FSP ATLAS
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Center for Particle Physics Siegen

Naturwissenschaftlich-Technische Fakultät

Universität Siegen

$t\bar{t}\gamma$ differential cross section measurements at 13 TeV with the ATLAS detector

Helmholtz Alliance annual meeting, Hamburg
Physics at the Terascale
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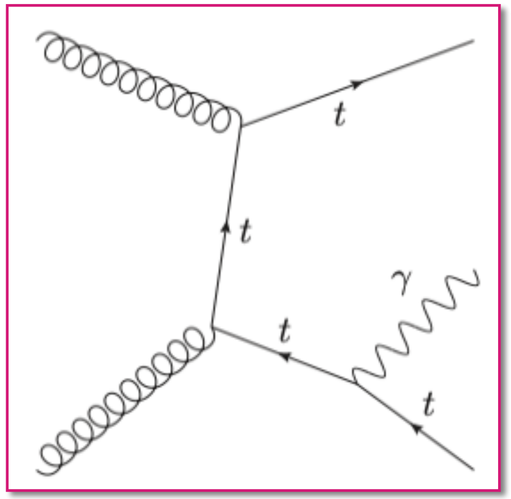
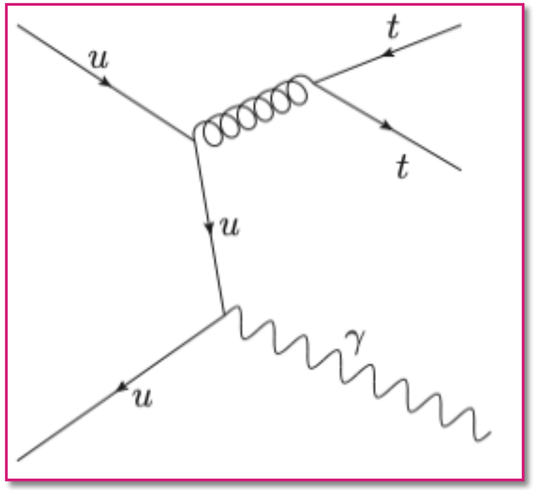
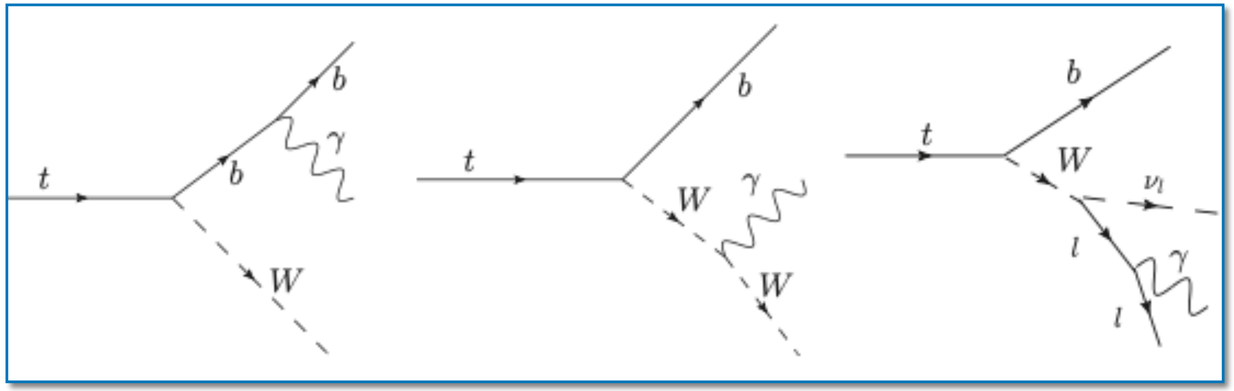
Buddhadeb Mondal, Carmen Diez Pardos, Ivor Fleck
Universität Siegen

Introduction

- $t\bar{t}\gamma$ probes the coupling between top quark and photon
- This topology is sensitive to new physics through anomalous dipole moment of top quark and also in the context of EFT
- Measurement is being performed using $139\ \mathrm{fb}^{-1}$ data collected by ATLAS detector in pp collision at $\sqrt{s} = 13\ \mathrm{TeV}$
- Semi-leptonic and dileptonic final state of the $t\bar{t}$ pair. **This talk focuses on semileptonic channel** (e+jets, mu+jets)
- $t\bar{t}\gamma$ events with photon radiated during top quark pair production or from initial parton considered as signal
- $t\bar{t}\gamma$ events with photon emited from decay products of top quark pair considered as background







Signal and Background simulation

Signal process: $pp \rightarrow t\bar{t}\gamma$

- Simulated at NLO as 2->3 process using Madgraph_aMC@NLO

Background process:

- Decay of $t\bar{t}\gamma$ is simulated as 2->7 process at LO
- K-factor of 1.50 is used for scaling to NLO cross section

- Other background process:

$t\bar{t},\ V+\text{jets},\ V\gamma+\text{jets},\ VV\gamma,\ t\bar{t}V\gamma,\ t+\gamma$

Background categorization based on photon source:

- **Prompt γ:** truth match to photon from lepton/quark/bosons

- **Non-prompt γ:**

electron mis-reconstructed as photon ($e \rightarrow \gamma$ fake)

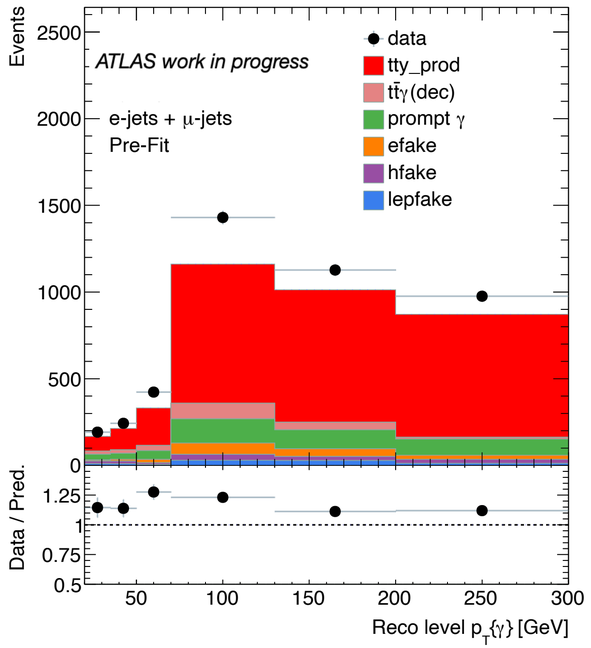
jet mis-reconstructed as photon, photon coming from hadron decay (hadron fake)

Event selection

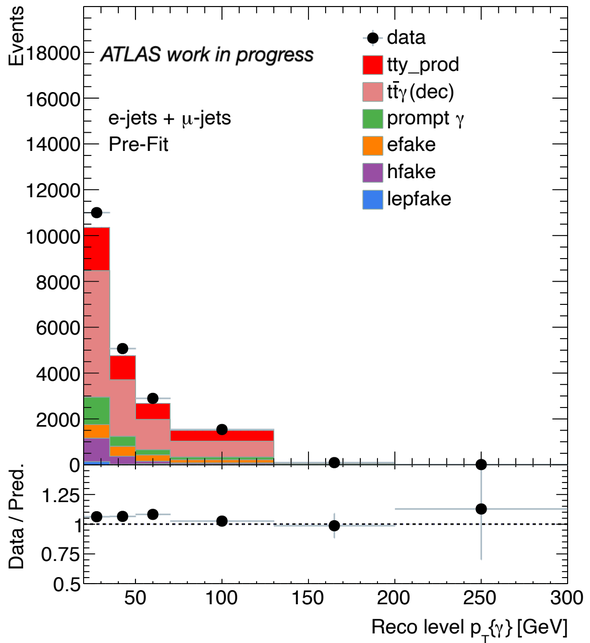
Channel	$e + jets$	$\mu + jets$
Common	$1e$	1μ
Photon	$1\gamma\ p_T > 20\ GeV$	
Jet	>= 4	
b-jet	>= 1	
$m(e,\gamma)$	Not in [86.19,96.19] GeV	
$\Delta R(\gamma, l)$	> 0.4	

- Signal and control regions defined by means of multi classification NN

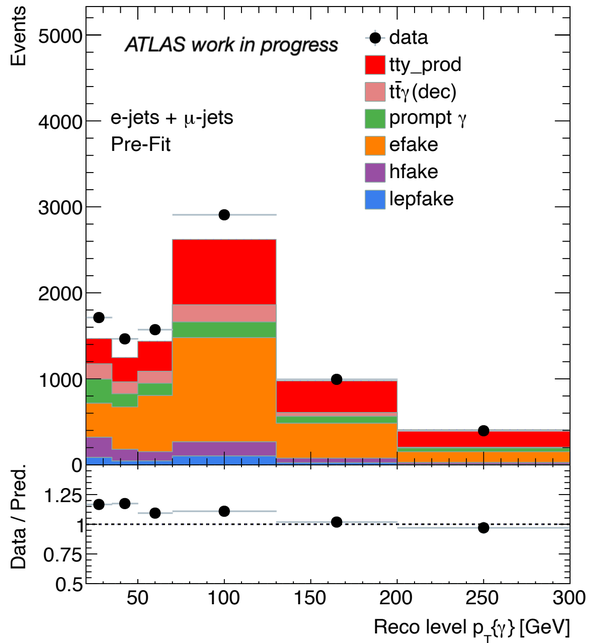
SR tty prod



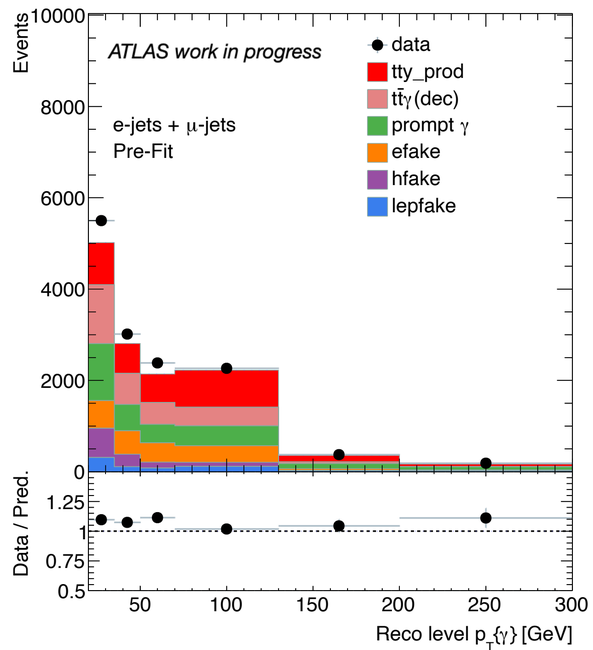
CR tty dec



CR fakes



CR other photons



Non-prompt background processes

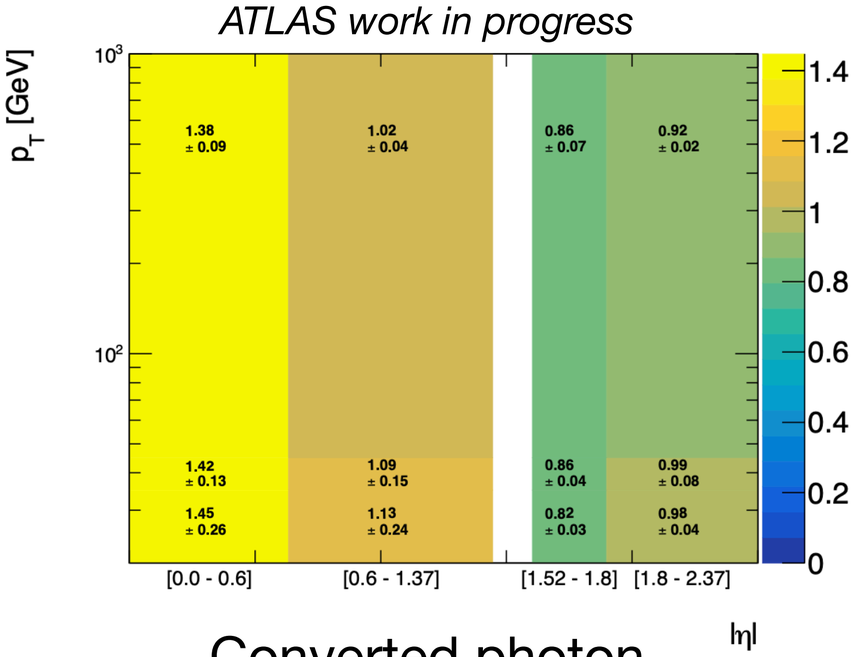
- Backgrounds with non-prompt objects estimated from data

$e \rightarrow \gamma$ fake:

- electron mis-reconstructed as photon
- Tag and probe approach is used
- Using $Z \rightarrow e^{+}e^{-}$, ee and $e\gamma$ CRs are defined in data and MC
- Fake rate (FR) is calculated both in data and MC,

$$\mathrm{FR}^{data/MC} = \frac{N_{e\gamma}^{data/MC}}{N_{ee}^{data/MC}}$$

- FR scale factor = $\frac{FR^{data}}{FR^{MC}}$
- 2D FR scale factor is estimated in p_T, $|\eta|$
  - estimated for converted and unconverted photon



Converted photon

Fiducial phase space

Differential cross-section measured at particle level in a fiducial phase space close to the selection at reconstruction level

- Exactly one lepton with $p_T > 25\ \mathrm{GeV},\ |\eta| < 2.5$
  - Leptons dressed using photons found within $\Delta R < 0.1$
- Jet Clustered using $\mathrm{anti-k_T}$ algorithms with radius $\Delta R = 0.4$, with $p_T > 25\ \mathrm{GeV},\ |\eta| < 2.5$, njets >=4
- One or more b-quark jet $p_T > 25\ \mathrm{GeV},\ |\eta| < 2.5$
  - b-quark jets identified using ghost-matching procedure
- $\Delta R(l, \gamma) > 0.4$

Differential cross section measurement

- Measurements for the following variables

$$p_T(\gamma),\ |\eta(\gamma)|,\ \min\Delta R(\gamma, l),\ \min\Delta R(\gamma, b), \min\Delta R(l, j), p_T(j1)$$

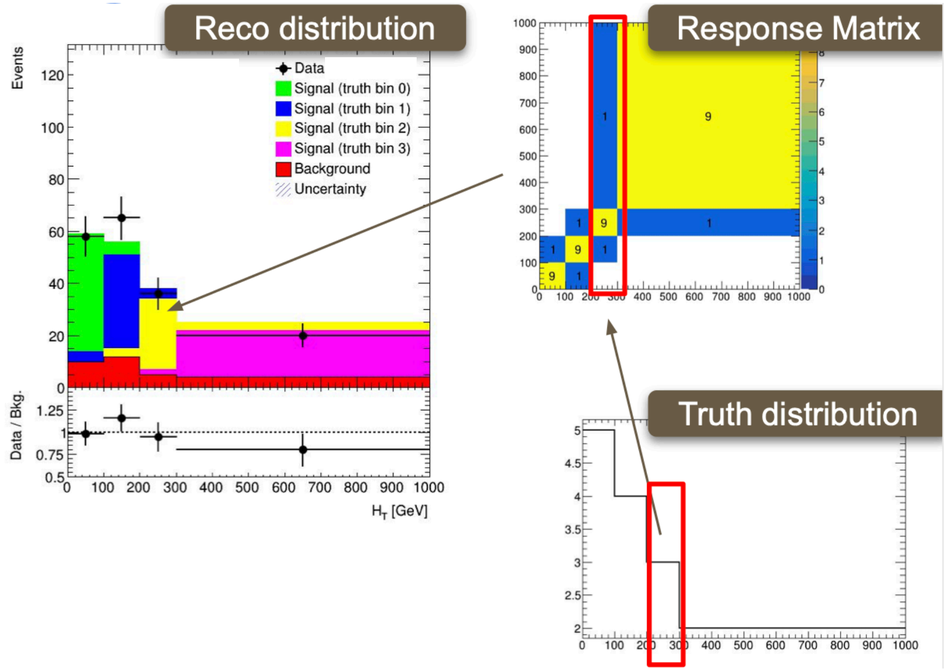
- Detector response and acceptance effects are represented by response matrix

- Differential cross section evaluated by applying unfolding procedure (next slide):
  - Unregularized profile likelihood unfolding

Fit and unfolding strategy

- Each bin of signal distribution at particle level is folded using response matrix to obtain distribution at reconstruction level
- A normalization factor (free parameter) is assigned to each bin at particle level
- Profile likelihood fit to the reco level distribution to fit signal normalization factors: adjust truth bin contents -> unfolded distribution
- Uncertainties are incorporated to the likelihood model as nuisance parameters with proper constraints

Toy example



Likelihood function

$$p(\vec{n}, \vec{a} \mid \vec{k}, \vec{\theta}) = \prod_i \text{Pois}(n_i \mid \nu_i(\vec{k}, \vec{\theta})) \cdot \prod_j c_j(a_j \mid \theta_j)$$

observed data

unconstrained parameters, e.g. POI

prediction (summed over samples)

constraint term (e.g. Gaussian)

auxiliary data, e.g. from CP group calibration measurement

constrained nuisance parameters

product over all bins in all channels

Systematic Uncertainties

Experimental sources:

- The jet energy scale and jet energy resolution
- Lepton and photon identification, reconstruction and isolation
- b-jet tagging
- Pileup modelling
- Trigger
- Integrated luminosity
- Uncertainty in $e \rightarrow \gamma$ fake, hadron fake, lepton fake estimation

Systematic Uncertainties

Background normalization: for background processes estimated with MC

- $t\bar{t}\gamma\ decay$: $\pm 20\,\%$ arising from the uncertainty in NLO/LO k-factor
- $W\gamma, t\bar{t}$: $\pm 20\,\%$
- $Wt\gamma, Z\gamma, t\bar{t}V, \mathrm{Diboson}$: $\pm 50\,\%$

Theoretical uncertainties: for signal and background processes

- Sources related to the matrix element calculation of the hard scattering process
  - The uncertainty from PDFs
  - QCD renormalization and factorization scales
- Sources related to the modelling of the parton shower and underlying events

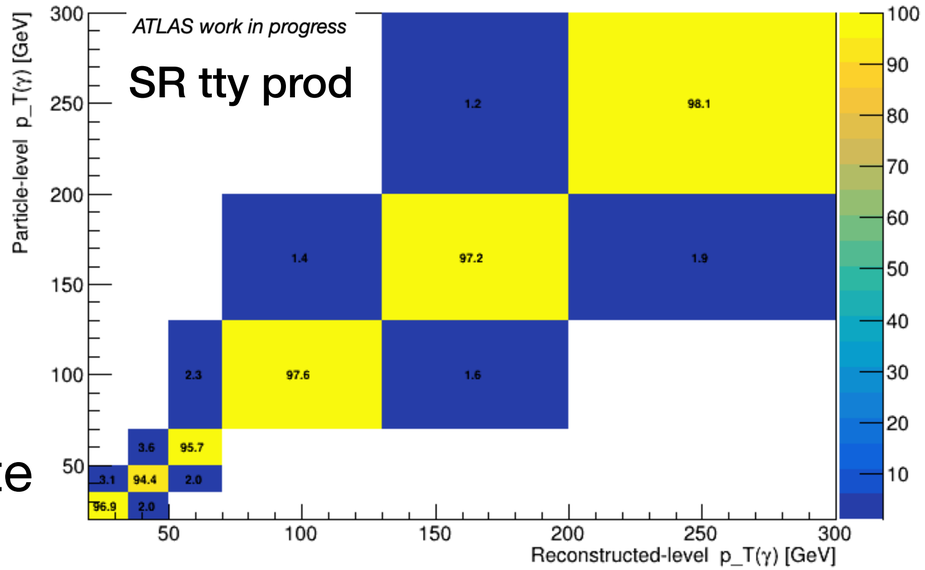
Results

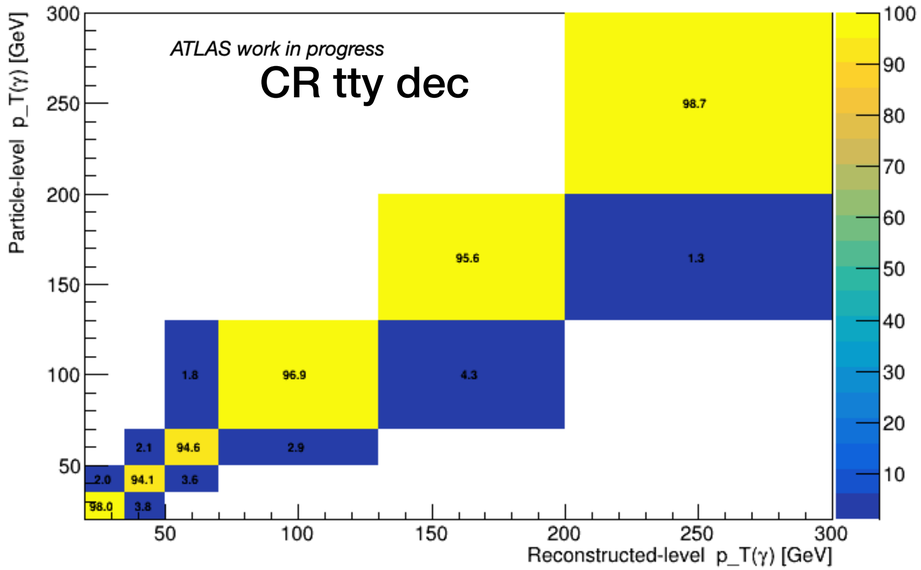
- Showing results of fit to Asimov data (pseudo data)
- Showing: migration matrix, absolute differential cross-section, ranking plot of syst. uncertainties with largest impact

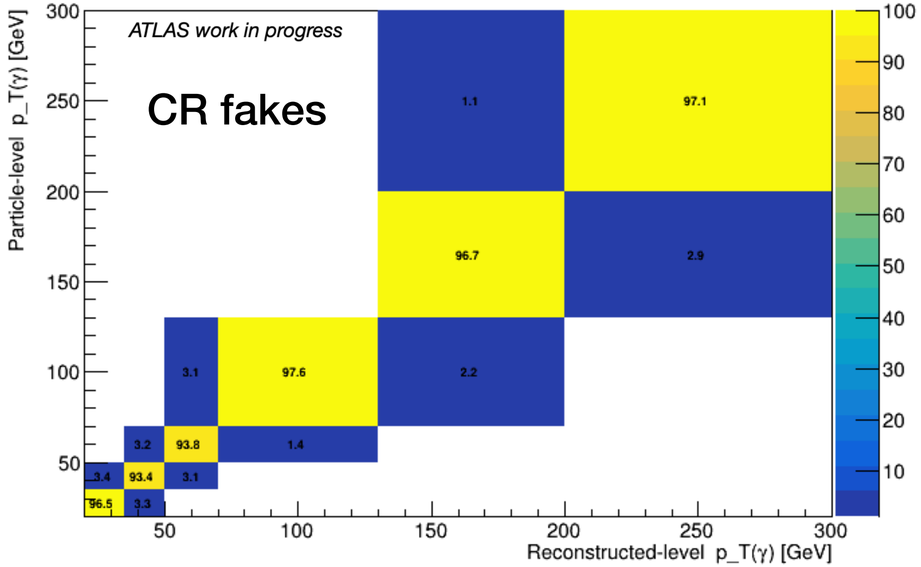
Migration matrices

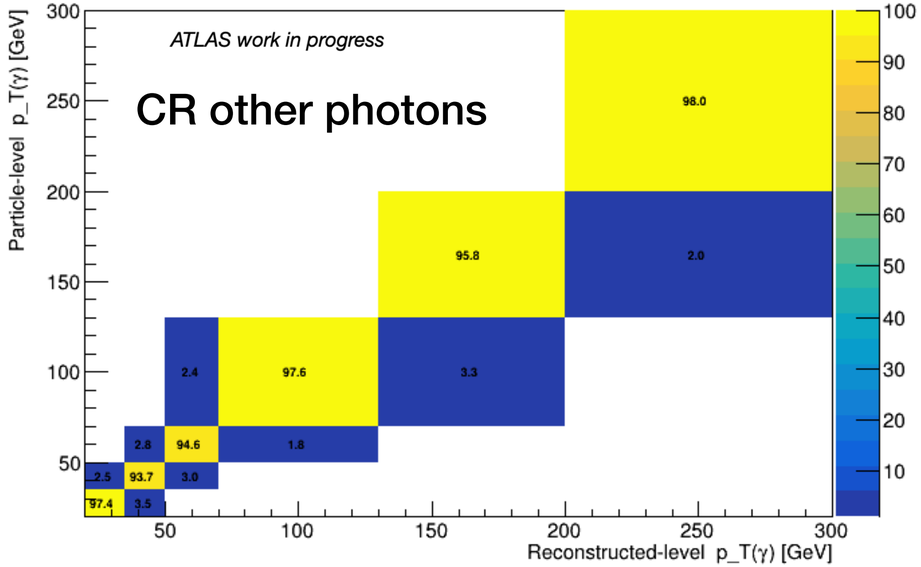
From particle level to different regions at reco level

~ 4% of the events migrate to neighbouring bins



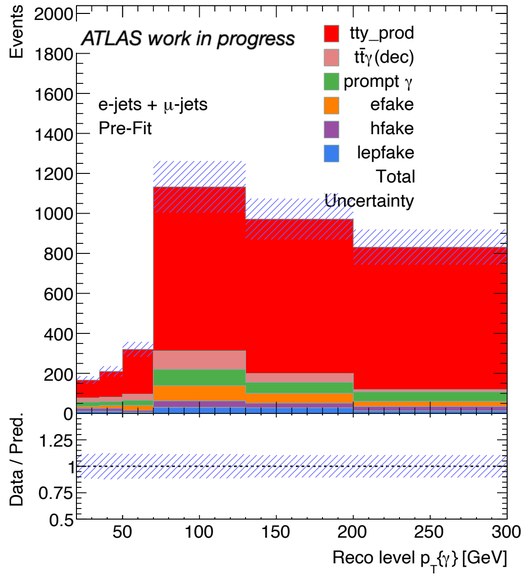


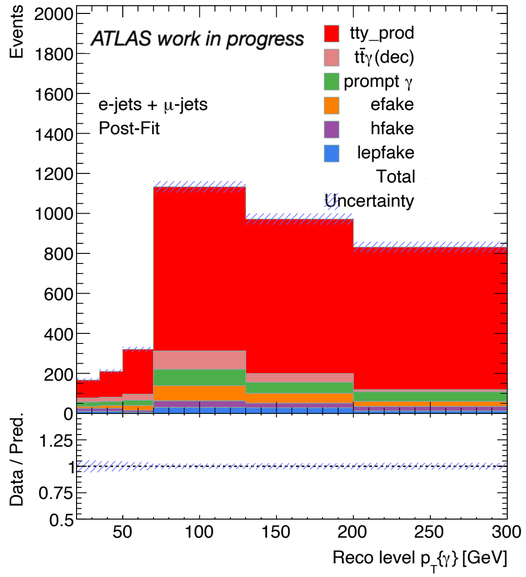




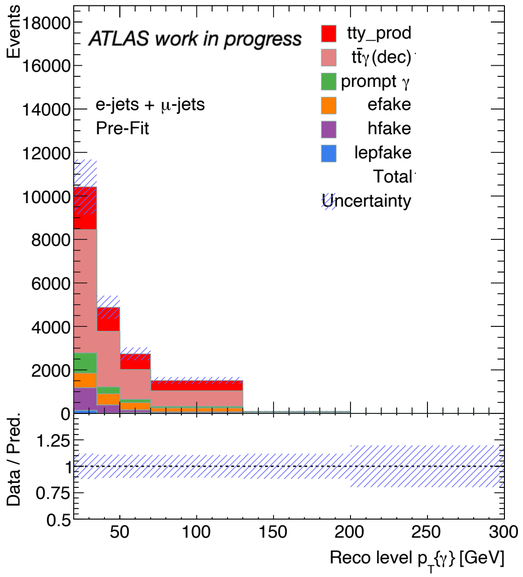
Pre-fit and post-fit distributions

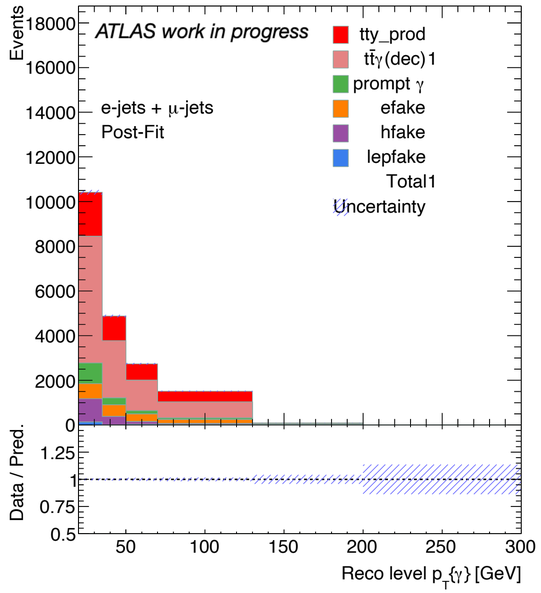
pre-fit SR tty prod post-fit



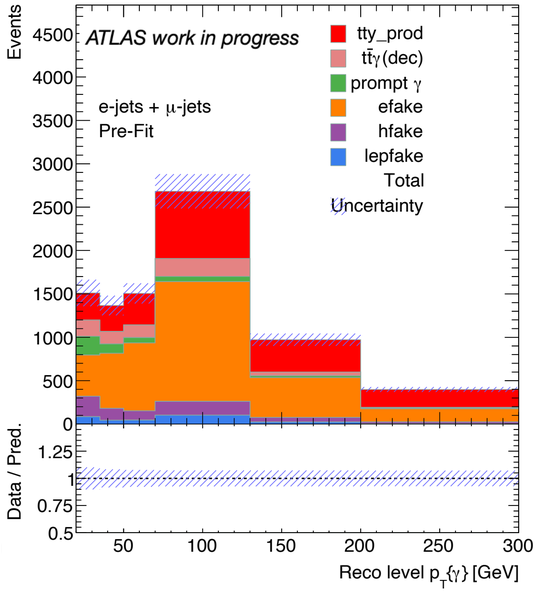


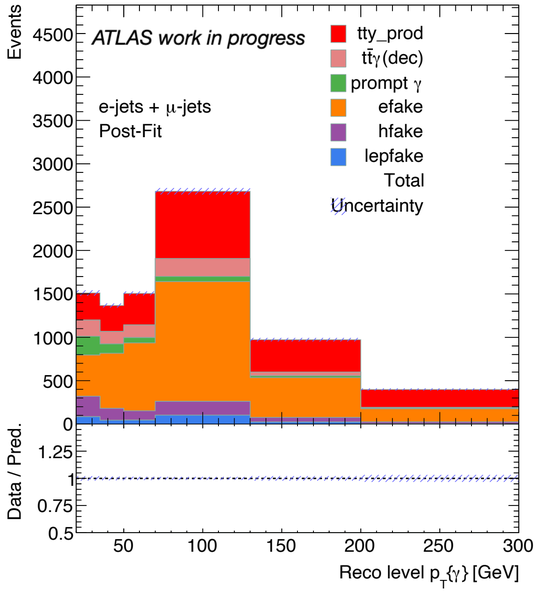
pre-fit CR tty dec post-fit



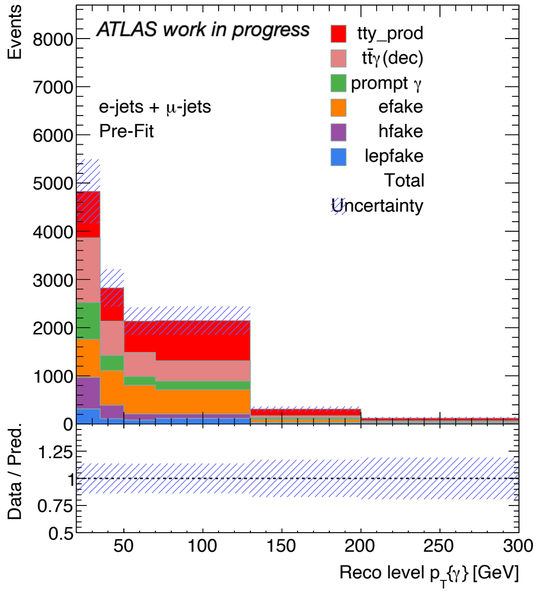


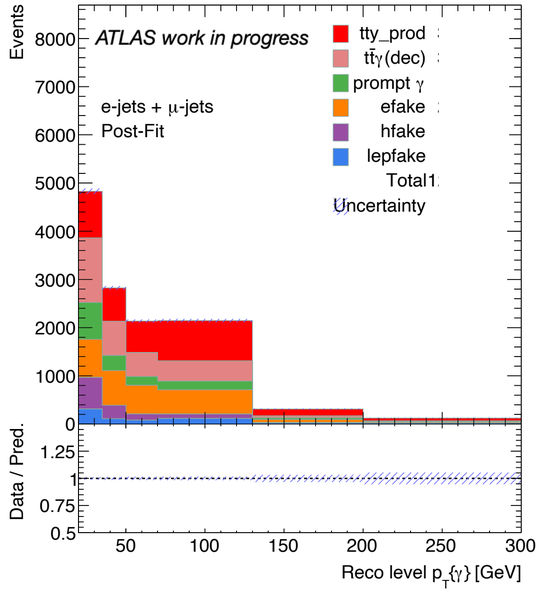
pre-fit CR fakes post-fit





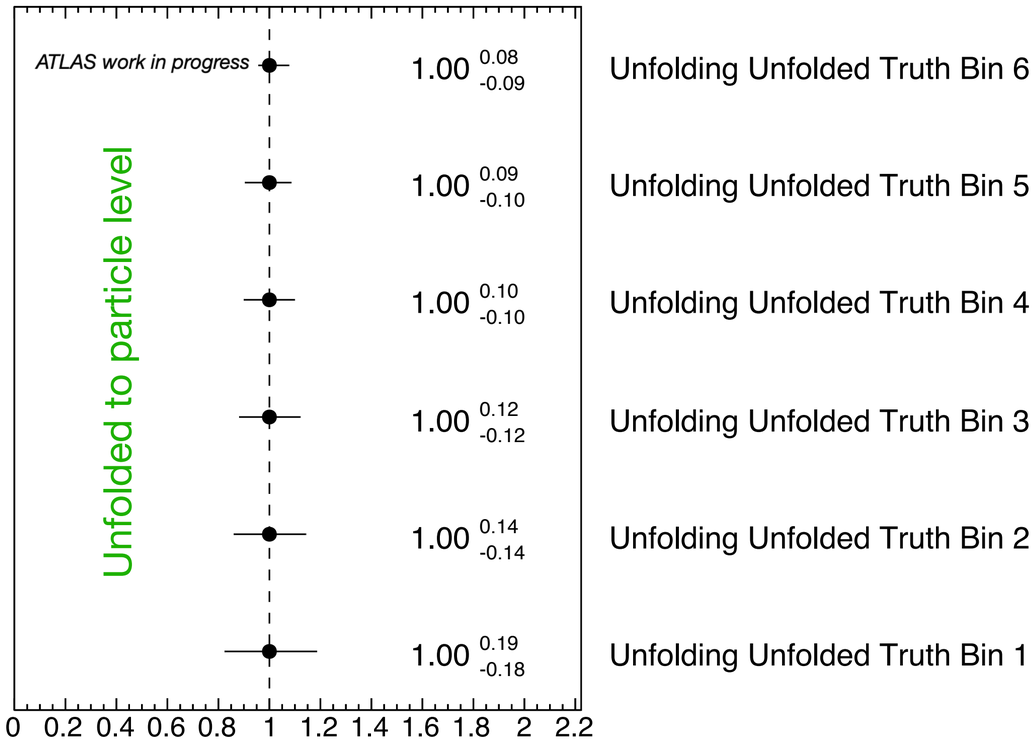
pre-fit CR other photons post-fit

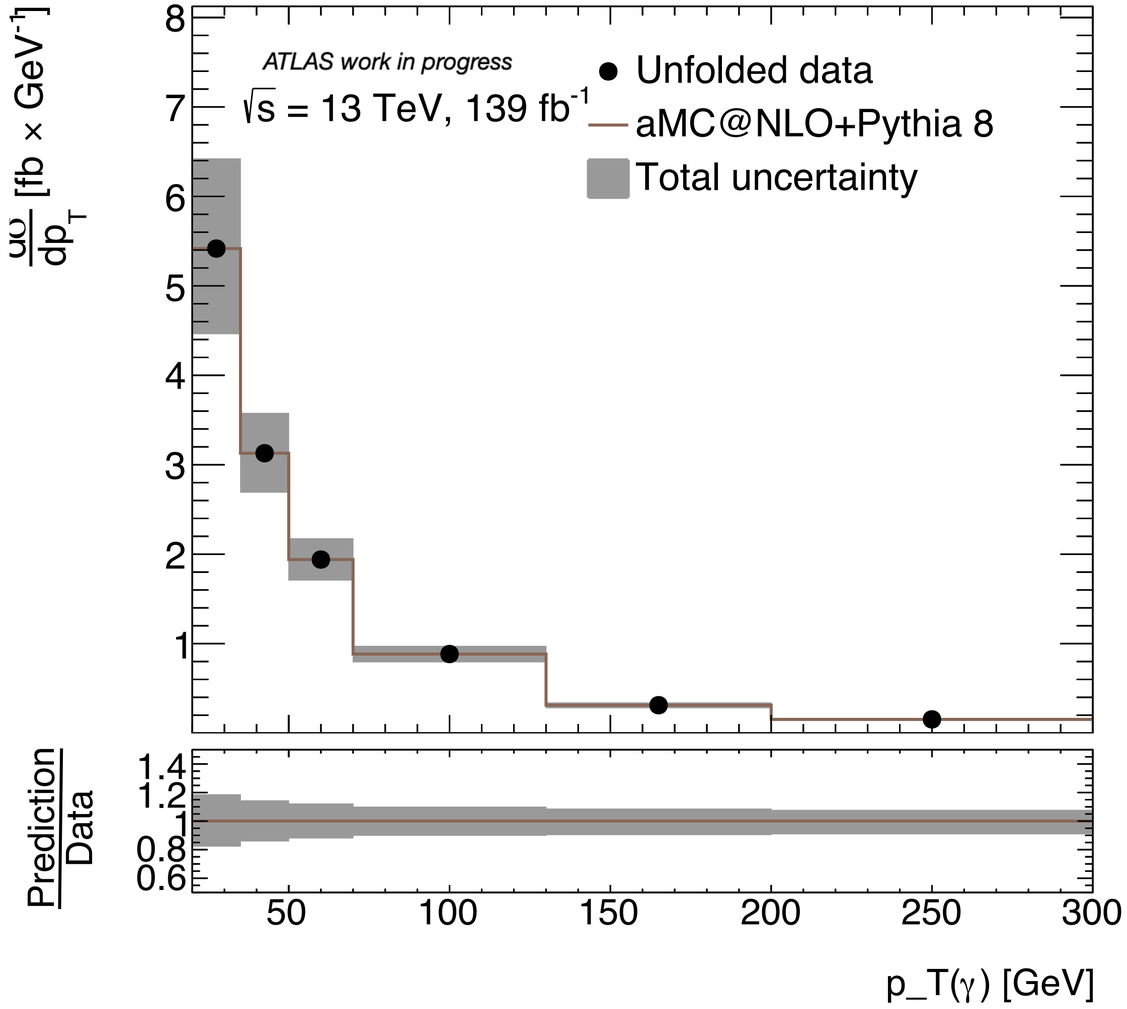




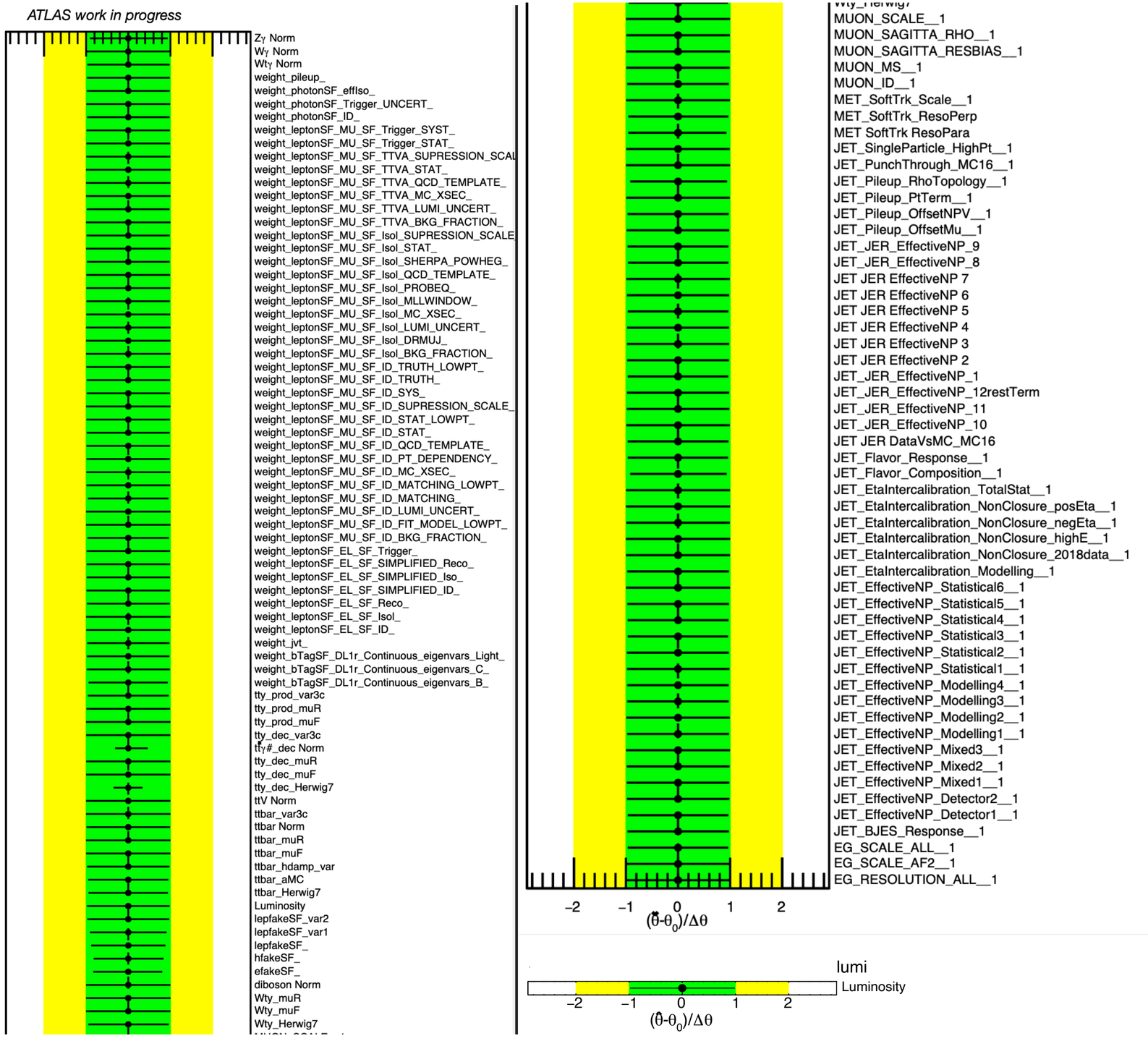
Unfolded distribution at particle level

- Fit performed to the Asimov dataset
- Uncertainties on norm factors ranges from 8% to 19%

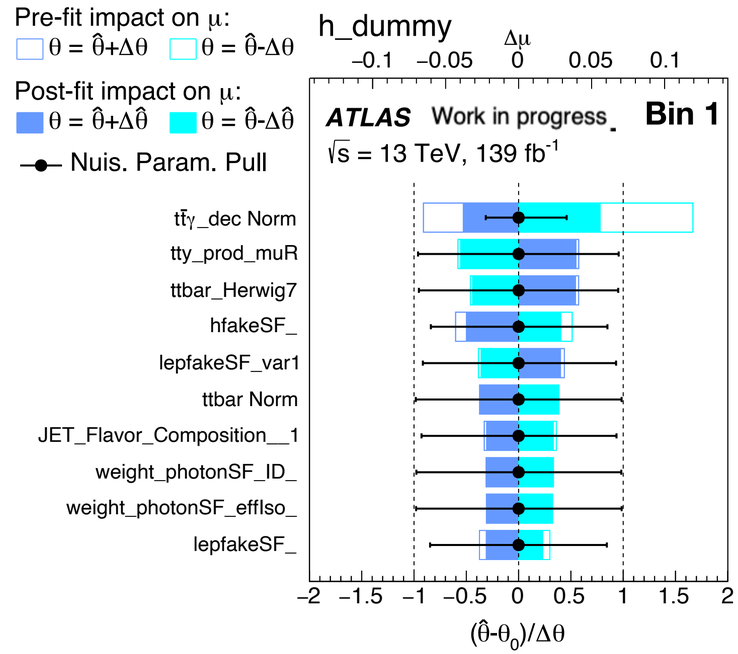


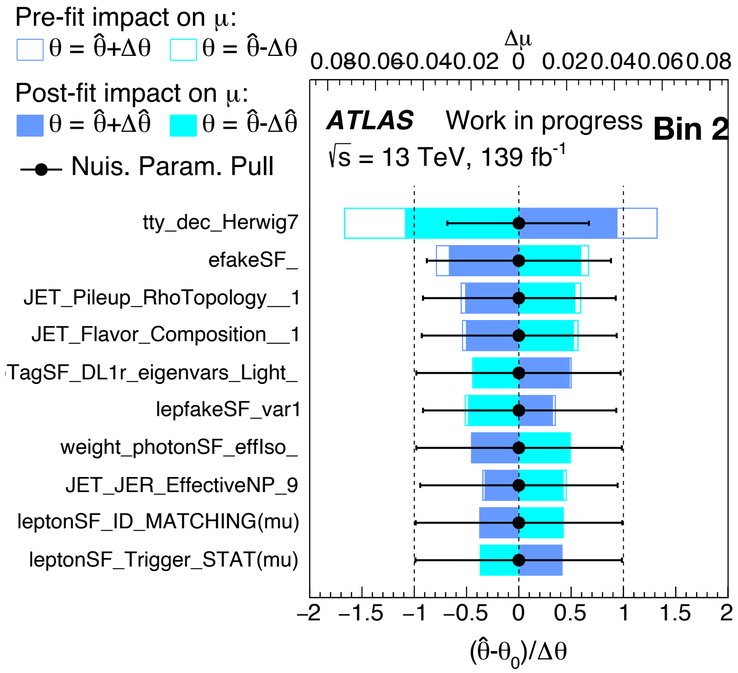


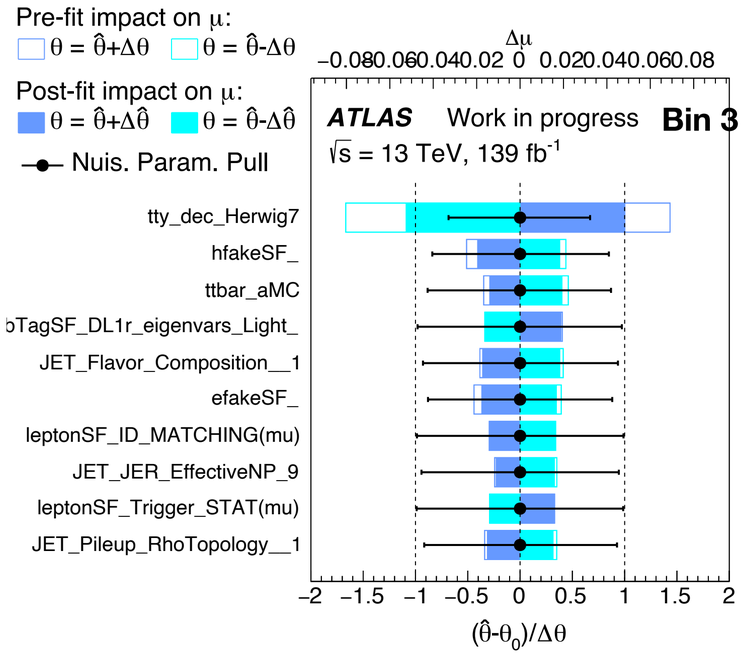
Nuisance parameters during fit

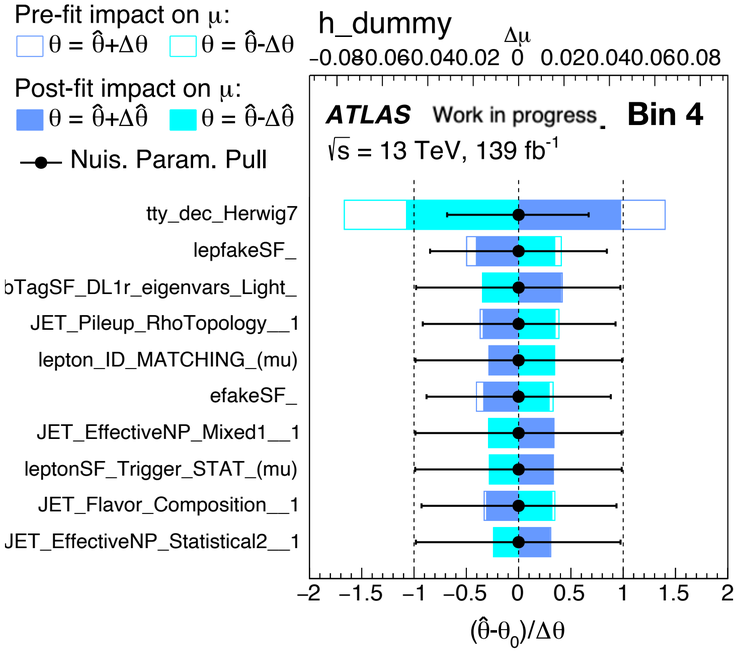


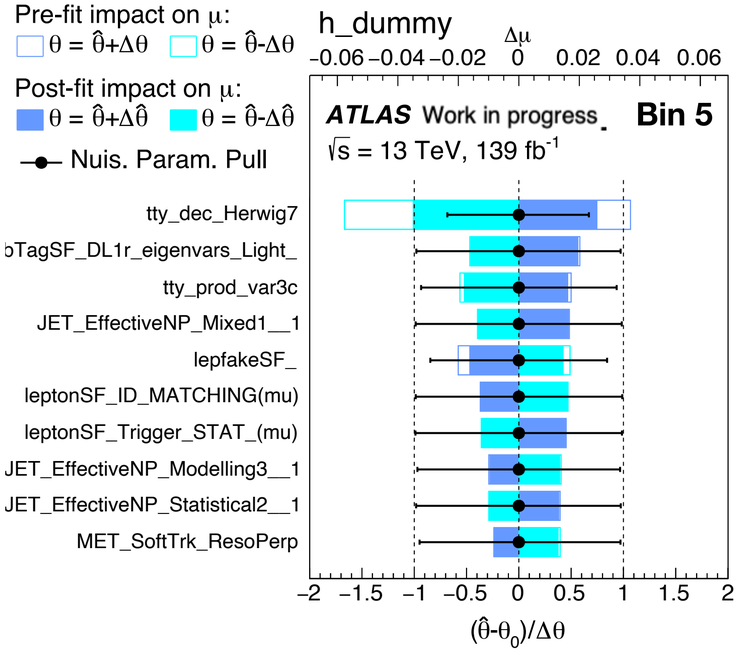
Ranking of nuisance parameters

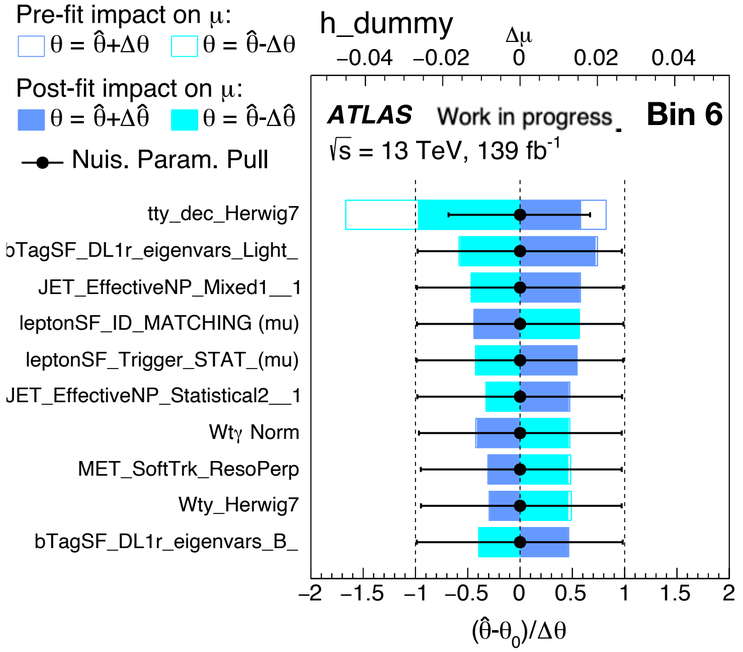








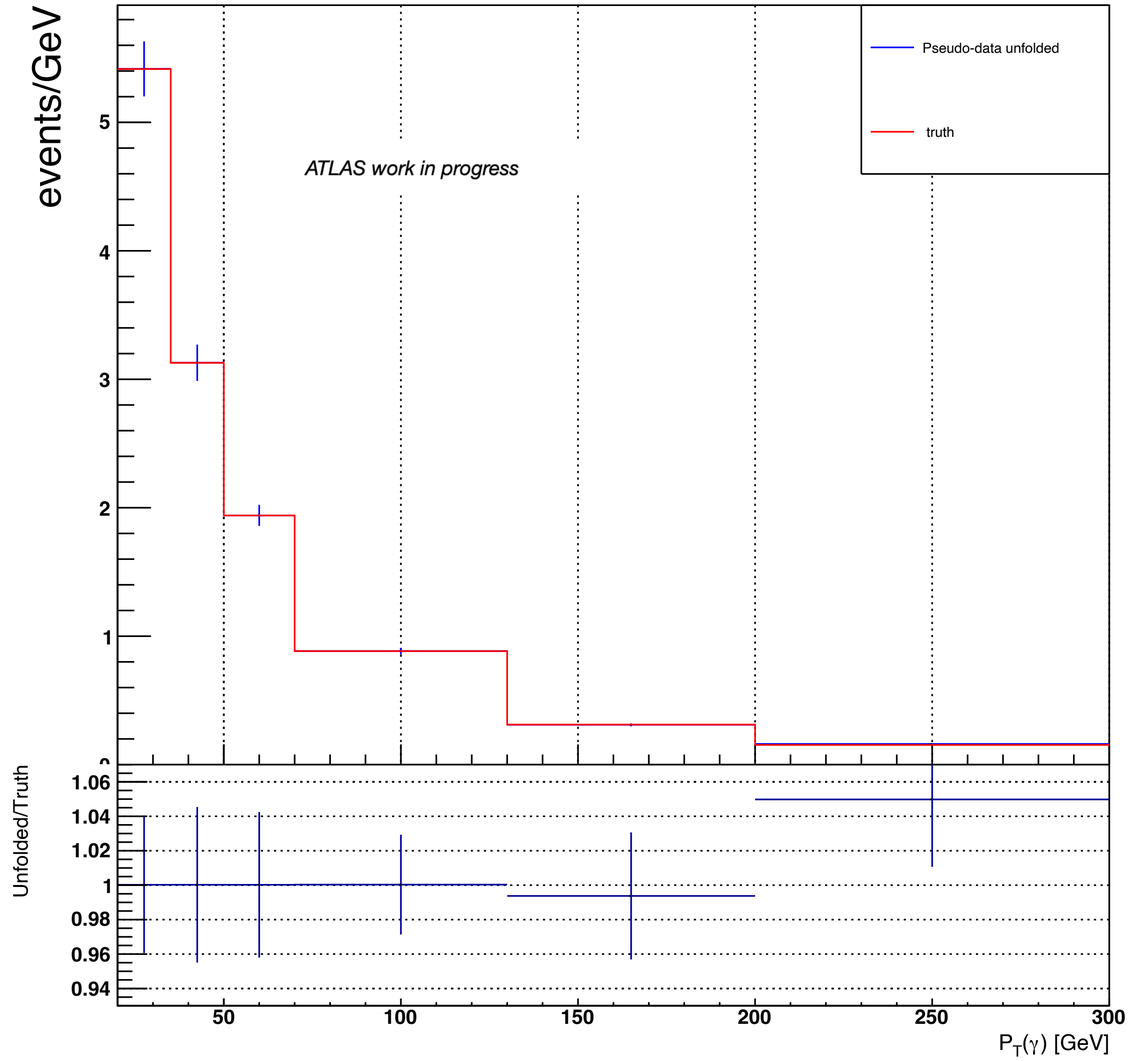




Unfolding tests

Closure test

- Aim is to identify any technical problems of the implementation of the procedure
- Pseudo-data (distribution at reconstruction level) unfolded using nominal MC sample and response matrix
- Unfolded spectra is compared with truth spectra
- Unfolding procedure perfectly corrects the detector response



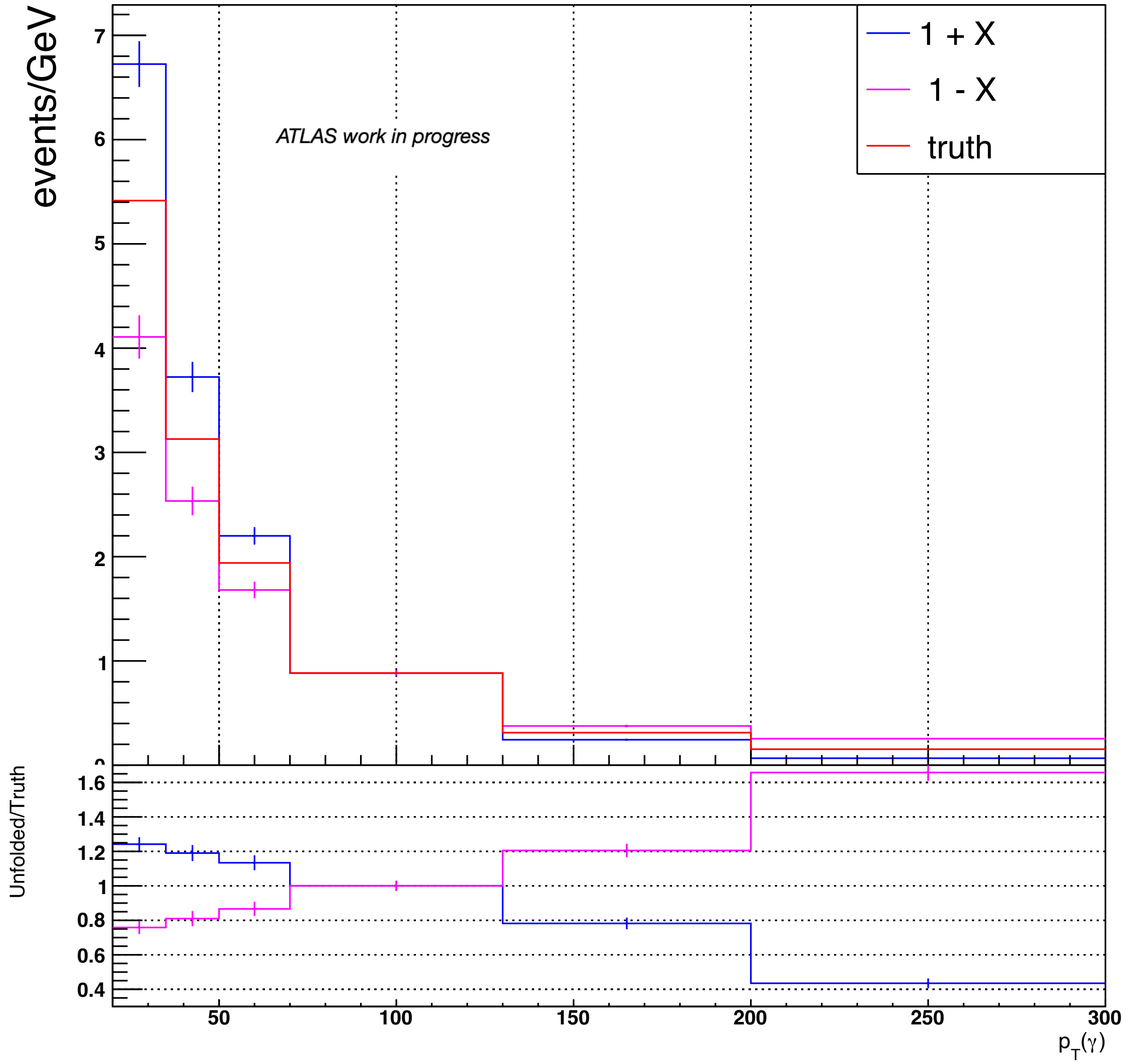
Unfolding tests

Stress test

- Aim is to check if unfolding procedure is biased to any specific shape
- Reco level signal distribution is reweighted

  weight = $1 + y \times \frac{100 - i}{300} = 1 + y \times X$

  where, i is the bin centre, y = -1, 1
- Reweighted pseudo-data distribution is unfolded using the nominal MC sample

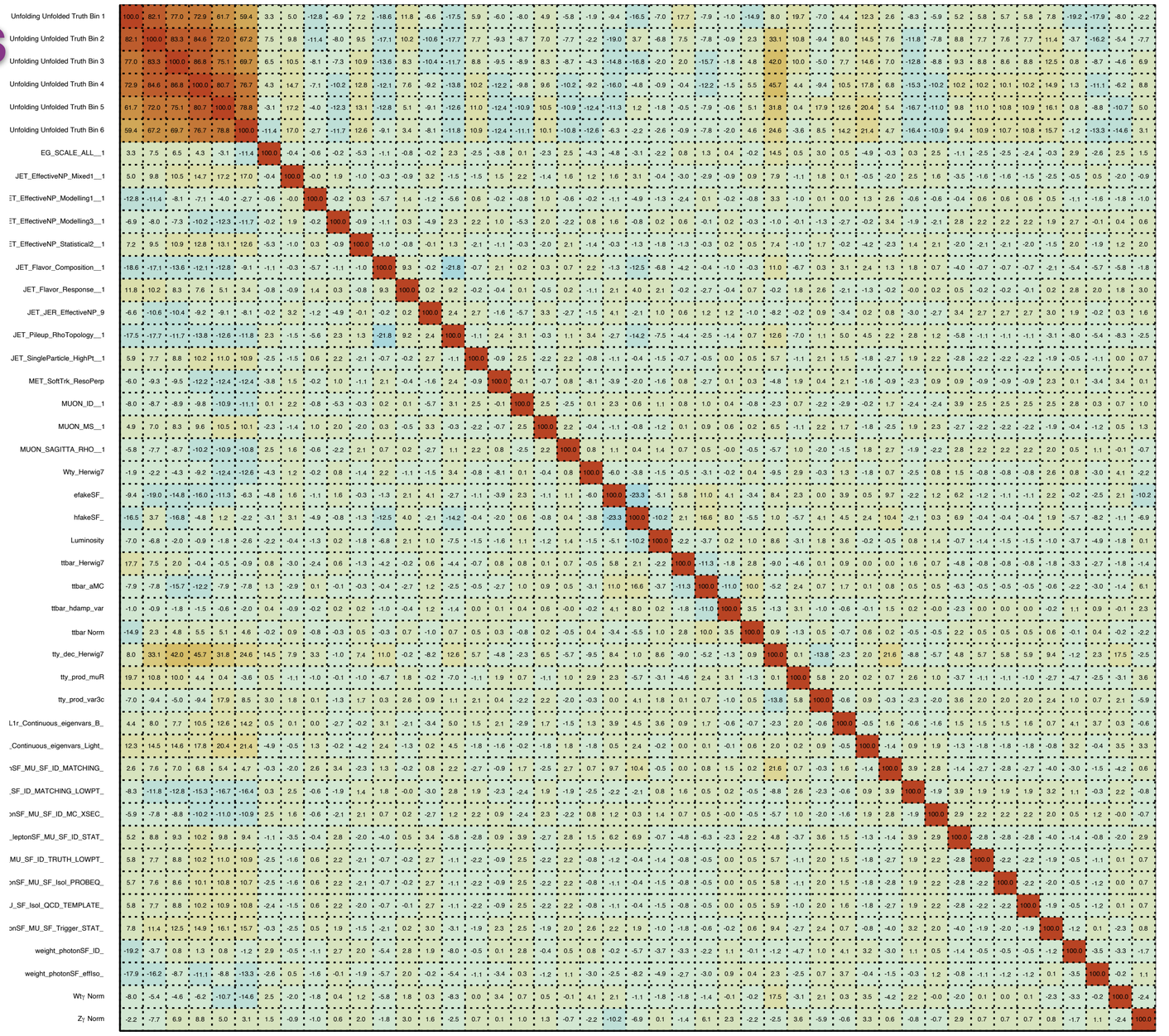


Summary

- Presented ongoing differential cross section measurement of $t\bar{t}\gamma$ process in single lepton channel using $139\ fb^{-1}$ data
- Measurement at particle-level in a fiducial region
- Results will be used to set limits on top-photon EFT coefficients

Backup

Correlation among NPs



Gamma factors