

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

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National Research Nuclear University “MEPhI”



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**MEPhI@Atlas meeting**

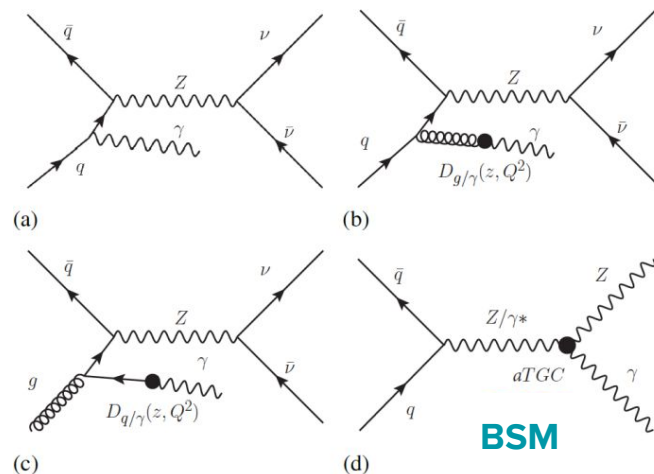
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July 22, 2022



# Motivation: general part

- Measuring the parameters of the **Standard Model (SM)** to very high precision is a pillar of the physics program of the LHC. Precision measurements provide a critical test of the consistency and limits of validity of the SM.
- Other LHC program is the search for new physics predicted by the **beyond SM (BSM)** theories. BSM theories predict the existence of new particles, which may be too massive to be produced at the LHC, but their quantum behaviour could help spot them.
- Precision measurements of **triple and quartic gauge couplings** are sensitive to BSM physics. One of these processes is **Z(vv)γ process**, which the group has been working on for a long time.
- The neutral decay channel of the Z boson has a higher branching ratio, but a worse resolution compared to the decay into charged leptons. So it can be used for combinations to increase the statistics. The hadron channel has even higher branching ratio, but it is difficult to work on it.



# Motivation: goals

[The previous study](#) for this channel was done using  $36.1 \text{ fb}^{-1}$  data.

This study uses the full Run2 statistics ( $139 \text{ fb}^{-1}$ ), which improves the measurement accuracy (expectation of an increase in the experimental sensitivity by a factor of 2).

➤ Standard Model:

It is planned to calculate integral and differential in  $\mathbf{E}_T^\gamma$ ,  $\mathbf{N}_{\text{jets}}$ ,  $\mathbf{p}_T^{\text{miss}}$ ,  $\Delta\Phi[\gamma, \mathbf{p}_T^{\text{miss}}]$ ,  $\mathbf{p}_T(\mathbf{Z}\gamma)$ ,  $\eta_\gamma$  cross-sections and compare the results with the theory predictions including NNLO QCD and [NLO EWK corrections](#).

➤ Beyond SM:

One of the goals is to obtain 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  $Z\gamma$  and  $ZZ$  + ratio of  $Z\gamma/ZZ$  cross-sections.

# Selection optimisation: multivariate method

Topology: high-energetic  $\gamma$  + high missing transverse momentum  $p_T^{\text{miss}}$

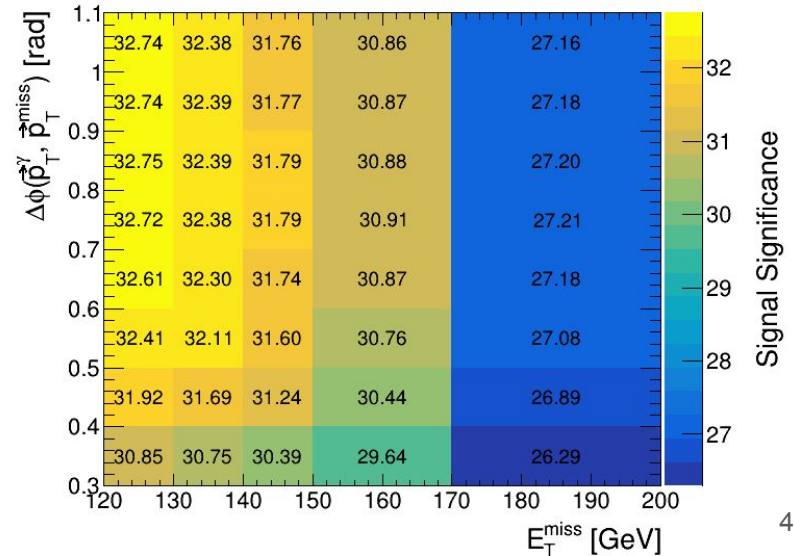
Preselections	Cut Value
$E_T^{\text{miss}}$	$> 120 \text{ GeV}$
$E_T^\gamma$	$> 150 \text{ GeV}$
Number of tight isolated photons	$N_\gamma = 1$
Lepton veto	$N_e = 0, N_\mu = 0$

2D illustration:

**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.



# Selection optimisation: increase in statistical significance

**Signal region (SR)** definition with the thresholds obtained by MV selection optimisation method:

	Selections	Cut Value
<b>SR</b>	$E_T^{\text{miss}}$	$> 130 \text{ GeV}$
	$E_T^{\text{miss}}$ significance	$> 11$
	$ \Delta\phi(\vec{p}_T^{\text{miss}}, \gamma) $	$> 0.6$
	$ \Delta\phi(\vec{p}_T^{\text{miss}}, j_1) $	$> 0.4$

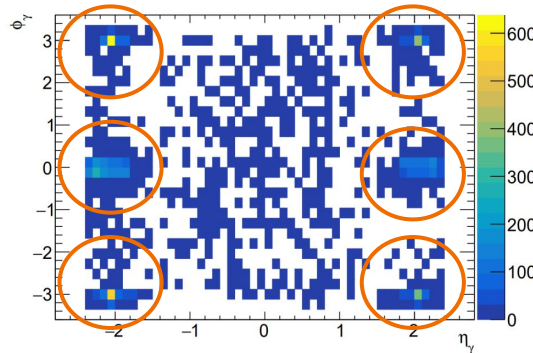
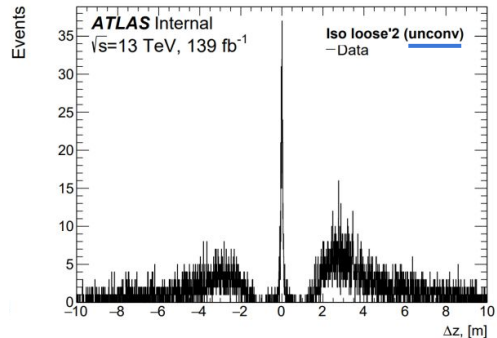
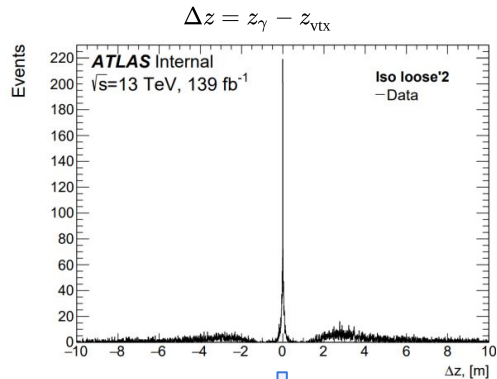
Impact of the used variables on the number of signal and background events and statistical significance:

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

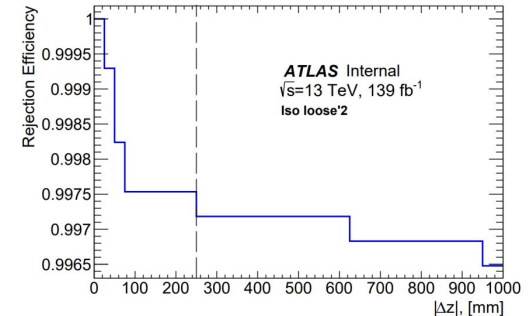
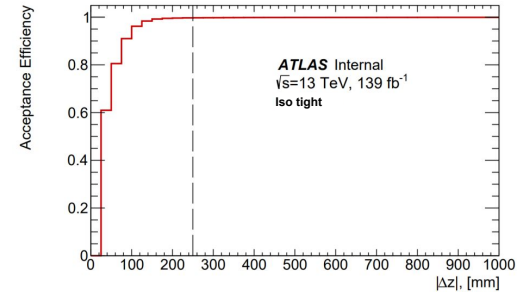
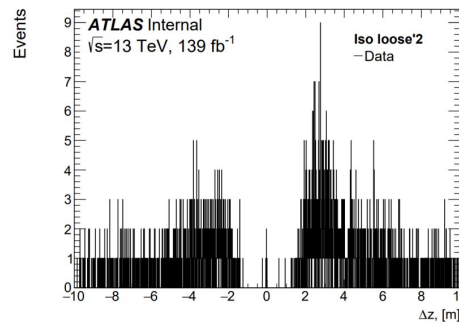
Moreover, there is no significant increase in statistical significance with using  $N_{\text{b-jets}}$  and  $p_T^{\text{SoftTerm}}$  variables.

# 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  $\pm \pi$  and  $\mathbf{0}$  (mainly due to the bending in the horizontal plane that occurs in the D1 and D2 dipoles and the LHC arc).



Cuts:  $|\phi| < 0.2$ ,  $|\phi| \in [2.9; 3.2]$  and  $|\eta| > 1.7$



$|\Delta z| < 250 \text{ mm}$

Rejection efficiency:  $(100 \pm 3)\%$   
 Acceptance efficiency:  $(99.7 \pm 0.9)\%$

# Background composition

Percentage of  
the total  
predicted  
background

## Background composition for $Z(\nu\nu)\gamma$ :

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

# jet $\rightarrow$ $\gamma$ misID background: correlation factor

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  $R = \frac{N_A N_D}{N_B N_C}$ .

**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:  $w_{s3}, F_{side}, \Delta E, E_{ratio}, w_{tot}$

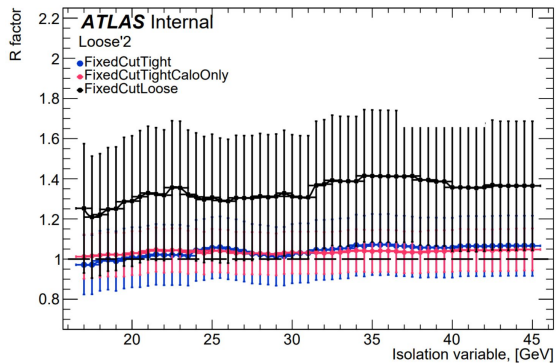
## FixedCutTightCaloOnly:

**A**: tight,  $E_T^{cone40} - 0.022 p_T^Y < 2.45$  [GeV]

**B**: tight,  $2.45 + \text{gap} < E_T^{cone40} - 0.022 p_T^Y$  [GeV]

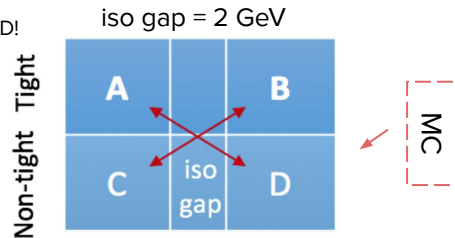
**C**: non-tight,  $E_T^{cone40} - 0.022 p_T^Y < 2.45$  [GeV]

**D**: non-tight,  $2.45 + \text{gap} < E_T^{cone40} - 0.022 p_T^Y$  [GeV]

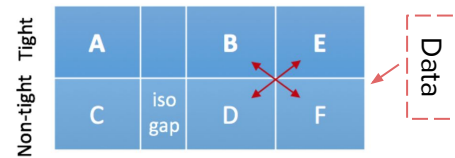


Isolation should not correlate with non-tight ID!

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



Isolated Non-isolated



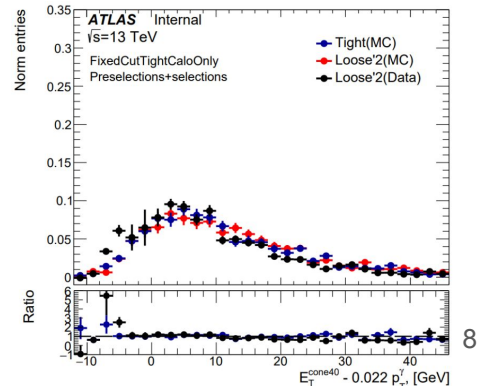
Isolated Non-isolated

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

## FixedCutTightCaloOnly

Data-driven

Cut	loose'2	loose'3	loose'4	loose'5
9.45	$1.08 \pm 0.11$	$1.14 \pm 0.11$	$1.12 \pm 0.10$	$1.13 \pm 0.10$
9.95	$1.07 \pm 0.10$	$1.13 \pm 0.10$	$1.15 \pm 0.10$	$1.15 \pm 0.10$
10.45	$1.09 \pm 0.10$	$1.14 \pm 0.10$	$1.14 \pm 0.10$	$1.15 \pm 0.10$
10.95	$1.18 \pm 0.11$	$1.23 \pm 0.11$	$1.21 \pm 0.10$	$1.22 \pm 0.10$
11.45	$1.23 \pm 0.11$	$1.27 \pm 0.11$	$1.22 \pm 0.10$	$1.22 \pm 0.10$





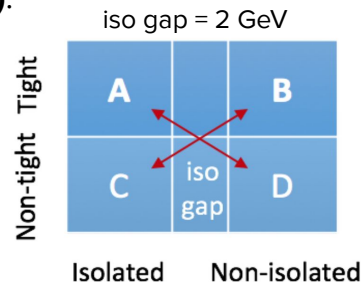
# jet $\rightarrow \gamma$ misID background: uncertainties

## ➤ Statistical uncertainty:

- The event yields of four regions in data and non jet  $\rightarrow \gamma$  background are varied by  $\pm 1\sigma$  independently (**4%**).
- The statistical uncertainty on the signal leakage parameters is negligible.

**Total statistics: 4%.**

Central value	1960 $\pm$ 83
<b>loose'3</b>	-334
<b>loose'4</b>	-397
<b>loose'5</b>	-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  $\pm 1\sigma$  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 $\pm$ 0.0002	0.1000 $\pm$ 0.0011	29%
$c_C$	0.00879 $\pm$ 0.00007	0.0092 $\pm$ 0.0003	4%
$c_D$	0.00070 $\pm$ 0.00002	0.00099 $\pm$ 0.00010	29%
$jet \rightarrow \gamma$ est.	1960	1785	9%

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

$$\sigma_{\text{iso}}^{\text{CB}}(\text{relative}) = \delta_{\text{iso}}^{\text{eff}} * (c_B + 1)/c_B$$

$$\sigma_{\text{ID}}^{\text{CC}}(\text{relative}) = \delta_{\text{ID}}^{\text{eff}} * (c_C + 1)/c_C$$

$$\sigma_{\text{iso}}^{\text{CD}}(\text{relative}) = \delta_{\text{iso}}^{\text{eff}} * (c_B + 1)/c_B$$

$$\sigma_{\text{ID}}^{\text{CD}}(\text{relative}) = \delta_{\text{ID}}^{\text{eff}} * (c_C + 1)/c_C$$

$$\delta_{\text{iso}}^{\text{eff}} = 0.013$$

$$\delta_{\text{iso/ID}}^{\text{eff}} = 0.013$$

**Total systematics: 26%.**

★ **Total number of jet  $\rightarrow \gamma$  events:** 1960  $\pm$  80  $\pm$  510. Z(vv)+jets and multi-jet MC predicts 1600  $\pm$  1200 events.

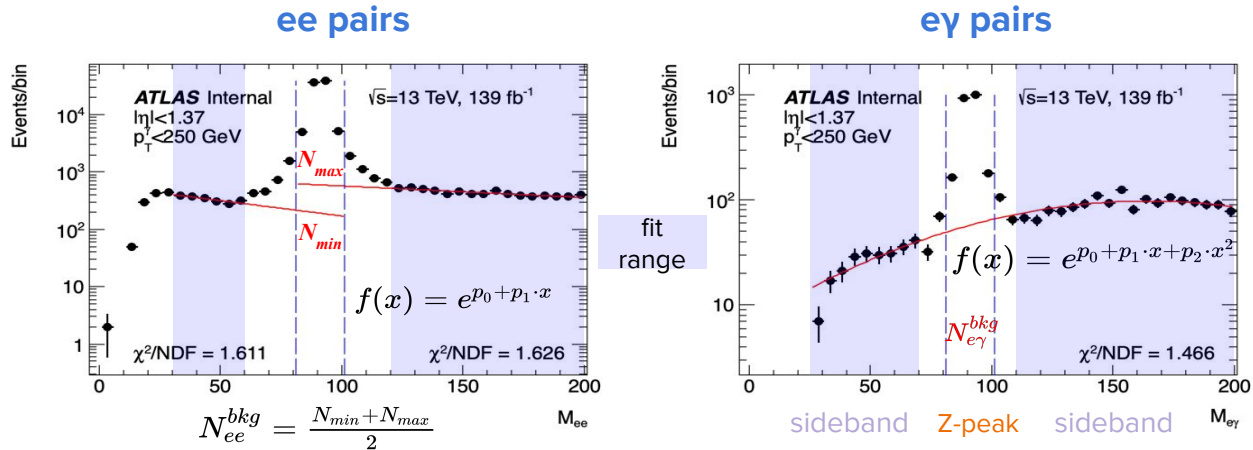
# $e \rightarrow \gamma$ misID background: Z-peak method

Source: W(lv), top and tt processes.

Estimation procedure:

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

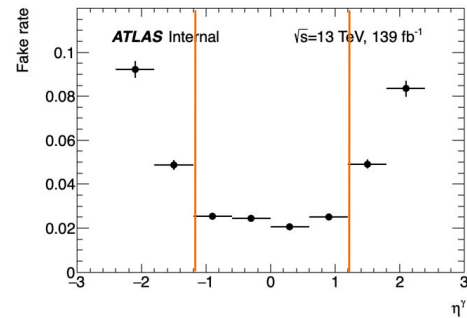
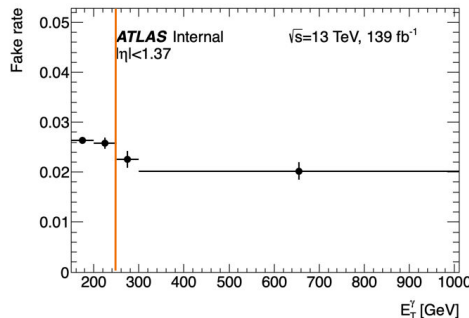
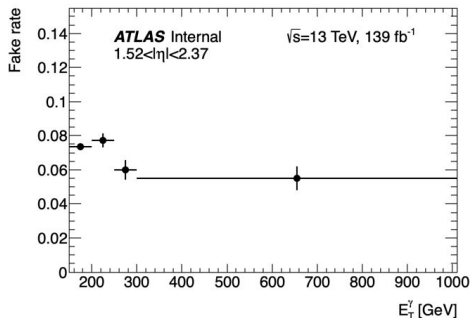
where  $N_{ee}$ ,  $N_{e\gamma}$  – number of ee and eγ events in Z-peak mass window ( $M_Z - 10$  GeV,  $M_Z + 10$  GeV),  $N_{bkg}$  – background in Z-peak mass window extrapolated from sideband with exponential pol1 or pol2 fit.



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

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

# $e \rightarrow \gamma$ misID background: uncertainties



Since  $e \rightarrow \gamma$  fake rate depends on  $\eta$  и  $p_T$ , it is estimated in three regions.

## 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%).

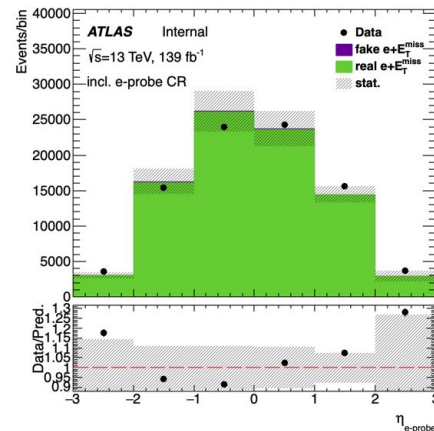
Total syst. on the background yield: 6%.

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

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

Contamination is determined as:

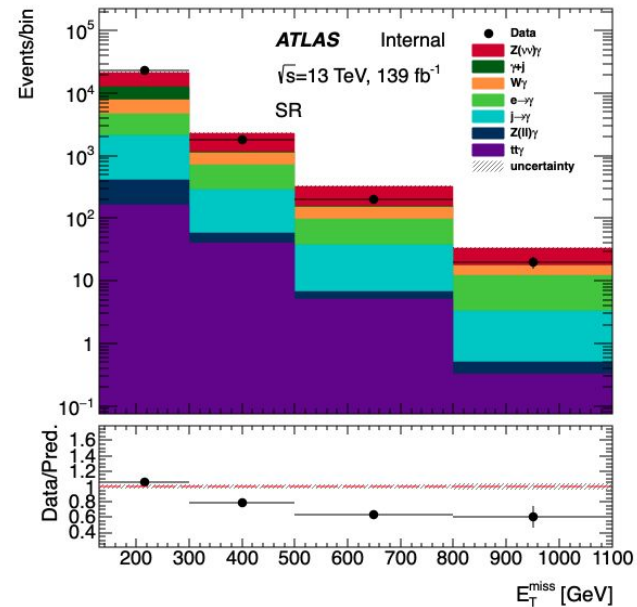
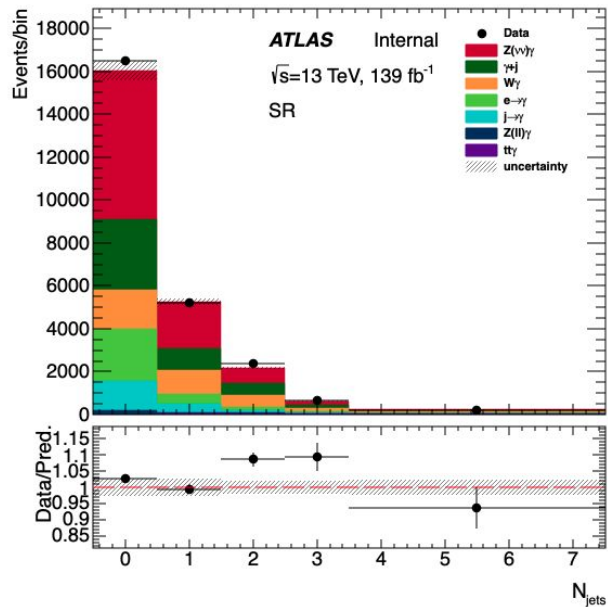
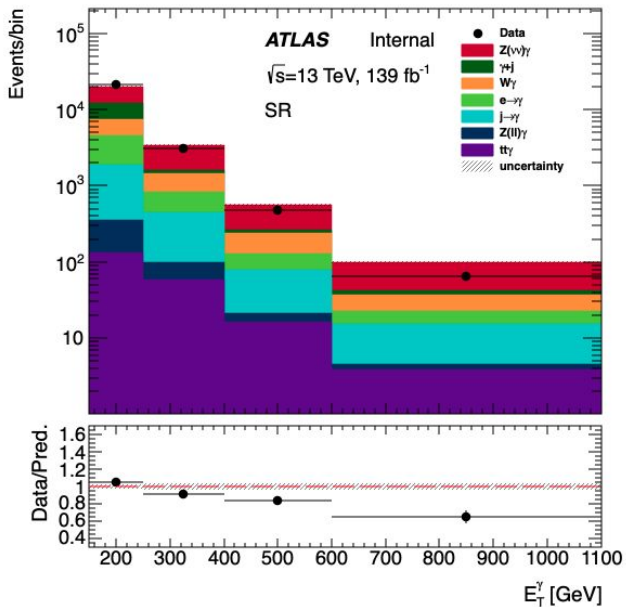
$$\frac{\text{fake } e + E_T^{\text{miss}}}{\text{real } e + E_T^{\text{miss}}}$$



## jet $\rightarrow$ $E_T^{\text{miss}}$ misID background: estimation strategy

- Background originating from  $\gamma$ +jets processes is significantly reduced by applying selections on  $E_T^{\text{miss}}$  and  $E_T^{\text{miss}}$ -**significance**.
- For now, **MC simulation** is used to estimate this background.
- The MC normalisation is estimated from the CR constructed in **low- $E_T^{\text{miss}}$ -significance range** ( $E_T^{\text{miss}}$ -significance < 11) with  $E_T^{\text{miss}}$  **selection relaxed** to  $E_T^{\text{miss}} > 100$  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**:  $E_T^{\text{miss}}$ -significance and other discriminative variable (e.g.  $\Delta\phi[\gamma, p_T^{\text{miss}}]$  or  $p_T^{\text{SoftTerm}}$ ) will be used to construct the sidebands.

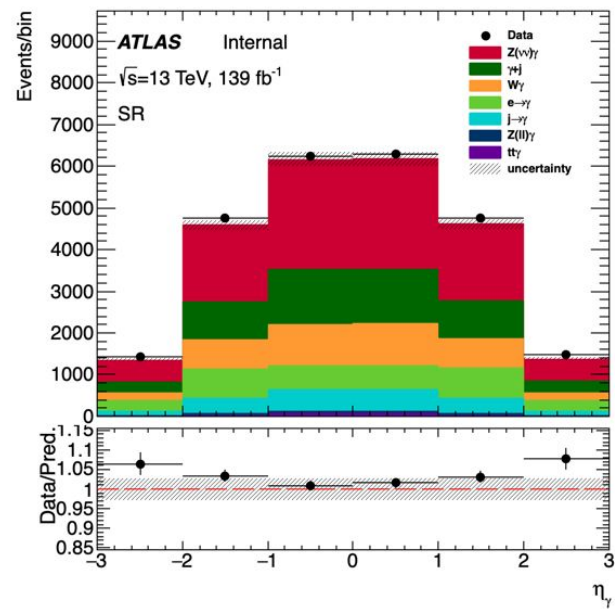
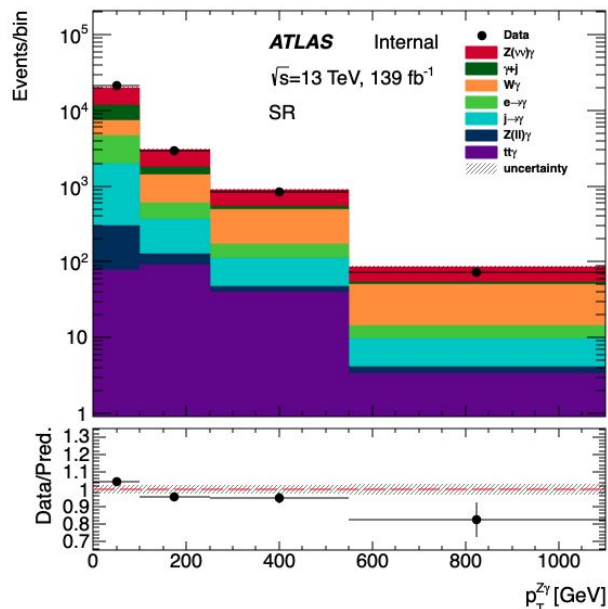
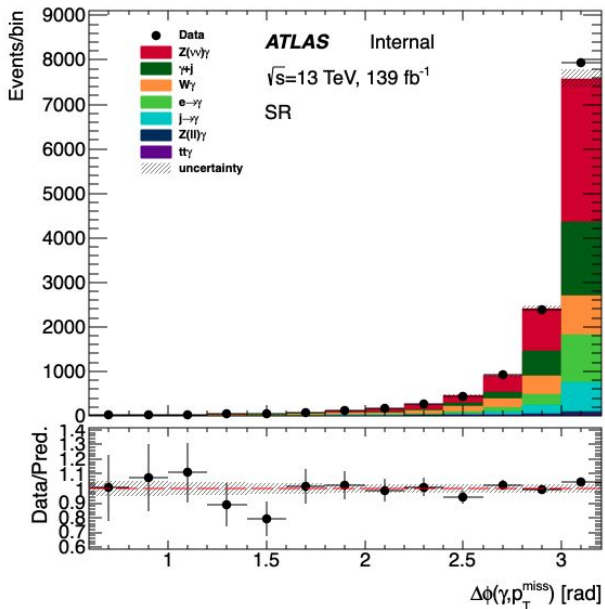
# Control plots



For jet $\rightarrow\gamma$  bkg, the shape is taken from Z( $\nu\nu$ ) $\gamma$  QCD MC.  $\gamma$ +jet bkg has 0.66 normalisation.  $e\rightarrow\gamma$  bkg: DD.

The total uncertainty includes the statistical uncertainty for all bkg, while for jet $\rightarrow\gamma$  and  $e\rightarrow\gamma$  bkg there is also the systematic uncertainty.

# Control plots



For jet $\rightarrow\gamma$  bkg, the shape is taken from  $Z(\nu\nu)\gamma$  QCD MC.  $\gamma$ +jet bkg has 0.66 normalisation.  $e\rightarrow\gamma$  bkg: DD.  
 The total uncertainty includes the statistical uncertainty for all bkg, while for jet $\rightarrow\gamma$  and  $e\rightarrow\gamma$  bkg there is also the systematic uncertainty.

# Summary

- Several steps of the inclusive  $Z(\nu\bar{\nu})\gamma$  Run2 analysis are already done: selection optimisation, data-driven estimation of  $\text{jet}\rightarrow\gamma$ ,  $e\rightarrow\gamma$  and (preliminary)  $E_T^{\text{miss}}\rightarrow\text{jet}$  misID backgrounds, control plots.
- Plans:
  - Re-optimize the SR after adding  $Z(\nu\bar{\nu})\gamma$  and  $W\gamma$  EWK samples +  $W(\tau\nu)$  samples with separation of lepton and hadron channels.
  - Estimate:
    - $E_T^{\text{miss}}\rightarrow\text{jet}$  background using 2D-sideband method.
    - pile-up background (expected to be negligible).
    - $W\gamma$  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,  $\Delta R(e, \mu) < 0.1$

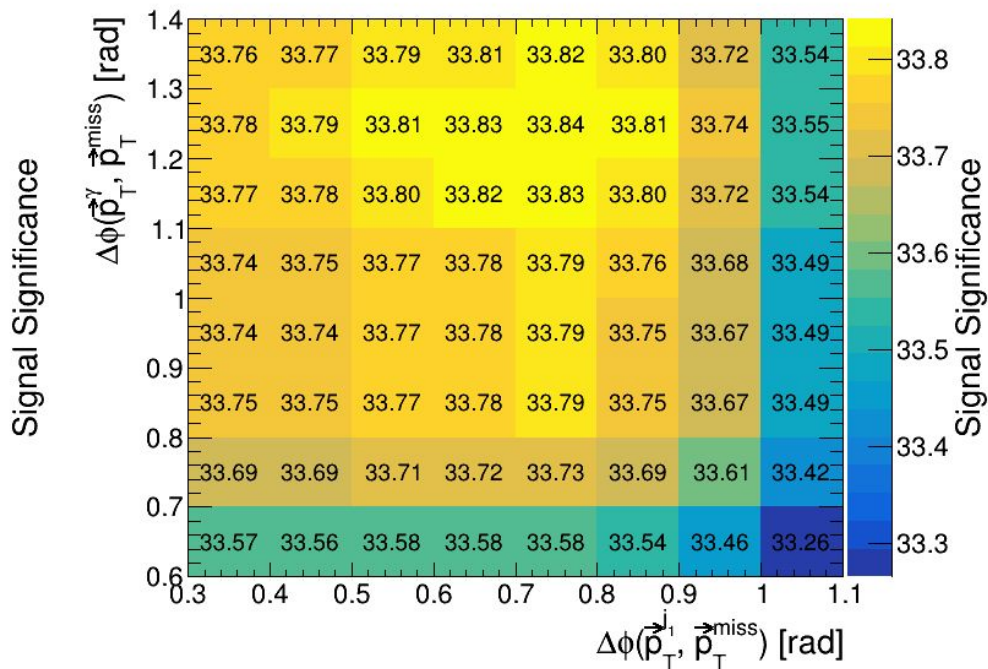
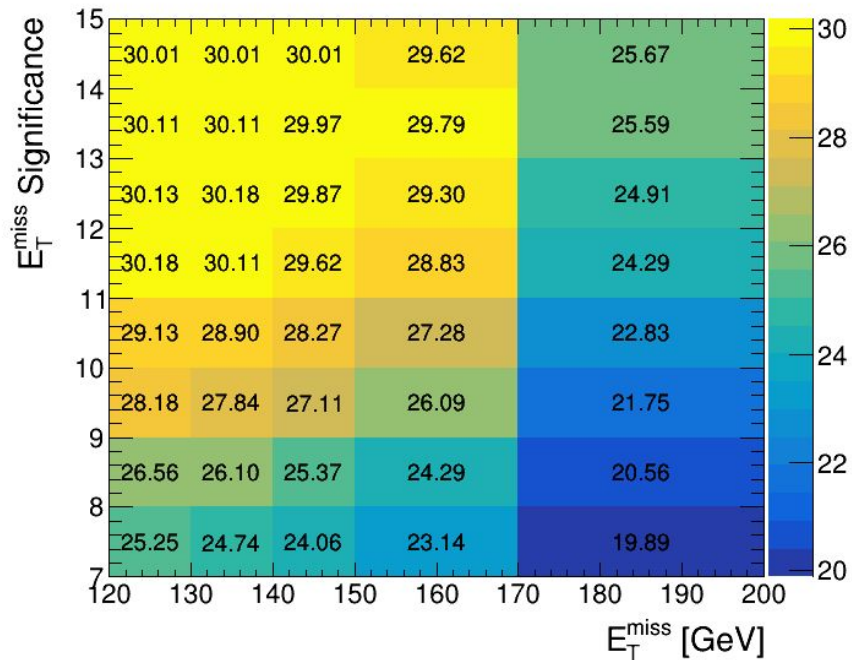
## Muon selection:

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

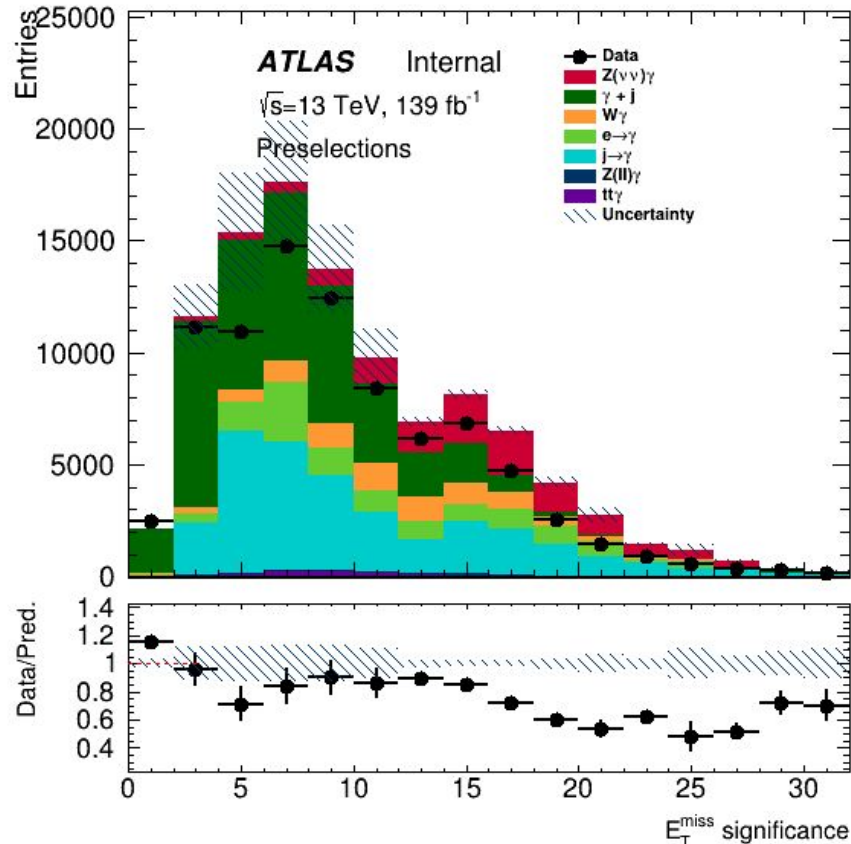
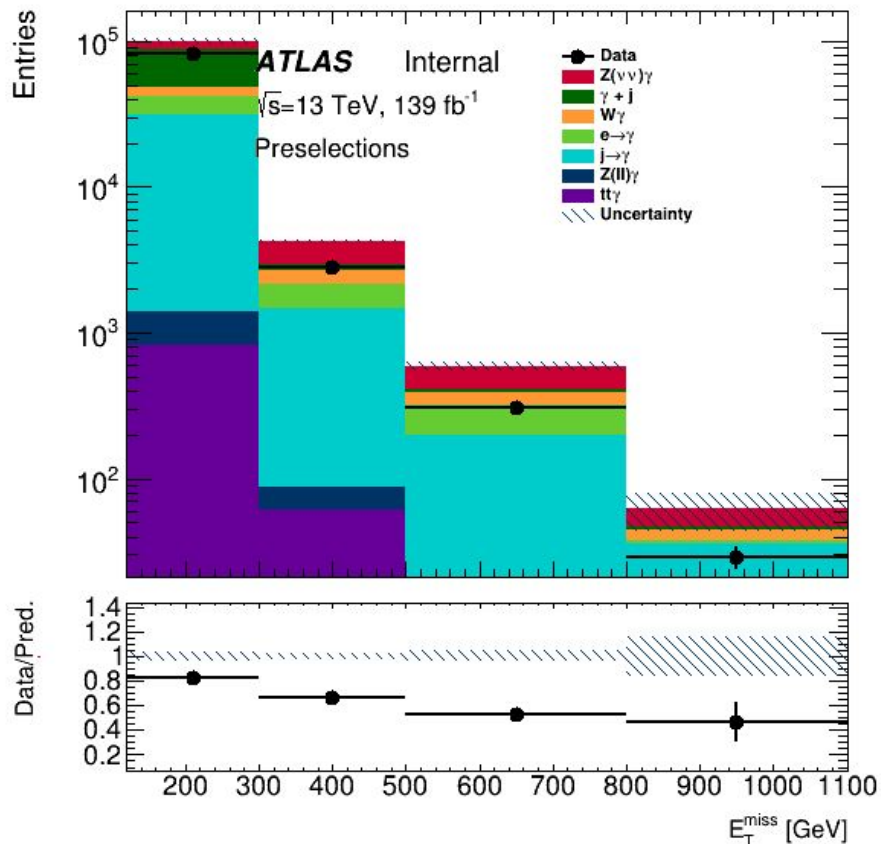
## Jet selection:

$E_T > 50$  GeV,  $|\eta| < 4.5$ , AntiKt4EMPFJet, tight JVT,  $\Delta R(\text{jet}, e/\mu/\gamma) < 0.4$

# Selection optimisation: multivariate method

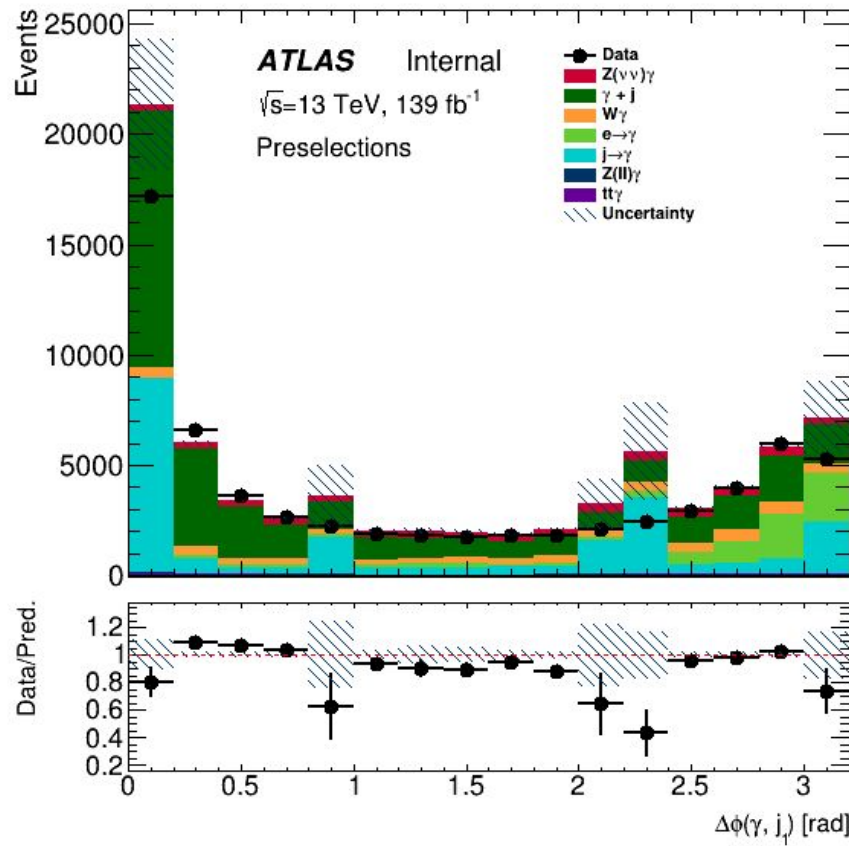
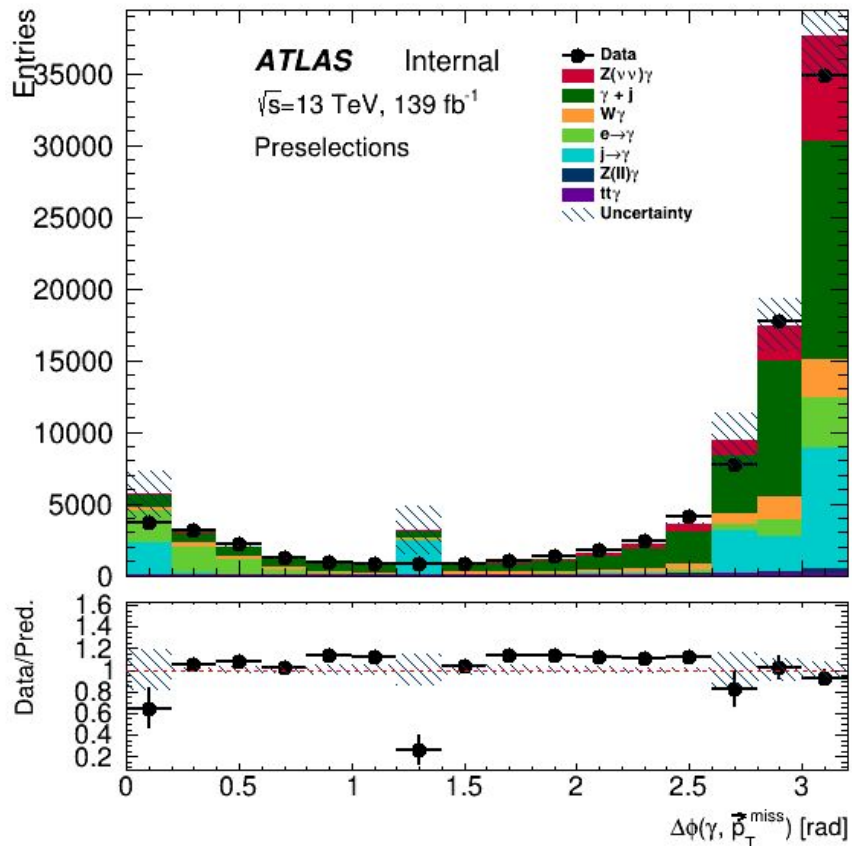


# Selection optimisation: distributions



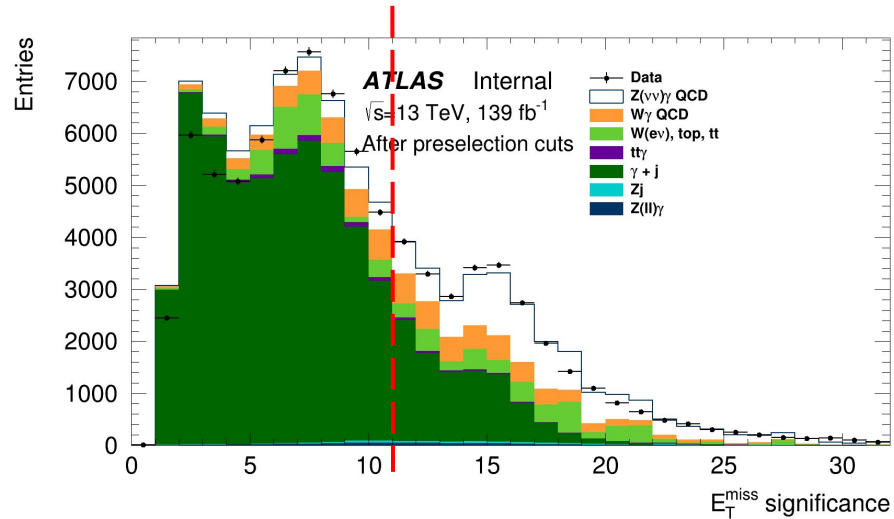
For jet $\rightarrow\gamma$  bkg, the shape is taken from Z(vv)+jets and multi-jet MC.  $\gamma$ +jet bkg has 0.66 normalisation.  $e\rightarrow\gamma$  bkg: W(ev), W(rv), top, tt MC.

# Selection optimisation: distributions

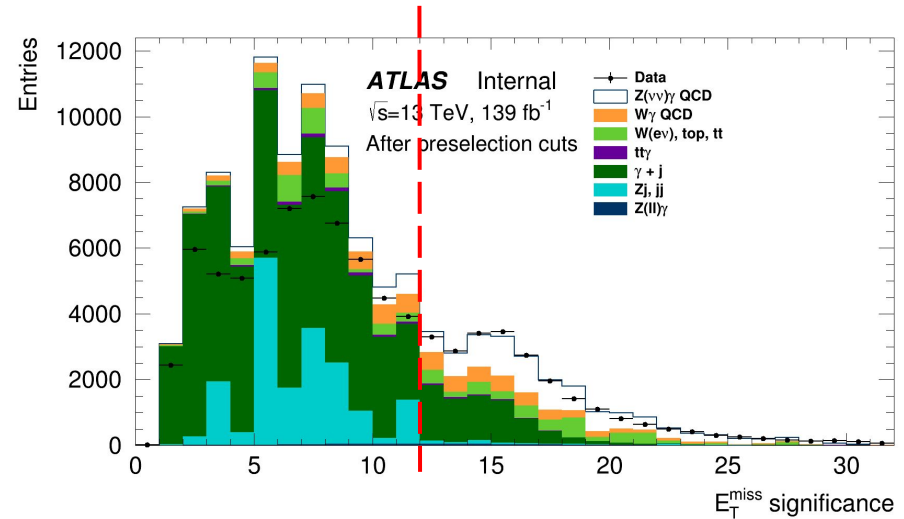


For  $\text{jet} \rightarrow \gamma$  bkg, the shape is taken from  $Z(\nu\nu)+\text{jets}$  and multi-jet MC.  $\gamma+\text{jet}$  bkg has 0.66 normalisation.  $e \rightarrow \gamma$  bkg:  $W(\text{ev})$ ,  $W(\text{rv})$ , top,  $t\bar{t}$  MC.

# Selection optimisation: multi-jet problematic normalisation



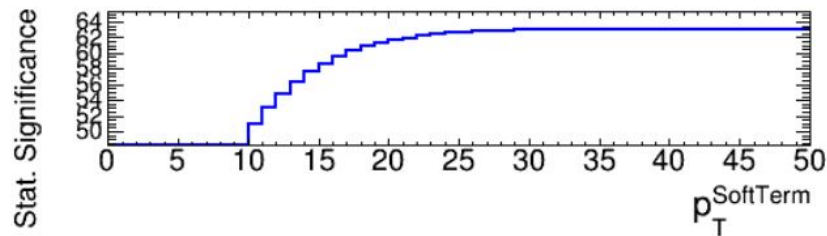
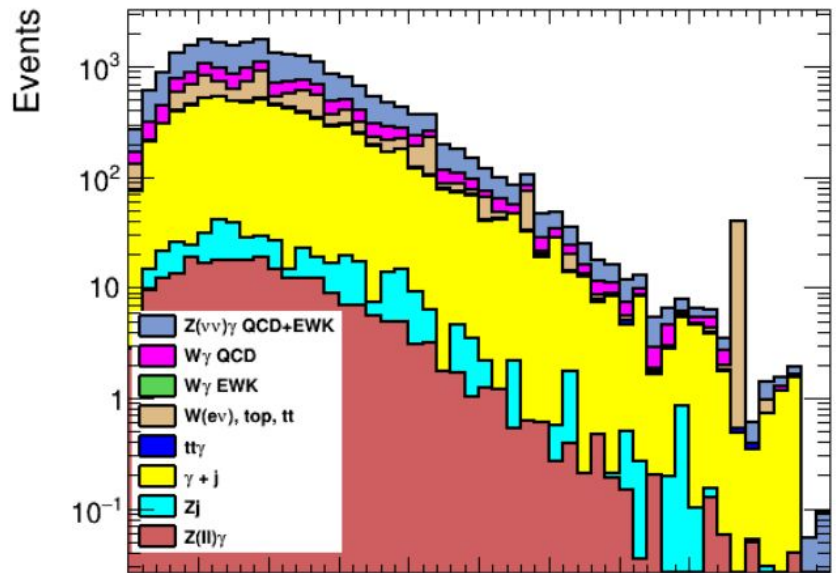
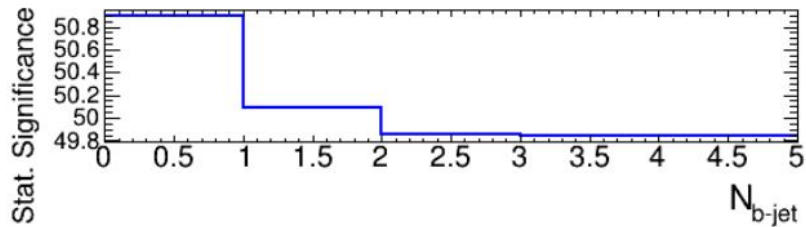
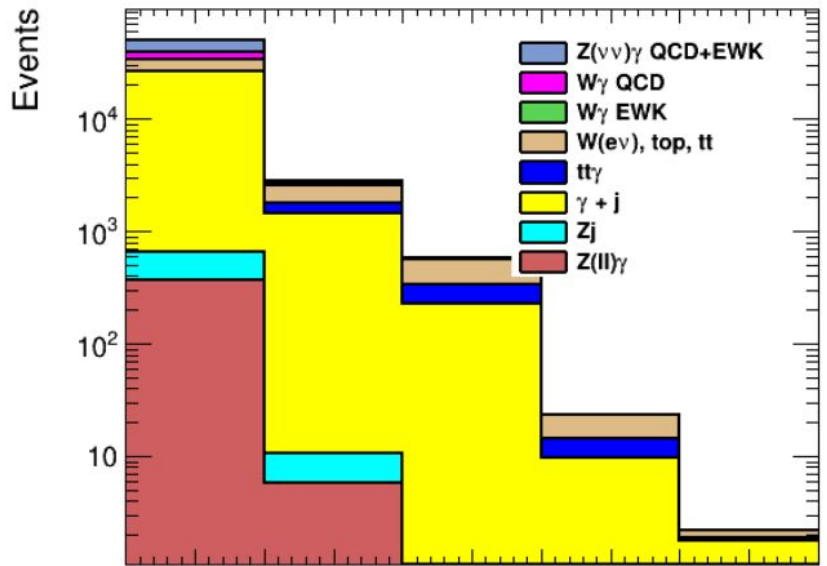
without multi-jet samples



with multi-jet samples

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

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



# Selection optimisation: event yields

Variable	FixedCutTight	FixedCutTightCaloOnly		
	W/O MultiJet	With 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	—
<b>Signal</b>				
Z( $\nu\nu$ ) $\gamma$ QCD	9752 $\pm$ 8	9840 $\pm$ 8	9355 $\pm$ 8	12380 $\pm$ 9
Z( $\nu\nu$ ) $\gamma$ EWK	0 $\pm$ 0	0 $\pm$ 0	0 $\pm$ 0	0 $\pm$ 0
<b>Total signal</b>	<b>9752 <math>\pm</math>8</b>	<b>9840 <math>\pm</math>8</b>	<b>9355 <math>\pm</math>8</b>	<b>12380 <math>\pm</math>9</b>
<b>Background</b>				
W $\gamma$ QCD	3610 $\pm$ 21	3645 $\pm$ 22	3265 $\pm$ 21	7456 $\pm$ 30
W $\gamma$ EWK	0 $\pm$ 0	0 $\pm$ 0	0 $\pm$ 0	0 $\pm$ 0
tt, top, W( $e\nu$ )	3128 $\pm$ 447	3463 $\pm$ 518	3328 $\pm$ 512	9039 $\pm$ 636
tt $\gamma$	210 $\pm$ 3	213 $\pm$ 3	165 $\pm$ 3	888 $\pm$ 6
$\gamma$ +j	7501 $\pm$ 78	7598 $\pm$ 78	6261 $\pm$ 71	59162 $\pm$ 203
Zj	213 $\pm$ 16	315 $\pm$ 20	295 $\pm$ 19	486 $\pm$ 23
Z(l) $\gamma$	266 $\pm$ 4	270 $\pm$ 4	242 $\pm$ 4	608 $\pm$ 7
MultiJet	—	1243.91 $\pm$ 1243.02	0.6 $\pm$ 0.4	18532 $\pm$ 4645
<b>Total bkg.</b>	<b>14928<math>\pm</math>455</b>	<b>15504<math>\pm</math>525</b>	<b>13558<math>\pm</math>518</b>	<b>96172 <math>\pm</math>4693</b>
<b>Stat. signif.</b>	<b>62.1<math>\pm</math>0.6</b>	<b>61.8<math>\pm</math>0.6</b>	<b>61.8<math>\pm</math>0.6</b>	<b>37.6 <math>\pm</math></b>

# Selection optimisation: isolation checks

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

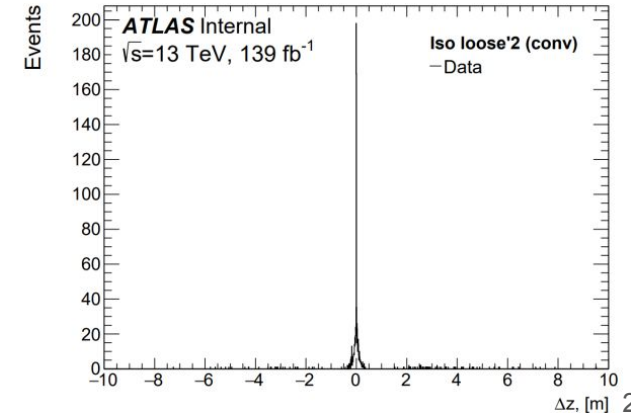
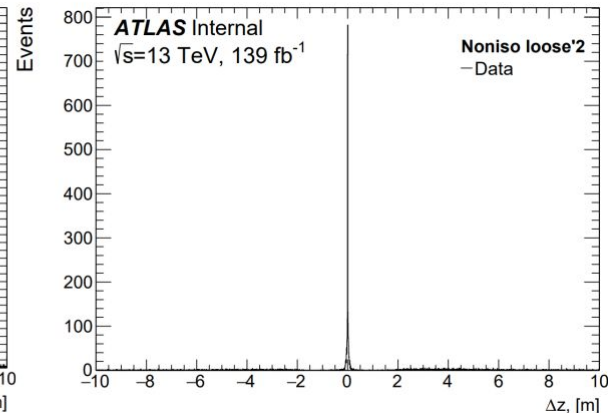
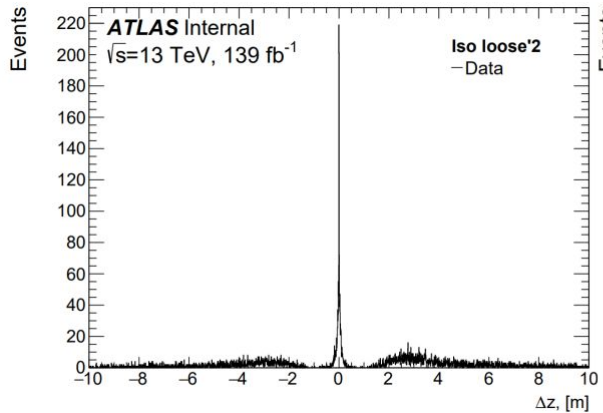
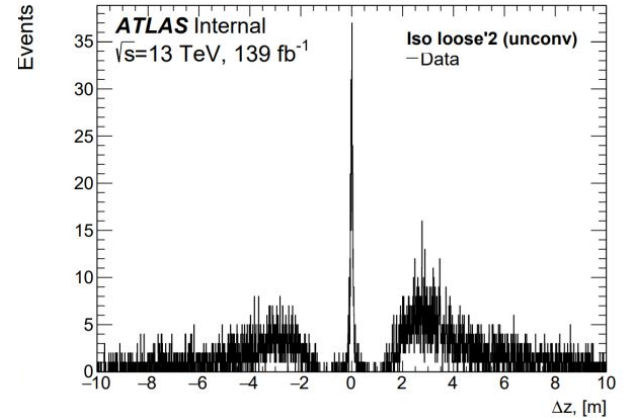
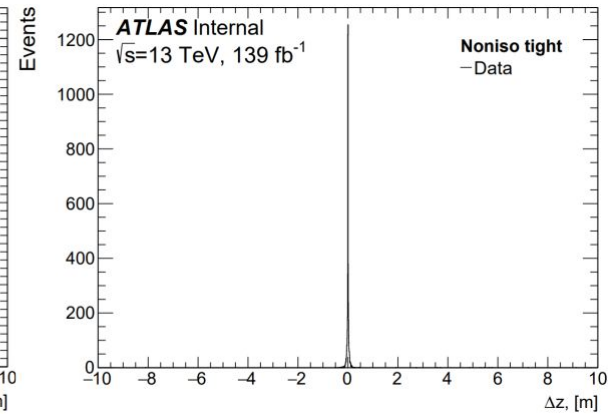
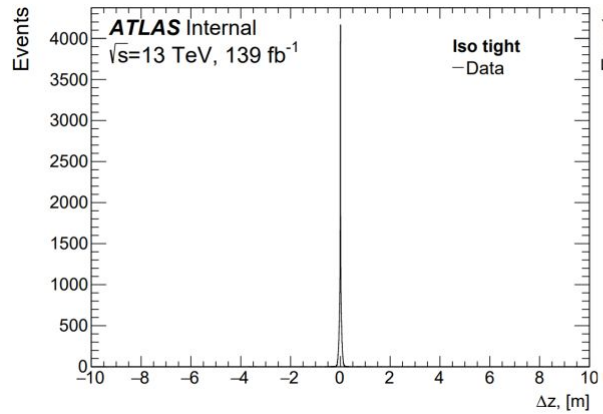
↑  
multivariate  
method

↑  
multivariate  
method

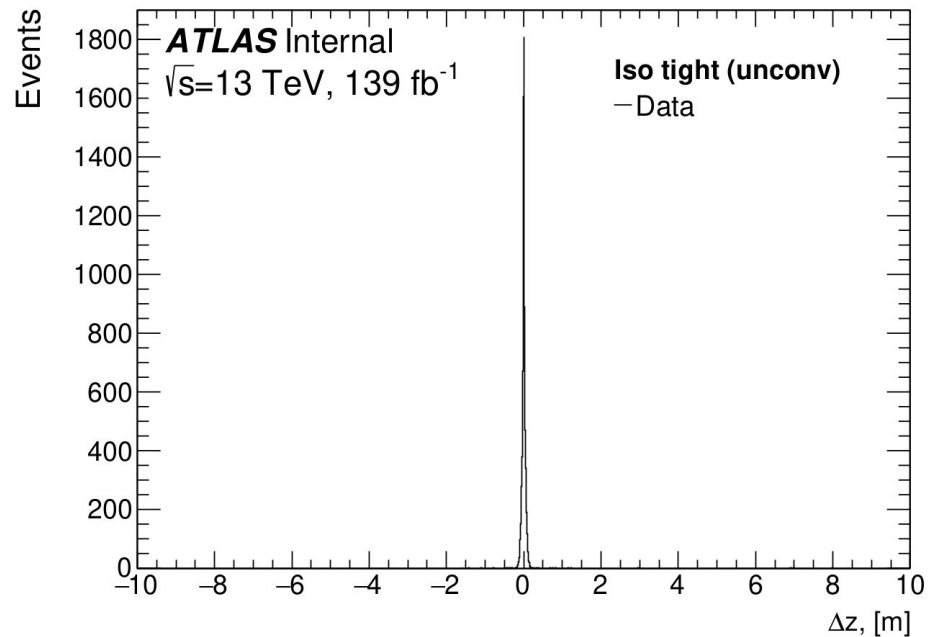
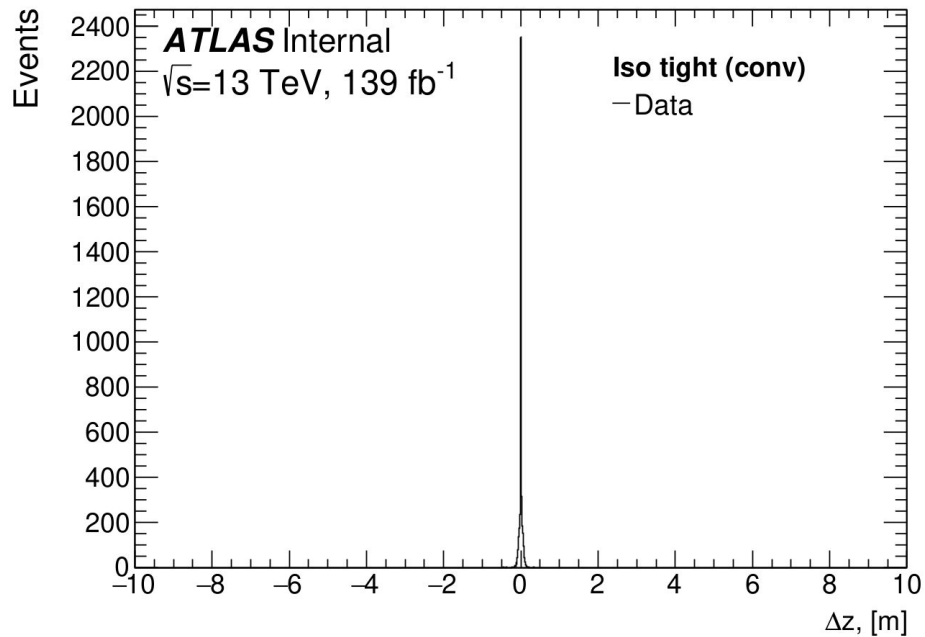
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method



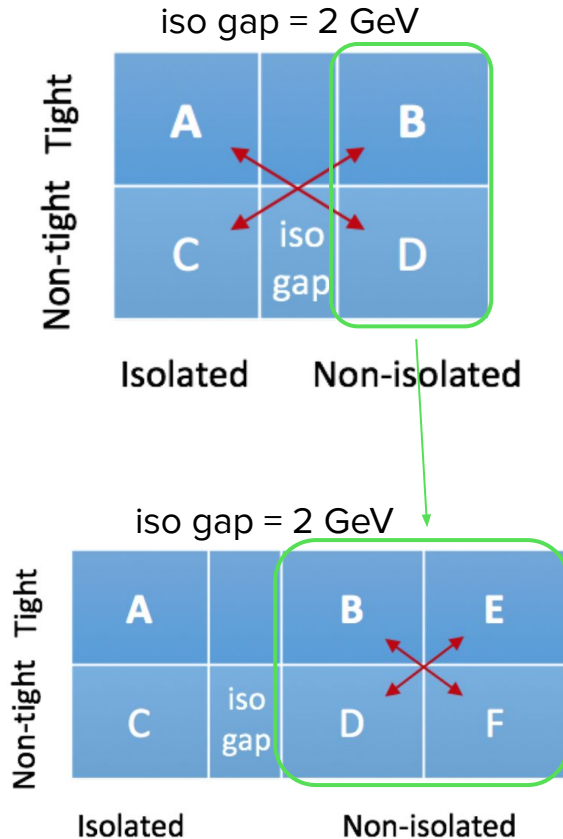
# Beam-induced background (BIB)



# Beam-induced background (BIB)



# jet $\rightarrow \gamma$ misID background: regions definition



## FixedCutTightCaloOnly:

- A:** tight,  $E_T^{\text{cone40}} - 0.022 p_T^\gamma < 2.45$  [GeV]
- B:** tight,  $2.45 + \text{gap} < E_T^{\text{cone40}} - 0.022 p_T^\gamma$  [GeV]
- C:** non-tight,  $E_T^{\text{cone40}} - 0.022 p_T^\gamma < 2.45$  [GeV]
- D:** non-tight,  $2.45 + \text{gap} < E_T^{\text{cone40}} - 0.022 p_T^\gamma$  [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:*  $w_{s3}, F_{side}, \Delta E$
- *loose'4:*  $w_{s3}, F_{side}, \Delta E, E_{ratio}$
- *loose'5:*  $w_{s3}, F_{side}, \Delta E, E_{ratio}, w_{tot}$

## FixedCutTightCaloOnly:

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

# jet $\rightarrow \gamma$ misID background: isolation working point

- Isolation: **FixedCutTight**, without upper cut

<b>FixedCutTight, (w/o upper cut)</b>				
MC				
	loose'2	loose'3	loose'4	loose'5
R-factor	1.05 $\pm$ 0.15	1.14 $\pm$ 0.15	1.19 $\pm$ 0.14	1.39 $\pm$ 0.17
Data-driven				
Cut	loose'2	loose'3	loose'4	loose'5
<b>7.95</b>	1.6 $\pm$ 0.3	1.5 $\pm$ 0.3	1.4 $\pm$ 0.3	1.4 $\pm$ 0.3
<b>8.45</b>	1.5 $\pm$ 0.3	1.5 $\pm$ 0.3	1.4 $\pm$ 0.3	1.4 $\pm$ 0.3
<b>8.95</b>	1.4 $\pm$ 0.3	1.3 $\pm$ 0.3	1.3 $\pm$ 0.3	1.3 $\pm$ 0.3
<b>9.45</b>	1.6 $\pm$ 0.4	1.5 $\pm$ 0.4	1.5 $\pm$ 0.4	1.5 $\pm$ 0.3
<b>9.95</b>	1.6 $\pm$ 0.4	1.5 $\pm$ 0.4	1.7 $\pm$ 0.4	1.6 $\pm$ 0.4

- Isolation: **FixedCutTight**, with upper cut 25.45 GeV

<b>FixedCutTight, (upper cut = 25.45 GeV)</b>				
MC				
	loose'2	loose'3	loose'4	loose'5
R-factor	1.06 $\pm$ 0.15	1.15 $\pm$ 0.16	1.21 $\pm$ 0.15	1.40 $\pm$ 0.17
Data-driven				
Cut	loose'2	loose'3	loose'4	loose'5
<b>8.45</b>	1.1 $\pm$ 0.2	1.1 $\pm$ 0.2	1.03 $\pm$ 0.18	1.06 $\pm$ 0.18
<b>8.95</b>	0.96 $\pm$ 0.18	0.97 $\pm$ 0.17	0.96 $\pm$ 0.17	0.97 $\pm$ 0.16
<b>9.05</b>	1.01 $\pm$ 0.18	1.02 $\pm$ 0.18	1.01 $\pm$ 0.18	1.01 $\pm$ 0.17
<b>9.45</b>	1.08 $\pm$ 0.19	1.10 $\pm$ 0.19	1.10 $\pm$ 0.19	1.12 $\pm$ 0.18
<b>9.95</b>	1.03 $\pm$ 0.18	1.03 $\pm$ 0.18	1.16 $\pm$ 0.19	1.16 $\pm$ 0.19
<b>10.45</b>	1.1 $\pm$ 0.2	1.1 $\pm$ 0.2	1.2 $\pm$ 0.2	1.2 $\pm$ 0.2
<b>10.95</b>	1.2 $\pm$ 0.2	1.2 $\pm$ 0.2	1.3 $\pm$ 0.2	1.3 $\pm$ 0.2

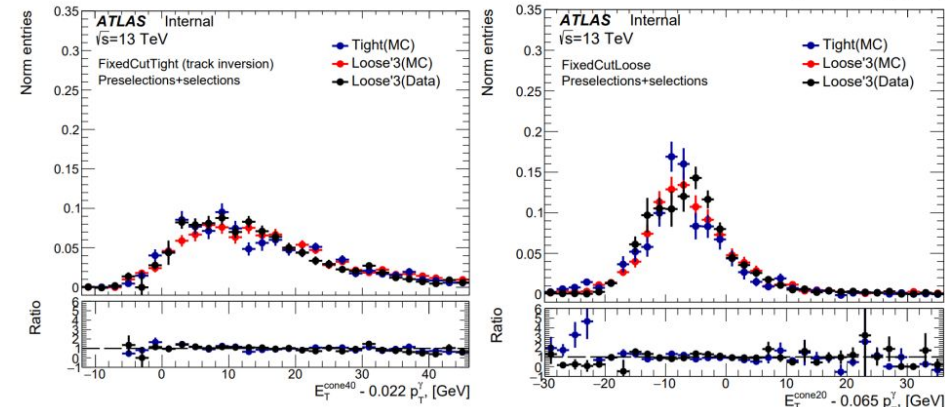
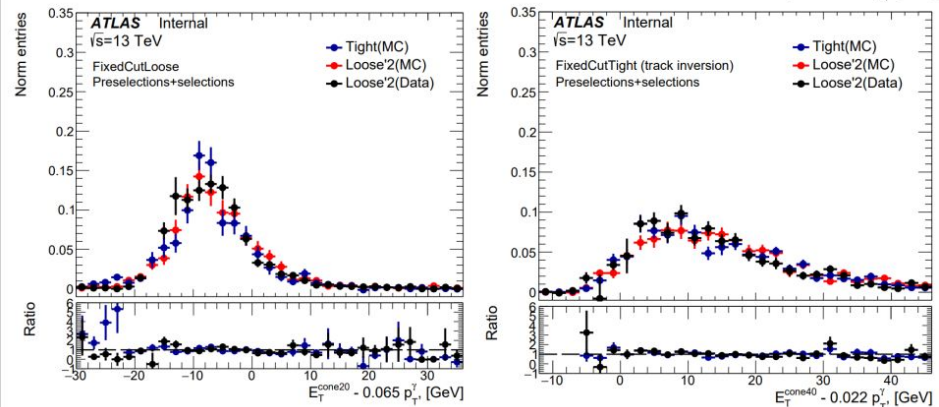
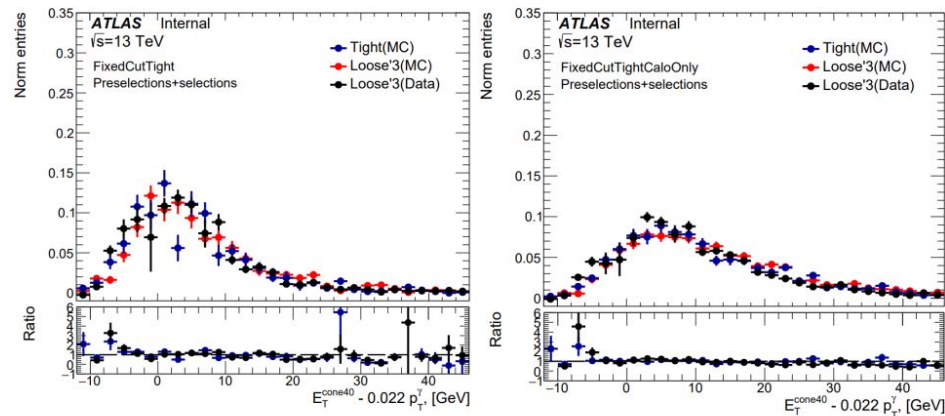
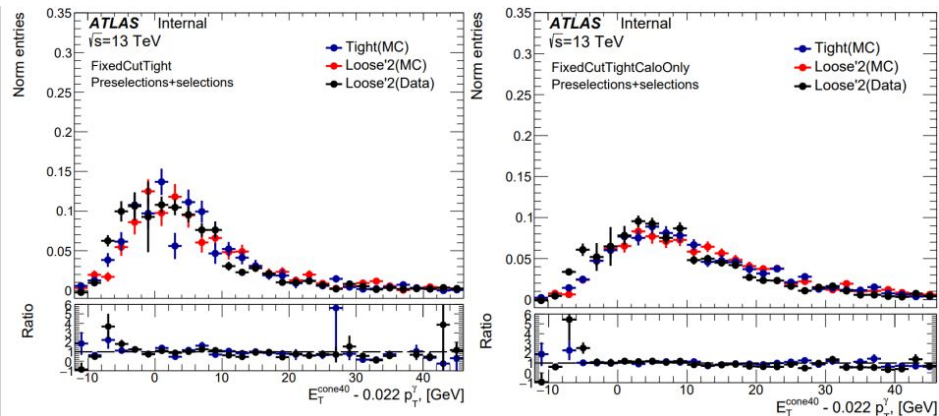
- Isolation: **FixedCutTight** and track inversion

<b>FixedCutTight (inversion), (w/o upper cut)</b>				
MC				
	loose'2	loose'3	loose'4	loose'5
R-factor	1.01 $\pm$ 0.12	1.15 $\pm$ 0.12	1.29 $\pm$ 0.13	1.58 $\pm$ 0.16
Data-driven				
Cut	loose'2	loose'3	loose'4	loose'5
<b>9.45</b>	1.09 $\pm$ 0.13	1.15 $\pm$ 0.13	1.09 $\pm$ 0.11	1.13 $\pm$ 0.11
<b>9.95</b>	1.08 $\pm$ 0.12	1.16 $\pm$ 0.12	1.11 $\pm$ 0.11	1.13 $\pm$ 0.10
<b>10.20</b>	1.07 $\pm$ 0.12	1.13 $\pm$ 0.12	1.09 $\pm$ 0.10	1.12 $\pm$ 0.10
<b>10.45</b>	1.09 $\pm$ 0.12	1.14 $\pm$ 0.12	1.10 $\pm$ 0.10	1.14 $\pm$ 0.10
<b>10.95</b>	1.18 $\pm$ 0.13	1.23 $\pm$ 0.12	1.17 $\pm$ 0.10	1.20 $\pm$ 0.10

- Isolation: **FixedCutTightCaloOnly**, without upper cut

<b>FixedCutTightCaloOnly, (w/o upper cut)</b>				
MC				
	loose'2	loose'3	loose'4	loose'5
R-factor	1.06 $\pm$ 0.10	1.14 $\pm$ 0.11	1.22 $\pm$ 0.10	1.40 $\pm$ 0.12
Data-driven				
Cut	loose'2	loose'3	loose'4	loose'5
<b>9.45</b>	1.08 $\pm$ 0.11	1.14 $\pm$ 0.11	1.12 $\pm$ 0.10	1.13 $\pm$ 0.10
<b>9.95</b>	1.07 $\pm$ 0.10	1.13 $\pm$ 0.10	1.15 $\pm$ 0.10	1.15 $\pm$ 0.10
<b>10.45</b>	1.09 $\pm$ 0.10	1.14 $\pm$ 0.10	1.14 $\pm$ 0.10	1.15 $\pm$ 0.10
<b>10.95</b>	1.18 $\pm$ 0.11	1.23 $\pm$ 0.11	1.21 $\pm$ 0.10	1.22 $\pm$ 0.10
<b>11.45</b>	1.23 $\pm$ 0.11	1.27 $\pm$ 0.11	1.22 $\pm$ 0.10	1.22 $\pm$ 0.10

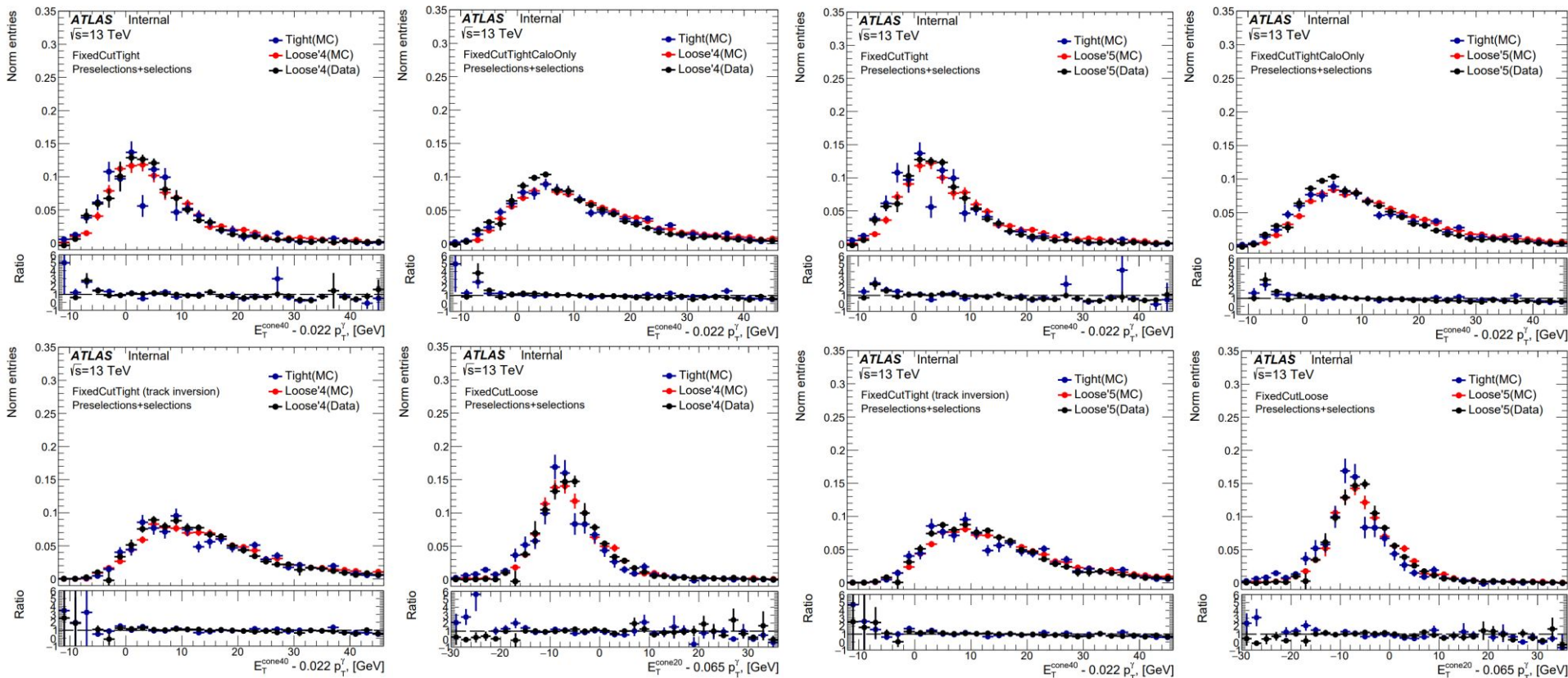
# jet $\rightarrow \gamma$ misID background: isolation working point



loose'2

loose'3

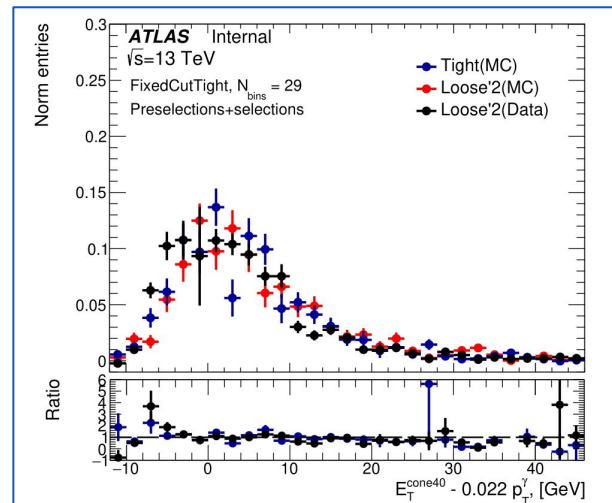
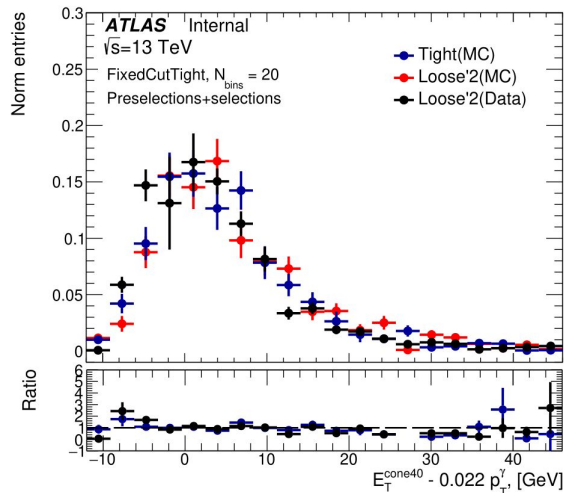
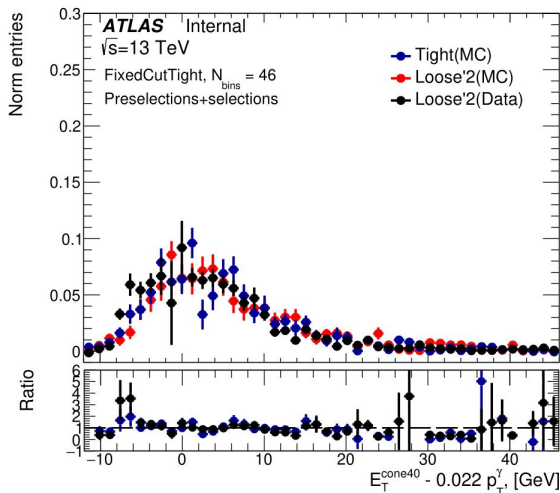
# jet $\rightarrow \gamma$ misID background: isolation working point



loose'4

loose'5

# jet $\rightarrow$ $\gamma$ misID background: isolation working point

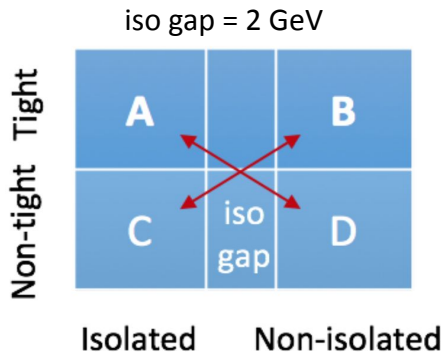


For blue point in 20 bin:  $0.0144971 \pm 0.00474881$   
 For black point in 20 bin:  $0.00177925 \pm 0.00131052$   
 For red point in 20 bin:  $0.00257787 \pm 0.00238254$   
 Ratio in 20 bin:  $5.62366 \pm 5.51433$

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

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

# jet $\rightarrow$ $\gamma$ misID background: estimation technique



The signal leakage parameters:

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

MC  $\rightarrow$

$$N_A^{\text{sig}} = \tilde{N}_A - R(\tilde{N}_B - c_B N_A^{\text{sig}}) \frac{\tilde{N}_C - c_C N_A^{\text{sig}}}{\tilde{N}_D - c_D N_A^{\text{sig}}}$$

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

The number of events arising in each of the regions:

$$N_A = N_A^{\text{sig}} + N_A^{\text{bkg}} + N_A^{\text{jet} \rightarrow \gamma};$$

$$N_B = c_B N_A^{\text{sig}} + N_B^{\text{bkg}} + N_B^{\text{jet} \rightarrow \gamma};$$

$$N_C = c_C N_A^{\text{sig}} + N_C^{\text{bkg}} + N_C^{\text{jet} \rightarrow \gamma};$$

$$N_D = c_D N_A^{\text{sig}} + N_D^{\text{bkg}} + N_D^{\text{jet} \rightarrow \gamma};$$

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

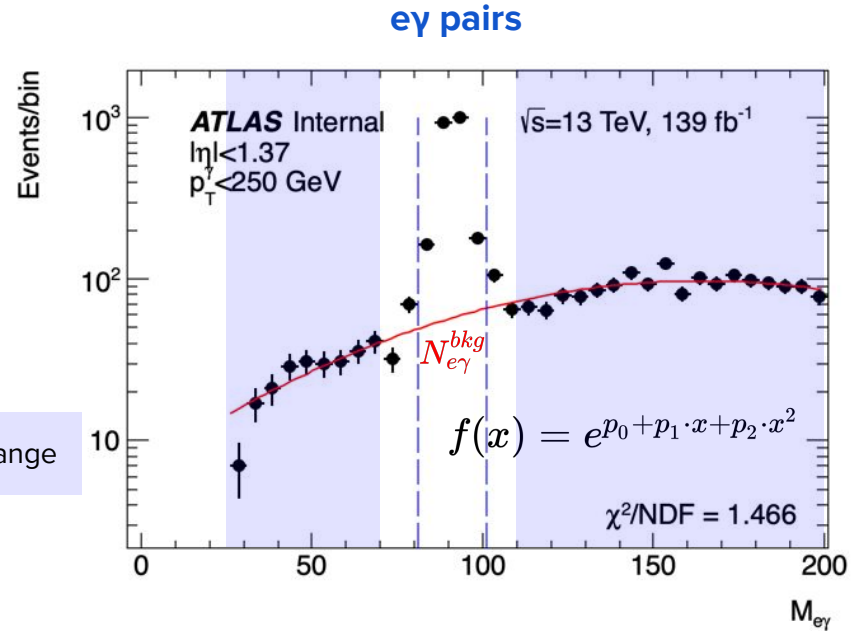
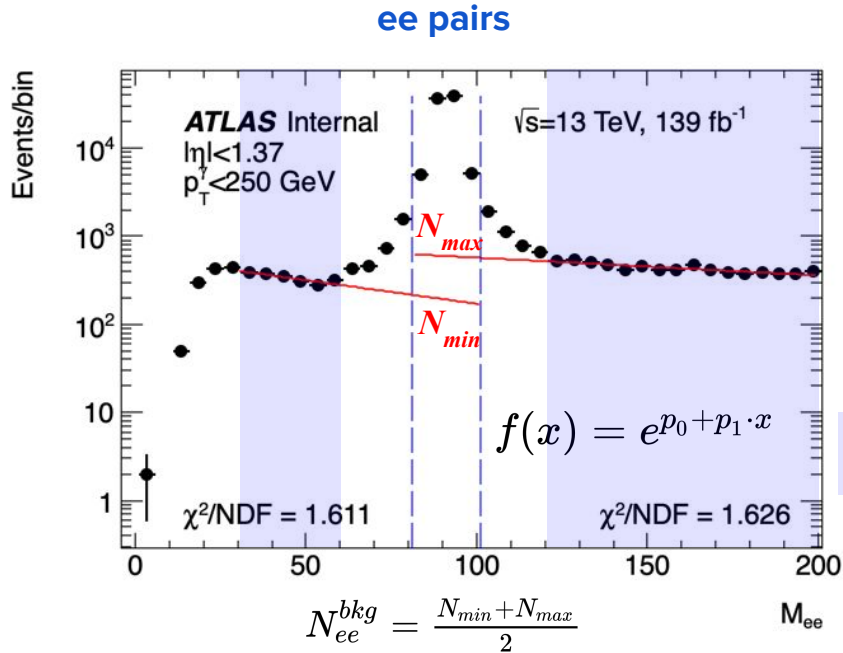
$$N_A^{\text{jet} \rightarrow \gamma}$$

$$\begin{cases} a = c_D - R c_B c_C; \\ b = \tilde{N}_D + c_D \tilde{N}_A - R(c_B \tilde{N}_C + c_C \tilde{N}_B); \\ c = \tilde{N}_D \tilde{N}_A - R \tilde{N}_C \tilde{N}_B. \end{cases}$$

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

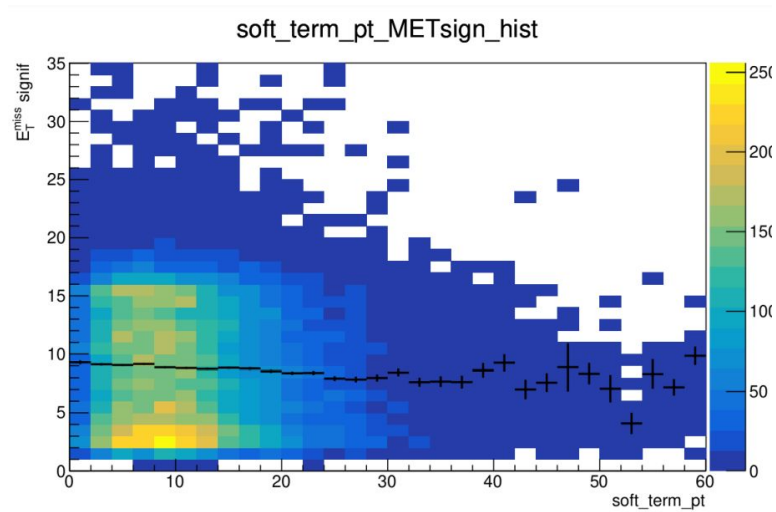
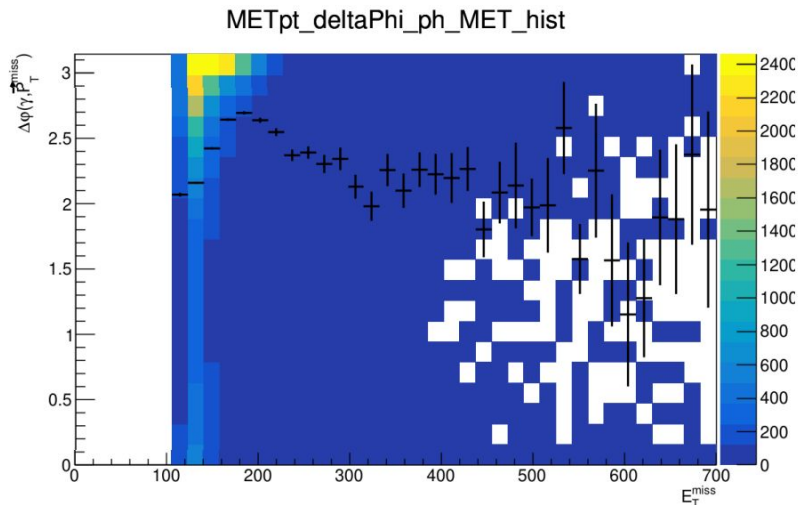


# $e \rightarrow \gamma$ misID background: background under Z peak



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

# $E_T^{\text{miss}} \rightarrow$ jet misID background: estimation strategy



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

R for variables configurations w/o soft term is very bad ( $\gg 1$ )

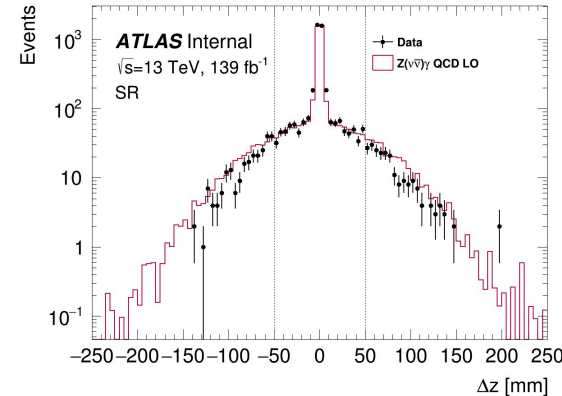
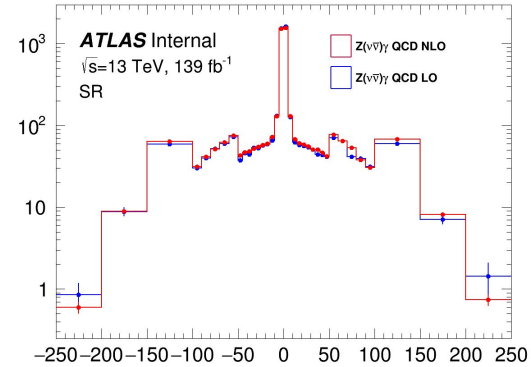
# Pile-up background

- In full Run2 Z( $\ell\gamma$ ) 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,  $E_T^{\text{miss}}$ , probability of such events should be much smaller.
- Fraction of pile-up background is calculated as:

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

- $SF_1$  is equal to the ratio of events in data to events in Sherpa MC sample near  $|\Delta z|$  around zero ( $4.61 \pm 0.07$ )
- $SF_2$  – normalization factor taking into account the mismodelling in the tails of  $|\Delta z|$  distribution (it was calculated for Sherpa Z $\gamma$  QCD by Z( $\ell\gamma$ ) inclusive team using events with FSR photons) ( $1.5 \pm 0.3$ )

$$f_{\text{PU}} = -(58 \pm 11)\%$$



# R factor data-driven optimization (I/IV)

- Optimization without  $W(\tau\nu)$  and with  $|\Delta\phi(E_T^{\text{miss}}, \gamma)| > 0.6$ , except FCLoose (cut 0.7)

FixedCutLoose (inverted), w/o upper cut				
MC				
	loose'2	loose'3	loose'4	loose'5
R-factor	$1.06 \pm 0.10$	$1.19 \pm 0.11$	$1.30 \pm 0.11$	$1.56 \pm 0.13$
Data-driven				
Cut	loose'2	loose'3	loose'4	loose'5
<b>8.95</b>	$1.14 \pm 0.12$	$1.08 \pm 0.10$	$1.00 \pm 0.08$	$0.97 \pm 0.08$
<b>9.45</b>	$1.10 \pm 0.11$	$1.04 \pm 0.10$	$0.96 \pm 0.08$	$0.94 \pm 0.07$
<b>9.95</b>	$1.08 \pm 0.11$	$1.03 \pm 0.09$	$0.96 \pm 0.08$	$0.95 \pm 0.07$
<b>10.45</b>	$1.03 \pm 0.10$	$0.99 \pm 0.09$	$0.92 \pm 0.07$	$0.91 \pm 0.07$
<b>10.95</b>	$1.08 \pm 0.11$	$1.01 \pm 0.09$	$0.93 \pm 0.07$	$0.93 \pm 0.07$
<b>11.45</b>	$1.09 \pm 0.11$	$1.00 \pm 0.09$	$0.94 \pm 0.07$	$0.92 \pm 0.07$

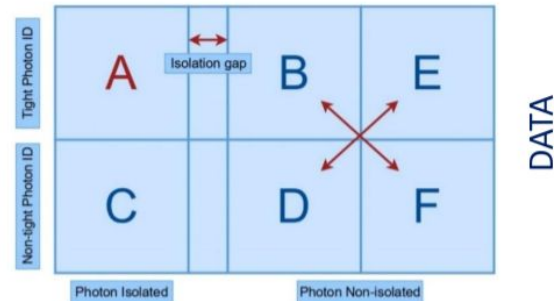
FixedCutTight (inversion), (w/o upper cut)				
MC				
	loose'2	loose'3	loose'4	loose'5
R-factor	$1.01 \pm 0.12$	$1.15 \pm 0.12$	$1.29 \pm 0.13$	$1.58 \pm 0.16$
Data-driven				
Cut	loose'2	loose'3	loose'4	loose'5
<b>9.45</b>	$1.10 \pm 0.08$	$1.16 \pm 0.07$	$1.12 \pm 0.06$	$1.17 \pm 0.06$
<b>9.95</b>	$1.12 \pm 0.06$	$1.17 \pm 0.07$	$1.13 \pm 0.06$	$1.17 \pm 0.06$
<b>10.20</b>	$1.09 \pm 0.07$	$1.14 \pm 0.07$	$1.12 \pm 0.06$	$1.16 \pm 0.06$
<b>10.45</b>	$1.10 \pm 0.07$	$1.15 \pm 0.07$	$1.13 \pm 0.06$	$1.17 \pm 0.06$
<b>10.95</b>	$1.16 \pm 0.07$	$1.22 \pm 0.07$	$1.18 \pm 0.06$	$1.22 \pm 0.06$

FixedCutTight, (upper cut = 25.45 GeV)				
MC				
	loose'2	loose'3	loose'4	loose'5
R-factor	$1.06 \pm 0.15$	$1.15 \pm 0.16$	$1.21 \pm 0.15$	$1.40 \pm 0.17$
Data-driven				
Cut	loose'2	loose'3	loose'4	loose'5
<b>8.45</b>	$1.15 \pm 0.13$	$1.16 \pm 0.12$	$1.16 \pm 0.11$	$1.21 \pm 0.11$
<b>8.95</b>	$1.11 \pm 0.13$	$1.11 \pm 0.12$	$1.14 \pm 0.11$	$1.17 \pm 0.11$
<b>9.45</b>	$1.20 \pm 0.14$	$1.22 \pm 0.13$	$1.27 \pm 0.13$	$1.30 \pm 0.12$
<b>9.95</b>	$1.16 \pm 0.14$	$1.17 \pm 0.13$	$1.23 \pm 0.12$	$1.28 \pm 0.12$
<b>10.45</b>	$1.19 \pm 0.14$	$1.20 \pm 0.14$	$1.22 \pm 0.12$	$1.26 \pm 0.12$

FixedCutTightCaloOnly, (w/o upper cut)				
MC				
	loose'2	loose'3	loose'4	loose'5
R-factor	$1.06 \pm 0.10$	$1.14 \pm 0.11$	$1.22 \pm 0.10$	$1.40 \pm 0.12$
Data-driven				
Cut	loose'2	loose'3	loose'4	loose'5
<b>9.45</b>	$1.16 \pm 0.07$	$1.21 \pm 0.06$	$1.20 \pm 0.06$	$1.23 \pm 0.06$
<b>9.95</b>	$1.15 \pm 0.06$	$1.20 \pm 0.06$	$1.20 \pm 0.05$	$1.22 \pm 0.05$
<b>10.45</b>	$1.16 \pm 0.06$	$1.21 \pm 0.06$	$1.20 \pm 0.06$	$1.22 \pm 0.05$
<b>10.95</b>	$1.22 \pm 0.07$	$1.27 \pm 0.06$	$1.24 \pm 0.06$	$1.26 \pm 0.06$

# R' estimation for data-driven regions

- R' is the correlation factor for MC in regions B-E, E, D-F, F
- $M_{\text{cut}}$  is the separation point of B-E and E regions,  $U_{\text{cut}}$  is the upper cut on the isolation



R'	$M_{\text{cut}}$ , GeV	$U_{\text{cut}}$ , GeV	loose'2	loose'3	loose'4	loose'5
FCTight	8.95	25.45	$1.02 \pm 0.16$	$1.13 \pm 0.18$	$1.11 \pm 0.16$	$1.26 \pm 0.18$
FCTight (invers.)	10.20	—	$1.6 \pm 0.3$	$1.7 \pm 0.2$	$1.57 \pm 0.18$	$1.68 \pm 0.19$
FCCaloOnly	9.95	—	$1.17 \pm 0.12$	$1.32 \pm 0.12$	$1.34 \pm 0.11$	$1.51 \pm 0.12$
FCLoose (invers.)	10.45	—	$1.35 \pm 0.15$	$1.37 \pm 0.13$	$1.32 \pm 0.11$	$1.42 \pm 0.12$

# Regions definition

Selections	Cut Value
$E_T^{\text{miss}}$	$> 120 \text{ GeV}$
$E_T^\gamma$	$> 150 \text{ GeV}$
Number of tight isolated photons	$N_\gamma = 1$
Number of jets	$N_{\text{jets}} \geq 2$
Lepton veto	$N_e = 0, N_\mu = 0$
$E_T^{\text{miss}}$ significance	$> 12$
$ \Delta\phi(\gamma, \vec{p}_T^{\text{miss}}) $	$> 0.4$
$ \Delta\phi(j_1, \vec{p}_T^{\text{miss}}) $	$> 0.3$
$ \Delta\phi(j_2, \vec{p}_T^{\text{miss}}) $	$> 0.3$
$p_T^{\text{SoftTerm}}$	$< 16 \text{ GeV}$

Table 2: Event selection criteria for  $Z(\nu\bar{\nu})\gamma jj$  candidate events.

Region	Var1	Var2
A	$(E_T^{\text{miss}} \text{ significance} > 12 \text{ AND } \Delta\phi(p_T^{\text{miss}}, j_1) > 0.3 \text{ AND } \Delta\phi(p_T^{\text{miss}}, j_2) > 0.3 \text{ AND } N_{\text{jets}} > 1)$	$(p_T^{\text{SoftTerm}} < 16 \text{ GeV AND } p_T^{\text{cone20}}/p_T < 0.05)$
B	$(E_T^{\text{miss}} \text{ significance} < 12 \text{ OR } \Delta\phi(p_T^{\text{miss}}, j_1) < 0.3 \text{ OR } \Delta\phi(p_T^{\text{miss}}, j_2) < 0.3 \text{ OR } N_{\text{jets}} \leq 1)$	$(p_T^{\text{SoftTerm}} < 16 \text{ GeV AND } p_T^{\text{cone20}}/p_T < 0.05)$
C	$(E_T^{\text{miss}} \text{ significance} > 12 \text{ AND } \Delta\phi(p_T^{\text{miss}}, j_1) > 0.3 \text{ AND } \Delta\phi(p_T^{\text{miss}}, j_2) > 0.3 \text{ AND } N_{\text{jets}} > 1)$	$(p_T^{\text{SoftTerm}} > 16 \text{ GeV OR } p_T^{\text{cone20}}/p_T > 0.05)$
D	$(E_T^{\text{miss}} \text{ significance} < 12 \text{ OR } \Delta\phi(p_T^{\text{miss}}, j_1) < 0.3 \text{ OR } \Delta\phi(p_T^{\text{miss}}, j_2) < 0.3 \text{ OR } N_{\text{jets}} \leq 1)$	$(p_T^{\text{SoftTerm}} > 16 \text{ GeV OR } p_T^{\text{cone20}}/p_T > 0.05)$

Table 12: Definition of two boolean variables used to define ABCD regions.  $p_T^{\text{SoftTerm}} < 60 \text{ GeV}$  requirement was applied to all regions.

# Cuts definition

```
cut1 = (n_ph == 1) && (ph_pt > 150) && (metTST_pt > 120) && (fabs(ph_z_point) < 250);  
cut2 = (n_e_looseBL == 0) && (n_mu == 0);  
cut3 = (ph_isem == 0) && ((ph_iso_et40 - 0.022 * ph_pt) < 2.45) && (soft_term_pt < 60);  
cut4A = A_Selection();  
cut4B = B_Selection();  
cut4C = C_Selection();  
cut4D = D_Selection();
```

# Backup 1

reproc-27-11-20

```
total = 99947.6
cut1 applied = 97412.2
cut2 applied = 96476.4
cut3 applied = 56342.3
cut4A applied = 122.173
cut4B applied = 36598.8
cut4C applied = 52.228
cut4D applied = 16588.9
```

reproc-30-09-21

```
total = 79116.5
cut1 applied = 77523.2
cut2 applied = 72555.3
cut3 applied = 57115
cut4A applied = 437.691
cut4B applied = 41491.9
cut4C applied = 91.1535
cut4D applied = 12763
```