Charge Asymmetry in $t\bar{t}\gamma$ Production with the ATLAS Experiment

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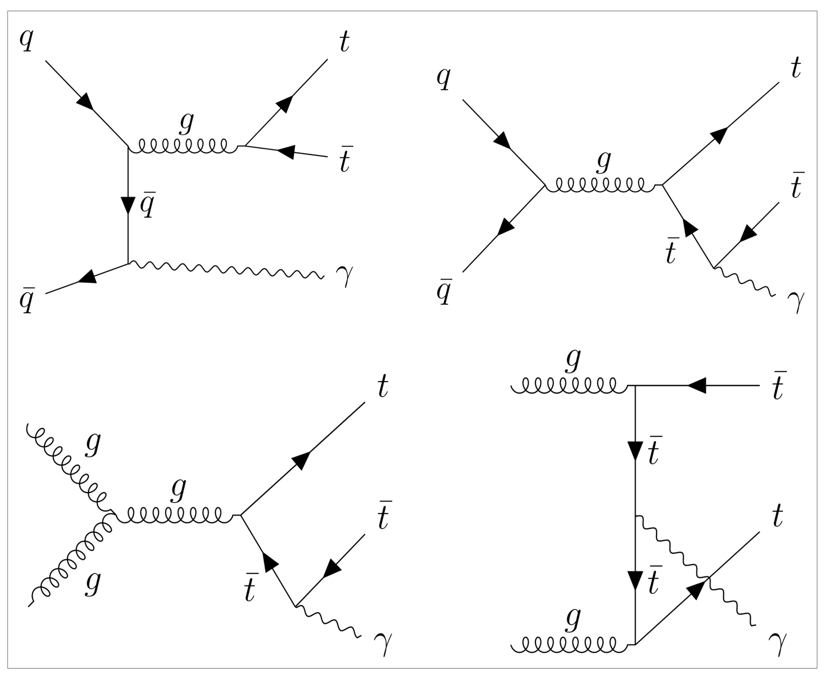
1. Motivation

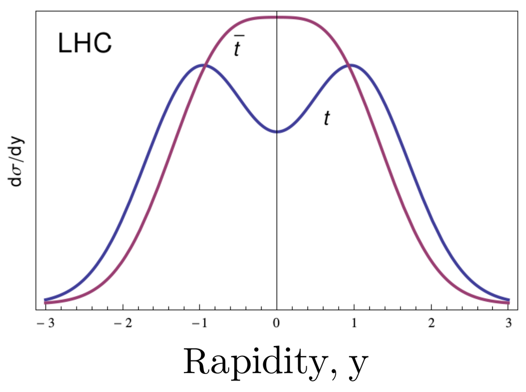
→ $t\bar{t}\gamma$ production is a rare Standard Model (SM) process
→ Gateway to probe top quark-photon interaction

→ Interferences among diagrams possible at NLO QCD and also LO QED
→ Never measured before
→ Expected to be sensitive to beyond SM effects[1]

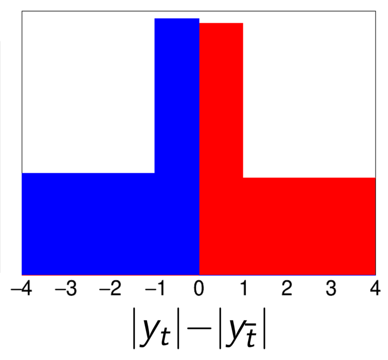
→ Indirect measurement via top quark pair charge asymmetry (A_C) can probe these interference effects[2]

→ The absolute asymmetry value is estimated to be larger than in $t\bar{t}$ production
→ Small cross section of the process makes the measurement very challenging





$$A_c = \frac{\sigma(|y_t| > |y_{\bar{t}}|) - \sigma(|y_t| < |y_{\bar{t}}|)}{\sigma(|y_t| > |y_{\bar{t}}|) + \sigma(|y_t| < |y_{\bar{t}}|)} = \frac{N(|y_t| > |y_{\bar{t}}|) - N(|y_t| < |y_{\bar{t}}|)}{N(|y_t| > |y_{\bar{t}}|) + N(|y_t| < |y_{\bar{t}}|)}$$



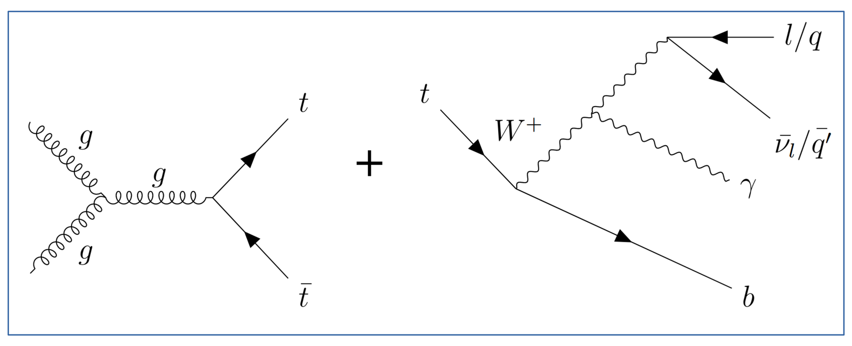
→ **First measurement** with ATLAS detector at 13 TeV in $t\bar{t}$ single lepton decay channel
→ Selecting events with one e or μ, one isolated photon, at least four jets, at least one b-tagged jet (77% efficiency)

→ A_C unfolded to fiducial phase space at particle level

2. Signal and Backgrounds

Signal: $t\bar{t}\gamma$ production (MG5_aMC@NLO+Pythia8, @NLO)

Background processes:
$t\bar{t}\gamma$ decay: Photon from top quark decay products in $t\bar{t}$ production (MG5_aMC@NLO+Pythia8, @LO with k-factors)



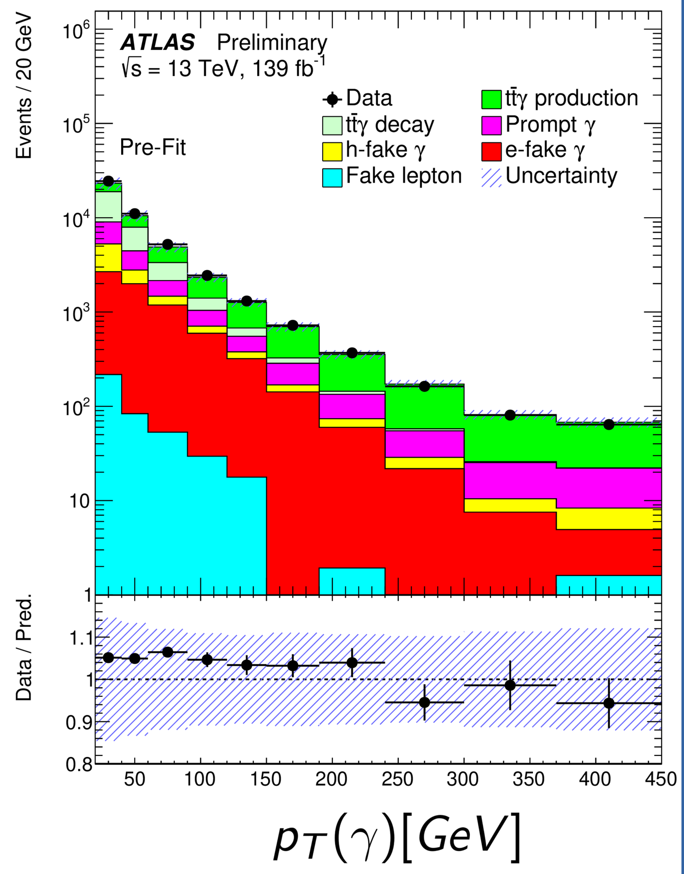
Prompt photon backgrounds:
Vγ, VVγ, singletop (t,s,tW)+γ, ttVγ (V = W,Z)

Fake photon backgrounds:

Hadronic fakes:
→ Jets faking photons or non-prompt photons from jets
→ using data-driven method

Electron fakes:
→ Electrons faking photons
→ using data-driven method

Fake-lepton background:
→ Leptons from QCD/multijet processes
→ using data-driven method



3. Discrimination of signal and background processes

→ Separation of signal from backgrounds is done with a neural network (NN) discriminator

Input variables:

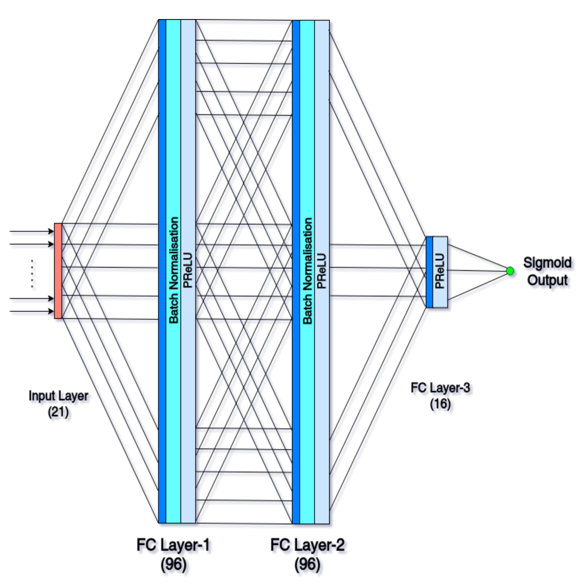
→ Kinematic variables of photon, lepton, jets

→ Distances and invariant masses of different combination of partilces

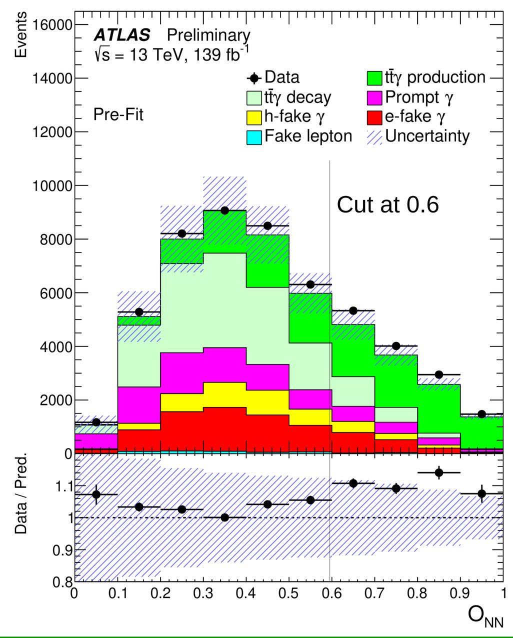
→ Conversion type of photon

→ b-tagging information

NN architecture



NN output



→ Based on the NN output, two regions are defined:

$O_{NN} < 0.6$
$O_{NN} > 0.6$

Prefit yields

	$O_{NN} < 0.6$	$O_{NN} \geq 0.6$
$t\bar{t}\gamma$ prod (signal)	6660 ± 350	6910 ± 340
$t\bar{t}\gamma$ decay	14 100 ± 3100	1900 ± 560
Prompt γ	6400 ± 2000	1300 ± 400
H-fake γ	3400 ± 1400	790 ± 360
E-fake γ	6420 ± 860	1480 ± 260
Lepton fake	410 ± 110	57 ± 35
Total	37 400 ± 4500	12 400 ± 1100
Data	38527	13763

4. Top quark reconstruction

→ Top quarks are reconstructed using **Kinematic Likelihood Fitter**[3]
→ Likelihood built for top quark pair in single lepton decay channel
→ Photon is not part of the $t\bar{t}$ system

5. Profile Likelihood Unfolding

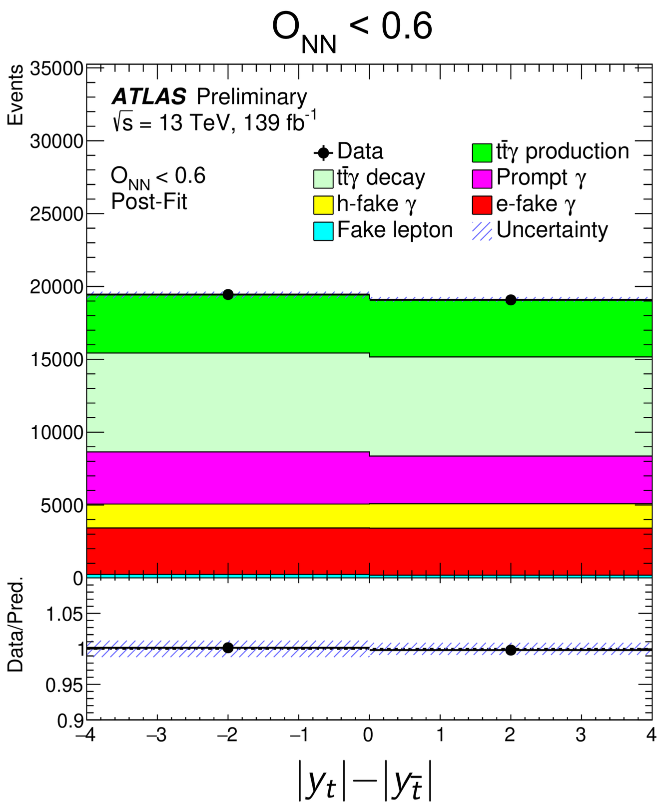
→ A profile likelihood unfolding fit is done to extract asymmetry, A_C in a fiducial phase space at particle level
→ Both the regions $O_{NN} < 0.6$ and $O_{NN} > 0.6$ are used in the fit
→ The signal is folded from the truth level using its migration matrices

→ Signal strengths (μ=σ/σ(SM)) assigned for each bin of truth level distribution
→ The signal strength of bin Δ|y|<0 (μ_1) at truth level is replaced by A_C from the following relation to use it directly in the likelihood as one of the parameters of interest:
$$\mu_1 = \frac{N_2}{N_1} \times \mu_2 \times \frac{1 - A_c}{1 - A_c}$$

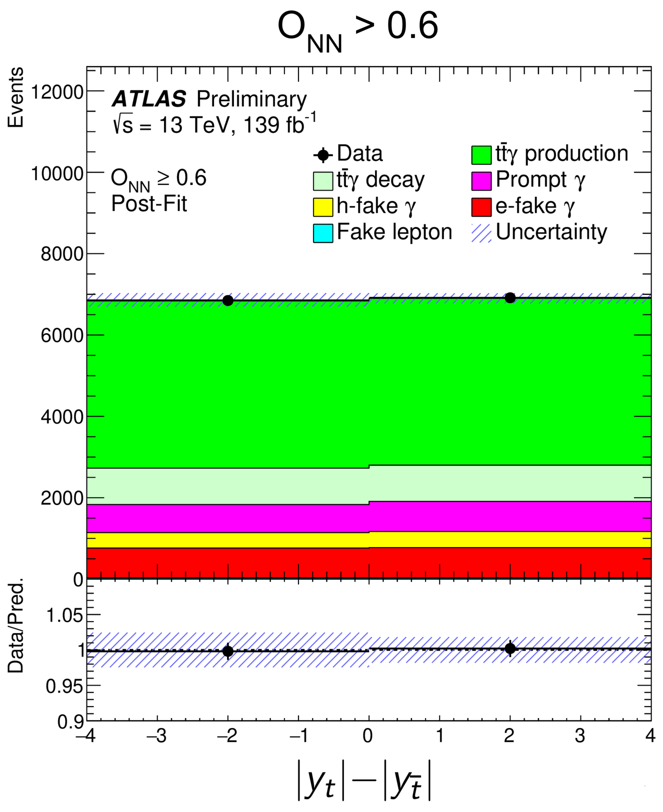
6. Results

Post-fit distributions:

$O_{NN} < 0.6$



$O_{NN} > 0.6$



Measured asymmetry:

A_C = -0.006 +- 0.030
= -0.006 +- 0.024(stat) +- 0.018(syst)

SM NLO prediction:
(MadGraph5_aMCAtNLO+Pythia8)

A_C = -0.0139 +- 0.001(scale)

→ The measurement agrees well with the Standard Model prediction

Uncertainty Breakdown

Total uncertainty	0.030
Statistical uncertainty	0.024
MC statistical uncertainties	
$t\bar{t}\gamma$ production	0.004
Background processes	0.008
Modelling uncertainties	
$t\bar{t}\gamma$ production modelling	0.003
Background modelling	0.002
Prompt background normalisation	0.003
Experimental uncertainties	
Jet and b-tagging	0.010
Fake lepton background estimate	0.005
E_T^{miss}	0.009
Fake photon background estimates	0.004
Photon	0.003
Other experimental	0.004

FSP ATLAS Erforschung von Universum und Materie

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References:
1. J. High Energ. Phys. 2014, 188 (2014)
2. Bergner, J. & Schulze, M. Eur. Phys. J. C (2019) 79: 189
3. NIM A 748 (2014) 18