Search for SM $tq\gamma$ production in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS experiment

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Outline

Introduction

Signal MC production

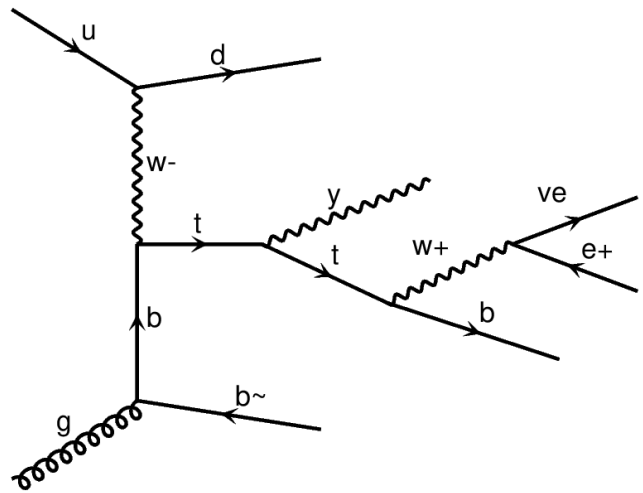
Data/MC comparison in pre-selection region

Estimation of $e \rightarrow \gamma$ fakes

Summary

Motivation

- Measurement of $\sigma(tq\gamma)$ provides an important precision test for the SM
- It is sensitive to
  - top quark's interaction with photon and $W^{\pm}$ bosons
  - top quark charge and its electric and magnetic dipole moments



- This process not been observed yet
- Final state contains: exactly 1ℓ, 1γ, 1 forward jet, 1 b-jet and MET$>$ 30 GeV
- Note: This analysis is different from FCNC $tq\gamma$ analysis which probes $t \to q\gamma$ interaction

Recent results from CMS

- CMS collaboration recently published a paper showing evidence for this process with 36 fb^{-1} of data collected in 2015-16 Phys. Rev. Lett. 121, 221802 (2018)
- Only considered single μ events
- Observed (expected) significance 4.4σ (3.0σ)
- Fiducial product of cross-section and branching ratio obtained:
  $\sigma(pp \to t\gamma j)\mathcal{B}(t \to \mu\nu b) = 115 \pm 17(\text{stat}) \pm 30(\text{syst})$ fb in the phase space $p_{T,\gamma} > 27$ GeV, $|\eta_\gamma| < 1.44$ and $\Delta R(X, \gamma) > 0.5$ for $X \in (\mu, j, b)$

ATLAS search for $tq\gamma$ production

- ATLAS collaboration has started a search for this process with 139 fb^{-1} of data collected during the Run-2 data taking period
- Single electron events are also included in addition to single μ events
- This analysis is still in progress. In today's talk, I will give you a brief overview about following topics
  - Signal MC production
  - Data/MC comparisons in pre-selection region
  - Estimation of $e \rightarrow \gamma$ fakes

Introduction

Signal MC production

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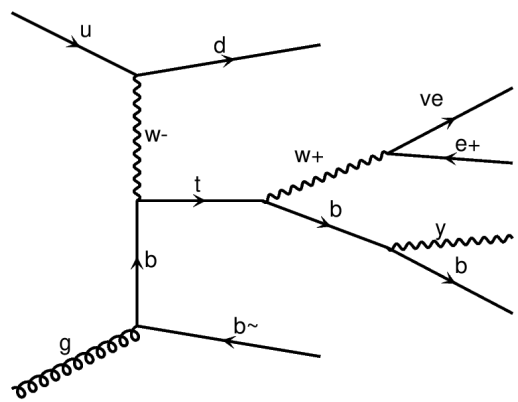
$tq\gamma$ MC production

- $tq\gamma$ MC sample has been produced with MADGRAPH5+PYTHIA8 at LO
- 4-flavour scheme is used (i.e., parton distribution functions for b-quarks is set to zero) as it provides a good modelling of event kinematics

- Photon radiation from top quark daughters has been included
- Generator level selection cuts:
  - $\Delta R(\gamma, X) > 0.2 \; \forall \; X \in (\ell, b, j)$
  - Photon $p_T \; > 10$ GeV
  - $|\eta_{(\ell,\,\gamma)}| \; < 5.0$
- Cross-section obtained from the generator = 1.389 pb



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Signal & background plots

Data/MC comparisons in a loose pre-selection region are presented in next two slides: Pre-selection region definition:

- Exactly one tight, isolated ℓ (=e, μ) with $p_T > 27$ GeV
- Exactly one tight, isolated photon with $p_T > 20$ GeV
- number of jets ≥ 1
- Exactly 1 b-tagged jet passing 85% efficiency working point of the b-tagging algorithm
- Missing $p_T > 30$ GeV
- Z-veto: $M(e\gamma) \notin (80, 100)$ GeV

Composition of pre-selection region

Major backgrounds:

- Prompt photon backgrounds: $tt\gamma$, $W\gamma$, $Z\gamma$
- Events with fake photons ($t\bar{t}$, Z+jets etc.)

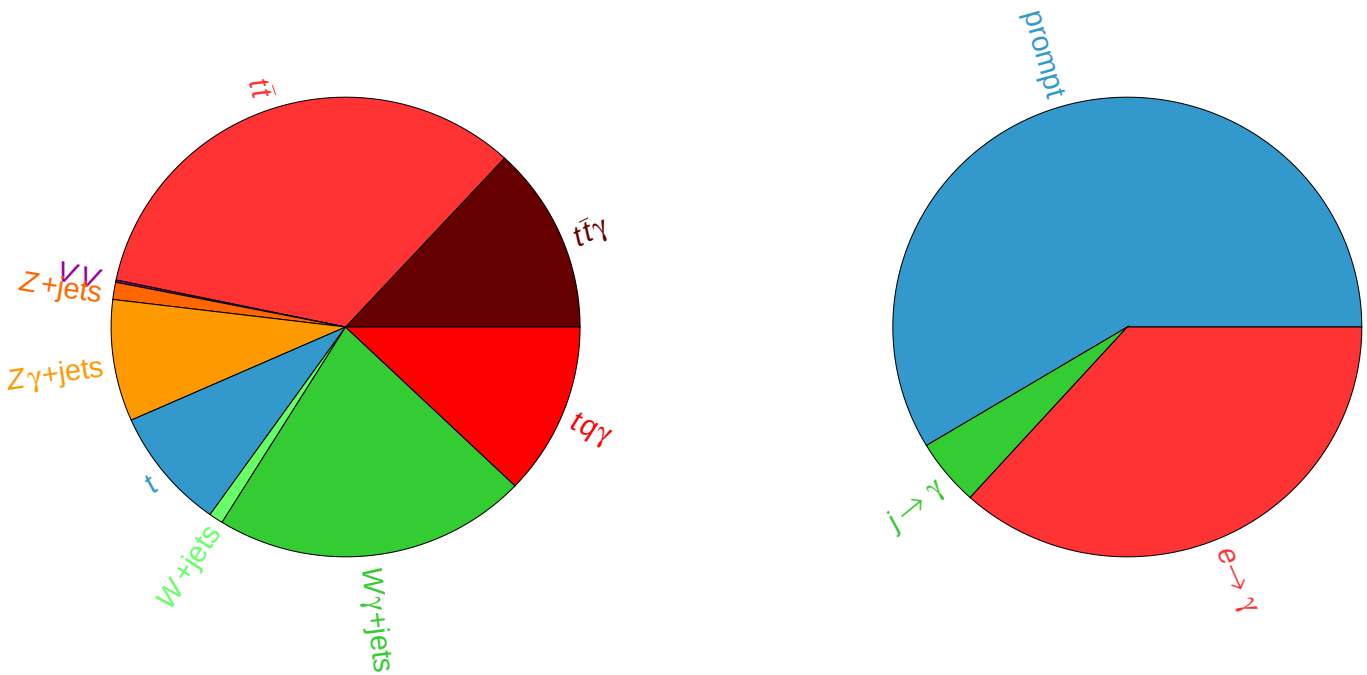
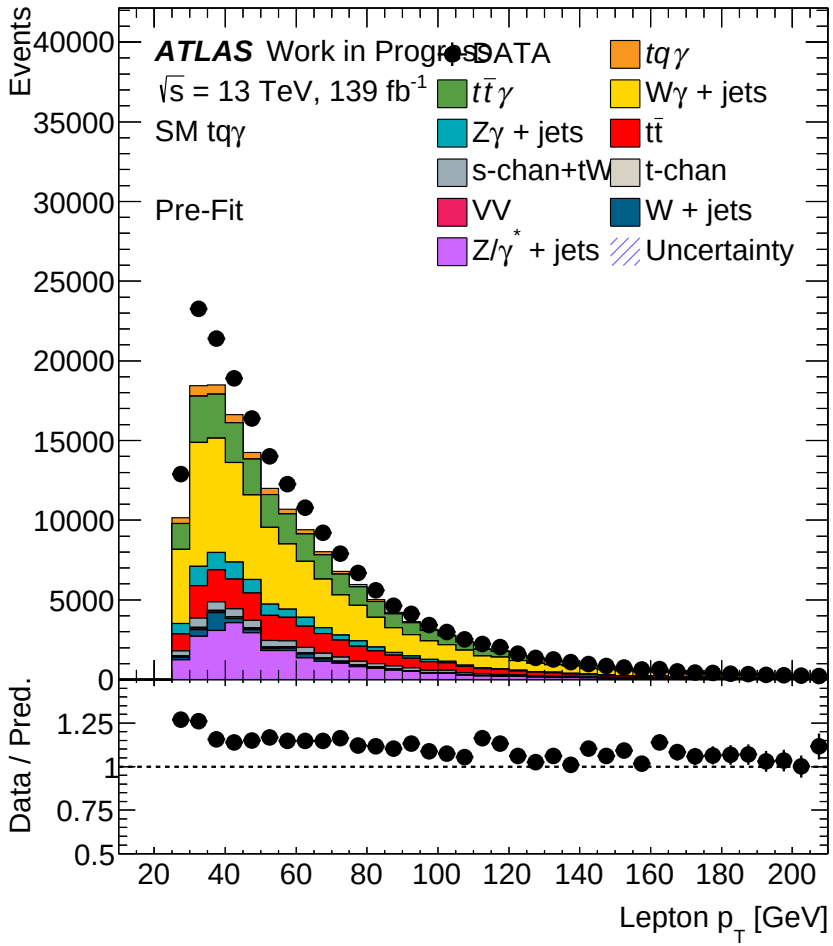
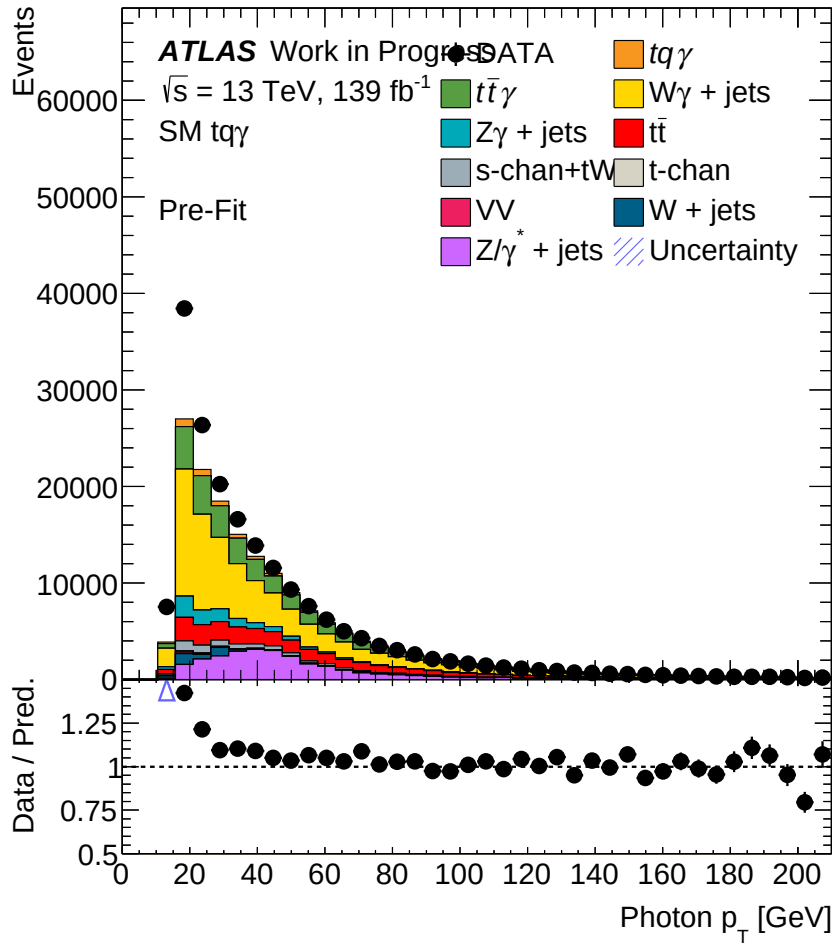


Figure: (a)Left: Signal and background composition (b)Right: Photon type composition in the pre-selection region

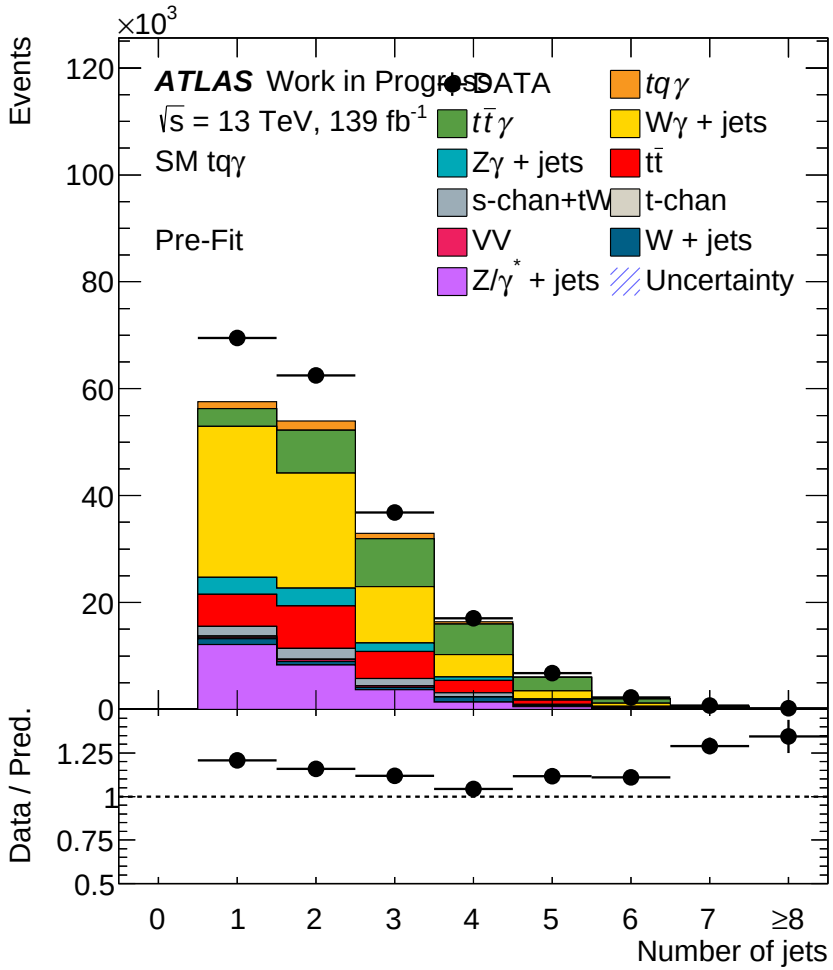
Pre-selection region plots

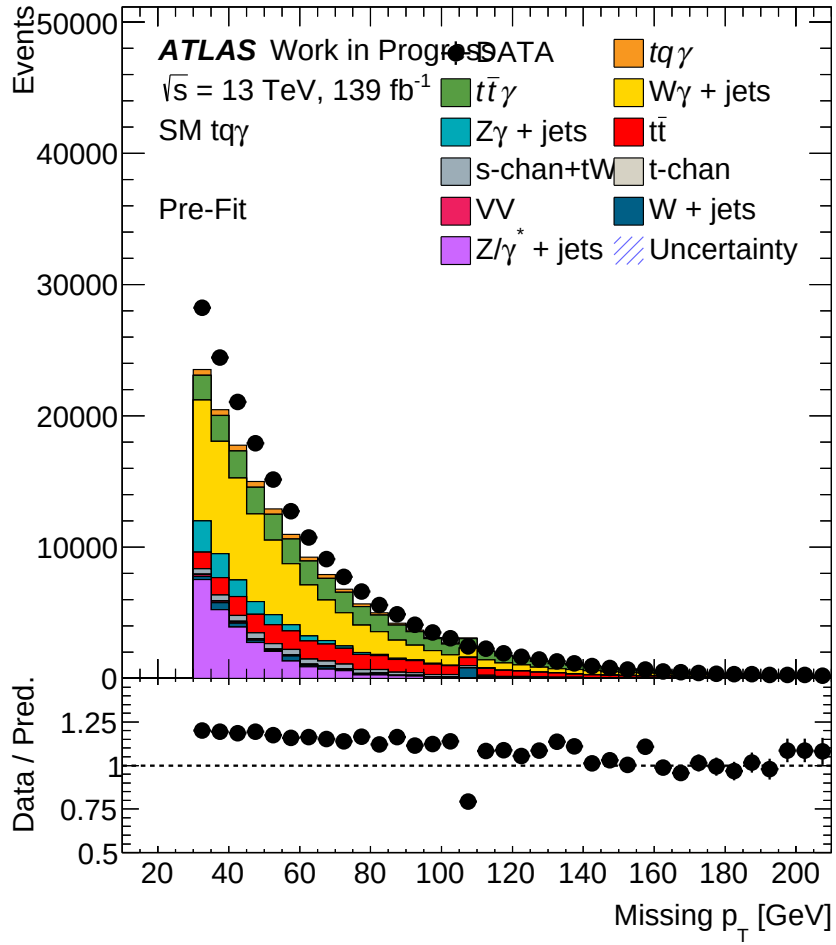
In general, data is 25% higher than MC estimates. This could be due to mismodelling of events with fake photons/leptons in the simulation.





Pre-selection region plots-2





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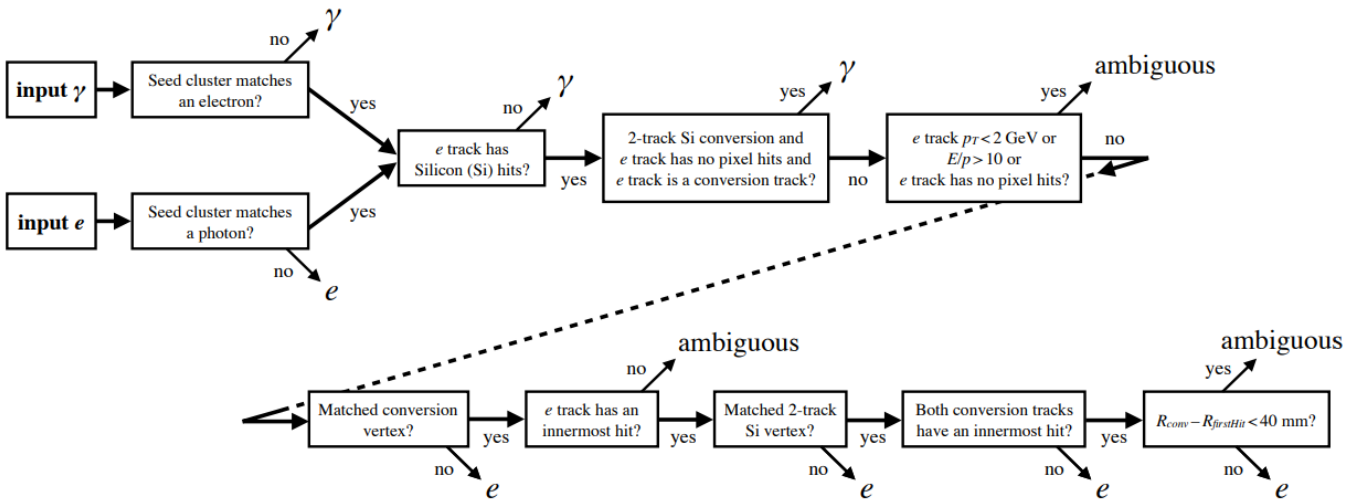
Electron to Photon fakes

- Electrons and photons are reconstructed very similarly in ATLAS $\Rightarrow$ an electron faking a photon may happen



- Based on the # tracks matching to the cluster, photons are reconstructed either as converted or as unconverted
- Rate of an electron faking as photon is $\sim 9\%$
- Simulation does not model these fakes well. Scale factors derived to correct simulation for any deviation from data

Z + jets Control Regions

Two control regions enriched with Z+jets are used for estimating $e \to \gamma$ scale factors

- $Z \to ee$: Events with two reconstructed electrons
- $Z \to e(e \to \gamma)$: Events with one reconstructed electron and one reconstructed photon. Reconstructed photon in the event is assumed to-be a misreconstructed electron

Object	$Z \to ee$	$Z \to e(e \to \gamma)$
Photons	=0 w/ $p_T > 20$ GeV	=1 w/ $p_T > 20$ GeV
Electrons	=2 (SFOS) w/ $p_T >$27 GeV	=1 w/ $p_T > 27$ GeV
missing p_T	< 30 GeV	< 30 GeV
$M(ee)$	[70, 110] GeV	-
$M(e\gamma)$	-	[70, 110] GeV

Scale Factor calculation with Template Fit method

- For $Z \to e\gamma$ process, template shape is obtained from MC simulation. Normalization is floated during the fit to the data
- For major bkgs ($W\gamma$ & $Z\gamma$), shape and normalization of $M(e\gamma)$ distribution are taken from the MC
- For other bkgs (VV, W+jets, γ+jets) $\Longrightarrow$ 3rd order Bernstein polynomials are used

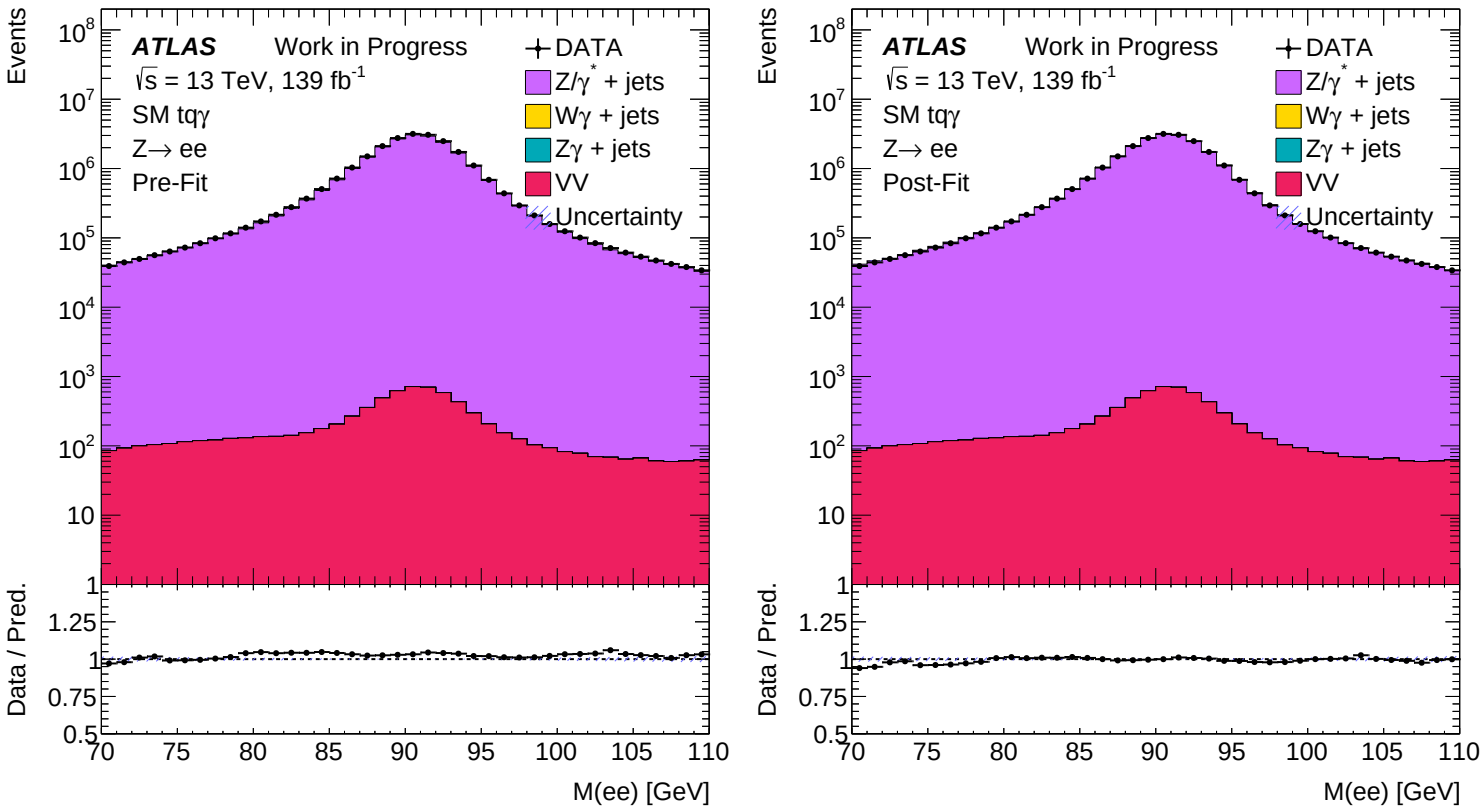
$$\text{Scale factor} = \frac{N_{sig}^{\text{Data}}(Z \to e\gamma) \;/\; N_{sig}^{\text{MC}}(Z \to e\gamma)}{\mu_{Zee}}$$

$$\text{Where, } \mu_{Zee} = \frac{N_{sig}^{\text{Data}}(Z \to e^+e^-)}{N_{sig}^{\text{MC}}(Z \to e^+e^-)}$$

μ_{Zee} calculation

- M(ee) distribution for $Z \rightarrow ee$ region is shown here before (left) and after(right) fitting to data

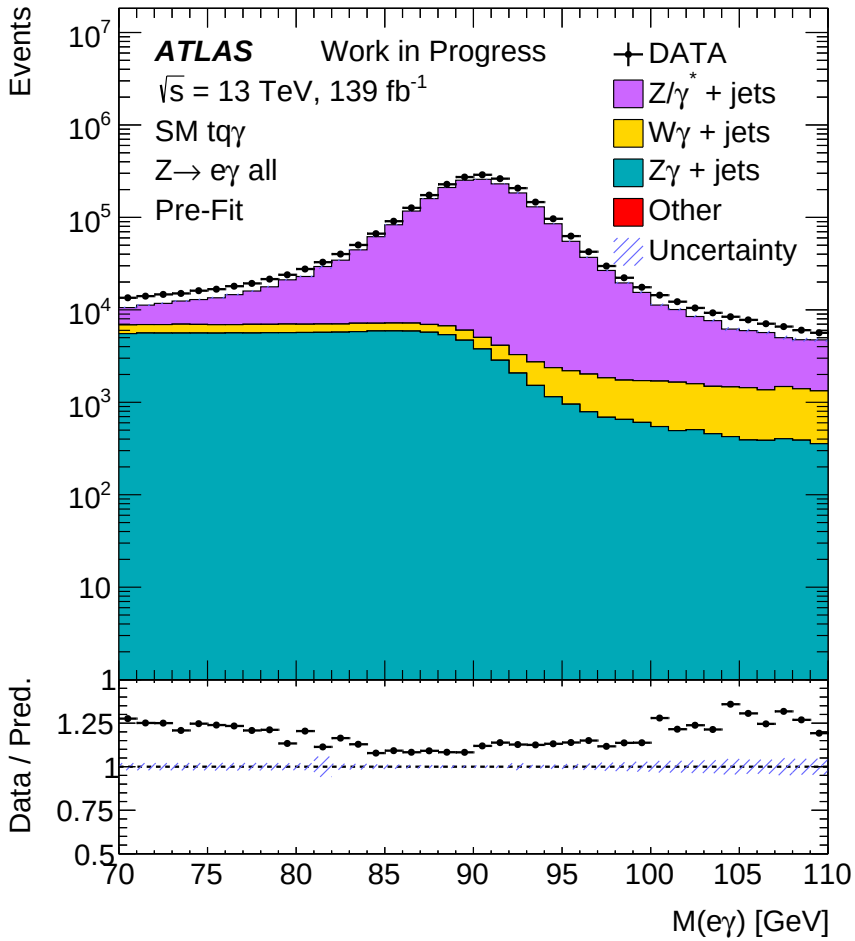
$$\mu_{Zee} = N_{sig}^{\text{Data}}(Z \rightarrow e^+e^-)/N_{sig}^{\text{MC}}(Z \rightarrow e^+e^-) \; = \; 1.03 \pm 0.00026$$

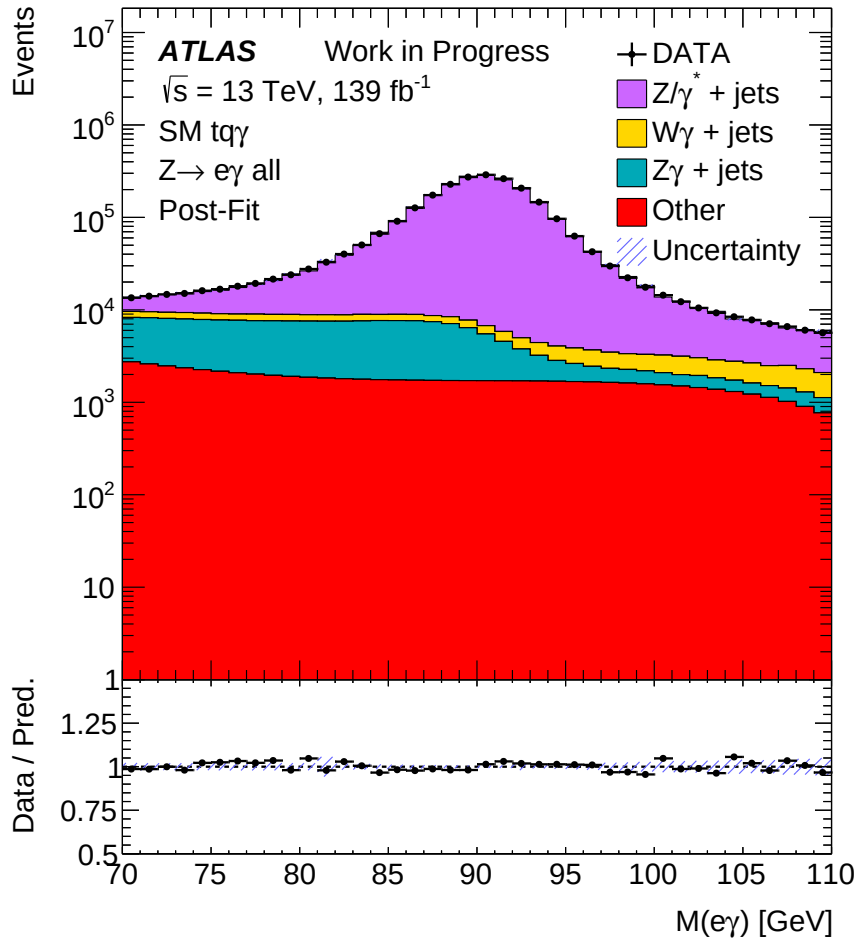


Fit to data in $Ze\gamma$ region

- M($e\gamma$) distribution for $Z \rightarrow e\gamma$ region is shown here before (left) and after(right) fitting to data

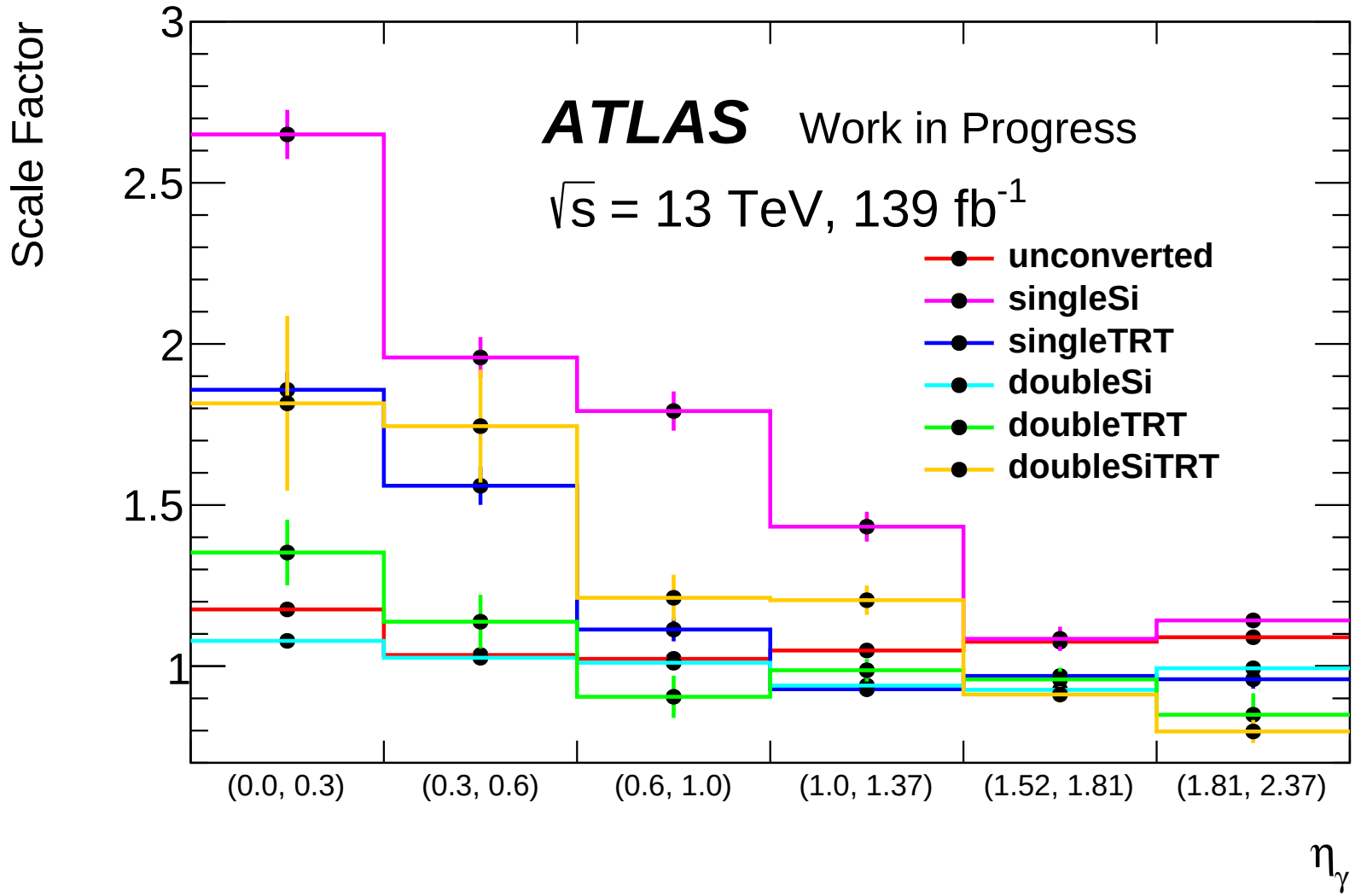
$$N_{sig}^{\text{Data}}(Z \rightarrow e\gamma) \; / \; N_{sig}^{\text{MC}}(Z \rightarrow e\gamma) = 1.10 \pm 0.0014$$





SF plot in bins of photon η and CT

- Scale factor has been calculated in bins of η_γ and photon conversion type



Summary

- Measurement of $tq\gamma$ cross-section provides an important precision test for Standard Model.
- ATLAS collaboration has started search for this process with the full Run-2 data (139 fb^{-1})
- In the current talk, I have summarized the signal MC production and $e \rightarrow \gamma$ fake estimation method
- Work in Progress: Fake lepton estimation, Neural Network for separating signal and backgrounds and Profile likelihood fit to data to get $tq\gamma$ Cross-section