modelling
- Notation: Tight (T), Medium (M), Loose (L), inclusive (inc)



Template Fit - CRs

HF el **Mat Conv** $t\bar{t}Z$ **VV**



Plots from Tamara Vazquez Schroeder, Stergios Kazakos

- Data/MC agreement for four different CRs
- Preliminary, do not include PLIV SFs
- Good agreement observed

Efficiencies & Scale Factors (Electrons, 2018)

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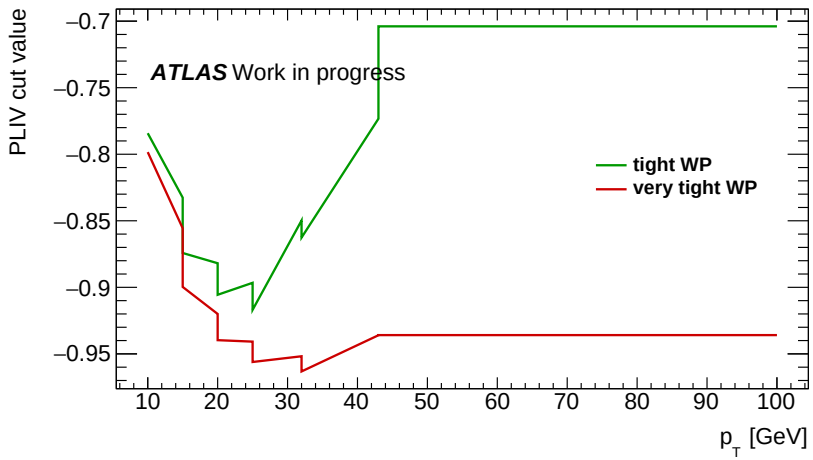
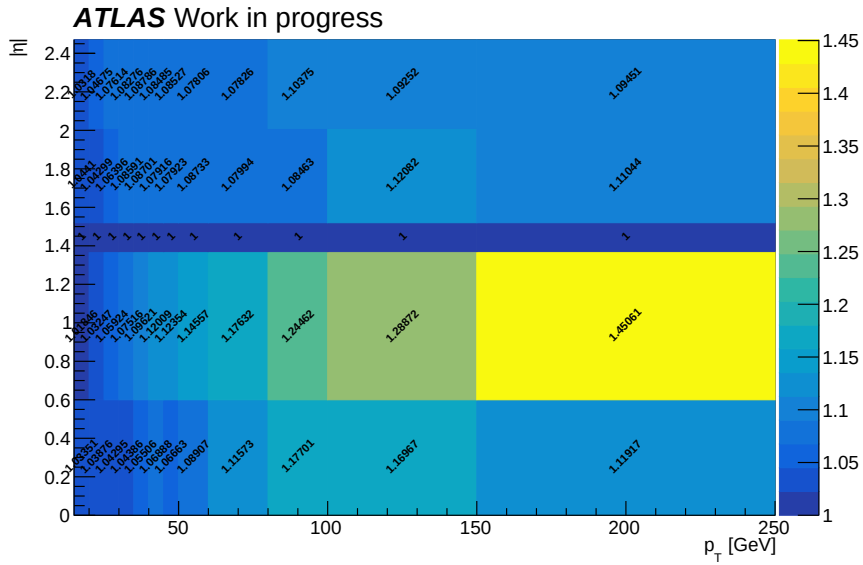
Calibration of PLIV WPs

example: tight not very tight

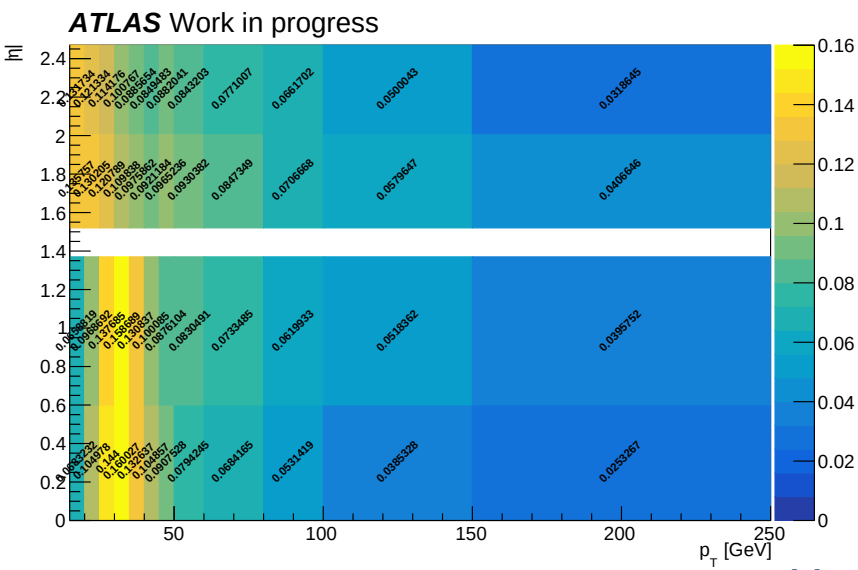
example: barrel electrons



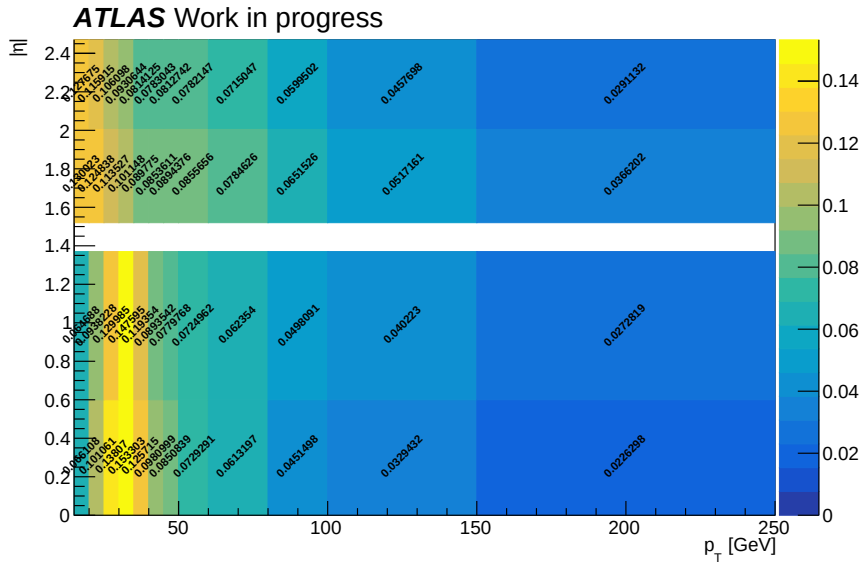
SF



Data Eff.



MC Eff.



Scale Factors (Electrons, 2018)

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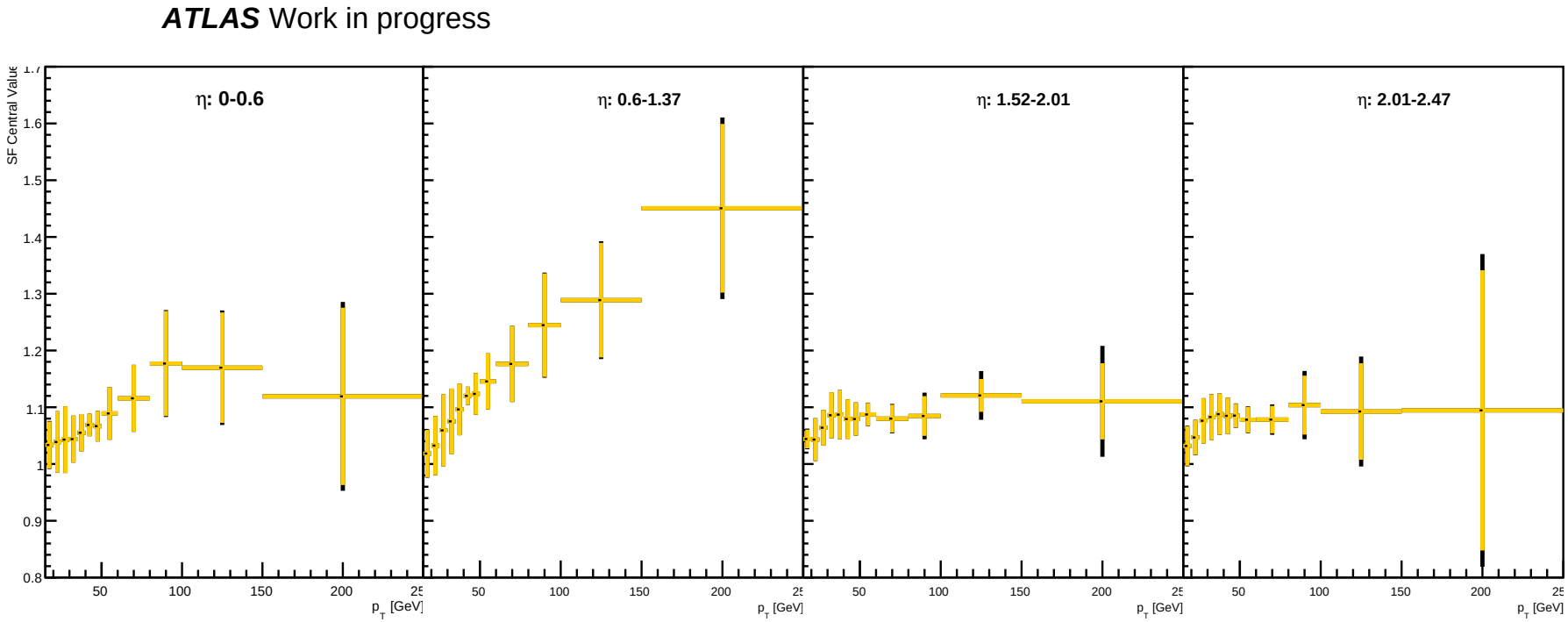

- SFs as function of p_T
- Syst. uncertainty in yellow
- Total uncertainty in black
- General tendency to high values
- Some η regions with "linear" trend (in all data taking periods)

Systematics include:

- Variation of the m_{ee} mass window
- Background template variations
- Tag-ID variations
- Pile-up
- Jet-modelling/Generator

SFs for Very Tight WP (Electrons, 2018)

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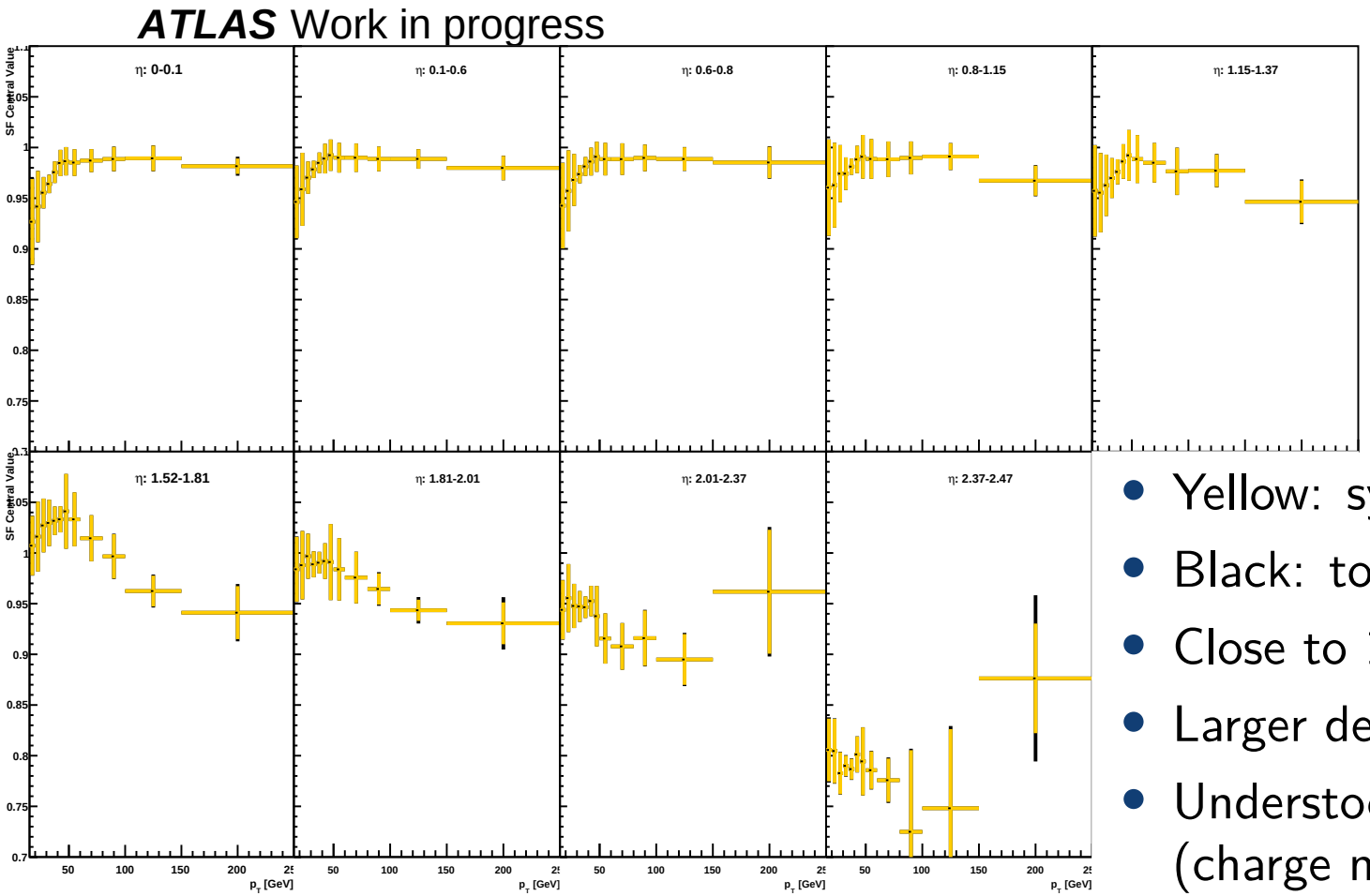

- Yellow: syst. uncertainty
- Black: total uncertainty
- Close to 1 in barrel
- Larger deviations in end-cap
- Understood behaviour (charge misID cut)

Additional Systematics

Jet modelling uncertainty:

- Comparison of Powheg+Pythia8 and Sherpa

$$\text{Uncertainty} = \frac{|SF(Sherpa) - SF(PP8)|}{SF(PP8)}$$

Pile-up uncertainty:

- Split into different μ regions
- For 2017/18: μ in either of three intervals (0,30],(30,40],(40,80]
- For 2015+16: μ in either of two intervals (0-23],(23,80]
- Take largest difference in SFs as uncertainty

Total Uncertainty (Electrons, 2018)

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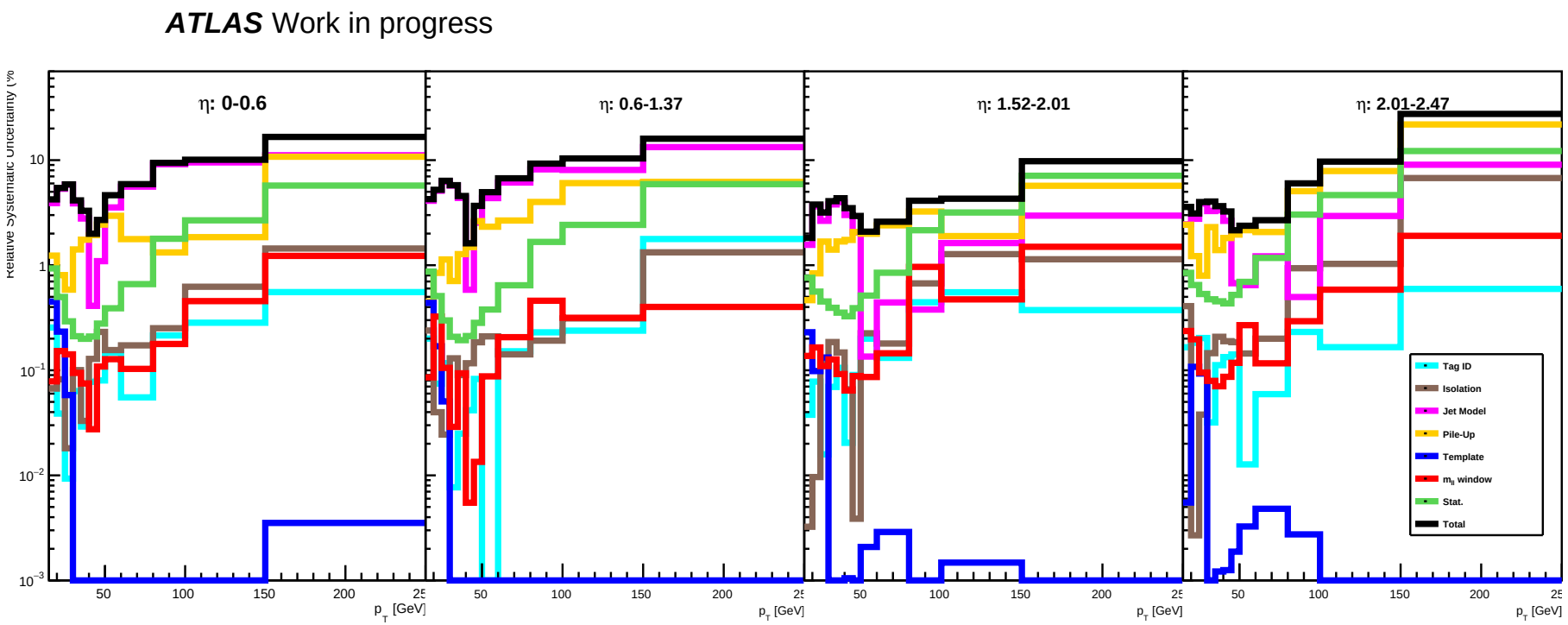

- For low/medium η: dominated by jet modelling uncertainty
- For medium/high η: dominated by stat./jet modelling/pile-up over different p_T regions
- ID/template/m_{ll} mostly below 2%

Template Fit - Results

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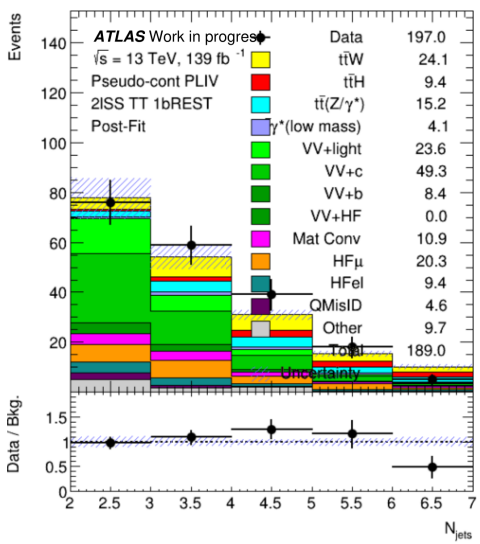
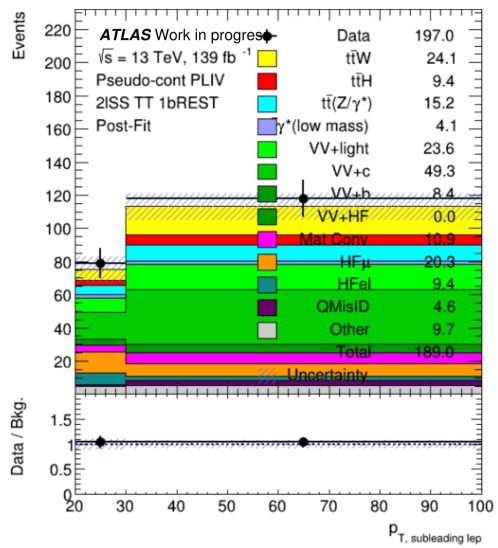
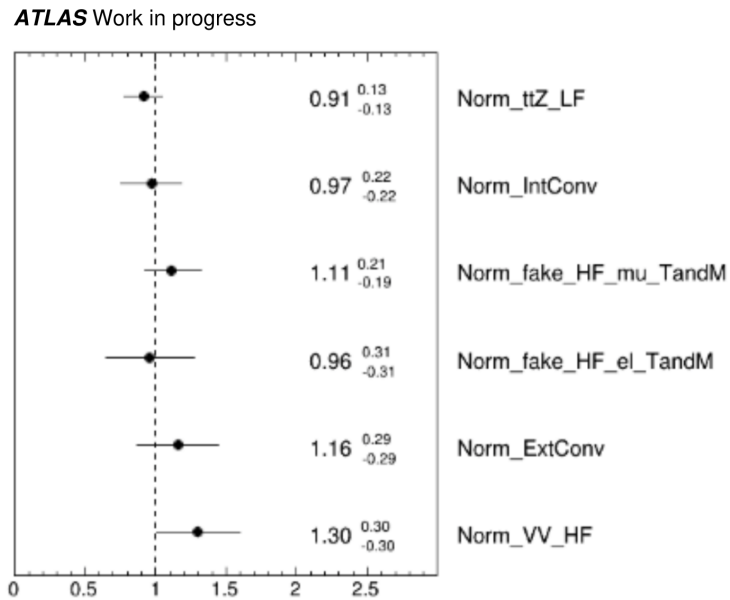
- Background only fit in 10 CRs ⇒
- Major pulls from $t\bar{t}Z$+HF modelling
- Major constraint in $t\bar{t}$ modelling
- TT region orthogonal to SR:

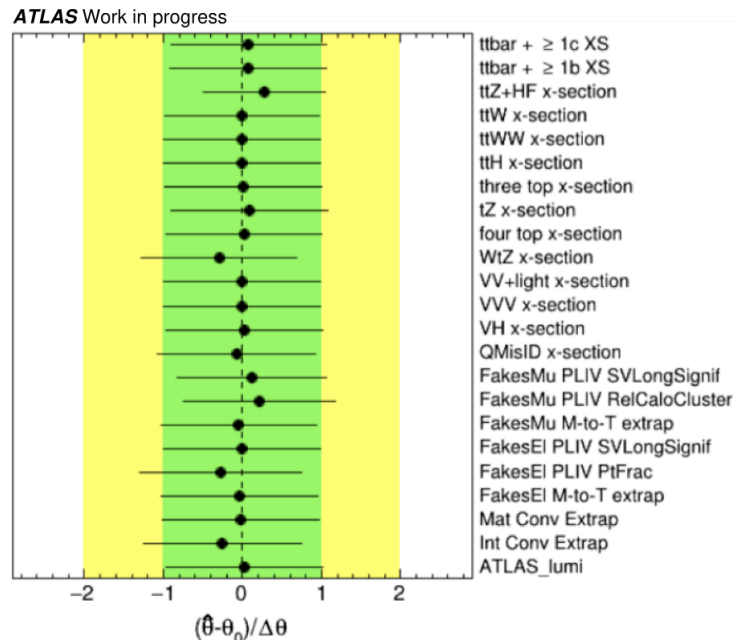




(stat. unc. only)

Plots from Tamara Vazquez Schroeder, Stergios Kazakos





Summary and Outlook

Summary:

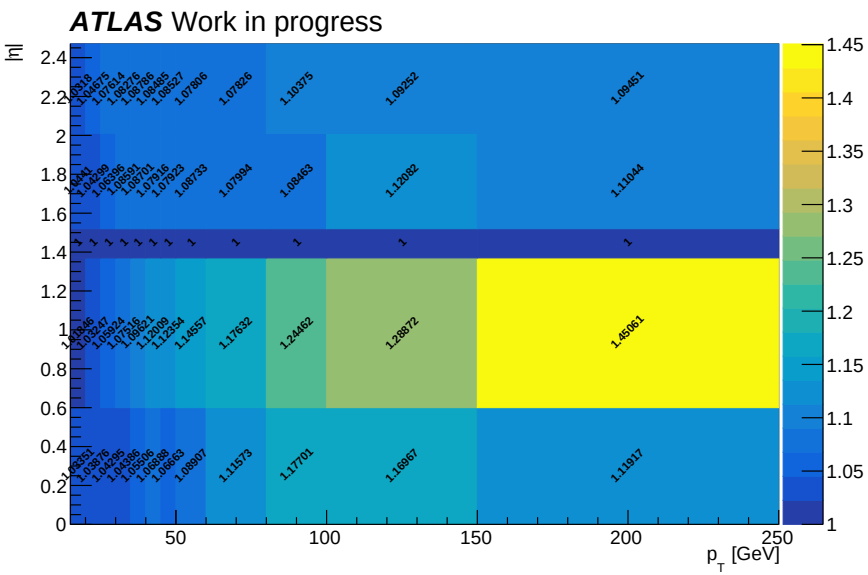
- PLIV calibration is being finalised and validated in the analysis
- Background model including control and validation regions is in place
- Background only fit shows reasonable results

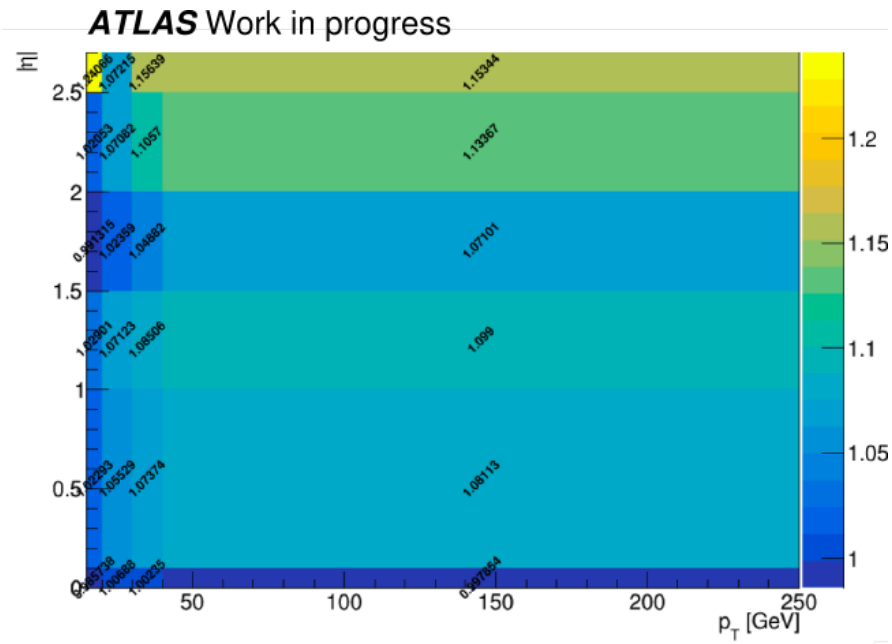
Outlook:

- Converge on how to calculate the systematic uncertainties (jet modelling)
- Test impact of systematics on fit

back-up

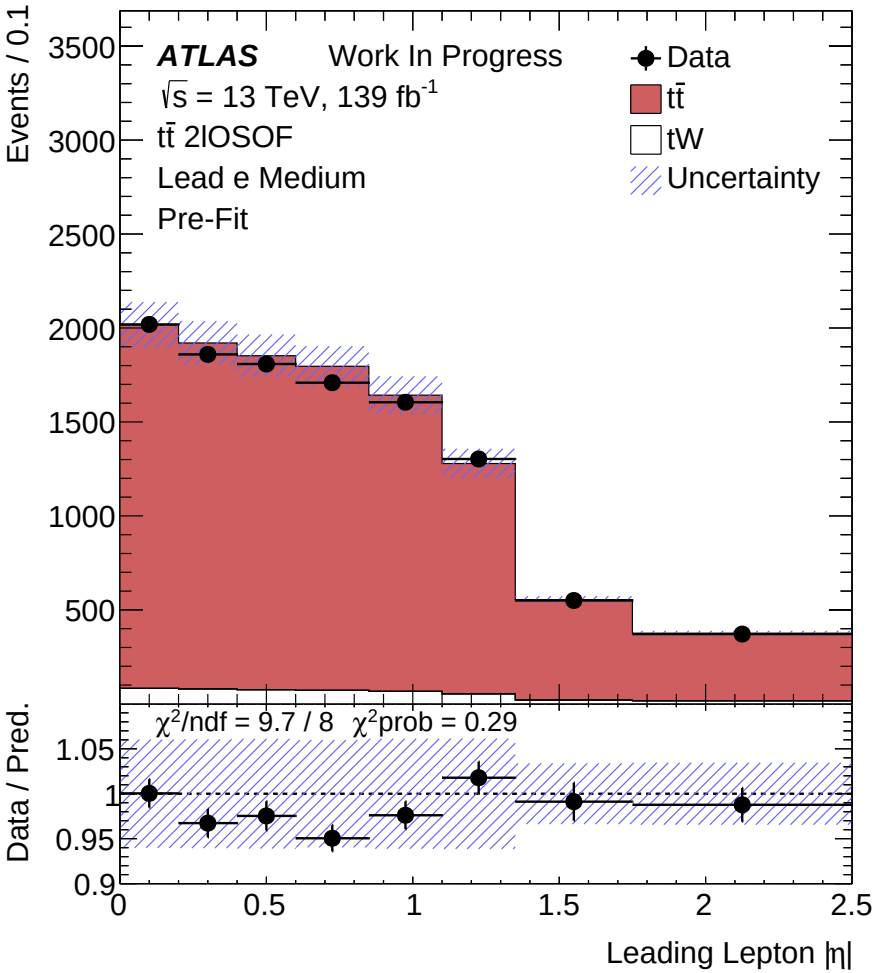
Muon PLIV SFs

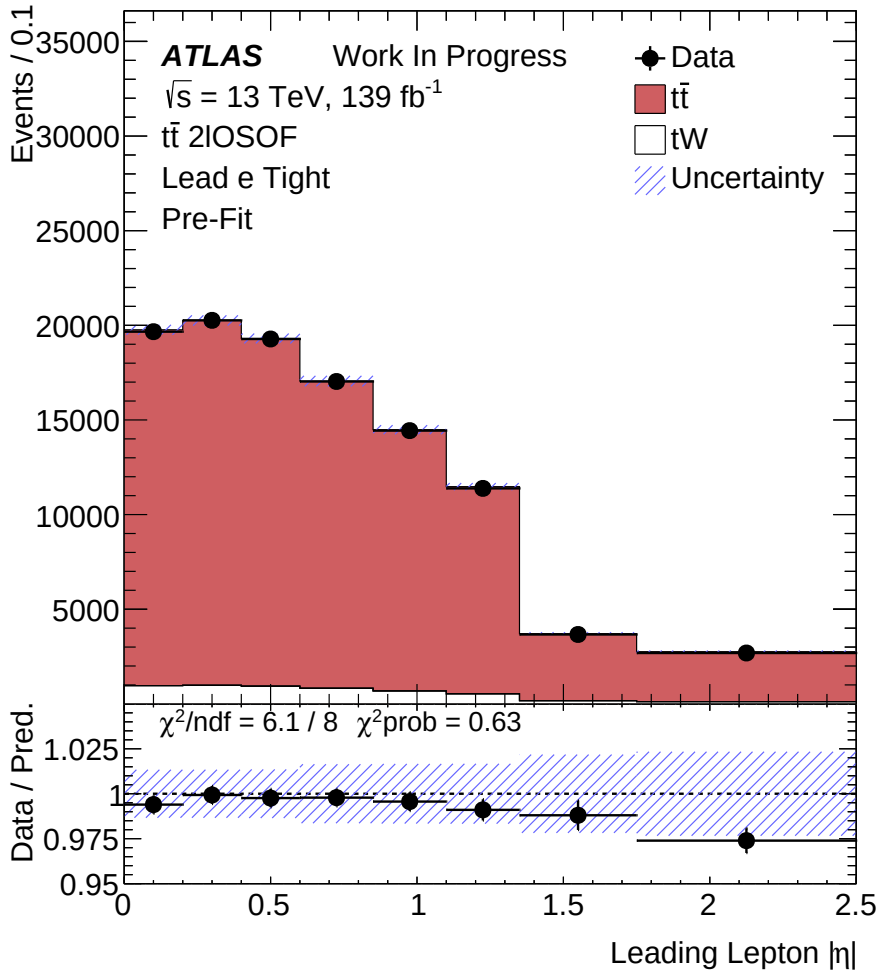




Due to statistics, the muon calibration uses a coarser p_T binning

Validation in the Analysis

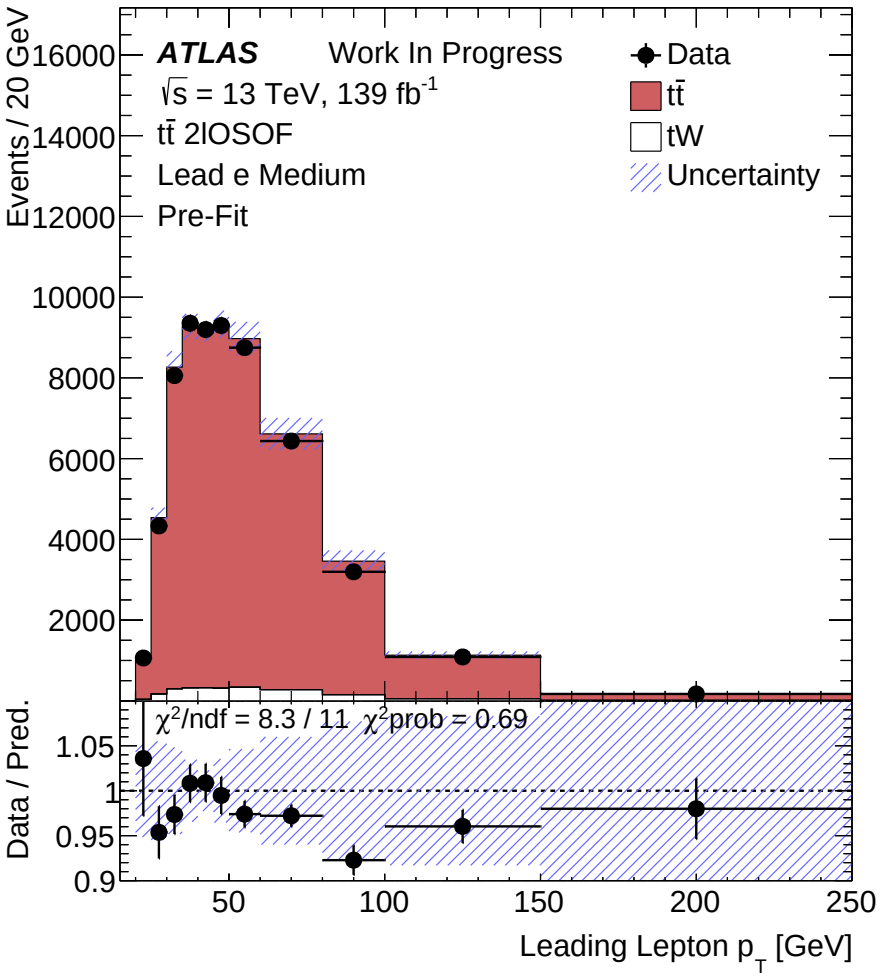


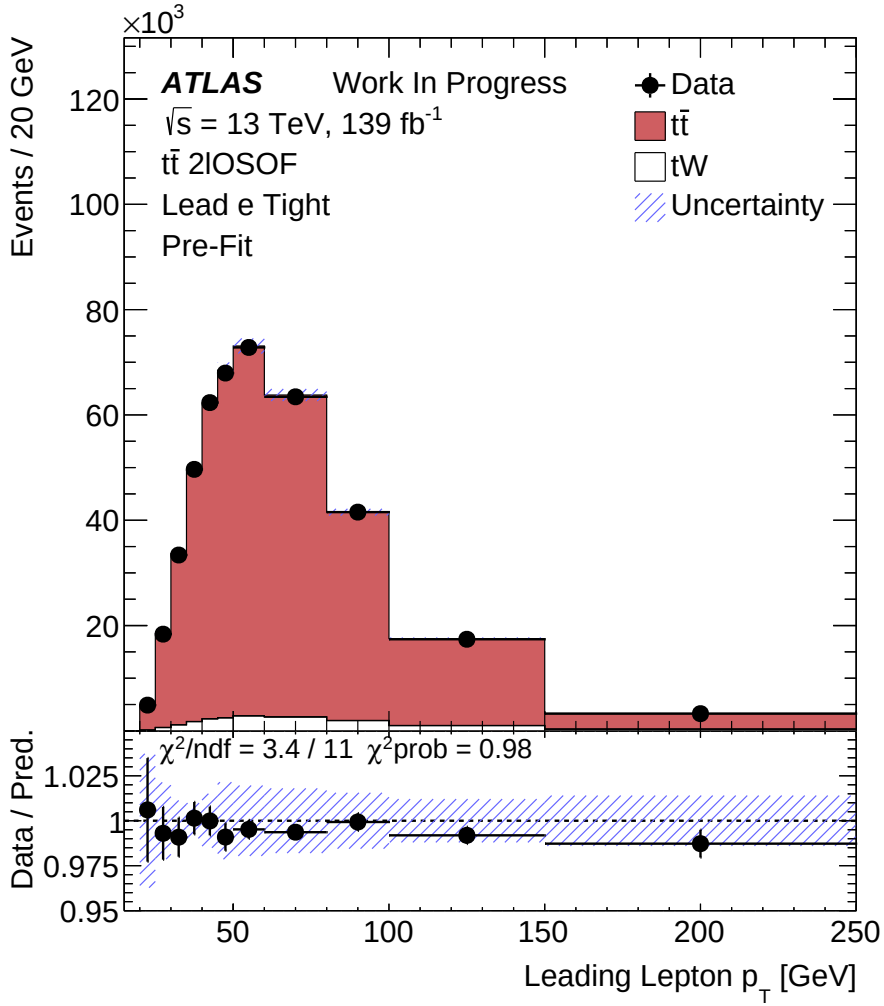


Plots from Brendon Bullard

SFs are also being validated in the context of the analysis and work well so far

Validation in the Analysis





Plots from Brendon Bullard

Using special control region that is close to our signal region

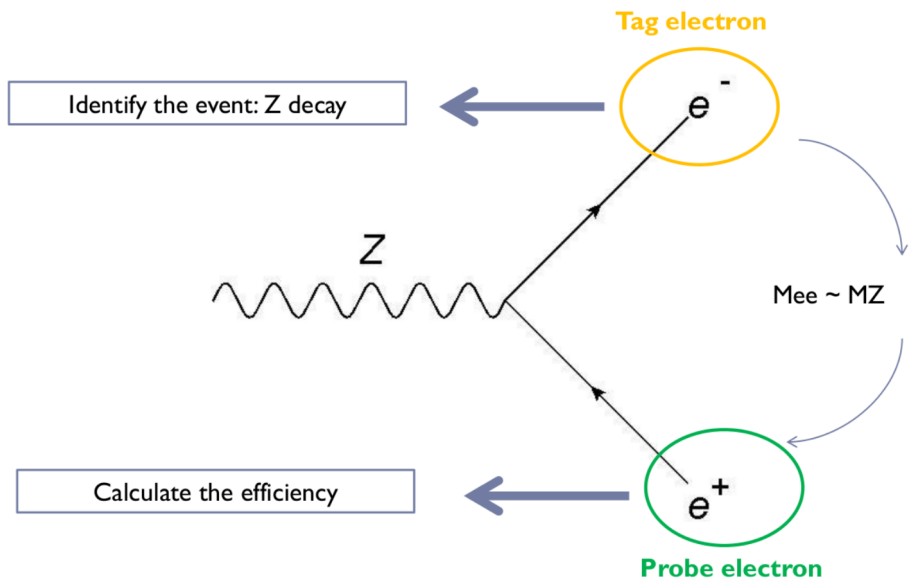
e/γ Tag & Probe Framework

- Normalisation and uncertainty on non-prompt leptons determined by template fit
- Central framework for electron scale factor calculations
- Use the framework to derive the WPs calibration
- Standard tag and probe approach
- Rewritten framework in advanced stage
- Will be relying on the established version during the transition phase

Idea of the e/γ Tag & Probe Framework

Using the measurement of $\varepsilon_{\text{reco}}$ in $Z \to ee$ events as an example

- One electron is tagged using very strict cuts
- This is supposed to identify the event as $Z \to ee$
- Other requirement is an additional EM-cluster (probe) that's isolated from jets
- Constraint on combined invariant mass



Idea of the e/γ Tag & Probe Framework

- Measurement is performed in two-dimensional bins (E_T,η)
- Estimate and subtract background in N_{reco} and N_{tot}
- Backgrounds are for example hadrons misidentified as electrons and non-prompt leptons
- Separate estimation for clusters with and without associated tracks
- Calculate $\varepsilon_{\text{reco}} = \frac{N_{\text{reco}} - B_{\text{reco}}}{N_{\text{tot}} - B_{\text{tot}}}$

In PLIV calibration:

- Measure efficiency of the prompt lepton identification

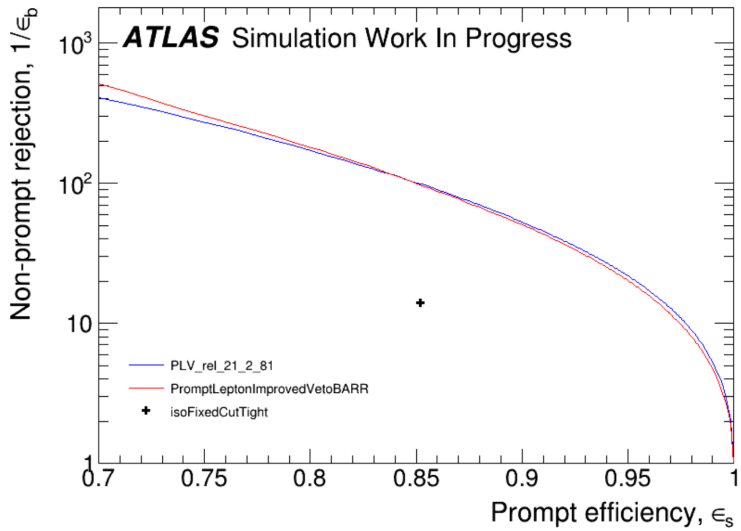
N.B.:

- By default, e/γ framework treats every syst. variation equally and declares the average to be the nominal SF
- In our analysis, one of the variations is declared as the nominal SF

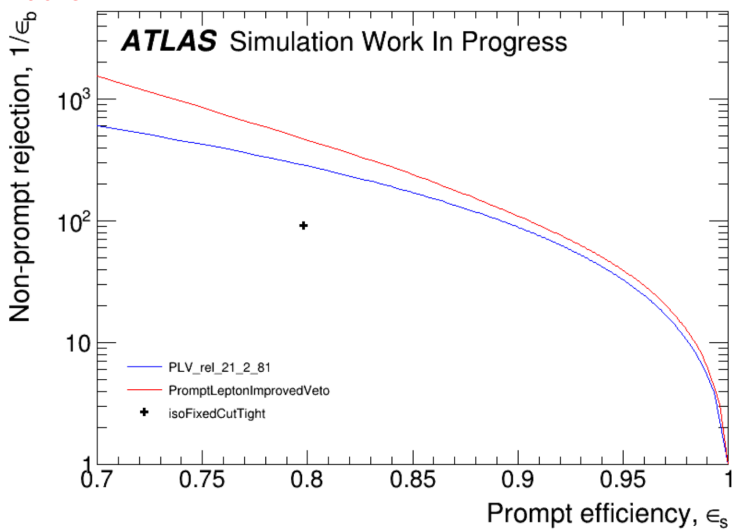
Comparison of Prompt Lepton Algorithms

- Both BDTs perform better than the fixed cut
- BDTs: only small difference for central electrons
- BDTs: PLIV much better for muons and end-cap electrons

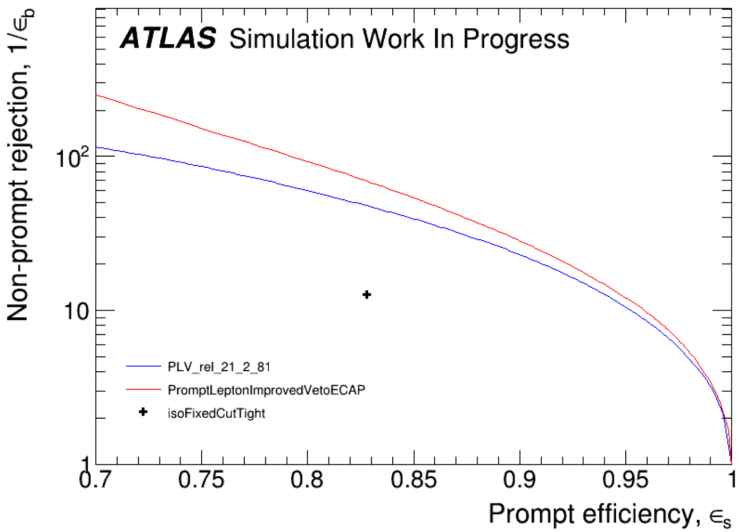
barrel El



Muons



end-cap El



Plots from Fudong He

Pile-Up Uncertainties

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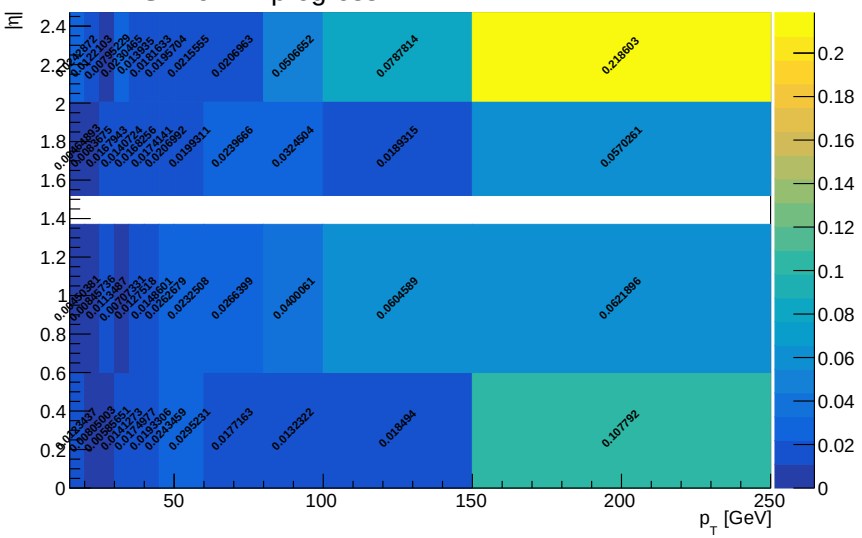
Tight, not Very Tight



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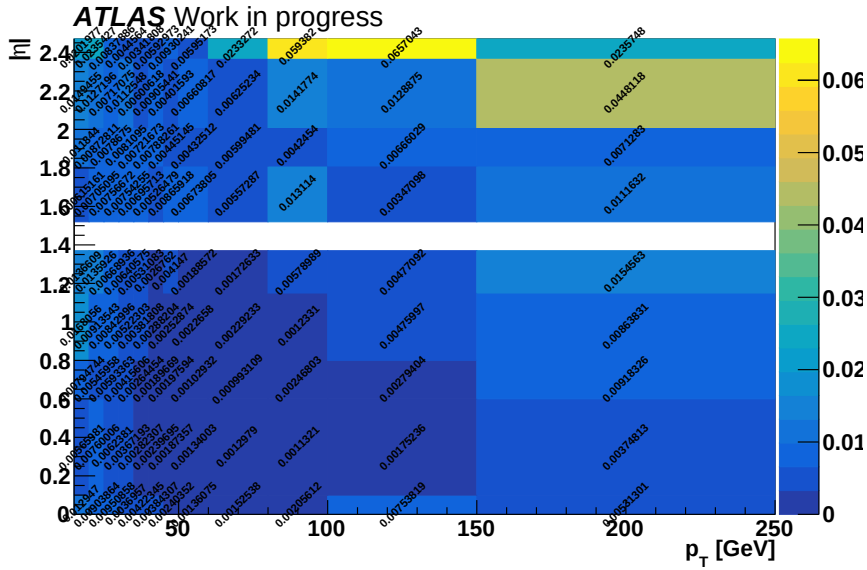

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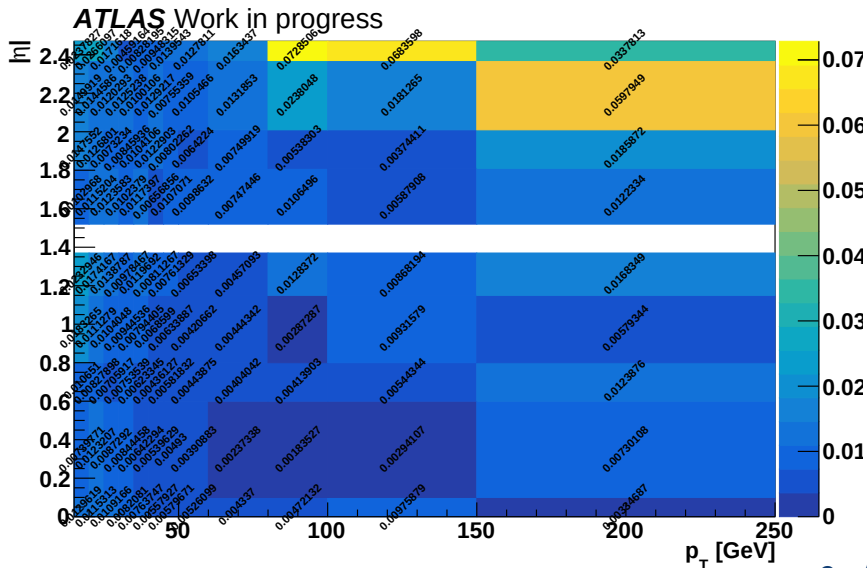

Jet Modelling Uncertainties

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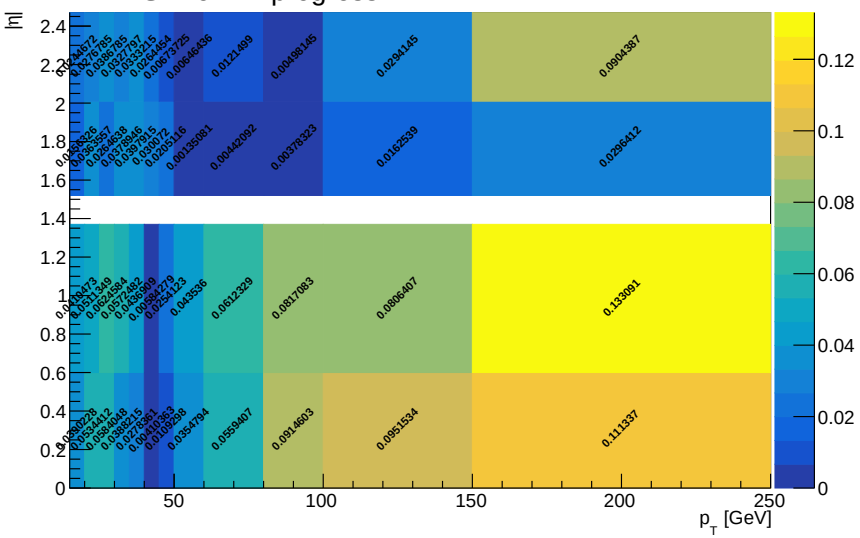

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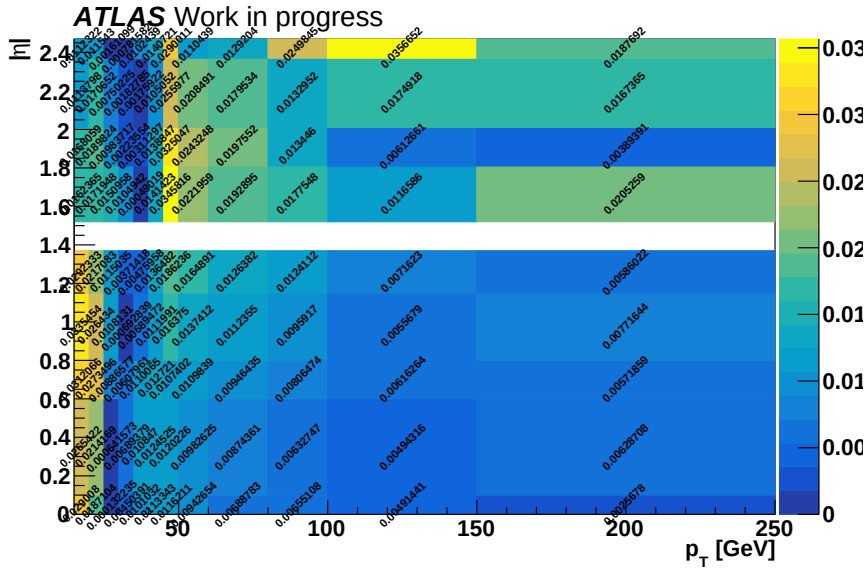

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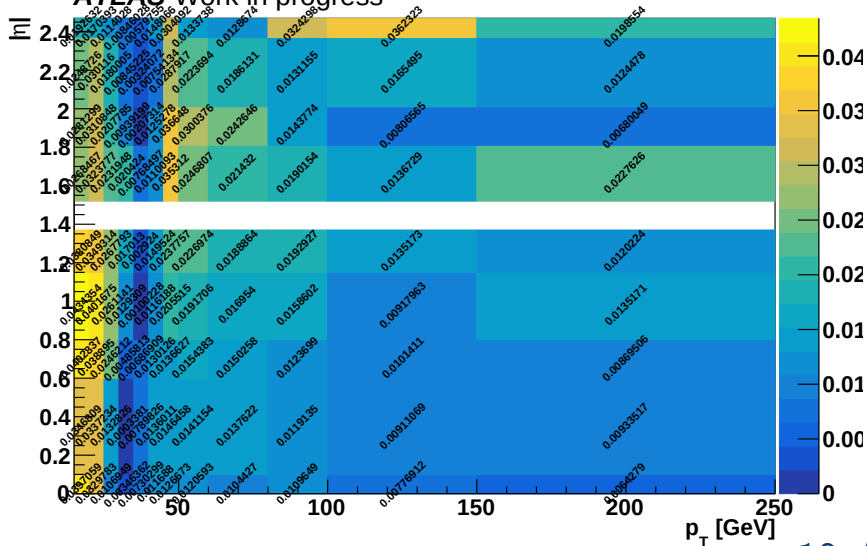

m_{ll} Window Uncertainties

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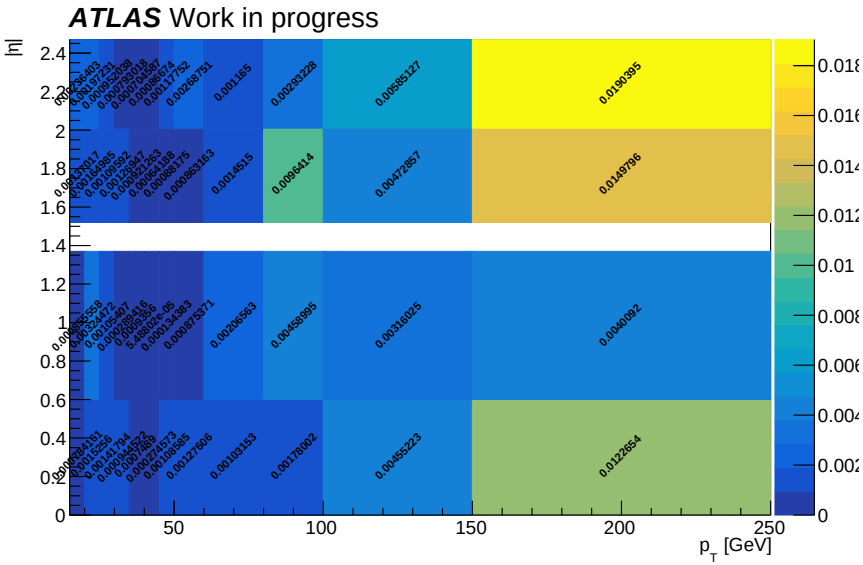
Tight, not Very Tight



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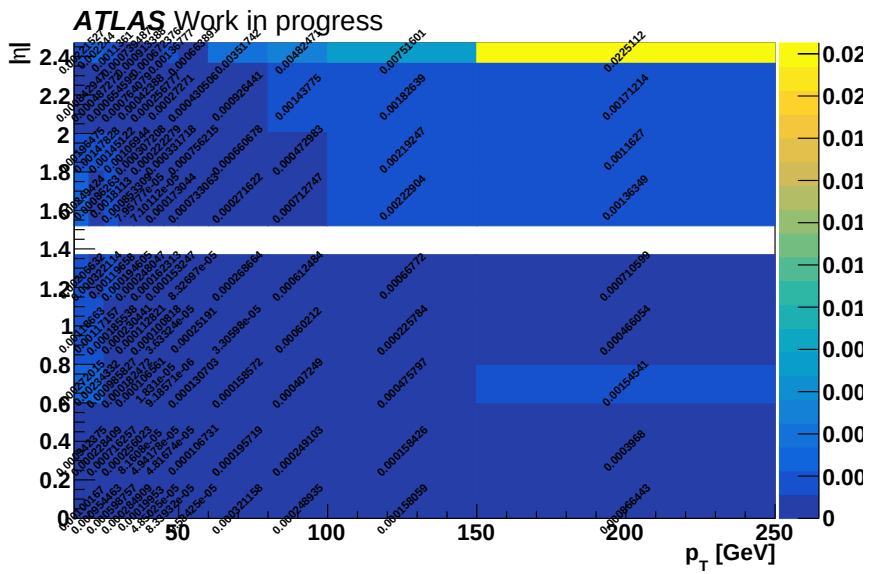

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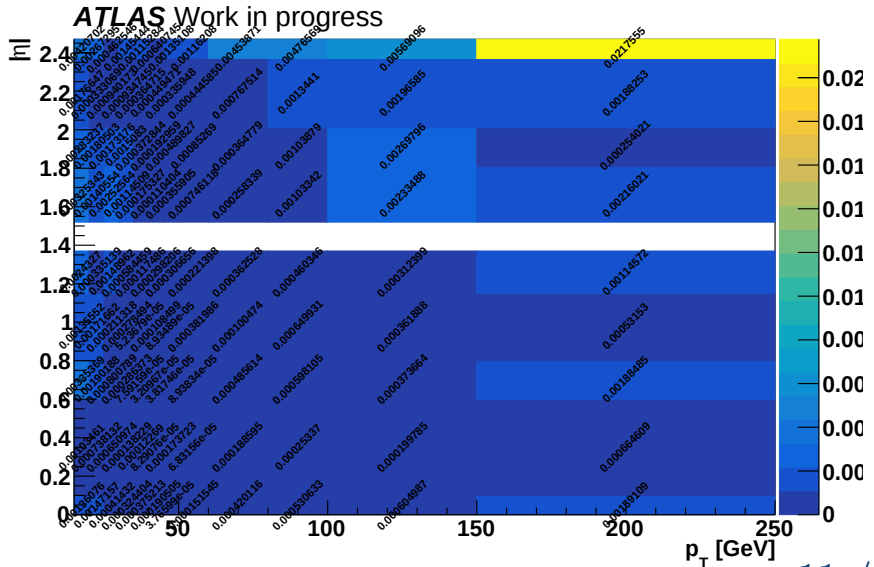

Tag-Iso Uncertainties

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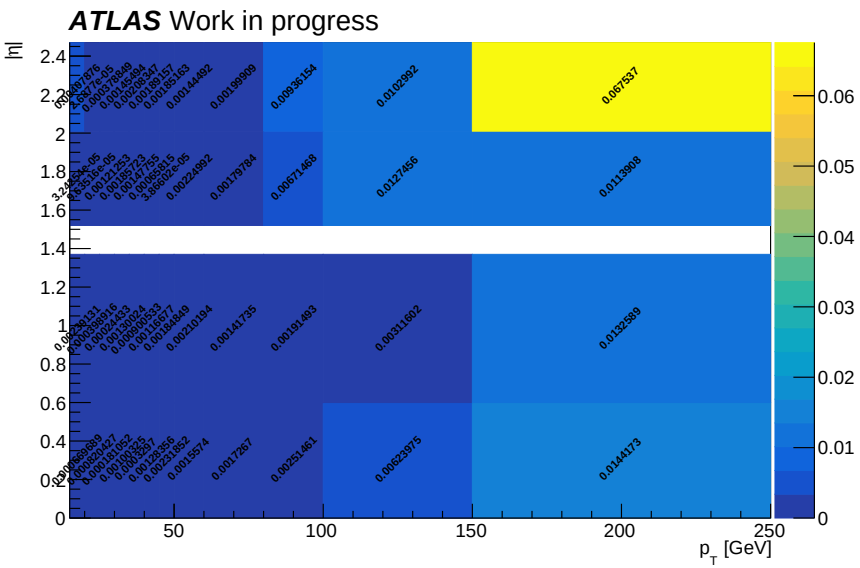
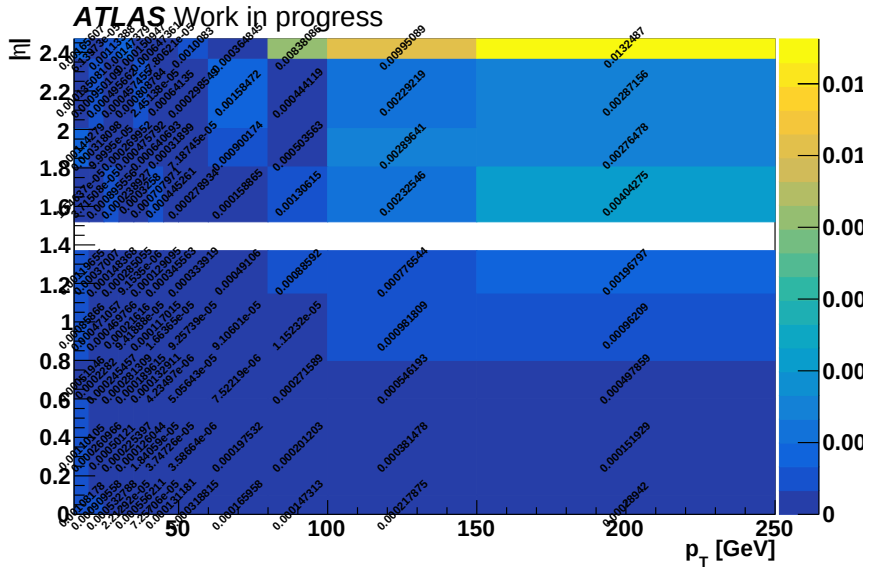
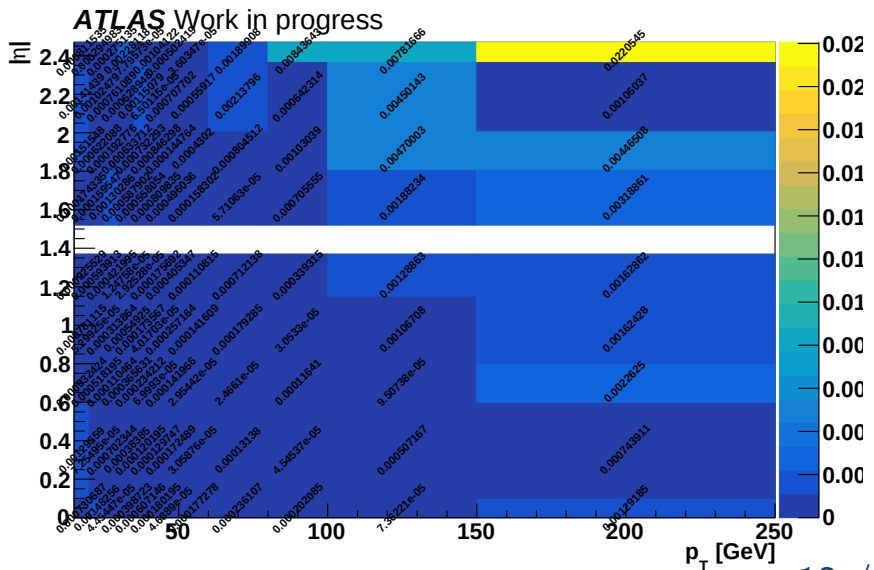
Tight, not Very Tight



Tight



Very Tight



Tag-ID Uncertainties

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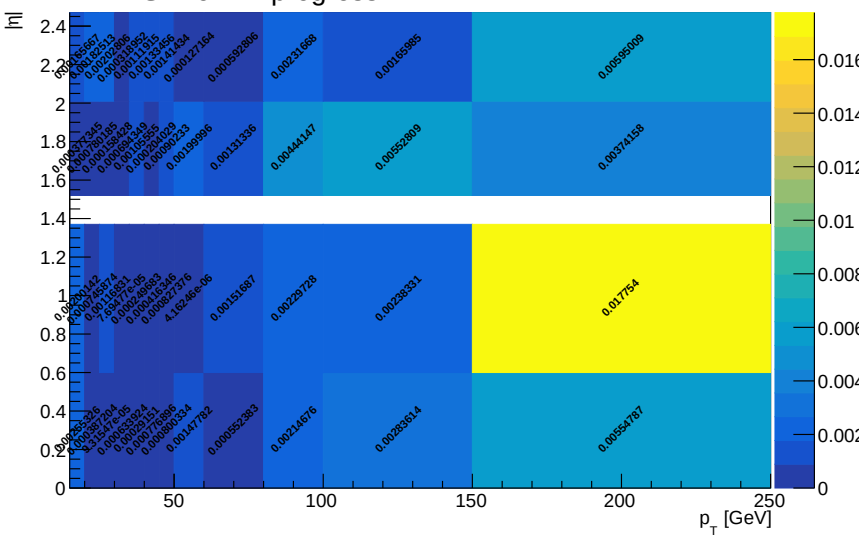
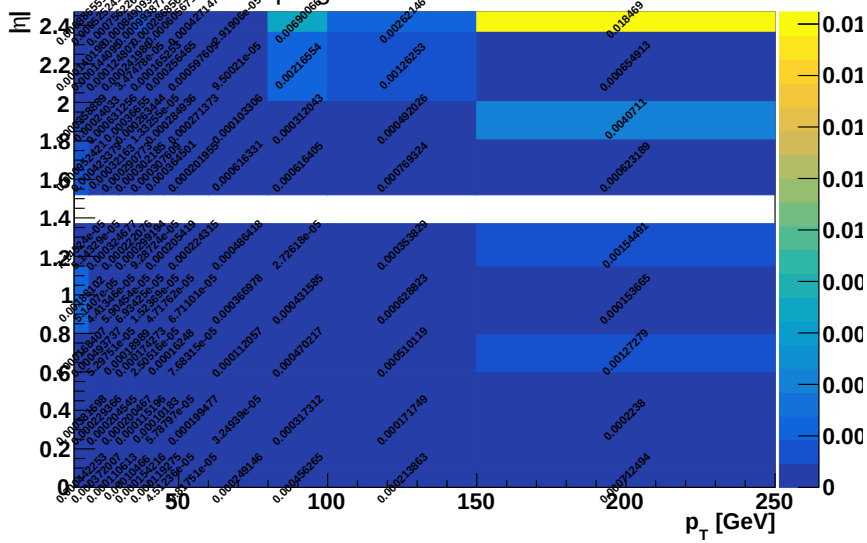
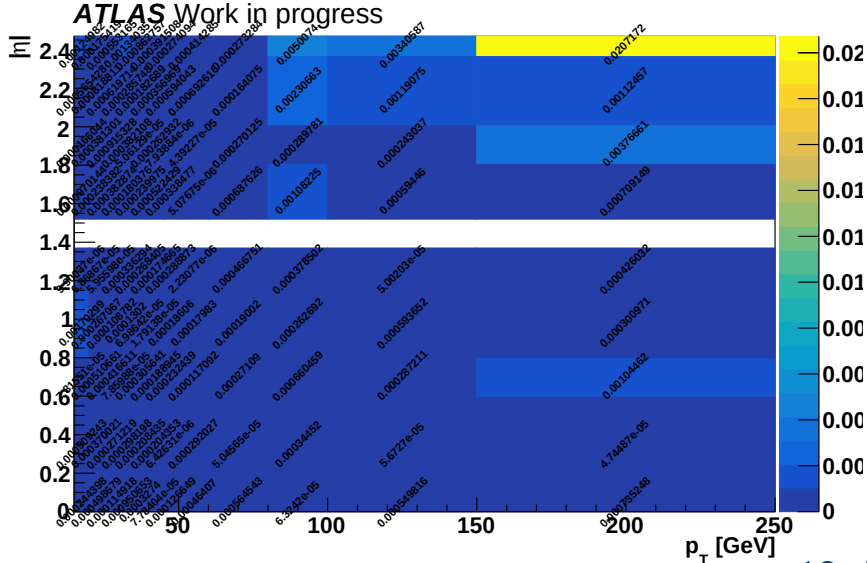
Tight, not Very Tight



Tight



Very Tight



Template Uncertainties

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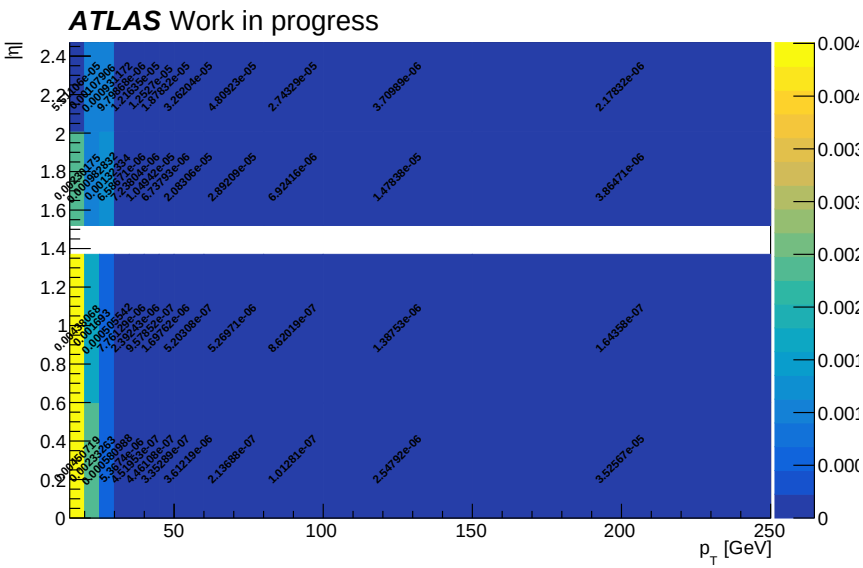
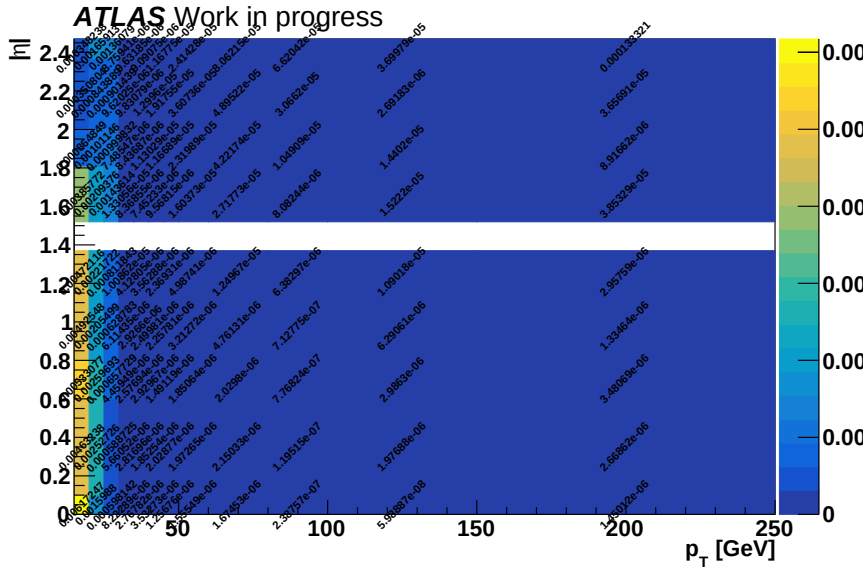
Tight, not Very Tight



Tight



Very Tight