Measurements of inclusive and differential cross-sections of combined $t\bar{t}\gamma$ and $tW\gamma$ production in the $e\mu$ channel at $\sqrt{s} = 13$ TeV with the ATLAS experiment

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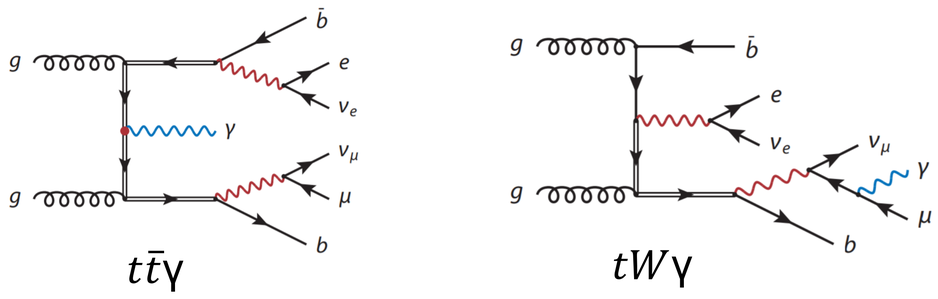
Introduction

- Precise measurement of top-quark pair production in association with a photon **probes the top-photon electroweak coupling**
- Measurements of **fiducial inclusive** and **differential $t\bar{t}\gamma$ + $tW\gamma$** cross-sections [1]
  - in the $e\mu$ channel, **cleanest $t\bar{t}$ decay channel**
  - at **parton level**, to allow **comparison with the most recent theory prediction**



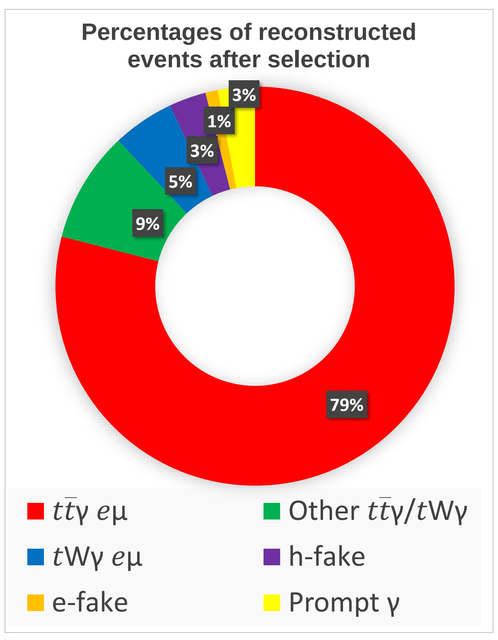
- The measurements are compared with **leading order (LO) Monte Carlo (MC) simulations** and **state-of-the-art calculation** [2], where the latter is the **first full computation** of $t\bar{t}$ with a hard γ **at next-to-leading-order (NLO)** in quantum chromodynamics, for $pp \to bW\bar{b}W\gamma$ including all resonant and non-resonant diagrams, interferences, and off-shell effects
- **Fiducial inclusive cross-section** is extracted using a **binned Maximum Likelihood Fit to the S_T** distribution (S_T: scalar sum of all transverse momenta in the event, including leptons, photons, jets and missing transverse momentum)
- **Fiducial differential** (absolute and normalised) **cross-sections** are measured as functions of $P_T(\gamma)$, $|\eta(\gamma)|$, $\Delta R(l,\gamma)$, $\Delta\eta(l,l)$, $\Delta\Phi(l,l)$ using the **Iterative Bayesian Unfolding** method

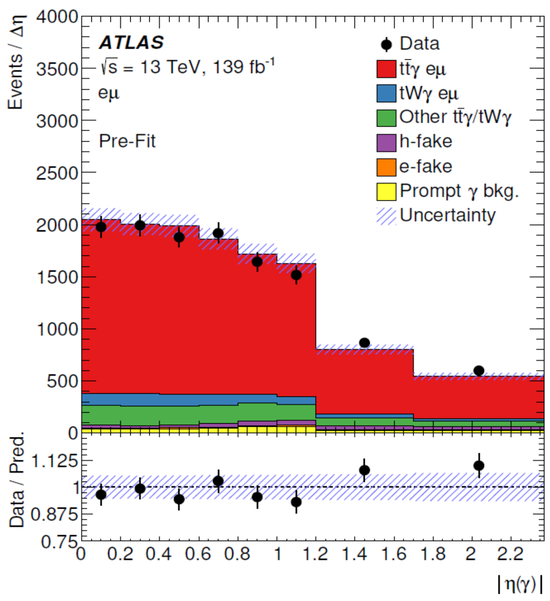
Event selection and fiducial region (parton level)

Event selection	
Leptons	Exactly one e and one μ with P_T > 25 GeV
Photons	Exactly one γ with P_T > 20 GeV
Jets	At least two jets with P_T > 25 GeV
B-tagged	At least one b-tagged jet (85% efficiency)
ΔR	$\Delta R(l,\gamma) > 0.4$

Fiducial region	
Leptons	Exactly one e and one μ with P_T > 25 GeV
Photons	Exactly one γ with P_T > 20 GeV
B-jets*	Exactly one b-jet and one $\bar{b}$-jet with P_T > 25 GeV
ΔR	$\Delta R(l,\gamma) > 0.4$, $\Delta R(e,\mu) > 0.4$, $\Delta R(b,\bar{b}) > 0.4$, and $\Delta R(l,b) > 0.4$

* Parton-level jets



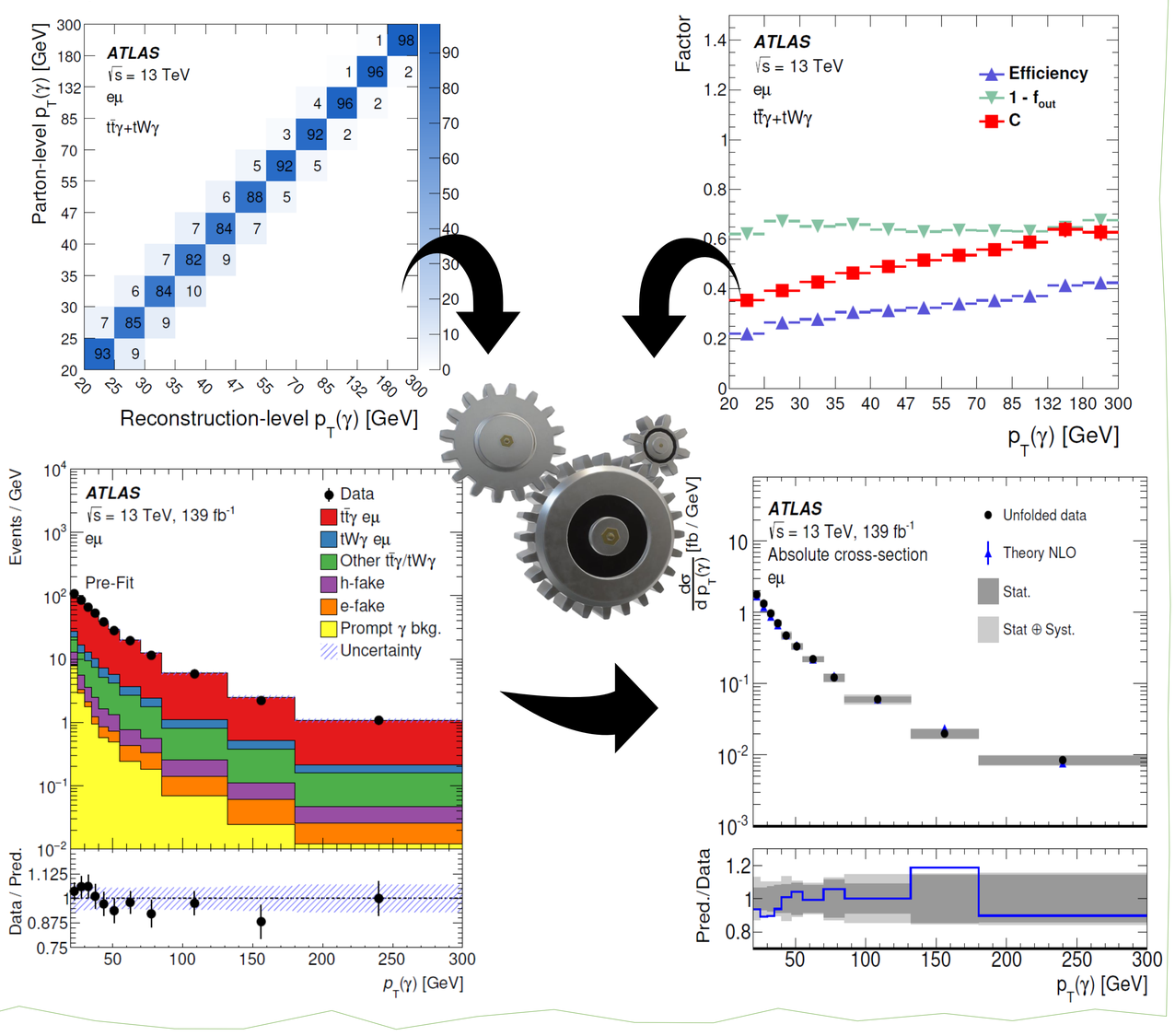


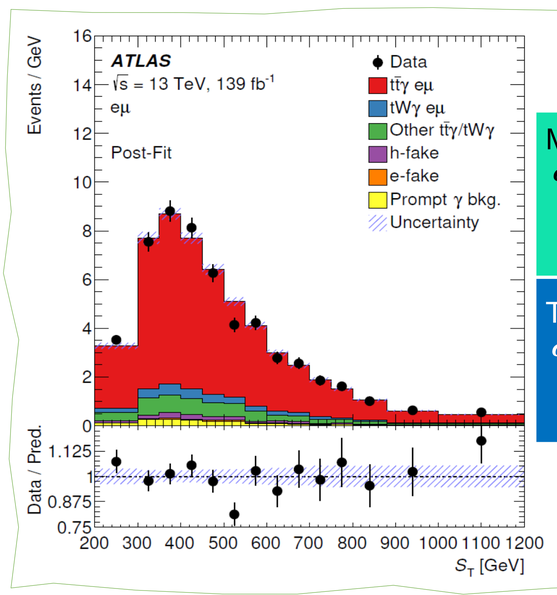
Unfolding machinery

- Using Iterative Bayesian Unfolding to remove detector effects and derive the true spectrum of the signal at parton level from the observed data
  - Bayesian statistics + minimising model-dependence by iterating (2 iterations) is used to invert the response matrix
- After unfolding, absolute and normalised cross-sections are compared with LO MC predictions and NLO calculation

$$P(C_i|E_j) = \frac{P(E_j|C_i)\cdot P_0(C_i)}{\sum_{l=1}^{n_C} P(E_j|C_l)\cdot P_0(C_l)} \quad [3]$$

C_i : Cause in bin i
E_j : Effect in bin j
$P_0(C_i)$: Initial probability of the causes
n_C : max. number of causes





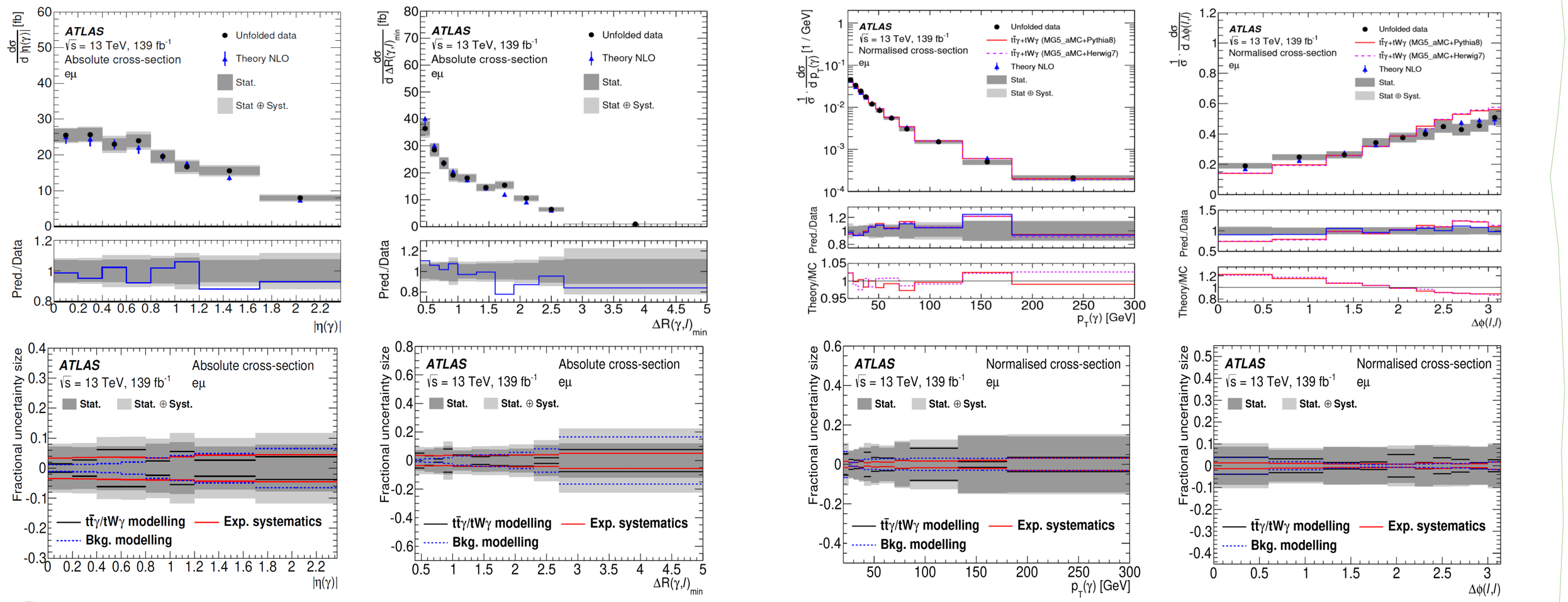
Inclusive results

Measured:
$\sigma_{fiducial} = 39.6 \pm 0.8(stat)^{+2.6}_{-2.2}(syst)$ fb $= 39.6\,^{+2.7}_{-2.3}$ fb

Theory NLO:
$\sigma_{NLO} = 38.5\,^{+1.2}_{-2.5}$ fb

Category	Uncertainty
$t\bar{t}\gamma/tW\gamma$ modelling	3.8%
Background modelling	2.1%
Photons	1.9%
Luminosity	1.8%
Jets	1.6%
Pile-up	1.3%
Leptons	1.1%
Flavour-tagging	1.1%
MC statistics	0.4%
Soft term E_T^{miss}	0.2%
$tW\gamma$ parton definition	2.8%
Total syst.	6.3%

Differential results



Conclusions

- The measured fiducial inclusive cross-section is found to be in good agreement with the predicted NLO cross-section
- The shape of the measured fiducial differential cross-sections is well described by the NLO calculation, while the LO MC simulation fails to describe such shape for some variables, such as $\Delta\Phi(l,l)$
- The precision of the measurements is dominated by the statistical uncertainties
- The systematic uncertainties of the measurements are dominated by the background and signal modelling

[1] ATLAS Collaboration, arXiv:2007.06946 [hep-ex], Accepted by JHEP
[2] JHEP 10 (2018) 158
[3] Nucl. Instrum. Meth. A 362 (1995) 487

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