Estimation of electron-to-photon fakes in SM $tq\gamma$ analysis

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Isolation & Fake Forum
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OUTLINE

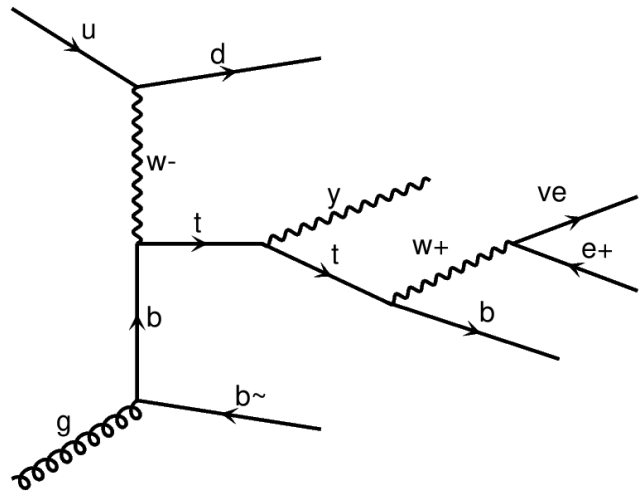
- In this talk, I will present
  - Brief introduction about $tq\gamma$ analysis
  - Data and MC samples
  - Object level selections
  - Pre-selection region composition
  - $e \to \gamma$ fake estimation method
- Björn Wendland will present $j \to \gamma$ fake estimation method in the next talk

Glance Entry:
https://glance.cern.ch/atlas/analysis/analyses/details.php?id=1765

Internal Note (partially complete):
https://cds.cern.ch/record/2712922

MOTIVATION FOR $tq\gamma$ ANALYSIS

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



- This process not been observed yet
- CMS published evidence for this process with partial Run-2 data https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.121.221802
- 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

DATA & MC SAMPLES

- This analysis uses full Run-2 data (139 fb^{-1}) collected by the ATLAS experiment in 2015-18

Process	Generator	DSID
$tq\gamma$	aMcAtNlo+Pythia8	412147
$t\bar{t}\gamma$	MadGraph5+Pythia8	410389
$W\gamma$ + jets	Sherpa 2.2.2	3645[21-35]
$Z\gamma$ + jets	Sherpa 2.2.4	3661[40-54]
$t\bar{t}$	Powheg+Pythia8	410470
single top	Powheg+Pythia8	41065[8-9], 41064[4-7]
W + jets	Sherpa 2.2.1	3641[56-97]
Z + jets	Sherpa 2.2.1	3641[00-41]
Diboson	Sherpa 2.2.2	3633[55-60], 363489, 36425[0, 3-5]

Overlap removal in V+jets and Vγ+jets samples

There are few overlaps between V+jets and Vγ+jets samples (V = $t\bar{t}, W, Z$). (Mainly due to QED final state radiation by the parton shower modelling)
A reconstructed photon is classified as:

- $e \rightarrow \gamma$ **fake**
  - if the truth particle matching to it is an electron
  - if the truth particle matching to it is a photon and there is a truth electron within a distance of ΔR <0.05
- $j \rightarrow \gamma$ **fake** if the parent of the truth particle corresponding to it is a hadron
- **Prompt photon** if it is not matching above definitions

Sample	Keep	Remove
V+jets	Events with fake photons	Events with prompt photons
Vγ+jets	Events with prompt photons	Events with fake photons

Object definitions

Object	ID	Isolation	min p_T	max $\lvert\eta\rvert$
Electron	TightLH	FCTight	27 GeV	2.47
Muon	Medium	FCTight	27 GeV	2.5
Photon	Tight	FixedCutTight	15 GeV	2.37
Jets	EMTopoJets		25 GeV	4.5
B-tagging	MV2c10 - 70% WP		25 GeV	2.5

- We are currently updating our analysis with new ntuples which have PFlowJets & DL1r b-tagging algorithm.

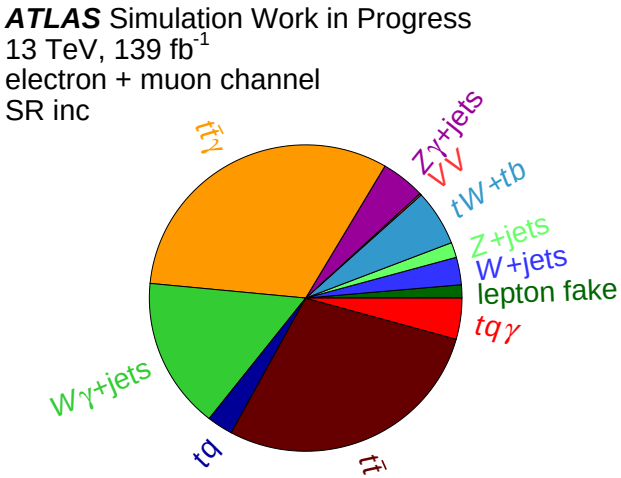
COMPOSITION OF PRE-SELECTION REGION

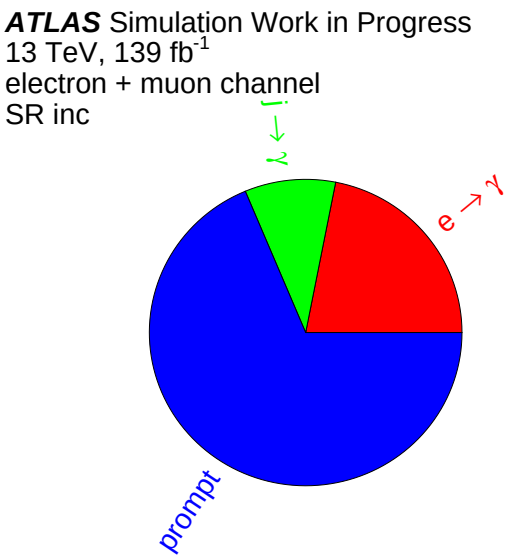
Selection:

- Exactly 1 lepton
- At lease 1-photon
- Exactly 1-bjet passing 70% WP
- Missing $p_T > 30$ GeV
- $M(e\gamma) \notin (70, 110)$ GeV

Major backgrounds:

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





WHAT ARE $e \to \gamma$ FAKES?

- In the ATLAS experiment, electrons and photons are reconstructed using very similar algorithms $\Rightarrow$ electrons may sometimes mis-reconstructed as photons
- Happens mainly due to tracking inefficiency or failure to find a match between the Inner Detector track and the electromagnetic cluster
- Simulation does not model these fakes well.
- Scale factors are derived from data, in bins of η_γ and photon conversion type, to correct the simulation for this mis-modelling.
- Rate of an electron faking as photon is $\sim 9\%$ (from data)

ESTIMATION OF $e \to \gamma$ FAKE RATE

- $e \to \gamma$ fake rate ($F_{e\to\gamma}$): Ratio of probability that an electron is mis-reconstructed as an photon to the probability that an electron is correctly reconstructed.
- $F_{e\to\gamma}$ can be estimated from Z+jets events that are reconstructed as e^+e^- and $e\gamma$ pairs,

$$F_{e\to\gamma} = \frac{N(Z \to e\gamma)}{2 \times N(Z \to e^+e^-)} \tag{1}$$

(A factor of 2 is included in the denominator as either of the two electrons can be mis-reconstructed as photon.)

$(e \to \gamma$ FAKE RATE) SCALE FACTOR

Scale factor to be applied to MC is given by

$$\text{Scale factor (SF)} = \frac{F^{\text{Data}}_{e\to\gamma}}{F^{\text{MC}}_{e\to\gamma}} \tag{2}$$

Simplifying,

$$\text{SF} = \frac{N^{\text{Data}}(Z \to e\gamma) \;/\; N^{\text{MC}}(Z \to e\gamma)}{N^{\text{Data}}(Z \to e^+e^-) \;/\; N^{\text{MC}}(Z \to e^+e^-)} = \boxed{\frac{\mu_{Ze\gamma}}{\mu_{Zee}}} \tag{3}$$

Where, $\mu_{Ze\gamma} = \dfrac{N^{\text{Data}}(Z \to e\gamma)}{N^{\text{MC}}(Z \to e\gamma)}$ and $\mu_{Zee} = \dfrac{N^{\text{Data}}(Z \to e^+e^-)}{N^{\text{MC}}(Z \to e^+e^-)}$

Control and Validation Regions

Two control regions and one validation region enriched with Z+jets events are used for estimating $e \to \gamma$ scale factors

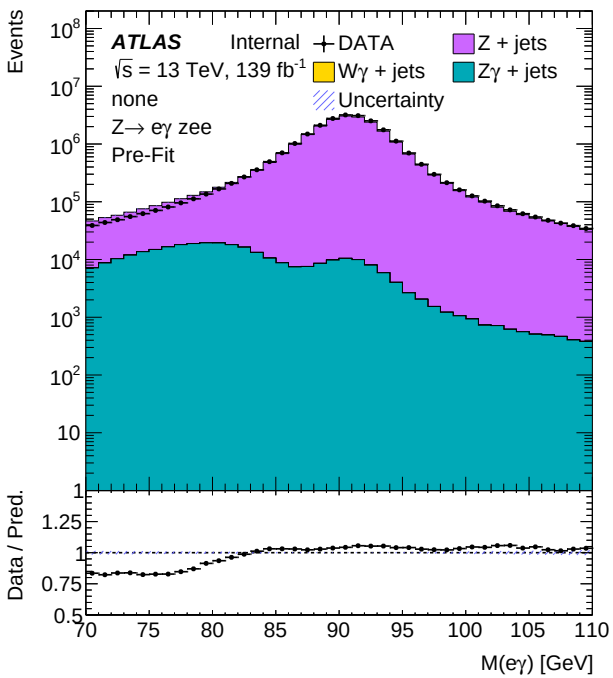
Object	$Z \to e^+e^-$ CR	$Z \to e\gamma$ CR	$Z \to e\gamma$ VR
Photons	=0 w/ $p_T > 15$ GeV	=1 w/ $p_T > 15$ GeV	=1 w/ $p_T > 15$ GeV
Electrons	=2 (OS) w/ $p_T > 27$ GeV	=1 w/ $p_T > 27$ GeV	=1 w/ $p_T > 27$ GeV
b-jets	-	=0 w/ $p_T > 25$ GeV	$\geq$1 w/ $p_T > 25$ GeV
Missing p_T	< 30 GeV	< 30 GeV	< 30 GeV
$M(e^+e^-)$	[70, 110] GeV	-	-
$M(e\gamma)$	-	[70, 110] GeV	[70, 110] GeV
Purpose	Measure μ_{Zee}	Measure $\mu_{Ze\gamma}$	Validate SFs

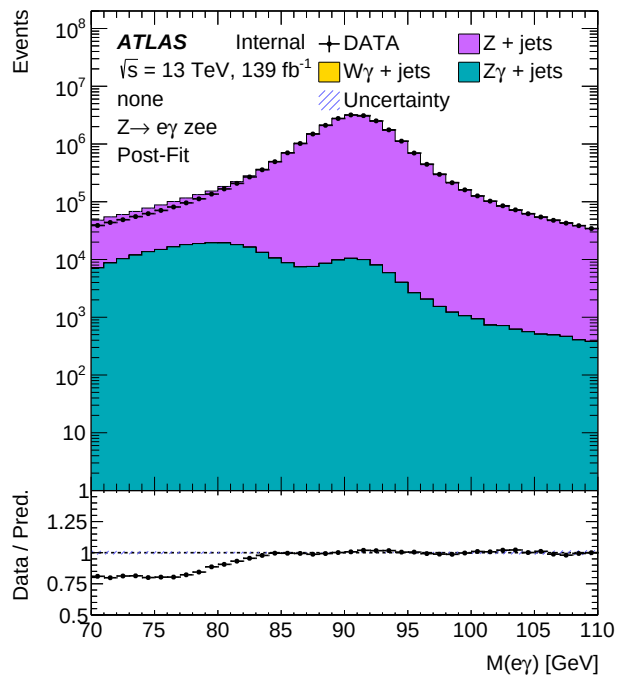
All regions are orthogonal to SR (inverted MET cut) and to each other

μ_{Zee} CALCULATION

- μ_{Zee} is measured by fitting MC templates of $M(e^+e^-)$ distribution, to data in $Z \to e^+e^-$ CR
- Normalization for the template of $Z \to e^+e^-$ process is determined from the fit
- Normalization for all other backgrounds are fixed to their MC expectations

Observed value of $\mu_{Zee} = 1.03 \pm 0.00026$





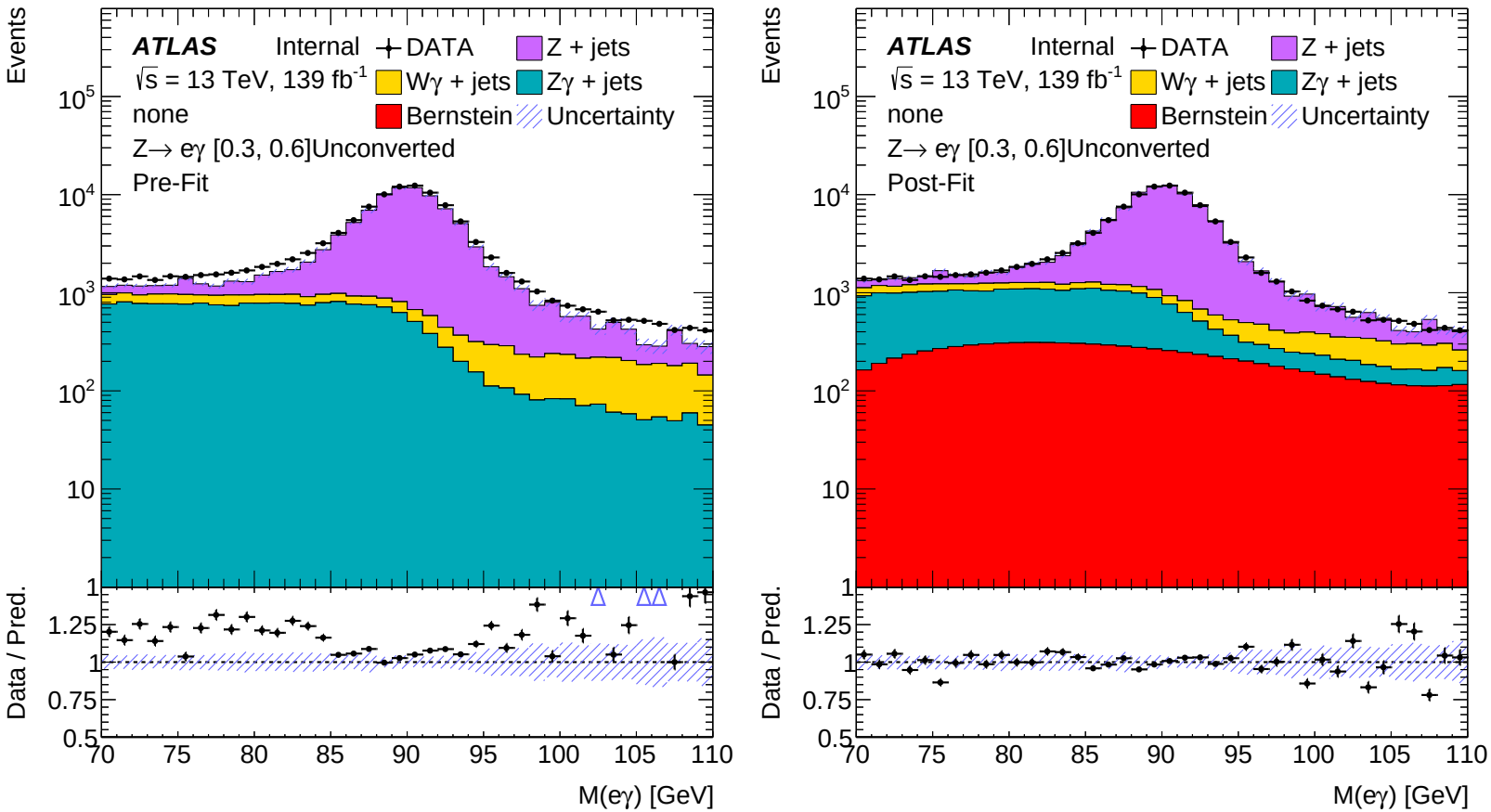
CALCULATION OF $\mu_{Ze\gamma}$

$\mu_{Ze\gamma}$ is measured by fitting templates of $M(e\gamma)$ distribution to data in the $Z \to e\gamma$ CR.

- Template shape of $M(e\gamma)$ distribution for $Z \to e\gamma$ process is obtained from MC. Normalization is determined from the fit.
- For major bkgs, $W\gamma$ and $Z\gamma$, both normalization and shape are obtained from MC.
- Third order Bernstein polynomials are used as $M(e\gamma)$ templates for missing rare backgrounds like VV, W+jets and γ+jets, etc.

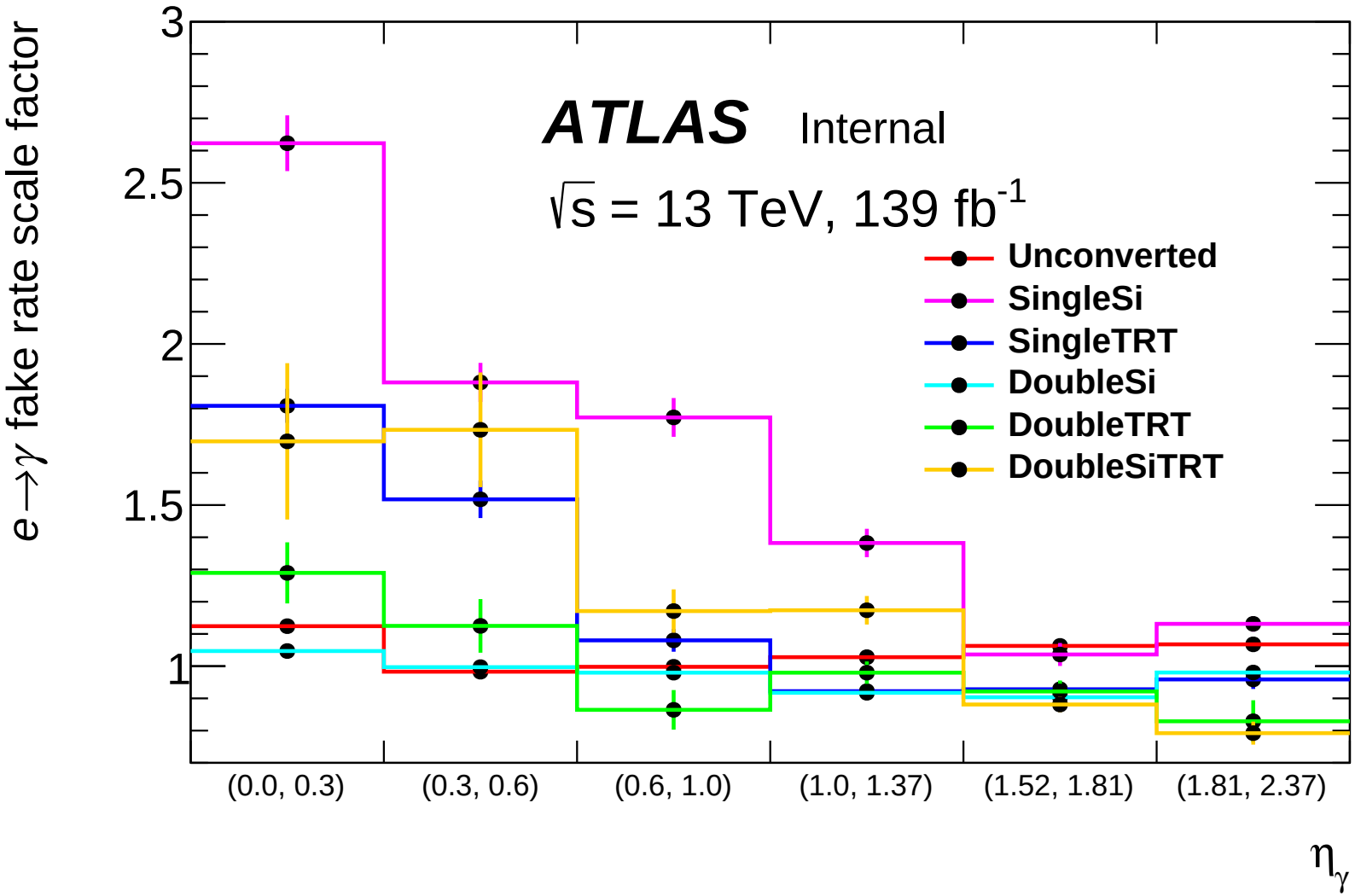
$\mu_{Ze\gamma}$ RESULTS

- M($e\gamma$) distribution for $Z \to e\gamma$ region is shown here before (left) and after(right) fitting to data
- Bin: Unconverted Photon and $\eta_\gamma \in (0.3, 0.6)$



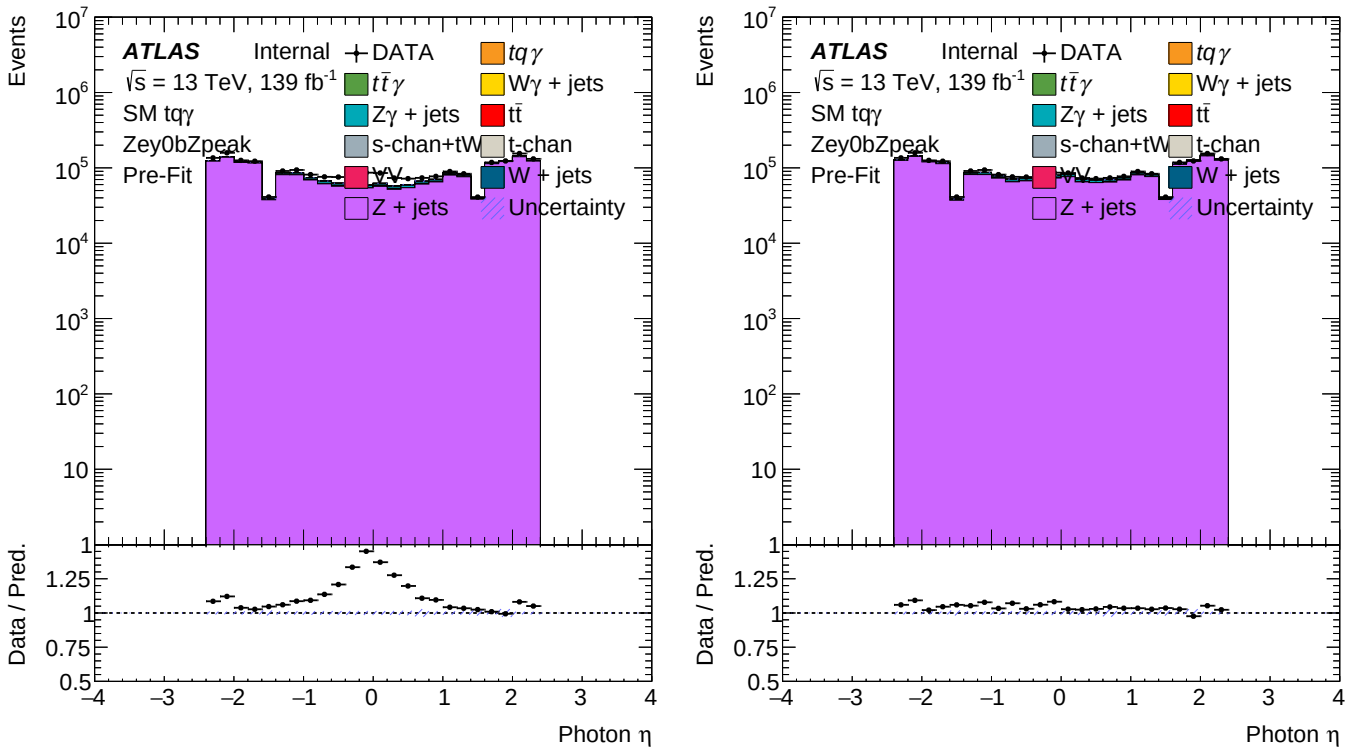
SFs IN BINS OF PHOTON η AND CT

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

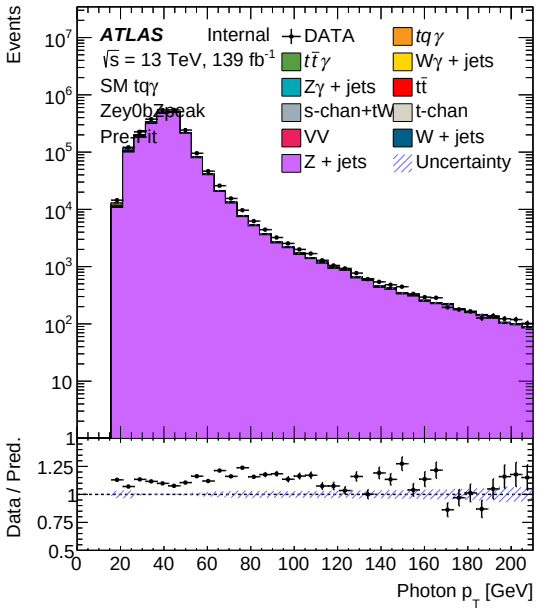


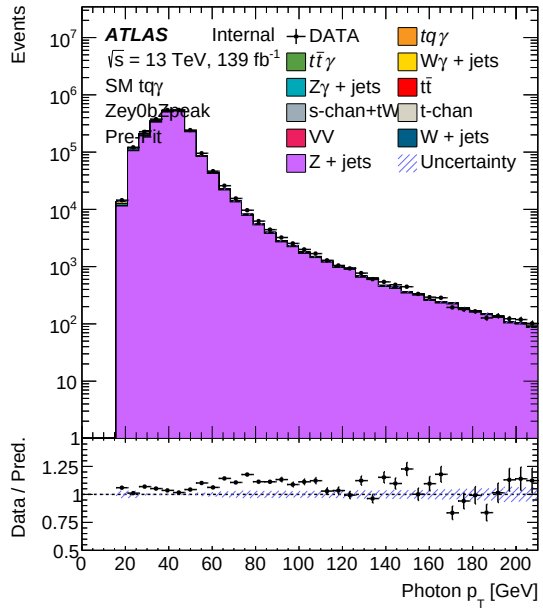
Closure test in $Z \to e\gamma$ CR

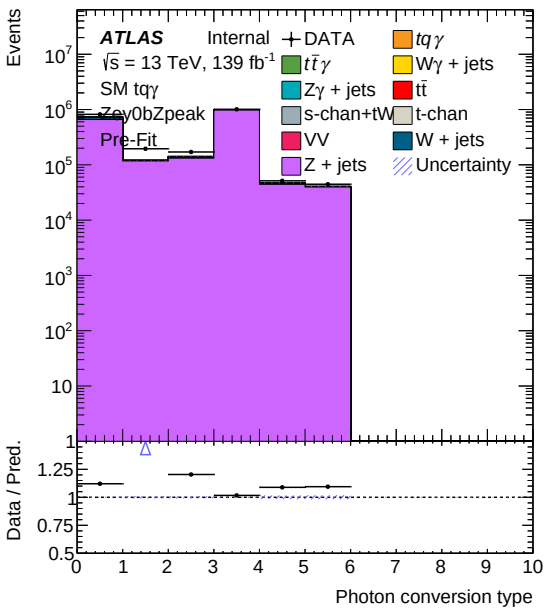
- SFs have been tested for closure in $Z \to e\gamma$ CR, the same region from which they are derived.
- Comparison of Data/MC plots without (left) and with (right) scale factors is presented here.
- SF corrections to MC, clearly, improves the agreement with data.

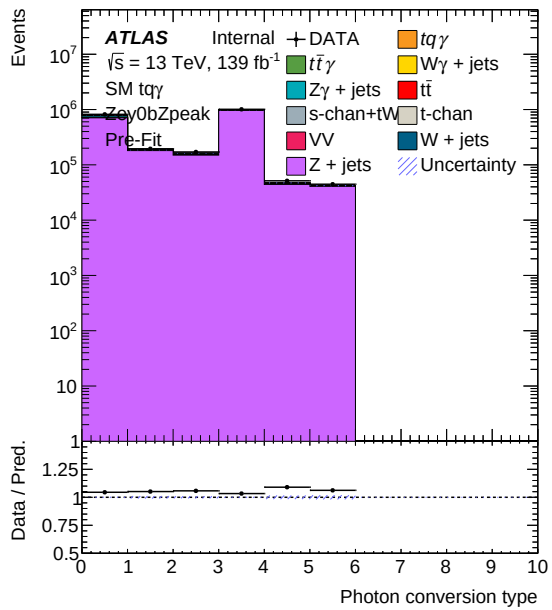


CLOSURE TEST - 2



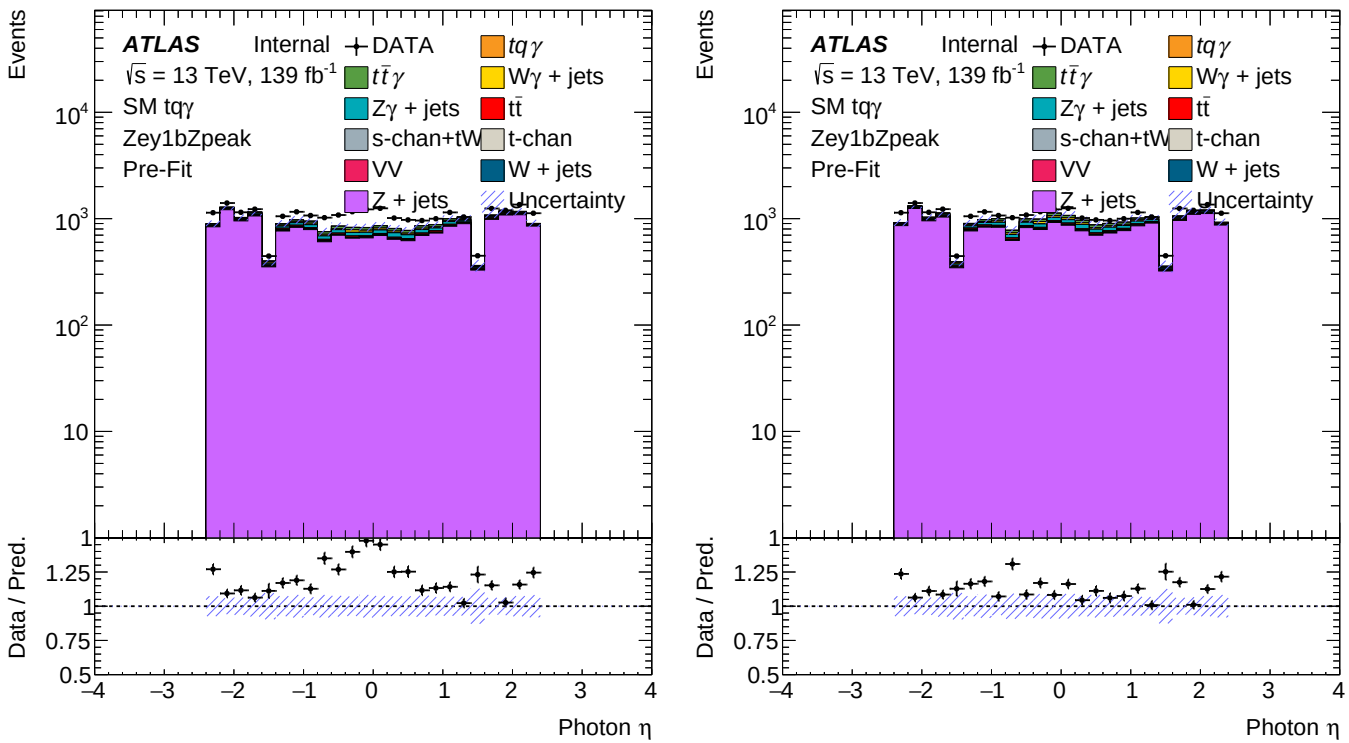




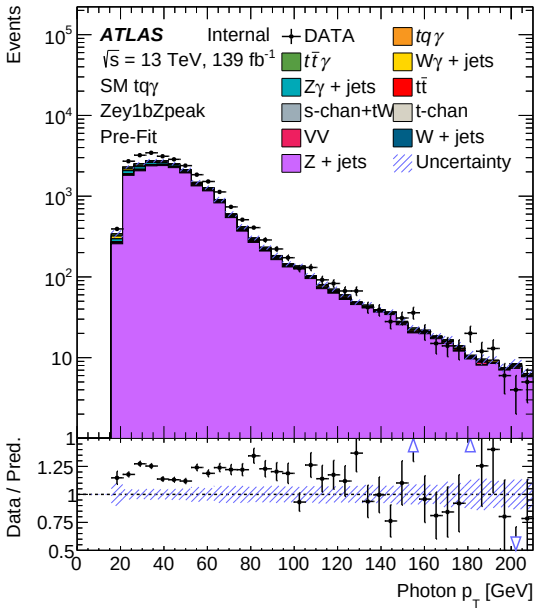


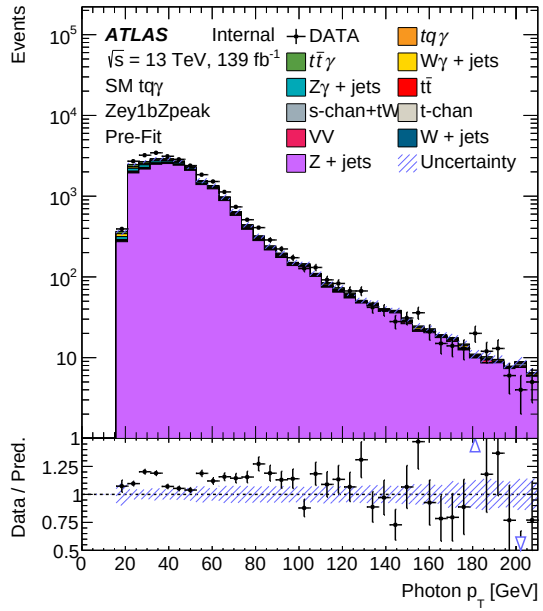
VALIDATION OF SFS IN $Z \to e\gamma$ VR

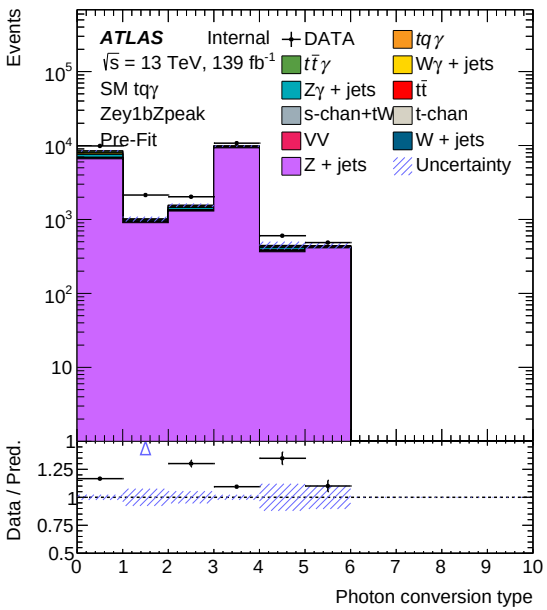
- SF corrections to MC have been tested in $Z \to e\gamma$ VR.
- Comparison of data and MC plots before (left) and after (right) applying SFs indicates that SFs improve the agreement between data and MC.

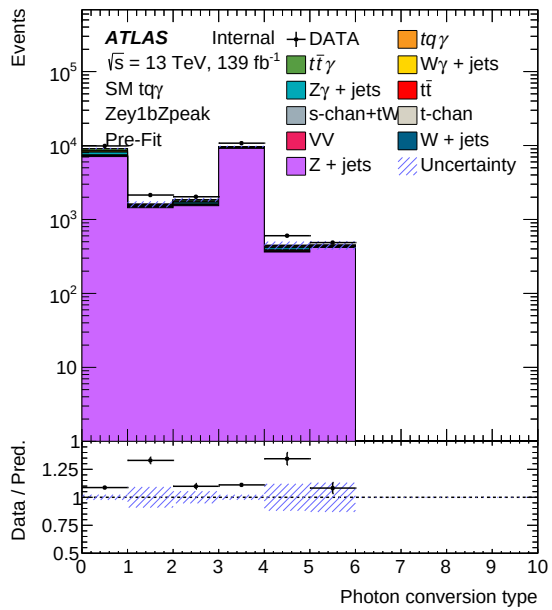


SF VALIDATION PLOTS - 2



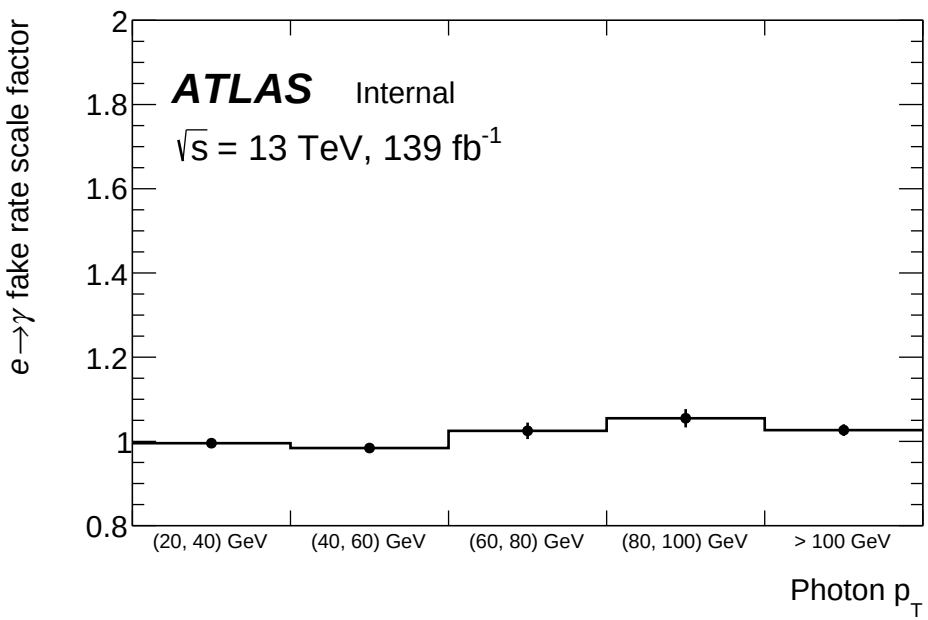






ADDITIONAL PARAMETERISATION IN PHOTON p_T

- Checked if additional parameterisation in $p_{T,\gamma}$ is needed after applying SF corrections to MC in bins of η_γ and conversion type.
- As shown below, SFs do not depend on the transverse momentum of photon.



Uncertainties on the SF measurement

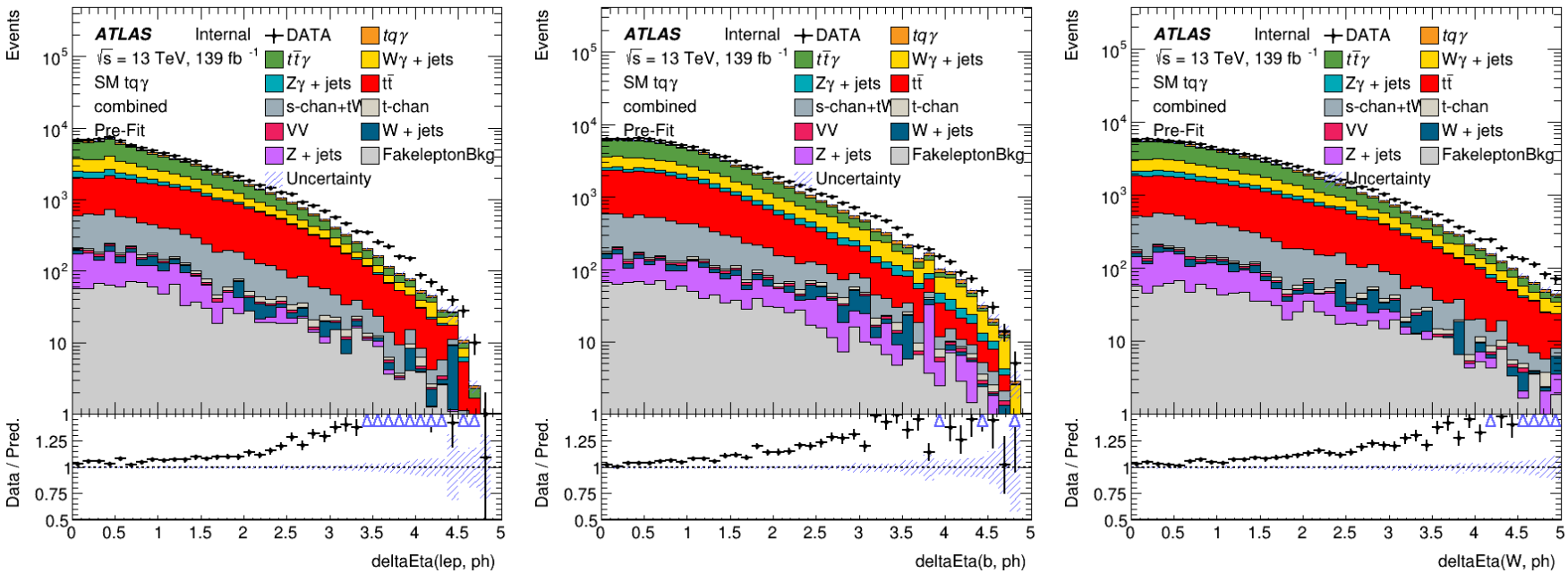
- Only MC statistical uncertainties have been considered
- As $\delta\sigma_{\mathrm{Z+jets}}$ affects both μ_{Zee} and $\mu_{Ze\gamma}$, it's contribution to SF measurement uncertainty is zero
- We do not expect any significant contributions from any other theoretical & experimental uncertainties

SUMMARY

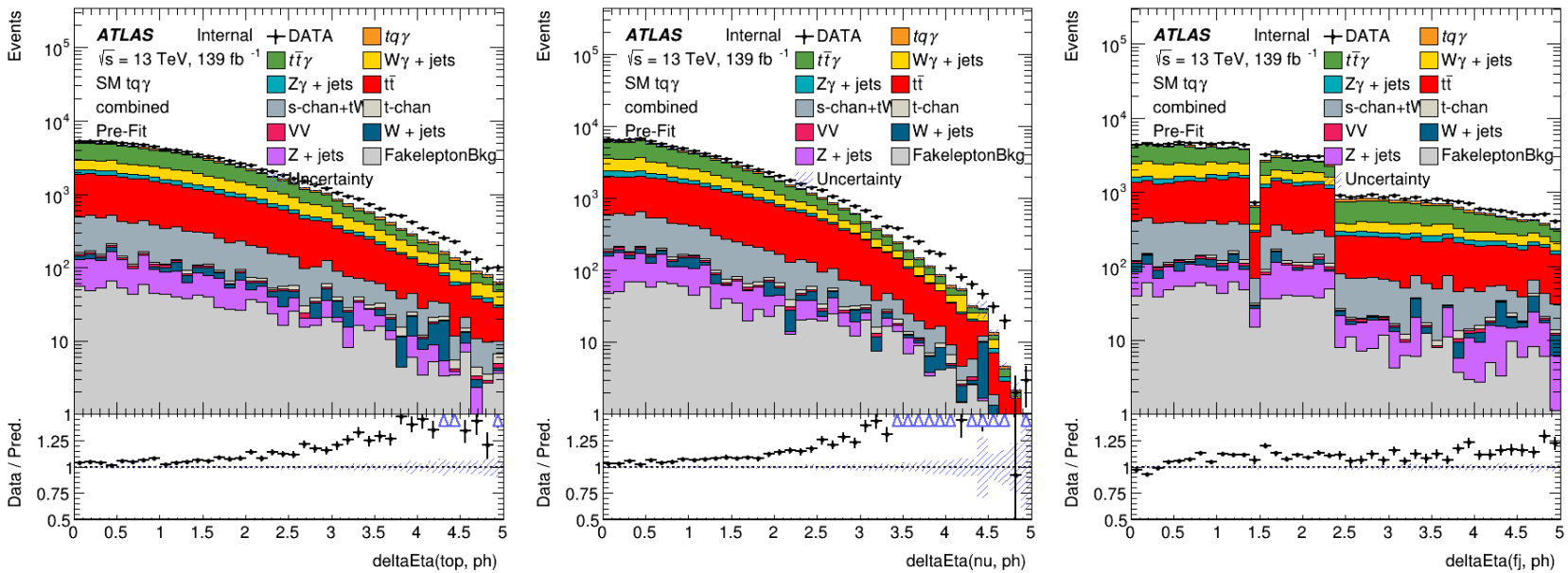
- Events with $e \to \gamma$ fakes constitute a major background in the $tq\gamma$ signal region
- Scale factors have been derived, in bins of η_γ and conversion type, from data to correct the Simulation for the mis-modelling of these fakes
- Closure test and validation region plots indicate that applying SF corrections to MC improves the agreement with data
- MC statistical uncertainties have been considered in the SF calculations. No other major source of uncertainties is expected

Question: Strange excess in signal region

We see excess in SR for high values of $\Delta\eta(\gamma,\ x)$, where, x = ℓ, b, W, j, t. Did any body see this type of excess?



Question: Strange excess in signal region - 2



BACKUP

PHOTON CONVERSION TYPE

Photon is reconstructed as converted photon if there are 1 or 2 tracks matched to the cluster else as unconverted photon.

Photon conversion type:

- unconverted = 0 : unconverted photon
- singleSi = 1 : one track only, with Si hits
- singleTRT = 2 : one track only, no Si hits (TRT only)
- doubleSi = 3 : two tracks, both with Si hits
- doubleTRT = 4 : two tracks, none with Si hits (TRT only)
- doubleSiTRT = 5 : two tracks, only one with Si hits