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

Diana Pyatiizbyantseva
on behalf of the ZnunuGamma group

National Research Nuclear University "MEPhI"

MEPhI@Atlas meeting

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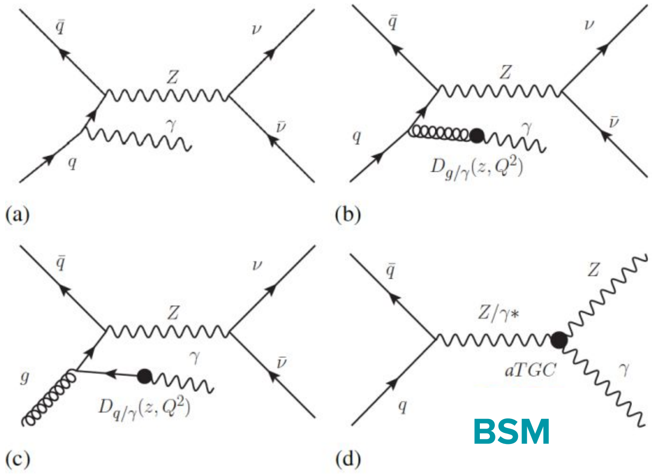
Motivation

➢ 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 for this channel — 36.1 fb^{-1} data.

Full Run2 statistics (139 fb^{-1}) ➔ increase of measurement accuracy (expectation of an increase in the experimental sensitivity by a factor of 2).

- Goal: integral and differential in $\mathbf{E_T^{\gamma}}$, $\mathbf{N_{jets}}$, $\mathbf{p_T^{miss}}$, $\mathbf{\Delta\phi[\gamma, p_T^{miss}]}$, $\mathbf{p_T(Z\gamma)}$, $\mathbf{\eta_{\gamma}}$ cross-sections. Comparison with theory predictions including NNLO QCD and NLO EWK corrections.



Glance: ANA-STDM-2018-54

➢ Beyond SM:

- The strongest up-to-date limits on anomalous neutral triple gauge-boson couplings (aTGCs) using vertex functions and EFT formalisms ➔ **interpretation**.

➢ **Combination** of the EFT limits between Zγ and ZZ + ratio of Zγ/ZZ cross-sections.

Selection optimisation: increase in statistical significance

Topology: high-energetic γ + high missing transverse momentum p_T^{miss}

Multivariate (MV) method of the selection optimisation takes into account the signal significance *Z* as a function of the threshold values of the variables:

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

The output of the MV optimisation procedure is a vector of threshold values of the variables at which the maximum *Z* is reached.

Uncomplicated method (unlike TMVA) is useful for differential cross-section measurements.

Preselections	Cut Value
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 120 GeV
E_{T}^{γ}	> 150 GeV
Number of tight isolated photons	$N_{\gamma} = 1$
Lepton veto	$N_e = 0,\ N_{\mu} = 0$
Selections	**Cut Value**
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 130 GeV
SR $E_{\mathrm{T}}^{\mathrm{miss}}$ significance	> 11
$\lvert\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, \gamma)\rvert$	> 0.6
$\lvert\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, j_1)\rvert$	> 0.4

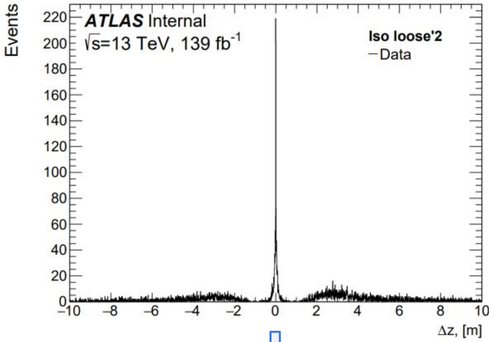
Selections	N_{signal}	$N_{bkg},\ \cdot 10^3$	Z
Preselections	12380 ± 9	77.6 ± 0.7	41.3 ± 0.2
Selections	9843 ± 8	15.5 ± 0.5	61.8 ± 0.6
- $E_{\mathrm{T}}^{\mathrm{miss}} > 130$ GeV	9939 ± 8	16.2 ± 0.5	61.5 ± 0.6
- $E_{\mathrm{T}}^{\mathrm{miss}}$ significance > 11	11261 ± 8	33.1 ± 0.6	53.5 ± 0.3
- $\lvert\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, \gamma)\rvert > 0.6$	9858 ± 8	16.0 ± 0.5	61.4 ± 0.6
- $\lvert\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, j_1)\rvert > 0.4$	10016 ± 8	17.6 ± 0.5	60.3 ± 0.6

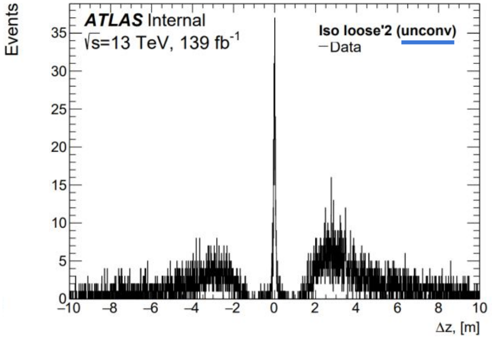
No significant increase in statistical significance with using $N_{b\text{-jets}}$ and $p_T^{SoftTerm}$ variables.

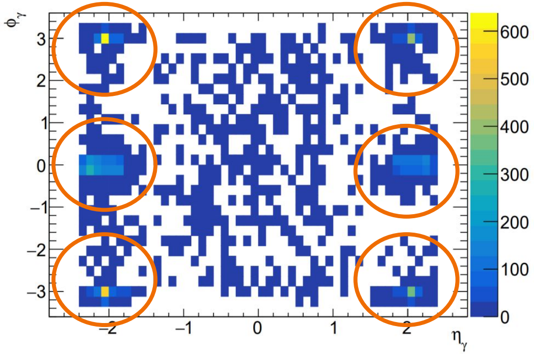
Photon pointing: beam-induced background (BIB)

- 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).

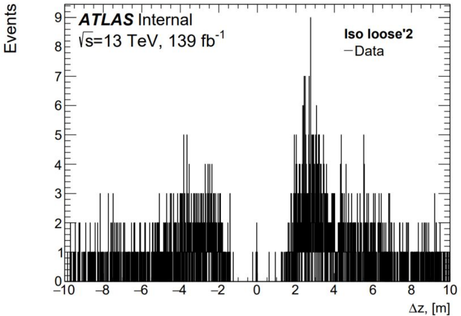
$\Delta z = z_\gamma - z_{\text{vtx}}$

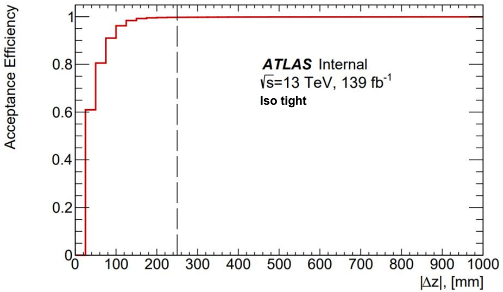


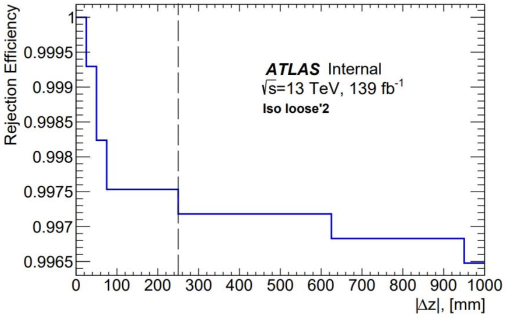




Cuts: |φ| < 0.2, |φ| ∈ [2.9; 3.2] and |η| > 1.7







|Δz| < 250 mm

Rejection efficiency: (100 ± 3)%

Acceptance efficiency: (99.7 ± 0.9)%

Background composition

Percentage of the total predicted background

Background composition for Z(νν)γ:

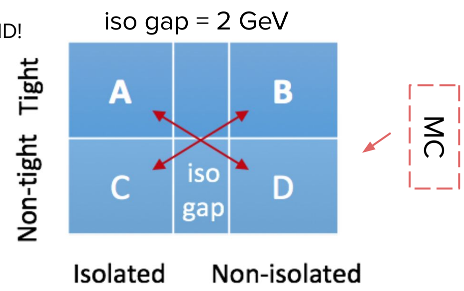
35 %	γ+jets – via MC → ABCD method based on E_T^{miss}-significance and additional variable
27 %	W(lν)γ – fit to data in additional CR based on N_{lep} (shape from MC)
21 %	e→γ – fake-rate estimation using Z-peak (tag-n-probe) method
14 %	jet→γ – ABCD method based on γ ID and isolation
1.9 %	$Z(l^+l^-)\gamma$ – via MC
1.5 %	ttγ – via MC

jet→γ misID background: correlation factor

Background is estimated from data using **2D-sideband method**:
<u>Photon isolation and identification variables</u> are used to construct the sidebands.

Isolation should not correlate with non-tight ID!

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



Correlation is measured in data and MC by $R = \frac{N_A N_D}{N_B N_C}$.

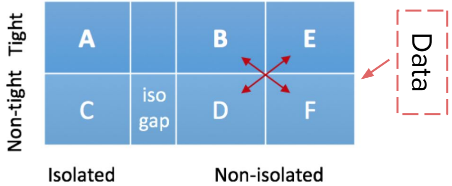
Non-tight: at least one of the cuts on the following variables should fail in these:

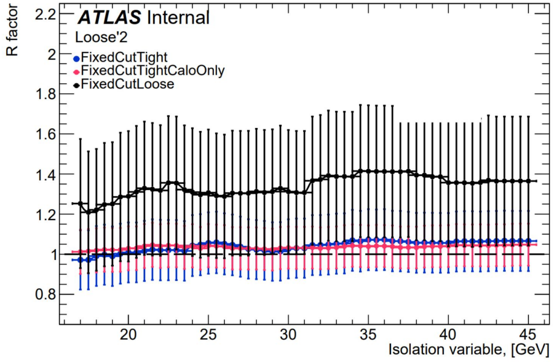
- *loose'2*: w_{s3}, F_{side}
- *loose'3*: $w_{s3}, F_{side}, \Delta E$
- *loose'4*: $w_{s3}, F_{side}, \Delta E, E_{ratio}$
- *loose'5*: $w_{s3}, F_{side}, \Delta E, E_{ratio}, w_{tot}$

FixedCutTightCaloOnly:

A: tight, $E_T^{cone40} - 0.022\, p_T^{\gamma} < 2.45$ [GeV]
B: tight, $2.45 + gap < E_T^{cone40} - 0.022\, p_T^{\gamma}$ [GeV]
C: non-tight, $E_T^{cone40} - 0.022\, p_T^{\gamma} < 2.45$ [GeV]
D: non-tight, $2.45 + gap < E_T^{cone40} - 0.022\, p_T^{\gamma}$ [GeV]

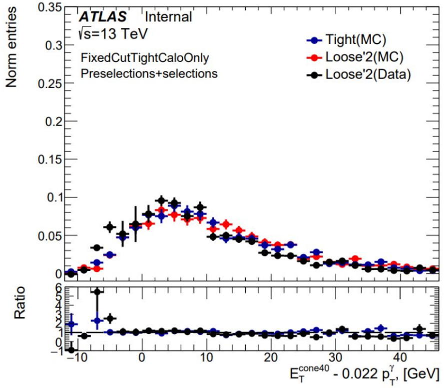
R factor	loose'2	loose'3	loose'4	loose'5
FixedCutTight (w/o upper cut)				
MC	1.05 ± 0.15	1.14 ± 0.15	1.19 ± 0.14	1.39 ± 0.17
Data-driven	1.4 ± 0.3	1.3 ± 0.3	1.3 ± 0.3	1.3 ± 0.3
FixedCutTight (upper cut = 25.45 GeV)				
MC	1.06 ± 0.15	1.15 ± 0.16	1.21 ± 0.15	1.40 ± 0.17
Data-driven	1.01 ± 0.18	1.02 ± 0.18	1.01 ± 0.18	1.01 ± 0.17
FixedCutTight (track inversion + upper cut = 25.45 GeV)				
MC	1.01 ± 0.12	1.15 ± 0.12	1.29 ± 0.13	1.58 ± 0.16
Data-driven	1.07 ± 0.12	1.13 ± 0.12	1.09 ± 0.10	1.12 ± 0.10
FixedCutTightCaloOnly				
MC	1.06 ± 0.10	1.14 ± 0.11	1.22 ± 0.10	1.40 ± 0.12
Data-driven	1.07 ± 0.10	1.13 ± 0.10	1.15 ± 0.10	1.15 ± 0.10





FixedCutTightCaloOnly

Data-driven				
Cut	loose'2	loose'3	loose'4	loose'5
9.45	1.08 ± 0.11	1.14 ± 0.11	1.12 ± 0.10	1.13 ± 0.10
9.95	1.07 ± 0.10	1.13 ± 0.10	1.15 ± 0.10	1.15 ± 0.10
10.45	1.09 ± 0.10	1.14 ± 0.10	1.14 ± 0.10	1.15 ± 0.10
10.95	1.18 ± 0.11	1.23 ± 0.11	1.21 ± 0.10	1.22 ± 0.10
11.45	1.23 ± 0.11	1.27 ± 0.11	1.22 ± 0.10	1.22 ± 0.10



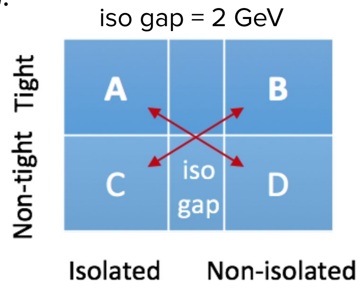
jet→γ misID background: uncertainties

➢ **Statistical uncertainty:**

- The event yields of four regions in data and non jet → γ background are varied by ±1σ independently **(4%)**.
- The statistical uncertainty on the signal leakage parameters is negligible.

Total statistics: 4%.

Central value	1960±83
loose'3	–334
loose'4	–397
loose'5	–472
Isolation gap +0.15 GeV	+33
Isolation gap –0.15 GeV	–22



➢ **Systematic uncertainty:**

- Anti-tight definition and isolation gap choice – variations of ABCD regions determination for ±1σ changes in data yield (**24%**).
- Uncertainty coming from the signal leakage parameters is obtained via using different generators and parton shower models (**9%**).

Signal leakage parameters	MadGraph+Pythia8, Sherpa 2.2	MadGraph+Herwig7, MadGraph+Pythia8	Relative deviation
c_B	0.0713 ± 0.0002	0.1000 ± 0.0011	29%
c_C	0.00879 ± 0.00007	0.0092 ± 0.0003	4%
c_D	0.00070 ± 0.00002	0.00099 ± 0.00010	29%
$jet \to \gamma$ est.	1960	1785	9%

- The iso/ID uncertainty on reconstruction photon efficiency $\delta_{eff}^{iso/ID}$ (**1.4%**):

  - $\sigma_{\rm iso}^{c_B}(\text{relative}) = \delta_{\rm iso}^{\rm eff} * (c_B + 1)/c_B$
  - $\sigma_{\rm ID}^{c_C}(\text{relative}) = \delta_{\rm ID}^{\rm eff} * (c_C + 1)/c_C$
  - $\sigma_{\rm iso}^{c_D}(\text{relative}) = \delta_{\rm iso}^{\rm eff} * (c_B + 1)/c_B$
  - $\sigma_{\rm ID}^{c_D}(\text{relative}) = \delta_{\rm ID}^{\rm eff} * (c_C + 1)/c_C$

$\delta^{eff}_{iso} = 0.013$
$\delta^{eff}_{iso/ID} = 0.013$

Total systematics: 26%.

★ **Total number of jet→γ events:** 1960 ± 80 ± 510. Z(νν)+jets and multi-jet MC predicts 1600 ± 1200 events.

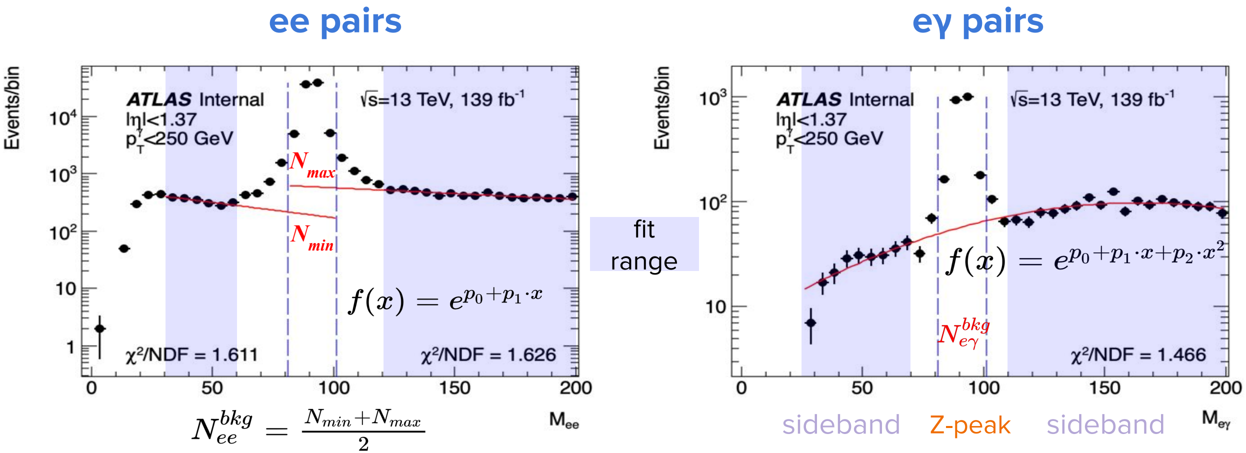
e→γ misID background: Z-peak method

<u>Source</u>: W(lν), top and tt processes.

<u>Estimation procedure</u>:

1. estimating e→γ fake rate as $rate_{e\to\gamma} = \frac{(N_{e\gamma} - N_{bkg})}{(N_{ee} - N_{bkg})}$,

where N_{ee}, $N_{e\gamma}$ – 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.

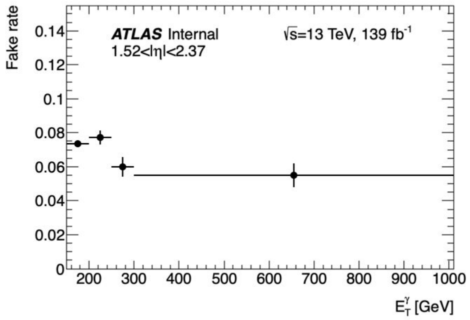


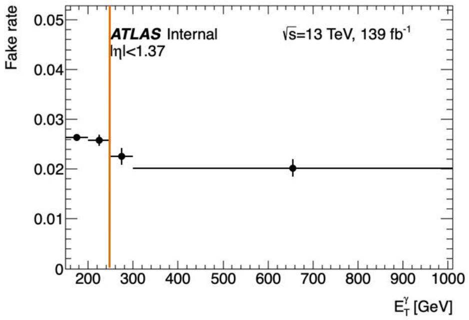
$$N_{ee}^{bkg} = \frac{N_{min} + N_{max}}{2}$$

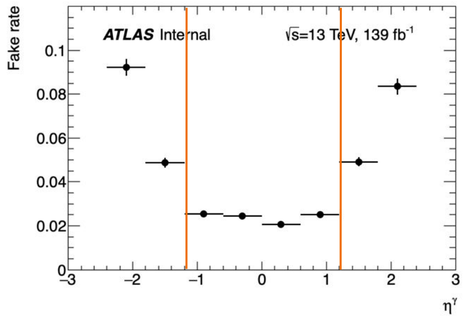
2. building e-probe CR (SR with electron instead of photon).

3. scaling data distributions from e-probe CR on fake rate.

e→γ misID background: uncertainties







Since e→γ fake rate depends on η и p_T, it is estimated in three regions.

$e \to \gamma$ fake rates		
	$150 < E_T^{\gamma} < 250$ GeV	$E_T^{\gamma} > 250$ GeV
$0 < \lvert\eta\rvert < 1.37$	$0.0240 \pm 0.0006 \pm 0.0009$	$0.0205 \pm 0.0013 \pm 0.0045$
$1.52 < \lvert\eta\rvert < 2.37$	$0.0696 \pm 0.0018 \pm 0.0072$	

Systematics:

1. *Fake-rate*:
   - Z-peak mass window variation (varies from 0.5% to 0.9%).
   - Background under Z-peak evaluation (varies from 2.2% to 10.4%).
   - Difference between "real fake rate" in Z(ee) MC and tag-and-probe method performed on Z(ee) MC (varies from 1.13% to 19.4%).

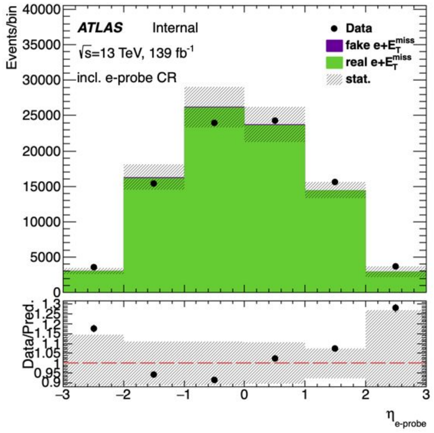
Total systematics on the fake-rate: 22%.

2. *E-probe CR*:
   - Impurity of the region (0.46%).

Total syst. on the background yield: 6%.

Contamination is determined as:

$$\frac{\text{fake } e{+}E_{\mathrm{T}}^{\text{miss}}}{\text{real } e{+}E_{\mathrm{T}}^{\text{miss}}}.$$



Total background (e-probe region scaled by fake-rate): 3070 ± 12 ± 187.

jet→E_T^{miss} misID background: estimation strategy

- Background originating from γ+jets processes is significantly reduced by applying selections on $\mathbf{E_T^{miss}}$ and **$\mathbf{E_T^{miss}}$-significance**.

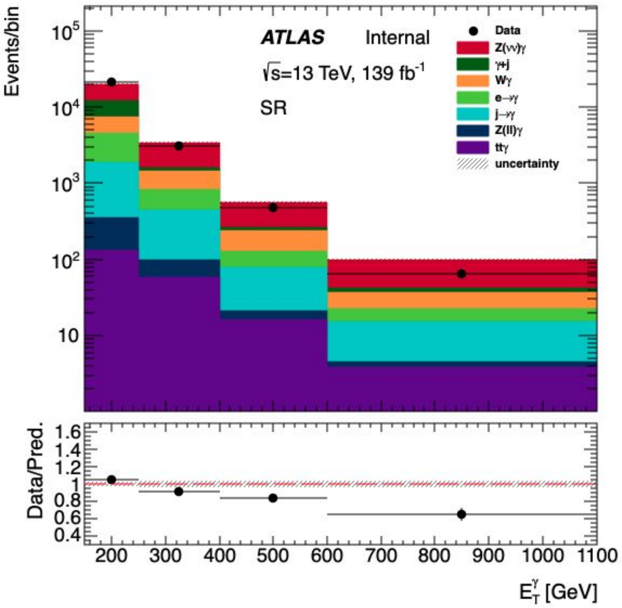
- For now, **MC simulation** is used to estimate this background.

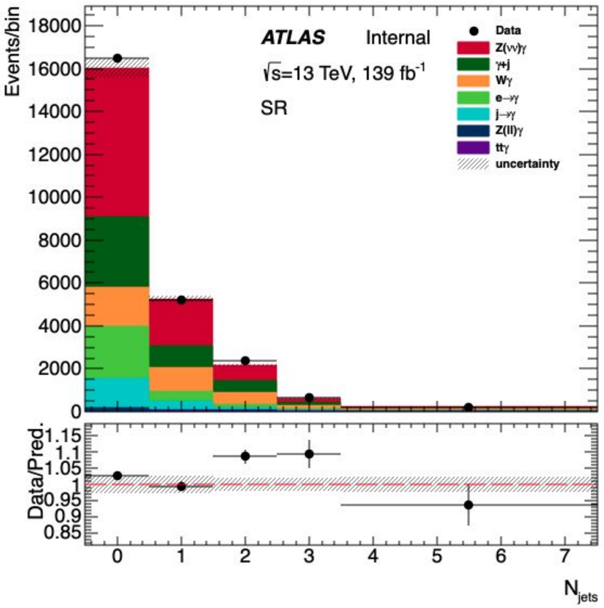
- The MC normalisation is estimated from the CR constructed in **low-$\mathbf{E_T^{miss}}$-significance range** (E_T^{miss}-significance < 11) with **$\mathbf{E_T^{miss}}$ selection relaxed** to $E_T^{miss} > 100$ GeV.

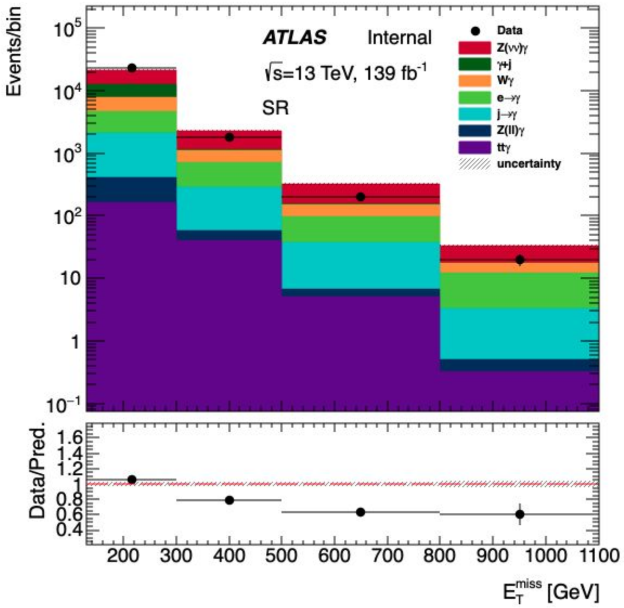
- Normalisation coefficient is equal to **0.66**, which is close to the normalisation factor obtained using 2D-sideband method in $Z(\nu\nu)\gamma$ EWK analysis (0.68).

- The plan is to estimate this background for each bin using **2D-sideband method**: E_T^{miss}-significance and other discriminative variable (e.g. $\Delta\phi[\gamma, p_T^{miss}]$ or $p_T^{SoftTerm}$) will be used to construct the sidebands.

Control plots

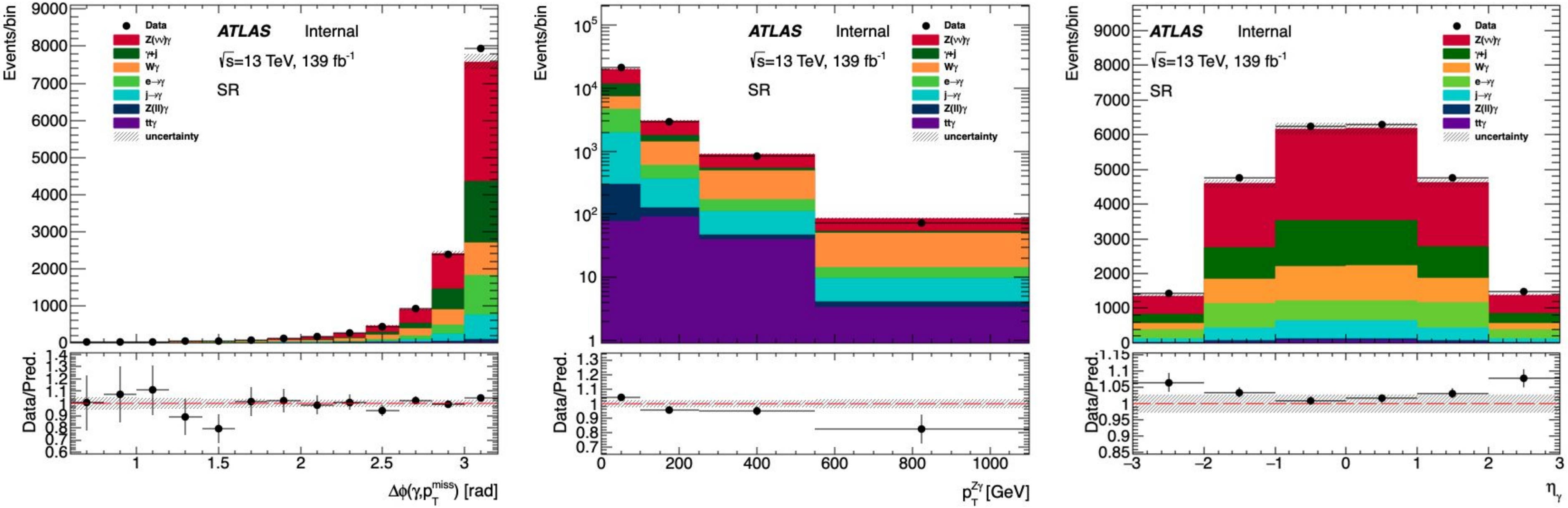






For jet→γ bkg, the shape is taken from Z(νν)γ QCD MC. γ+jet bkg has 0.66 normalisation. e→γ bkg: DD.
The total uncertainty includes the statistical uncertainty for all bkgs, while for jet→γ and e→γ bkgs there is also the systematic uncertainty.

Control plots



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Summary

- Several steps of the inclusive $Z(\nu\bar{\nu})\gamma$ Run2 analysis are already done: selection optimisation, data-driven estimation of jet→γ, e→γ and (preliminary) E_T^{miss}→jet misID backgrounds, control plots.
- Plans:
  - Re-optimise the SR after adding $Z(\nu\bar{\nu})\gamma$ and Wγ EWK samples + W(τν) samples with separation of lepton and hadron channels.
  - Estimate:
    - E_T^{miss}→jet background using 2D-sideband method.
    - pile-up background (expected to be negligible).
    - Wγ background.
  - Uncertainties.
  - Cross-section measurements.
  - Limits on aTGCs.
  - EB request till the end of the year.

Back-up

Object selections

Photon selection:

$E_T^{\gamma} > 10$ GeV, $|\eta| < 2.37$, crack region excluded, cluster quality cut, ambiguity cut, tight ID, FixedCutTightCaloOnly isolation, $\Delta R(\gamma, e/\mu) < 0.4$

Electron selection:

$p_T > 4.5$ GeV, $|\eta| < 2.47$, crack region excluded, loose ID, $\Delta R(e,\mu) < 0.1$

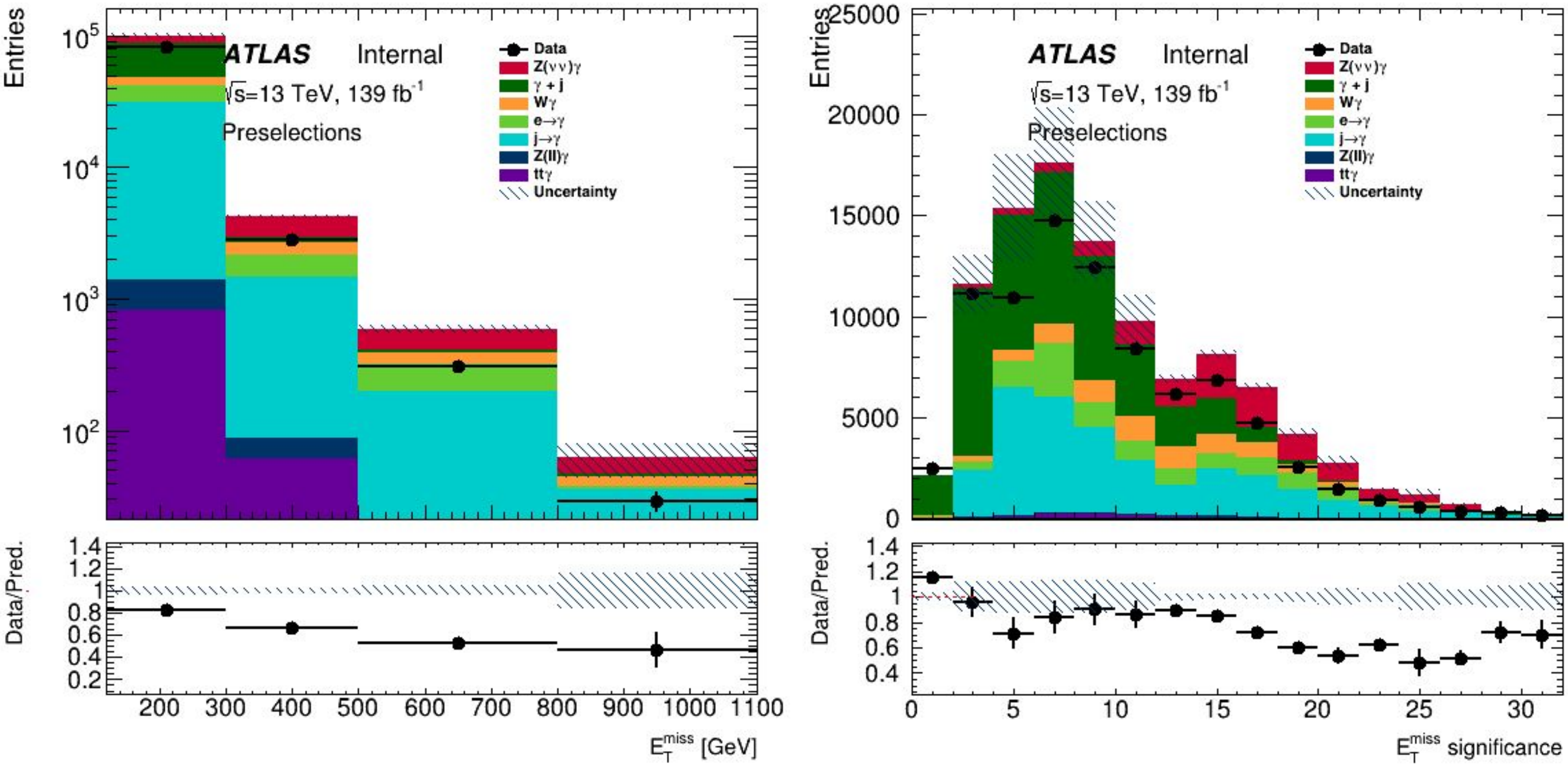
Muon selection:

$p_T > 4$ GeV, $|\eta| < 2.47$, crack region excluded, loose ID, $|z_0{}^*\sin\theta| < 0.5$ mm, d_0 signif. < 3

Jet selection:

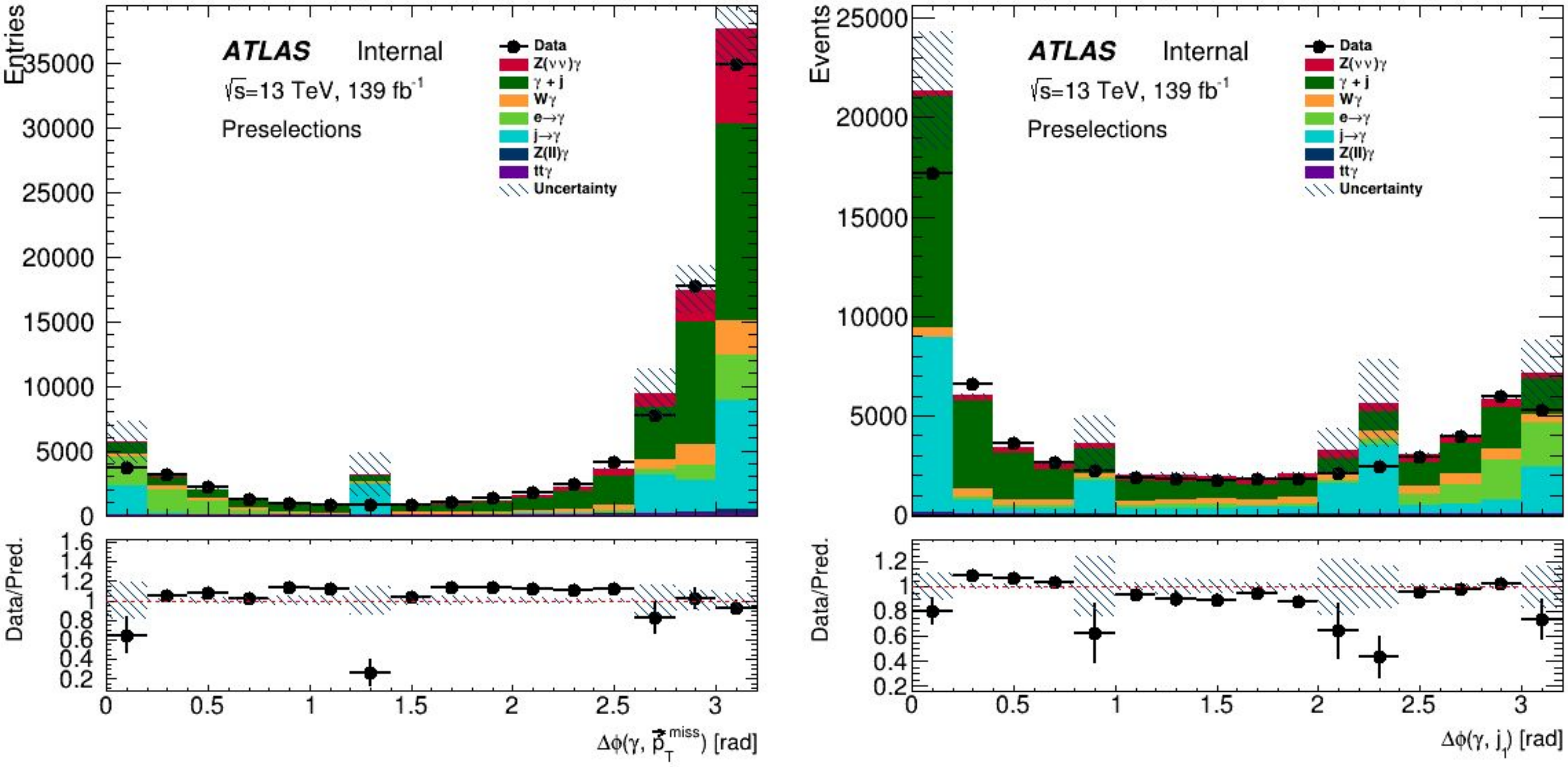
$E_T > 50$ GeV, $|\eta| < 4.5$, AntiKt4EMPFlowJets, tight JVT, $\Delta R(jet,e/\mu/\gamma) < 0.4$

Selection optimisation: distributions



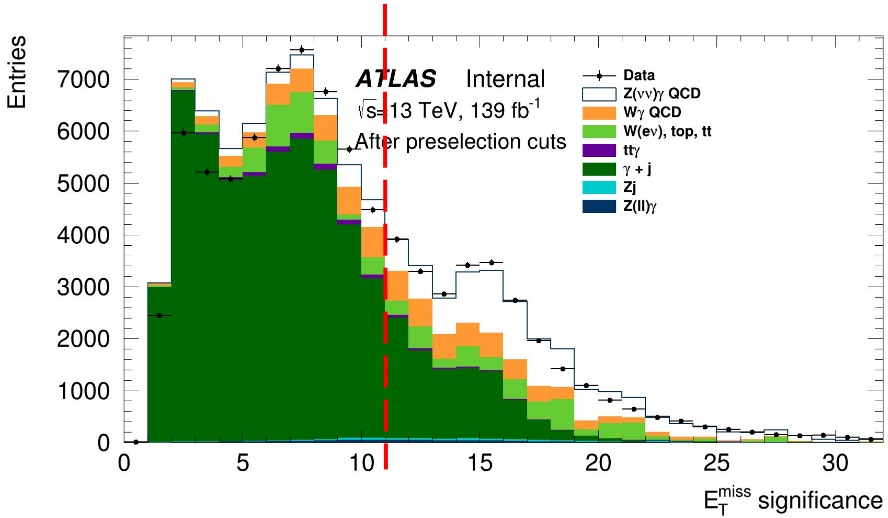
For jet→γ bkg, the shape is taken from Z(νν)+jets and multi-jet MC. γ+jet bkg has 0.66 normalisation. e→γ bkg: W(eν), W(τν), top, tt MC.

Selection optimisation: distributions

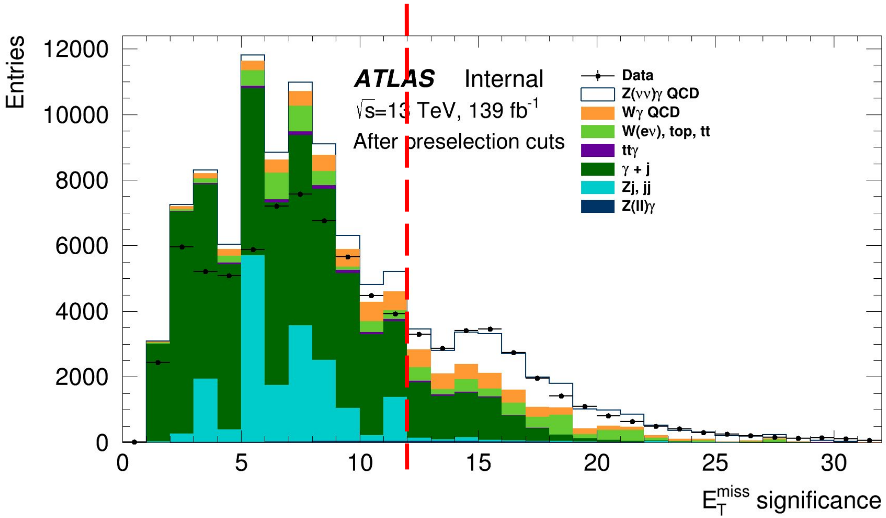


For jet→γ bkg, the shape is taken from Z(νν)+jets and multi-jet MC. γ+jet bkg has 0.66 normalisation. e→γ bkg: W(eν), W(τν), top, tt MC.

Selection optimisation: multi-jet problematic normalisation



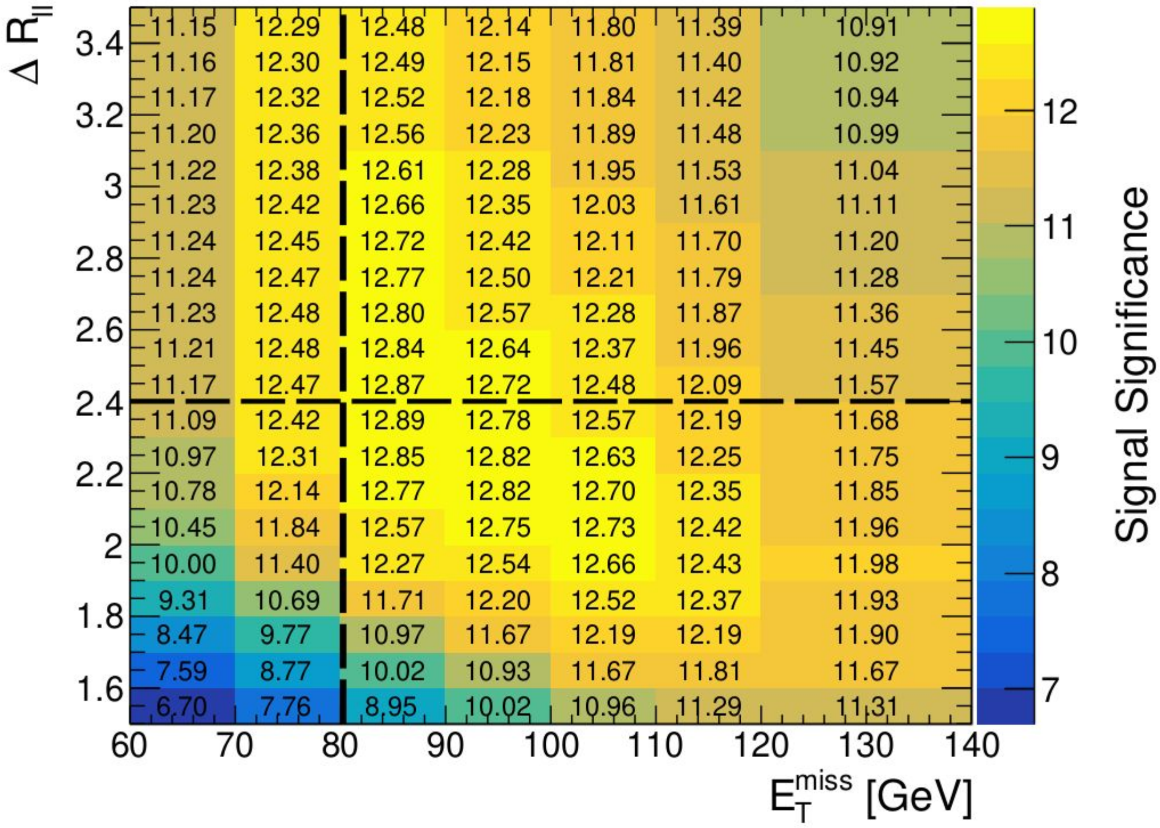
without multi-jet samples



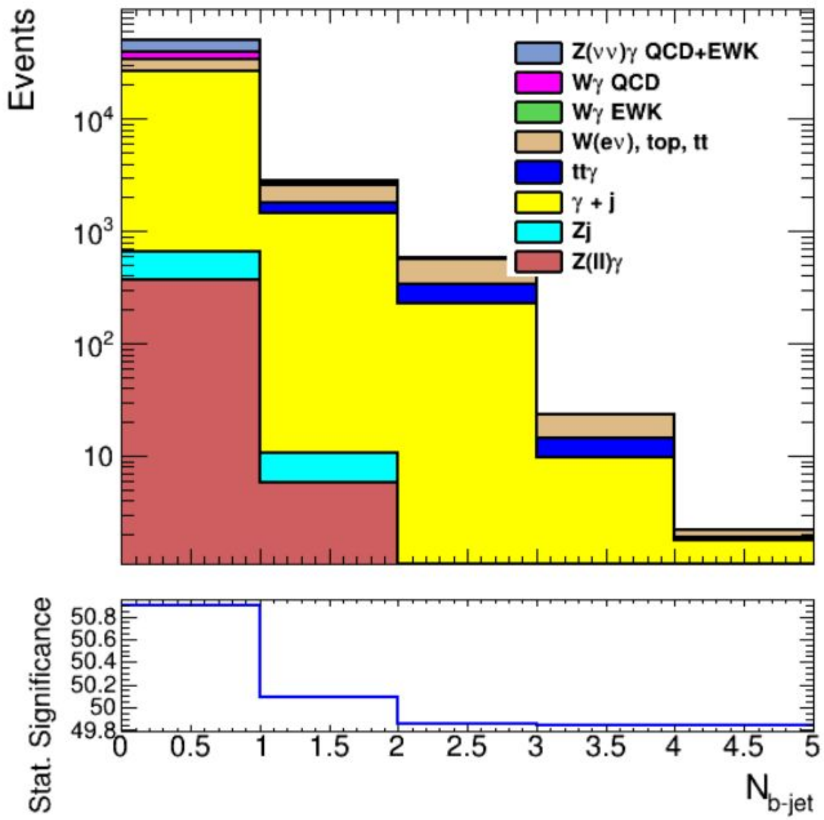
with multi-jet samples

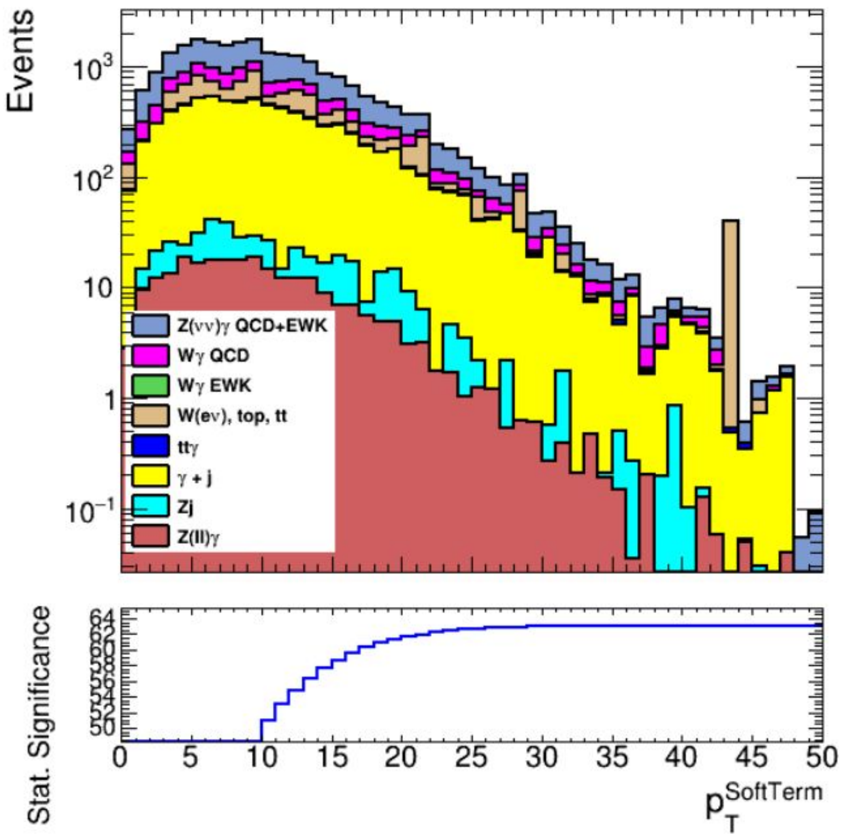
Multi-jet samples are not used for the optimisation procedure due to their problematic normalisation.

Multivariate method of optimisation (2D example)



Selection optimisation: $N_{b\text{-}jet}$ and $p_T^{SoftTerm}$





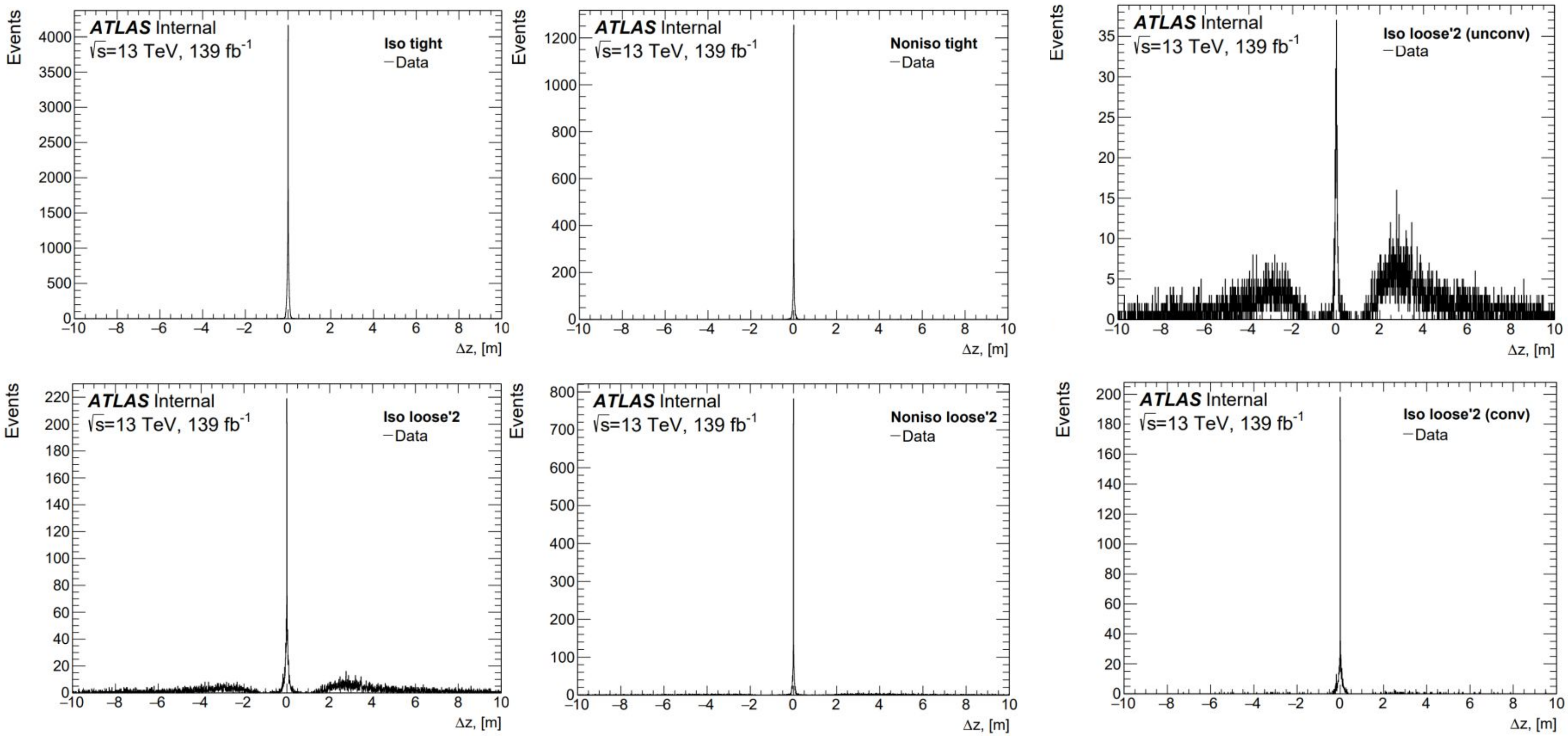
Selection optimisation: event yields

	FixedCutTight	FixedCutTightCaloOnly		
Variable	W/O MultiJet		With MultiJet	With MultiJet
E_T^{miss} $signif.$	>11	>11	>12	—
$\Delta\phi(E_T^{miss}, \gamma)$	>0.6	>0.7	>0.7	—
$\Delta\phi(E_T^{miss}, j_1)$	>0.4	>0.4	>0.4	—
E_T^{miss}, GeV	>130	>130	>130	—
Signal				
Z($\nu\nu$)γ QCD	9752 ±8	9840 ±8	9355 ±8	12380 ±9
Z($\nu\nu$)γ EWK	0 ±0	0 ±0	0 ±0	0 ±0
Total signal	9752 ±8	9840 ±8	9355 ±8	12380 ±9
Background				
Wγ QCD	3610 ±21	3645 ±22	3265 ±21	7456 ±30
Wγ EWK	0 ±0	0 ±0	0 ±0	0 ±0
tt, top, W(eν)	3128 ±447	3463 ±518	3328 ±512	9039 ±636
ttγ	210 ±3	213±3	165 ±3	888 ±6
γ+j	7501 ±78	7598 ±78	6261 ±71	59162 ±203
Zj	213 ±16	315 ±20	295 ±19	486 ±23
Z(ll)γ	266 ±4	270 ±4	242 ±4	608 ±7
MultiJet	—	1243.91 ± 1243.02	0.6+-0.4	18532±4645
Total bkg.	14928±455	15504±525	13558±518	96172 ±4693
Stat. signif.	62.1±0.6	61.8±0.6	61.8±0.6	37.6 ±

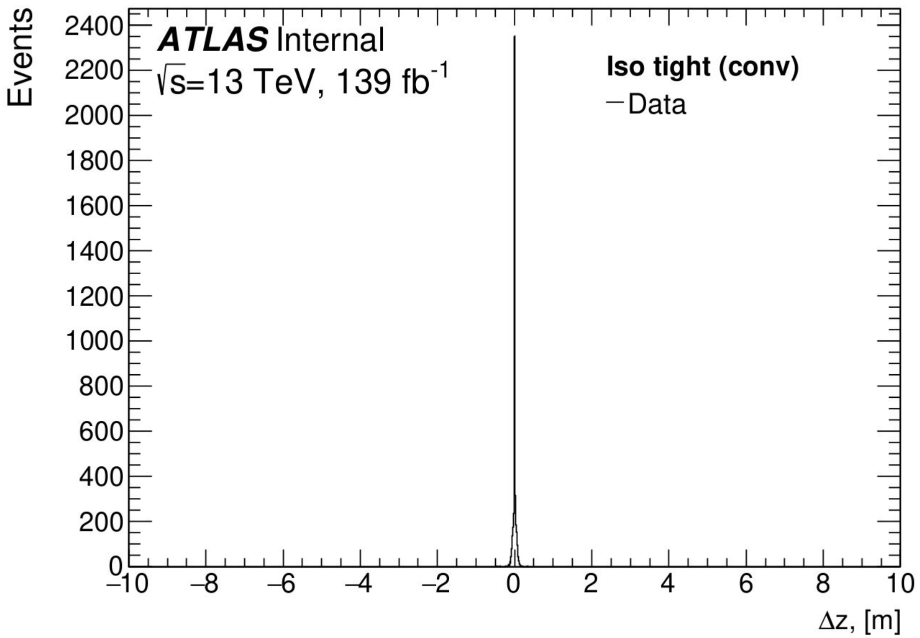
Selection optimisation: isolation checks

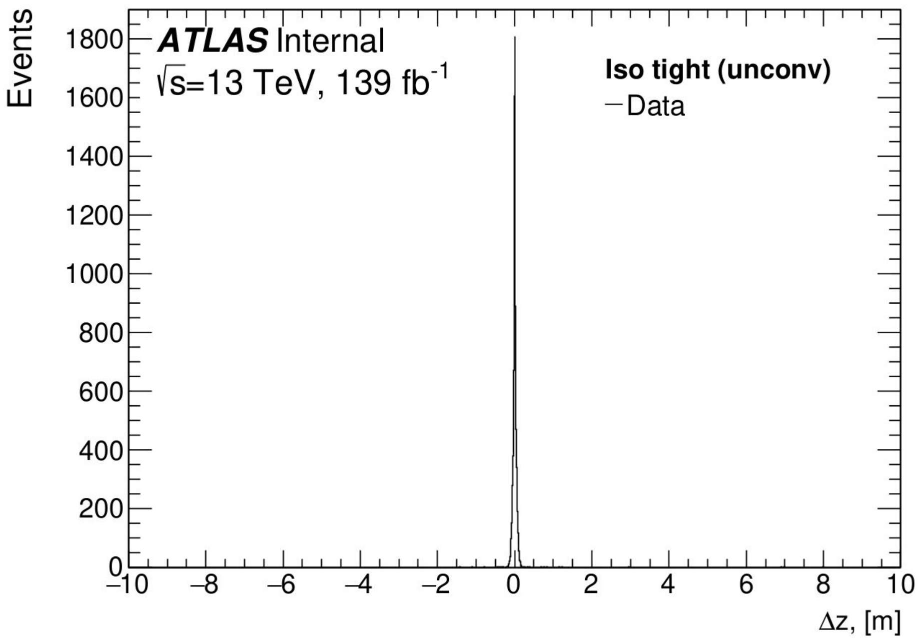
Isolation	FixedCutTight		FixedCutTightCaloOnly					
Multijet	–	+	–	+	–	+	+	+
Selections	+ E_T^{miss} sign > **11** + $\|\Delta\varphi(\gamma, E_T^{miss})\|$ > **0.6** + $\|\Delta\varphi(j_1, E_T^{miss})\|$> 0.4 + E_T^{miss} > 130		+ E_T^{miss} sign > **11** + $\|\Delta\varphi(\gamma, E_T^{miss})\|$ > **0.6** + $\|\Delta\varphi(j_1, E_T^{miss})\|$> 0.4 + E_T^{miss} > 130		+ E_T^{miss} sign > **11** + $\|\Delta\varphi(\gamma, E_T^{miss})\|$ > **0.7** + $\|\Delta\varphi(j_1, E_T^{miss})\|$> 0.4 + E_T^{miss} > 130		–	+ E_T^{miss} sign > **12** + $\|\Delta\varphi(\gamma, E_T^{miss})\|$ > **0.7** + $\|\Delta\varphi(j_1, E_T^{miss})\|$> 0.4 + E_T^{miss} > 130
Signal	9752 ± 8	9752 ± 8	9843 ± 8	9843 ± 8	9840 ± 8	9840 ± 8	12381 ± 9	9355 ± 8
Background	14928 ± 455	16172 ± 1324	15520 ± 525	16764 ± 1349	15505 ± 525	16749 ± 1349	96172 ± 4693	13558 ± 518
Significance	62.1 ± 0.6	60.6 ± 1.5	61.8 ± 0.6	60.3 ± 1.5	61.8 ± 0.6	60.3 ± 1.5	37.6 ± 0.8	61.8 ± 0.7
	↑ multivariate method				↑ multivariate method			↑ multivariate method

Beam-induced background (BIB)

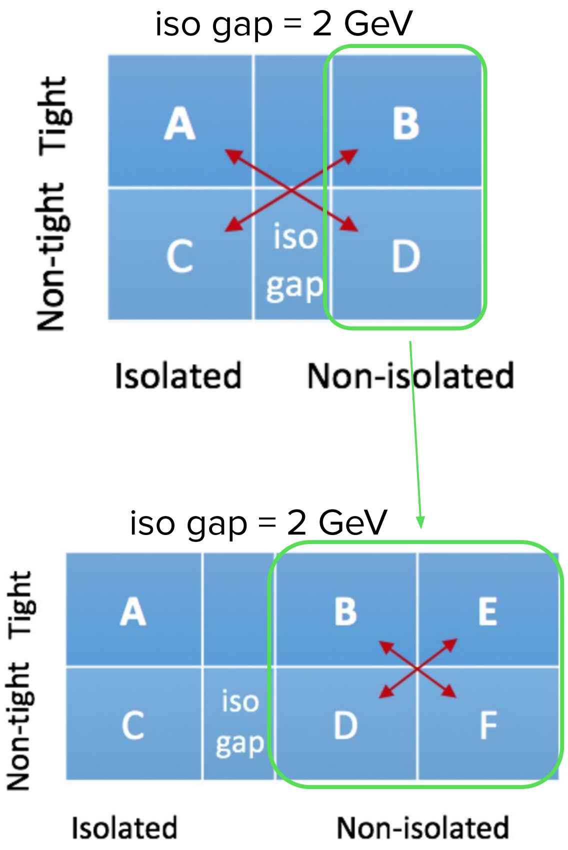


Beam-induced background (BIB)





jet→γ misID background: regions definition



FixedCutTightCaloOnly:

A: tight, $E_T^{cone40} - 0.022\ p_T^{\gamma} < 2.45$ [GeV]
B: tight, $2.45 + gap < E_T^{cone40} - 0.022\ p_T^{\gamma}$ [GeV]
C: non-tight, $E_T^{cone40} - 0.022\ p_T^{\gamma} < 2.45$ [GeV]
D: non-tight, $2.45 + gap < E_T^{cone40} - 0.022\ p_T^{\gamma}$ [GeV]

Non-tight: at least one of the cuts on the following variables should fail in these:

- $loose'2$: 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}

FixedCutTightCaloOnly:

B-E: tight, $4.45 < E_T^{cone40} - 0.022\ p_T^{\gamma} < 9.95$ [GeV]
D-F: non-tight, $4.45 < E_T^{cone40} - 0.022\ p_T^{\gamma} < 9.95$ [GeV]
E: tight, $9.95 < E_T^{cone40} - 0.022\ p_T^{\gamma}$ [GeV]
F: non-tight, $9.95 < E_T^{cone40} - 0.022\ p_T^{\gamma}$ [GeV]

jet→γ misID background: isolation working point

- Isolation: FixedCutTight, without upper cut

FixedCutTight, (w/o upper cut)				
MC				
	loose'2	loose'3	loose'4	loose'5
R-factor	1.05 ± 0.15	1.14 ± 0.15	1.19 ± 0.14	1.39 ± 0.17

Data-driven				
Cut	loose'2	loose'3	loose'4	loose'5
7.95	1.6 ± 0.3	1.5 ± 0.3	1.4 ± 0.3	1.4 ± 0.3
8.45	1.5 ± 0.3	1.5 ± 0.3	1.4 ± 0.3	1.4 ± 0.3
8.95	1.4 ± 0.3	1.3 ± 0.3	1.3 ± 0.3	1.3 ± 0.3
9.45	1.6 ± 0.4	1.5 ± 0.4	1.5 ± 0.4	1.5 ± 0.3
9.95	1.6 ± 0.4	1.5 ± 0.4	1.7 ± 0.4	1.6 ± 0.4

- Isolation: FixedCutTight, with upper cut 25.45 GeV

FixedCutTight, (upper cut = 25.45 GeV)				
MC				
	loose'2	loose'3	loose'4	loose'5
R-factor	1.06 ± 0.15	1.15 ± 0.16	1.21 ± 0.15	1.40 ± 0.17

Data-driven				
Cut	loose'2	loose'3	loose'4	loose'5
8.45	1.1 ± 0.2	1.1 ± 0.2	1.03 ± 0.18	1.06 ± 0.18
8.95	0.96 ± 0.18	0.97 ± 0.17	0.96 ± 0.17	0.97 ± 0.16
9.05	1.01 ± 0.18	1.02 ± 0.18	1.01 ± 0.18	1.01 ± 0.17
9.45	1.08 ± 0.19	1.10 ± 0.19	1.10 ± 0.19	1.12 ± 0.18
9.95	1.03 ± 0.18	1.03 ± 0.18	1.16 ± 0.19	1.16 ± 0.19
10.45	1.1 ± 0.2	1.1 ± 0.2	1.2 ± 0.2	1.2 ± 0.2
10.95	1.2 ± 0.2	1.2 ± 0.2	1.3 ± 0.2	1.3 ± 0.2

- Isolation: FixedCutTight and track inversion

FixedCutTight (inversion), (w/o upper cut)				
MC				
	loose'2	loose'3	loose'4	loose'5
R-factor	1.01 ± 0.12	1.15 ± 0.12	1.29 ± 0.13	1.58 ± 0.16

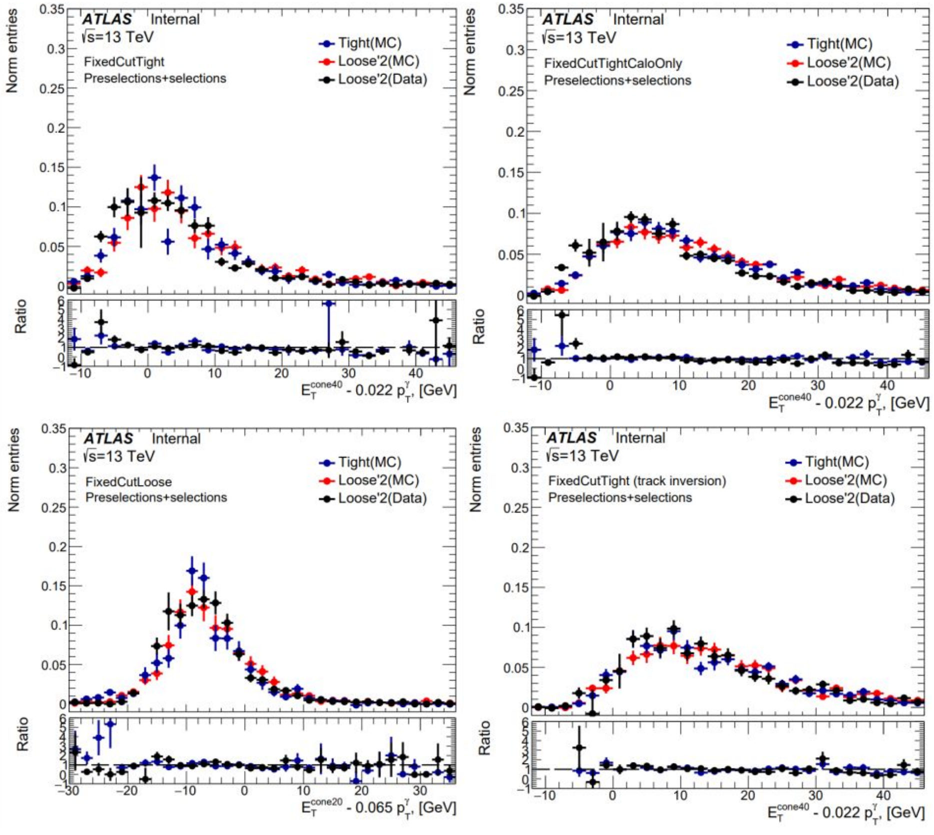
Data-driven				
Cut	loose'2	loose'3	loose'4	loose'5
9.45	1.09 ± 0.13	1.15 ± 0.13	1.09 ± 0.11	1.13 ± 0.11
9.95	1.08 ± 0.12	1.16 ± 0.12	1.11 ± 0.11	1.13 ± 0.10
10.20	1.07 ± 0.12	1.13 ± 0.12	1.09 ± 0.10	1.12 ± 0.10
10.45	1.09 ± 0.12	1.14 ± 0.12	1.10 ± 0.10	1.14 ± 0.10
10.95	1.18 ± 0.13	1.23 ± 0.12	1.17 ± 0.10	1.20 ± 0.10

- Isolation: FixedCutTightCaloOnly, without upper cut

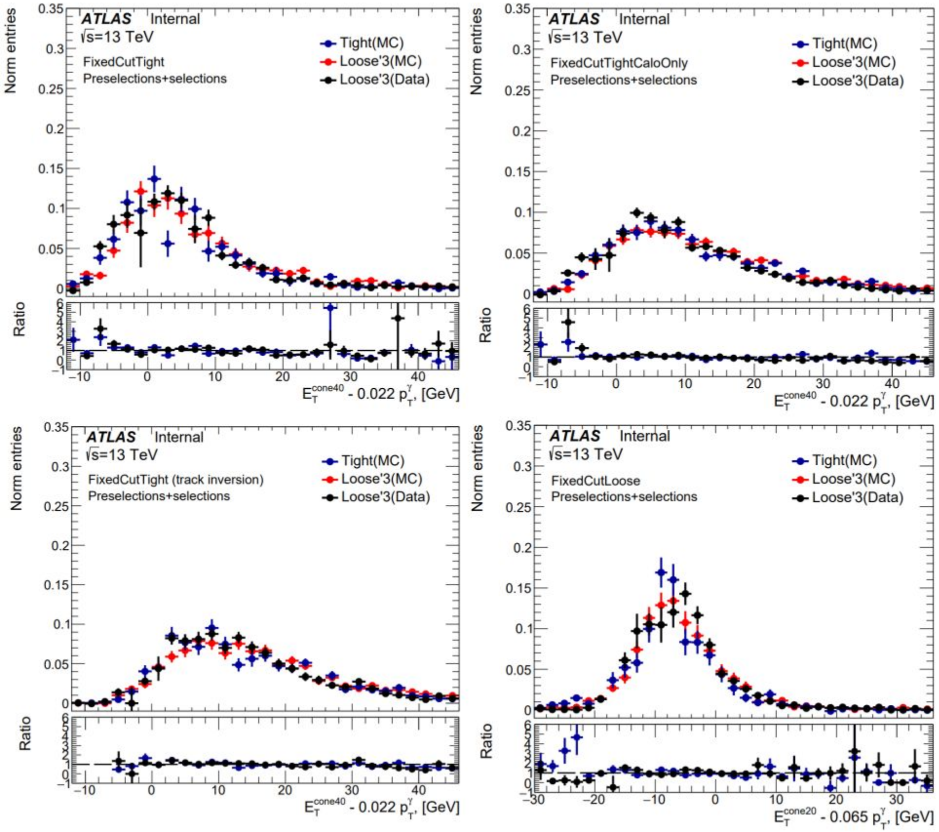
FixedCutTightCaloOnly, (w/o upper cut)				
MC				
	loose'2	loose'3	loose'4	loose'5
R-factor	1.06 ± 0.10	1.14 ± 0.11	1.22 ± 0.10	1.40 ± 0.12

Data-driven				
Cut	loose'2	loose'3	loose'4	loose'5
9.45	1.08 ± 0.11	1.14 ± 0.11	1.12 ± 0.10	1.13 ± 0.10
9.95	1.07 ± 0.10	1.13 ± 0.10	1.15 ± 0.10	1.15 ± 0.10
10.45	1.09 ± 0.10	1.14 ± 0.10	1.14 ± 0.10	1.15 ± 0.10
10.95	1.18 ± 0.11	1.23 ± 0.11	1.21 ± 0.10	1.22 ± 0.10
11.45	1.23 ± 0.11	1.27 ± 0.11	1.22 ± 0.10	1.22 ± 0.10

jet→γ misID background: isolation working point

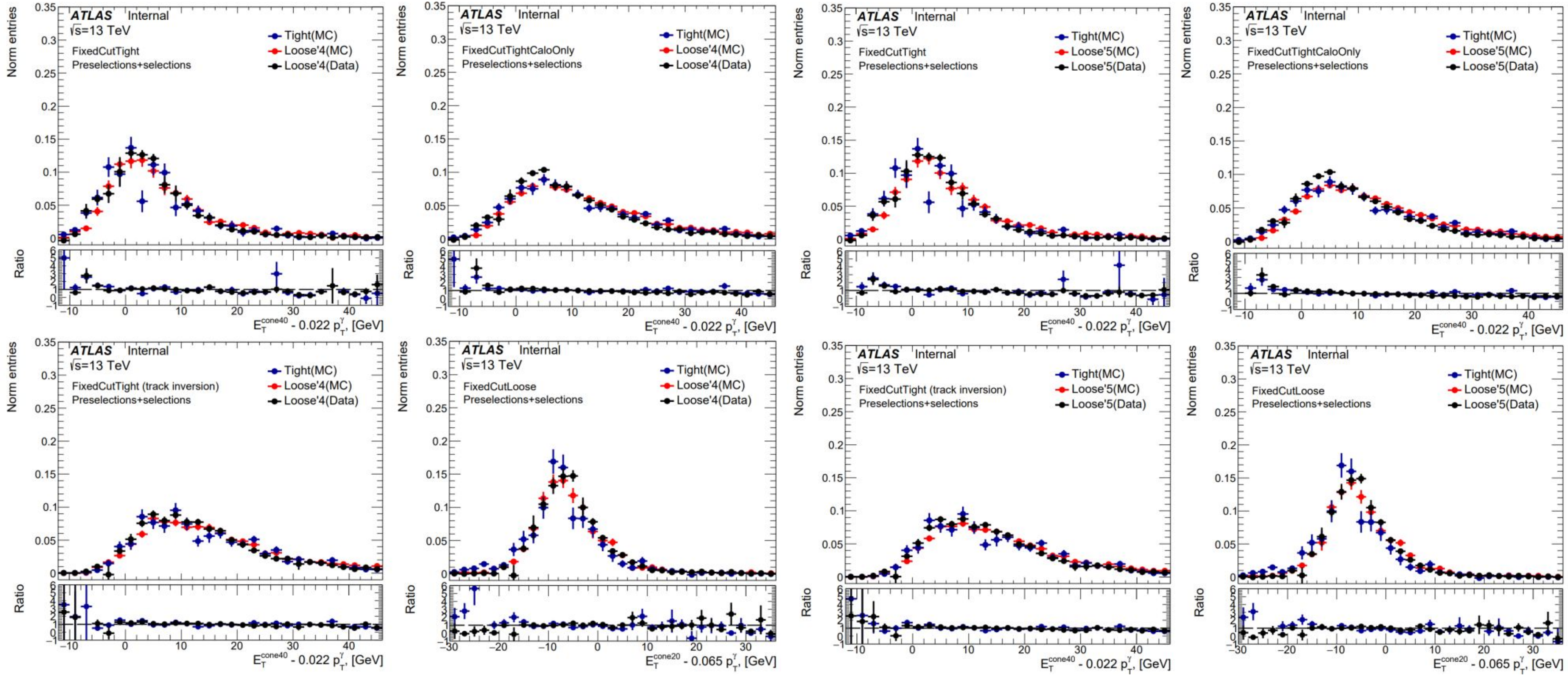


loose'2



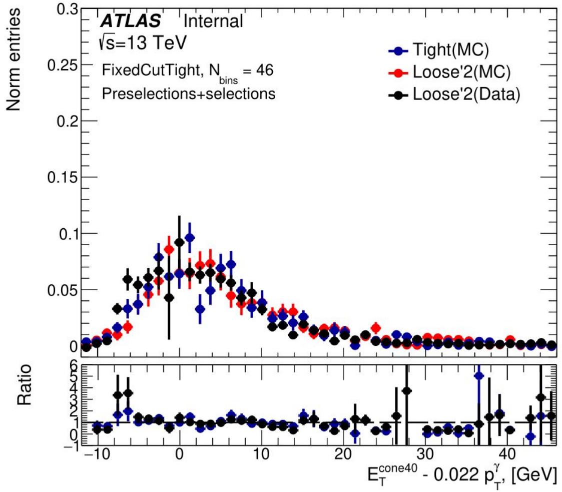
loose'3

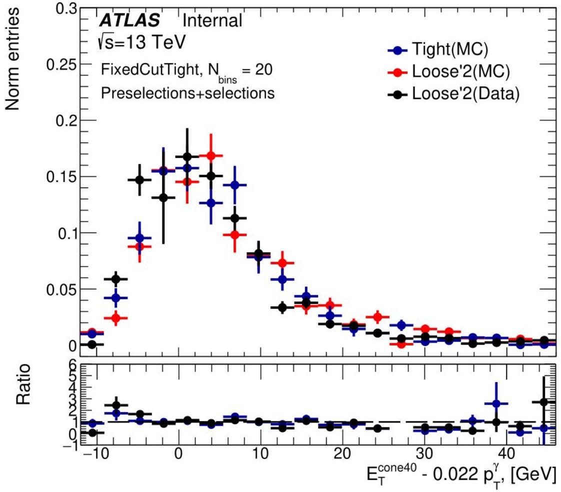
jet→γ misID background: isolation working point

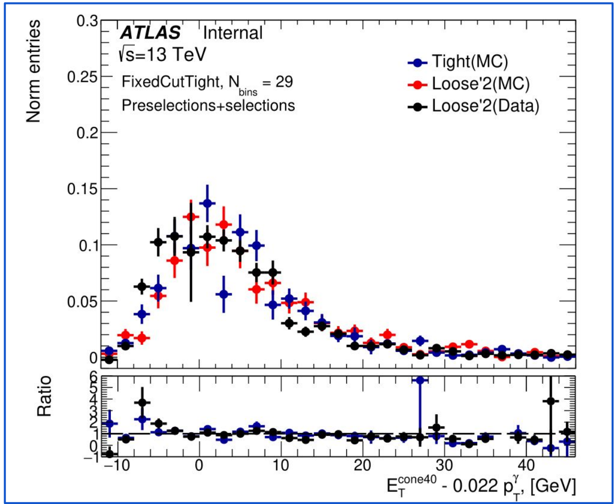


loose'4 ***loose'5***

jet→γ misID background: isolation working point







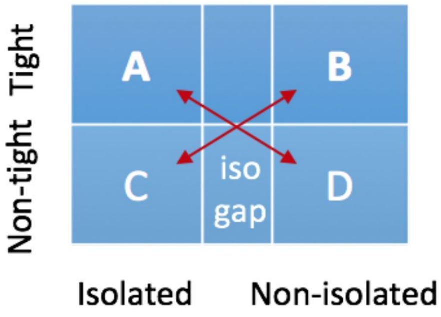
For blue point in 20 bin: 0.0144971 +- 0.00474881
For black point in 20 bin: 0.00177925 +- 0.00131052
For red point in 20 bin: 0.00257787 +- 0.00238254
Ratio in 20 bin: 5.62366 +- 5.51433

$$\Delta\left(\frac{x}{y}\right) = \sqrt{\left(\frac{\Delta x}{y}\right)^2 + \left(\frac{x\Delta y}{y^2}\right)^2}$$

For blue point in 28 bin: -0.00022147 +- 0.00140026
For black point in 28 bin: 0.00342036 +- 0.0014042
For red point in 28 bin: 0.000896954 +- 0.00102111
Ratio in 28 bin: -0.246913 +- 1.58623 (blue point), 3.81331 +- 4.6148 (black point)

jet→γ misID background: estimation technique

iso gap = 2 GeV



The signal leakage parameters:

$$c_i = \frac{N_i^{\text{sig}}}{N_A^{\text{sig}}}$$ MC

$$\widetilde{N}_i = N_i - N_i^{\text{bkg}}$$

$$N_{\text{A}}^{\text{sig}} = \widetilde{N}_{\text{A}} - R(\widetilde{N}_{\text{B}} - c_{\text{B}} N_{\text{A}}^{\text{sig}}) \frac{\widetilde{N}_{\text{C}} - c_{\text{C}} N_{\text{A}}^{\text{sig}}}{\widetilde{N}_{\text{D}} - c_{\text{D}} N_{\text{A}}^{\text{sig}}}$$

$$\begin{cases} a = c_D - R c_B c_C; \\ b = \widetilde{N}_{\text{D}} + c_D \widetilde{N}_{\text{A}} - R(c_B \widetilde{N}_{\text{C}} + c_C \widetilde{N}_{\text{B}}); \\ c = \widetilde{N}_{\text{D}} \widetilde{N}_{\text{A}} - R \widetilde{N}_{\text{C}} \widetilde{N}_{\text{B}}. \end{cases}$$

$$N_{\text{A}}^{\text{sig}} = \frac{b - \sqrt{b^2 - 4ac}}{2a}$$

The number of events arising in each of the regions:

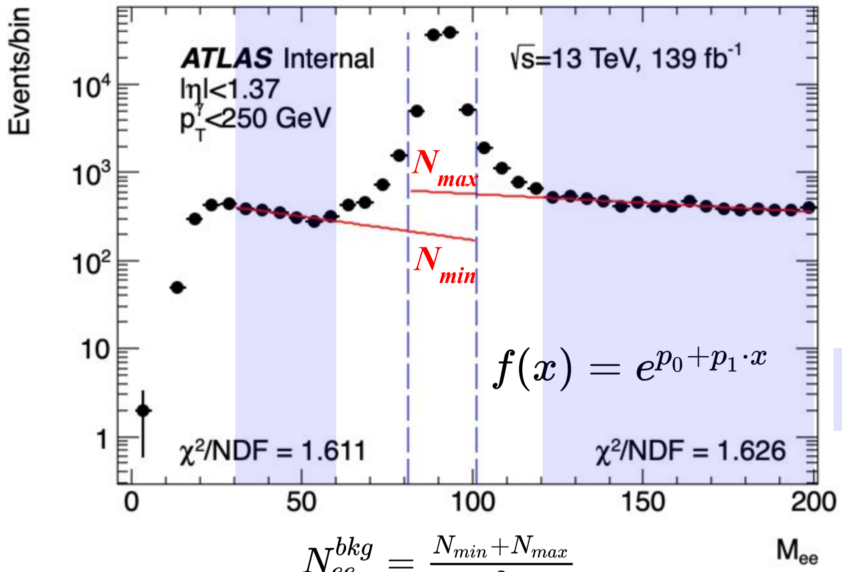
$$N_A = N_A^{\text{sig}} + N_A^{\text{bkg}} + N_A^{\text{jet}\to\gamma};$$
$$N_B = c_{\text{B}} N_A^{\text{sig}} + N_B^{\text{bkg}} + N_B^{\text{jet}\to\gamma};$$
$$N_C = c_{\text{C}} N_A^{\text{sig}} + N_C^{\text{bkg}} + N_C^{\text{jet}\to\gamma};$$
$$N_D = c_{\text{D}} N_A^{\text{sig}} + N_D^{\text{bkg}} + N_D^{\text{jet}\to\gamma};$$

$$N_{\text{A}}^{\text{jet}\to\gamma}$$

	Data	Wγ QCD	Wγ EWK	W(eν), *top*, *tt*	*tt*γ	γ + jet	Z(*ll*)γ
A	24946 ± 158	3655 ± 22	145.9 ± 0.7	3070 ± 12	213 ± 3	5016 ± 52	270 ± 4
B	5163 ± 72	337 ± 8	14.1 ± 0.2	140.9 ± 0.5	21.9 ± 1.0	161 ± 9	15.1 ± 1.3
C	1586 ± 40	32 ± 2	1.42 ± 0.07	41.92 ± 0.14	2.2 ± 0.3	36 ± 4	2.4 ± 0.4
D	2805 ± 53	3.0 ± 0.6	0.21 ± 0.03	0 ± 0	0.82 ± 0.19	0.8 ± 0.4	0.19 ± 0.11

e→γ misID background: background under Z peak

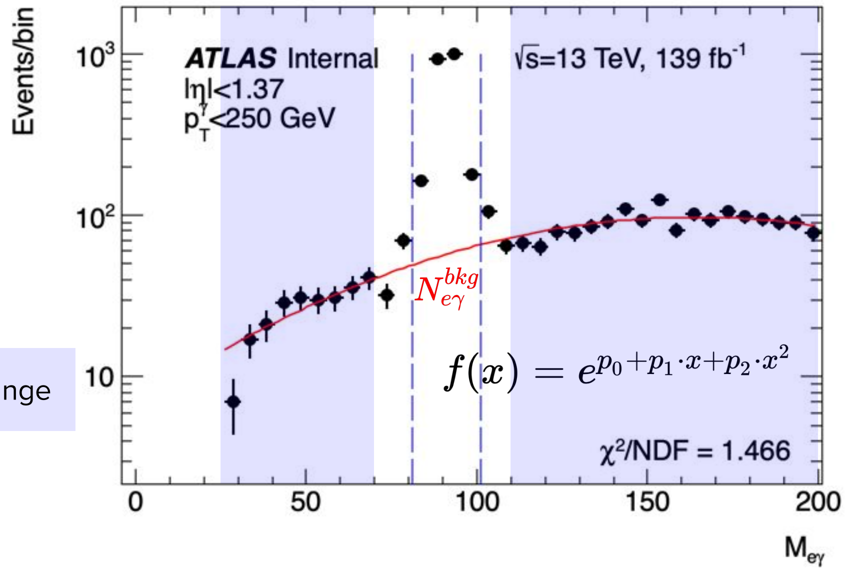
ee pairs



$$N_{ee}^{bkg} = \frac{N_{min}+N_{max}}{2}$$

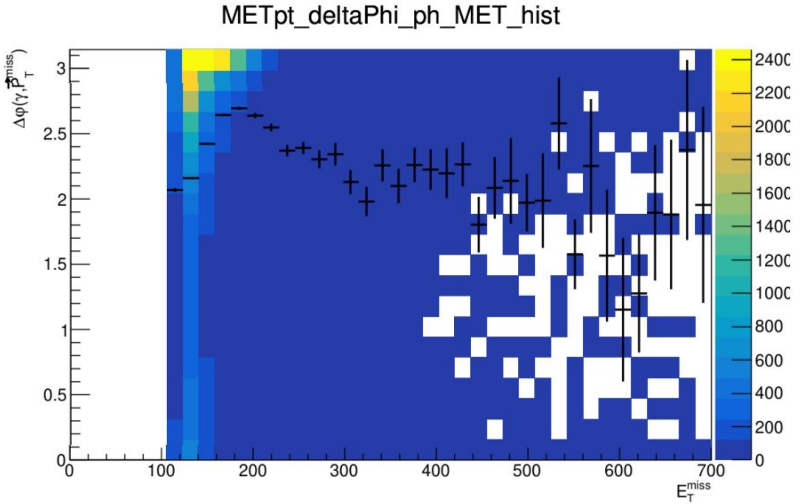
fit range

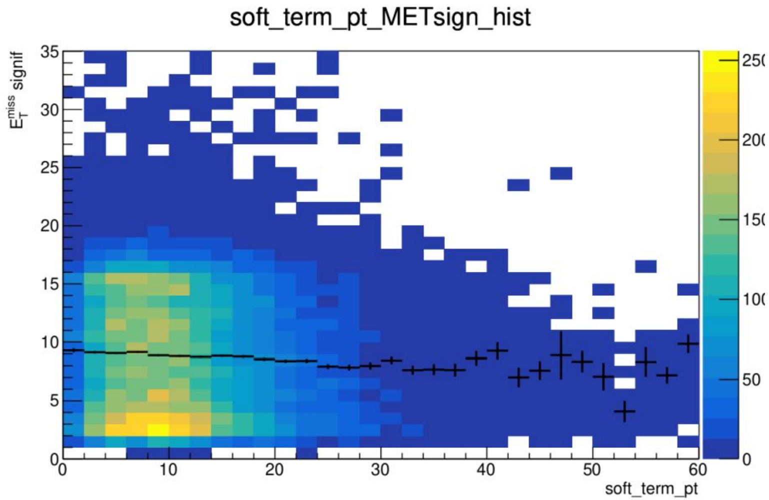
eγ pairs



- Systematics on bkg estimation under Z peak are evaluated by variation of N^{bkg} values in ee and eγ pairs.
- N_{min} and N_{max} values are used as variations of N_{ee}^{bkg}. In eγ pairs extrapolation function parameters are varied by their statistical uncertainties one by one. Resulting integral of the function is used for variation of $N_{e\gamma}^{bkg}$.
- Sum in quadrature of the largest variations of $N_{e\gamma}^{bkg}$ and N_{ee}^{bkg} is taken as systematics.

E_T^{miss}→jet misID background: estimation strategy





var1 var2	E_T^{miss}signif >11 $p_T^{SoftTerm} < 16$	1.3101
var1 var2	E_T^{miss}signif >11 && $\Delta\phi$(jet_lead, p_T^{miss}) > 0.4 $p_T^{SoftTerm} < 16$	1.24685
var1 var2	E_T^{miss}signif >11 && $\Delta\phi$(jet_lead, p_T^{miss}) > 0.4 && $\Delta\phi(\gamma, p_T^{miss}) > 0.6$ $p_T^{SoftTerm} < 16$	1.24627

R for variables configurations w/o soft term is very bad (>>1)

Pile-up background

- In full Run2 Z(ll)γ inclusive analysis it was found that events with Z and photon from different primary vertices have non-negligible probability (up to **5%** of the total event yield)
- Since our final state assumes high energetic photons, E_T^{miss}, probability of such events should be much smaller.

- Fraction of pile-up background is calculated as:

$$f_{PU} = \frac{N^{|\Delta z|>50mm}_{\text{data, 2-track Si}} - N^{|\Delta z|>50mm}_{\text{single pp, 2-track Si}}}{N_{\text{data, 2-track Si}} \times 0.32}, \quad N^{|\Delta z|>50mm}_{\text{single pp, 2-track Si}} = SF_1 \times SF_2 \times N^{|\Delta z|>50mm}_{\text{MC, 2-track Si}}$$

- SF_1 is equal to the ratio of events in data to events in Sherpa MC sample near |Δz| around zero (4.61±0.07)
- SF_2 – normalization factor taking into account the mismodelling in the tails of |Δz| distribution (it was calculated for Sherpa Zγ QCD by Z(ll)γ inclusive team using events with FSR photons) (1.5±0.3)

f_{PU}= -(58±11)%