Recent results on associated top-quark production and searches for new top-quark phenomena with the ATLAS detector

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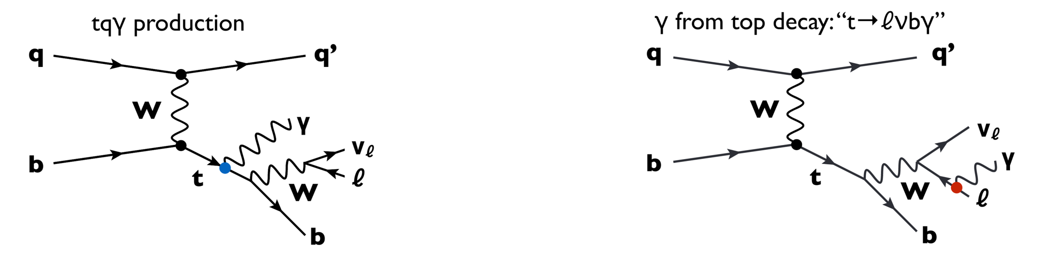
Observation of $tq\gamma$ production

Motivation

- $pp \to tq\gamma$ is a rare processes predicted in the SM ($\sim$ once in 50 billion pp collisions)
- $\sigma(tq\gamma)$ is sensitive to
  - top quark's interaction with photon and $W^{\pm}$ bosons
  - electric and magnetic dipole moments of the top quark

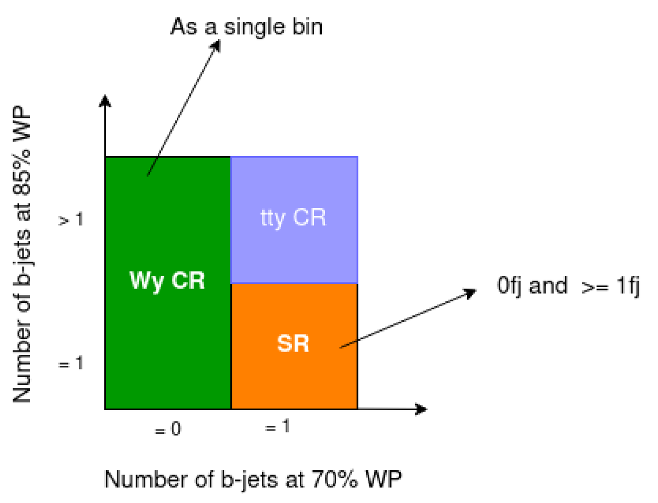


- CMS published evidence for this process with 35.9 fb^{-1} (Phys. Rev. Lett. 121 (2018) 221802)
- First observation of the process by ATLAS using the full Run-2 dataset (139 fb^{-1})
- Final state at leading order has exactly 1ℓ, 1γ, 1 forward jet, 1 b-jet, a neutrino which manifests as the imbalance in transverse momentum

Analysis Strategy

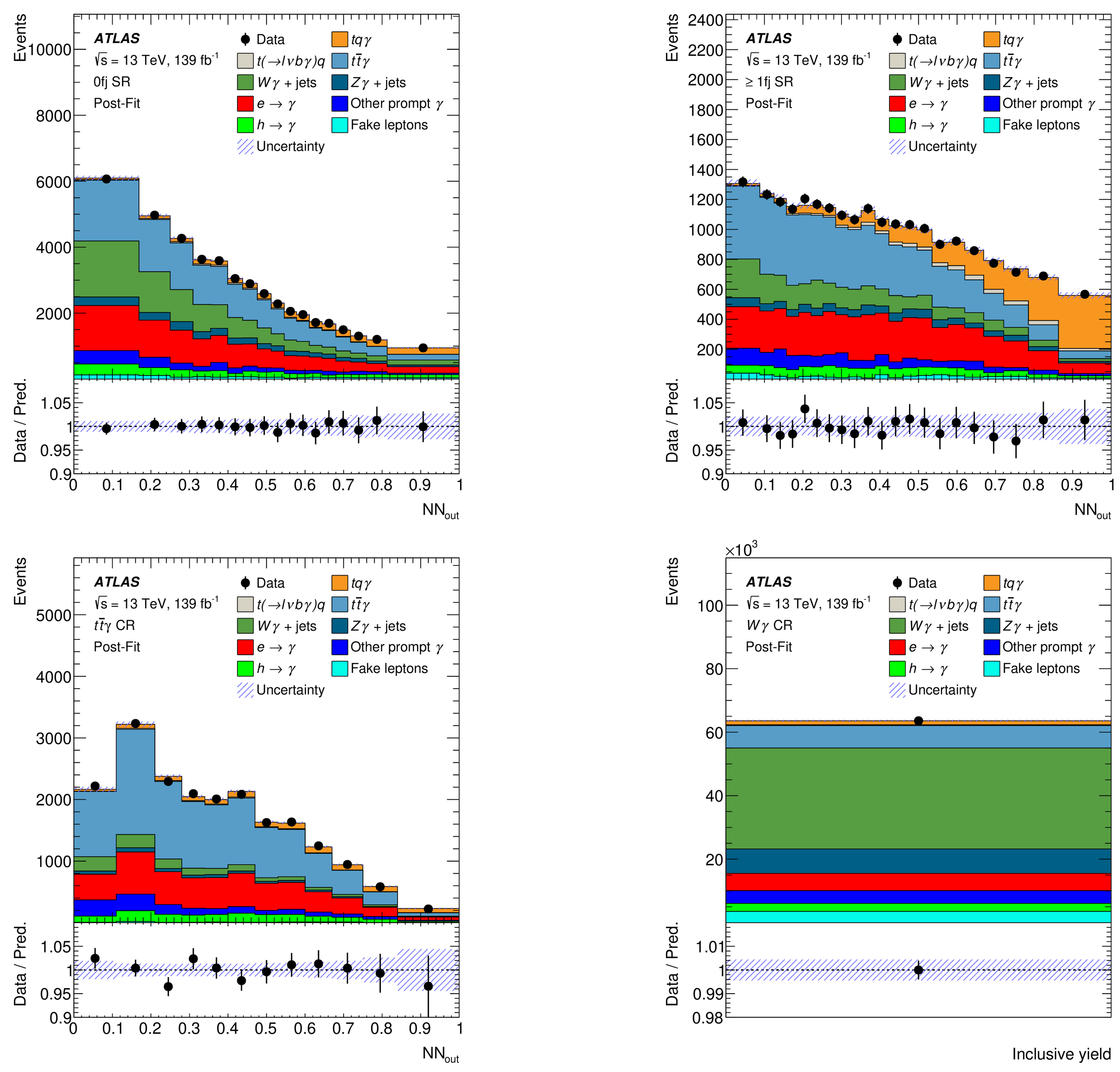
- Two signal regions (SR) are defined based on the # of forward jets: 0fj and $\geq$ 1fj
- Control regions (CR) are used for determining the normalization for prompt photon bkgs: $t\bar{t}\gamma$ CR and $W\gamma$ CR

- Fake photon bkgs are estimated by applying data-driven corrections to MC prediction
  - Tag and Probe method for $e \to \gamma$ fakes
  - ABCD method for $h \to \gamma$ fakes
- Fake lepton bkg is estimated from data using Matrix Method
- A neural network is trained in each signal region to separate the signal from the background.



Results

- A simultaneous profile likelihood fit is performed in 2 SRs, $t\bar{t}\gamma$ CR and $W\gamma$ CR
- Obs. (exp.) significance: 9.3 (6.8) σ $\implies$ First observation of $tq\gamma$ production



At parton level: $\sigma_{tq\gamma} \times \mathcal{B}(t \to \ell\nu b)$ = $688 \pm 23\,(\text{stat.})\,^{+75}_{-71}\,(\text{syst.})$ fb

- Phase space definition: $\geq$ 1 photon with $p_T^{\gamma} > 20$ GeV, $|\eta| < 2.37$ and Frixione-isolated within an isolation radius of $\Delta R = 0.2$
- $\sim$ 33 % higher than the prediction by MadGraph5_aMC@NLO: $515\,^{+36}_{-42}$ fb

At particle level: $\sigma_{tq\gamma} \times \mathcal{B}(t \to \ell\nu b) + \sigma_{t(\to \ell\nu b\gamma)}$ = $303 \pm 9\,(\text{stat.})\,^{+33}_{-32}(\text{syst.})$ fb

- Phase space definition is closer to the SR definition
- $\sim$ 40 % higher than the generator prediction: $217\,^{+27}_{-15}$ fb

Compatible with SM within 2.1 (2.0) σ at parton (particle) level

- Leading systematic uncertainties: $t\bar{t}\gamma$ modelling, limited $tq\gamma$ MC stats, limited bkg stats and modelling of $t\bar{t}$

More details: arXiv:2302.01283

Observation of $t\bar{t}t\bar{t}$ production

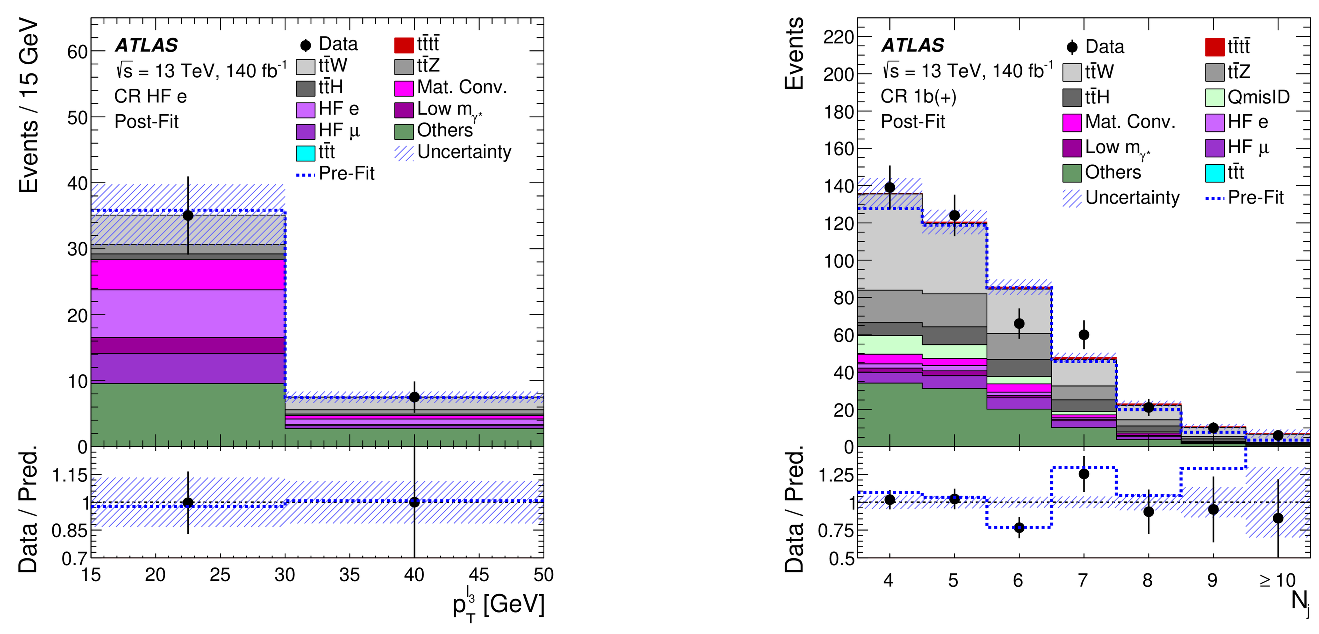
Motivation

- $t\bar{t}t\bar{t}$ production is a rare process featuring a spectacular heaviest particle final state
- Cross-section of this process $\sigma(t\bar{t}t\bar{t})$ is
  - sensitive to the top-quark Yukawa coupling, and its CP properties
  - enhanced in many BSM models like gluino pair production in SUSY
  - sensitive to various four-fermion interactions and also the Higgs oblique parameter in EFT framework

- The analysis uses full Run-2 data (140 fb^{-1})
- Final states with two leptons with the same charge (2LSS) or three leptons (3L) are considered in the analysis

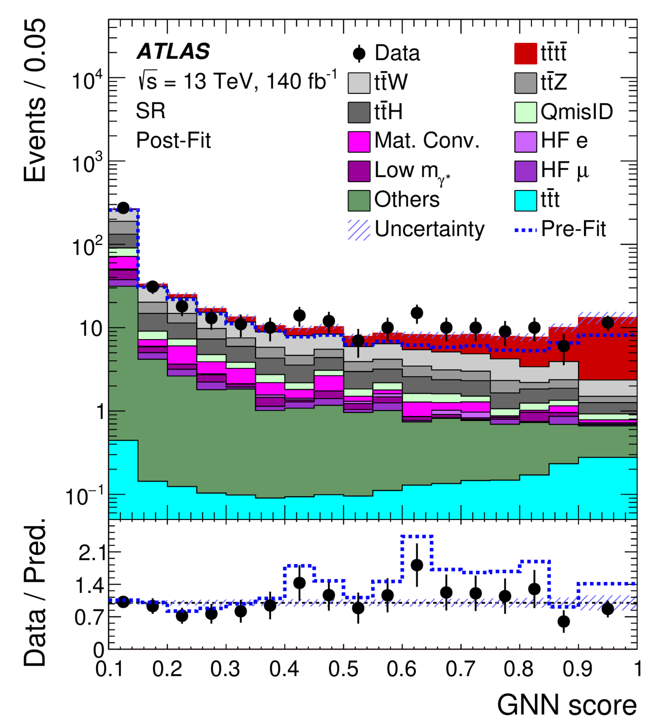
Analysis Strategy

- Signal region events: $\geq$ 6 jets with $\geq$ 2 b-tagged jets and $H_T > 500$ GeV
- Major bkgs: $t\bar{t}W$+jets, $t\bar{t}Z$+jets, $t\bar{t}H$+jets and processes with non-prompt leptons
- Normalizations for non-prompt lepton bkgs are determined using the Template method in four CRs
- A dedicated data-driven technique is used for finding $t\bar{t}W$ normalization per jet bin in 4 $t\bar{t}W$ CRs



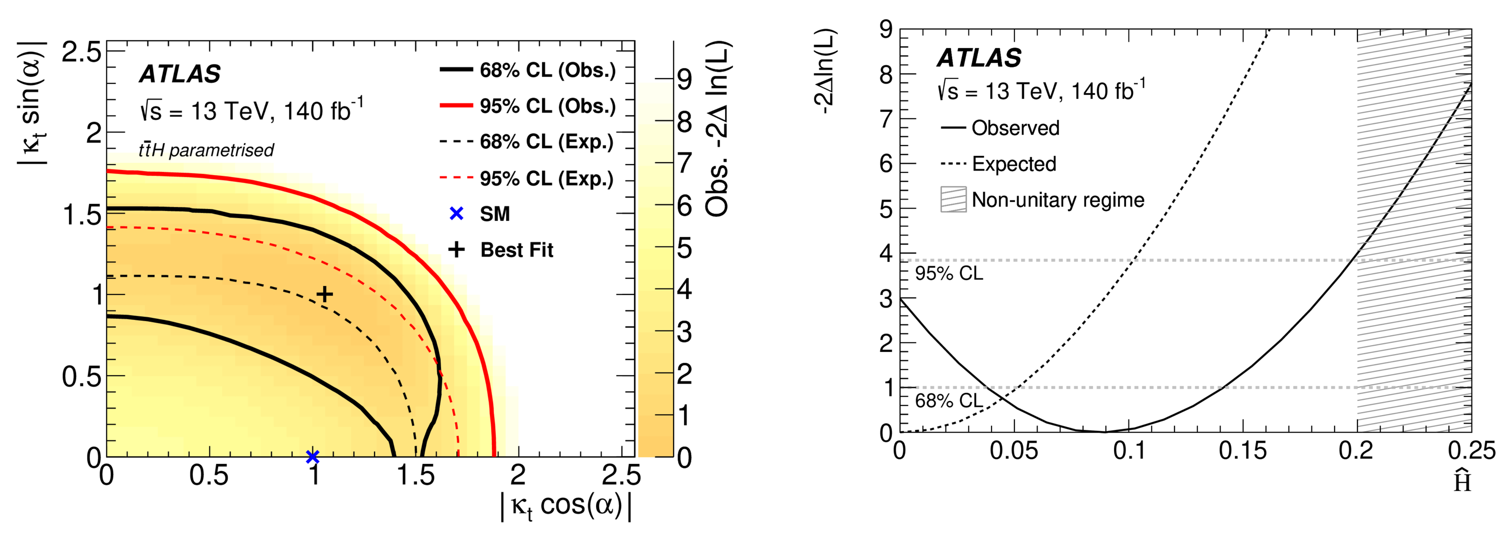
Results

- A Graph Neural Network is used for separating four-top production from bkg
- Obs. (exp.) significance: 6.1 (4.3) σ $\implies$ Observation of $t\bar{t}t\bar{t}$ production
- Measured cross-section $\sigma(t\bar{t}t\bar{t})$ = $22.5\,^{+6.6}_{-5.6}$ fb
- **It is consistent within 1.8 σ of the SM prediction** (13.4 $\pm$ 1.4 fb) arXiv:2212.03259
- Leading systematic uncertainty sources: signal modeling and data-driven estimate of $t\bar{t}W$ bkg



Interpretation in new physics scenarios

- Limits are set on the top-Higgs Yukawa interaction, which can be parameterized as a function of two parameters: a multiplicative modifier (κ_t) and a CP-mixing angle (α): $\mathcal{L} = -\frac{1}{\sqrt{2}}\kappa_t y_t \bar{t}(\cos(\alpha) + i\sin(\alpha)\gamma_5)th$
- For CP-even coupling, obs. (exp.) limit: $|\kappa_t| < 1.8$ (1.6) at 95% CL



- Obs. (exp.) limit for Higgs oblique parameter ($\hat{H}$), which modifies the off-shell Higgs interactions is 0.20 (0.12)

More details: Eur. Phys. J. C 83, 496 (2023)