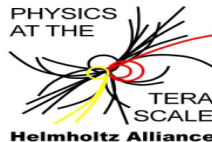


Measurement of differential $t\bar{t}\gamma$ cross sections at $\sqrt{s} = 13$ TeV with the ATLAS detector and EFT interpretation

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Bundesministerium
für Bildung
und Forschung



Aim : Measure differential tt γ cross section in lepton+jets channel with full run 2 data set.

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

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

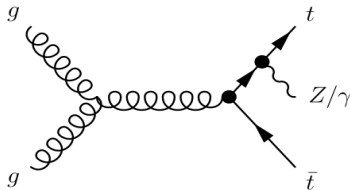
$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \frac{1}{\Lambda^2} \sum_i C_i O_i + \mathcal{O}(\Lambda^{-4})$$

- ▶ tt γ 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 p $_T$ (γ)



- ▶ 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 $p_T(\text{jet}) > 25$ [GeV], $|\eta(\text{jet})| < 2.37$, at least b-tagged jet
- ▶ lepton
 - ▶ either 1 electron or muon with $p_T(\text{lep}) > 25$ [GeV], $|\eta(\text{lep})| < 2.37$
- ▶ $\Delta R(\gamma, \text{jet}) \geq 0.4$
- ▶ $\Delta R(\gamma, \text{lep}) \geq 1.0$
- ▶ $m(\gamma, e\ell)$ veto [85,95] GeV

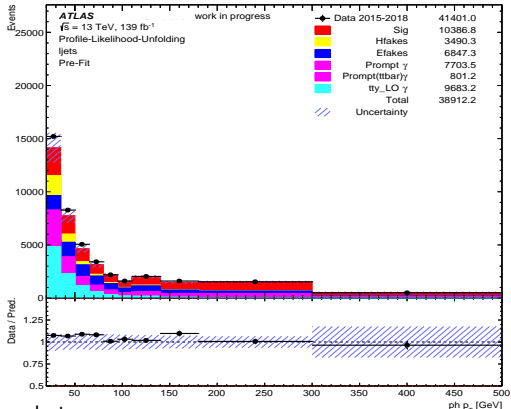
Backgrounds:

Electron fakes: Electron mis-identified as photon

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

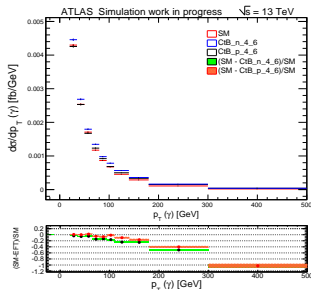
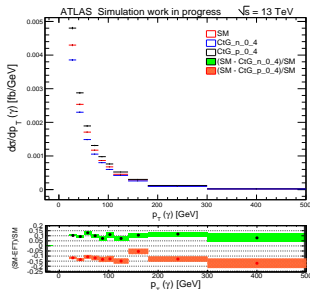
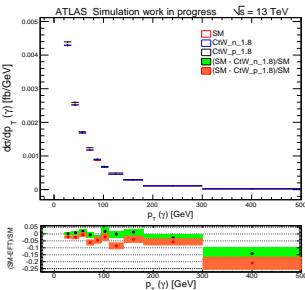
Prompt γ : Any background process with prompt photon e.g $W\gamma$, $Z\gamma$ or $t\bar{t}$

$t\bar{t}$ LO decay: Events where photon originated from either of top quark decay



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

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

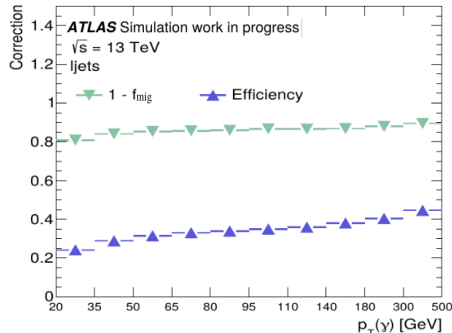
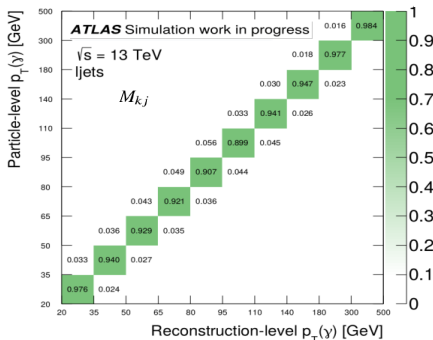


Differential cross section obtained using PLU

Likelihood:
$$\mathcal{L} = \prod_j \prod_i P(N_{i,j} | N_{i,j}^s + \sum_b N_{i,j}^b) \times \prod_t G(\vartheta | \theta_t, 1)$$

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

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

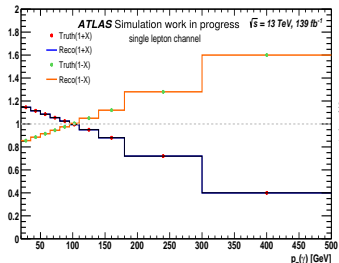


Stress Test:

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

$$\text{weight} = 1 + y \cdot \frac{100 - i}{500}$$

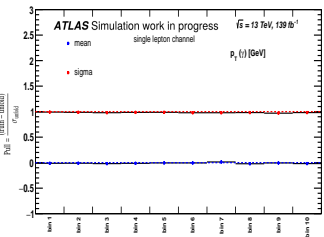
$$= 1 + X \text{ while } y = \pm 1$$



Pull Test:

Indicates no bias
mean = 0
 $\sigma = 1$
produced 10k Toys

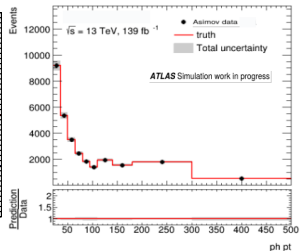
$$\text{Pull} = \frac{(\text{truth} - \text{unfold})}{\sigma_{\text{unfold}}}$$



Closure Test:

recovers truth spectrum

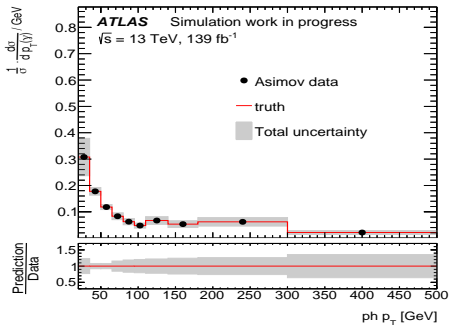
i.e unfolding procedure works as expected



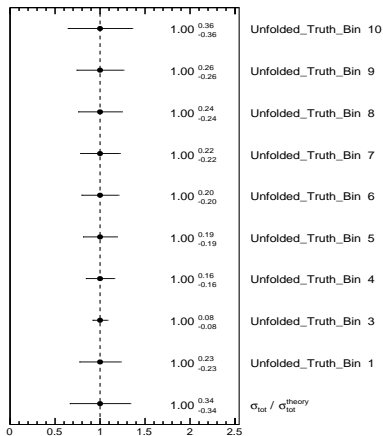
Normalized Differential Cross Section

Systematic Uncertainties

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



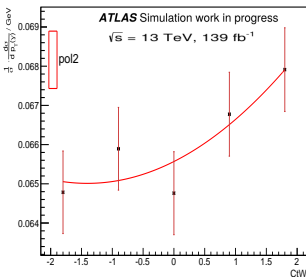
$\sqrt{s} = 13 \text{ TeV}, 139 \text{ fb}^{-1}$
ATLAS Simulation work in progress



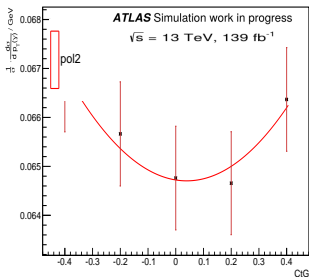
$$\text{Effective Cross Section: } \sigma_{eff} = \sigma_{SM} + \frac{C_i}{\Lambda^2} \cdot \sigma_i^{(1)} + \frac{C_i^2}{\Lambda^4} \cdot \sigma_{ii}^{(2)}$$

- ▶ 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.

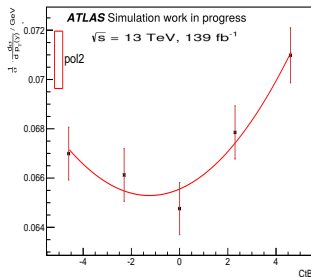
ph_pt_110_140

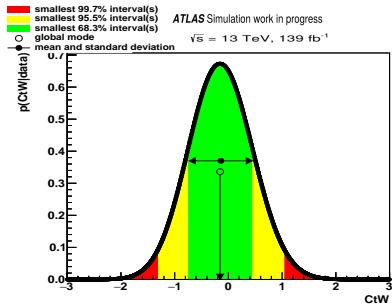


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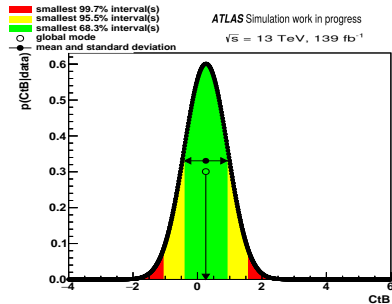


ph_pt_110_140





$$O_{tW} = [-0.8, 0.4]$$



$$O_{tB} = [-0.45, 1]$$

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

Summary

- ▶ Measurement of normalized differential cross section of $t\bar{t}\gamma$ 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

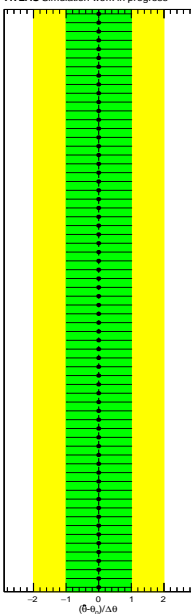
- ▶ Extend the study to perform simultaneous limit extraction of operators.

Backup

Nui. par. (0.1 % pruning, $P(\gamma)$)

ATLAS Simulation work in progress

$\sqrt{s} = 13 \text{ TeV}, 139 \text{ fb}^{-1}$



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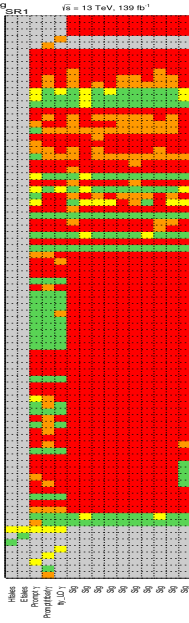
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```

Profile-Likelihood-Unfolding

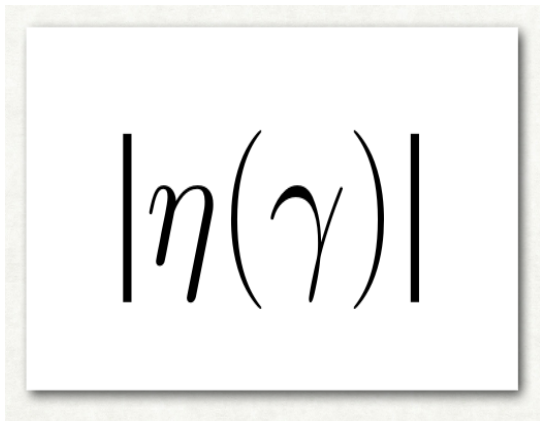
$\sqrt{s} = 13 \text{ TeV}, 139 \text{ fb}^{-1}$

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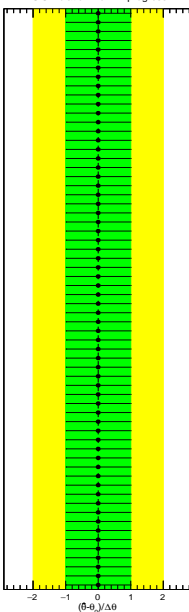
■ Not present
■ Kept
■ Shapes dropped
■ Norm. dropped
■ Dropped



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

ATLAS Simulation work in progress

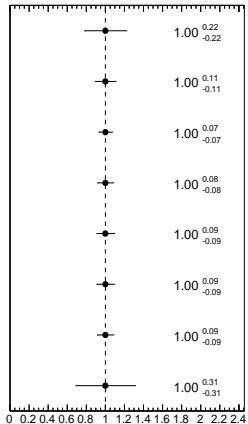
$\sqrt{s} = 13 \text{ TeV}, 139 \text{ fb}^{-1}$



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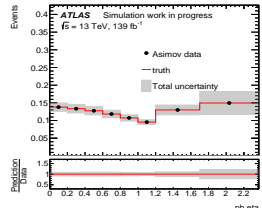
ATLAS Simulation work in progress

$\sqrt{s} = 13 \text{ TeV}, 139 \text{ fb}^{-1}$



- Unfolding 8
- Unfolding 7
- Unfolding 6
- Unfolding 5
- Unfolding 4
- Unfolding 3
- Unfolding 1

$\sigma_{tot} / \sigma_{theory}$

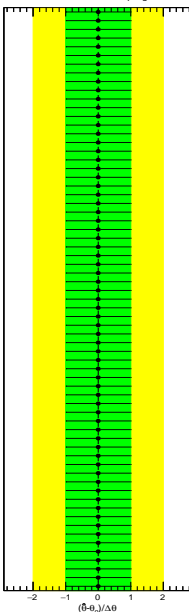


$$\Delta R(\gamma, l)$$

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

ATLAS Simulation work in progress

$\sqrt{s} = 13 \text{ TeV}, 139 \text{ fb}^{-1}$



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ATLAS Simulation work in progress

$\sqrt{s} = 13 \text{ TeV}, 139 \text{ fb}^{-1}$

