Measurement of differential $t\bar{t}\gamma$ cross sections at $\sqrt{s}$ = 13 TeV with the ATLAS detector and EFT interpretation

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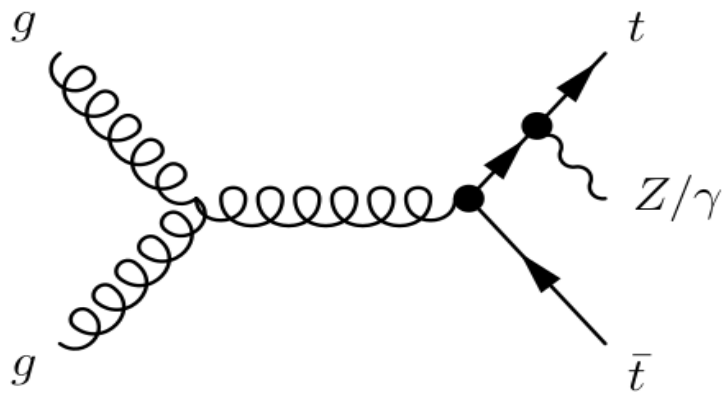
$t\bar{t}\gamma$ and EFT Interpretation

Aim : Measure differential $t\bar{t}\gamma$ cross section in lepton+jets channel with full run 2 data set.

$\sigma_{tt\gamma}$: Handle for the top quark and photon coupling $(t\gamma)$.

EFT is a model independent approach to probe the possible deviations from Standard Model.

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \frac{1}{\Lambda^2}\sum_i C_i O_i + \mathcal{O}\left(\Lambda^{-4}\right)$$



- $t\bar{t}\gamma$ vertices are sensitive to three Dimension-6 operators

$gt\bar{t}(O_{tG})$ and $t\bar{t}\gamma(O_{tB}, O_{tW})$

arXiv: 1601.08193

Results are shown using pseudo data for $\mathrm{p_T}(\gamma)$

$tt\gamma$ Sample

- MadGraph5_aMC@NLO
  - $tt\gamma$ NLO $2 \rightarrow 3$ where γ comes from production
  - $tt\gamma$ NLO Production $2 \rightarrow 3$ TEFT_EW UFO Model (EFT sample)

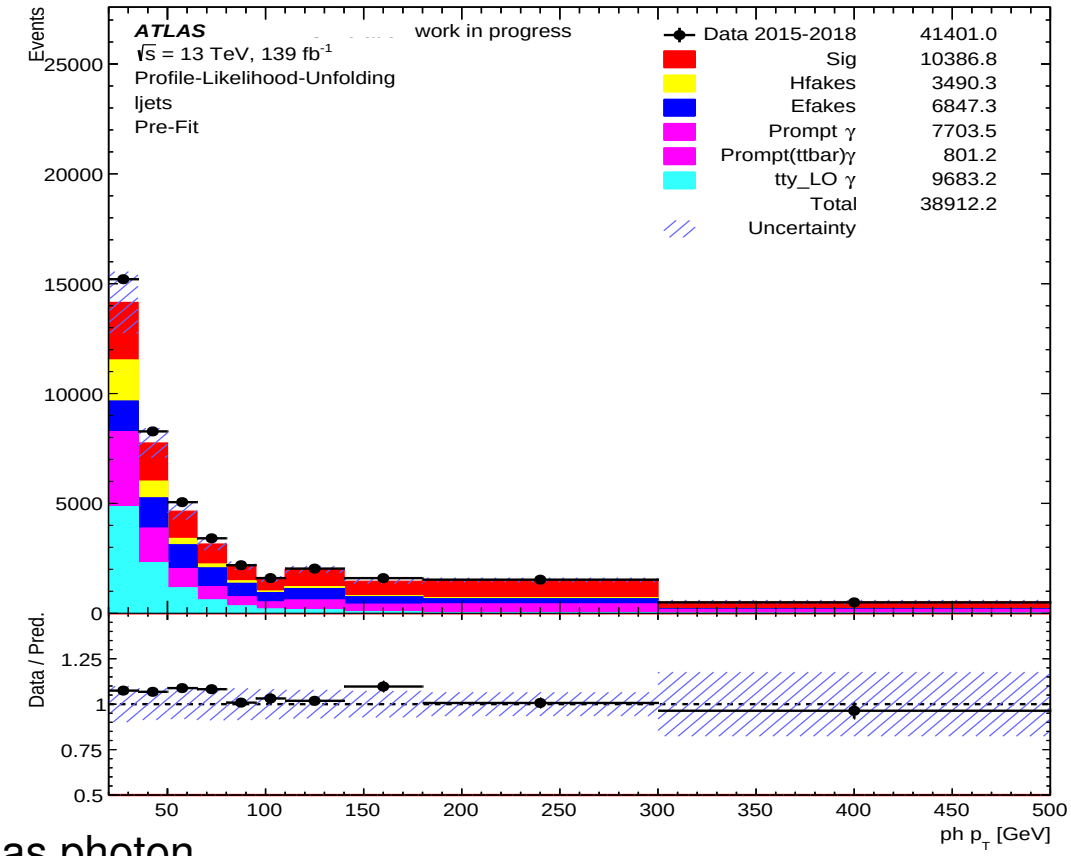
EFT Samples

- O_{tG} = $\pm$ 0.4 , O_{tB} = $\pm$ 4.6, O_{tW} = $\pm$ 1.8
  Current limits from arXiv: 1901.05965

- SM nearly zero value of operators in EFT model i.e $(\sim 0, \sim 0, \sim 0)$.
- EFT samples are:
  - O_{tG} = $\pm$ 0.4, $\pm$ 0.2, O_{tB} = $\pm$ 4.6, $\pm$ 2.3, O_{tW} = $\pm$ 1.8, $\pm$ 0.9
  - $(O_1, \sim 0 , \sim 0)$
  - $(O_1, O_2, \sim 0)$
  - (O_1, O_2 , O_3)

Event Selection

- Photon
  - exactly one photon with $p_T(\gamma)$ > 20 [GeV], (0< $|\eta(\gamma)|$ < 1.37) or (1.52 < $|\eta(\gamma)|$ < 2.37)
- Jets
  - at least 4 with $p_T(\mathrm{jet})$ > 25 [GeV], $|\eta(\mathrm{jet})|$< 2.37, at least b-tagged jet
- lepton
  - either 1 electon or muon with $p_T(\mathrm{lep})$ > 25 [GeV], $|\eta(\mathrm{lep})|$< 2.37
- ΔR(γ, jet) $\geqslant$ 0.4
- ΔR(γ, lep) $\geqslant$ 1.0
- m(γ, el) veto [85,95] GeV



Backgrounds:

Electron fakes: Electron mis-identified as photon

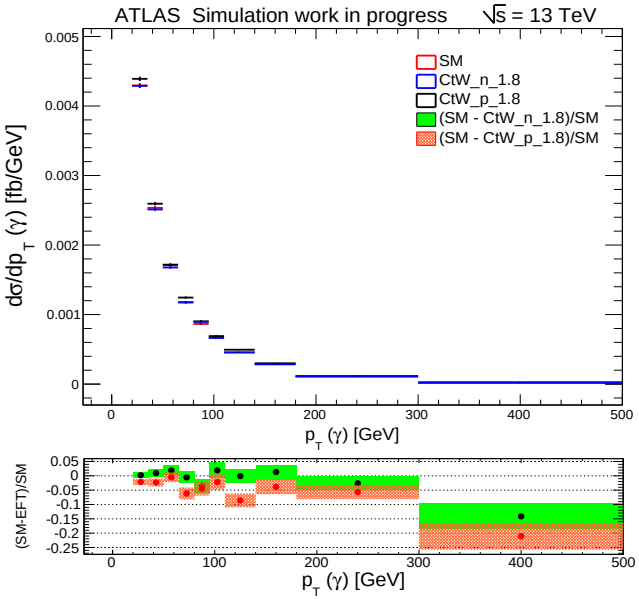
Hadron fakes: Photons from hadrons or mis-identified jets as photons

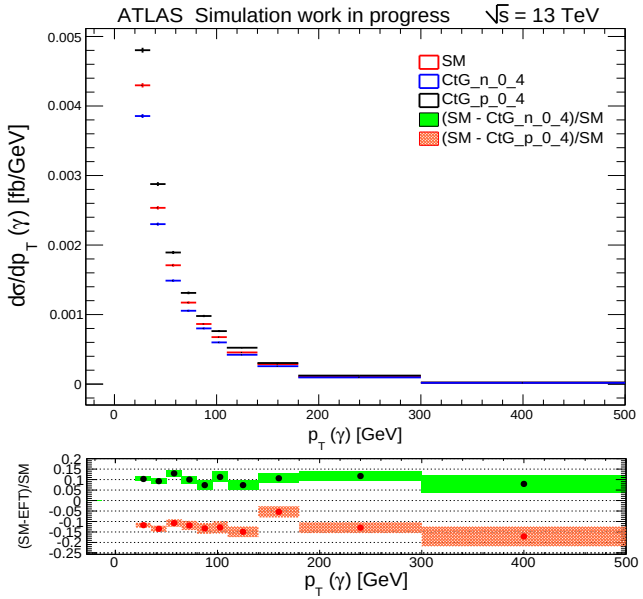
Prompt γ: Any background process with prompt photon e.g Wγ, Zγ or $t\bar{t}$

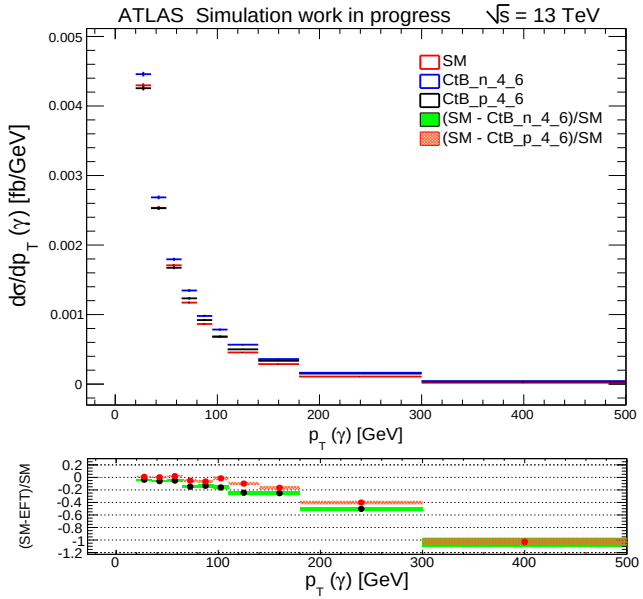
ttγ LO decay: Events where photon originated from either of top quark decay

SM and EFT samples: $\mathrm{P_T}(\gamma)$ distribution

- Photon kinematic variables are expected to be most sensitive to the EFT operator especially $\mathrm{P_T}(\gamma)$
- O_{tG} affects $gt\bar{t}$ vertex: mostly impact production rate







Profile Likelihood Unfolding (PLU)

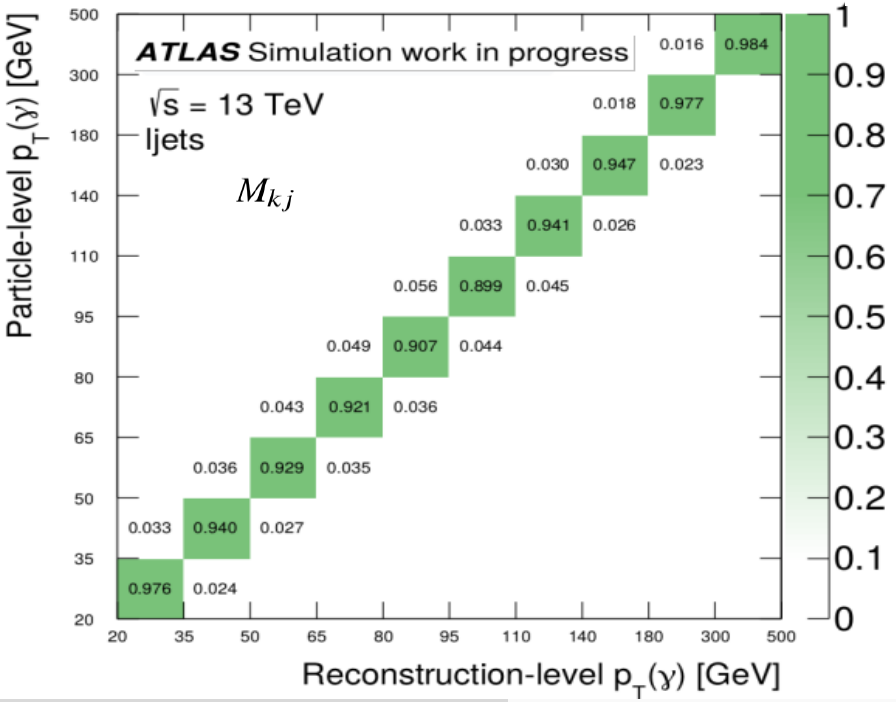
Differential cross section obtained using PLU

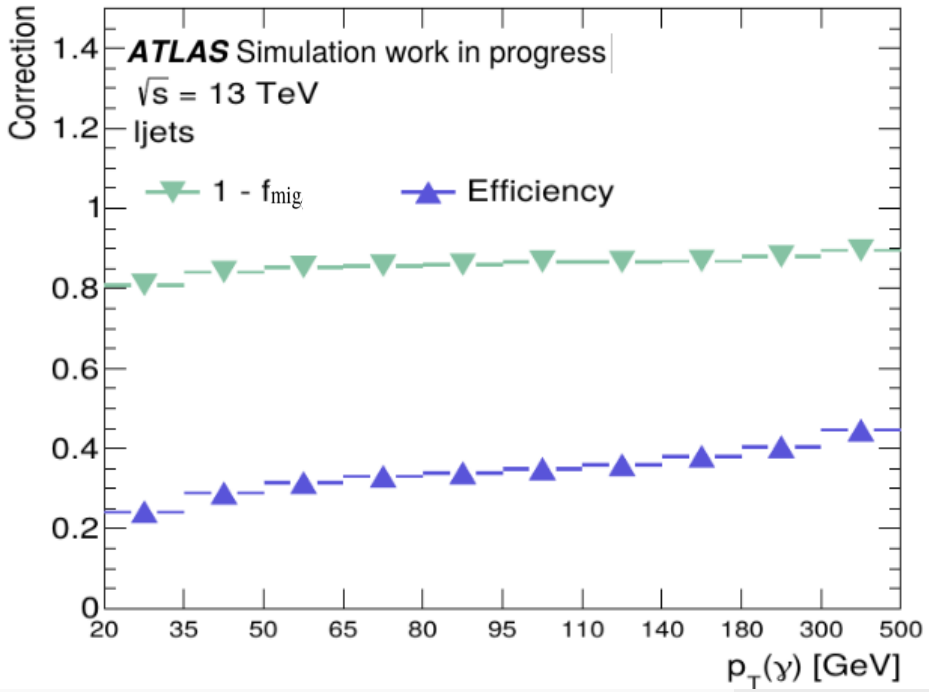
Likelihood:

$$\mathcal{L} = \prod_j \prod_i P(N_{i,j} | N^s_{i,j} + \sum_b N^b_{i,j}) \times \prod_t G(\vartheta | \theta_t, 1)$$

$$N_{\text{reco},j} = N_{\text{data},j} - N_{\text{bkgs},j}$$

$$N_{\text{reco},j} = \frac{1}{1 - f_{\text{mig},j}} \times \sum_k (L \times \sigma^{\text{diff}}_k \times \epsilon_k \times M_{kj})$$





Unfolding Tests

Stress Test:

Verifies independence of unfolding procedure to the shape of particle level distribution.
Adhoc reweighing method is used

weight = 1 + y $\cdot \frac{100-i}{500}$
= $1 + X$ while y = ± 1

Pull Test:

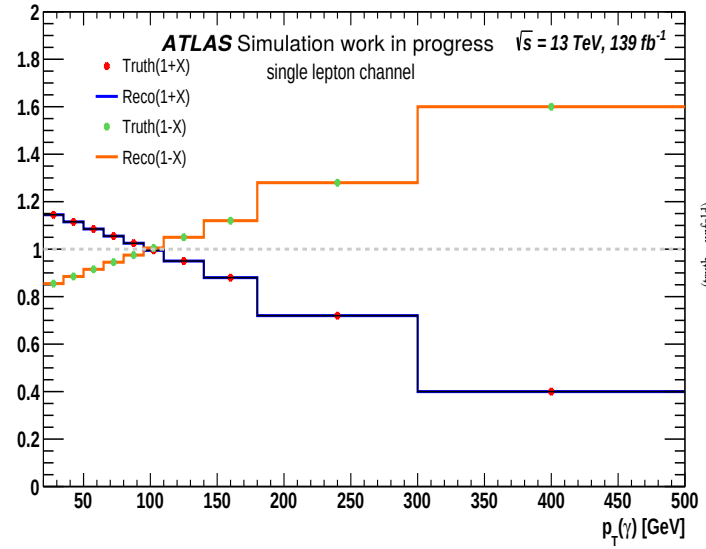
Indicates no bias
mean = 0
σ = 1
produced 10k Toys

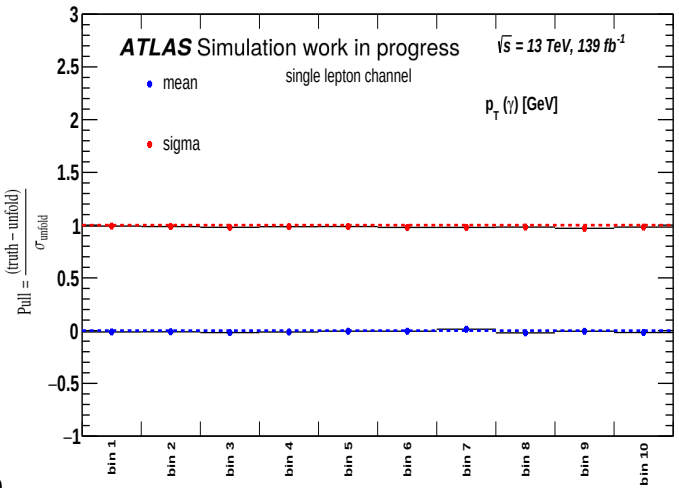
$$\text{Pull} = \frac{(\text{truth} - \text{unfold})}{\sigma_{\text{unfold}}}$$

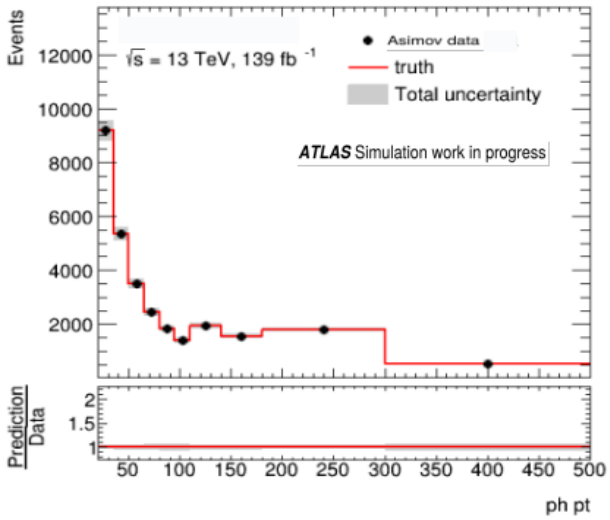
Closure Test:

recovers truth spectrum

i.e unfolding procedure works as expected

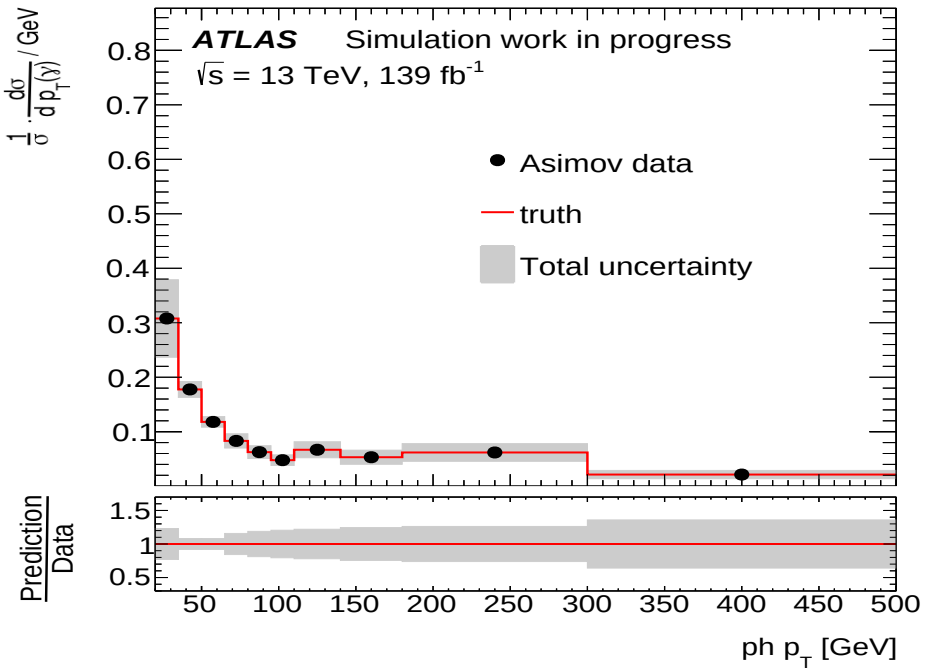


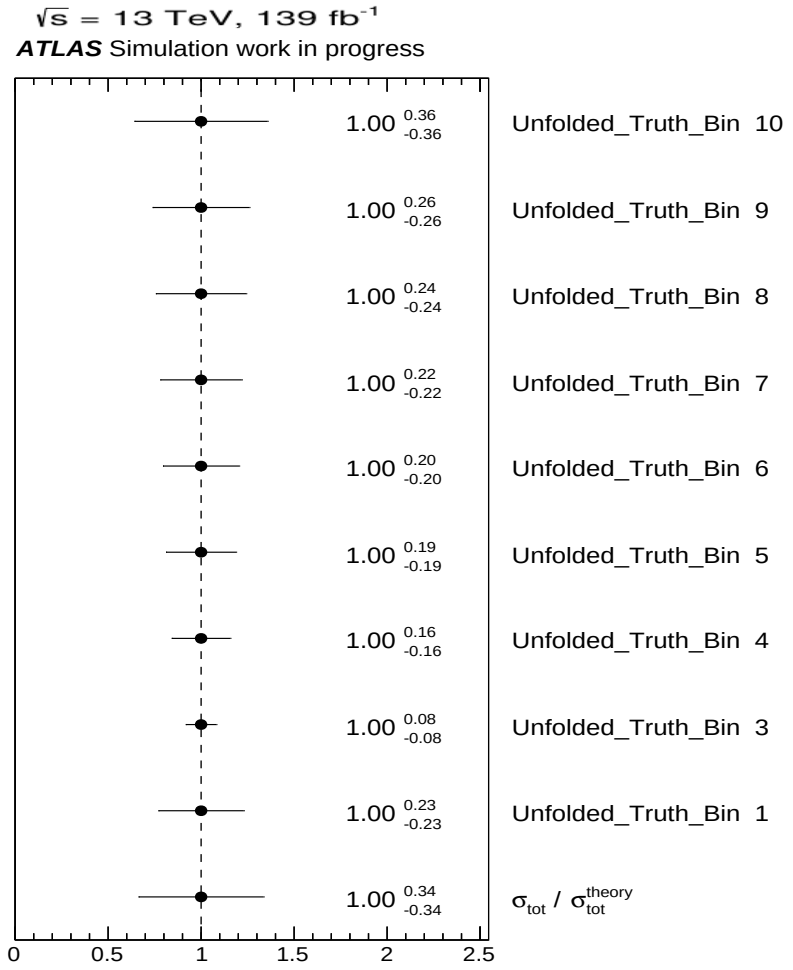




Normalized Differential Cross Section

- Systematic Uncertainties
  - $t\bar{t}\gamma$ modeling
  - Experimental (signal and background)
  - $t\bar{t}$ modeling
  - Background normalization $\pm 20\%$ except data driven fakes

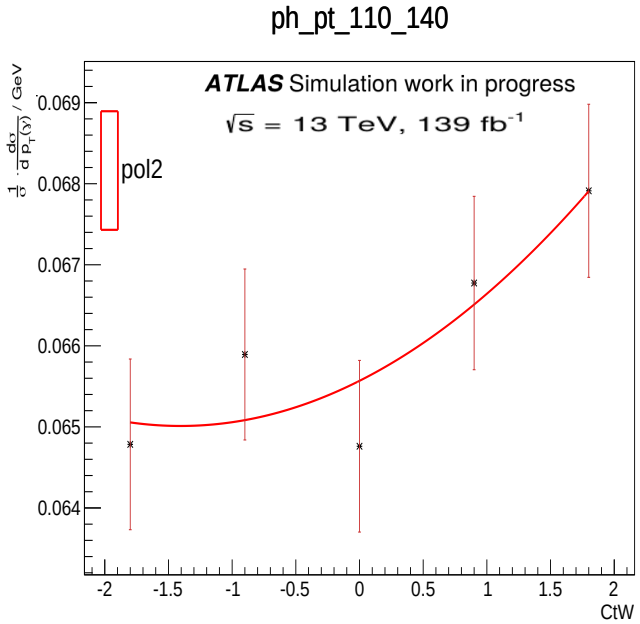


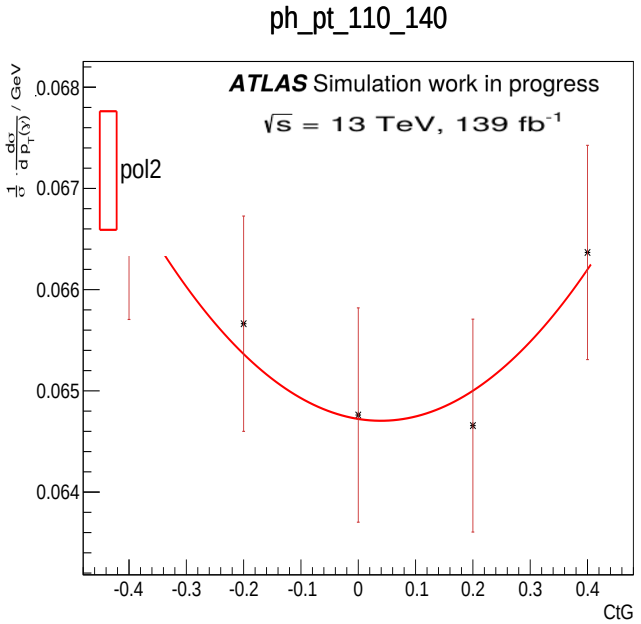


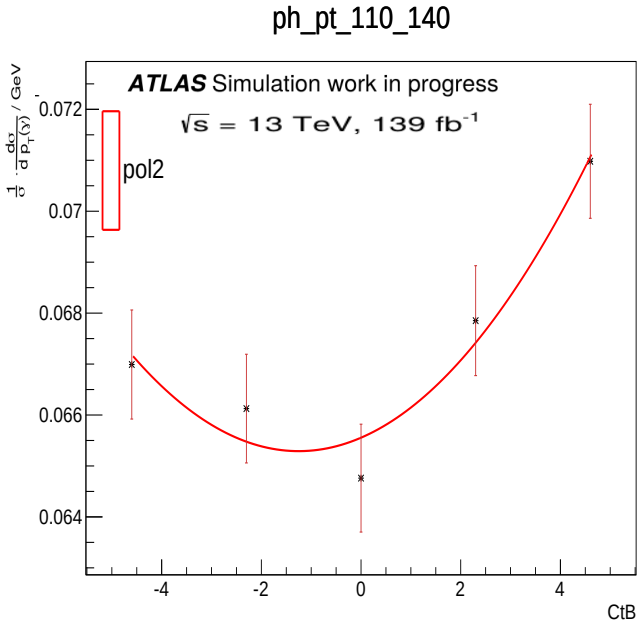
Parametrization

Effective Cross Section: $\sigma_{eff} = \sigma_{SM} + \frac{C_i}{\Lambda^2}.\sigma_i^{(1)} + \frac{C_i^2}{\Lambda^4}.\sigma_{ii}^{(2)}$

- Dependence of the normalized σ_{eff} is parameterized in each bin of $P_T(\gamma)$ and fit with polynomial of order 2.
- Example one $P_T(\gamma)$ bin for three operators.

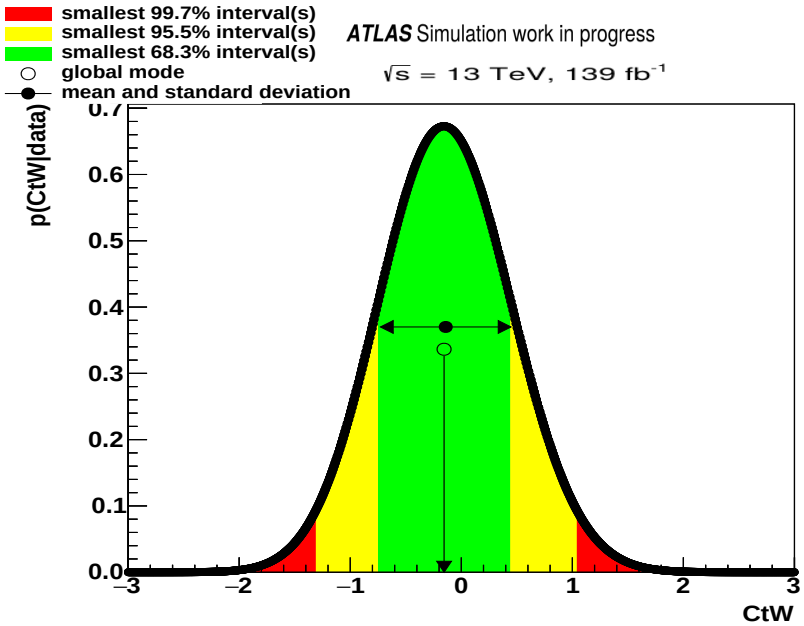




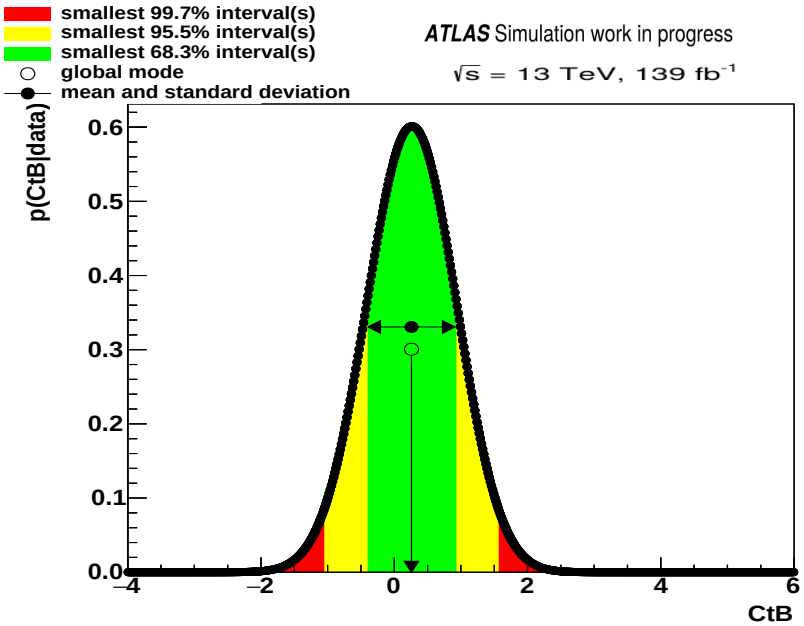


EFT Interpretation

Tool used: EFTfitter (arXiv: 1605.05585)



O_{tW} = [-0.8, 0.4]



O_{tB} = [-0.45, 1]

- Using Asimov results to estimate the sensitivity to each operator individually

Summary and Outlook

Summary

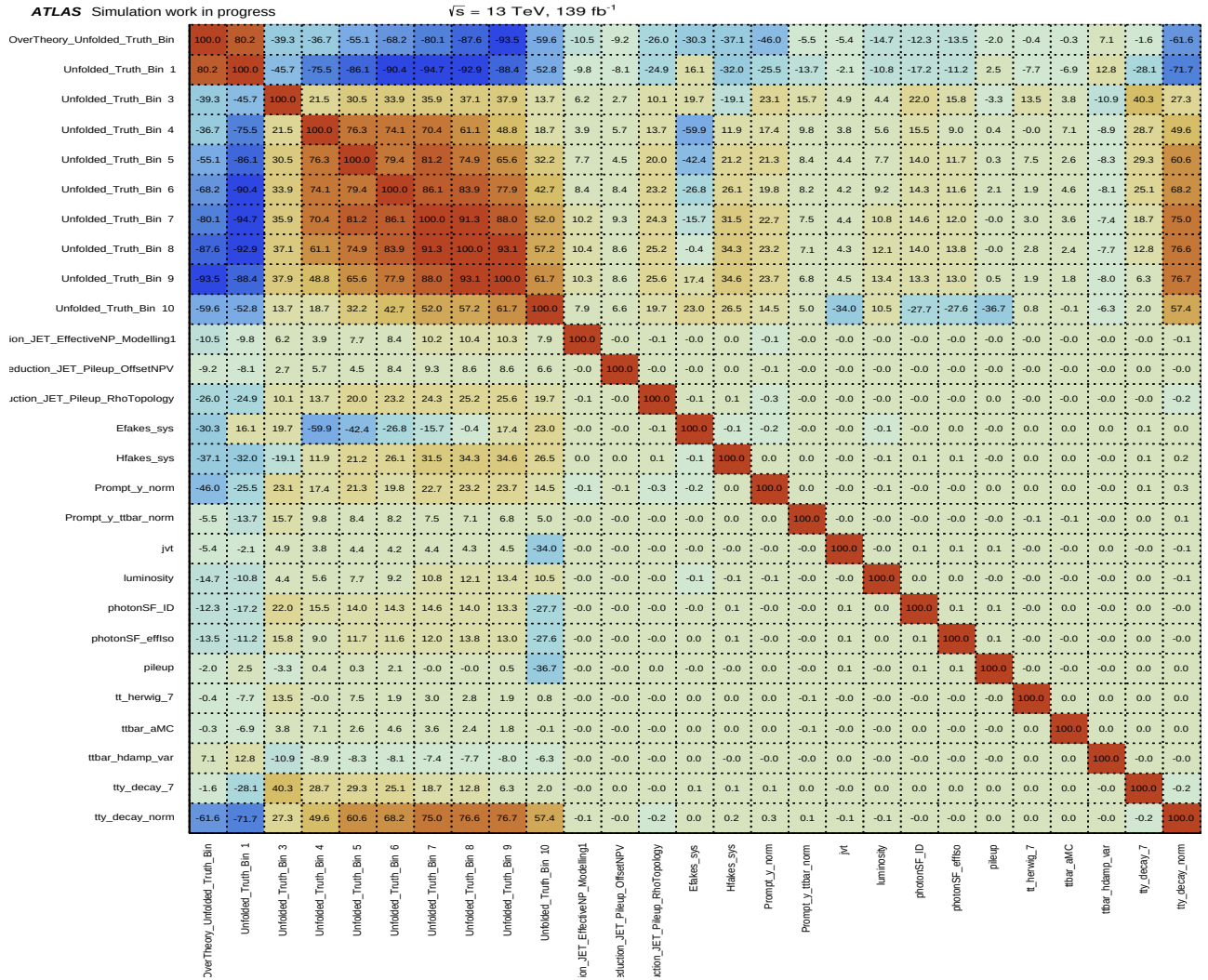
- Measurement of normalized differential cross section of ttγ in lepton + jets channel is done as a function of $P_T(\gamma)$.
  - Showing only Asimov results
  - Unfolding results are robust
- Sensitivity due to two dimension six operator O_{tW} and O_{tB} is estimated from Asimov data as a function of $P_T(\gamma)$.

Outlook

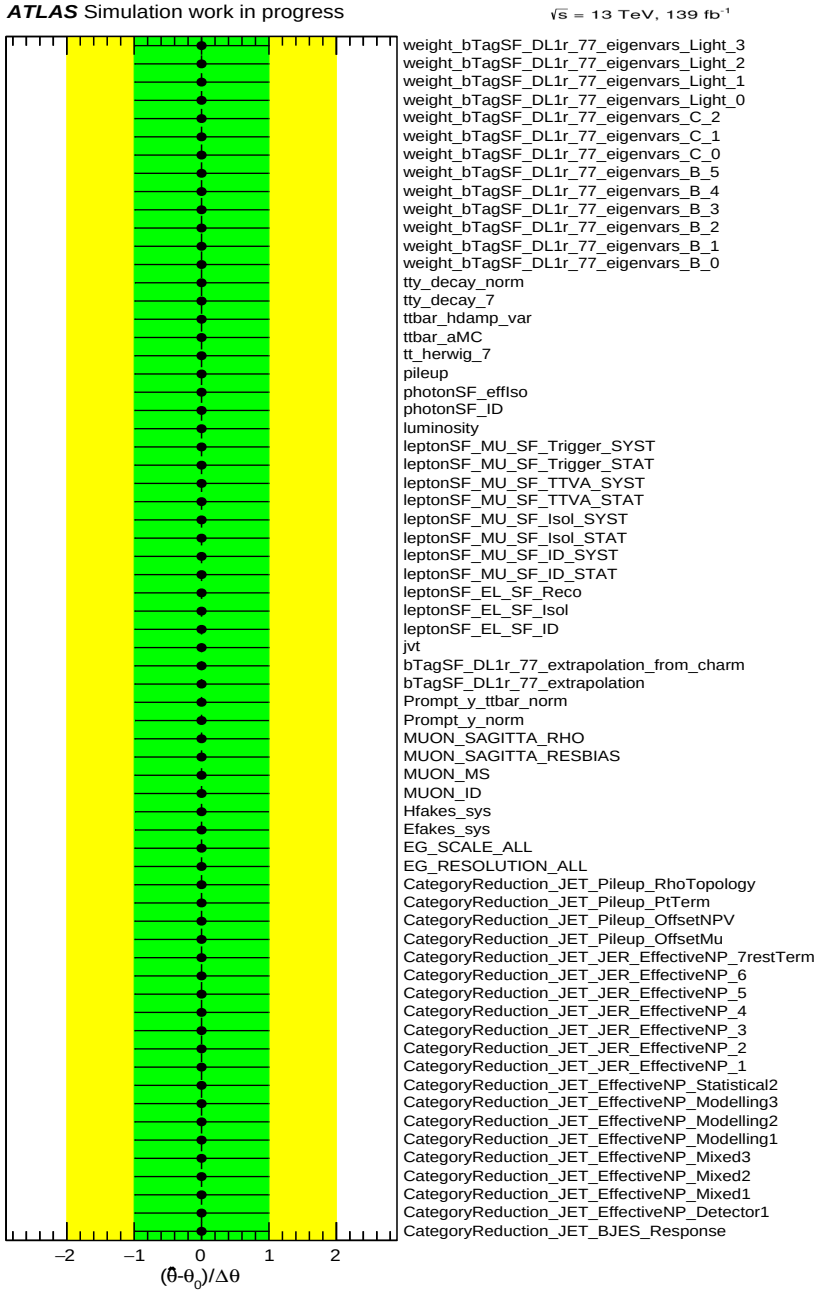
- Extend the study to perform simultaneous limit extraction of operators.

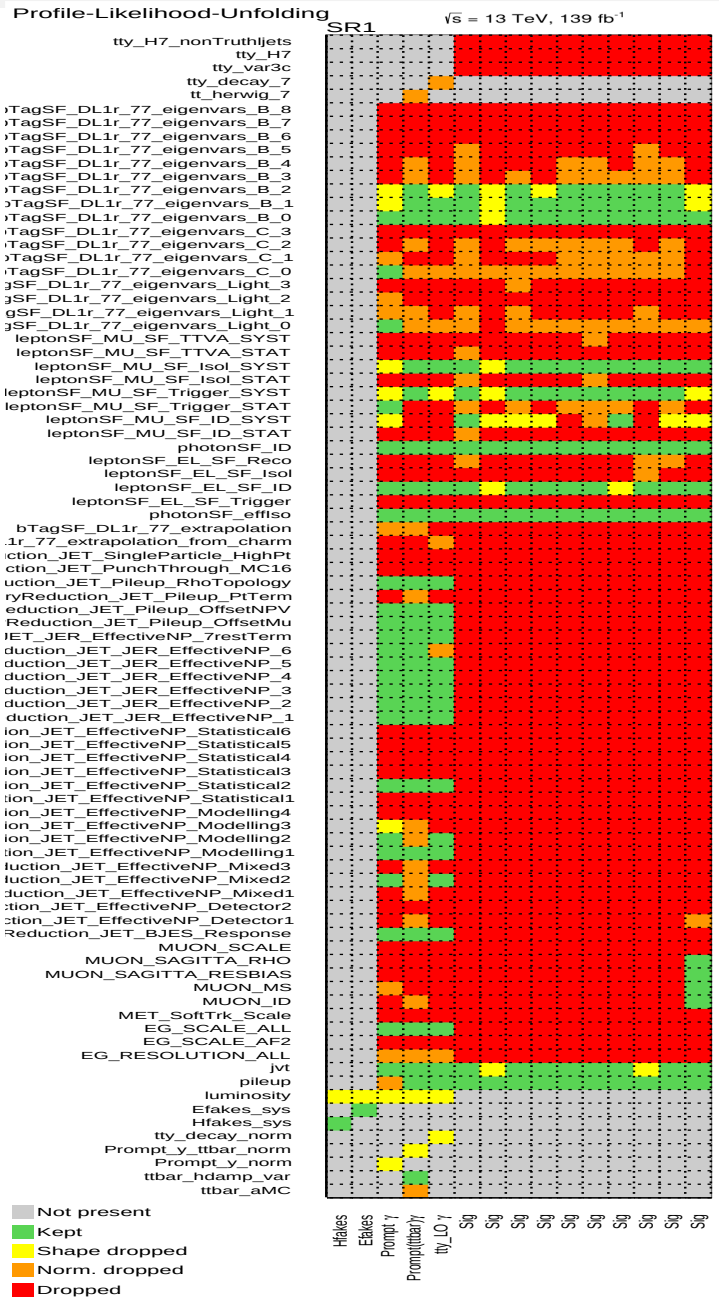
Backup

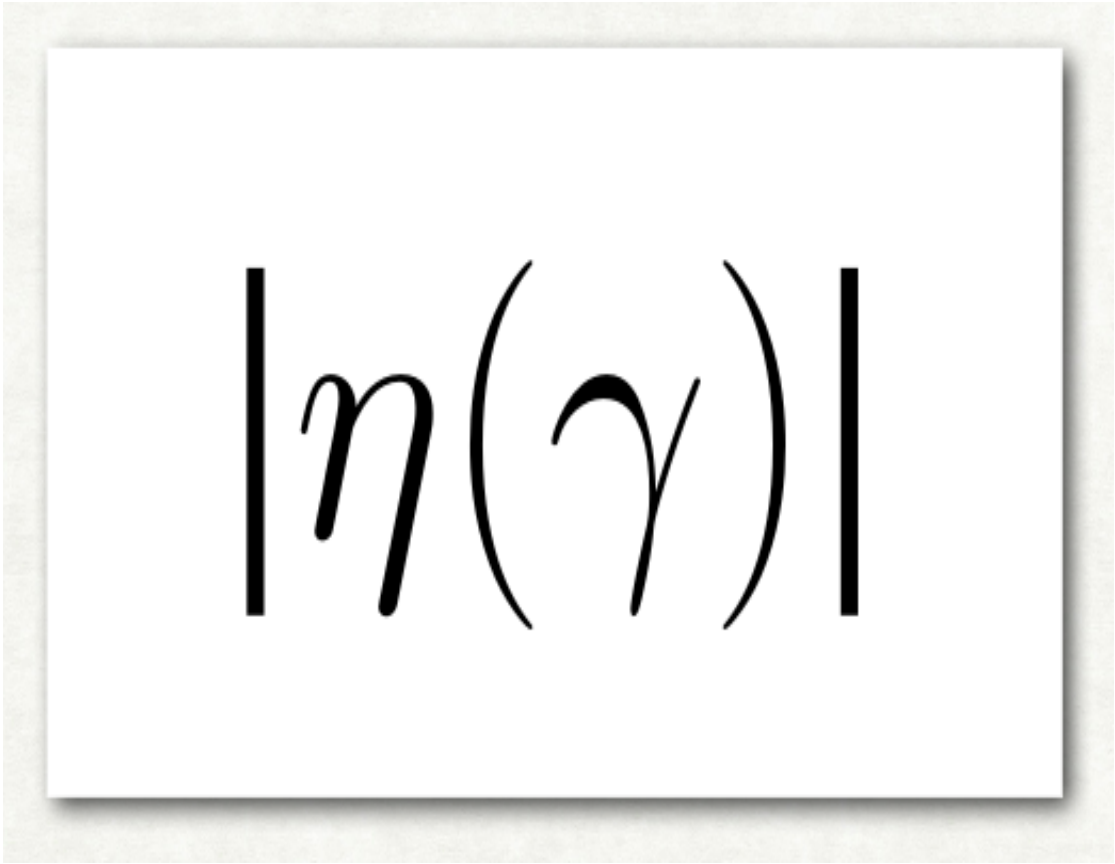
Correlation Matrix (0.1 % pruning)



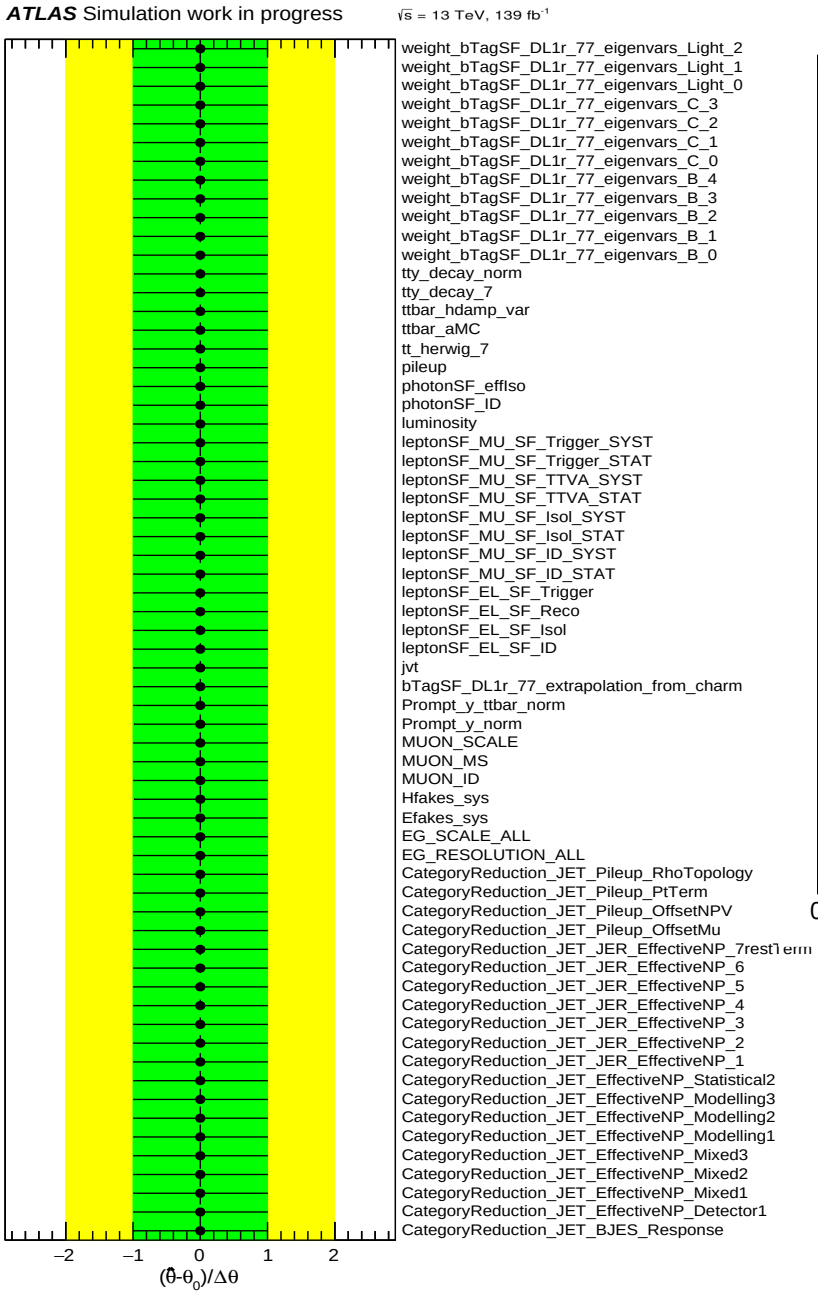
Nui. par. (0.1 % pruning) $P_T(\gamma)$

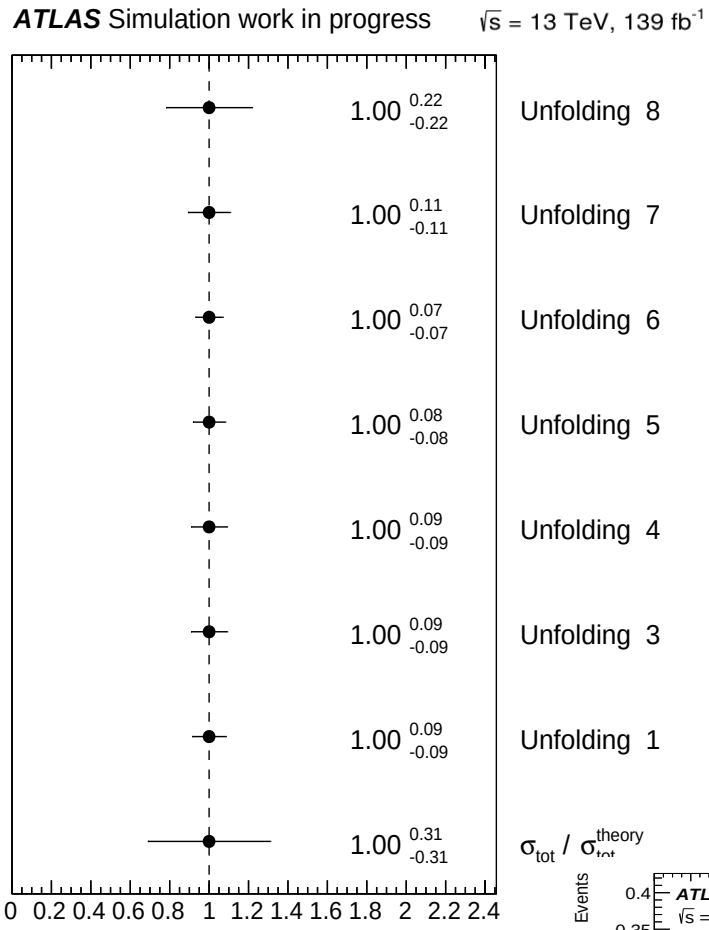


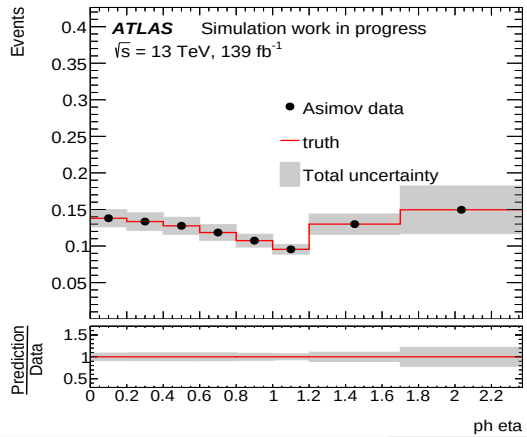


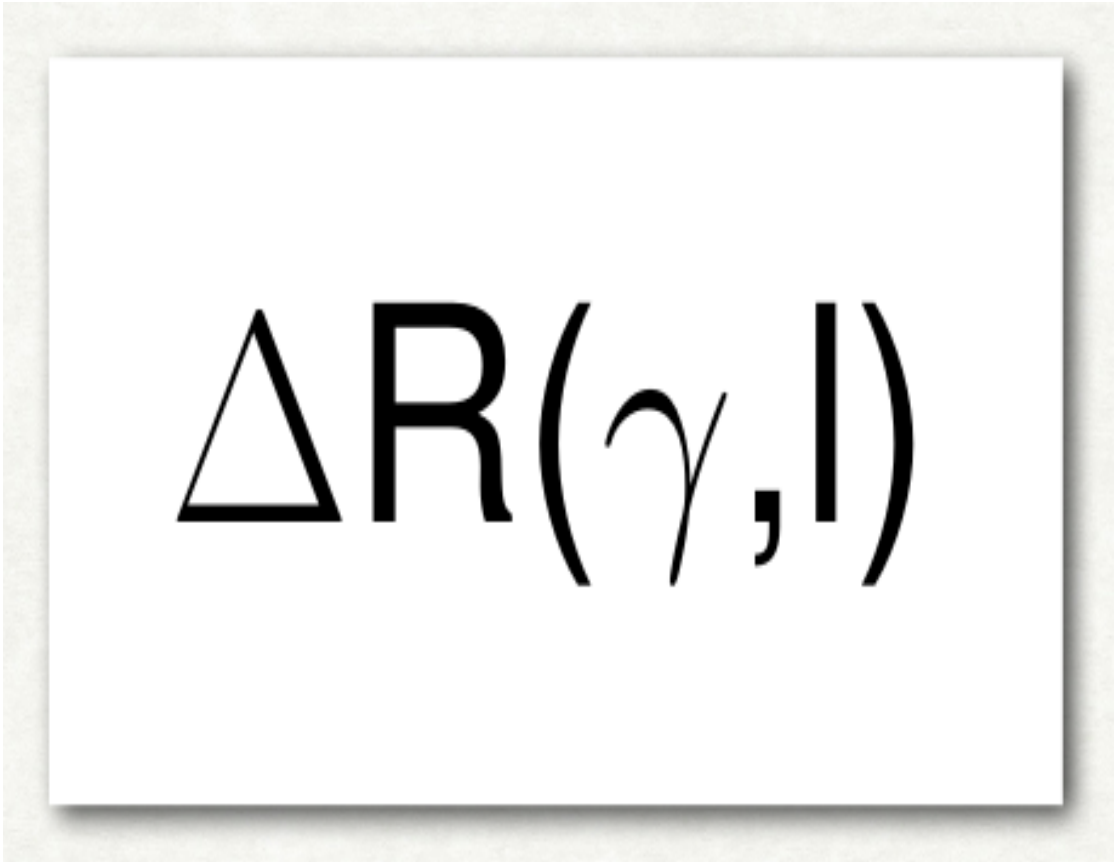

$|\eta(\gamma)|$

Nui. par. (0.1 % pruning) , Normalized Cross Section and Norm Factor








ΔR(γ,l)

Nui. par. (0.1 %) , Normalized Cross Section and Norm Factor