Inclusive $Z(\nu\bar{\nu})\gamma$ full Run2 analysis report

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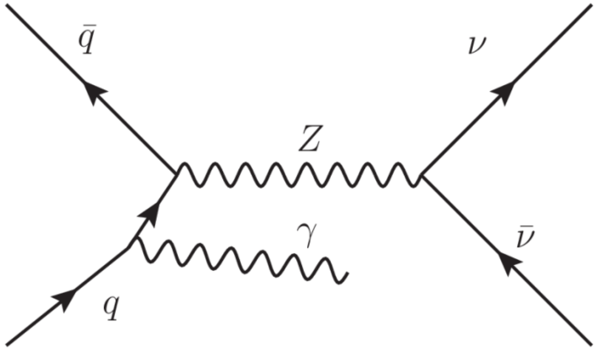
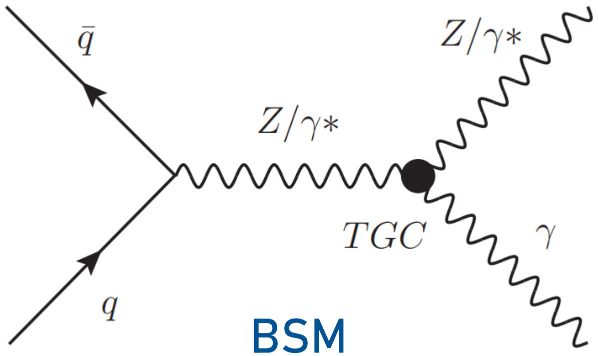
Motivation

- Standard Model:

⇨ A higher branching ratio of the neutral decay channel in comparison to the charged lepton decays of Z boson and better background control in comparison with the hadronic channel.

⇨ Previous study of this channel — 36.1 fb^{-1} data. Full Run2 statistics (140 fb^{-1}) → increase of measurement accuracy (expect the experimental sensitivity to increase by a factor of 2).





BSM

Glance: ANA-STDM-2018-54

- Goal:

⇨ To obtain integrated and differential cross-sections for 10 observables: E_T^γ, p_T^{miss}, N_{jets}, η_γ, $\Delta\varphi(\gamma, p_T^{miss})$, $\Delta\varphi(j_1, j_2)$, $\Delta R(Z, \gamma)$, p_T^{j1}, p_T^{j2}, $m_T^{Z\gamma}$ and compare the results with the theory predictions including NNLO QCD and NLO EWK corrections.

- Beyond SM:

⇨ To obtain the strongest up-to-date limits on anomalous neutral triple gauge-boson couplings (aTGCs) using vertex functions and EFT formalisms.

⇨ Possible combination of the EFT limits between Zγ and ZZ.

Selection optimisation

- Topology: high-energetic photon and MET.
- Multivariate (MV) method of the selection optimization takes into account the signal significance S as a function of the threshold values of the variables:

$$S = N_{\text{signal}} / \sqrt{N_{\text{signal}} + N_{\text{bkg}}}$$

⇨ The result of the MV optimization process is a set of threshold values for the variables that yield the maximum S.

Selections	Cut Value
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 130 GeV
E_{T}^{γ}	> 150 GeV
Number of tight isolated photons	$N_{\gamma} = 1$
Lepton veto	$N_{e} = 0, N_{\mu} = 0$
τ veto	$N_{\tau} = 0$
$E_{\mathrm{T}}^{\mathrm{miss}}$ significance	> 11
$\lvert\Delta\phi(\gamma, \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}})\rvert$	> 0.6
$\lvert\Delta\phi(j_1, \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}})\rvert$	> 0.3

← The significance is increased by 3% (for τ veto)

	all cuts	presel. only
Signal		
$Z(\nu\nu)\gamma$QCD	10711 ± 8	13438±9
$Z(\nu\nu)\gamma$EWK	166.3 ± 0.3	300.5±0.4
Total signal	10878 ± 8	13738±9
Background		
$W\gamma$ QCD	3310 ± 21	6393±28
$W\gamma$ EWK	109.4 ± 0.6	293.5±1.1
tt, top	177 ± 5	1991±18
$W(e\nu)$	3591 ± 487	7934±540
$tt\gamma$	178 ± 3	746±6
γ+j	8123 ± 82	63766±211
Zj	415 ± 21	635±25
$Z(ll)\gamma$	211 ± 4	399±5
$W(\tau\nu)$	640 ± 69	2222±127
Total bkg.	16779 ± 499	84380±595
Stat. signif.	65.4 ± 0.6	43.86±0.14

Beam-induced background suppression: |Δz| < 250 mm

The optimisation procedure is done for three different photon isolation working points FixedCutTight, FixedCutTightCaloOnly and FixedCutLoose.

Background composition

Percentage of the data

Background composition for $Z(\nu\bar{\nu})\gamma$:

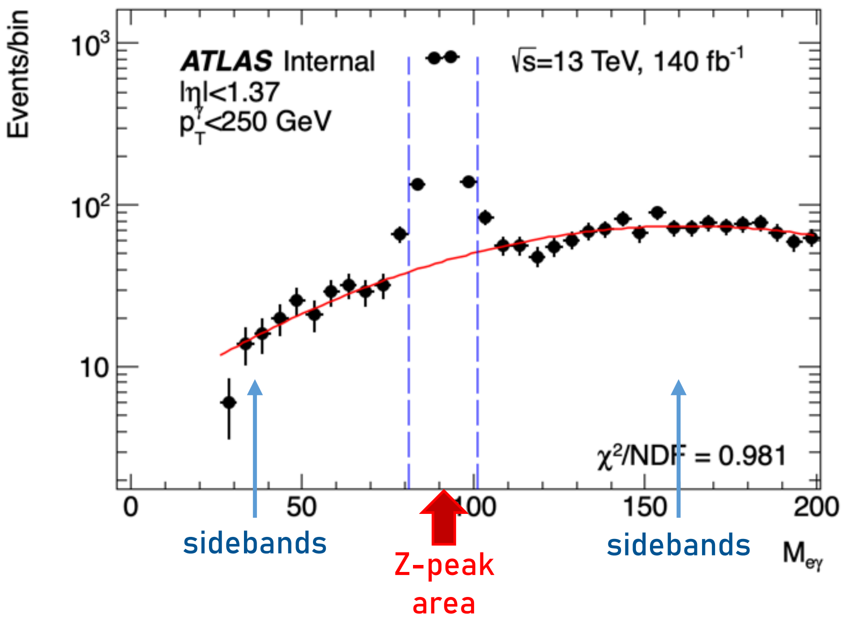
35%	γ + jets – fit to data in additional CR based on MET significance (shape from MC);
15%	$W(\rightarrow l\nu)\gamma$ and $tt\gamma$ – fit to data in additional CR based on N leptons (shape from MC);
11%	$e \rightarrow \gamma$ – fake-rate estimation using Z-peak (tag-n-probe) method;
8%	jet $\rightarrow \gamma$ – ABCD method based on photon ID and isolation (shape from Slice Method);
0.9%	$Z(l^+l^-)\gamma$ – via MC;

$e \to \gamma$ misID background: Z-peak method

- Background estimation method:
  1. Estimating $e \to \gamma$ fake-rate as $rate_{e\to\gamma} = \frac{(N_{e\gamma} - N_{bkg})}{(N_{ee} - N_{bkg})}$,

     where $N_{e\gamma}$, N_{ee} – number of ee and eγ events in Z-peak mass window (M_Z–10 GeV, M_Z+10 GeV), N^{bkg} – background in Z-peak mass window extrapolated from sideband with exponential pol1 or pol2 fit.

     Additional Wγ background rejection: E_T^{miss} < 40 GeV.



eγ pair selection:
signal region photon with p_T>150 GeV (probe), selected Tight electron with p_T>25 GeV (tag)

ee pair selection:
selected electron with p_T>150 GeV (probe), selected opposite sign Tight electron with p_T>25 GeV (tag)

Since fake rate depends on p_T and η (see backup), three regions are considered:
|η|<1.37, p_T<250 GeV and *|η|<1.37, p_T>250 GeV* and *1.52<|η|<2.37* (flat distribution on p_T)

2. Building e-probe control region (CR): signal region with selected Tight electron with p_T>150 GeV instead of photon.
3. Scaling data distributions from e-probe CR by fake rate value.

$e \to \gamma$ misID background: systematics

- Systematics on fake-rate estimation (ascending contribution):

⇨ Z peak mass window variation (varies from 0.3% to 0.7%).

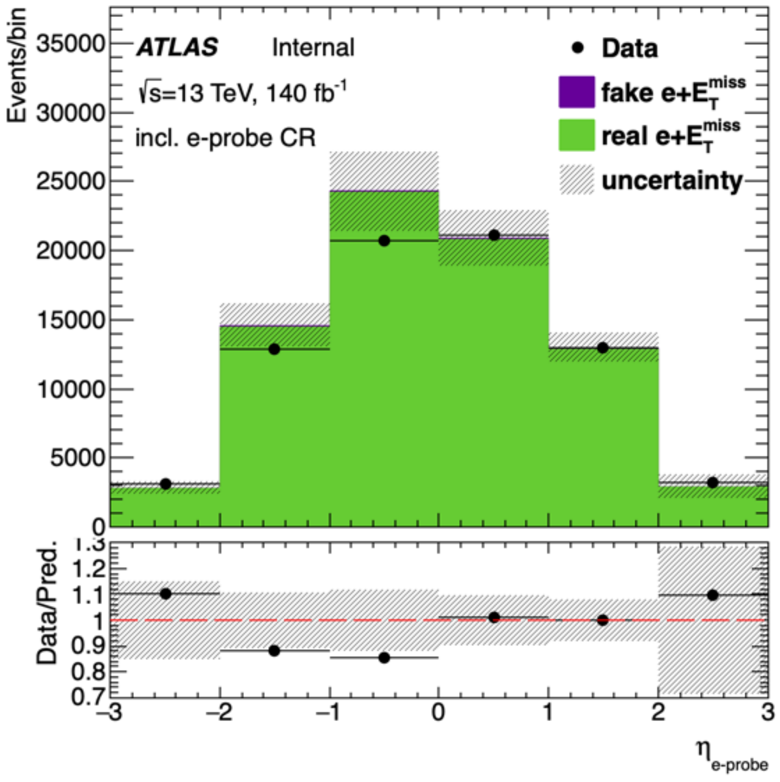
⇨ Background under Z peak evaluation (varies from 3% to 14%).

⇨ Difference between "real fake rate" in Z(ee) MC and tag-and-probe method performed on Z(ee) MC (varies from from 3% to 15%).

	$150<E_T^\gamma<250$ GeV	$E_T^\gamma>250$ GeV
$0<\|\eta\|<1.37$	0.0234±0.0006±0.0010	0.0193±0.0013±0.0038
$1.52<\|\eta\|<2.37$	0.0714±0.0019±0.0074	

First uncertainty is statistical, second is systematical.

Total systematics on fake-rate does not exceed 20%



Background estimation result:

Signal region 2608 ± 11 ± 162

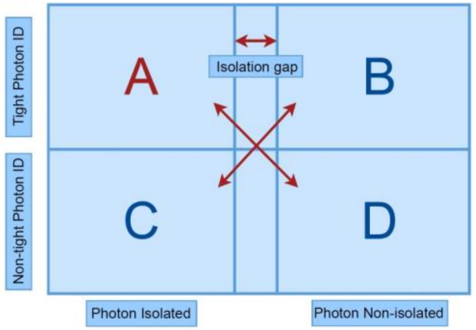
<u>Total syst. on the background yield:</u> 6%

jet → γ misID background: ABCD-method

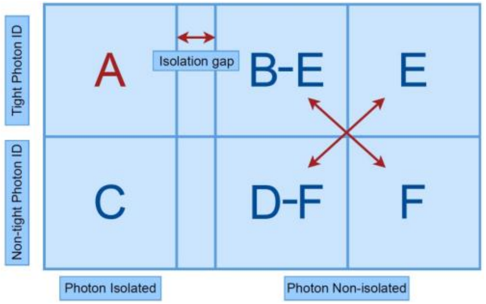
- A pair of photons from the decay of neutral mesons (typically a π^0), contained in hadronic jets, can give a signature of EM shower similar to a single isolated photon signature of the electromagnetic (EM) shower.
- Background is estimated from data using 2D-sideband method: photon isolation and identification variables are used to construct the sidebands.
- Correlation is measured in data and MC by $R = \frac{N_A N_D}{N_B N_C}$
- FixedCutLoose isolation working point is used with iso gap of 2 GeV

Isolation should not correlate with non-tight ID!

$$\frac{N_A^{jet\to\gamma}}{N_B} = \frac{N_C}{N_D}$$



MC



Data

In ABCD

R factor	*loose'2*	*loose'3*	*loose'4*	*loose'5*
MC	1.1 ± 0.2	1.1 ± 0.2	1.1 ± 0.2	1.4 ± 0.3

Cut, GeV	*loose'2*	*loose'3*	*loose'4*	*loose'5*
MC				
4.5	1.18 ± 0.19	1.15 ± 0.16	1.08 ± 0.13	1.11 ± 0.13
7.5	1.12 ± 0.14	1.16 ± 0.13	1.10 ± 0.11	1.11 ± 0.11
10.5	1.15 ± 0.14	1.16 ± 0.13	1.11 ± 0.11	1.12 ± 0.11
Data-driven				
4.5	0.99 ± 0.11	1.05 ± 0.11	1.07 ± 0.09	1.09 ± 0.09
7.5	1.13 ± 0.11	1.09 ± 0.09	1.06 ± 0.08	1.05 ± 0.08
10.5	1.00 ± 0.10	0.99 ± 0.09	0.96 ± 0.07	0.96 ± 0.07

In B-E, E, D-F and F

	R_{data}	R'	R
loose'2	0.99 ± 0.11	1.18 ± 0.19	1.1 ± 0.2
loose'3	1.05 ± 0.11	1.15 ± 0.16	1.1 ± 0.2
loose'4	1.07 ± 0.09	1.08 ± 0.13	1.1 ± 0.2
loose'5	1.09 ± 0.09	1.11 ± 0.13	1.4 ± 0.3

Resulting R for MC and data

R factor	*loose'2*	*loose'3*	*loose'4*	*loose'5*
MC	0.99 ± 0.15	1.05 ± 0.11	1.07 ± 0.10	1.1 ± 0.3

jet → γ misID background: uncertainties

- Statistical uncertainty:

⇨ The event yields of four regions in data and non jet → γ background are varied by ±1σ independently (9%).

⇨ The statistical uncertainty on the signal leakage parameters is negligible.

Total statistics: 9%.

Central value	1765^{+164}_{-160}
Loose'2	+240
Loose'4	+85
Loose'5	−55
Isolation gap +0.3 GeV	−60
Isolation gap −0.3 GeV	+33

- Systematic uncertainty :

⇨ Anti-tight definition and isolation gap choice – variations of ABCD regions determination by ±1σ changes in data yield (14%).

⇨ The deviations from the nominal value from varying R factor by ± 0.10 (10%).

Central value	1765^{+164}_{-160}
$R + \Delta R$	+180
$R - \Delta R$	−178

⇨ Uncertainty coming from the signal leakage parameters is obtained via using different generators and parton shower models (0.7%).

Signal leakage parameters	MadGraph+Pythia8, Sherpa 2.2	MadGraph+Pythia8, MadGraph+Pythia8	Relative deviation
c_B	$(278 \pm 4) \cdot 10^{-5}$	$(47 \pm 2) \cdot 10^{-4}$	7%
c_C	$(3205 \pm 14) \cdot 10^{-5}$	$(330 \pm 6) \cdot 10^{-4}$	3%
c_D	$(178 \pm 11) \cdot 10^{-6}$	$(39 \pm 5) \cdot 10^{-5}$	120%
$jet \to \gamma$ estimation	1765	1752	0.7%

⇨ The iso/ID uncertainty on reconstruction photon efficiency $\delta_{eff}^{iso/ID}$ (1.3%).

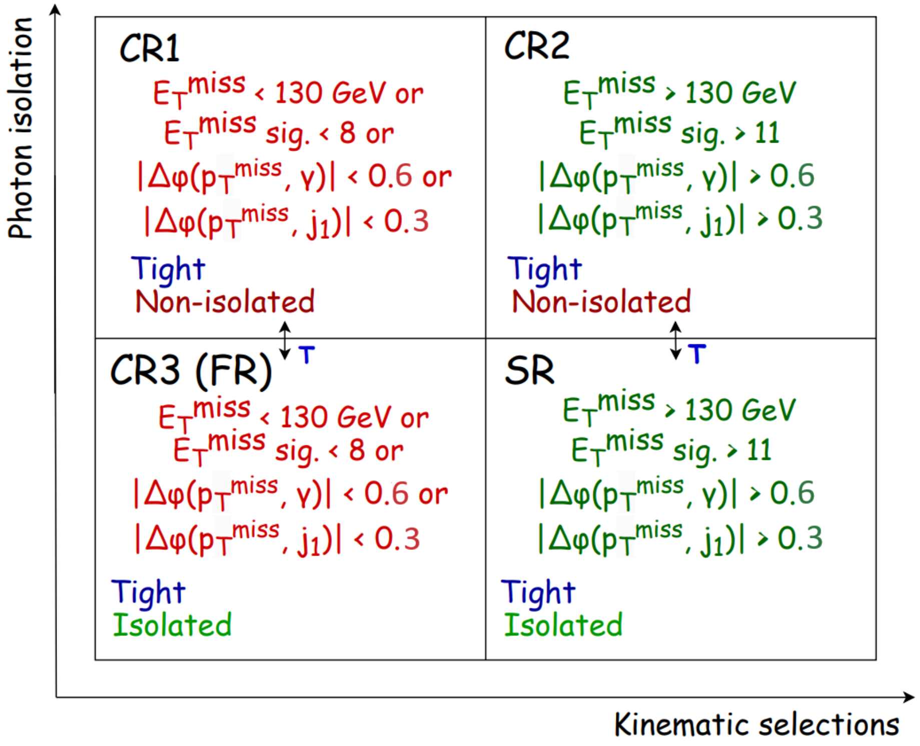
Total systematics: 17%.

⇨ Total number of jet → γ events: 1770 ± 160 ± 300. Z(νν)+jets and multi-jet MC predicts 2000 ± 1300 events.

jet → γ misID background: slice method

- The jet → γ background shape cannot be properly modeled with MC. For this reason, the shape of jet → γ background is estimated via slice method.
- The proposed slice method splits the phase space into four orthogonal regions based on kinematic cuts and the photon isolation.
- The non-isolated regions are split into a set of successive intervals (slices) based on the photon isolation.

⇨ Four isolation slices are chosen: [0.065, 0.090, 0.115, 0.140, 0.165].



$$N^{jet\to\gamma}_{\mathrm{CR1(i)}} = N^{\mathrm{data}}_{\mathrm{CR1(i)}} - N^{Z(\nu\bar{\nu})\gamma}_{\mathrm{CR1(i)}} - N^{\mathrm{bkg}}_{\mathrm{CR1(i)}}$$

$$H^{[0.A,0.B]}_{jet\to\gamma} = H^{[0.A,0.B]}_{\mathrm{data}}[X] - H^{[0.A,0.B]}_{\mathrm{sig}}[X] - H^{[0.A,0.B]}_{\mathrm{bkg}}[X]$$

$$\Delta^{CR2}[X] = \frac{1}{2}\left(\frac{H^{[0.065,0.09]}_{jet\to\gamma}[X] - H^{[0.115,0.14]}_{jet\to\gamma}[X]}{2} + \frac{H^{[0.09,0.115]}_{jet\to\gamma}[X] - H^{[0.14,0.165]}_{jet\to\gamma}[X]}{2}\right)$$

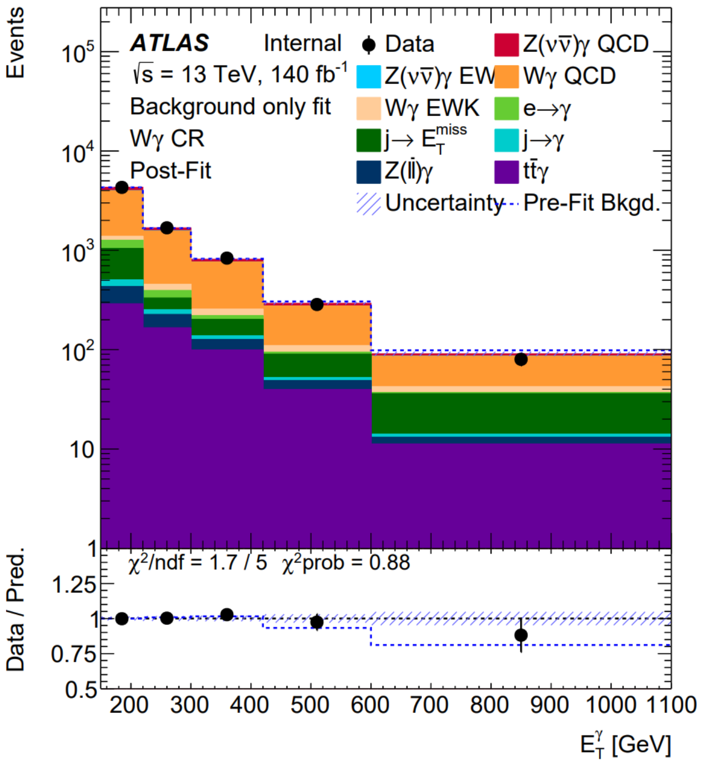
⇨ The jet → γ shape in the SR: $H^{SR}_{jet\to\gamma} = H^{[0.065,0.09]}_{jet\to\gamma}[X] + \Delta^{CR2}[X]$ ← The correction term

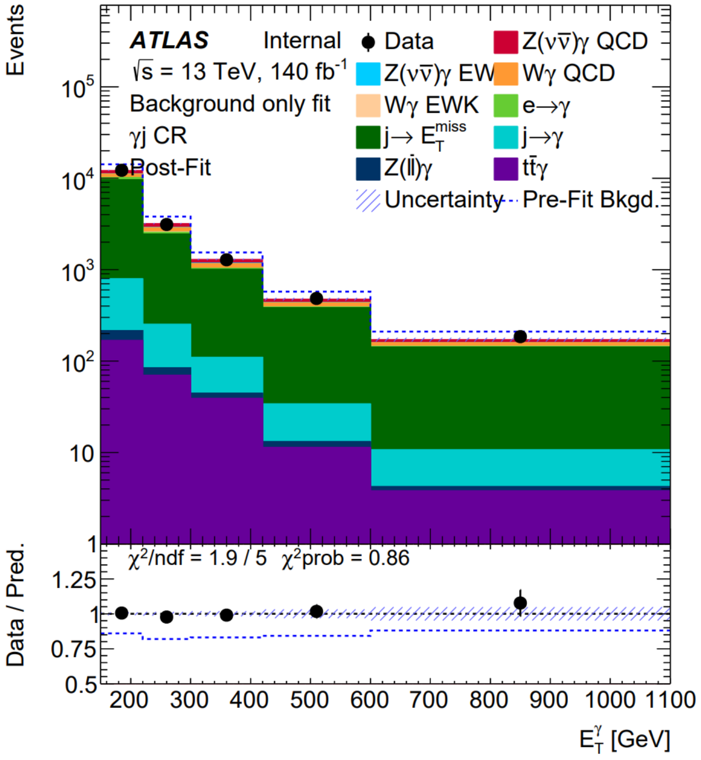
Template fit

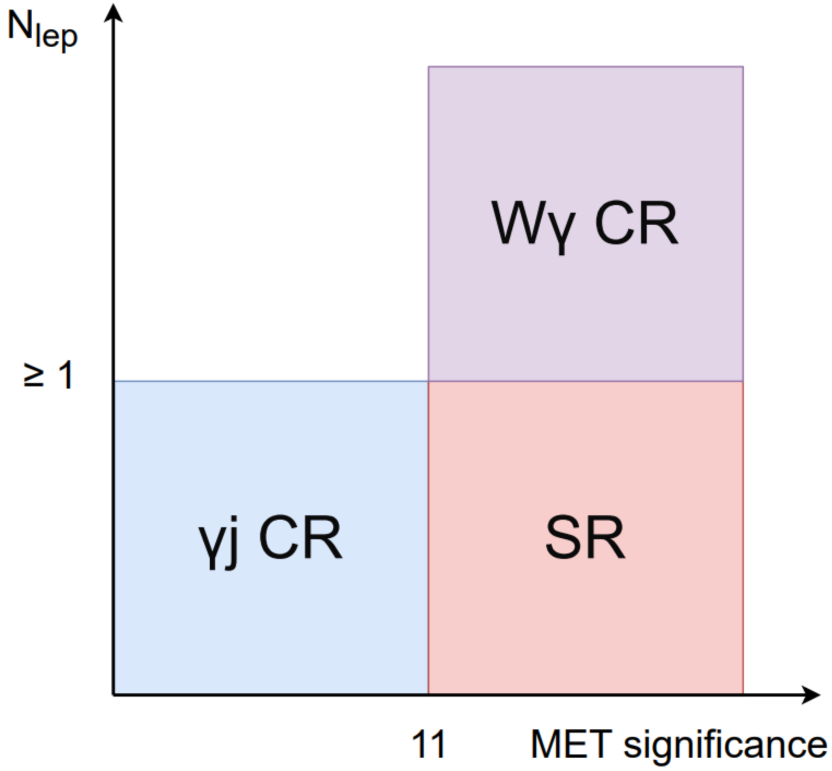
- Three free parameters are introduced in the combined fit: a signal strength parameter μ(Zg) and two normalization factors μ(Wg) and μ(γj) used to scale the yields of W(lv)γ and ttγ and γ+jets processes.

⇨ The binned likelihood function used in the analysis is:

$$\mathcal{L}(\mu,\theta) = \prod_{r}^{\text{regions}} \left[\prod_{i}^{\text{bins}\in r} \text{Pois}(N_i^{\text{data}} | \mu \nu_i^s \eta^s(\theta) + \nu_i^b \eta^b(\theta)) \right] \cdot \prod_{i}^{\text{nuis. par.}} \mathcal{L}(\theta_i)$$







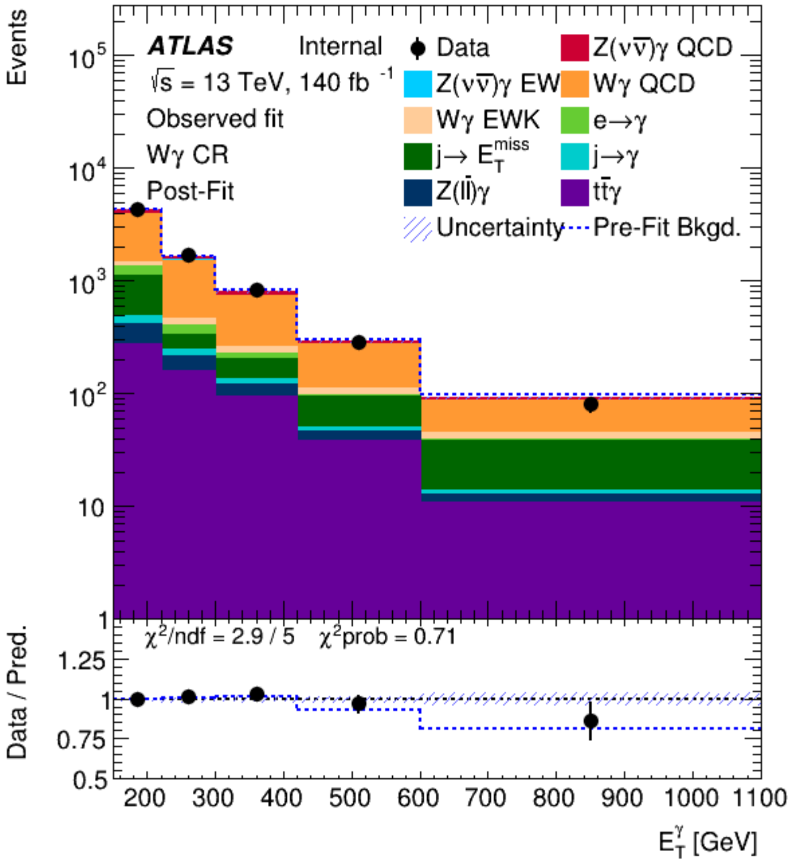
Results of background only fit:

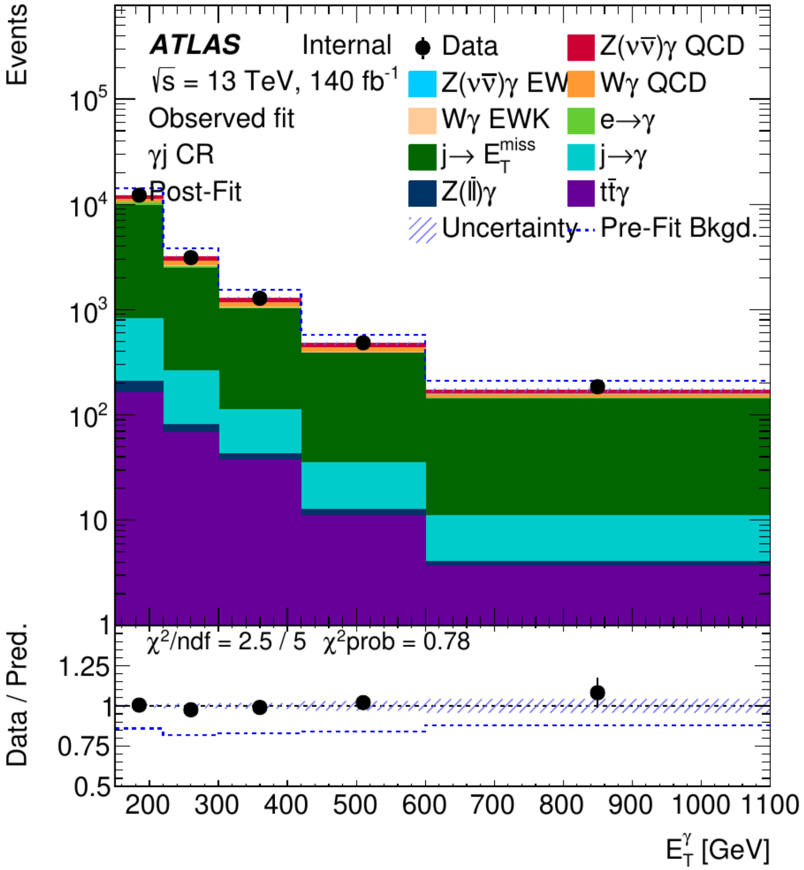
μ(Wg) = 0.93 ± 0.13

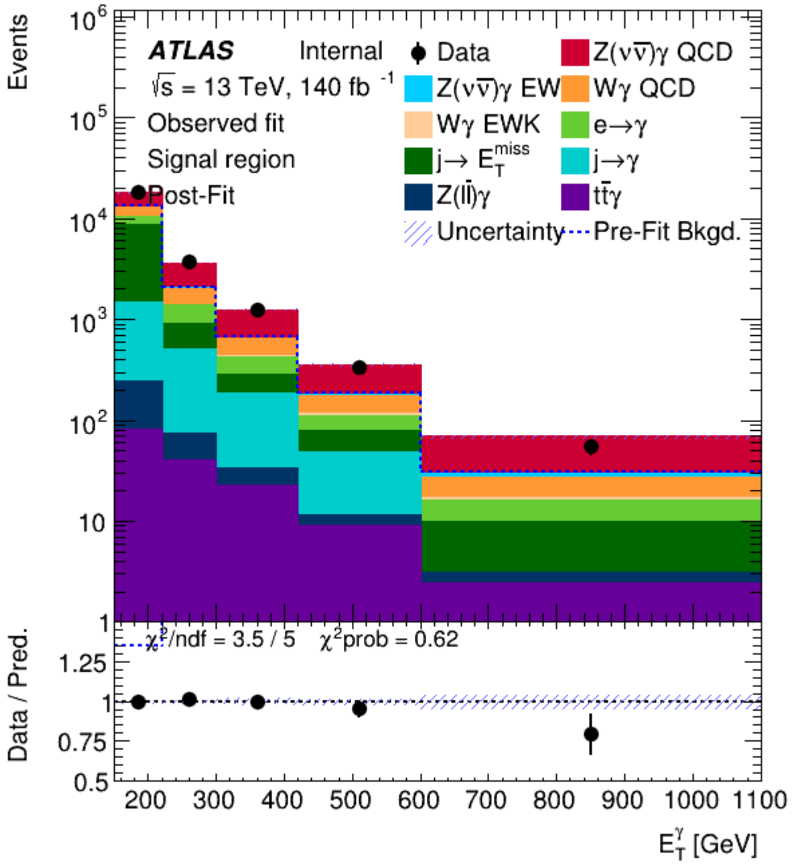
μ(γj) = 0.74 ± 0.12

Template fit

- Using the Asimov data: $\mu_{Z\gamma}$ = 1.00 ± 0.08 , $\mu_{W\gamma}$ = 0.93 ± 0.12 and $\mu_{\gamma j}$ = 0.74 ± 0.10. Expected signal significance 69 σ.
- Fit in the SR and CRs:



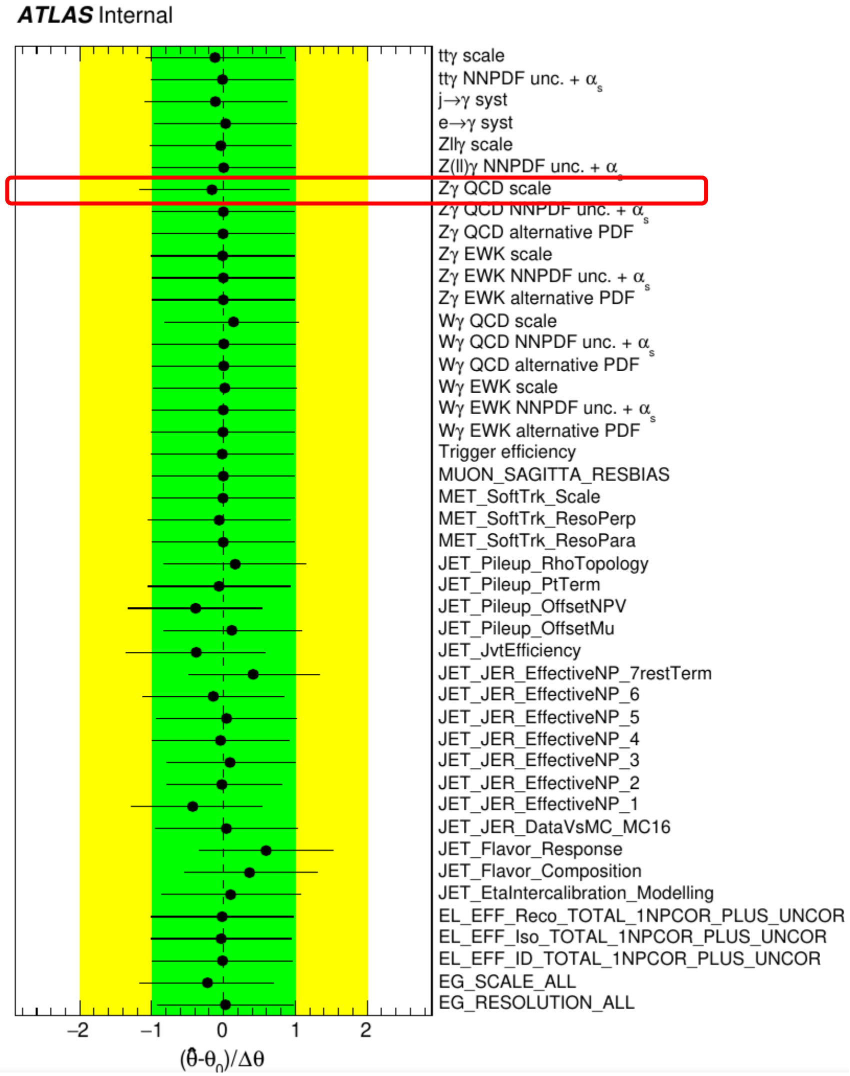




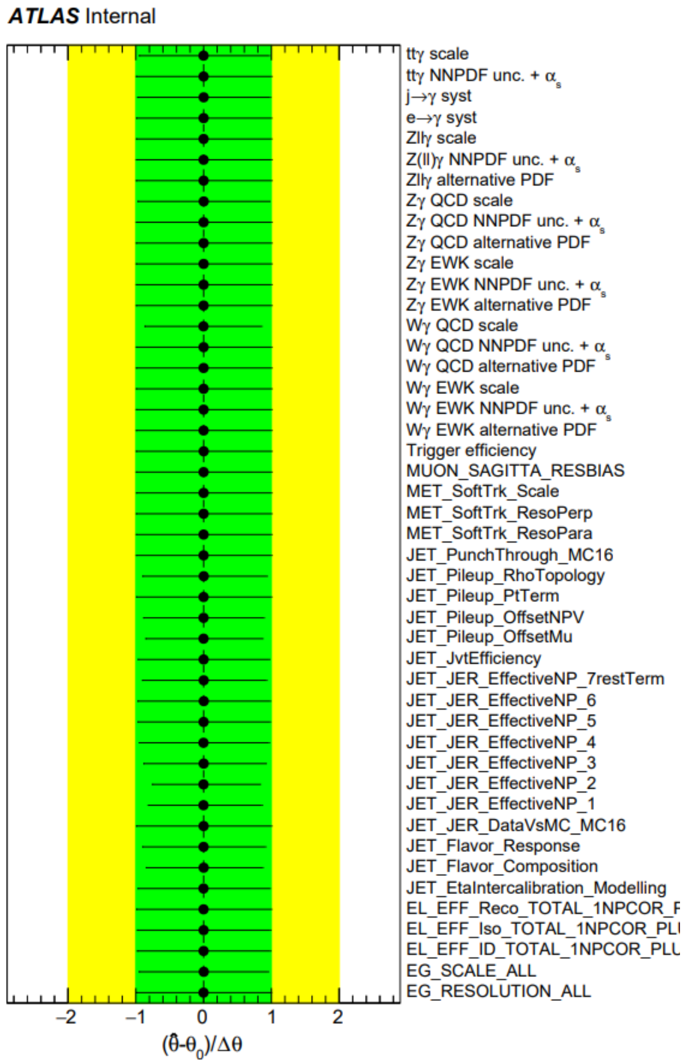
⇨ $\mu_{Z\gamma}$ = 0.70 ± 0.06, $\mu_{W\gamma}$ = 0.92 ± 0.06 and $\mu_{\gamma j}$ = 0.88 ± 0.08. Observed signal significance 50 σ.

Template fit

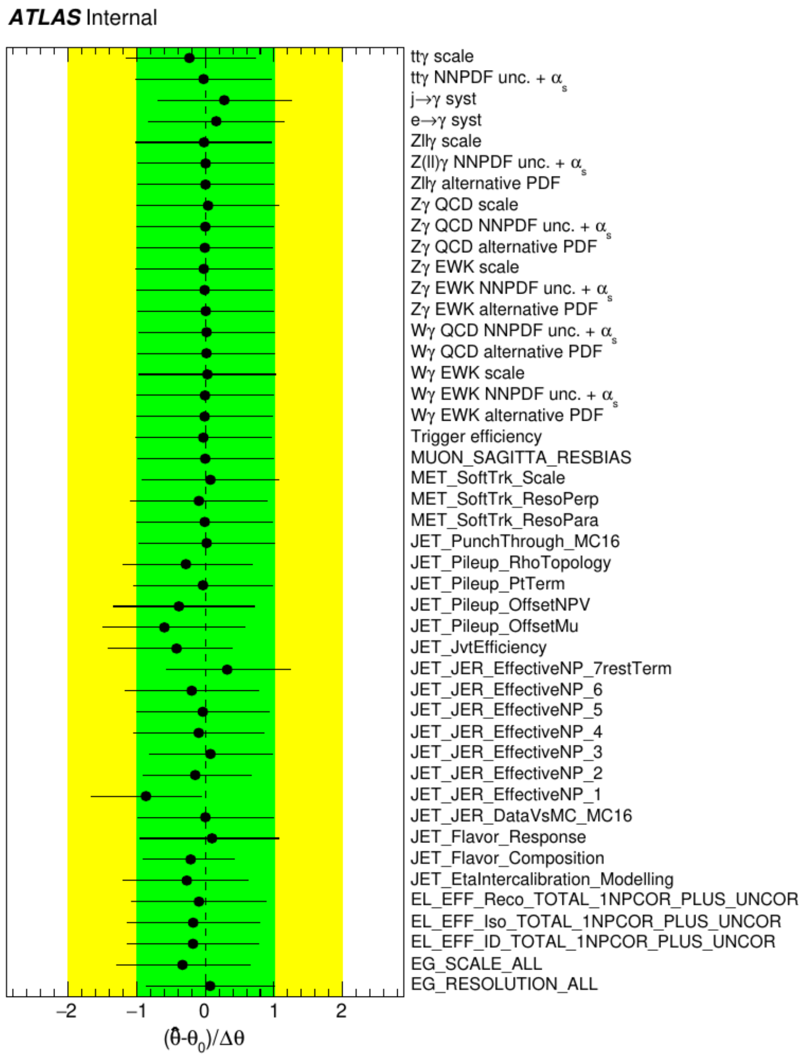
Background only + max. symm.



Asimov



Observed



Unfolding and differential measurement

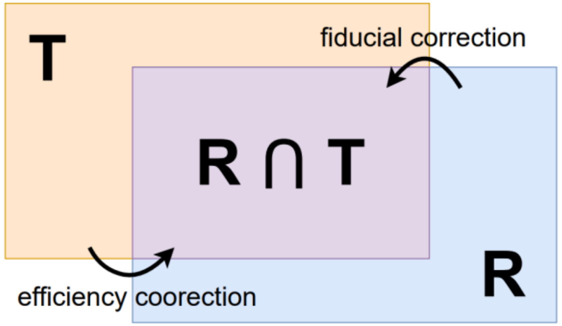
- The goal of unfolding is to take the measured observable and translate it into the true observable.

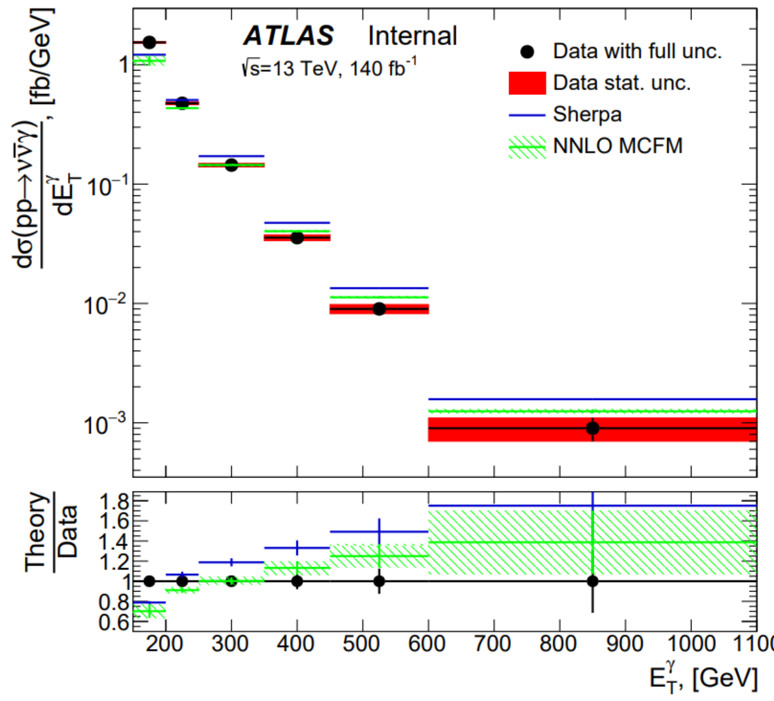
⇨ The response matrix R relates true vector x and observed vector y: $\hat{R}\mathbf{x} = \mathbf{y}$

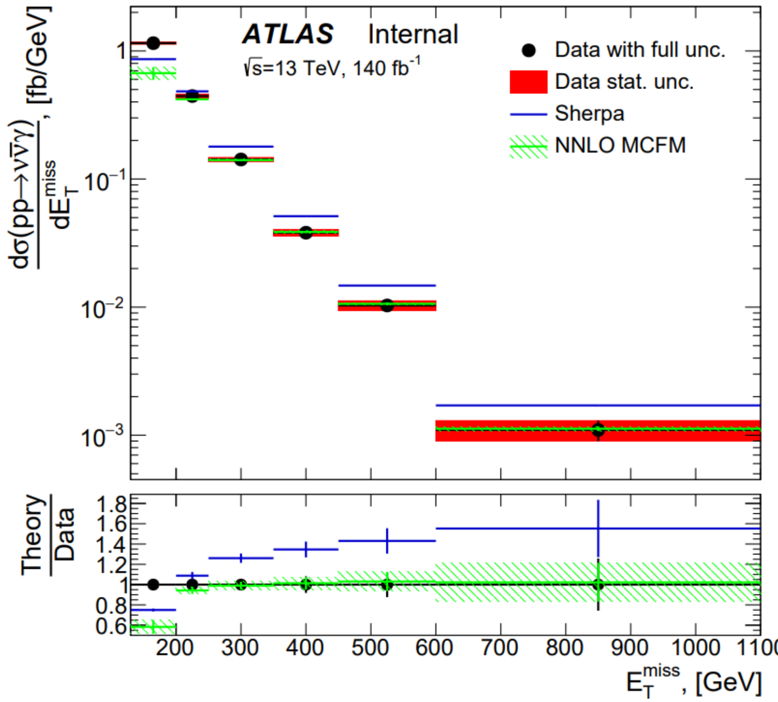
⇨ The response matrix is defined as: $R_{ij} = \frac{1}{\alpha_i}\varepsilon_j M_{ij}$ Migration matrix: $M_{ij} = \frac{N_{ij}^{\text{det.} \cap \text{fid.}}}{N_j^{\text{det.} \cap \text{fid.}}}$

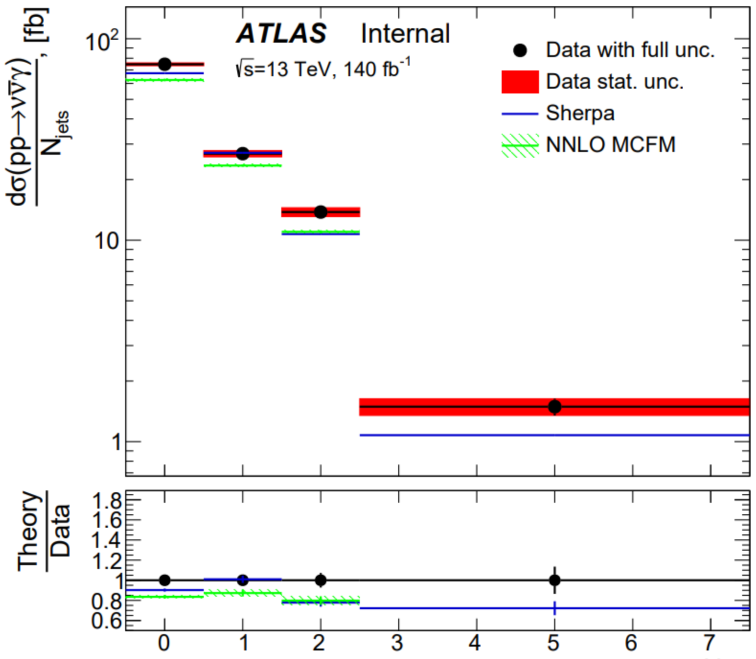
⇨ The unfolding procedure is performed according to the maximum likelihood method via TRExFitter.

⇨ The differential cross-section is defined by equation: $\frac{\sigma_j}{\Delta x_j} = \frac{N_j^{\text{unfold}}}{(\int \mathcal{L}dt) \cdot \Delta x_j}$







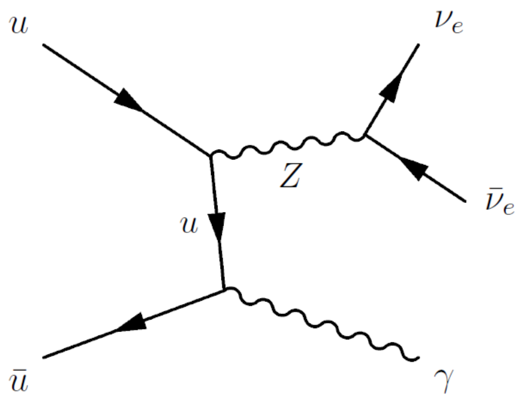


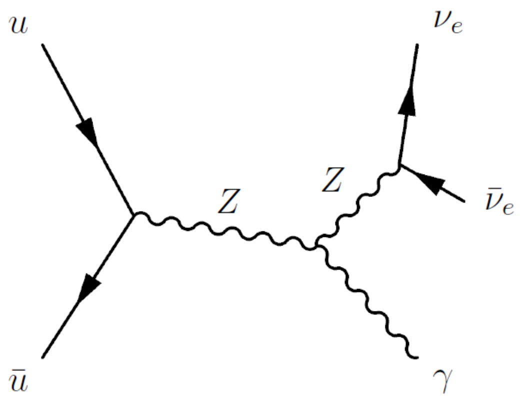
Need update after fit finalization!

aTGC: introduction

- $Z(\nu\nu)\gamma$ production is very sensitive to the neutral triple gauge couplings (aTGCs). aTGCs are zero in the SM at the tree level.

- Two ways to describe aTGCs: effective field theory and vertex function approach.
  Both formalisms were improved by theorists and new terms in both formalisms appear.





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⇨ State-of-the-art UFO models are needed to generate the events. For both formalisms models with new terms were created.
EFT: model NTGC_all, JIRA ticket. VF: model NTGC_VF, JIRA ticket.

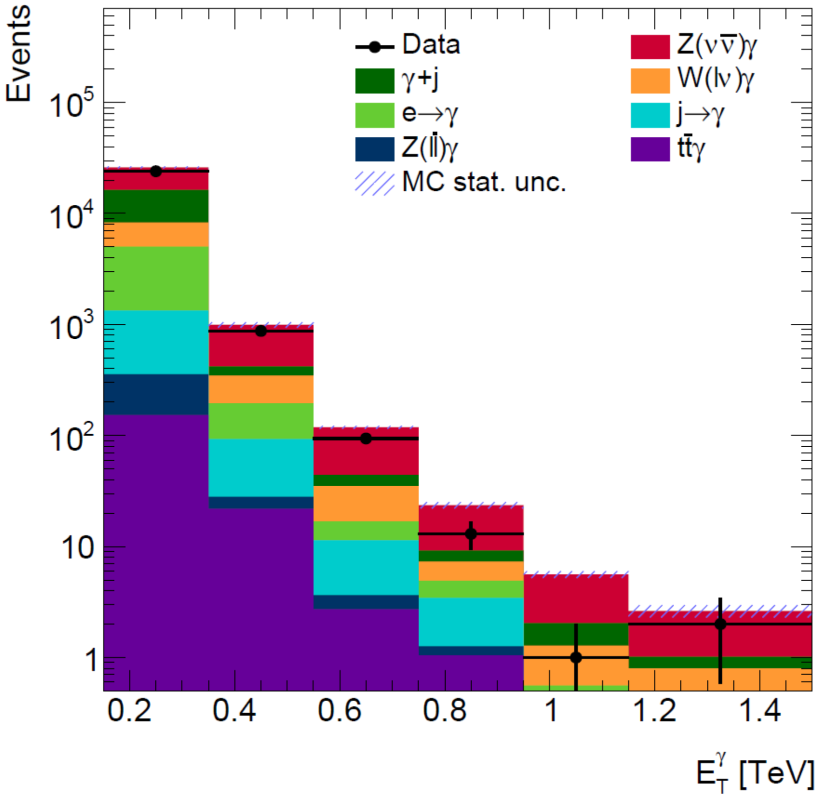
EFT: 6 Wilson coefficients (C_{G+}/Λ^4, C_{G-}/Λ^4, $C_{\tilde{B}W}/\Lambda^4$, C_{BW}/Λ^4, C_{BB}/Λ^4, C_{WW}/Λ^4).

VF: 12 parameters (h_i^V;i=1..6;V=Z,γ). Only i=3..5 are planned to be constrained.

aTGC: current results

- Plan is to search for CP-conserving effects only. Search for CP-violating effects requires identification of the decay products.
- EFT samples were prepared, VF samples request in progress.
- Strategy: reco-level fit of the E_T^γ distribution. Preliminary results:

Coefficient	Expected limits [TeV^{-4}]
C_{G+}/Λ^4	[-0.0065; 0.0047]
C_{G-}/Λ^4	[-0.30; 0.34]
$C_{\tilde{B}W}/\Lambda^4$	[-0.35; 0.34]
C_{BW}/Λ^4	[-0.63; 0.63]
C_{BB}/Λ^4	[-0.25; 0.25]
C_{WW}/Λ^4	[-1.3; 1.3]



Summary

- All steps of inclusive $Z(\nu\bar{\nu})\gamma$ Run2 analysis are already done: selection optimisation, data-driven estimation of $e \rightarrow \gamma$ and jet $\rightarrow \gamma$, fit procedure, control plots, unfolding, differential cross-sections.

Plans:

⇨ To solve problems systematics.

⇨ To update and to obtain other observables differential cross-section plots.

⇨ To continue work on limits on aTGCs.

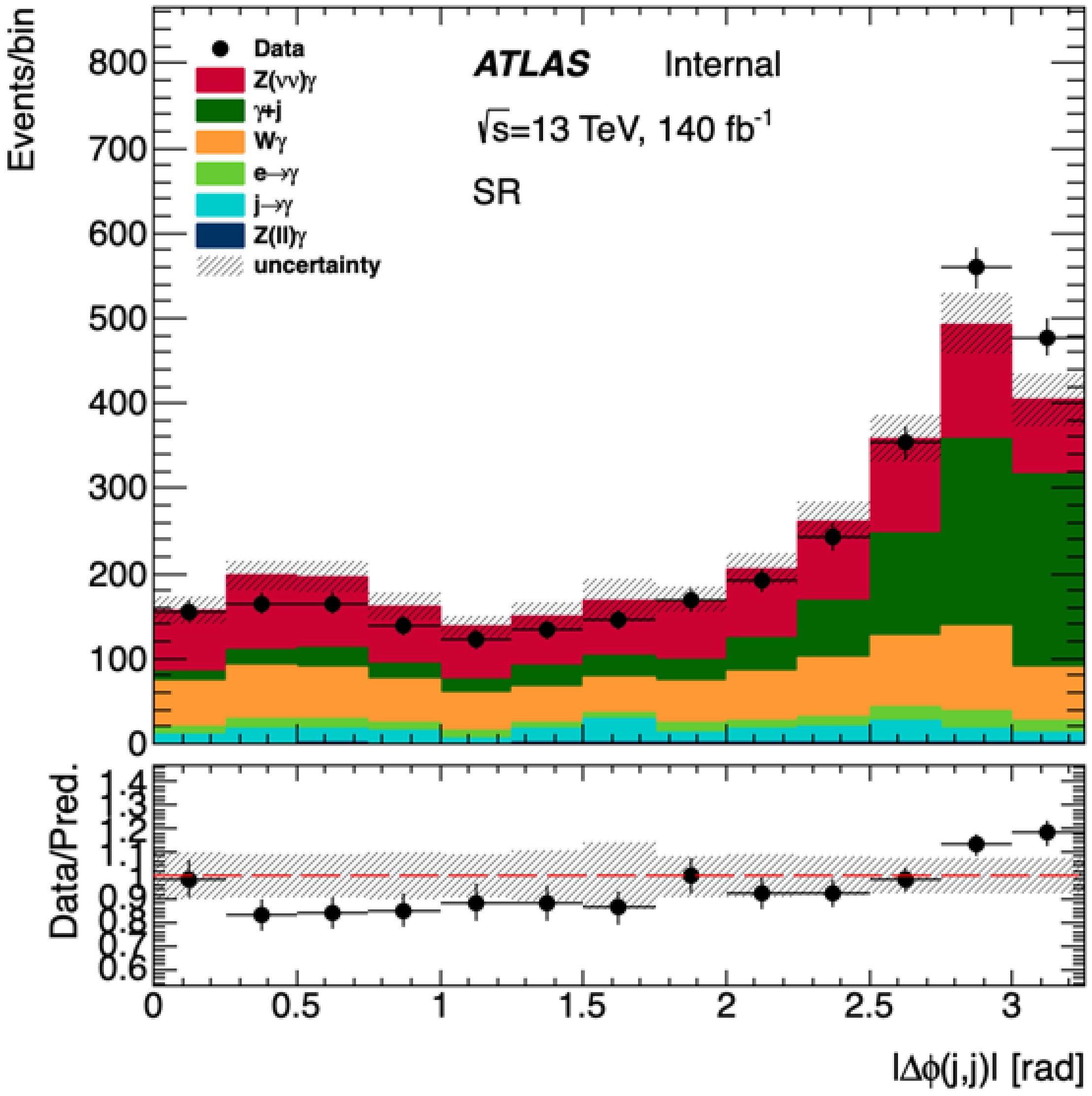
⇨ Almost all chapters of the internal note are ready, but need update.

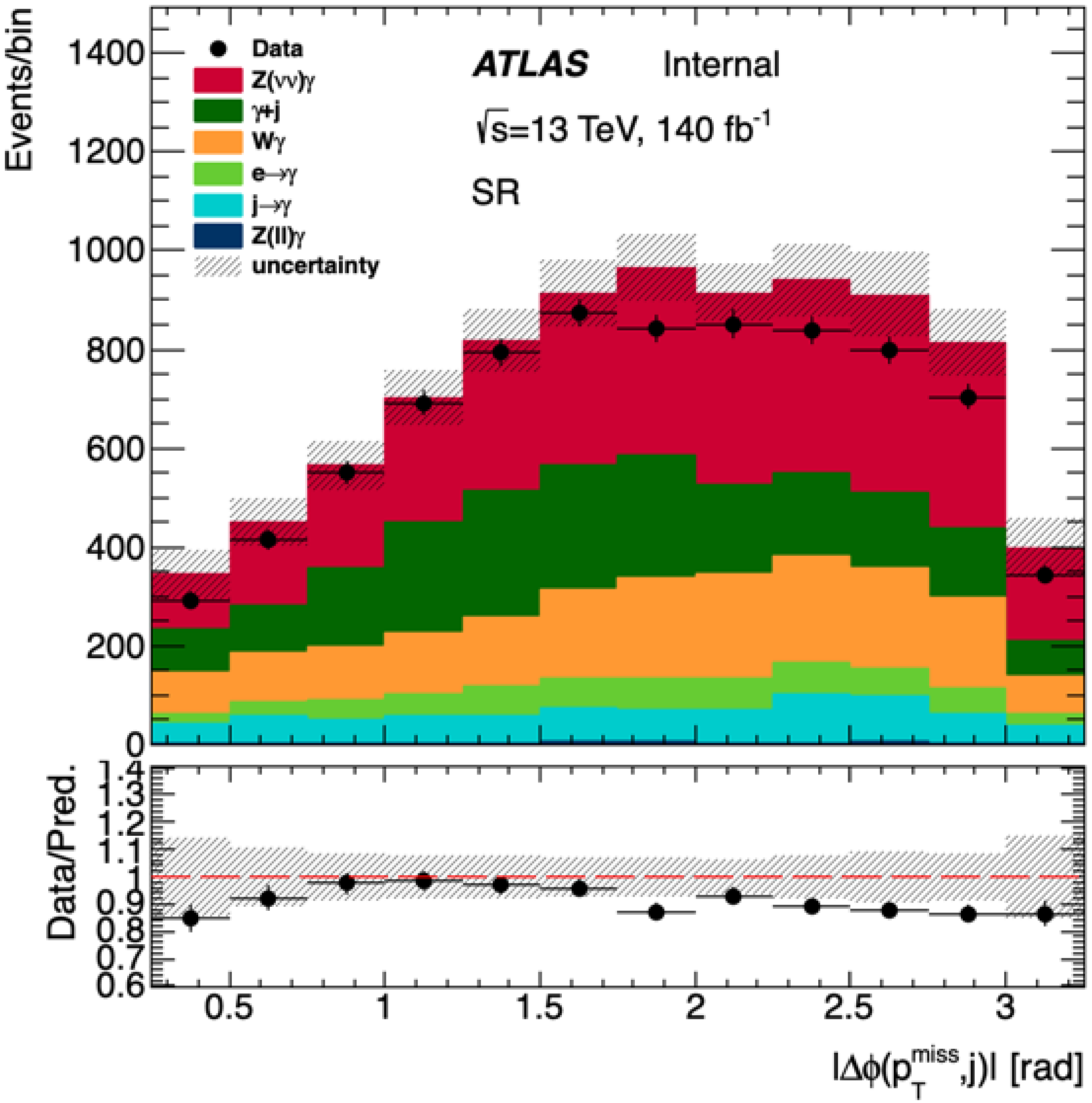
⇨ EB request ASAP.

Thank you for your attention!

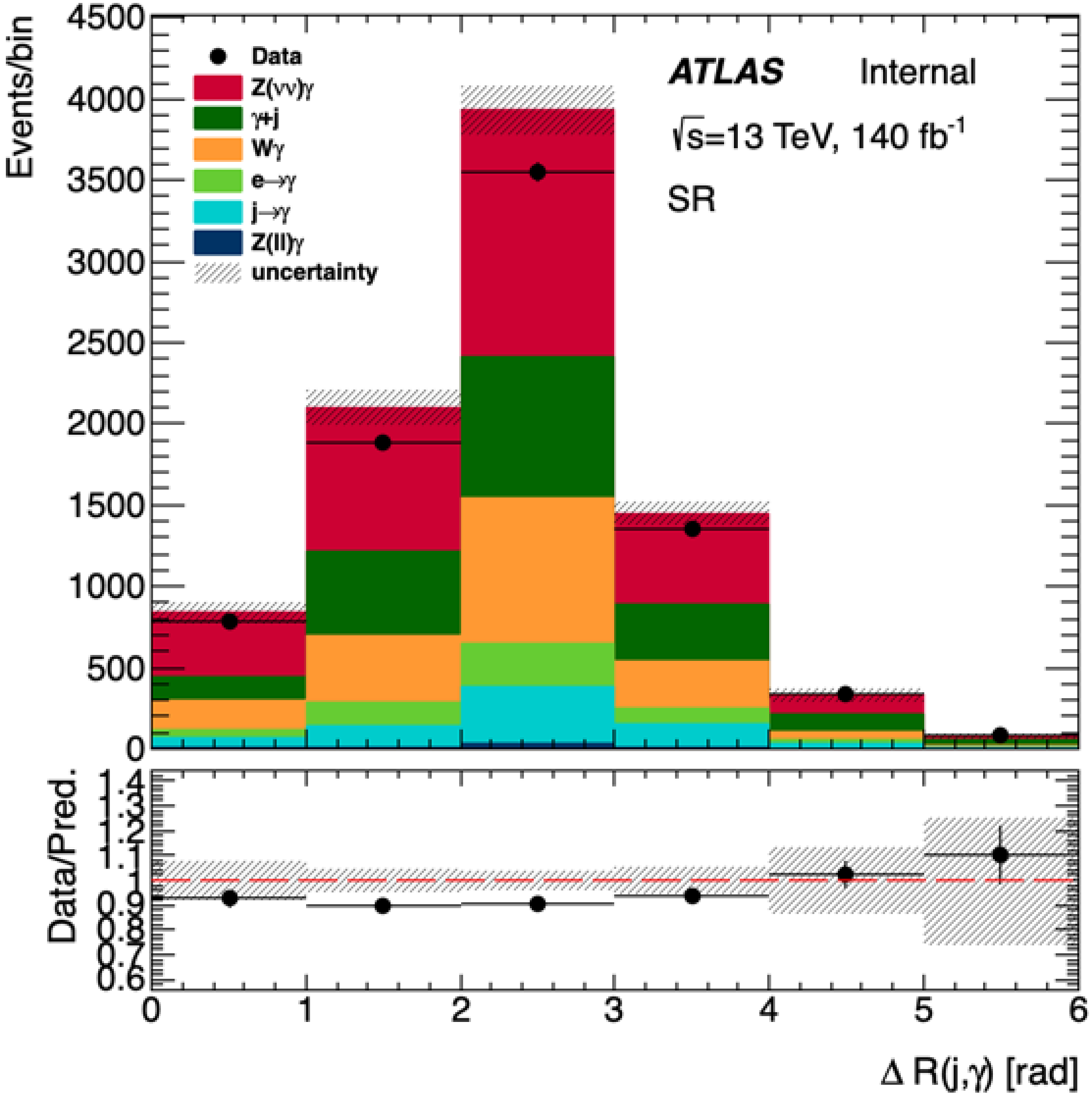
BACK-UP

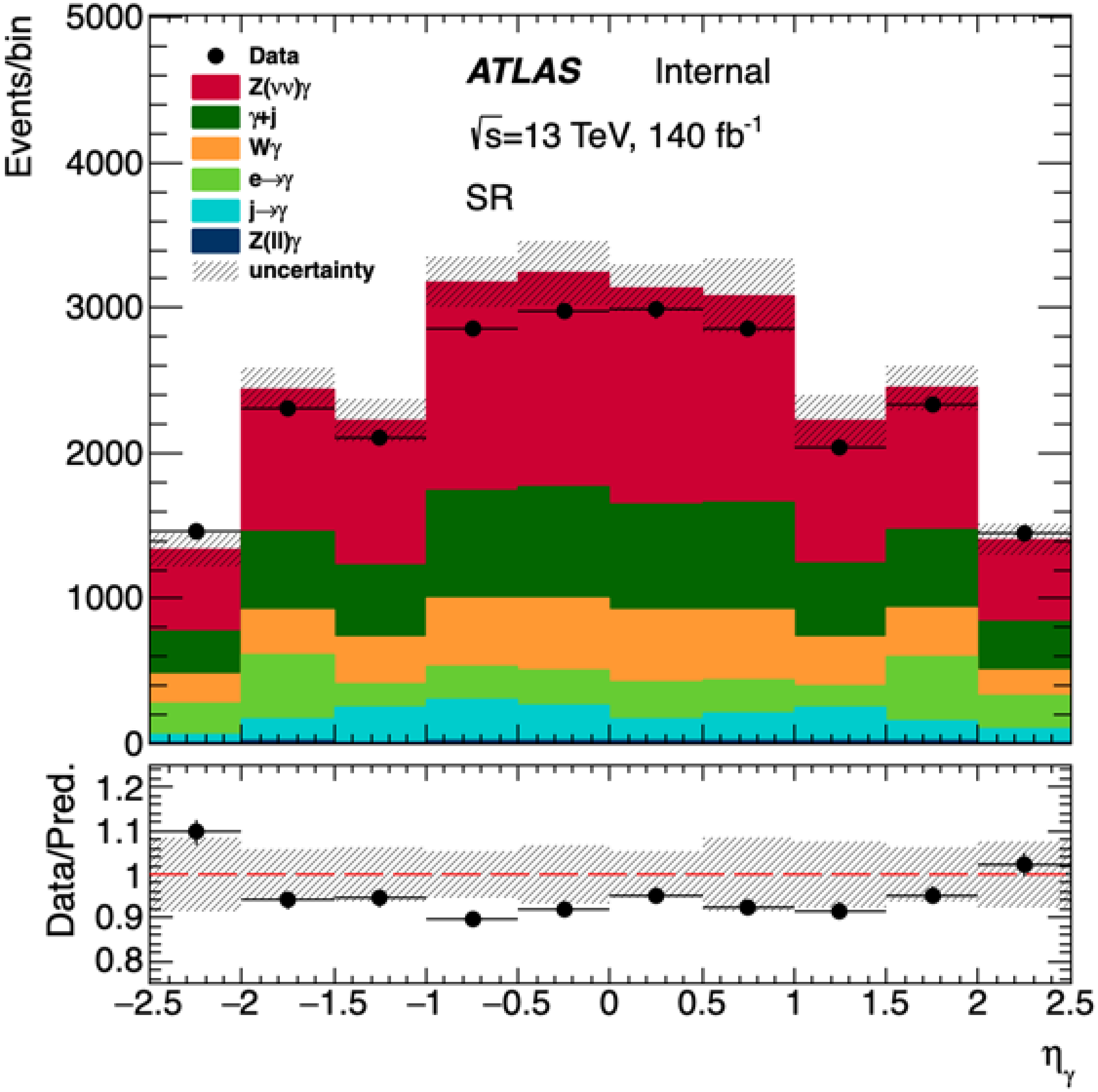
Control plots





Control plots





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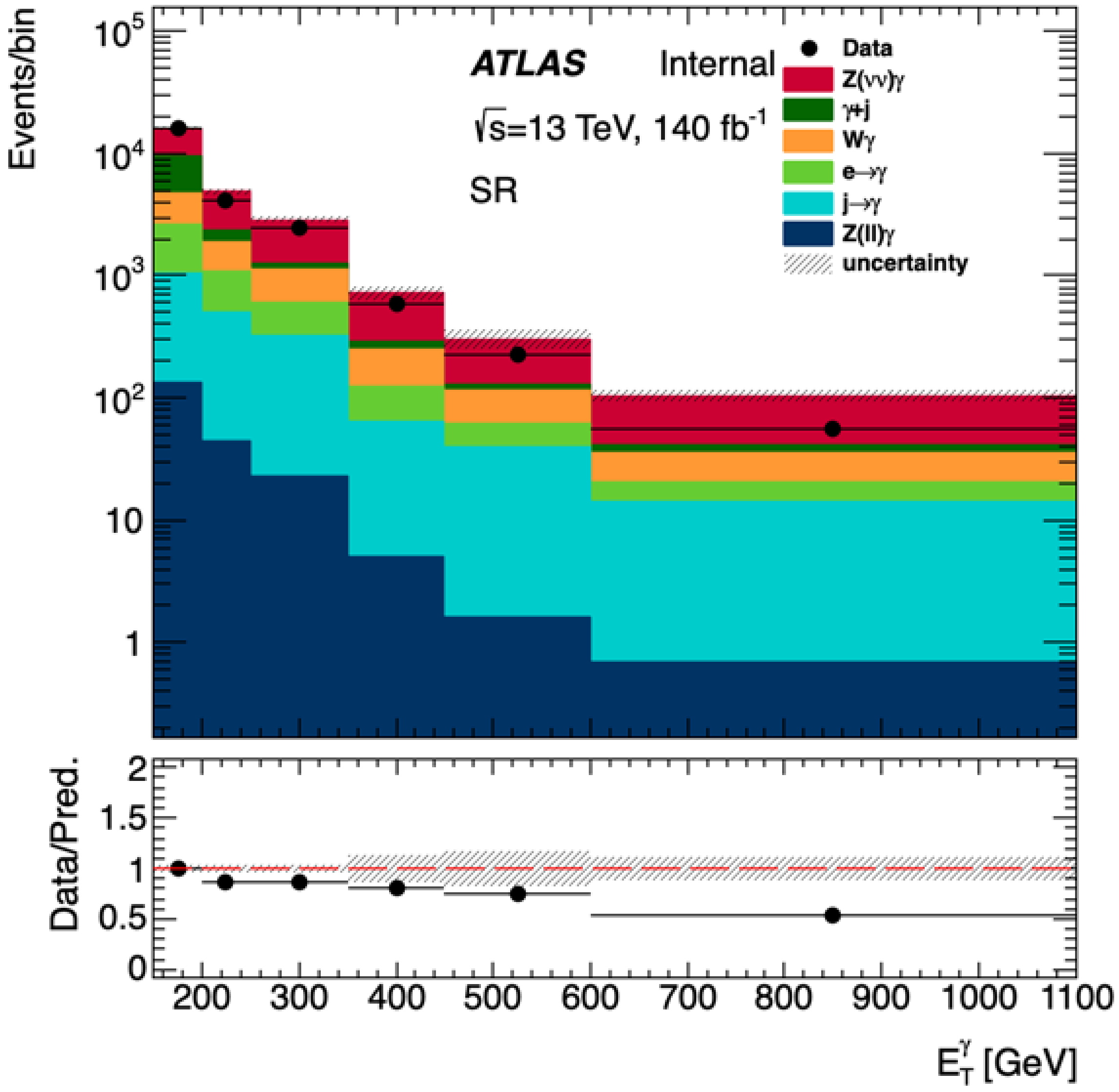

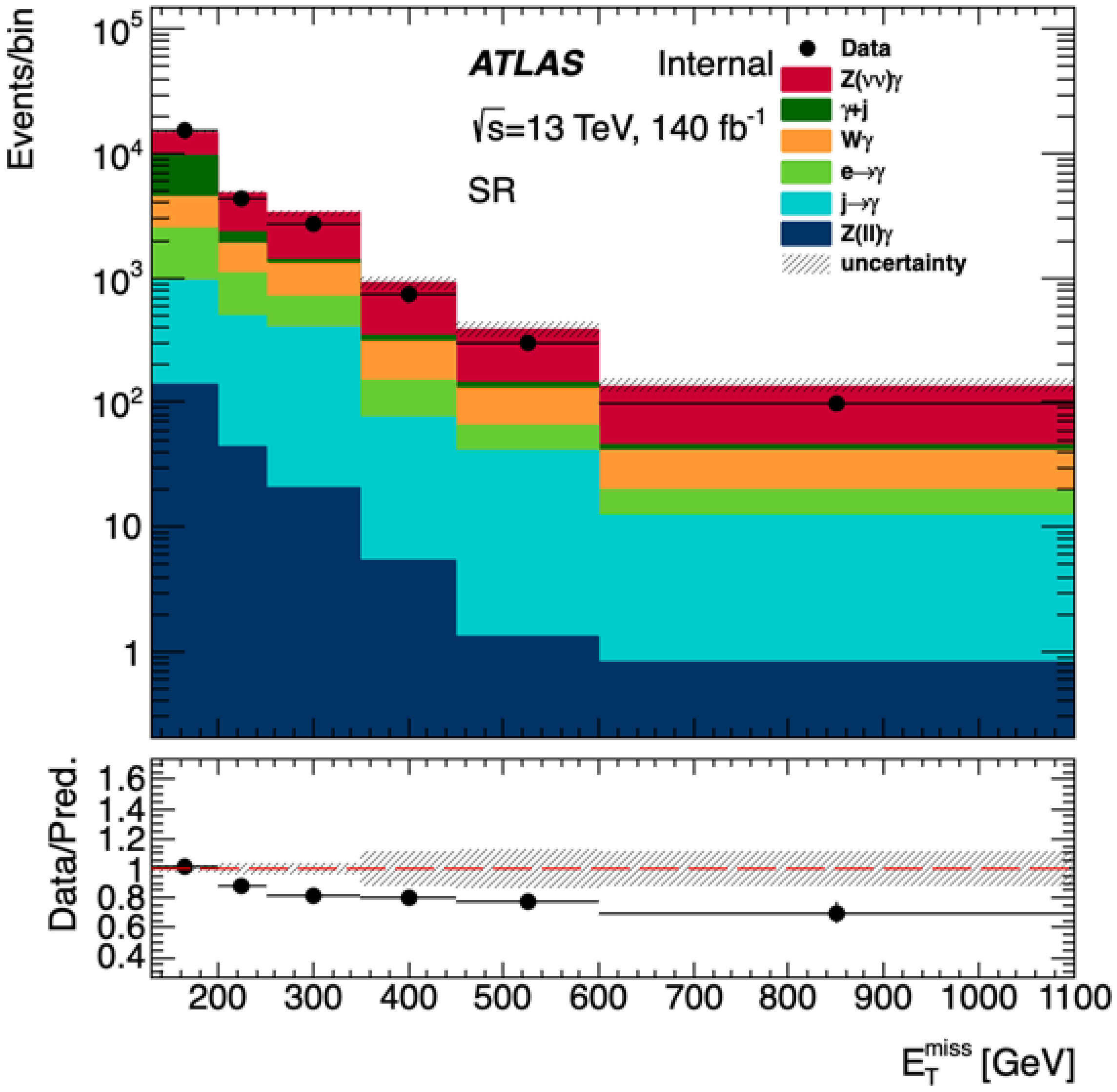

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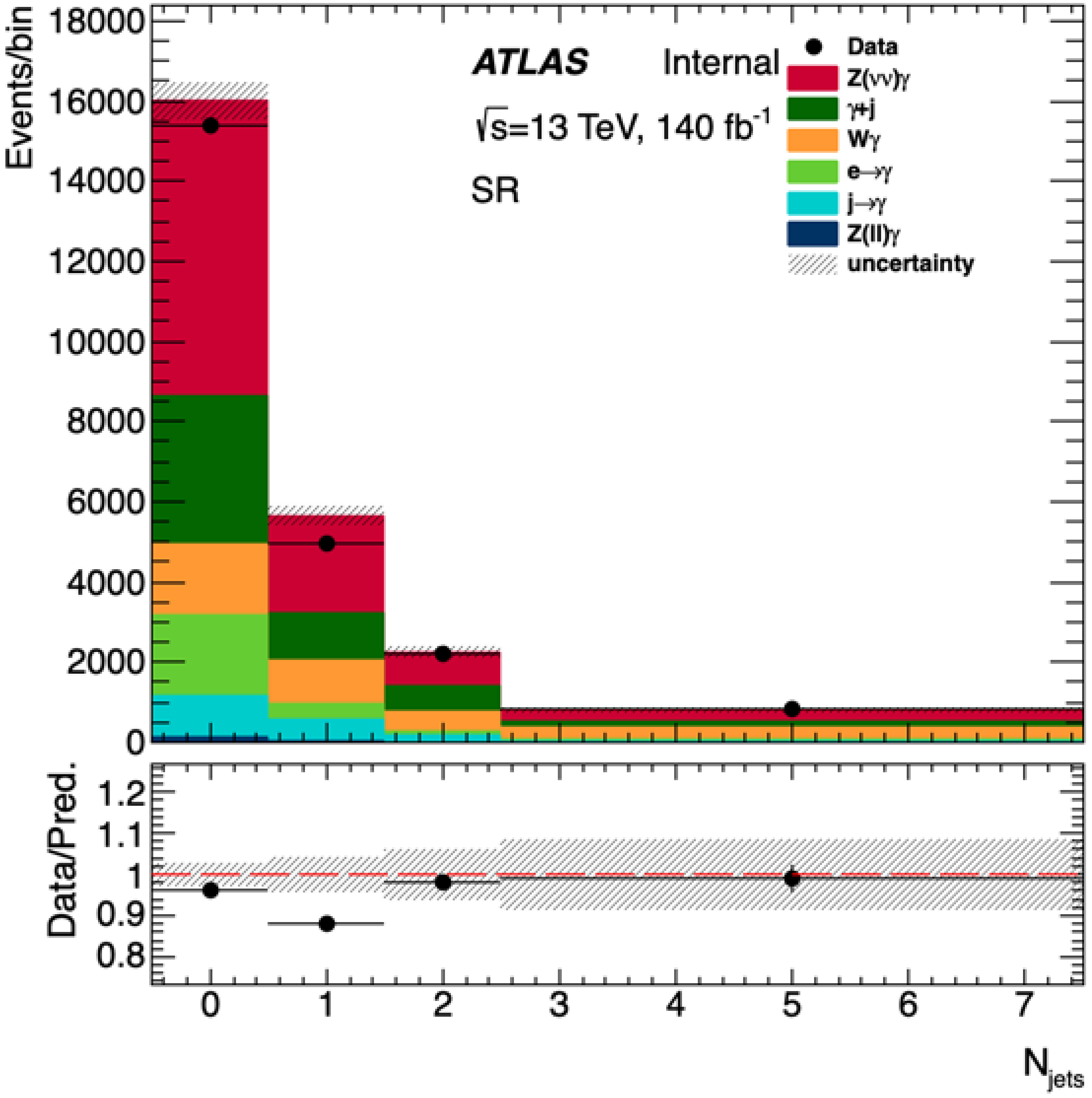

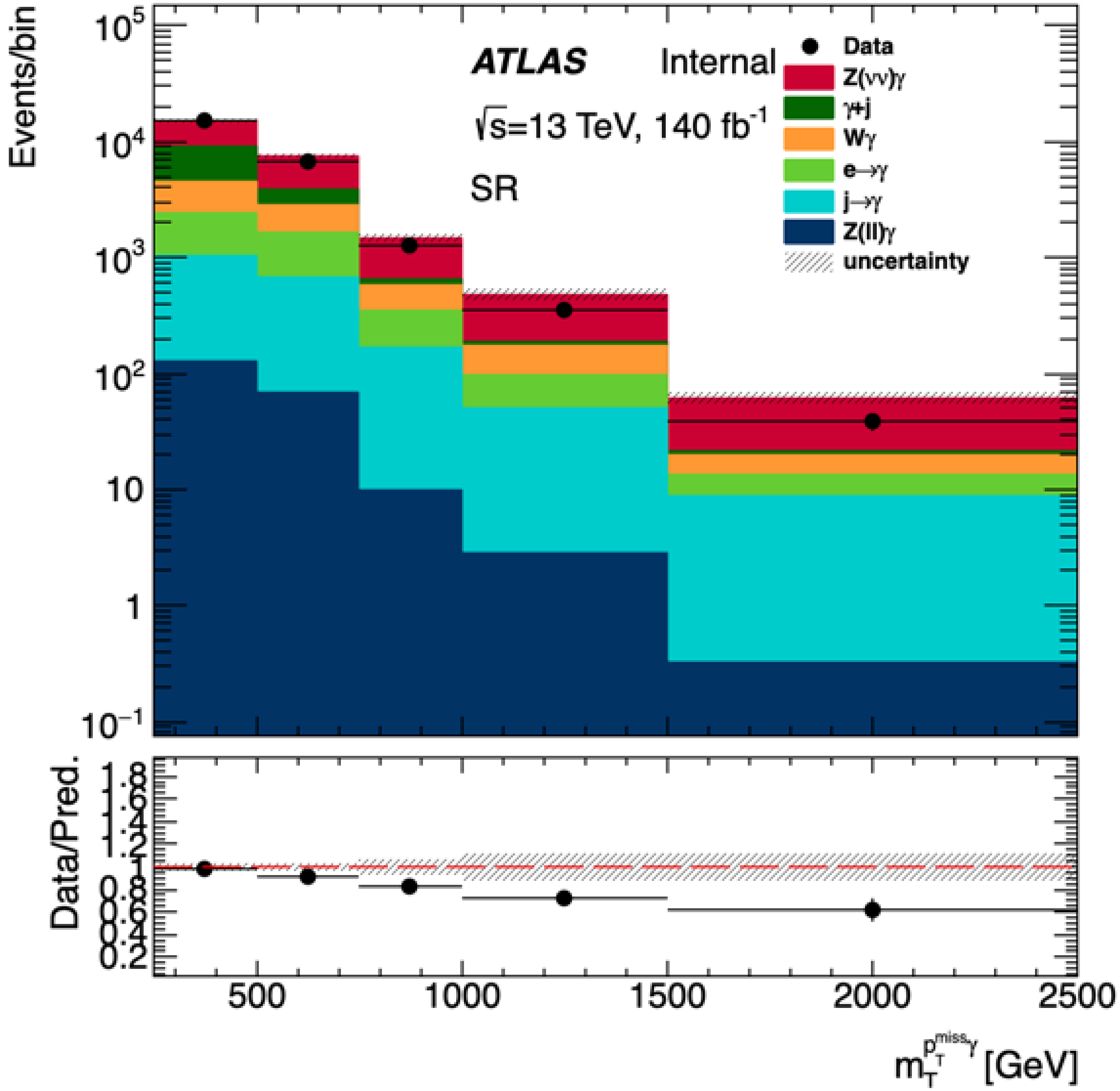

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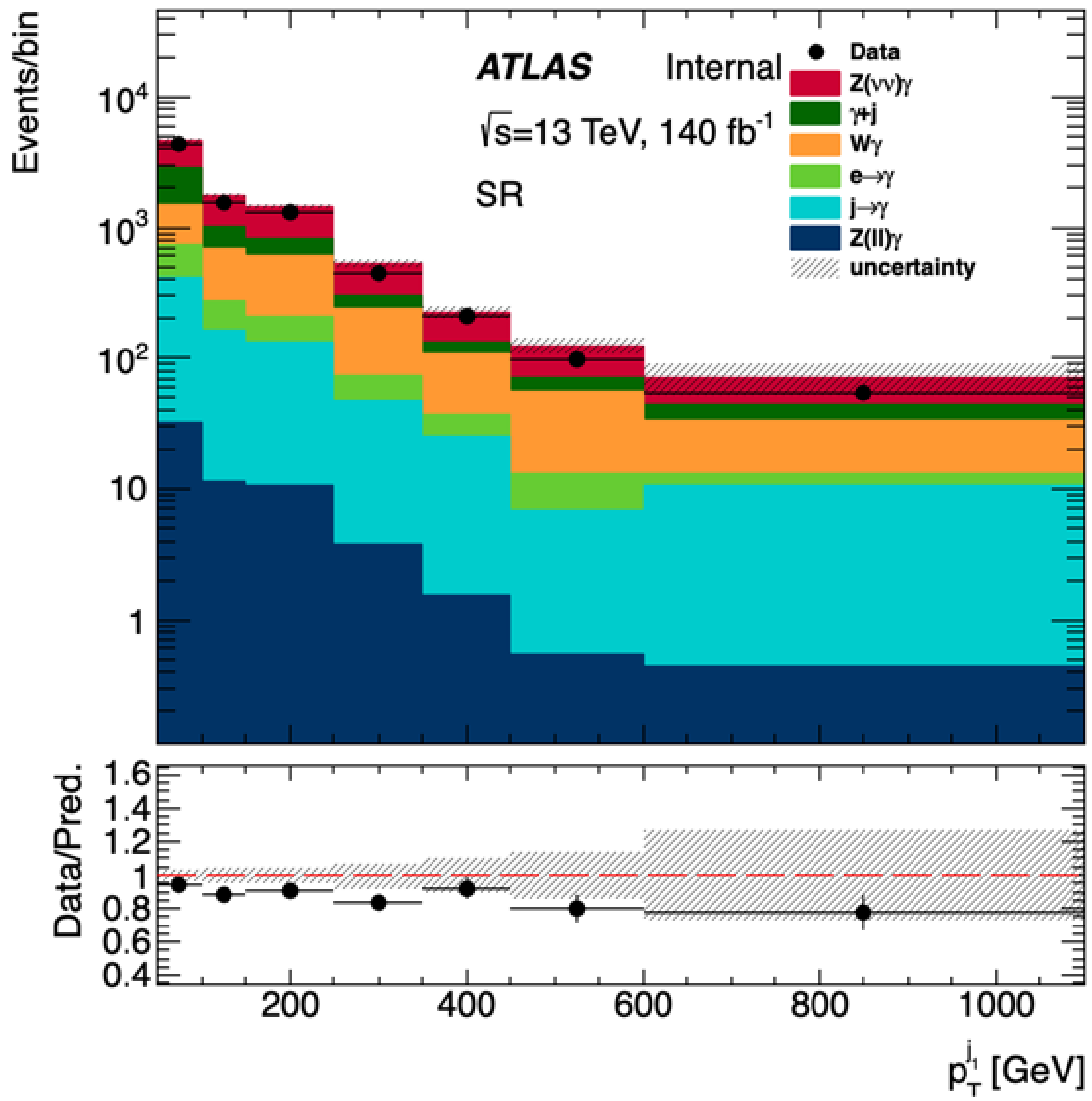
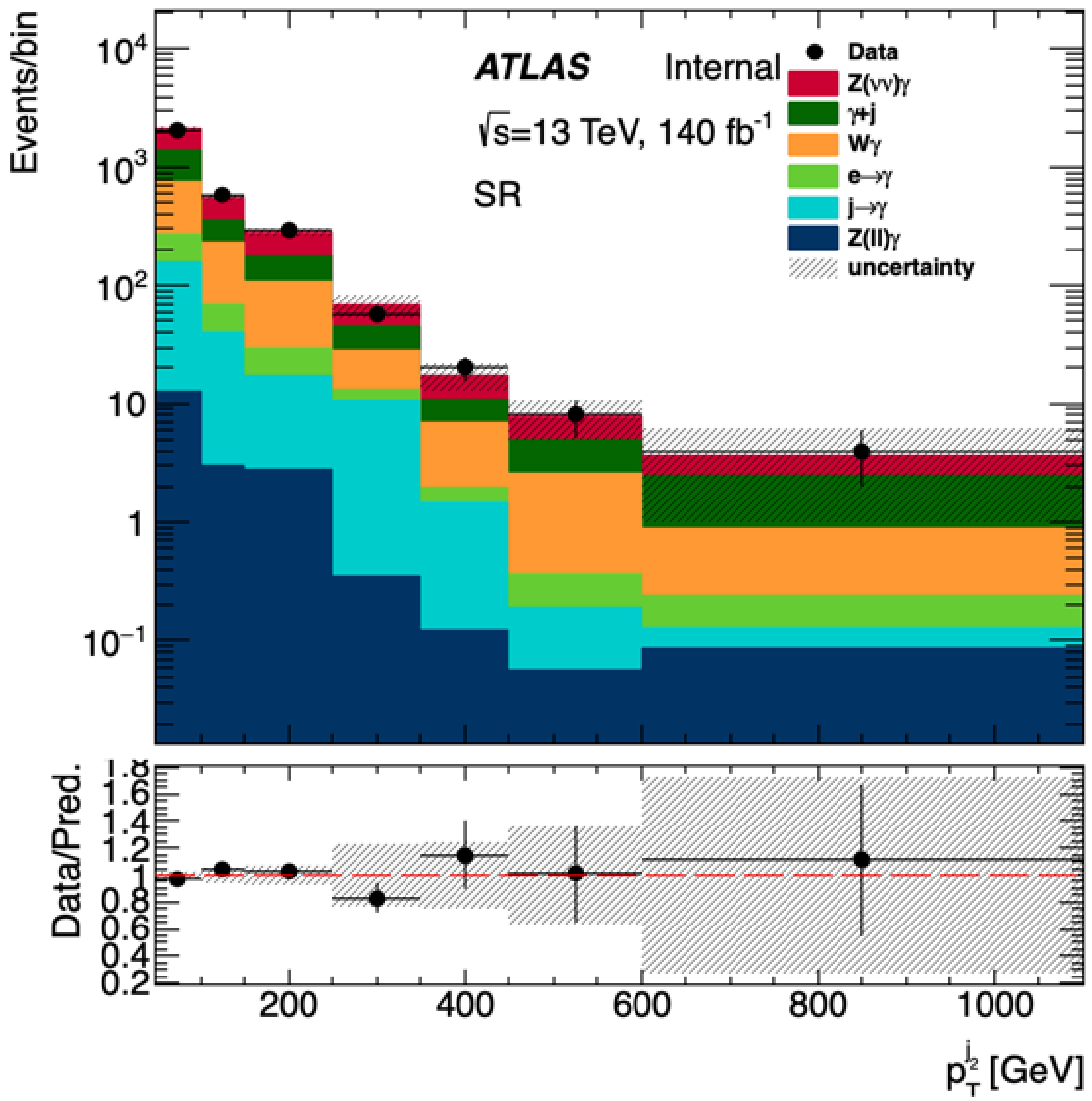


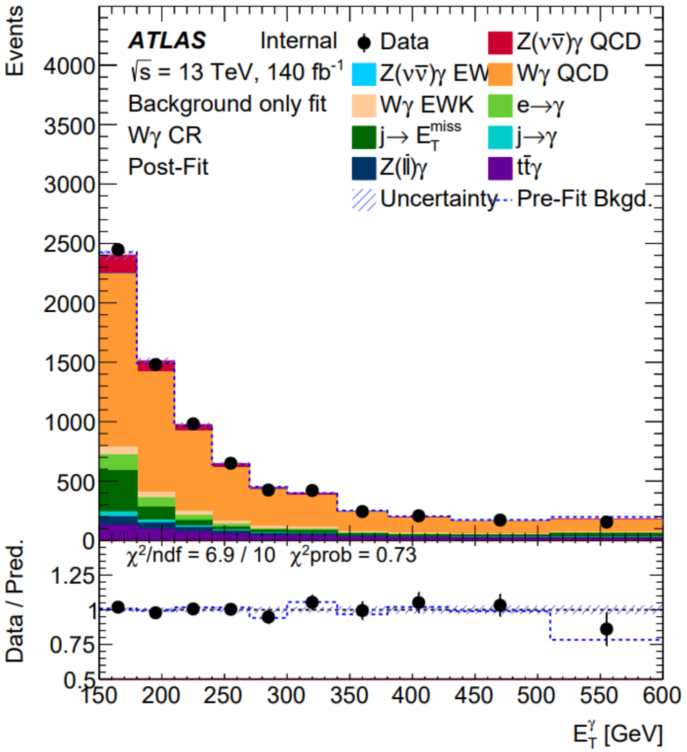


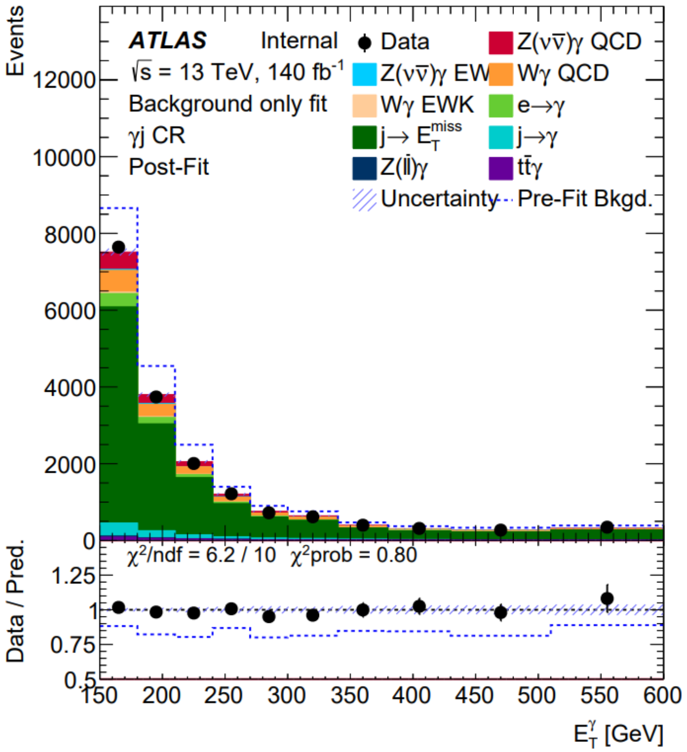
Template fit

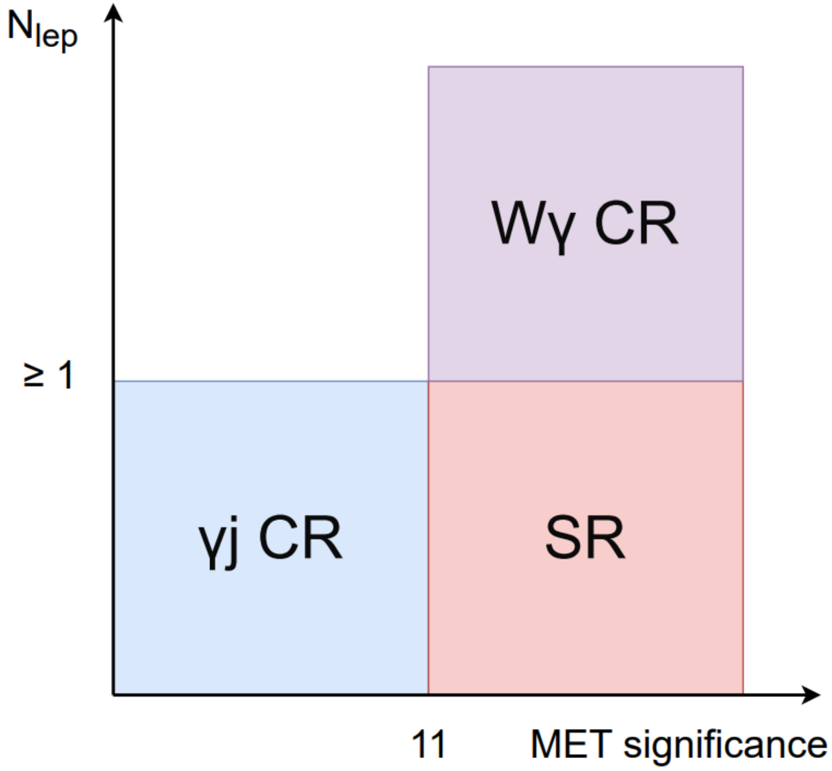
- Three free parameters are introduced in the combined fit: a signal strength parameter μ(Zg) and two normalization factors μ(Wg) and μ(γj) used to scale the yields of W(lν)γ and ttγ and γ+jets processes.

⇨ The binned likelihood function used in the analysis is:

$$\mathcal{L}(\mu,\theta) = \prod_{r}^{\text{regions}} \left[\prod_{i}^{\text{bins}\in r} \text{Pois}(N_i^{\text{data}} | \mu \nu_i^s \eta^s(\theta) + \nu_i^b \eta^b(\theta)) \right] \cdot \prod_{i}^{\text{nuis. par.}} \mathcal{L}(\theta_i)$$





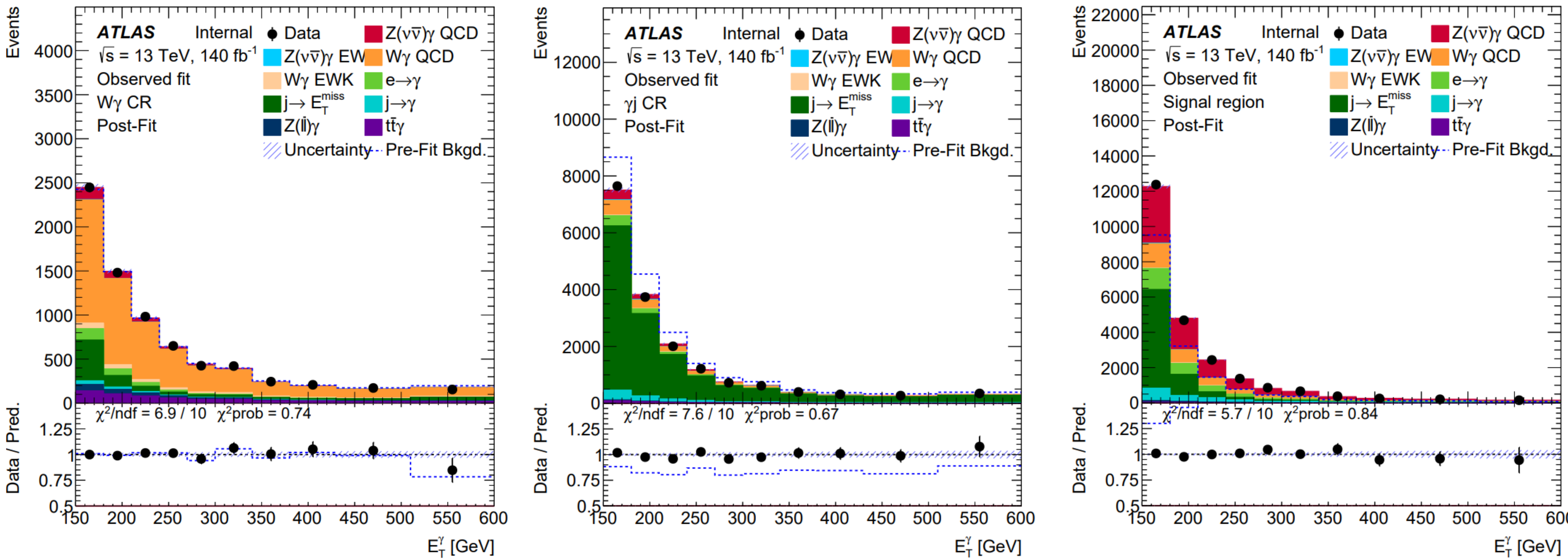


Results of background only fit:

μ(Wg) = 1.00 ± 0.06
μ(γj) = 0.70 ± 0.07

Template fit

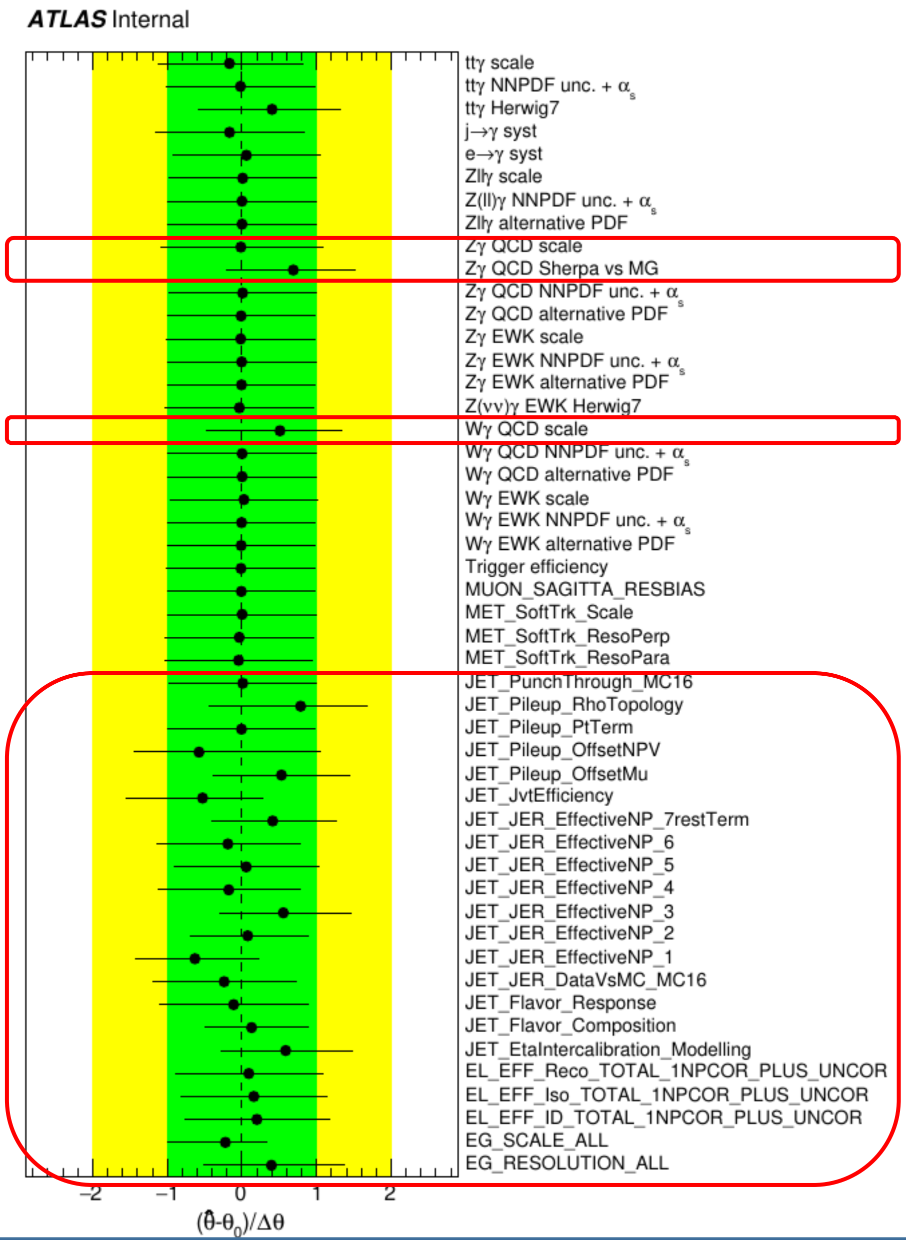
- Using the Asimov data: $\mu_{Z\gamma}$ = 1.00 ± 0.07 , $\mu_{W\gamma}$ = 1.00 ± 0.18 and $\mu_{\gamma j}$ = 0.70 ± 0.06. Expected signal significance 69 σ.
- Fit in the SR and CRs:



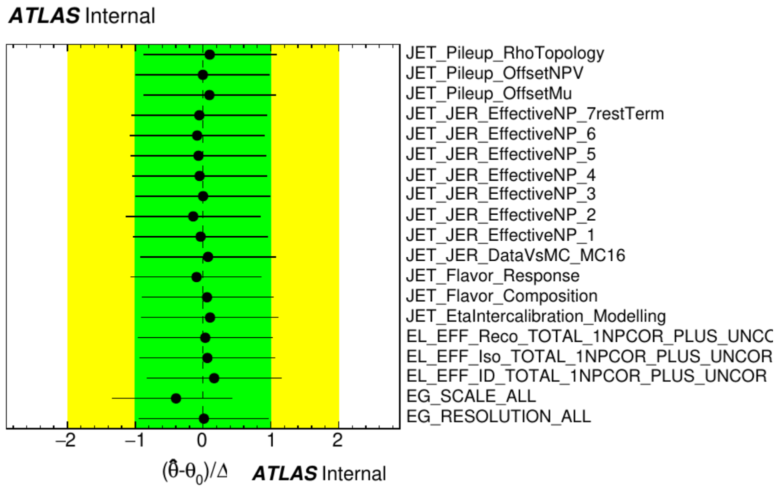
⇨ $\mu_{Z\gamma}$ = 0.90 ± 0.13, $\mu_{W\gamma}$ = 0.97 ± 0.06 and $\mu_{\gamma j}$ = 0.84 ± 0.05. Observed signal significance 64 σ.

There are some problems with jet systematics!

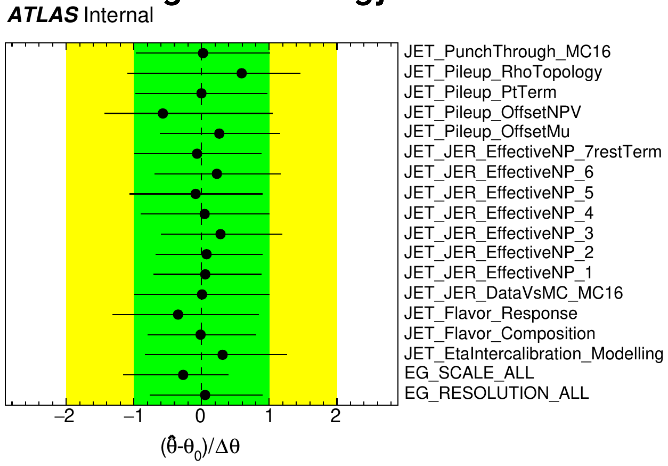
Problems with template fit

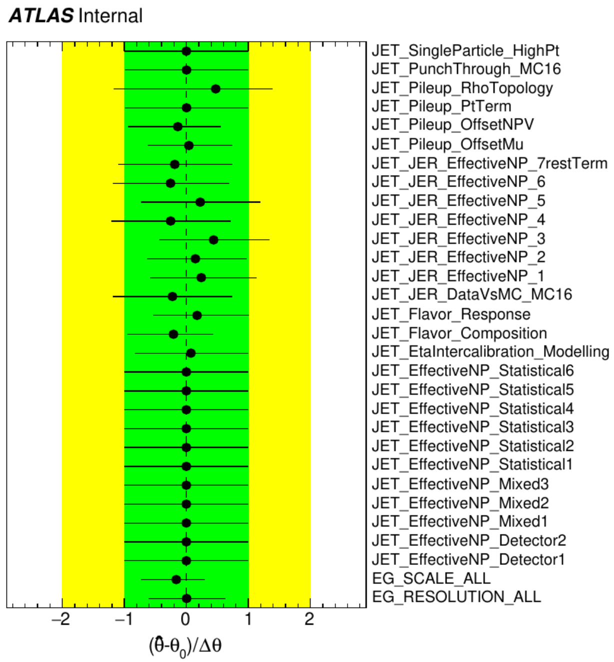


Fit in all CRs w/o gj sample (syst):



Fit in all CRs with cut on MET signif < 9 in gj CR:

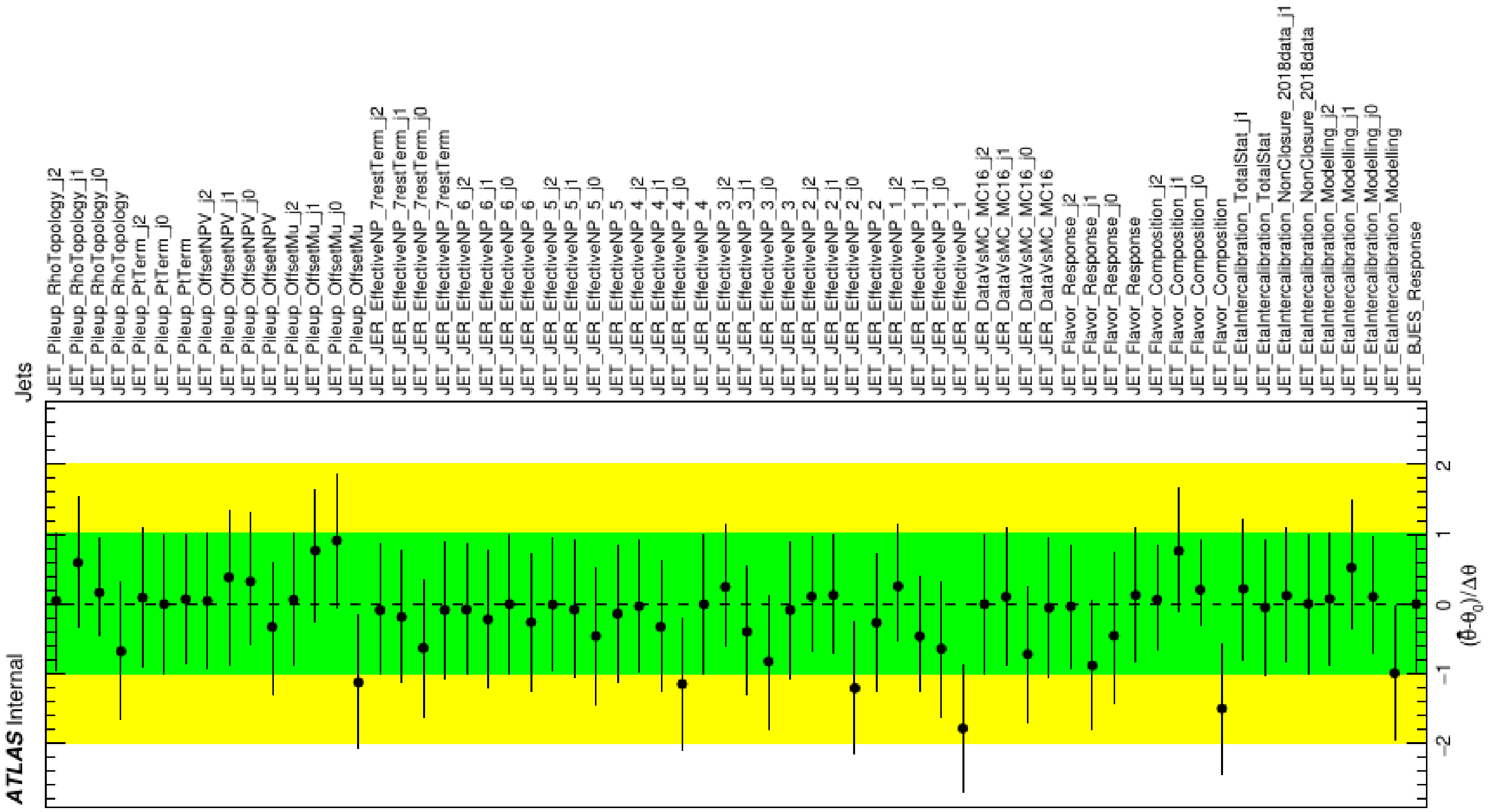


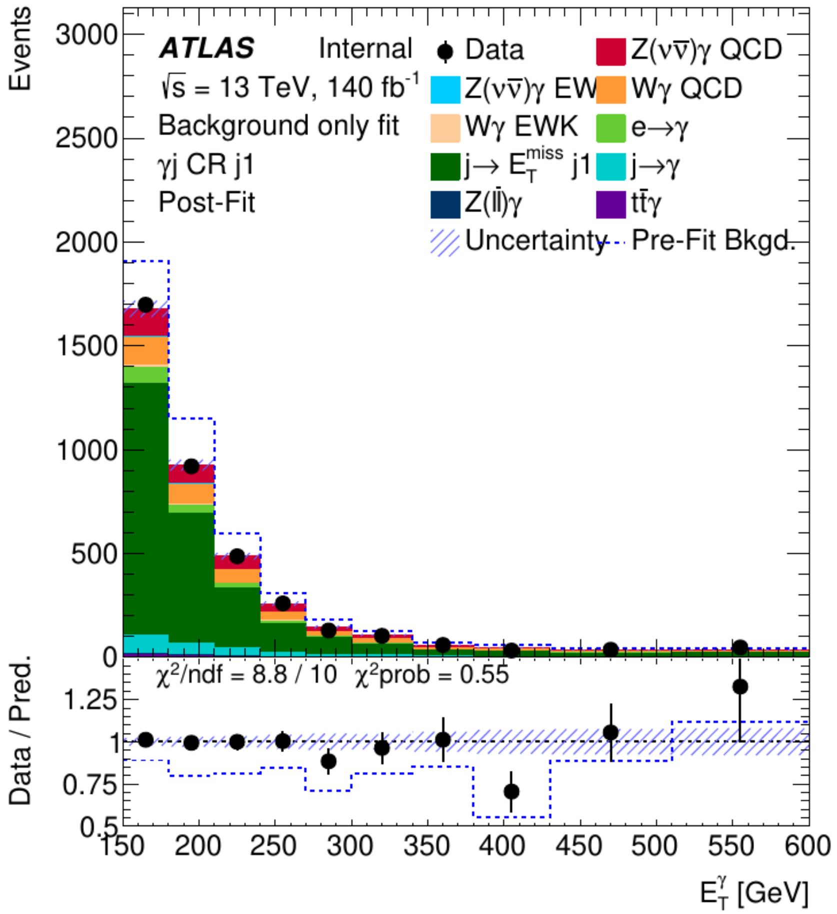


Fit in all CRs with gj sample with cut on pT soft term:

Problems with template fit: categorisation

- There was an attempt to categorise the events based on N_{jets} in the gj CR (background only fit)

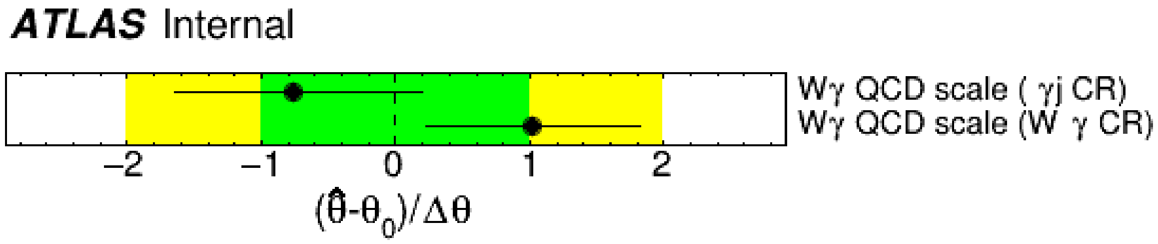


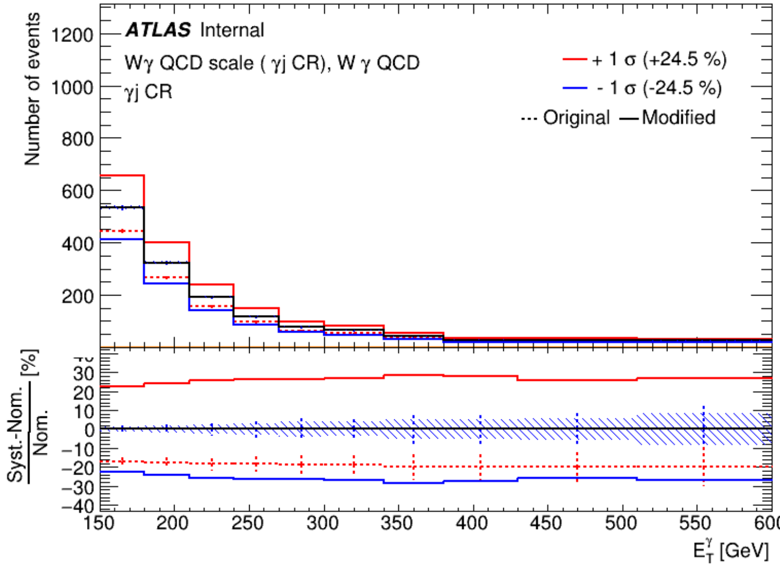


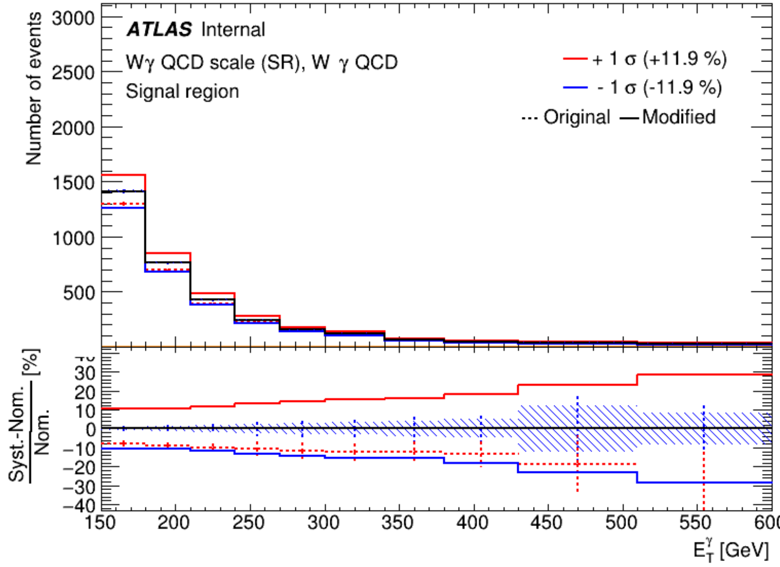
⇨ $\mu_{W\gamma}$ = 1.06 ± 0.04, $\mu_{\gamma j(0)}$ = 0.78 ± 0.09, $\mu_{\gamma j(1)}$ = 0.72 ± 0.09 and $\mu_{\gamma j(2)}$ = 0.73 ± 0.14.

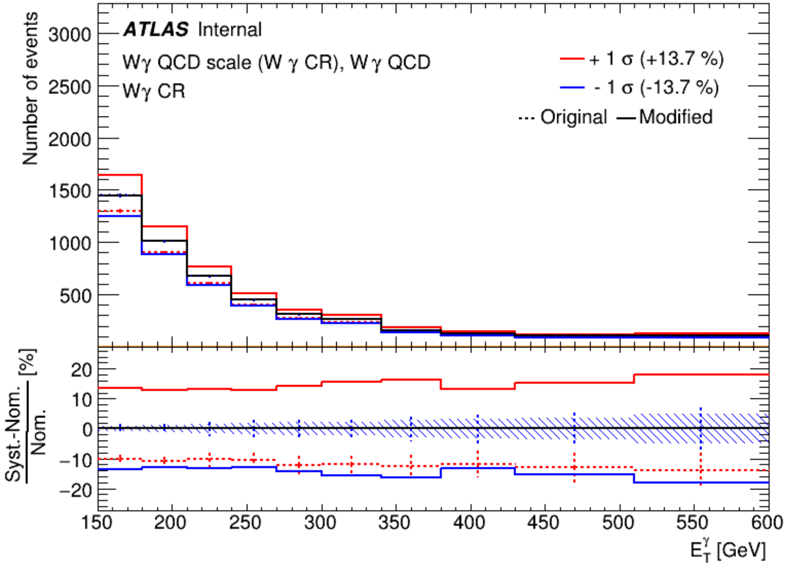
more information in back-up

Wγ QCD scale: decorrelation





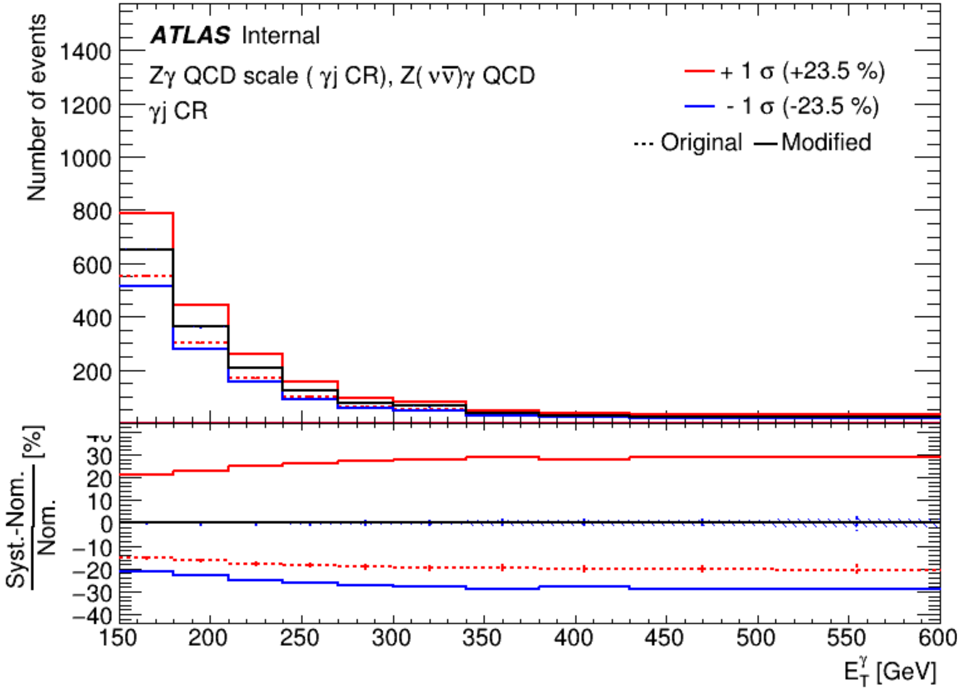


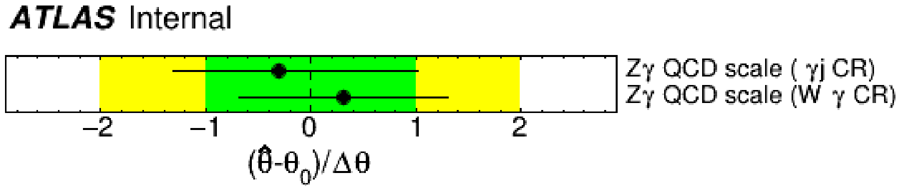


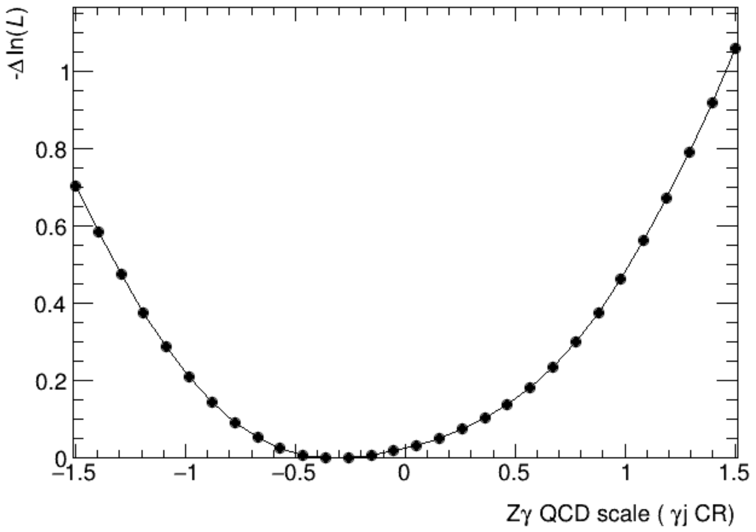
Wγ CR causes the shift

The central value is ~0.5 with all systematics adding → no problem?

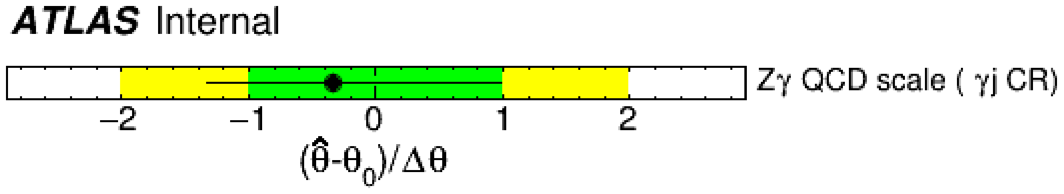
Zγ QCD scale: decorrelation



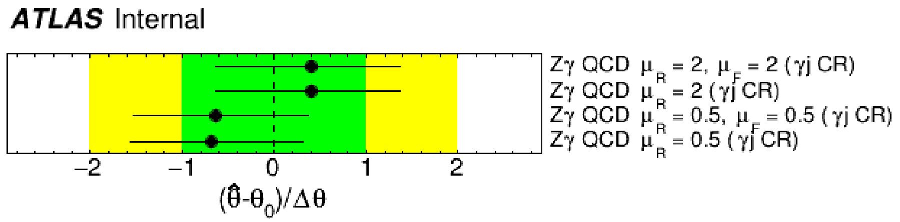




γj CR causes the problem:
flat systematics,
smooth LH curve,
asymmetric behaviour:
-0.313866 +1.3354 -1.00375



Still problematic

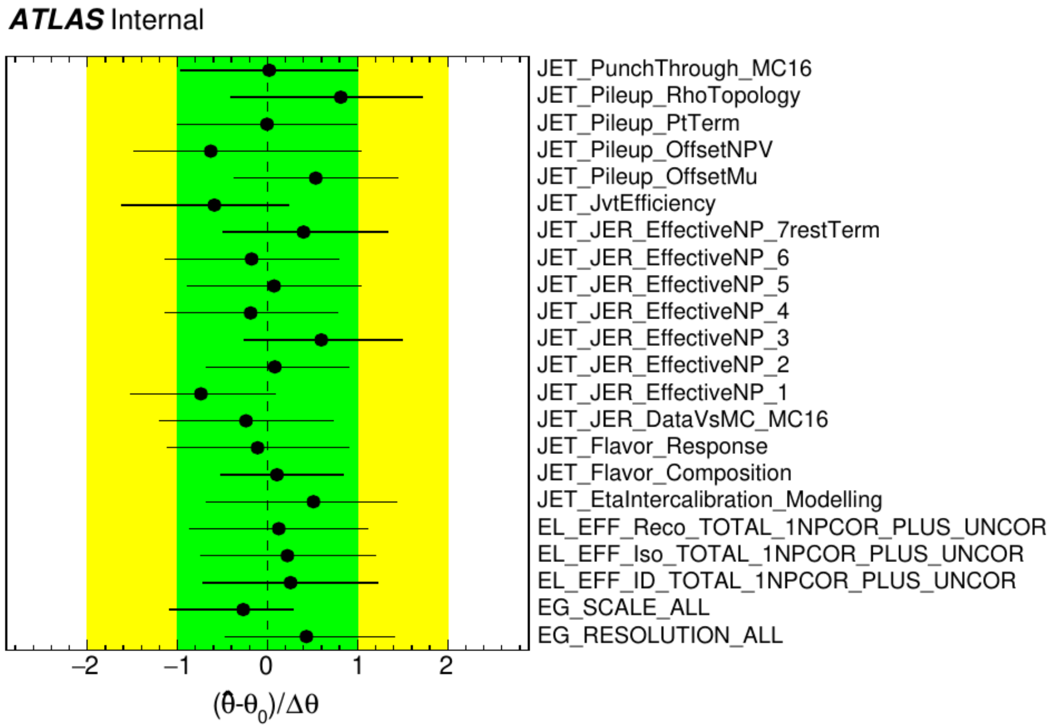


All variations:

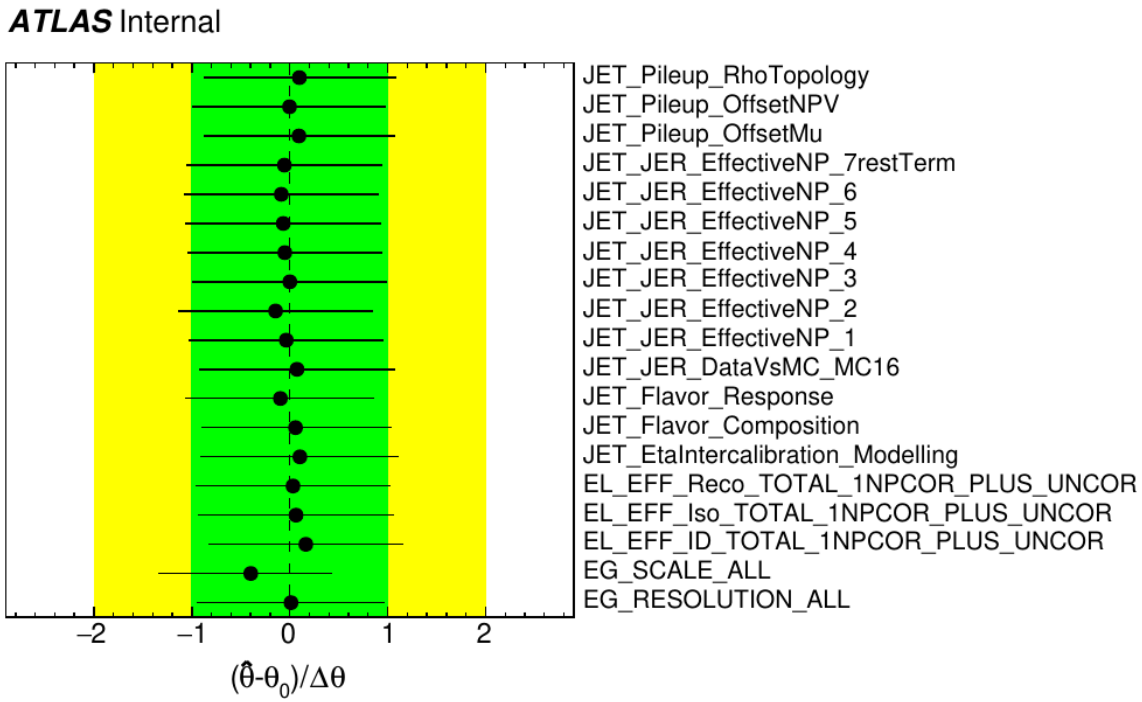
Not clear what's going wrong

Fit procedure

Fit in all CRs with gj sample

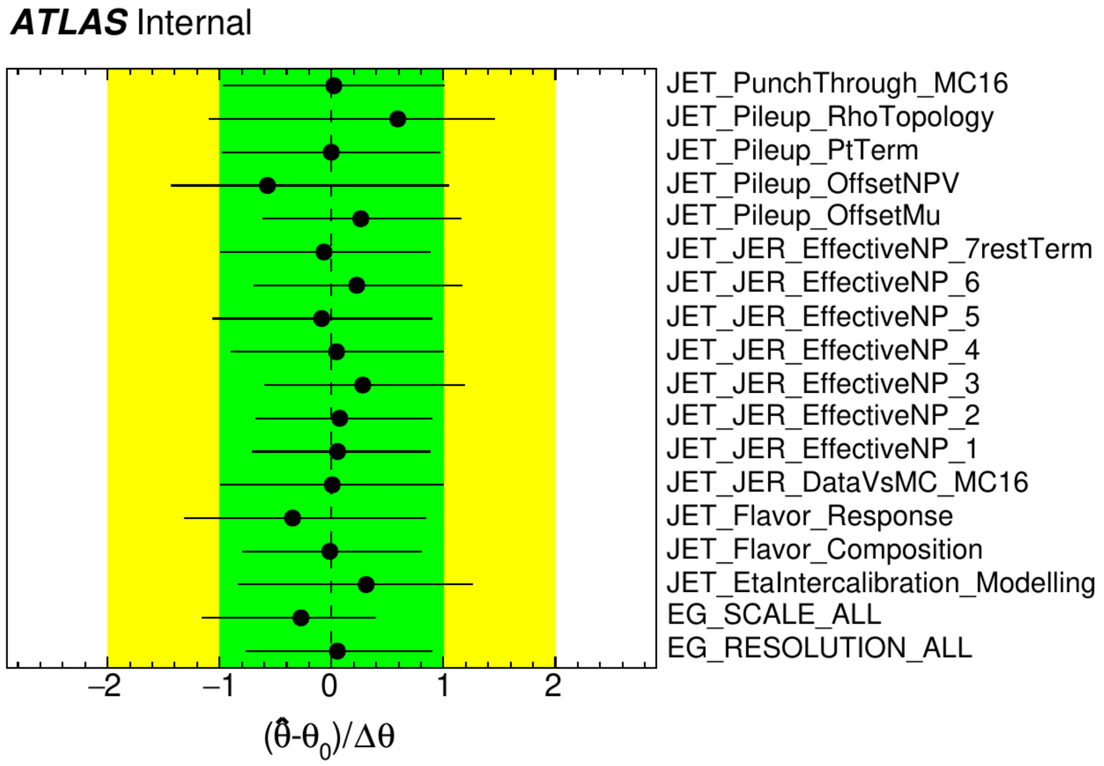


Fit in all CRs w/o gj sample

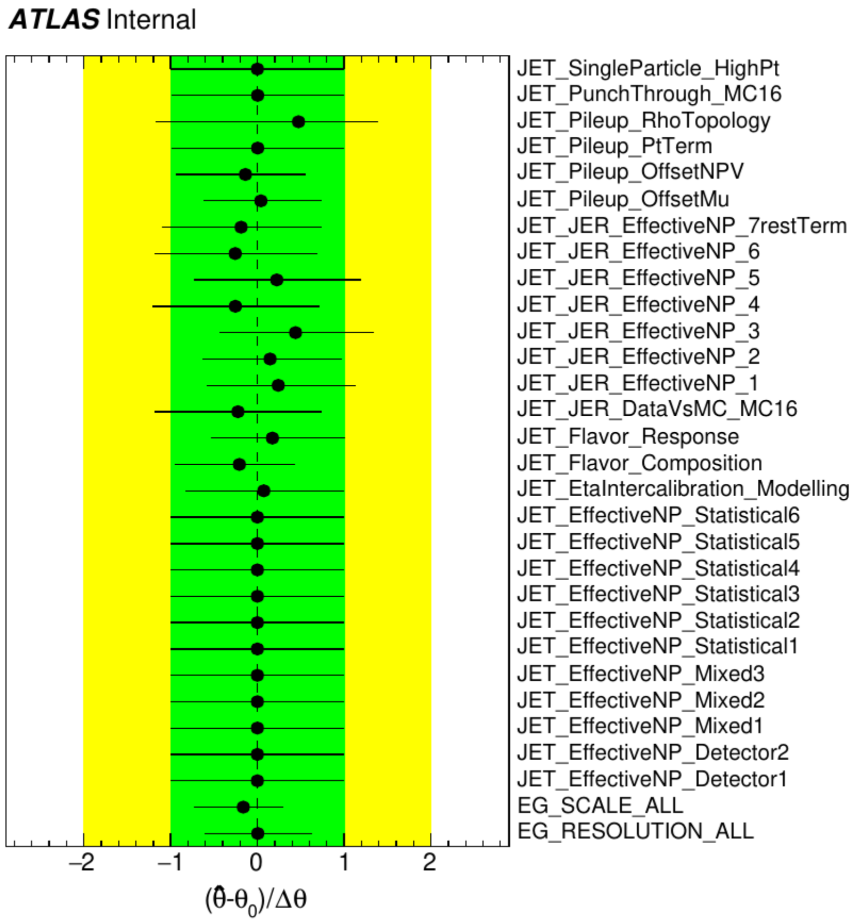


Fit procedure

Fit in all CRs with gj sample with cut on MET signif < 9 in gj CR

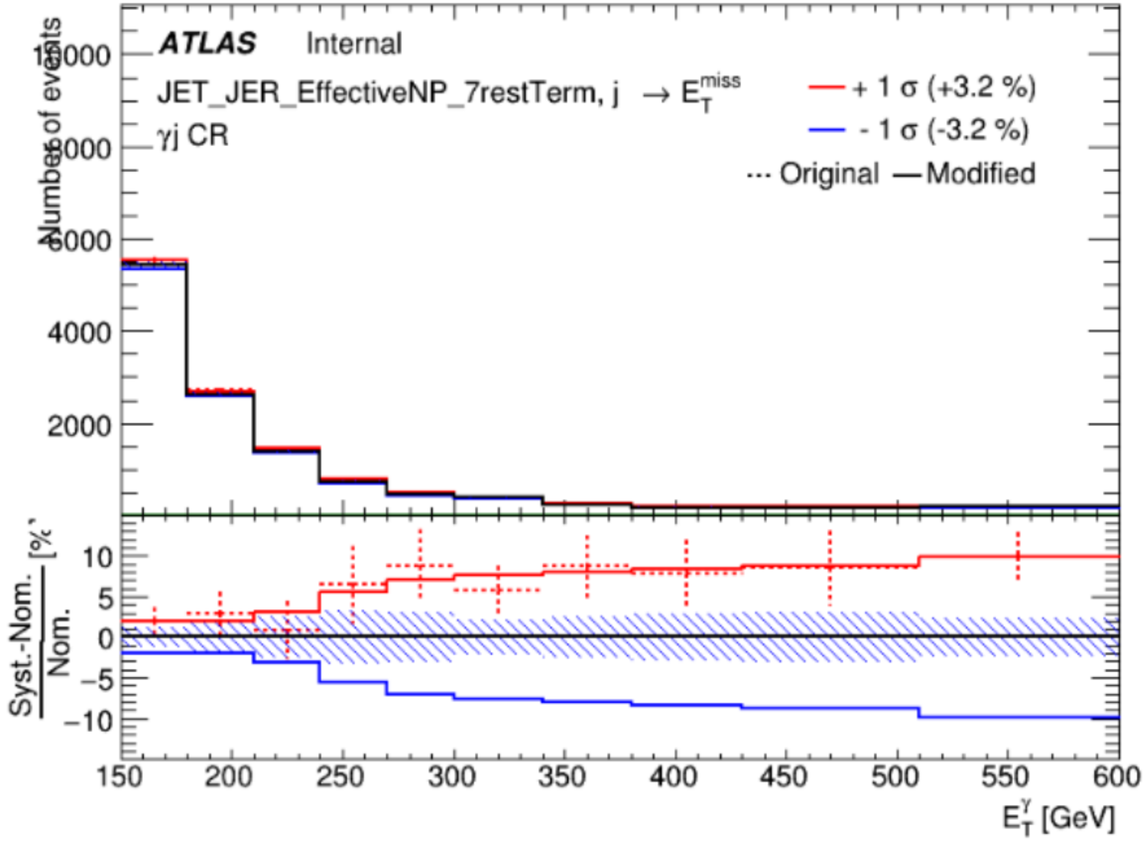


Fit in all CRs with gj sample with cut on pT soft term

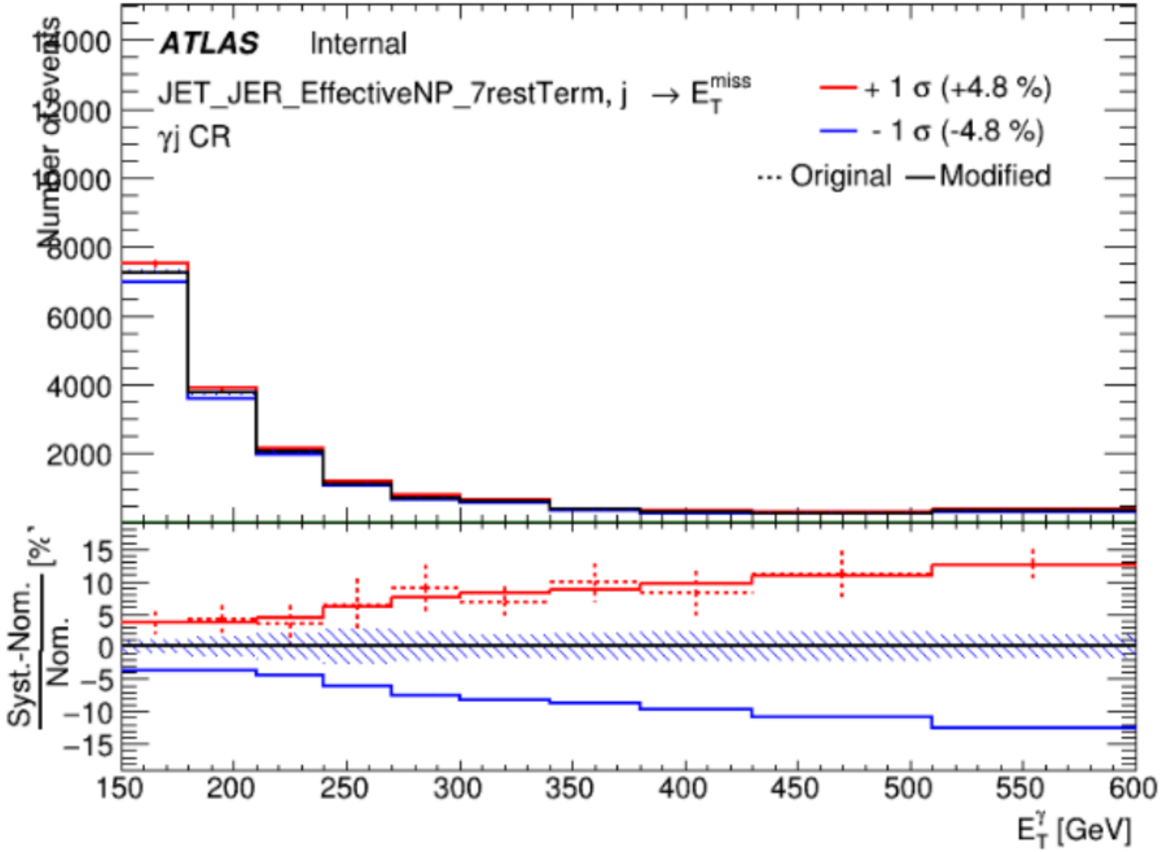


Fit procedure

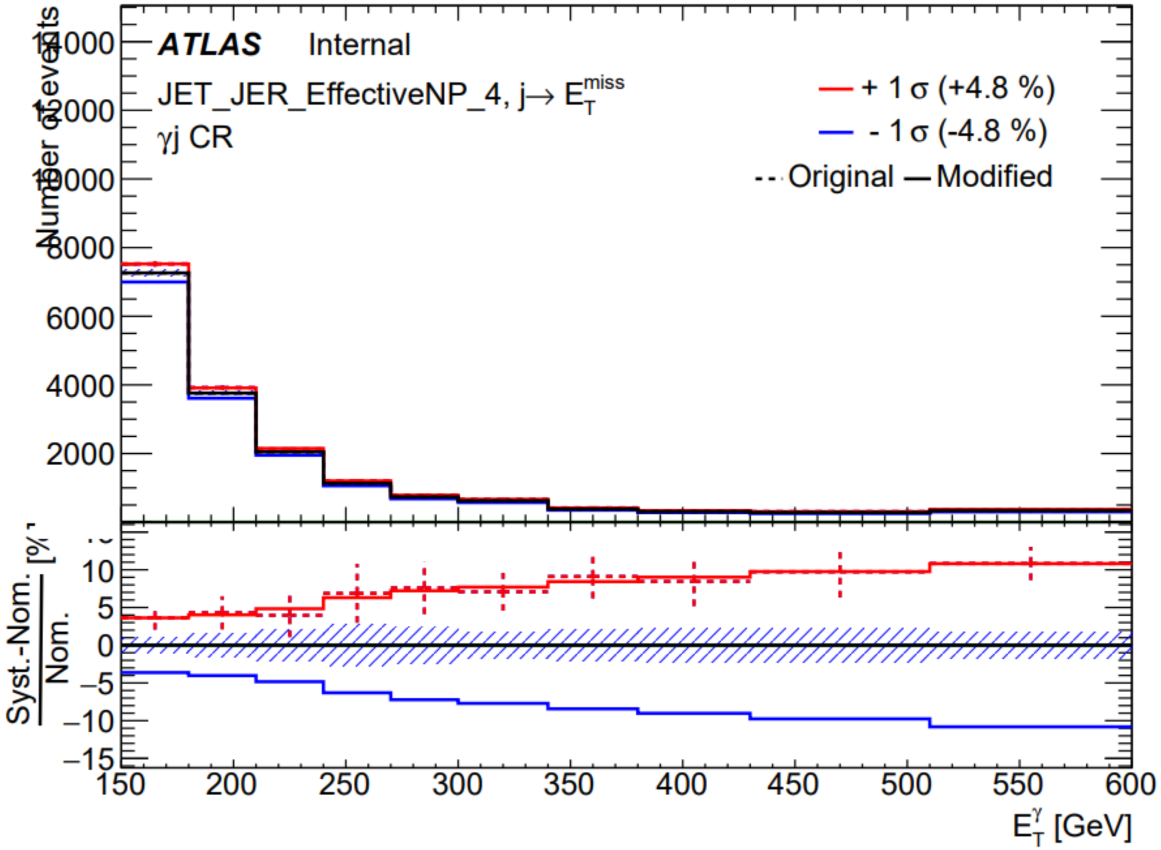
Reproc 21-02-23 with softterm

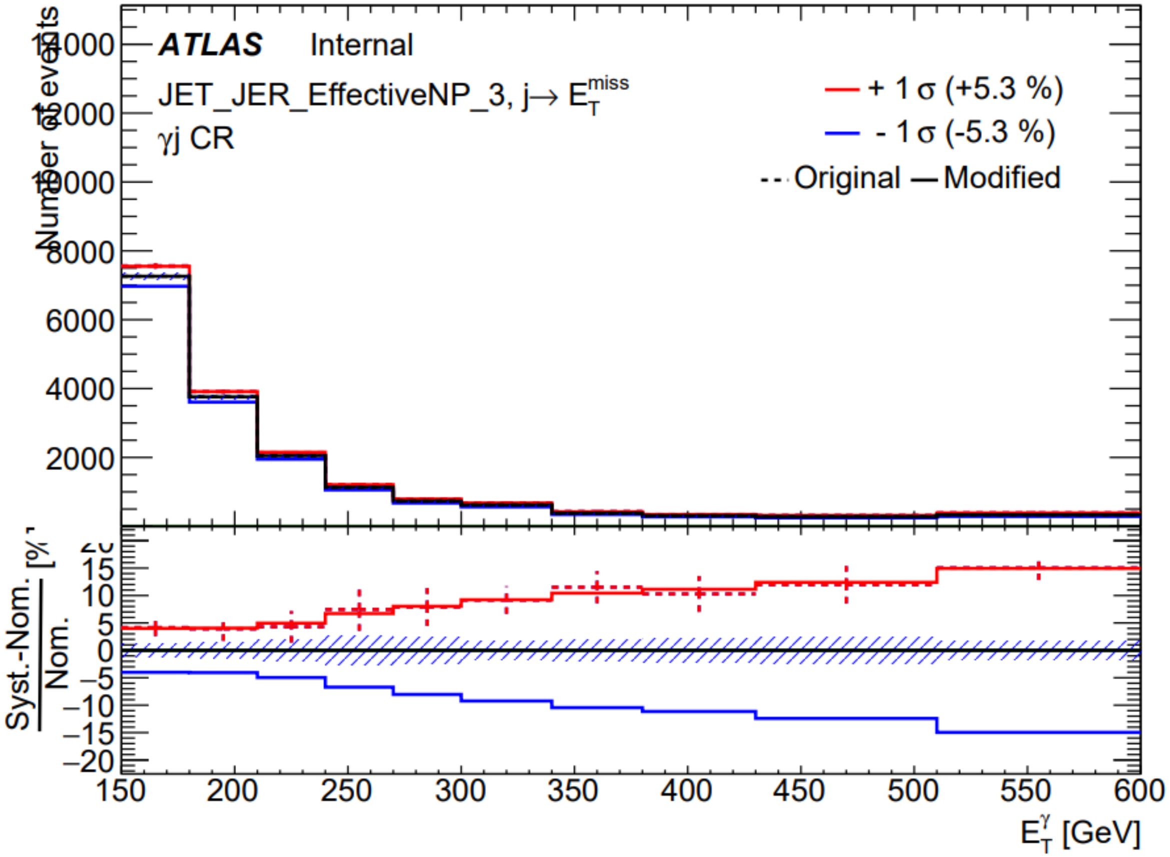


Reproc 03-11-23 w/o softterm

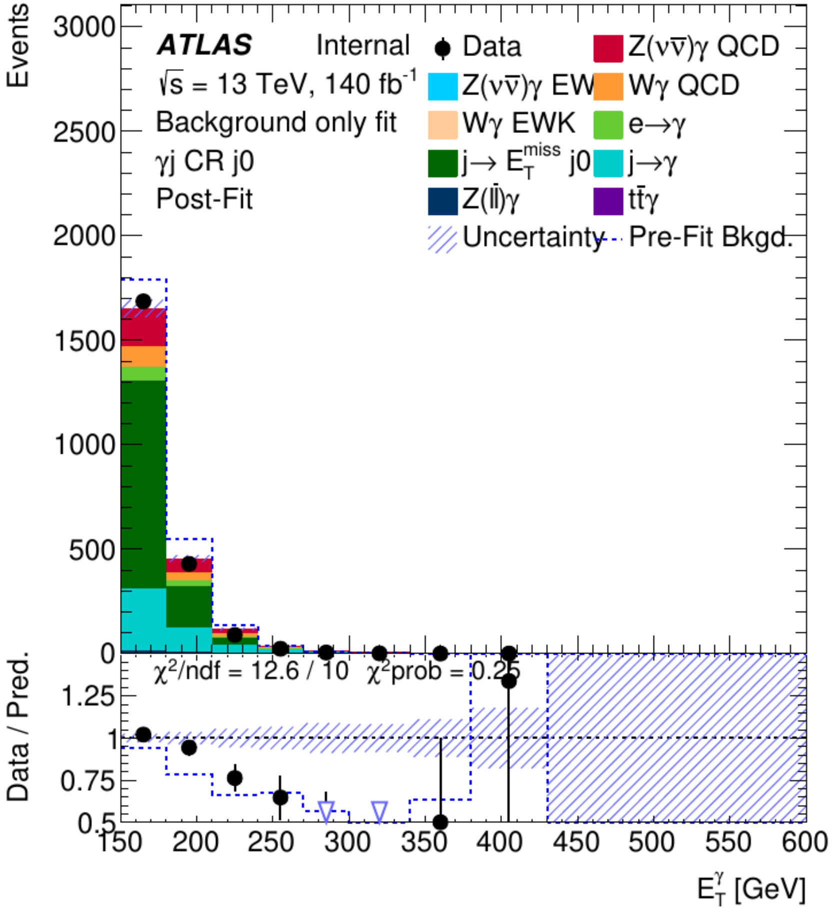


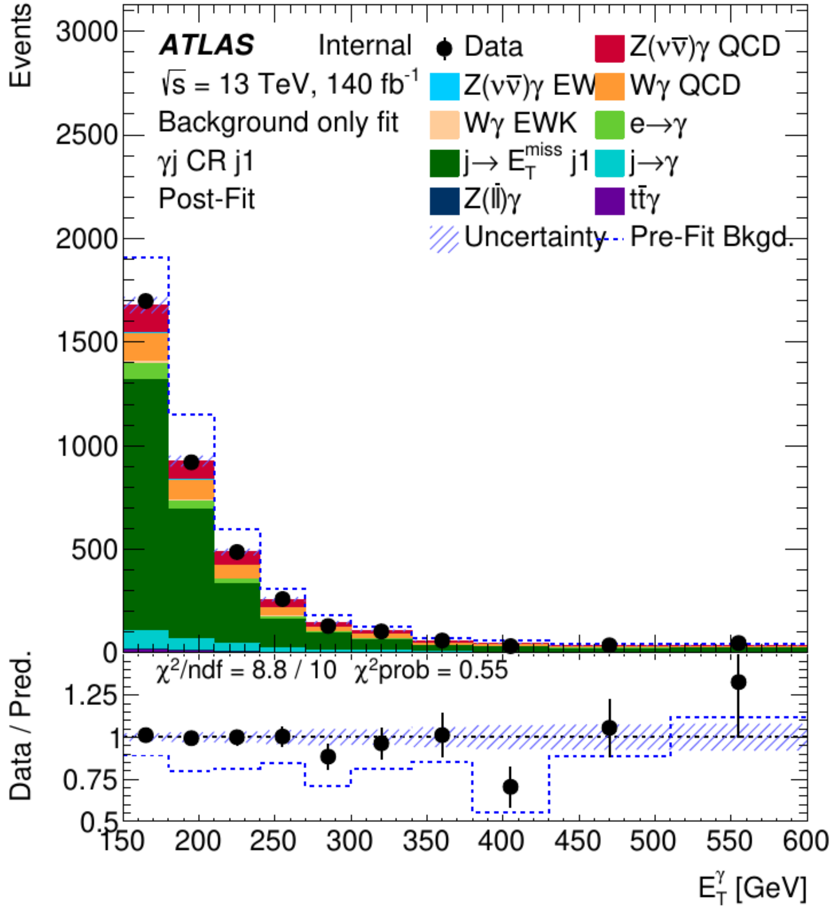
Fit procedure

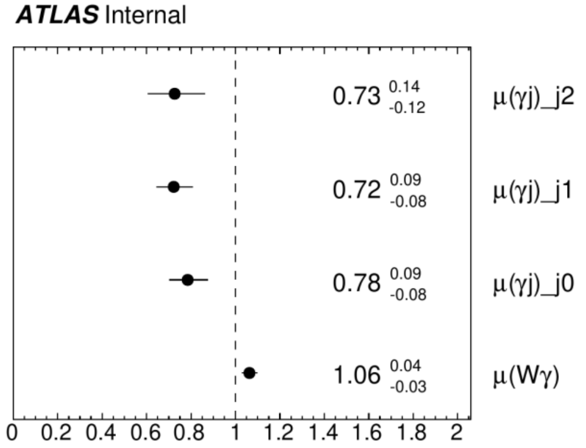


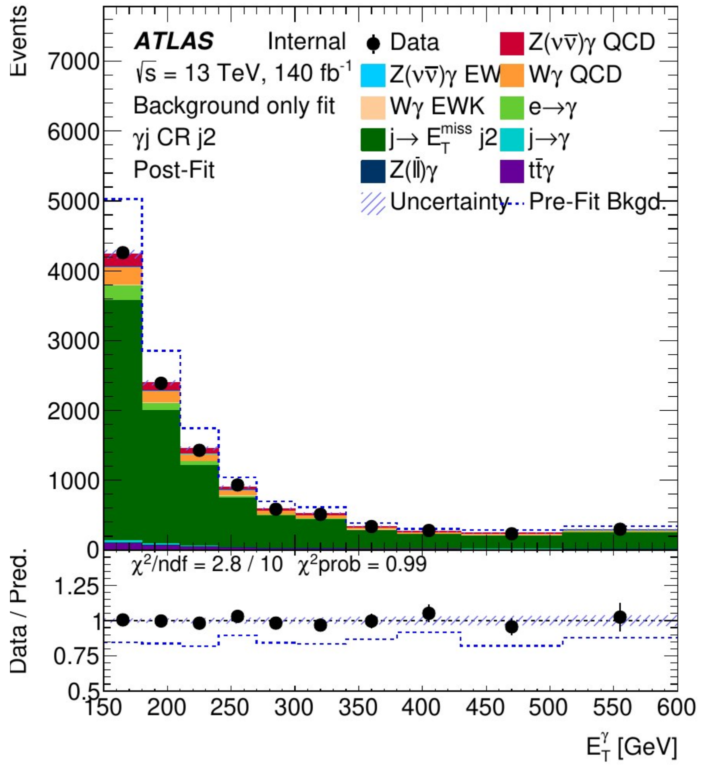


Fit procedure



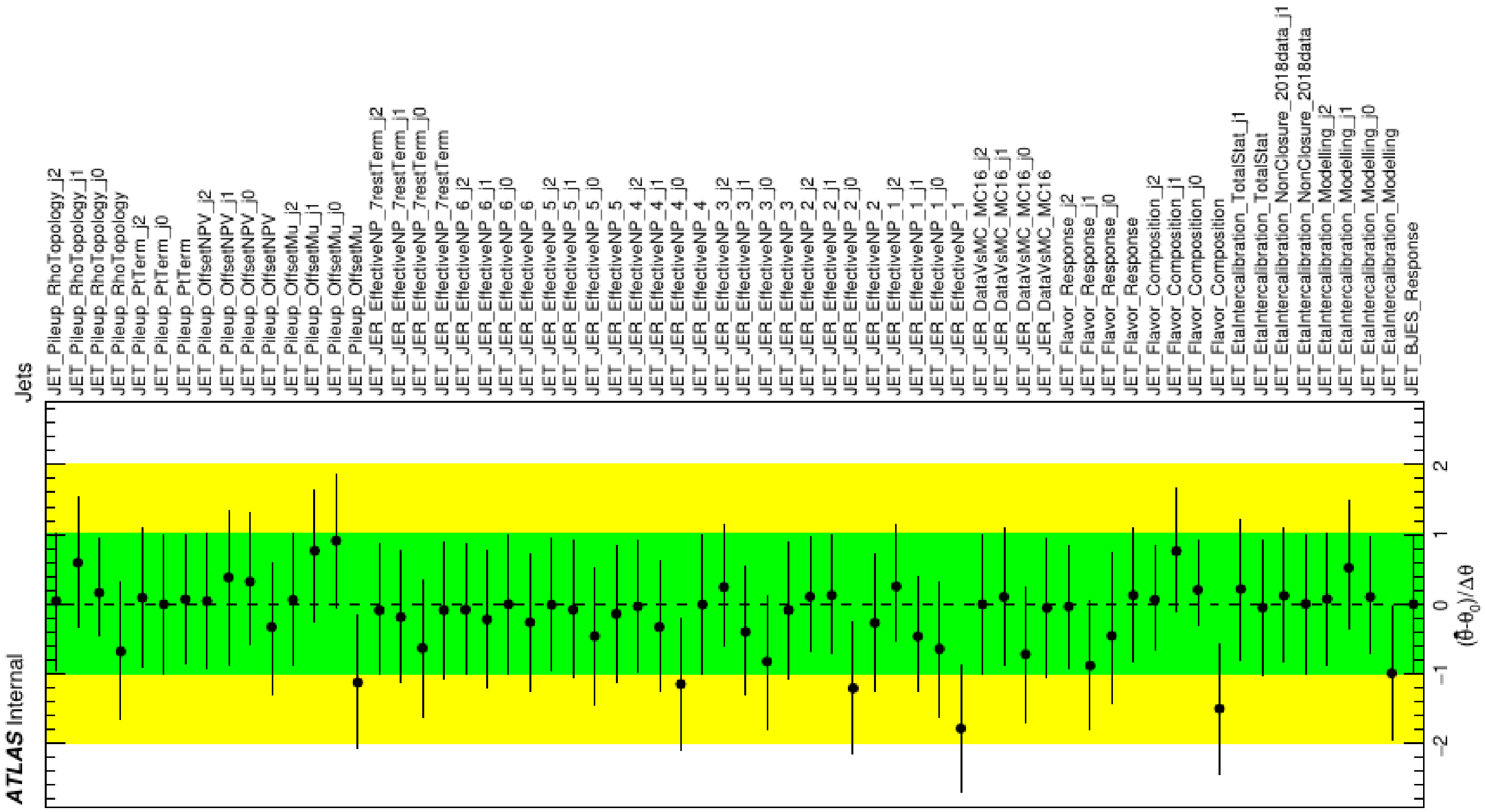


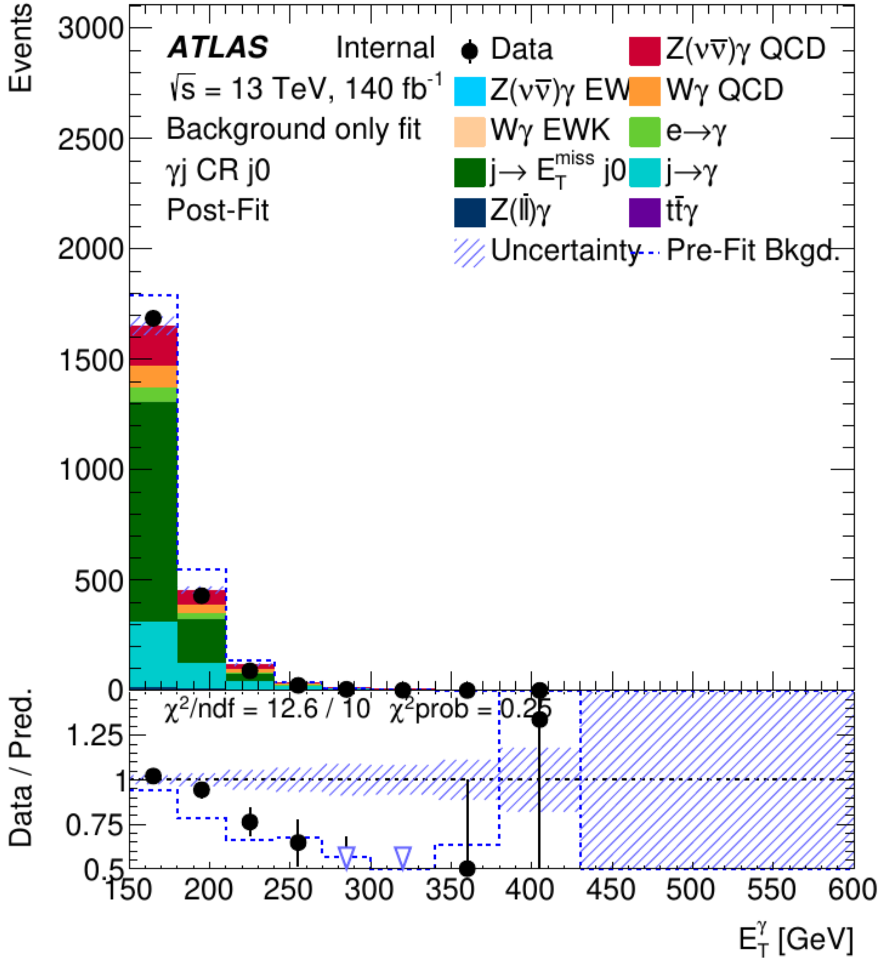




Problems with template fit: categorisation

- There was an attempt to categorise the events based on N_{jets} in the gj CR (background only fit)

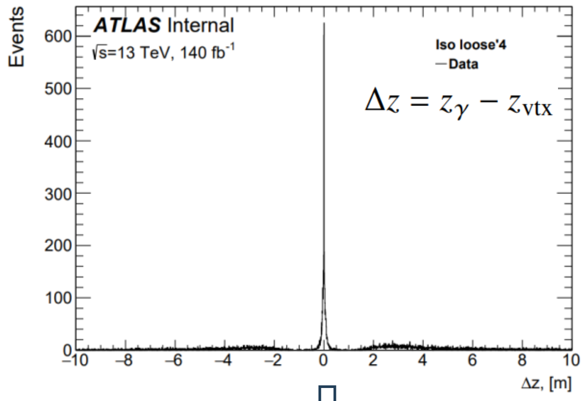


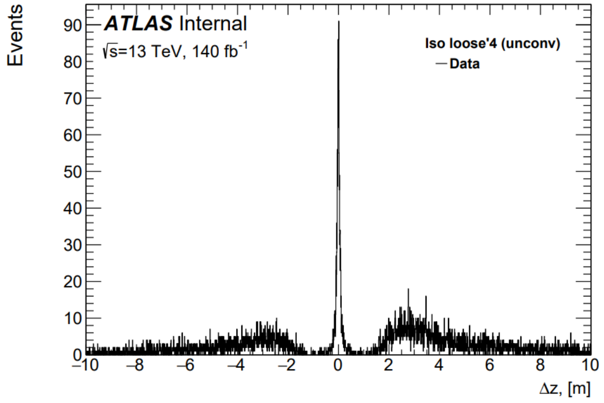


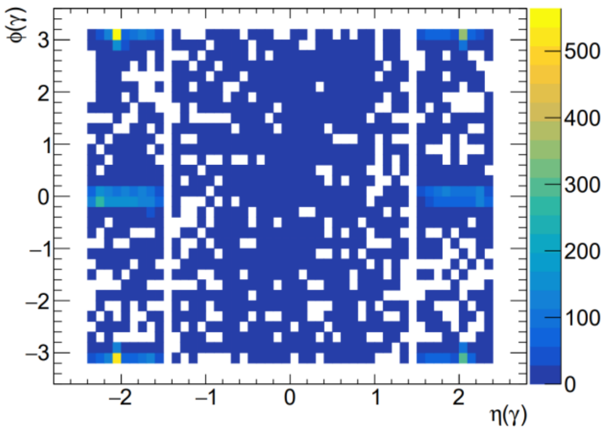
⇨ $\mu_{W\gamma}$ = 1.06 ± 0.04, $\mu_{\gamma j(0)}$ = 0.78 ± 0.09, $\mu_{\gamma j(1)}$ = 0.72 ± 0.09 and $\mu_{\gamma j(2)}$ = 0.73 ± 0.14.

Beam-induced background (BIB)

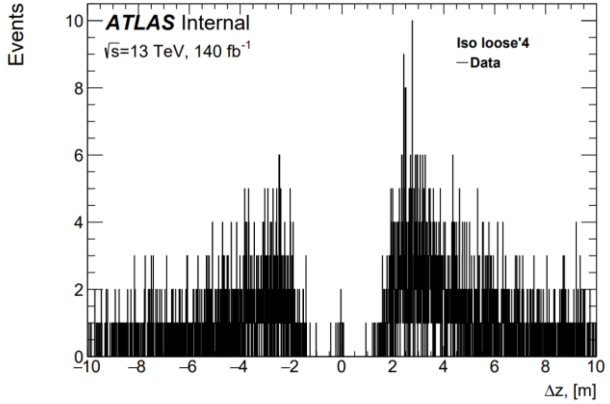
- Muons from pion and kaon decays in hadronic showers, induced by beam losses in non-elastic collisions with gas and detector material, deposit large amount of energy in calorimeters through radiative processes (= fake jets).
- The characteristic peaks of the fake jets due to BIB concentrate at ± π and 0 (mainly due to the bending in the horizontal plane that occurs in the D1 and D2 dipoles and the LHC arc).

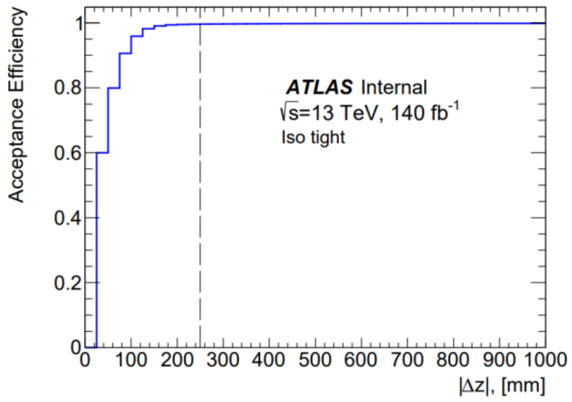


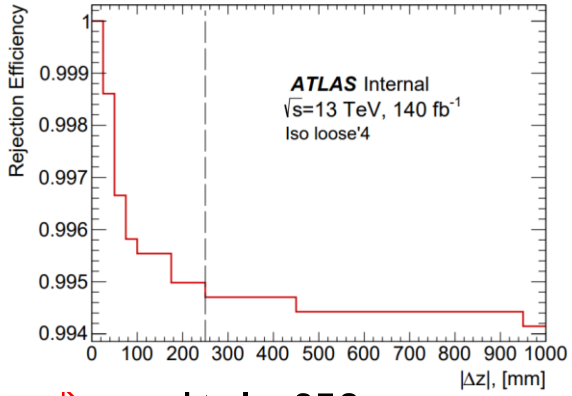




Cuts: |ϕ| < 0.2, |ϕ| ∈ [2.8; 3.2] and |η| > 1.6







|Δz| < 250 mm

Rejection efficiency: (100 ± 2)%

Acceptance efficiency: (99.6 ± 0.9)%

Selection optimisation

Variable	1	2	3	4
$E_T^{miss} signif.$	> 11			—
$\Delta\phi(E_T^{miss}, \gamma)$	> 0.6			—
$\Delta\phi(E_T^{miss}, j_1)$	> 0.3			—
E_T^{miss}, GeV	>130			—
Signal				
$Z(\nu\nu)\gamma$QCD	9928 ± 8	10021 ± 8	10711 ± 8	13934 ± 9
$Z(\nu\nu)\gamma$EWK	151.6 ± 0.3	153.6 ± 0.3	166.3 ± 0.3	312.3 ± 0.4
Total signal	10080±8	10175 ± 8	10878 ± 8	14247 ± 9
Background				
Wγ QCD	3022 ± 20	3061 ± 20	3310 ± 21	6795 ± 29
Wγ EWK	99.9 ± 0.6	101.3 ± 0.6	109.4 ± 0.6	309.8 ± 1.1
tt, top	156 ± 5	176 ± 5	201 ± 6	2800 ± 22
W($e\nu$)	3091 ± 453	3409 ± 521	3591 ± 487	8540 ± 663
ttγ	161 ± 3	163 ± 3	178 ± 3	787 ± 6
γ+j	7642 ± 79	7757 ± 80	8123 ± 82	67517 ± 217
Zj	221 ± 16	328 ± 20	415 ± 21	2583 ± 50
Z(ll)γ	197 ± 4	200 ± 4	211 ± 4	426 ± 5
W($\tau\nu$)	412 ± 65	575 ± 72	640 ± 69	4615 ± 138
Total bkg.	15002 ± 465	15770 ± 533	16779 ± 499	94373 ± 714
Stat. signif.	63.6 ± 0.6	63.2 ± 0.6	65.4 ± 0.6	43.23 ± 0.14

Table 33: The results of selection optimisation at three different working points *FixedCutTight*, *FixedCutTightCaloOnly*, *FixedCutLoose*.

Selection optimisation

	E_T^{miss} signif. E_T^{miss}, GeV $\Delta\phi(E_T^{miss},\gamma)$ $\Delta\phi(E_T^{miss},j_1)$	E_T^{miss} signif. E_T^{miss}, GeV $\Delta\phi(E_T^{miss},\gamma)$ $\Delta\phi(E_T^{miss},j_1)$	E_T^{miss} signif. E_T^{miss}, GeV $\Delta\phi(E_T^{miss},\gamma)$ $\Delta\phi(E_T^{miss},j_1)$	E_T^{miss} signif. E_T^{miss}, GeV $\Delta\phi(E_T^{miss},\gamma)$ $\Delta\phi(E_T^{miss},j_1)$	E_T^{miss} signif. E_T^{miss}, GeV $\Delta\phi(E_T^{miss},\gamma)$ $\Delta\phi(E_T^{miss},j_1)$
Signal					
$Z(\nu\nu)\gamma$QCD	10711 ± 8	12307±9	10819±8	10728±8	10849±8
$Z(\nu\nu)\gamma$EWK	166.3 ± 0.3	251.5±0.4	167.6±0.3	168.3±0.3	171.0±0.3
Total signal	10878 ± 8	12559±9	10987±8	10897±8	11020±8
Background					
$W\gamma$ QCD	3310 ± 21	4741±24	3385±21	3389±21	3440±22
$W\gamma$ EWK	109.4 ± 0.6	210.4±0.9	111.2±0.6	112.8±0.7	115.3±0.7
tt, top	177 ± 5	631±10	204±6	267±7	209±6
$W(e\nu)$	3591 ± 487	4372±517	3827±506	3883±487	3627±487
$tt\gamma$	178 ± 3	508±5	179±3	183±3	192±3
γ+j	8123 ± 82	24991±139	8552±84	8156±82	9668±86
Zj	415 ± 21	546±24	419±21	417±21	428±21
$Z(ll)\gamma$	211 ± 4	284±4	216±4	212±4	231±4
$W(\tau\nu)$	640 ± 69	945±100	651±69	821±70	655±69
Total bkg.	16779 ± 499	37229±546	17544±518	17440±499	18566±500
Stat. signif.	65.4 ± 0.6	56.3±0.3	65.0±0.6	64.7±0.6	64.1±0.5

Table 34: Comparison of statistical significance and event returns when each of the optimised variables is excluded. The excluded variable is highlighted in red.

$e \rightarrow \gamma$ misID background: Z-peak method

Selections	Cut Value
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 130 GeV
$E_{\mathrm{T}}^{e-probe}$	> 150 GeV
Number of loose non-isolated photons	$N_{\gamma} = 0$
Number of tight probe electrons	$N_{e-probe} = 1$
Lepton veto	$N_{\mu} + N_{\tau} = 0$
$E_{\mathrm{T}}^{\mathrm{miss}}$ significance	> 11
$\lvert\Delta\phi(e - probe, \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}})\rvert$	> 0.6
$\lvert\Delta\phi(j_1, \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}})\rvert$	> 0.3

Table 5: Event selection criteria for e-probe CR events.

Event yield	real $e + E_{\mathrm{T}}^{\mathrm{miss}}$ (MC)	fake $e + E_{\mathrm{T}}^{\mathrm{miss}}$ (MC)	data
e-probe CR	78079 ± 4078	465 ± 34	74076

Table 6: Event yields for real $e + E_{\mathrm{T}}^{\mathrm{miss}}$ and fake $e + E_{\mathrm{T}}^{\mathrm{miss}}$ prediction and observed data in probe-electron control regions. Indicated uncertainties are statistical.

$e \longrightarrow \gamma$ misID background: Z-peak method

fake rate	$150 < E_T^{\gamma} < 250$ GeV $0 < \|\eta\| < 1.37$	$E_T^{\gamma} > 250$ GeV $0 < \|\eta\| < 1.37$	$1.52 < \|\eta\| < 2.37$	Total
syst. on fake-rate estimation.	4%	20%	10%	
syst. from stat. unc. on fake-rate	3%	7%	3%	
syst. from impurity of CR	0.16%	0.16%	0.16%	
Total rel. syst.	5%	21%	10%	
Event yield in (incl.) e-probe CR	49673	11492	20855	
Fake-rate	0.0234	0.0193	0.0714	
$e \rightarrow \gamma$ event yield in SR	1062	200	1345	2608
Total abs. syst.	58	42	134	162

Table 35: Systematics breakdown for $e \rightarrow \gamma$ background for SR.

Missing transverse momentum is calculated as the sum of the following terms:

$$E_{\mathrm{x(y)}}^{\mathrm{miss}} = E_{\mathrm{x(y)}}^{\mathrm{miss,e}} + E_{\mathrm{x(y)}}^{\mathrm{miss},\mu} + E_{\mathrm{x(y)}}^{\mathrm{miss},\tau_{\mathrm{had}}} + E_{\mathrm{x(y)}}^{\mathrm{miss},\gamma} + E_{\mathrm{x(y)}}^{\mathrm{miss,jets}} + E_{\mathrm{x(y)}}^{\mathrm{miss,SoftTerm}},$$

$e \to \gamma$ misID background: Z-peak method

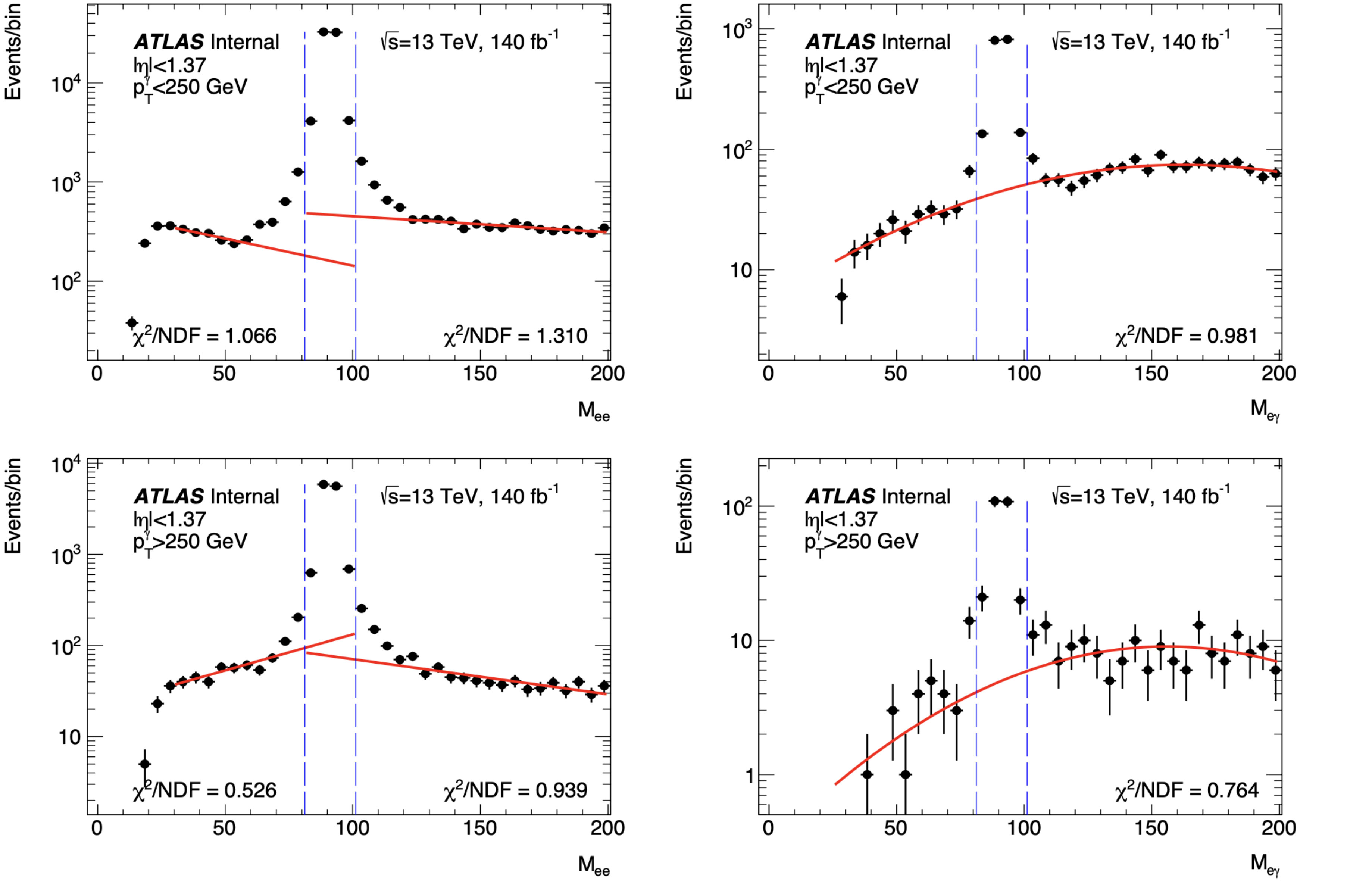
fake rate	$150 < E_T^\gamma < 250$ GeV $0 < \lvert\eta\rvert < 1.37$	$E_T^\gamma > 250$ GeV $0 < \lvert\eta\rvert < 1.37$	$1.52 < \lvert\eta\rvert < 2.37$
$Z(ee)$ MC tag-n-probe	0.0218 ± 0.0004	0.0197 ± 0.0005	0.0762 ± 0.0012
$Z(ee)$ MC mass window variation	0.0217 ± 0.0004	0.0198 ± 0.0005	0.0765 ± 0.0012
$Z(ee)$ MC ”real”	0.022 ± 0.002	0.023 ± 0.002	0.084 ± 0.004

Table 33: Electron-to-photon fake rates estimated in MC.

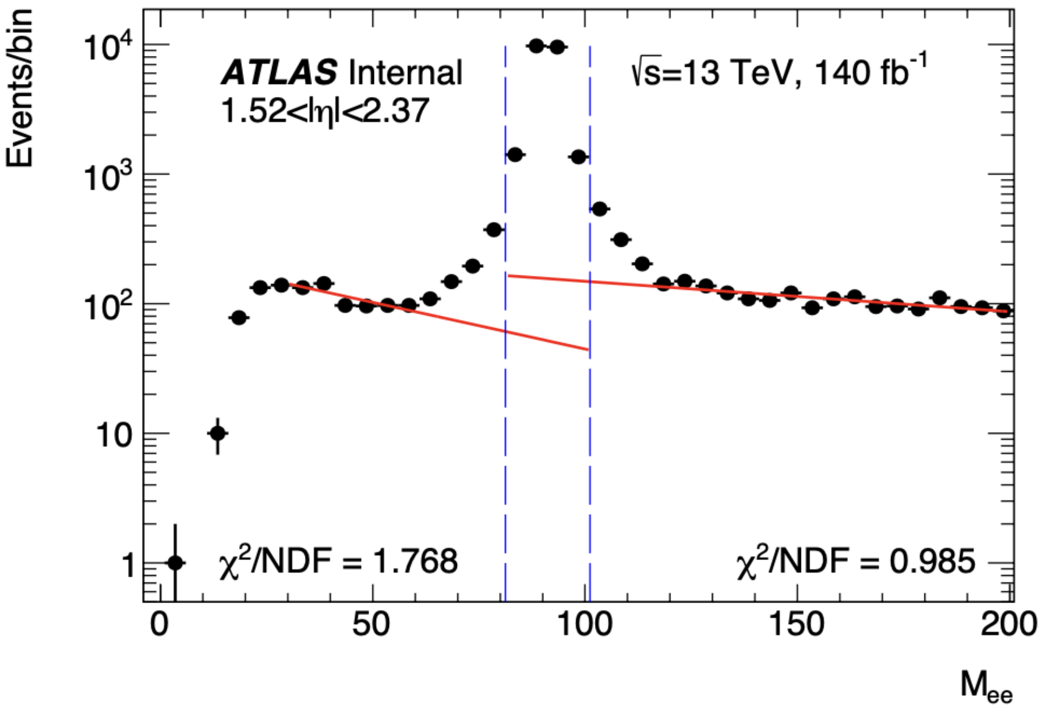
fake rate	$150 < E_T^\gamma < 250$ GeV $0 < \lvert\eta\rvert < 1.37$	$E_T^\gamma > 250$ GeV $0 < \lvert\eta\rvert < 1.37$	$1.52 < \lvert\eta\rvert < 2.37$
syst. from mass window var.:	0.3%	0.7%	0.4%
syst. from tag-n-probe and real f.r.:	3%	15%	10%
Background fit variation	4%	14%	3%
Total syst.:	4%	20%	10%

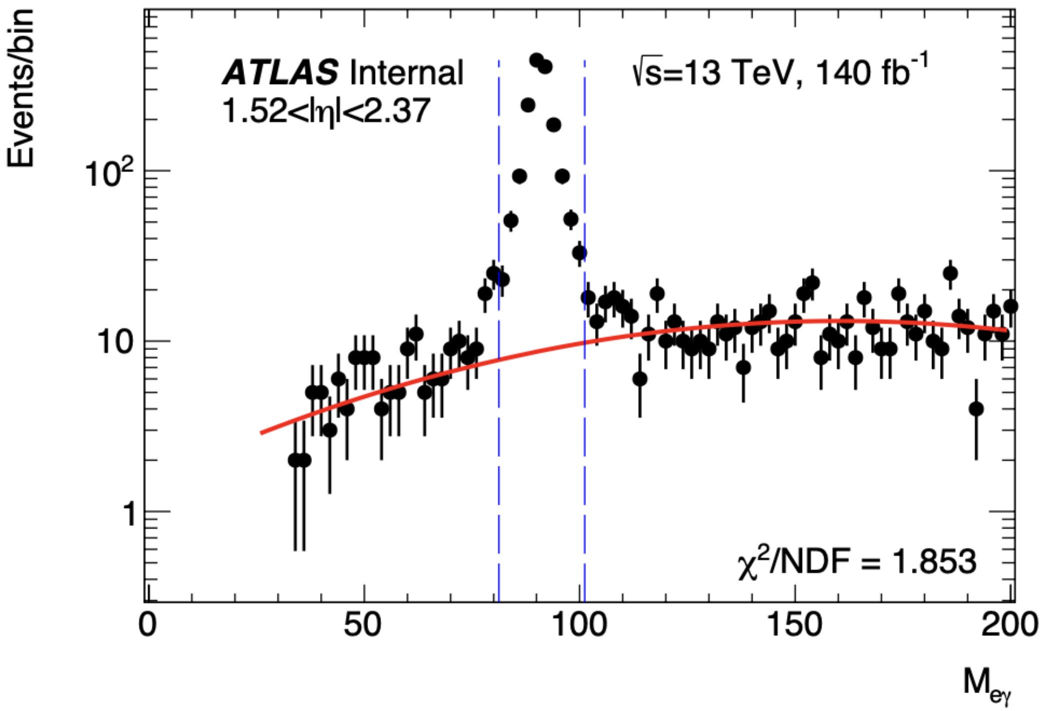
Table 34: Electron-to-photon fake rate systematics components.

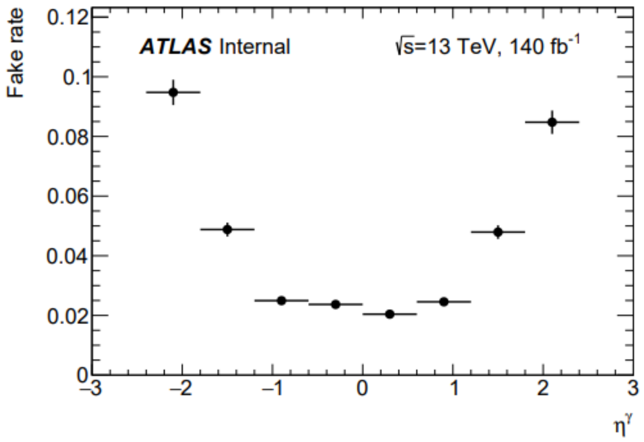
$e \to \gamma$ misID background: Z-peak method

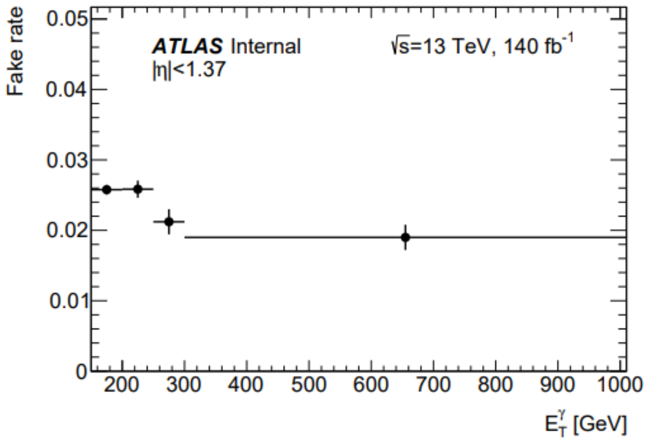


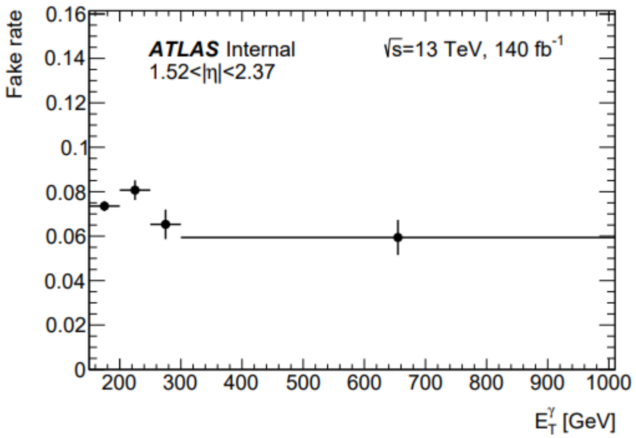
$e \to \gamma$ misID background: Z-peak method











jet → γ misID background: ABCD method

- Tight and isolated region (region A – equivalent to $Z\gamma$ signal region described in Sec. 4.7): events have a leading photon candidate that is isolated ($E_{\mathrm{T}}^{\mathrm{cone20}} - 0.065 p_{\mathrm{T}}^{\gamma} < 0$ GeV) and passes the *tight* selection.
- Tight but not isolated region (control region B): events have a leading photon candidate that is not isolated ($E_{\mathrm{T}}^{\mathrm{cone20}} - 0.065 p_{\mathrm{T}}^{\gamma} >$ iso gap) and passes the *tight* selection.
- Non-tight and isolated region (control region C): events have a leading photon candidate that is isolated ($E_{\mathrm{T}}^{\mathrm{cone20}} - 0.065 p_{\mathrm{T}}^{\gamma} < 0$ GeV) and passes the *non-tight* selection.
- Non-tight and not isolated region (control region D): events have a leading photon candidate that is not isolated ($E_{\mathrm{T}}^{\mathrm{cone20}} - 0.065 p_{\mathrm{T}}^{\gamma} >$ iso gap) and passes the *non-tight* selection.

- *loose'2*: w_{s3}, F_{side}
- *loose'3*: w_{s3}, F_{side}, ΔE
- *loose'4*: w_{s3}, F_{side}, ΔE, E_{ratio}
- *loose'5*: w_{s3}, F_{side}, ΔE, E_{ratio}, w_{tot},

$$N_{\mathrm{A}}^{Z(\nu\bar{\nu})\gamma} = \tilde{N}_{\mathrm{A}} - R(\tilde{N}_{\mathrm{B}} - c_{\mathrm{B}} N_{\mathrm{A}}^{Z(\nu\bar{\nu})\gamma}) \frac{\tilde{N}_{\mathrm{C}} - c_{\mathrm{C}} N_{\mathrm{A}}^{Z(\nu\bar{\nu})\gamma}}{\tilde{N}_{\mathrm{D}} - c_{\mathrm{D}} N_{\mathrm{A}}^{Z(\nu\bar{\nu})\gamma}}.$$

$$N_{\mathrm{A}} = N_{\mathrm{A}}^{Z(\nu\bar{\nu})\gamma} + N_{\mathrm{A}}^{\mathrm{bkg}} + N_{\mathrm{A}}^{\mathrm{jet}\to\gamma};$$
$$N_{\mathrm{B}} = c_{\mathrm{B}} N_{\mathrm{A}}^{Z(\nu\bar{\nu})\gamma} + N_{\mathrm{B}}^{\mathrm{bkg}} + N_{\mathrm{B}}^{\mathrm{jet}\to\gamma};$$
$$N_{\mathrm{C}} = c_{\mathrm{C}} N_{\mathrm{A}}^{Z(\nu\bar{\nu})\gamma} + N_{\mathrm{C}}^{\mathrm{bkg}} + N_{\mathrm{C}}^{\mathrm{jet}\to\gamma};$$
$$N_{\mathrm{D}} = c_{\mathrm{D}} N_{\mathrm{A}}^{Z(\nu\bar{\nu})\gamma} + N_{\mathrm{D}}^{\mathrm{bkg}} + N_{\mathrm{D}}^{\mathrm{jet}\to\gamma};$$

$$c_{\mathrm{B}} = \frac{N_{\mathrm{B}}^{Z(\nu\bar{\nu})\gamma}}{N_{\mathrm{A}}^{Z(\nu\bar{\nu})\gamma}}; \quad c_{\mathrm{C}} = \frac{N_{\mathrm{C}}^{Z(\nu\bar{\nu})\gamma}}{N_{\mathrm{A}}^{Z(\nu\bar{\nu})\gamma}}; \quad c_{\mathrm{D}} = \frac{N_{\mathrm{D}}^{Z(\nu\bar{\nu})\gamma}}{N_{\mathrm{A}}^{Z(\nu\bar{\nu})\gamma}}.$$

$$N_{\mathrm{A}}^{Z(\nu\bar{\nu})\gamma} = \frac{b - \sqrt{b^2 - 4ac}}{2a},$$

$$a = c_{\mathrm{D}} - R c_{\mathrm{B}} c_{\mathrm{C}};$$
$$b = \tilde{N}_{\mathrm{D}} + c_{\mathrm{D}} \tilde{N}_{\mathrm{A}} - R(c_{\mathrm{B}} \tilde{N}_{\mathrm{C}} + c_{\mathrm{C}} \tilde{N}_{\mathrm{B}});$$
$$c = \tilde{N}_{\mathrm{D}} \tilde{N}_{\mathrm{A}} - R \tilde{N}_{\mathrm{C}} \tilde{N}_{\mathrm{B}}.$$

	Data	$W\gamma$	$e \to \gamma$	$tt\gamma$	γ+jet	$Z(ll)\gamma$
A	23375 ± 153	3420 ± 21	2608 ± 11	178 ± 3	8123 ± 82	211 ± 4
B	270 ± 16	17.7 ± 1.3	4.269 ± 0.016	0.46 ± 0.14	7 ± 3	0.6 ± 0.2
C	4393 ± 66	108 ± 3	92.8 ± 0.3	6.1 ± 0.5	259 ± 13	7.1 ± 0.6
D	497 ± 22	0.6 ± 0.2	0 ± 0	0.07 ± 0.05	0.06 ± 0.06	0 ± 0

jet → γ misID background: slice method

To take into account the dependence of the estimate on the photon isolation, the non-isolated regions are split into a set of into successive intervals (slices) based on the photon isolation. In this way, the number of $jet \to \gamma$ background events in each non-isolated slice i of the CR1 $N^{jet\to\gamma}_{\mathrm{CR1(i)}}$ is derived as follows:

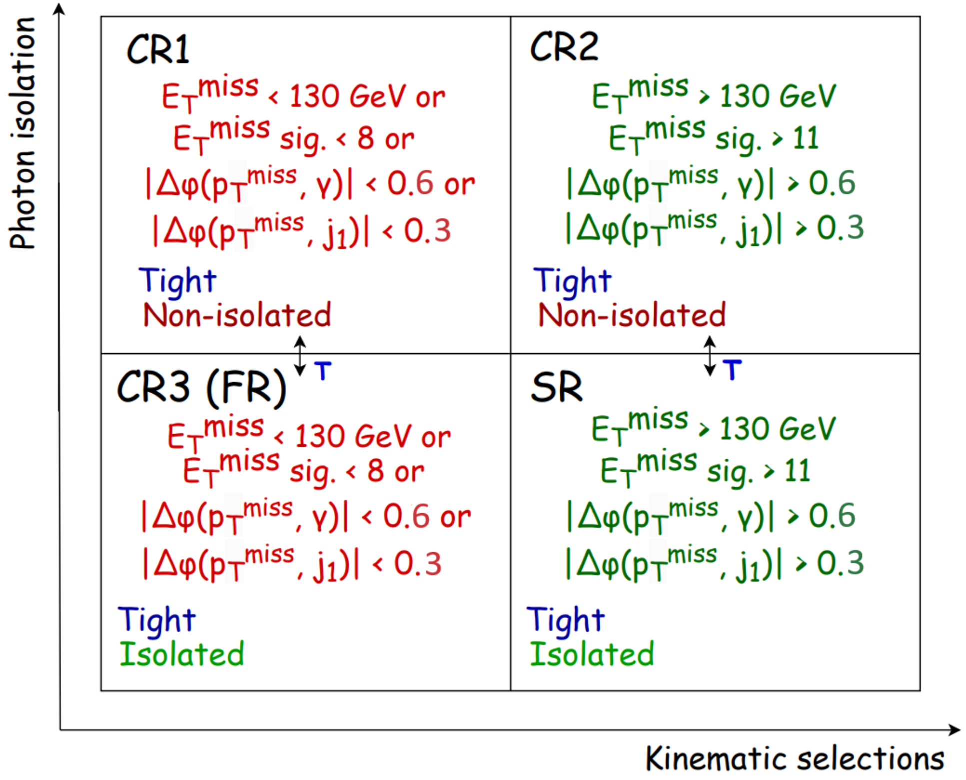
$$N^{jet\to\gamma}_{\mathrm{CR1(i)}} = N^{\mathrm{data}}_{\mathrm{CR1(i)}} - N^{\mathrm{Z}(\nu\bar{\nu})\gamma}_{\mathrm{CR1(i)}} - N^{\mathrm{bkg}}_{\mathrm{CR1(i)}},$$

Four isolation slices are chosen: [0.065, 0.090, 0.115, 0.140, 0.165].

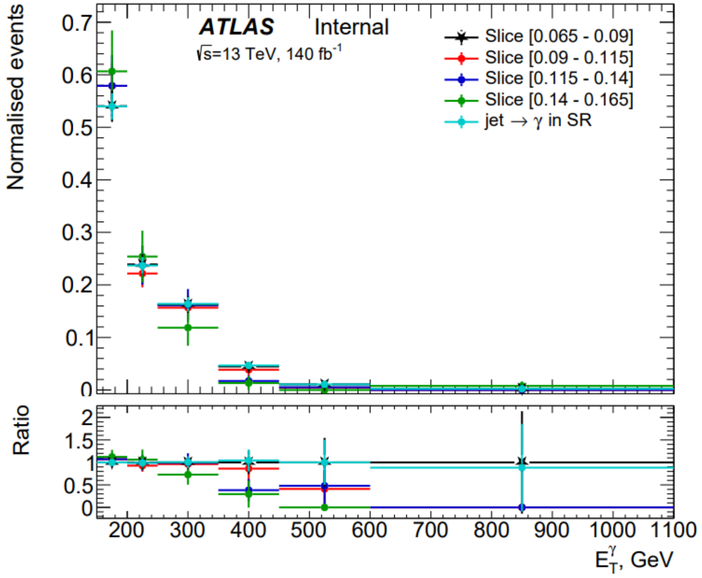
$$H^{[0.A,0.B]}_{jet\to\gamma} = H^{[0.A,0.B]}_{\mathrm{data}}[X] - H^{[0.A,0.B]}_{\mathrm{sig}}[X] - H^{[0.A,0.B]}_{\mathrm{bkg}}[X],$$

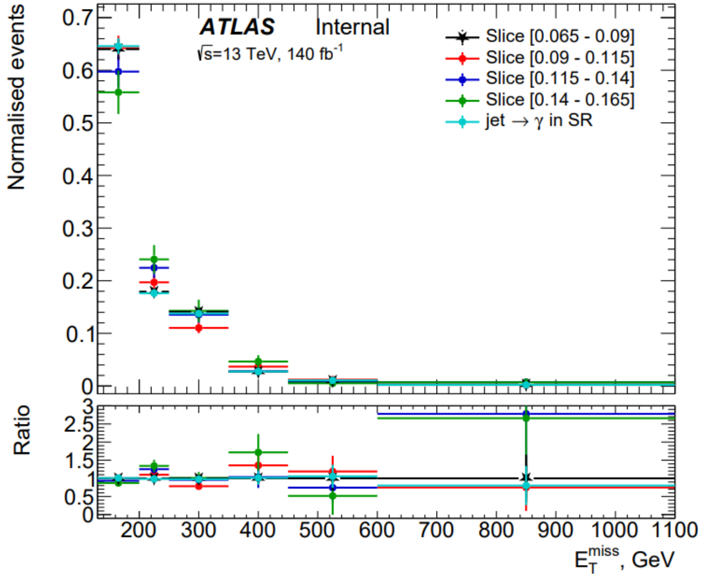
$$\Delta^{CR2}[X] = \frac{1}{2}\left(\frac{H^{[0.065,0.09]}_{jet\to\gamma}[X] - H^{[0.115,0.14]}_{jet\to\gamma}[X]}{2} + \frac{H^{[0.09,0.115]}_{jet\to\gamma}[X] - H^{[0.14,0.165]}_{jet\to\gamma}[X]}{2}\right),$$

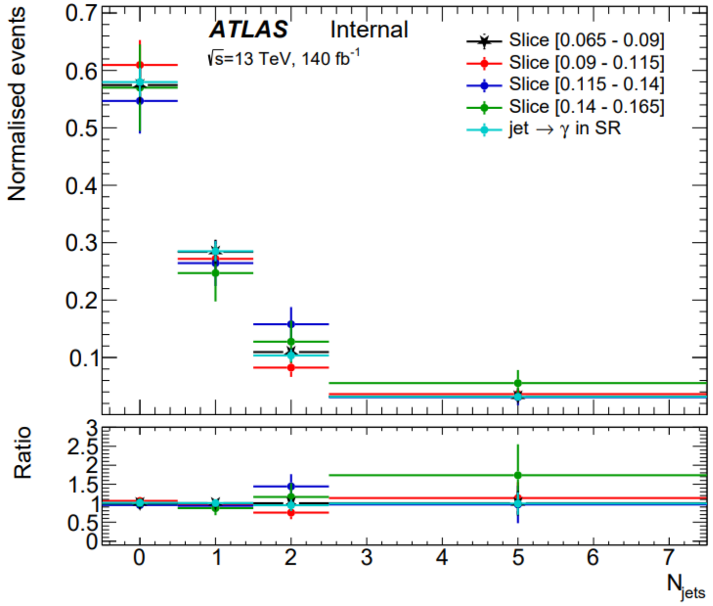
$$H^{SR}_{jet\to\gamma} = H^{[0.065,0.09]}_{jet\to\gamma}[X] + \Delta^{CR2}[X].$$

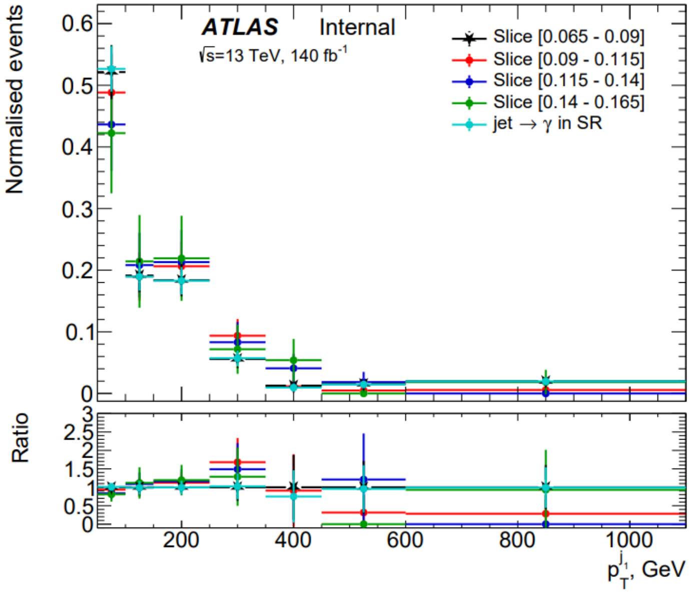


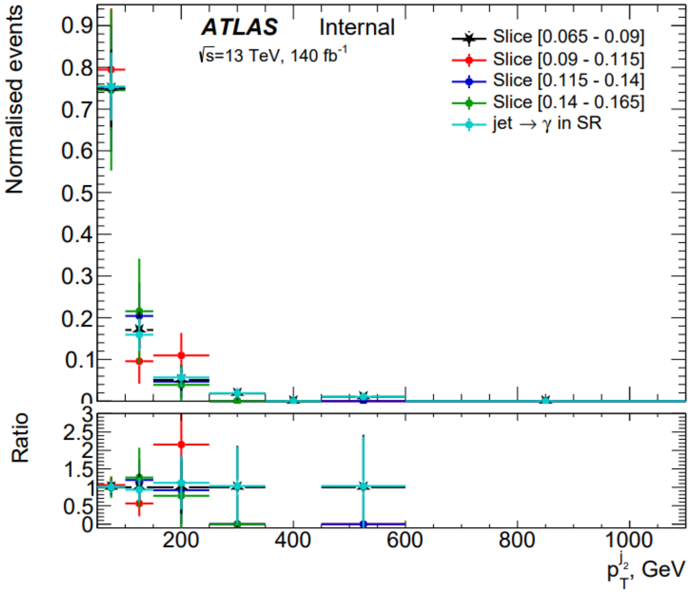
jet → γ misID background: slice method

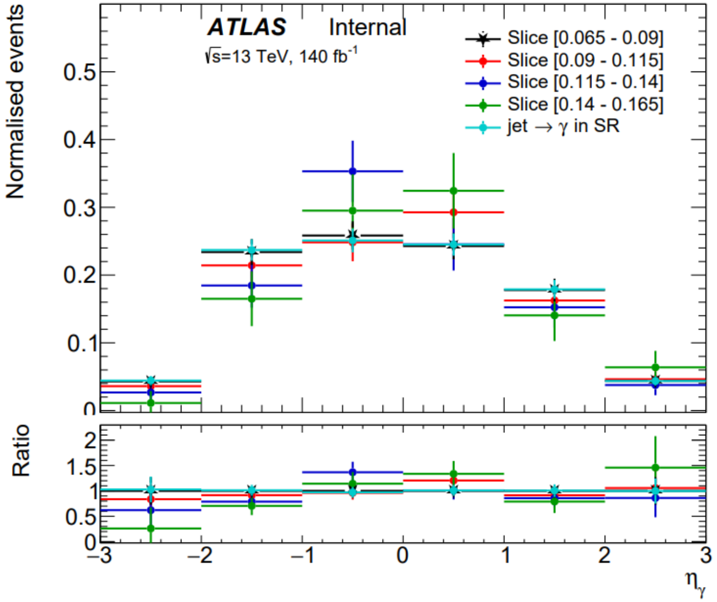






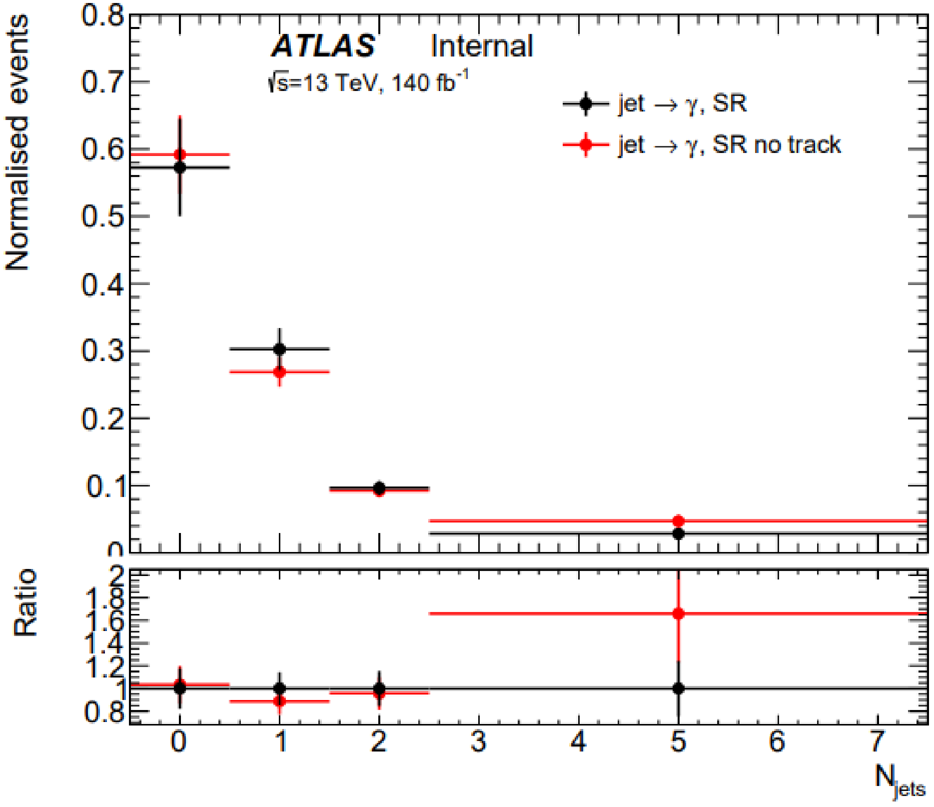


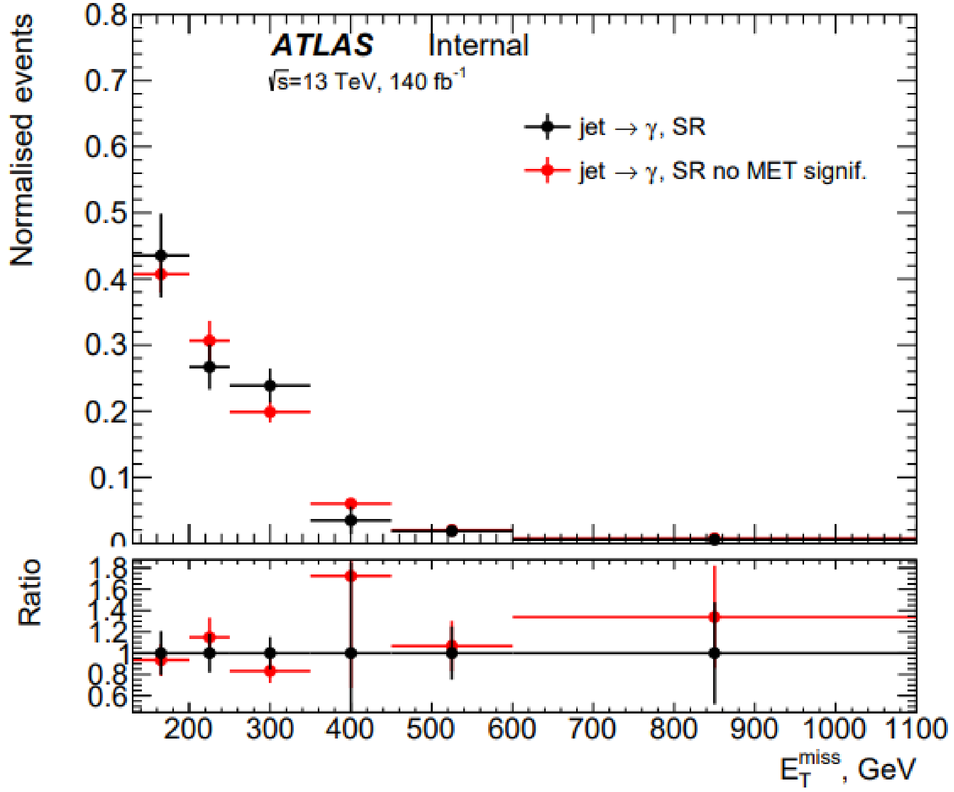




jet → γ misID background: slice method

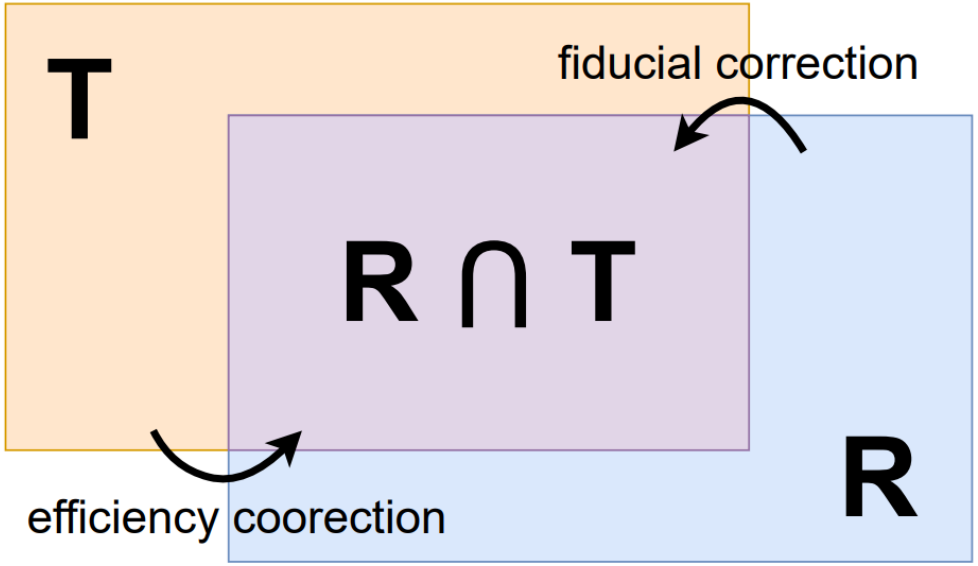
The detailed procedure of $jet \to \gamma$ background shape estimation is presented in Section 5.2.2. To increase the statistics in the anti-isolated slices, the cut on track isolation is relaxed. Figure 51 shows that the shape of the $jet \to \gamma$ distribution in the SR does not change when relaxing track isolated in the CR2. Figure 52 shows that the shape of the $jet \to \gamma$ distribution for $E_{\mathrm{T}}^{\mathrm{miss}}$ in the SR does not change when relaxing cut on $E_{\mathrm{T}}^{\mathrm{miss}}$ significance in the CR2.





Unfolding procedure

$$R_{ij} = \frac{1}{\alpha_i}\varepsilon_j M_{ij}, \quad M_{ij} = \frac{N_{ij}^{\text{det.}\cap\text{fid.}}}{N_j^{\text{det.}\cap\text{fid.}}}. \quad \alpha_i = \frac{N_i^{\text{det.}\cap\text{fid.}}}{N_i^{\text{det.}}}. \quad \varepsilon_j = \frac{N_j^{\text{det.}\cap\text{fid.}}}{N_j^{\text{fid.}}}. \quad \frac{\sigma_j}{\Delta x_j} = \frac{N_j^{\text{unfold}}}{(\int \mathcal{L}dt)\cdot \Delta x_j},$$



Correction factor	Value
$A_{Z\gamma}$	0.9049 ± 0.0008
$C_{Z\gamma}$	0.7487 ± 0.0007

The unfolding procedure by folding can be performed with following steps:

- Myltiplying the response matrix $\hat{R}$ and the particle-level distribution:

$$F_{ij} = R_{ij}\cdot T_j = \begin{pmatrix} \vec{r}_1 \\ \vec{r}_1 \\ \vdots \\ \vec{r}_n \end{pmatrix} \cdot \begin{pmatrix} t_1 \\ t_1 \\ \vdots \\ t_n \end{pmatrix} = \begin{pmatrix} \vec{f}_1 \\ \vec{f}_1 \\ \vdots \\ \vec{f}_n \end{pmatrix},$$

- Myltiplying each of the n histograms by the NFs $\mu_j = (\mu_1, \mu_2, \ldots, \mu_n)$:

$$G_{ij} = F_{ij}\cdot \mu_j = \begin{pmatrix} \vec{f}_1 \\ \vec{f}_1 \\ \vdots \\ \vec{f}_n \end{pmatrix} \cdot \begin{pmatrix} \mu_1 \\ \mu_1 \\ \vdots \\ \mu_n \end{pmatrix} = \begin{pmatrix} \vec{g}_1 \\ \vec{g}_1 \\ \vdots \\ \vec{g}_n \end{pmatrix}.$$

The next step is to add all vecors $\vec{g}_j$. As a result we get one histogram with m bins.

- Fit the folded distribution by tuning NFs μ_j. As a result one gets the fitted parameters $\mu'_j = (\mu'_1, \mu'_2, \ldots, \mu'_n)$.
- Dot multiply normalised NFs and truth histogram.

Unfolding procedure

Fiducial region:

Category	Cut
Photons	Isolated, $E_T^{\gamma} > 150$ GeV $\|\eta\| < 2.37$ excluding $1.37 < \|\eta\| < 1.52$
Jets	$\|\eta\| < 4.5$ $p_T > 50$ GeV $\Delta R(jet, \gamma) > 0.3$
Lepton	$N_l = 0$
Neutrino	$p_T^{\nu\bar{\nu}} > 130$ GeV
Events	$\|\Delta\phi(\vec{p}_T^{miss}, \gamma)\| > 0.7$ $\|\Delta\phi(\vec{p}_T^{miss}, j_1)\| > 0.4$ $p_T^{\nu\bar{\nu}}$ significance > 11

$$\mathcal{L}(\sigma, \theta, \lambda) = \prod_i P\left(N_i | \mathcal{L}_{\text{int}} \sum_j \mathcal{R}_{ij}(\vec{\theta})\sigma_j(\vec{\theta}) + \mathcal{B}_i(\vec{\theta}, \lambda)\right) \times \prod_k G(\theta_k)$$

$$N_j = \mathcal{L}_{\text{int}}\sigma_j \text{ with } \sigma_j = \mu_j \sigma_j^{\text{MC}}$$

$$\mathcal{L}(\sigma, \theta, \lambda) = \mathcal{L}(\sigma, \theta, \lambda)_{\text{noreg.}} \times \left(-\frac{\tau^2}{2} \sum_{i=2}^{i+2<N_{\text{bins}}} ((\mu_i - \mu_{i-1}) - (\mu_{i+1} - \mu_i))^2\right)$$

$$\frac{\sigma_j}{\Delta x_j} = \frac{N_j^{\text{unfold}}}{(\int \mathcal{L} dt) \cdot \Delta x_j}$$

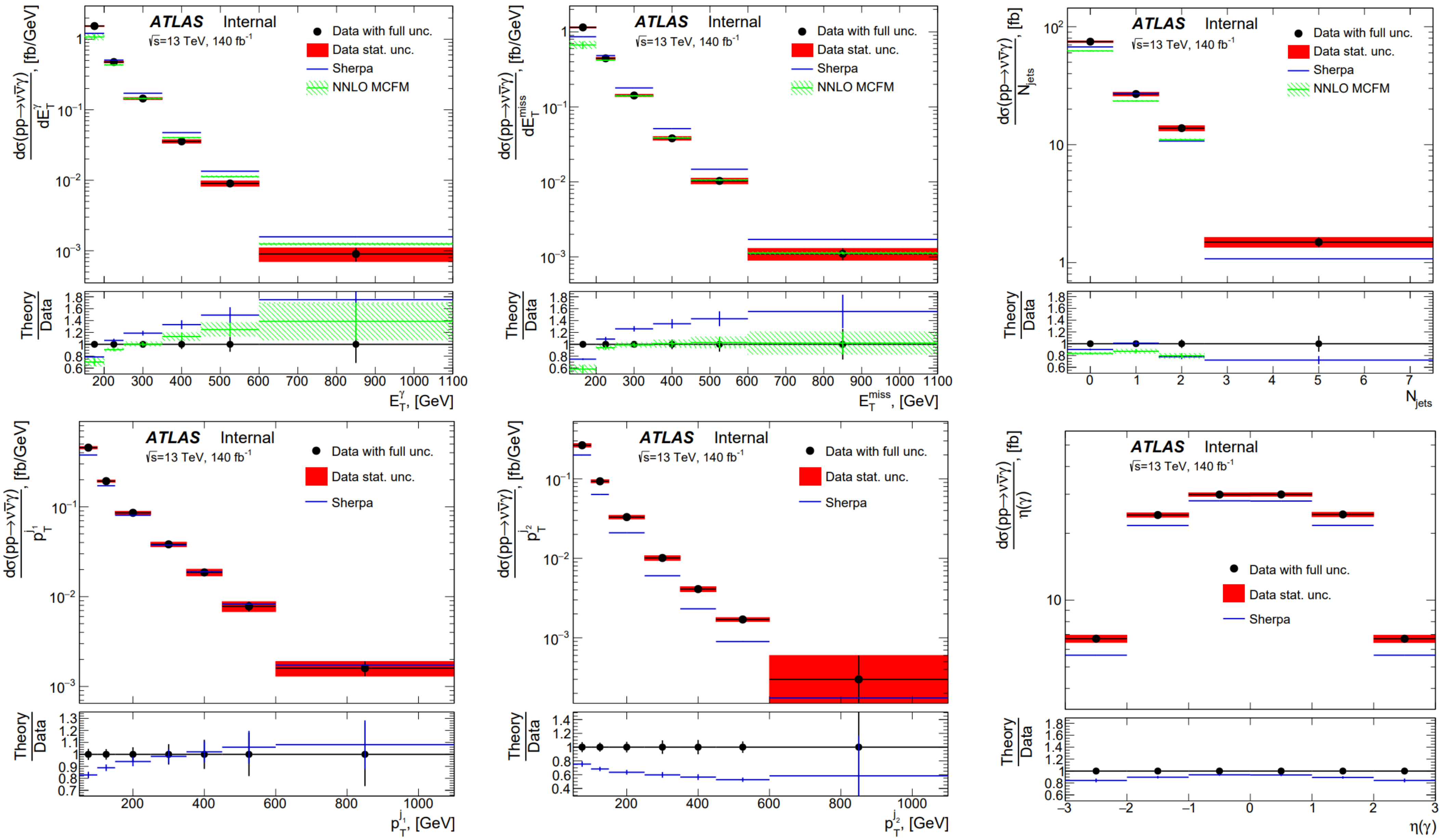
Observable	Binning
p_T^{γ}	[150, 200], [200, 250], [250, 350], [350, 450], [450, 600], [600, 1100]
E_T^{miss}	[130, 200], [200, 250], [250, 350], [350, 450], [450, 600], [600, 1100]
N_{jets}	[-0.5, 0.5], [0.5, 1.5], [1.5, 2.5], [2.5, 7.5]
η_{γ}	[-3, -2, -1, 0, 1, 2, 3]
$p_T^{j_1}$	[50, 100, 150, 250, 350, 450, 600, 1100]
$p_T^{j_2}$	[50, 100, 150, 250, 350, 450, 600, 1100]
$\|\Delta\phi(j, j)\|$	[0.0 - 3.2], 16 bins
$\|\Delta\phi(p_T^{\text{miss}}, j)\|$	[0.4 - 3.2], 14 bins

Table 29: Summary of the differential measurements in the analysis

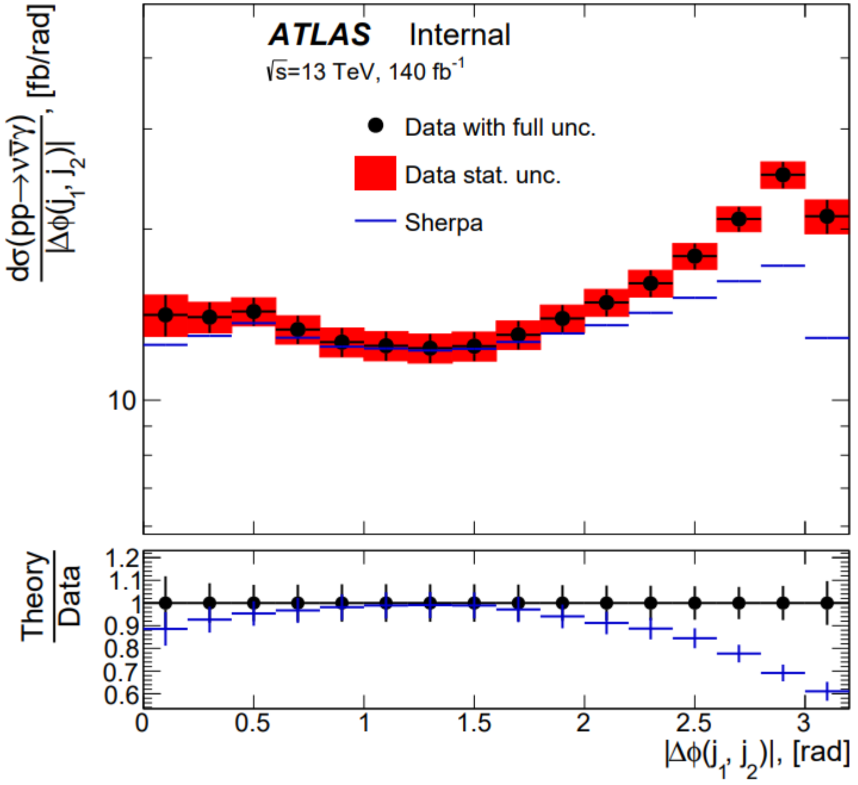
Extended fiducial region:

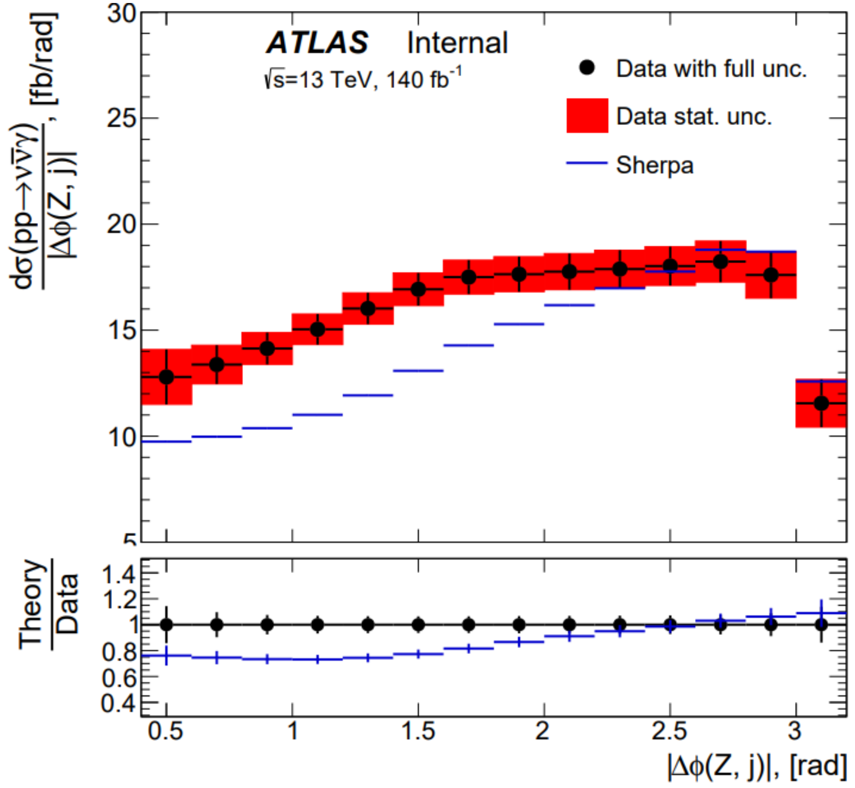
Category	Cut
Photons	Isolated, $E_T^{\gamma} > 150$ GeV $\|\eta\| < 2.37$
Jets	$\|\eta\| < 4.5$ $p_T > 50$ GeV $\Delta R(jet, \gamma) > 0.3$
Neutrino	$p_T^{\nu\bar{\nu}} > 130$ GeV

Unfolding procedure



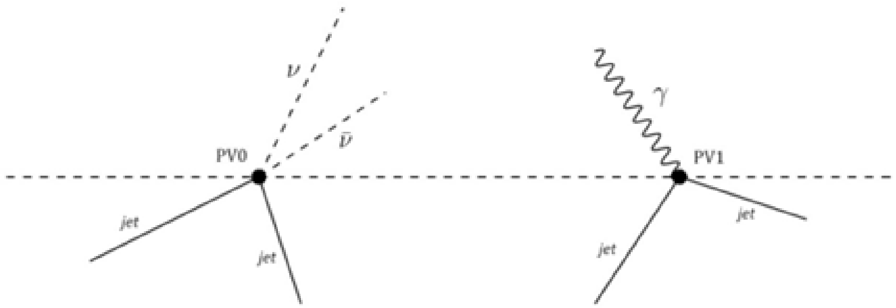
Unfolding procedure





OMC method

Overlay Monte-Carlo (OMC) Method



Strategy:

1. To estimate the number of pile-up events (referred to as A+B) in the diboson production (referred to as AB) the overlay Monte-Carlo (OMC) method uses separate A and B samples at the particle-level.
2. The overlay of B over A is performed by adding objects (photons, jets, etc.) from B into A;
3. The variables that define the AB final state are calculated in order to form a valid combined A+B event (referred to as OMC event). These variables are used to be checked against analysis selections;
4. The weight of the combined A+B event is determined as:

$$w_{\mathrm{A+B}} = \frac{w_{\mathrm{A}} w_{\mathrm{B}}}{\langle w_{\mathrm{A}} \rangle \langle w_{\mathrm{B}} \rangle} \frac{L \sigma_{\mathrm{A+B}}}{N_{\mathrm{OMC}}}$$

$$\sigma_{\mathrm{A+B}} = \langle \mu \rangle \frac{\sigma_{\mathrm{A}} \sigma_{\mathrm{B}}}{\sigma_{\mathrm{inel}}}$$

5. The number of A+B events at the particle-level is defined as the sum of OMC sample weights:

$$N^{\mathrm{gen}}_{\mathrm{A+B}} = \sum w_{\mathrm{A+B}}$$

6. The predicted number of pile-up events at the detector-level in the SR is estimated as follows:

$$N^{\mathrm{rec}}_{\mathrm{A+B}} = N^{\mathrm{gen}}_{\mathrm{A+B}} \mathrm{C}$$

*Correction factor (C) is defined as the reconstructed MC signal AB events passing all selections divided by the number of MC signal AB events at the particle-level within the fiducial region.

OMC method

- The Z boson (taken as A) and the photon (taken as B) components of Z+γ OMC events are taken from Zj and γ+j MC samples, respectively;
- The particle-level photon from γ+j process is being overlayed over random particle-level Z boson from Zj process until it becomes a part of Z+γ OMC event, that passes the fiducial region requirements;
- The procedure for such a combination of events is performed for every γ+j sample with a certain Zj sample in each of the MC simulation campaigns (MC16a, MC16d, MC16e);
- Iterating through all γ+j events requires significant computing resources, therefore only 100k events of every statistically large γ+j sample are used to form OMC sample;
- The total number of pile-up events at the particle-level is obtained by combining each γ+j sample sequentially with each Zj sample.

Definition of the fiducial region:

Category	Cut
Photons	Isolated, $E_{\mathrm{T}}^{\gamma} > 150$ GeV
	$\lvert\eta\rvert < 2.37$ excl. $1.37 < \lvert\eta\rvert < 1.52$
Jets	$\lvert\eta\rvert < 4.5$
	$p_T > 50$ GeV
	$\Delta R(jet, \gamma) > 0.3$
Lepton	$N_l = 0$
Neutrino	$p_{\mathrm{T}}^{\nu\bar{\nu}} > 130$ GeV
Events	Significance $E_{\mathrm{T}}^{\mathrm{miss}} > 11$
	$\lvert\Delta\phi(\vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}, \gamma)\rvert > 0.6$
	$\lvert\Delta\phi(\vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}, j_1)\rvert > 0.3$

The weight and the cross section of the combined Z+γ event:

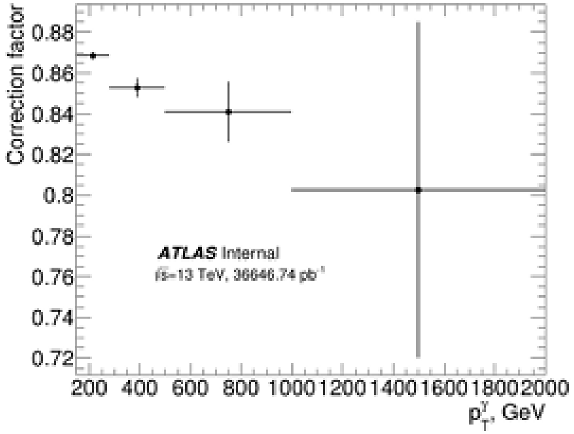
$$w_{Z+\gamma} = \frac{w_Z w_\gamma}{\langle w_Z\rangle\langle w_\gamma\rangle}\frac{L\sigma_{Z+\gamma}}{N_{\mathrm{OMC}}}$$

$$\sigma_{Z+\gamma} = \langle\mu\rangle\frac{\sigma_Z \cdot SF_Z \cdot \sigma_\gamma \cdot SF_\gamma}{\sigma_{\mathrm{inel}}}$$

OMC method

- The C-factor is parameterized by the transverse momentum of the photon, since the total number of pile-up events at the particle-level is summed from the number of pile-up events calculated for each γ+j sample.

$$C = \frac{N^{\text{rec}}_{Z\gamma}}{N^{\text{gen}}_{Z\gamma}}$$



The estimates of correction factor obtained with Z(νν)γ MC signal for 4 intervals of the transverse momentum of the photon [150; 280; 500; 1000; 2000] GeV:

p_T^γ, ГэВ	MC16a	MC16d	MC16e
150-280	0.8685±0.0018	0.8155±0.0017	0.8246±0.0014
280-500	0.853±0.005	0.818±0.004	0.822±0.004
500-1000	0.841±0.015	0.803±0.014	0.829±0.012
1000-2000	0.80±0.08	0.84±0.11	0.73±0.06

$$N^{SR}_{Z+\gamma} = N^{FR}_{Z+\gamma} C$$

- The final estimate* of background events due to multiple pp collisions: $N^{SR}_{Z+\gamma}$ = 2.938 ± 0.018(stat.) events; *(more in back-up)

The statistical uncertainties come from:

- The uncertainty of the weights w_γ and w_Z of events used in the combination of γ+j samples with Zj samples;
- The uncertainty of C-factor;
- The uncertainty of SF-factors;

The fraction of pile-up events in relation to the data obtained using the OMC method is (0.01257 ± 0.00011)%.