Standard Model tests with $Z(\nu\nu)\gamma$ production processes

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National Research Nuclear University "MEPhI"

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Personpower

Evgeny Soldatov – PostDoc (and MEPhI lecturer)   **analysis co-contact**
Other activities: ATLAS e/gamma PhotonID group convener, ATLAS SM group derivation software contact, ATLAS MEPhI group deputy team leader, analysis co-contact

Anastasia Kurova – PhD student, 4th year   **analysis co-contact**
Other activities: supervision of bachelor student

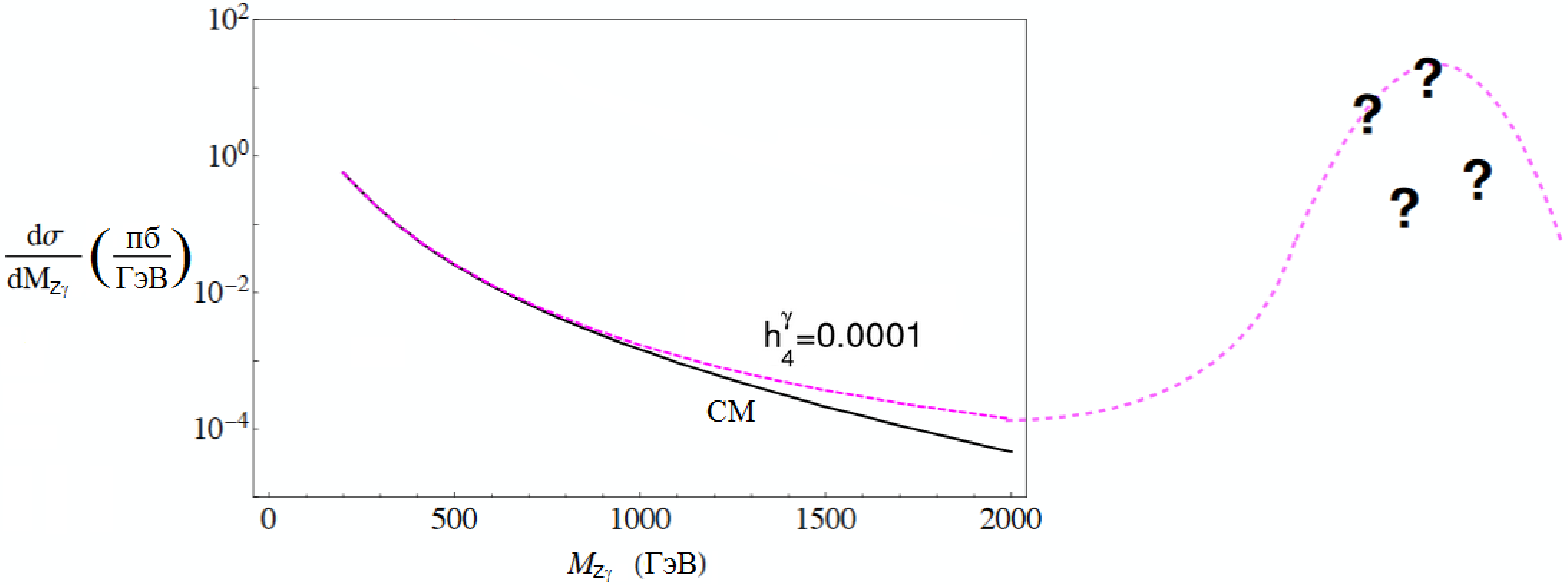
Aleksandr Petukhov – PhD student, 1st year
Other activities: Qualification task “TRT PID with NN”

Diana Pyatiizbyantseva – PhD student, 2nd year
Other activities: Improvement of the TRT hit classification

Also we have two bachelor students:
Artur Semushin,
Dmitriy Zubov

Introduction

- The goal of our studies is to test SM with high precision and to find any deviation from it.
- The deviation can appear, if there is a new physics at high energies. This method to search for the new physics becomes very important, if the new physics scale is above the energy range accessible by the LHC.



- Multiboson production is a very sensitive tool to test SM EWK theory. Also it is possible to have very precise theoretical predictions for this field.
- Interesting feature of Zγ production is that all triple gauge couplings and most of quartic gauge couplings, containing these particles, are forbidden in SM.
- The choice of neutrino channel is motivated by a higher Z boson branching ratio into neutrinos in comparison to the charged lepton decays of Z and better background control in comparison with the hadronic channel.

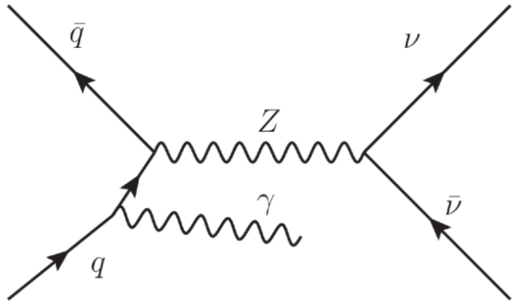
Previous Run2 analysis

JHEP 12 (2018) 010

- We used 2015+2016 dataset for relatively quick measurement of inclusive Z(νν)+γ production and search of aTGCs.

MC signal: Sherpa NLO; Main bkgs: Wγ, γ+jet, e→γ misID, jet→γ misID

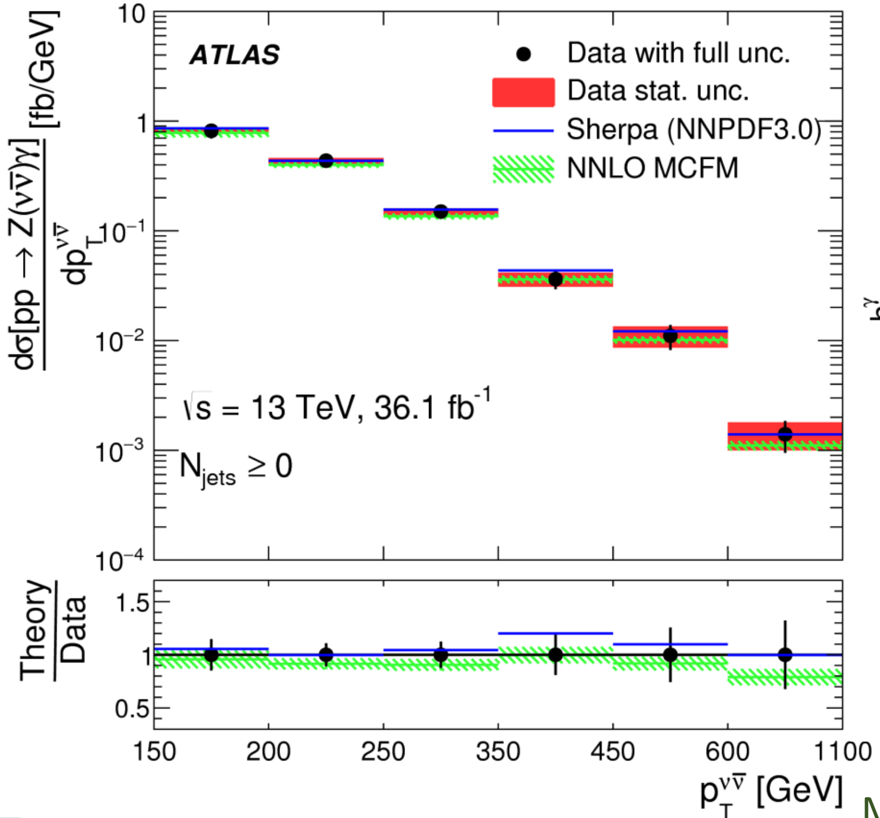
from MC with normalization from data CRs (Wγ, γ+jet); data-driven (e→γ misID, jet→γ misID)



➢ **Measurement** of integrated and differential cross-sections (vs. $E_T[\gamma]$, $p_T[miss]$, N_{jets})

$\sigma^{ext.fid.}$ [fb] Measurement	$\sigma^{ext.fid.}$ [fb] NNLO MCFM Prediction
$N_{jets} \geq 0$	
$83.7^{+3.6}_{-3.5}$ (stat.)$^{+6.9}_{-6.2}$ (syst.)$^{+1.7}_{-2.0}$ (lumi.)	78.1 ± 0.2(stat.)± 4.7(syst.)
$N_{jets} = 0$	
$52.4^{+2.4}_{-2.3}$ (stat.)$^{+4.0}_{-3.6}$ (syst.)$^{+1.2}_{-1.1}$ (lumi.)	55.9 ± 0.1(stat.)± 3.9(syst.)

Good agreement!



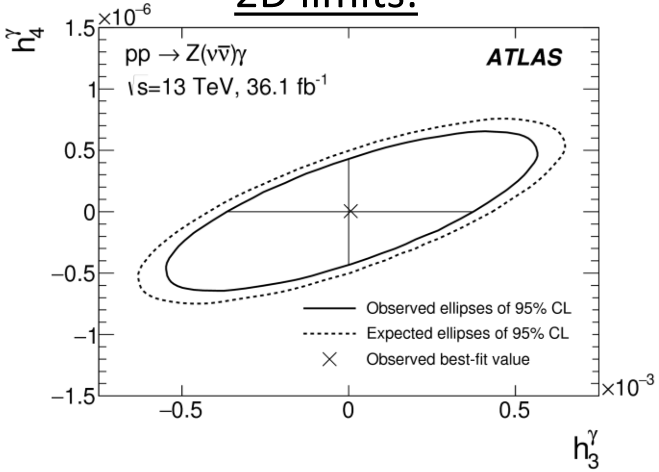
➢ **Setting limits** on anomalous TGC in $h_i(V)$ vertex functions and EFT formalisms

Dim-8 EFT formalism:

Parameter	Limit 95% CL	
	Measured [TeV^{-4}]	Expected [TeV^{-4}]
$C_{\widetilde{B}W}/\Lambda^4$	$(-1.1,\ 1.1)$	$(-1.3,\ 1.3)$
C_{BW}/Λ^4	$(-0.65,\ 0.64)$	$(-0.74,\ 0.74)$
C_{WW}/Λ^4	$(-2.3,\ 2.3)$	$(-2.7,\ 2.7)$
C_{BB}/Λ^4	$(-0.24,\ 0.24)$	$(-0.28,\ 0.27)$

Still the best limits on anomalous nTGC!

2D limits:

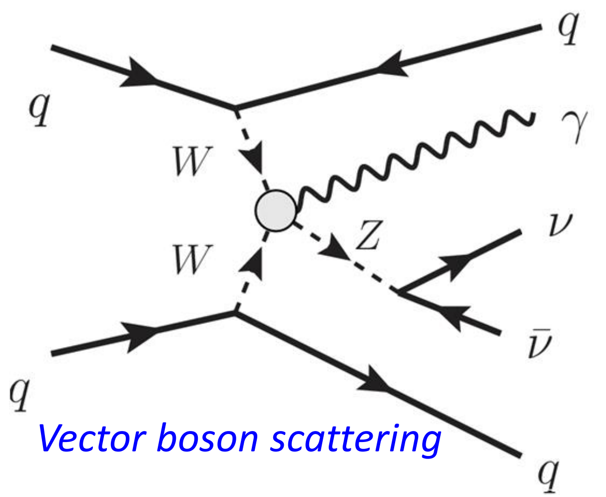


Main uncertainties are from statistics, MC modelling, data-driven bkgs.

Introduction, motivation of the current analysis

Topology: **γ+p_T(miss)+2 hadronic jets**. All objects are with high energy.

- EWK production (QCD=0; QED≤5) – aim of the study
- QCD production (QCD=2; QED=2) – main irreducible background.



Vector boson scattering

➢ **The main goal of this study is to <u>have an observation or evidence for the Z(νν)γ EWK process</u> for the first time.**

- We will measure integrated cross-section

➢ **EWK Z(νν)γ production is the one of the most sensitive final states to <u>SM and anomalous QGCs (O_M and O_T operators).</u>**

- We will set limits on anomalous couplings parameters using EFT formalism

Dimension 8 operators

	WWWW	WWZZ	ZZZZ	WWAZ (SM)	WWAA	ZZZA (Beyond SM)	ZZAA (Beyond SM)	ZAAA (Beyond SM)	AAAA
$\mathcal{O}_{S,0/1}$	✓	✓	✓						
$\mathcal{O}_{M,0/1/6/7}$	✓	✓	✓	✓	✓	✓	✓		
$\mathcal{O}_{M,2/3/4/5}$		✓	✓	✓	✓	✓	✓		
$\mathcal{O}_{T,0/1/2}$	✓	✓	✓	✓	✓	✓	✓	✓	✓
$\mathcal{O}_{T,5/6/7}$		✓	✓	✓	✓	✓	✓	✓	✓
$\mathcal{O}_{T,8/9}$			✓			✓	✓	✓	✓

Editorial board:

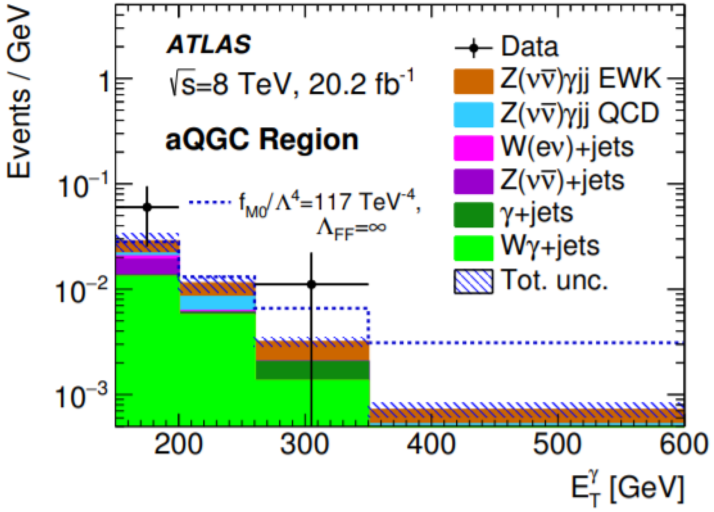
LI, Shu (TDLI)
PRICE, Darren (Manchester)
RESCONI, Silvia (Milano) – Chair

Target:

Public results for ICHEP

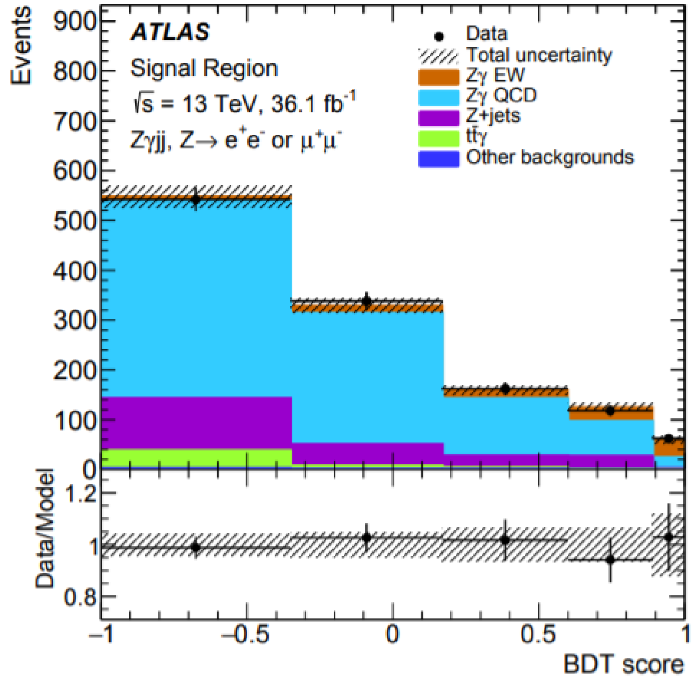
Measurement status in the world

➢ ATLAS neutrino channel results with 20 fb^{-1} @ 8 TeV: 4 observed events, with 2±1 background events **(~1σ)**

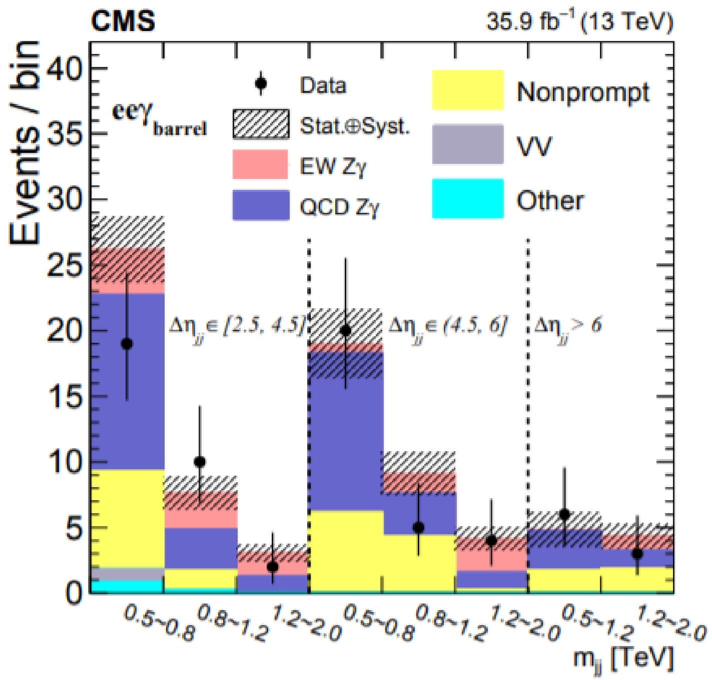


Neutrino channel was used only for aQGC limits setting

➢ ATLAS ch. lepton channel results with 36 fb^{-1} @ 13 TeV: 1222 observed events, with 1119 background events (**4.1σ**)
Published in Phys. Lett. B 803 (2020) 135341



➢ CMS ch. lepton channel results with 36 fb^{-1} @ 13 TeV: 285 observed events, with 210±10 background events (**4.7σ**)
Submitted to JHEP



No observation of Zγ EWK process still.
No evidence of Z(νν)γ EWK.

Selections, signal and control regions

Main event selections:

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

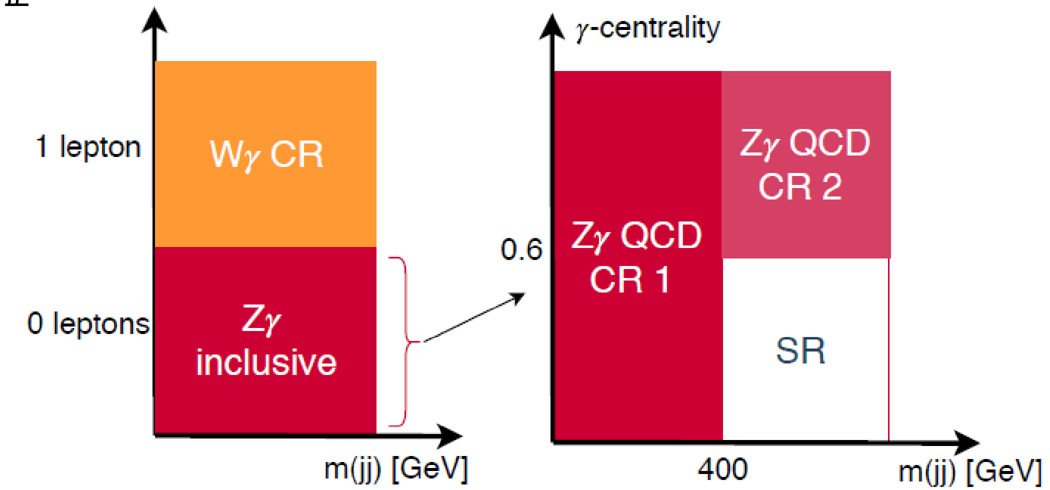
Object selections are summarized in back-up

- Full Run2 dataset is used.

We construct 4 regions: 1 SR and 3 CRs:

$W\gamma$ control region	
$N_{leptons}$	$= 1$
$Z\gamma jj$ QCD control region 1	
$N_{leptons}$	$= 0$
m_{jj}	< 400 GeV
$Z\gamma jj$ QCD control region 2	
$N_{leptons}$	$= 0$
m_{jj}	> 400 GeV
γ-centrality	> 0.6
$Z\gamma jj$ EWK signal region	
$N_{leptons}$	$= 0$
m_{jj}	> 400 GeV
γ-centrality	< 0.6

- MC at low m_{jj} is compatible with data → no low cut on m_{jj}
- γ-centrality cut was implemented to construct additional CR in order to check the possible m_{jj} mismodeling at high values



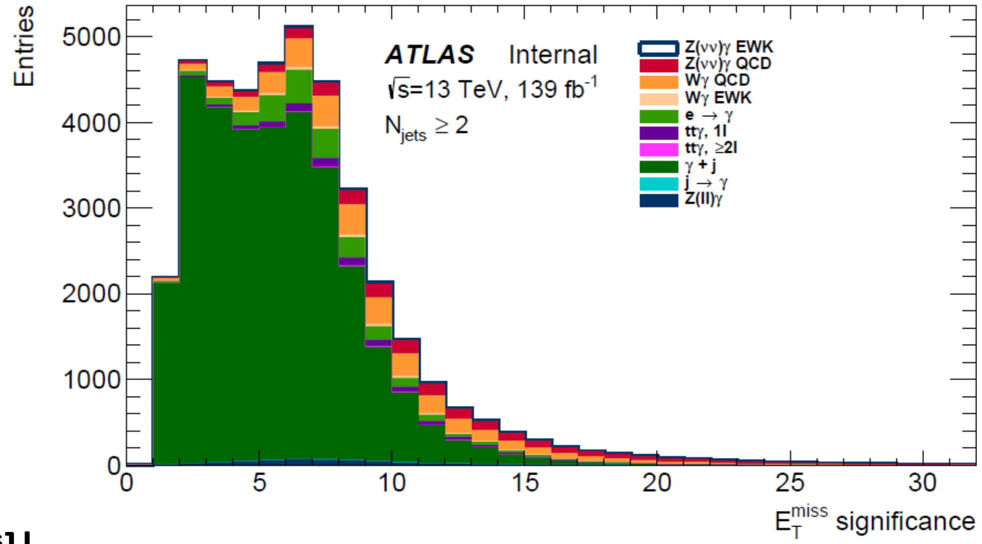
Selection optimization

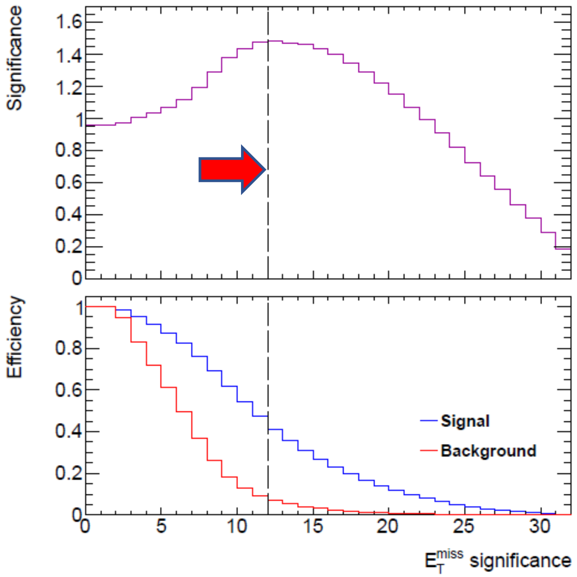
- ➢ Optimizing additional cuts to get better statistical significance.

Initial significance: **0.96**

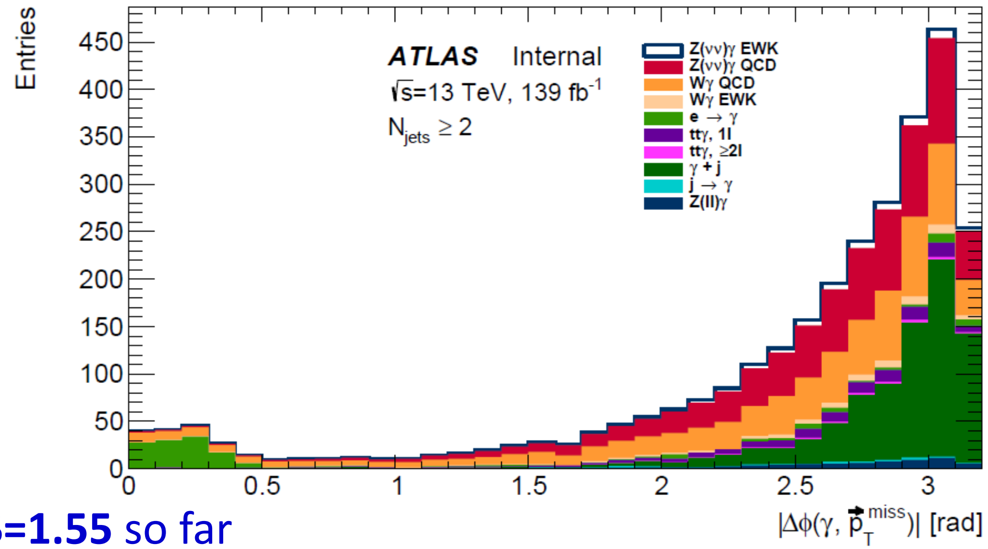
- **E_T^{miss}-significance**

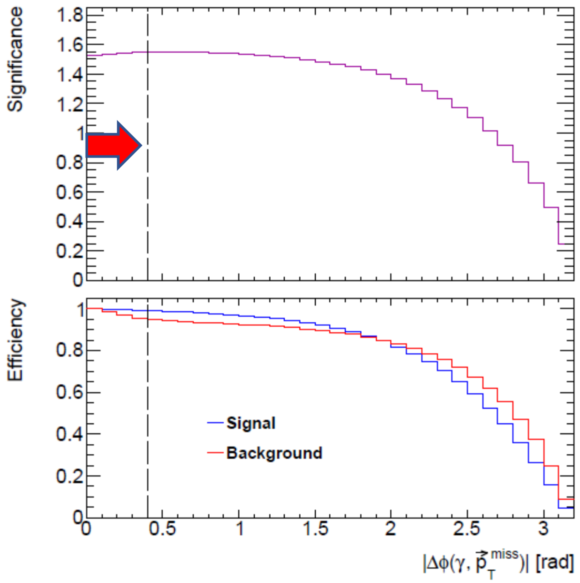
$$S = N_{signal}/\sqrt{N_{signal} + N_{bkg}}, eff = N_{passed}/N_{all}$$





- **|Δφ[γ, p_T^{miss}]|**



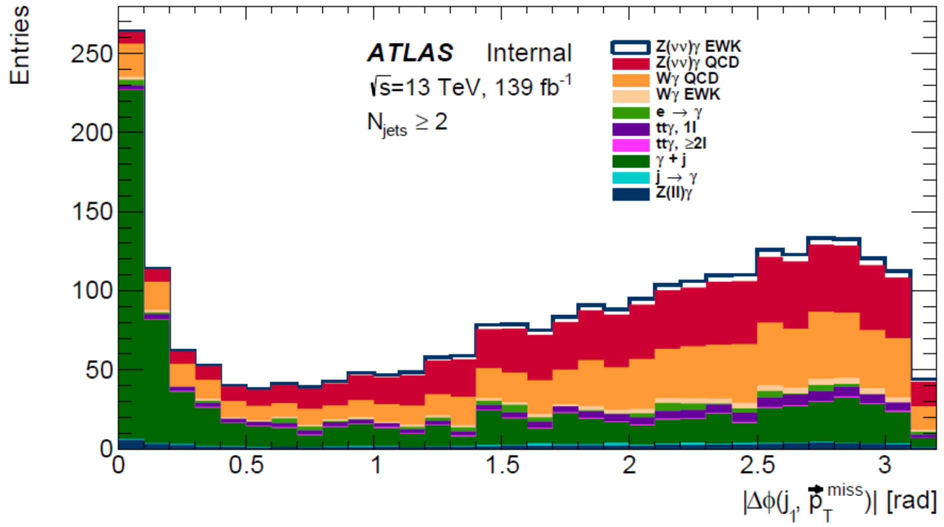


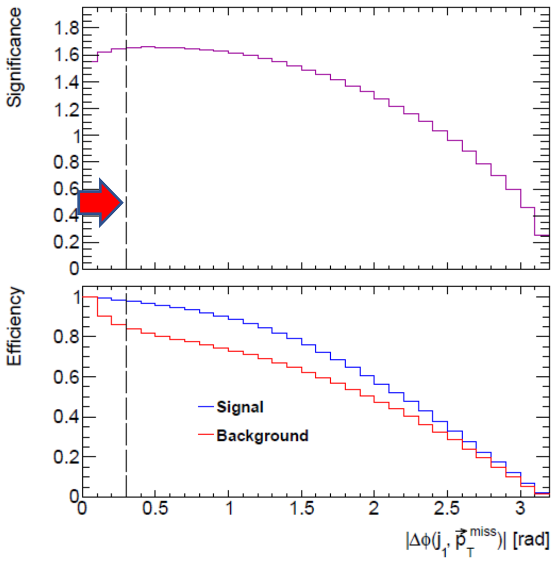
- ➢ Resulting **S=1.55** so far

Selection optimization II

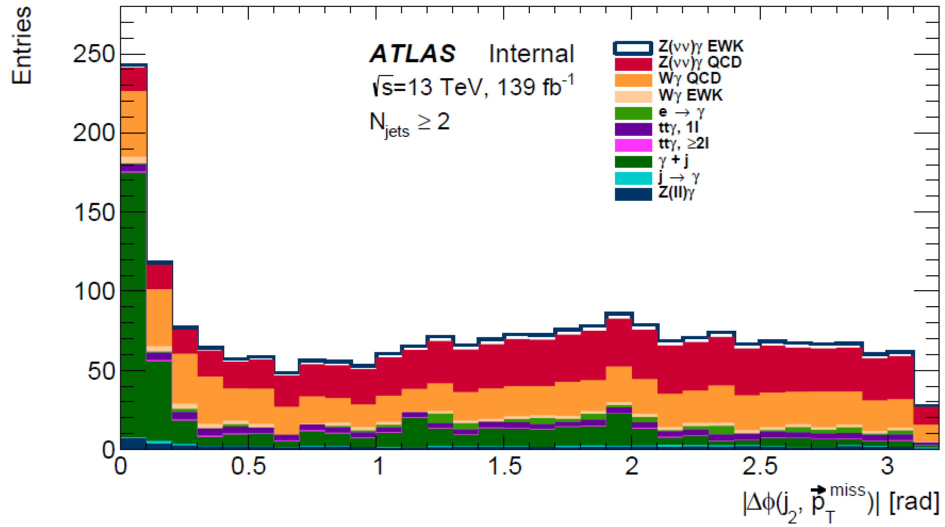
- Optimizing additional cuts to get better statistical significance.

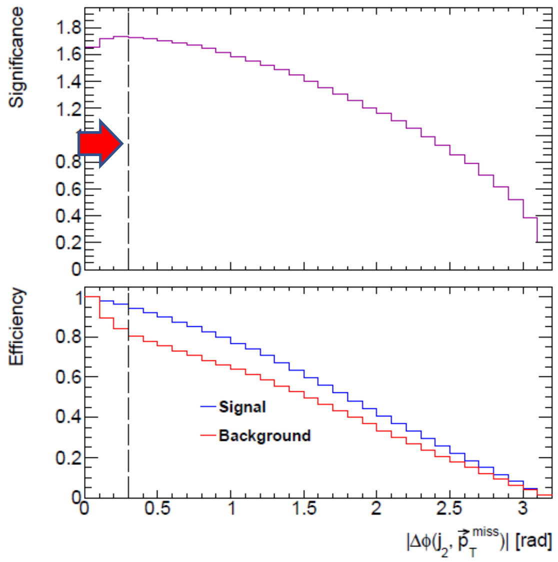
- $|\Delta\varphi[j_1, p_T^{miss}]|$





- $|\Delta\varphi[j_2, p_T^{miss}]|$



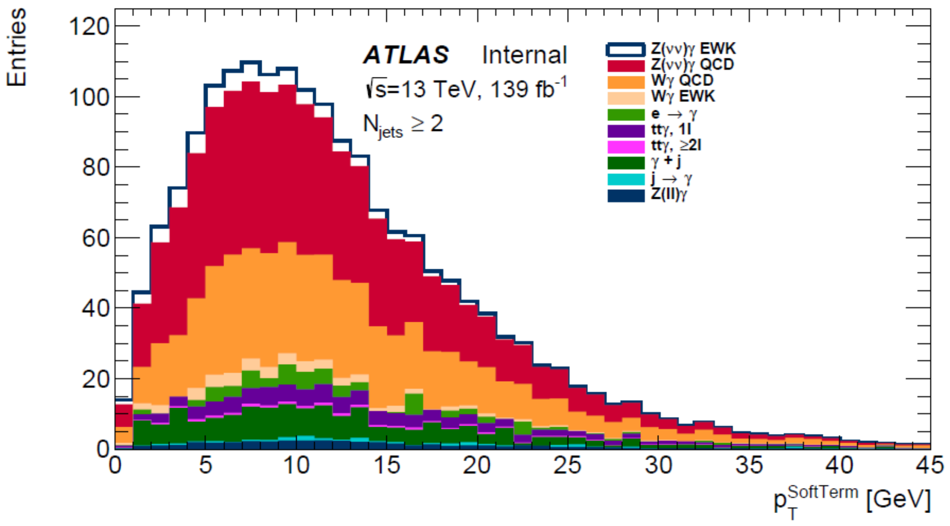


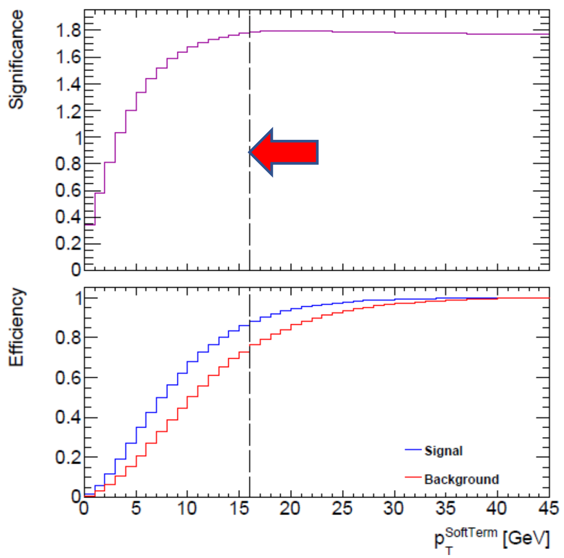
- Resulting **S=1.73**

Selection optimization III

- Optimizing additional cuts to get better statistical significance.

- **p_T^{miss} soft term**





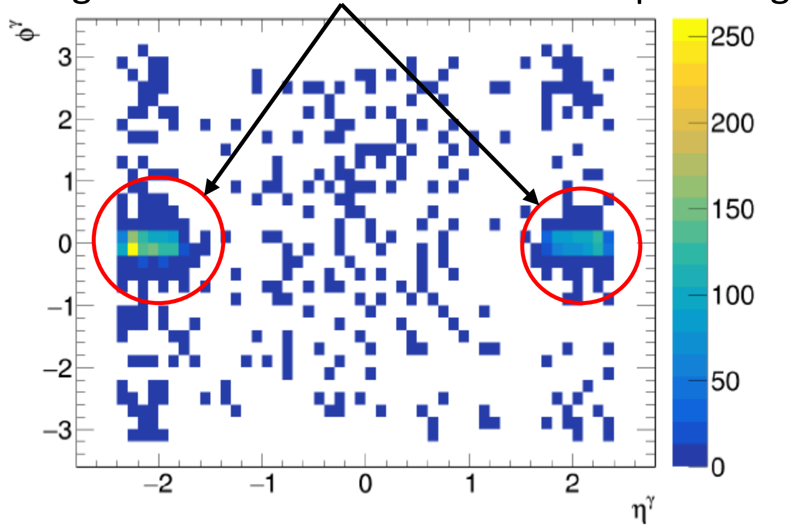
- Resulting **S=1.78**

Photon pointing selection

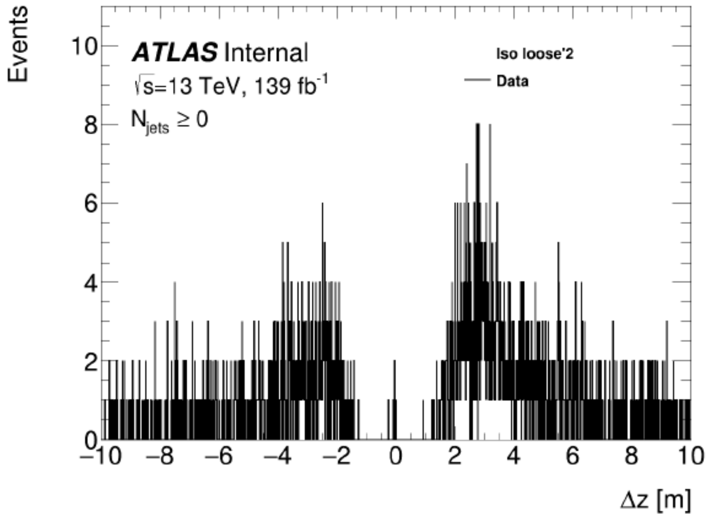
- Loose isolated photons are contaminated by beam-induced background

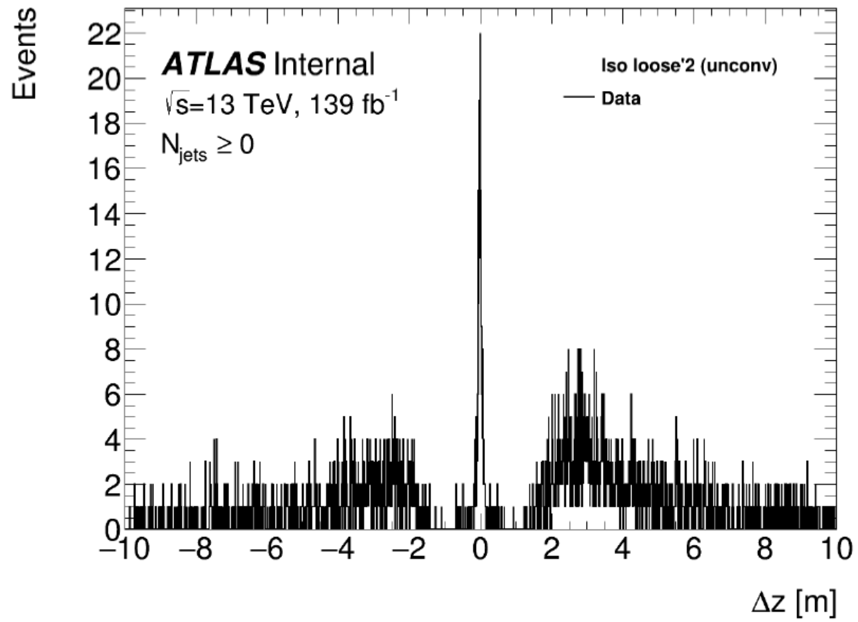
  Most of background is concentrated in unconverted photon candidates

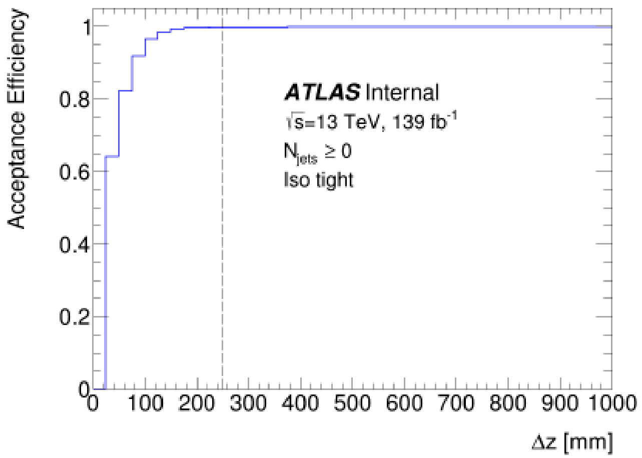
Background is concentrated at small φ and high η

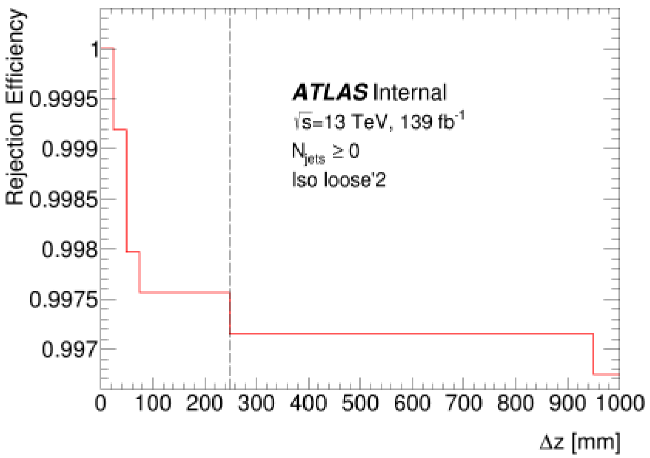


Applying |φ|<0.2, |η|>1.7









- Absolute value of z coordinate pointed by the photon candidate with respect to the identified primary vertex is required to be **less than 250 mm**

Background composition

Even after optimization of the selection, the final state remains quite contaminated:

- Zγ QCD
- W(→lν)γ
- W(→lν)γ EWK

} simultaneous fit to data (shape from MC)

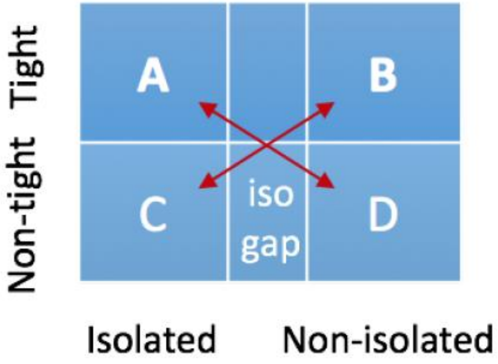
- e→γ – fake rate estimation using Z-peak (tag-n-probe) method
- ttγ – estimated partially with Wγ from the fit, partially directly from MC
- γ+jet – ABCD method based on E_T^{miss}-significance and soft term
- jet→γ – ABCD method based on γ ID and isolation
- $Z(\to l^+l^-)\gamma$ – via MC

jet→γ misID background

➢ Background is estimated from data using 2D-sideband method:
Photon isolation and identification variables are used to construct the sidebands

FixedCutTight

$$\frac{N_A^{\text{jet}\to\gamma}}{N_B} = \frac{N_C}{N_D},$$ other backgrounds were subtracted



➢ Main uncertainty is connected with a signal presence in BCD regions and a correlation between the regions

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

Used as nominal

R factor	*loose'2*	*loose'3*	*loose'4*	*loose'5*
MC	1.02 ± 0.12	1.12 ± 0.12	1.21 ± 0.12	1.41 ± 0.14
Data-driven	0.94 ± 0.06	0.96 ± 0.06	0.90 ± 0.05	0.92 ± 0.05

- Signal leakage is measured by $C_X = \frac{N_X^{sig}}{N_A^{sig}}$ in MC (X=B,C,D) (10%)

Signal leakage parameters	MadGraph+Pythia8	MadGraph+Herwig7
c_B	0.0313 ± 0.0005	0.0315 ± 0.0006
c_C	0.0085 ± 0.0003	0.0089 ± 0.0003
c_D	0.00031 ± 0.00005	0.00043 ± 0.00006
$jet \to \gamma$ estimation	41^{+17}_{-19}	−1(2%)

Central value	41^{+17}_{-19}
Loose'3	−6
Loose'4	−4
Loose'5	−7
Isolation gap +0.9 GeV	+6
Isolation gap −0.6 GeV	−2

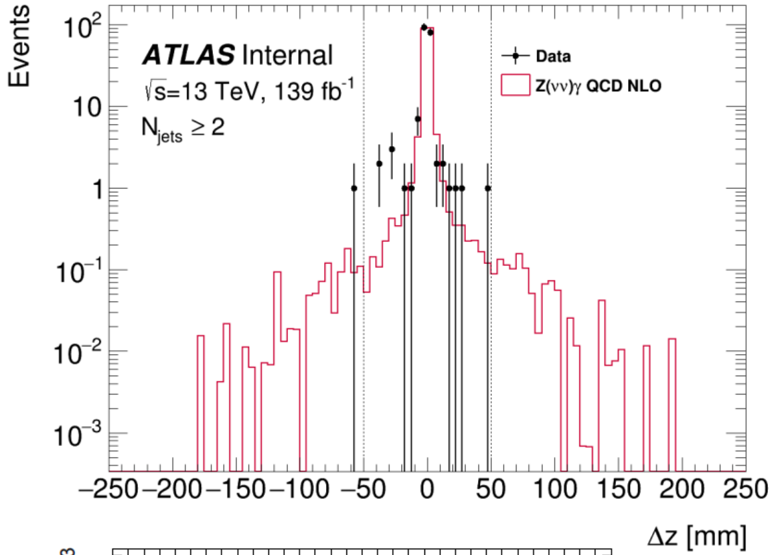
➢ Also there is a systematic uncertainty on anti-tight definition and isolation gap (17%, which fully covers the R-factor variation)

Full systematics on the background yield is equal to **20%**

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.



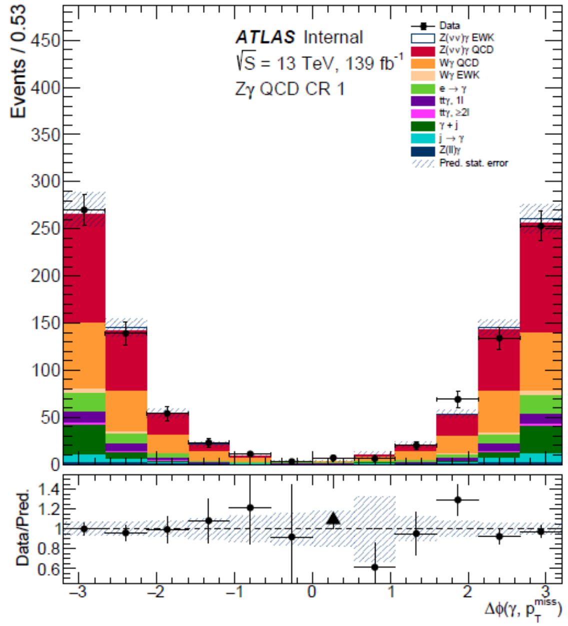
- Fraction of pile-up background is calculated as:

$$f_{PU} = \frac{N^{|\Delta z|>15mm}_{\text{data, 2-track Si}} - SF_1 \times SF_2 \times N^{|\Delta z|>15mm}_{\text{MC, 2-track Si}}}{N_{\text{data, 2-track Si}} \times 0.76}$$

|Δz| requirement was relaxed, because of low statistics

- SF_1 is equal to the ratio of events in data to events in Sherpa MC sample near |Δz| around zero (4.1±0.3)
- SF_2 – normalization factor taking into account the mismodelling in the tails of |Δz| distribution (was calculated for Sherpa Zγ QCD by Zγ inclusive team for us using events with FSR photons) (1.27±0.07)
- N_{data}(|Δz|>15mm)=11±3

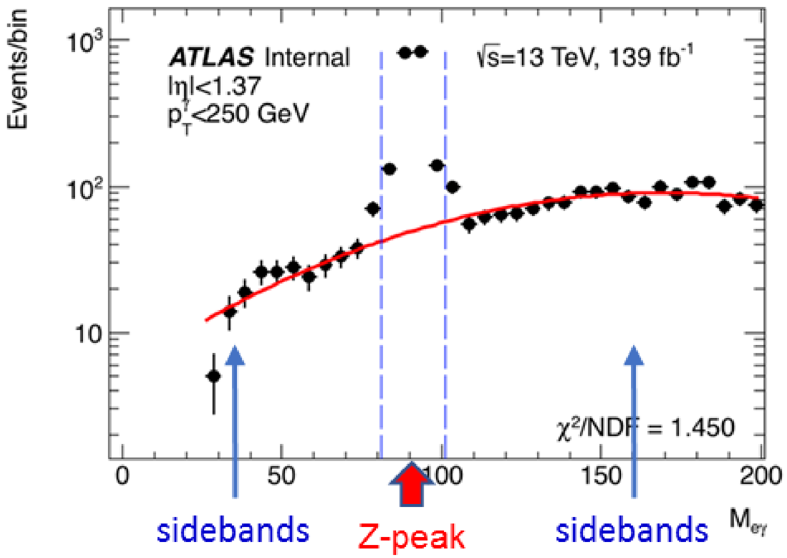
f_{PU}=1.9±1.9%



- ✓ 1.9% global systematic uncertainty is conservatively added to take this possible background into account
- ✓ Δφ distributions in CR1 are checked in order to check the impact of pile-up background on the shapes

Electron misidentification as photon (e→γ)

Background estimation method:



1. estimating e→γ 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 on fake rate

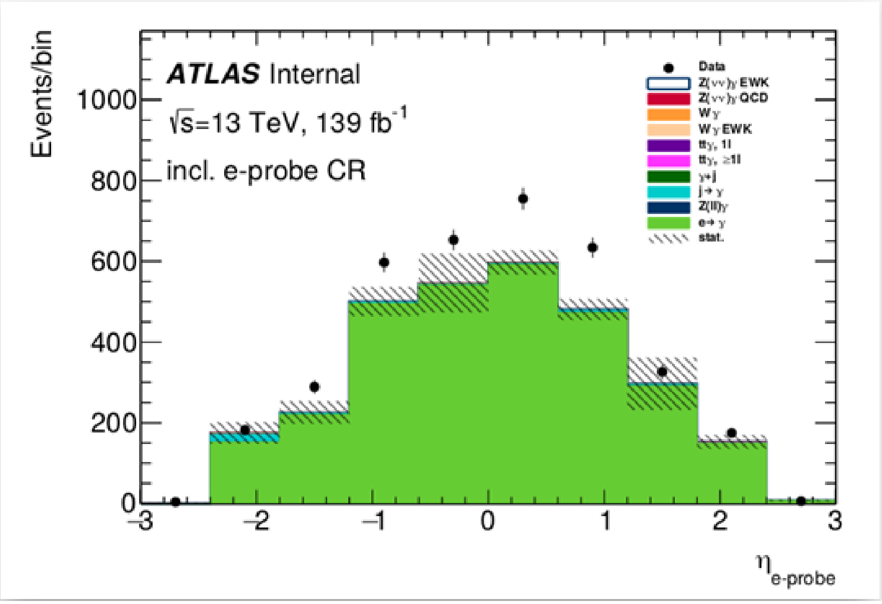
e→γ: systematics and result

Systematics on fake-rate estimation (ascending contribution):

- Z peak mass window variation (varies from 0.3% to 0.6%).
- Background under Z peak evaluation (varies from 3.2% to 10.8%)
- Difference between "real fake rate" in Z(ee) MC and tag-and-probe method performed on *Z*(*ee*) MC (varies from 3% to 13.4%).
- Difference between "real fake rate" from *W* (*eν*) and *Z* (*ee*) MC (varies from 1.9% to 29.2%).

$e \to \gamma$ fake rates		
	$150 < E_T^{\gamma} < 250$ GeV	$E_T^{\gamma} > 250$ GeV
$0 < \|\eta\| < 1.37$	$0.0205 \pm 0.0005 \pm 0.0061$	$0.0183 \pm 0.0012 \pm 0.0032$
$1.52 < \|\eta\| < 2.37$	$0.0571 \pm 0.0016 \pm 0.0094$	

First uncertainty is statistical, second is systematical.
Total systematics on fake-rate does not exceed **29.6%**



Percent of e-probe CR contamination is taken as additional systematic uncertainty: 1-2% (depending on region)

Background estimation result:

Zγ inclusive region 97 ± 3 ± 7
Signal region 14.3 ± 0.7 ± 0.7

Total syst. on the background yield: **7.2%**

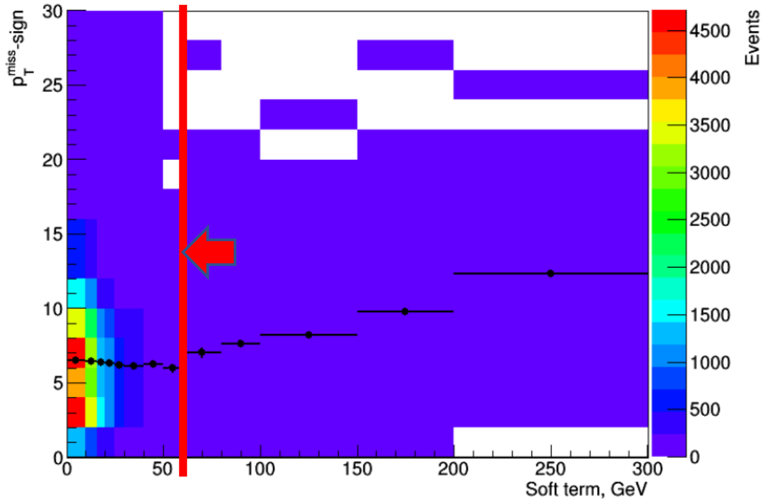
Fake E_T(miss) background

- Background is estimated from data using 2D-sideband method:

E_T^{miss}-significance and E_T^{miss} soft term are used to construct the sidebands

- To decrease the correlation, the upper bound (60 GeV) on soft term was set

- To enlarge the statistics in the side-band regions, the "modified" 2D side-band is formed (relaxed cuts: N_{jets}, $|\Delta\varphi[j_1, p_T^{miss}]|$, $|\Delta\varphi[j_2, p_T^{miss}]|$)



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

- Systematics:
  - Signal leakage parameter (13.2%)
  - Correlation, conservatively estimated by variation of the R factor (27.3%)
  - Definition of the upper soft term boundary in ABCD regions (2.4%).

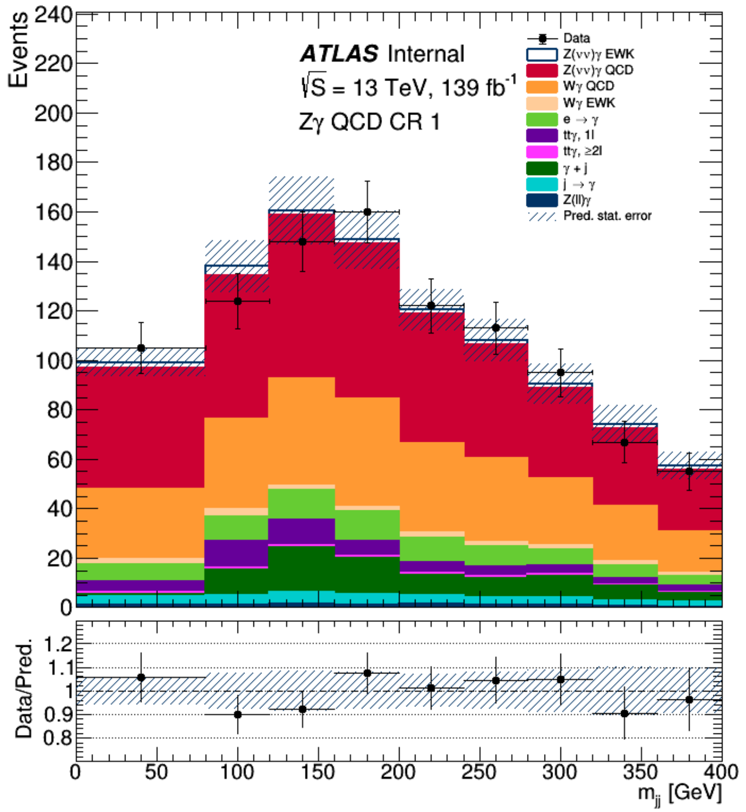
Total syst. on the background yield: **30%**

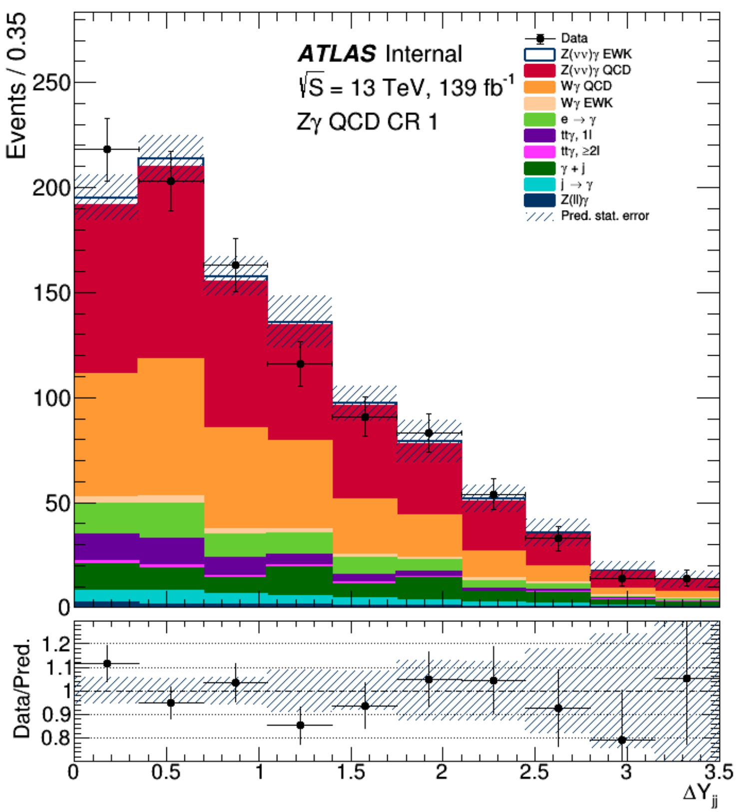
CRs selection	R-factor
$p_T^{SoftTerm} > 18$ GeV AND $p_T^{SoftTerm} < 60$ GeV	0.99 ± 0.16
$p_T^{SoftTerm} > 16$ GeV AND $p_T^{SoftTerm} < 30$ GeV	1.07 ± 0.19
E_T^{miss} significance < 9 OR $\Delta\phi(p_T^{miss}, j_1) < 0.3$ OR $\Delta\phi(p_T^{miss}, j_2) < 0.3$ OR $N_{jets} \leq 1$	1.00 ± 0.16
E_T^{miss} significance < 12 OR $\Delta\phi(p_T^{miss}, j_1) < 0.1$ OR $\Delta\phi(p_T^{miss}, j_2) < 0.1$ OR $N_{jets} \leq 1$	1.00 ± 0.16
Nominal	1.00 ± 0.16

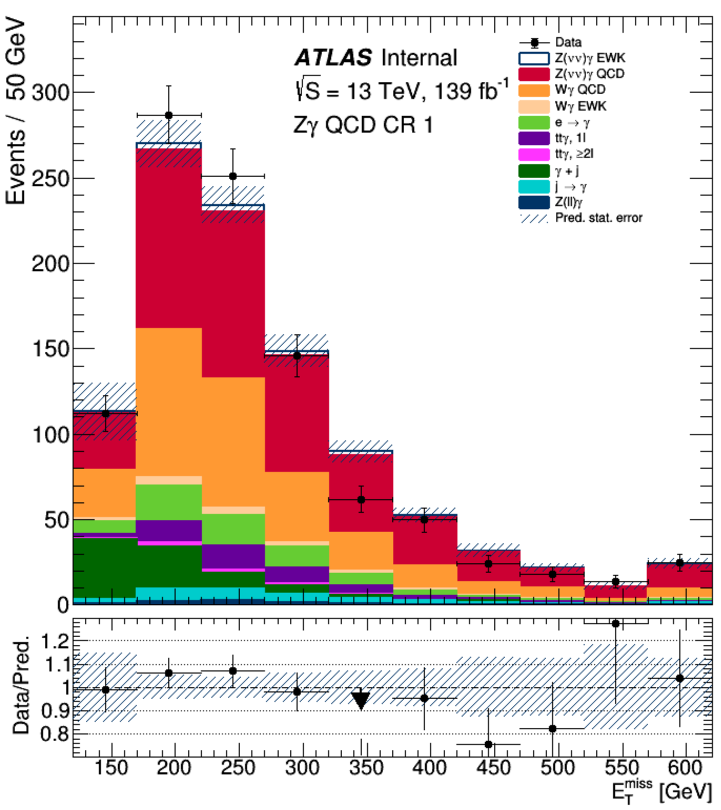
Cross-check method of MET significance fitting is in progress.

Control plots

➢ Comparison of the data and MC distributions for the input variables used to create the BDT

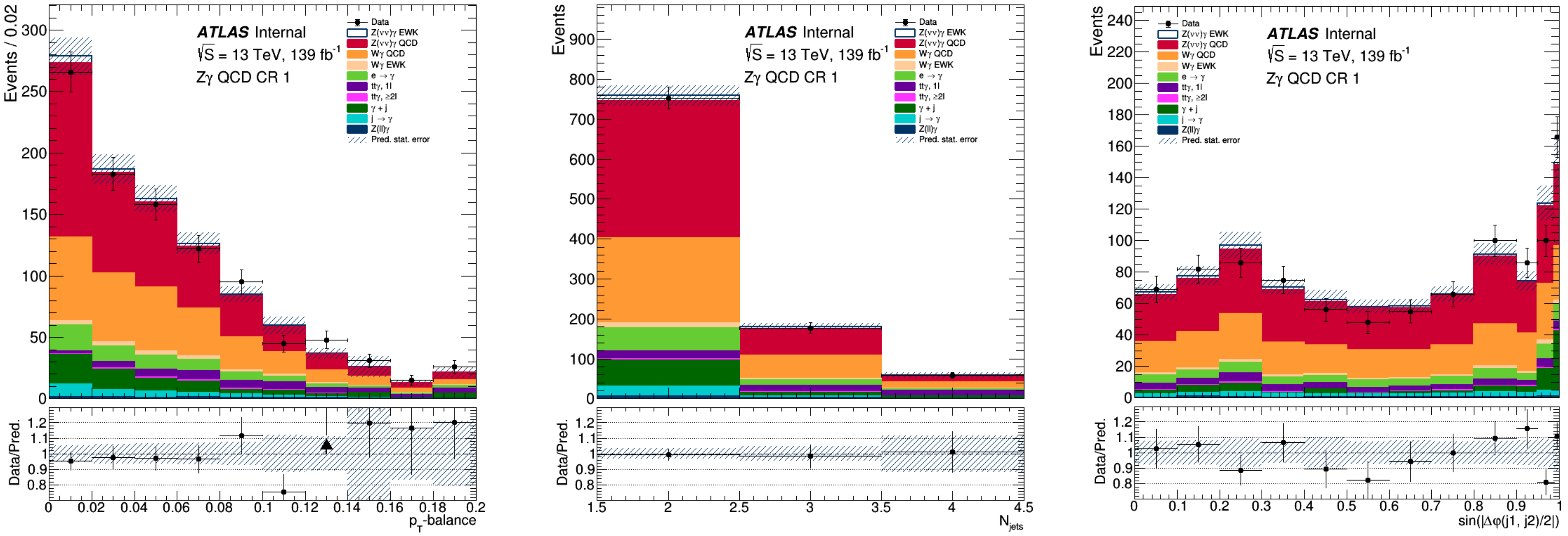






Control plots II

- Comparison of the data and MC distributions for the input variables used to create the BDT



Multivariate analysis

- Gradient Boosted Decision Trees are used

Parameter	Value
Number of trees	600
Shrinkage	0.05
Max tree depth	3
Number of cuts	20
Min node size	5%

- Cross training is performed to use all available statistics

Datasets are split by event number into odd and even

	Train	Test & application
Odd algorithm	**Odd** events	**Even** events
Even algorithm	**Even** events	**Odd** events

- Final response distribution is obtained by summing the response of even and odd events

Input variable selection

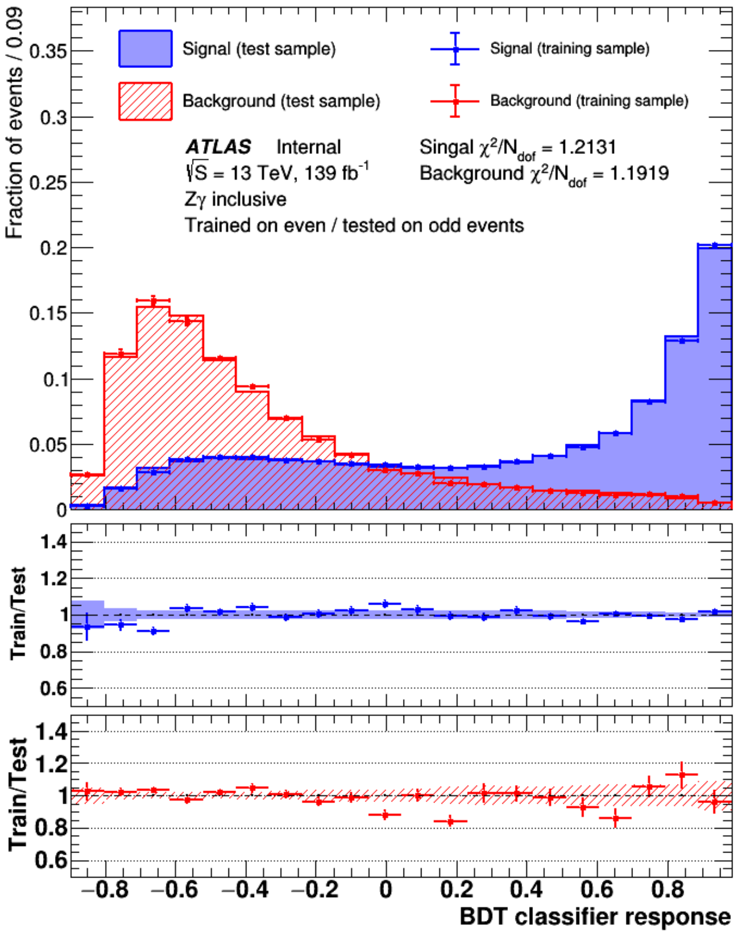
1. m_{jj}
2. $\Delta Y(j_1, j_2)$
3. E_T^{miss}
4. p_T-balance
5. $\eta(j_2)$
6. $p_T(j_1)$
7. $\eta(\gamma)$
8. p_T-balance (reduced)
9. N_{jets}
10. $\sin(|\Delta\varphi(j_1, j_2)/2|)$
11. $\Delta Y(j_1, \gamma)$

- Variables were selected with *"N−1"* and *"N+1"* algorithms and checked for redundancy with correlation coefficients.
- γ-centrality was not considered because it is used to define Zγ QCD CR 2 and SR.

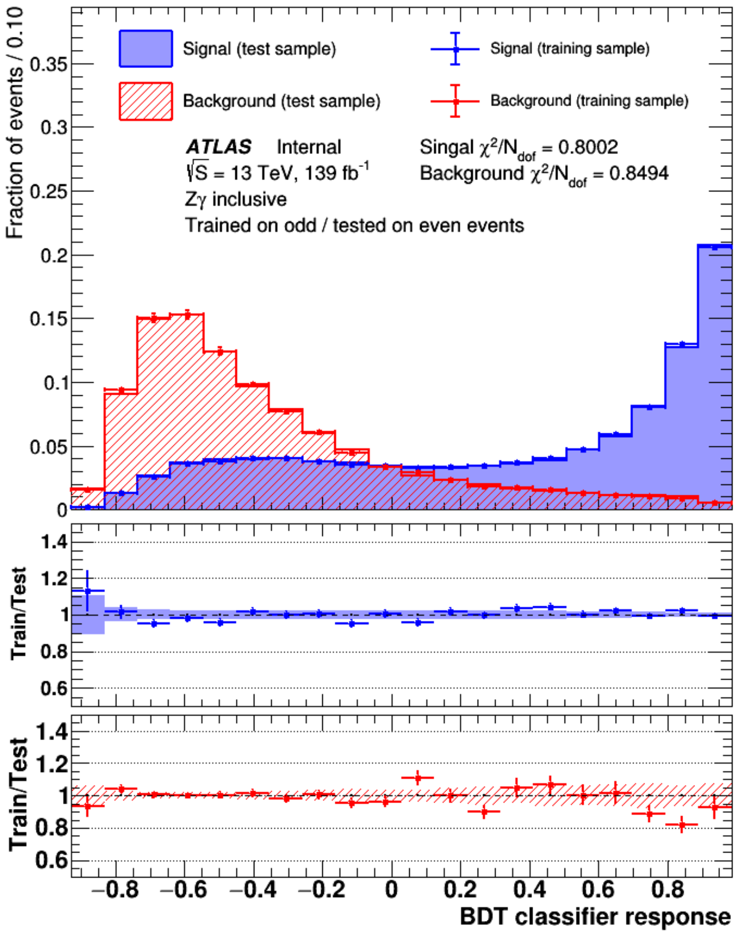
The classifier is trained in the $Z\gamma$ inclusive region to increase its stability and estimated measurement significance.

BDT classifier training

Even algorithm



Odd algorithm



Fit: setup

The Z(νν)γ EWK is measured with the maximum-likelihood parameter estimation for binned distributions (templates) referred to as fit. The fit is also used to evaluate normalization for some of the backgrounds, the effect of the systematic uncertainties and the measurement significance.

Samples	Norm. coef.	Systematics
Z(νν)γ EWK	μ_{EWK} **POI**	MC estimated, Theory systematics Experimental syst. Flat syst. : • luminosity • Trigger eff. • Pile-up yield
Z(νν)γ QCD	μ_{QCD}	
Wγ QCD, Wγ EWK, ttγ 1l	$\mu_{W\gamma}$	
ttγ ≥2l, Z(ll)+γ		
e→γ, γ+j, j→γ		Data-driven, flat syst.

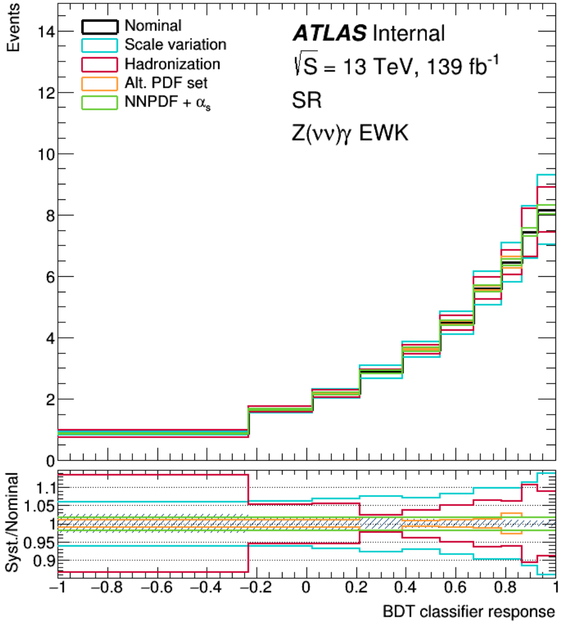
- **Templates**
  m_{jj} in CRs and **BDT response** in SR

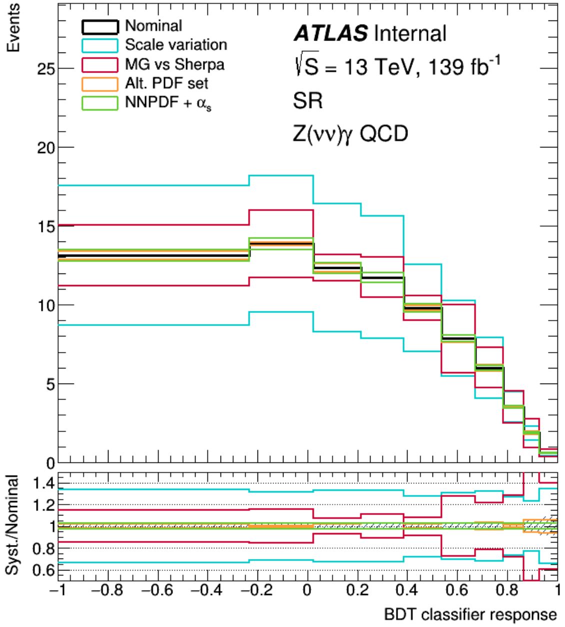
- To account for limited MC statistics there is also an NP for every bin with MC stat error > *5%*

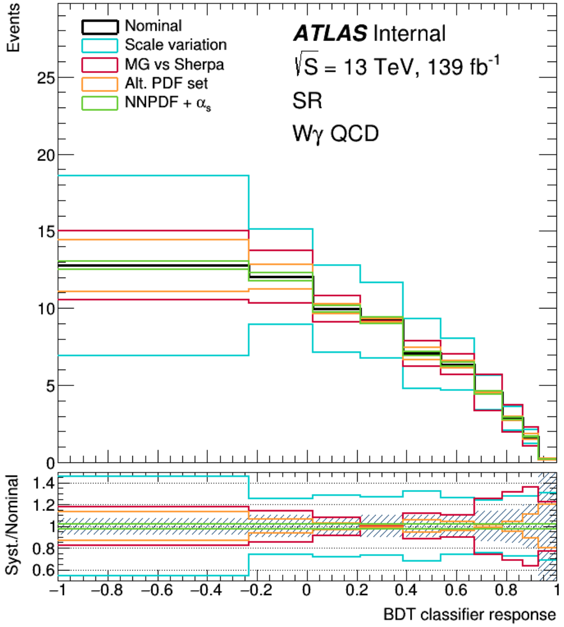
- **Fit procedure:**

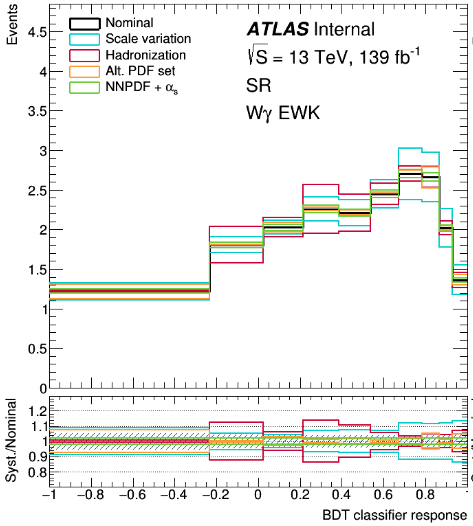
1. Fit MC to data in CRs with μ_{QCD} and $\mu_{W\gamma}$ as parameters of interest (POI).
2. Use fitted parameter values to create Asimov pseudodata.
3. Fit MC to Asimov pseudodata in all regions with μ_{EWK} as POI and obtain the estimated median discovery significance.

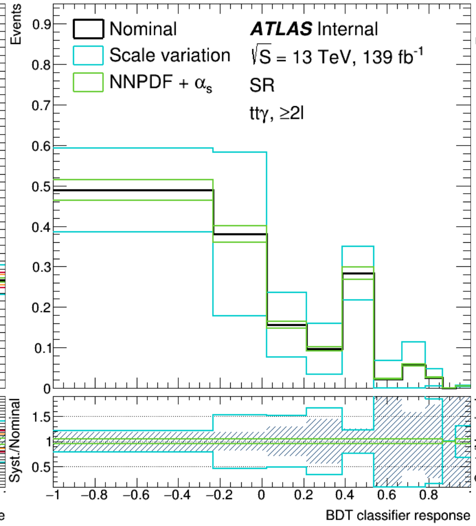
Systematics

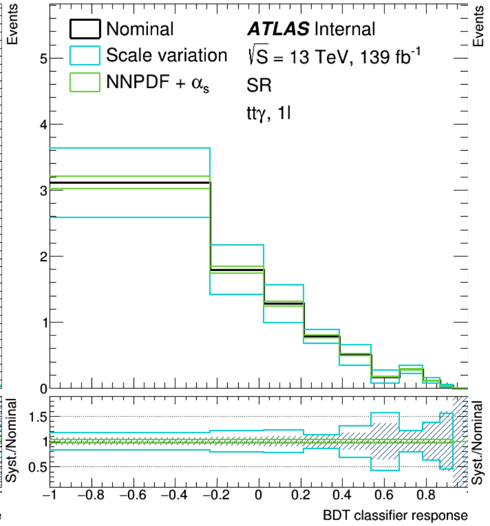


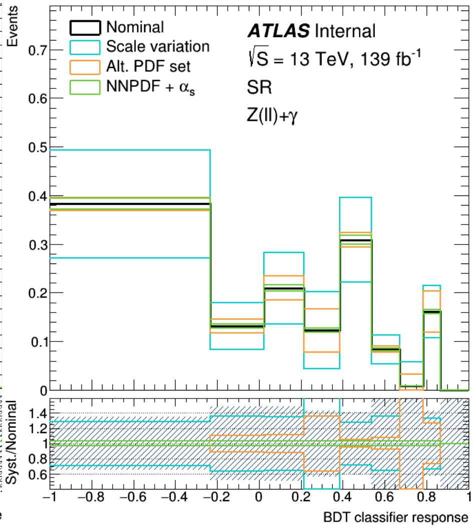












- All of the theory systematic uncertainties are implemented in the fit.
- Only scale and PDF set variations are available in the ttγ samples right now (new samples are now available).
- Scale uncertainties are decorrelated between the regions
- More details on systematic uncertainties (incl.experimental) can be found in back-up slides

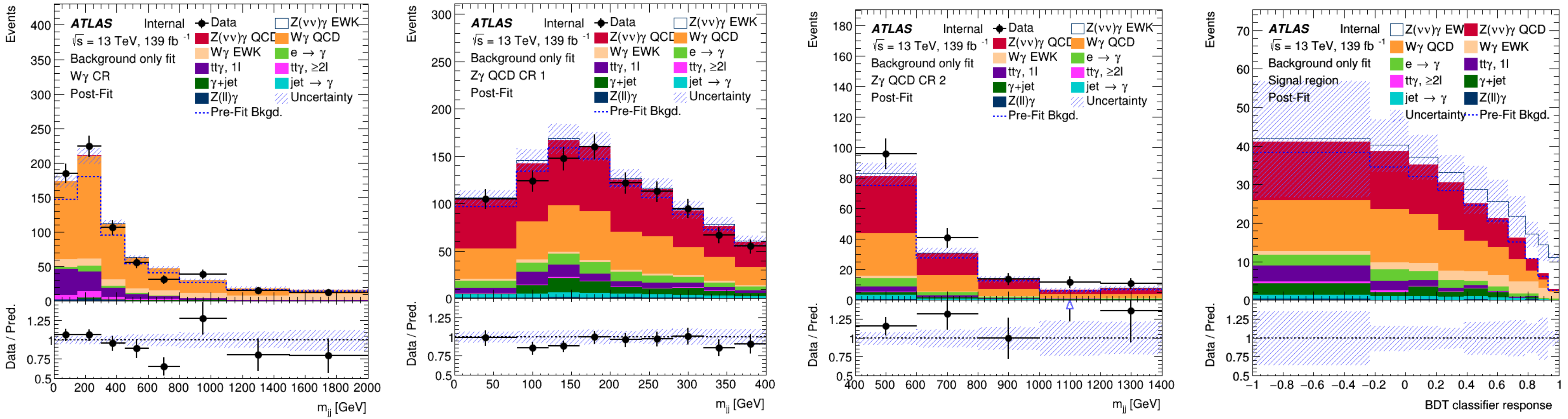
Event yields

Overview of the expected and observed number of events in the analysis for various regions with the exception of the signal region (after fit).

	$W\gamma$ CR	$Z\gamma$ inclusive	$Z\gamma$ QCD CR 1	$Z\gamma$ QCD CR 2	Signal region
$Z(\nu\nu)\gamma$ EWK	0.11 ± 0.04	65 ± 25	18 ± 8	3.4 ± 1.7	43 ± 16
$Z(\nu\nu)\gamma$ QCD	1.1 ± 0.5	610 ± 220	450 ± 50	65 ± 7	84 ± 10
$W\gamma$ QCD	450 ± 40	370 ± 110	325 ± 32	48 ± 5	76 ± 7
$W\gamma$ EWK	69 ± 13	38 ± 12	20 ± 4	3.4 ± 0.7	23 ± 5
$e \to \gamma$	18.9 ± 1.5	97 ± 7	74 ± 5	9.0 ± 0.9	14.3 ± 1.2
$tt\gamma, 1l$	93 ± 23	64 ± 20	60 ± 15	5.2 ± 1.9	10.2 ± 3.0
$tt\gamma, \geq 2l$	24 ± 7	9.2 ± 2.5	6.7 ± 1.9	0.61 ± 0.29	1.6 ± 0.8
γ+jet	5 ± 6	80 ± 35	66 ± 31	3 ± 4	12 ± 9
jet$\to \gamma$	0.1 ± 0.7	41 ± 20	31 ± 17	4 ± 6	6 ± 7
$Z(\ell\ell)\gamma$	8.2 ± 2.8	10.8 ± 3.4	8.2 ± 2.5	1.2 ± 0.4	1.5 ± 0.4
Total	672 ± 28	1380 ± 330	1060 ± 50	143 ± 10	271 ± 14
Data	670 ± 30		990 ± 30	174 ± 13	

Fit: results

- Background-only fit results



- Fit to Asimov data results

μ_{EWK}	$1.01^{+0.28}_{-0.24}$ (stat) $^{+0.25}_{-0.20}$ (syst)
μ_{QCD}	0.97 ± 0.08 (stat) $^{+0.24}_{-0.21}$ (syst)
$\mu_{W\gamma}$	1.38 ± 0.05 (stat) ± 0.18 (syst)

Estimated median discovery significance:
3.6 σ

Interference

- Amplitude of EWK+QCD will contain interference term:

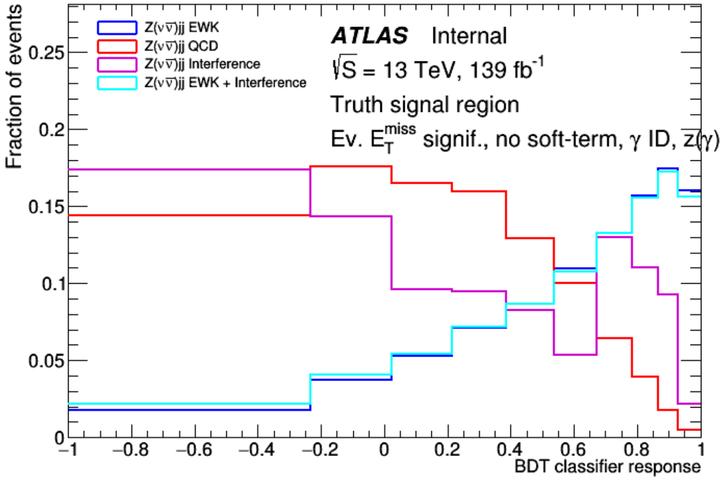
$$|M^2| = |M_{EWK} + M_{QCD}|^2 = |M_{EWK}|^2 + |M_{QCD}|^2 + 2 \times Re(M^*_{EWK} \cdot M_{QCD})$$

This effect should be estimated in terms of size and how it can change our distributions (including BDT score)

- EWK $Z(\nu\nu)\gamma jj$: QCD=0, QED=8 (amplitude: $|M_{EWK}|^2$)
- QCD $Z(\nu\nu)\gamma jj$: QCD=4, QED=4 (amplitude: $|M_{QCD}|^2$)
- Interference $Z(\nu\nu)\gamma jj$: $QCD^2 = 2$, $QED^2 = 6$ (amplitude: $2 \times Re(M^*_{EWK} \times M_2)$)

We use MadGraph direct interference generation: **QCD²==2**

420k events were generated



Results for SR:

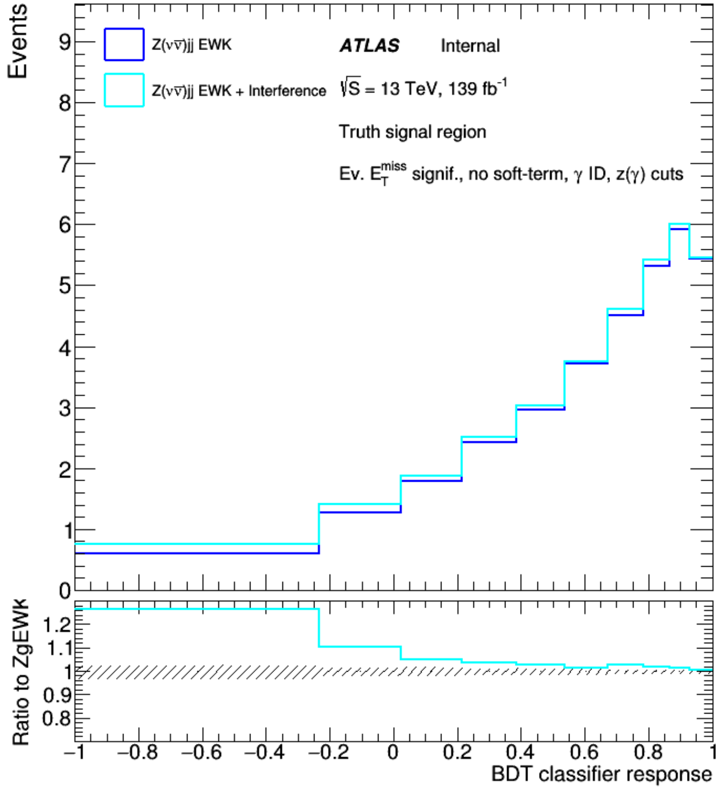
INT/EWK=**2.7%**

INT/QCD=**1.5%**

BDT shape difference (on the right)

Reweighted fullsim EWK sample on EWK+INT using truth level (ΔY[jj] distribution) leads to decrease of the significance **by 5%.**

Fullsim interference sample is requested



Shape of interference is closer to QCD Zγ than to EWK

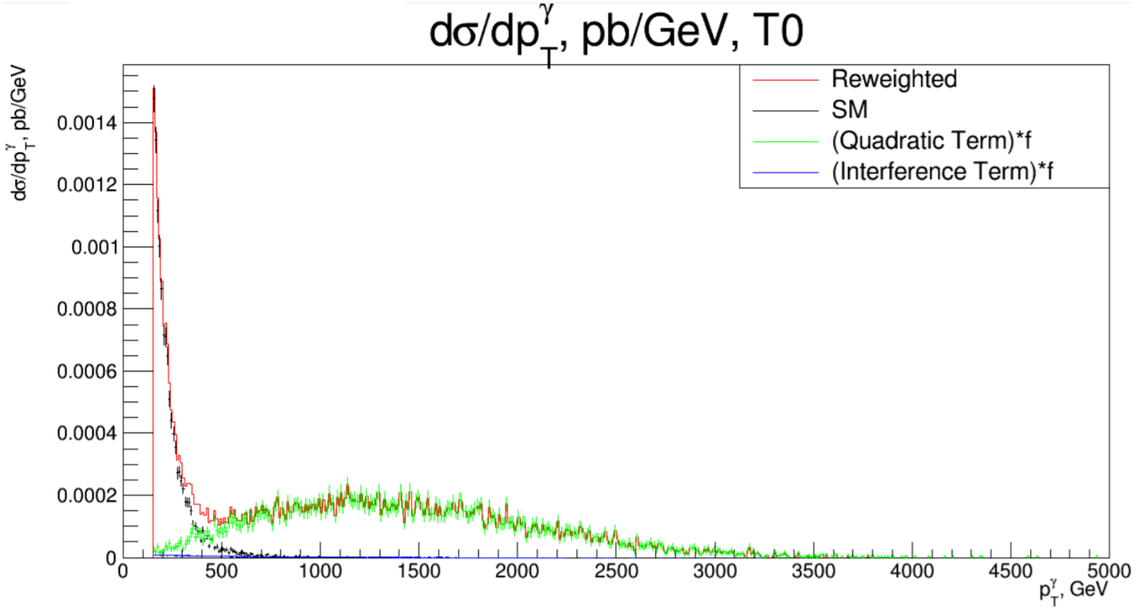
AQGC status

➢ Decomposition method in MadGraph is planned to use
Discussions with aQGC re-interpretation team:
Slides (December), slides (August)

➢ To solve the unitarity issue, the clipping method is planned to use.

➢ MC samples will be ordered in the short schedule.

➢ Statistical framework based on HistFactory will be used for limit setting.



Issues:

- New model *SM_Ltotal_Ind5_UFO* from Oscar Eboli is in testing – gives a bit different results than the old models. Investigating.

- With old model one can not generate all requested events for the full amplitude

Launchpad: https://answers.launchpad.net/mg5amcnlo/+question/688567
Changing the value of parameters or a phase space a bit. We have ~6% disagreement in validation at the moment. Investigating with experts.

List of contributions

A. Kurova	Analysis co-contact, framework development, data-driven background estimation ($e \to \gamma$), cross-section extraction, $tt\gamma$ background normalization strategy, shape dependence study for theoretical systematics
A. Petukhov	Multivariate analysis, template fit, sytematic uncertainties evaluation
D. Pyatiizbyantseva	Selection optimizations, data-driven background estimation ($jet \to \gamma$, pile-up), beam-induced background suppression
A. Romaniouk	Supervisor
E. Soldatov	Analysis contact, MC generation, background estimation ($\gamma + jet$), template fit, aQGC

Conclusions

- Full analysis flow is ready, preliminary results are shown:
  - ✓ Selections, background estimations are mature, good data-expectations agreement in control regions
  - ✓ All main systematics are included
  - ✓ The fit for the final result extraction is stable, minor updates are foreseen (decorrelation, full-simulated interference application, symmetrization issues, etc)
  - ✓ Expected significance is **3.6σ**

- To finalize and to do:
  - ✓ Reoptimization of the BDT classifier
  - ✓ Check the fJVT impact on analysis
  - ✓ Add several minor systematics
  - ✓ Anomalous QGC study

- Analysis is fully documented
  - ✓ Documentation is ready for review.
  https://cds.cern.ch/record/2696408

ATLAS EXPERIMENT

ATLAS Note

ANA-STDM-2018-59-INT1

10th February 2020

CERN

Draft version 0.2

Measurement of the electroweak $Z(\nu\bar{\nu})\gamma jj$ production cross section in pp Collisions at $\sqrt{s}$=13 TeV with the ATLAS Detector

Most important comments from Editorial Board are in the next slides…

Comments from EB

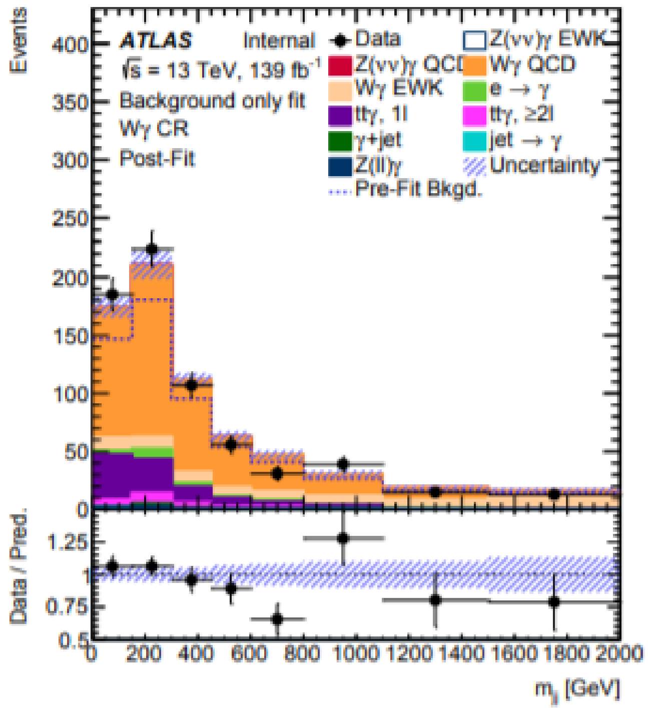


Fig 31: it seems there is a trend in the bottom left figure, is it understood ?

=> We are thinking about it.

1) We decided to switch to another ttγ sample, which includes FSR photons, so it can solve the problem

2) If not, we plan to use reweighting.

* Related to the above, I notice that you do have a Wγ CR post-fit plot of the mjj spectrum in slide 19 of the EB presentation, where there does appear to be some potential mismodelling in mjj which would be consistent with that seen elsewhere. Obviously the effect is not very significant given the statistical precision, but I was wondering if you could estimate to what extent this influences the fit?

A simple (hopefully? let me know if not so) check would be to reweight the Wγ MC to match the data in this CR (shape and normalisation) then propagate this into the BDT response / mjj fit and see if/how the results change. One might imagine that with a shape variation allowed, you might prefer a little more Wgamma at low mass and less at high mjj, leading to a fit with a different EWK contribution, depending on how the Wγ BDT template is affected by this change.

Comments from EB

* Theory systematics:

you have considered QCD scale, parton shower and PDF uncertainties on the EWK signal samples, but I don't think you have anything which captures normalisation and shape uncertainties originating from the matrix element calculations of the signal -- can signal samples with Madgraph vs. Sherpa be produced to test this potential source of modelling uncertainty? (As you do for the strong background process.)

Are there alternative ways to consider potential mismodelling / model dependence in the signal ME part of the calculation?

Sherpa vs Madgraph was used as a signal variation in the Z(l+l-)gamma jj paper.

=> We plan to try VBFNLO, since we do not have Sherpa MC and Sherpa2.2 has a color-connection bug in the hadronization.

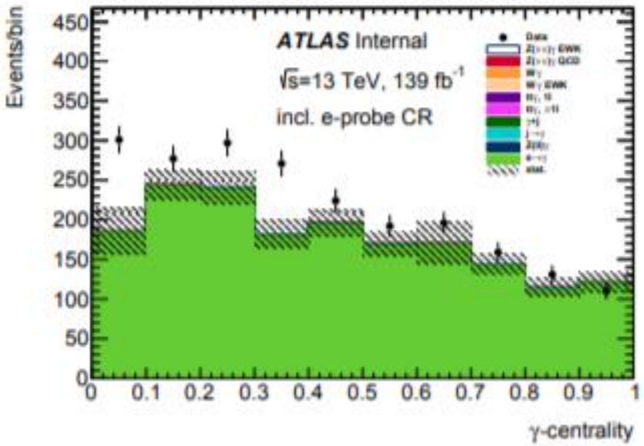
Comments from EB

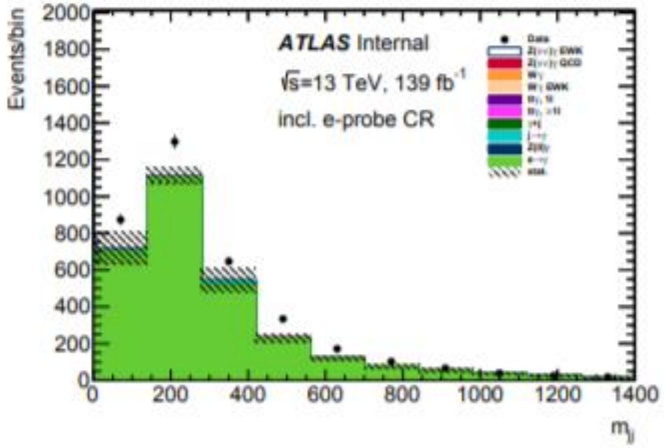
* For the fake rate determination for e->photon in Appendix D: the fits are obviously not great, and you do some variation to try and capture potential variations but it's unclear how trustworthy this is at capturing the real uncertainty (or if indeed this is an overestimate). It certainly limits you in how fine a binning you can perform these fits in.

-- Did you consider performing a full signal+background fit including the Z peak to stabilise things, and make use of the full data available to you? I'm sure a parametrisation of this data is a 'solved problem' in Standard Model group (or at the very least in egamma CP) who could advise of a good fit function.

-- Alternatively, maybe Same-Sign background events would give a potential description of combinatorics under the Z peak?

-- Could you comment on the data to MC description in Figs 13/14? No mention of the disagreements seen is made?





Comments from EB

* It is important to confirm the model-independence of the results: in particular I think it would be useful to repeat your analysis with a modified signal spectrum with an injected BSM signal and check that you can recover the injected signal from the measured spectra.

-- For this test you shouldn't retrain the BDT or EWK signal templates, but test with pseudodata (SM+BSM) that you can detect and measure / are sensitive to the BSM component, and any inherent biases towards the SM. This is a good test of robust data-driven analysis design and the validity of any aQGC (or other BSM) interpretations you include in the paper, and will be a real strength to be able to outline in the paper itself.

-- I'd suggest testing a variety of operators/coefficients if applicable to get a good sense of any dependencies / different high energy effects. -- It might be also worth thinking about testing robustness against any lower-energy BSM signatures within the direct energy reach of this measurement: what happens if you inject a (toy) signal that induces a narrow-width resonance in mjj [some BSM model with MET+photon+(X->jj)] for example? [No specific MC samples required.]

-- Beyond this, it would be useful to briefly explore if there exist some BSM samples that people in ATLAS are already using for VBF-style MET+photon searches (or Higgs->inv. + photon?) you can get hold of so you can test more BSM signatures that modify spectra in a different way to high energy EFT effects. No need to generate new signals of course, just useful to check for MC signal derivations of opportunity. (Would mean you get a BSM interpretation for the paper for free if you did this check.)

Comments from EB

l218: would the VBF Z esp. the VBF Z(vv) sample be taken into account for the estimation of its contribution in the VBS Zvvgam measured fiducial phasespace? It would be very interesting to quantify such contribution as long as we don't differentiate such bgd from our VBS Zvvgam signal from DATA. This may also indicate how much overlap it gives VBF Z and VBS Zgam processes.

Comments from EB

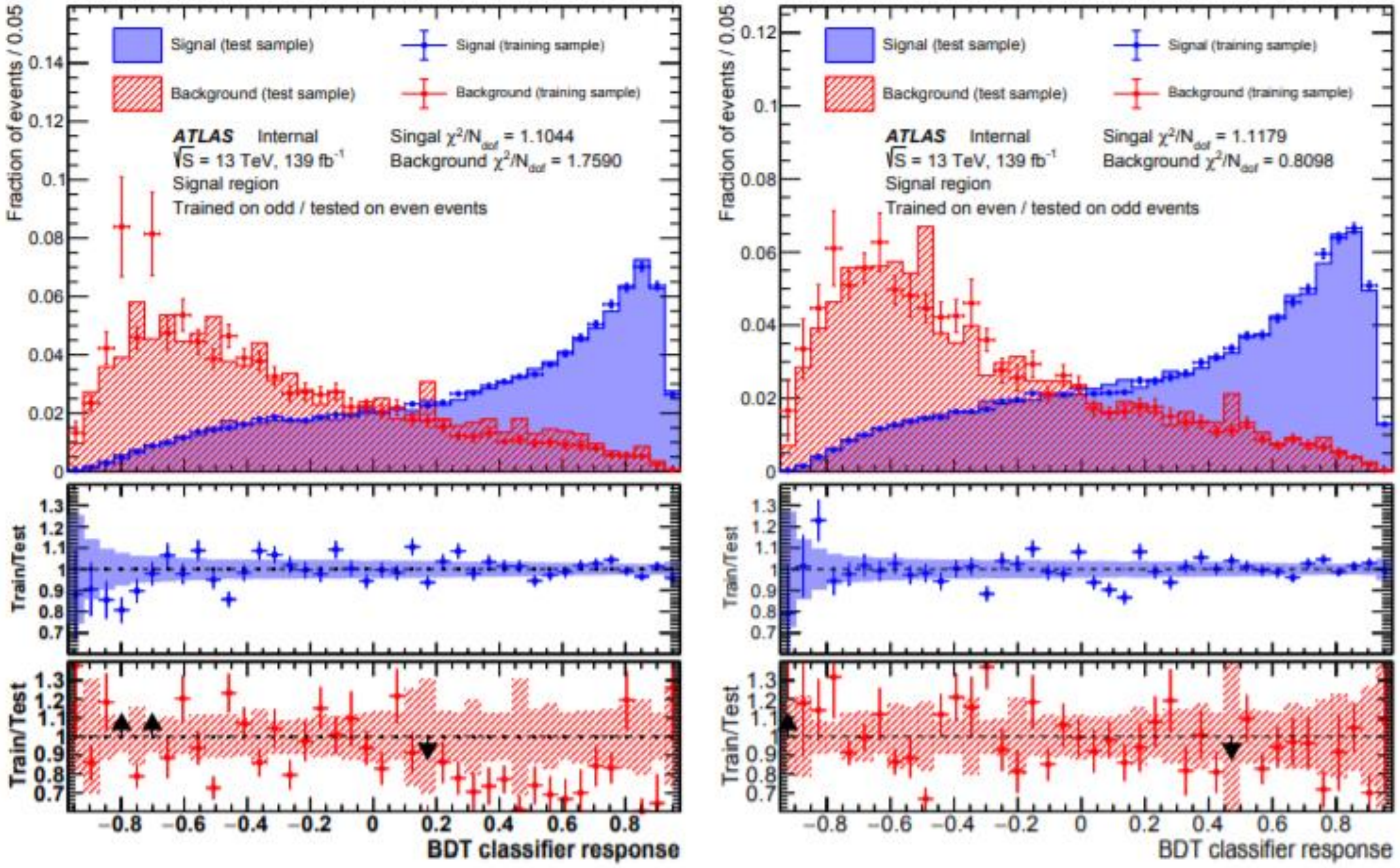
l649: in fact, it's different parton shower models instead of different generators. Do we have any new sherpa Zgam VBS sample of signal so that leakage can be examined here accordingly?

=> No, we don’t have. We are going to use for this estimation Zg QCD samples.

Comments from EB

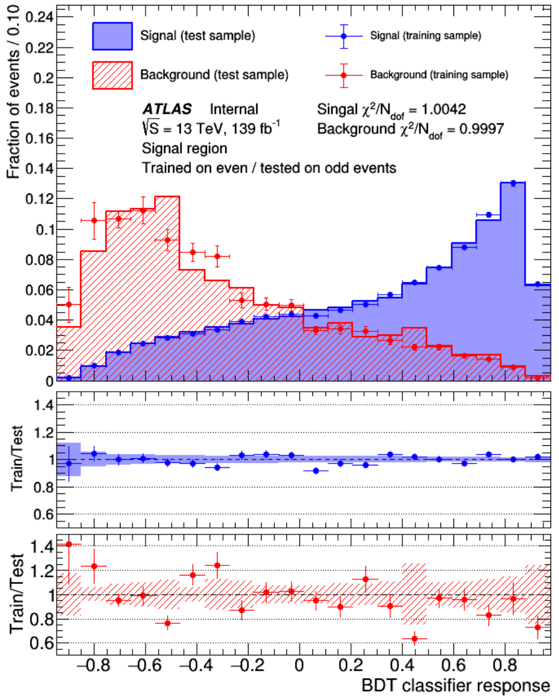
Figure 25: did you check if some of the bgd shape fluctuation would be due to one or two specific bgd sample input which are low in stat.? And see if the removal/adding would stablize the shape and how it would impact the final training result?

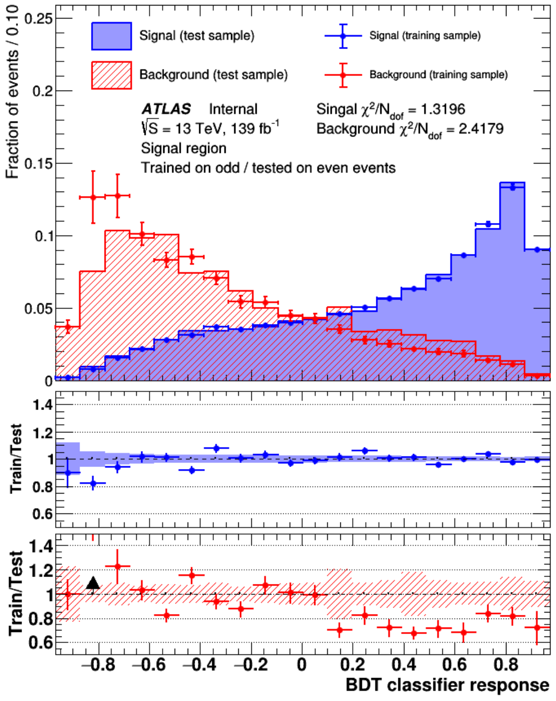
⇒ Yes. We've removed gamma+jet, since statistics is very low, it improved the result



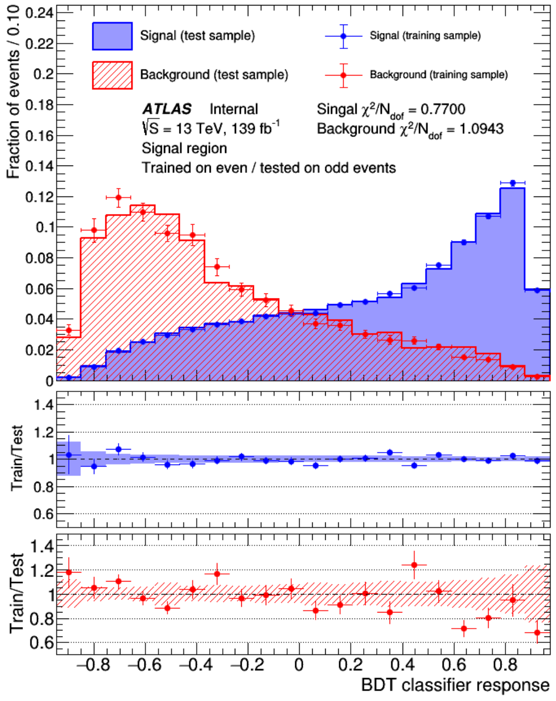
Comments from EB

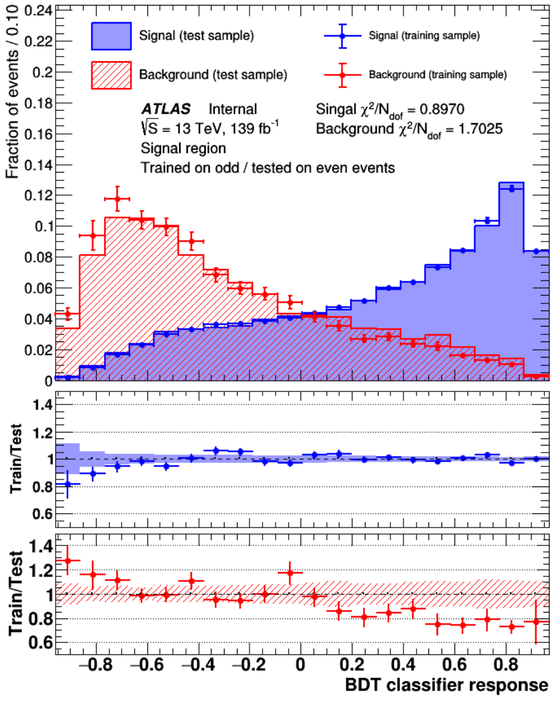
With g+jet, SR





Without g+jet, SR





Back-up slides

Object selections

Photon selection:

E_T>10 GeV, |η|<2.37, crack region rejection, cluster quality cut, ambiguity cut, photon cleaning, Loose ID, ΔR(γ,e/μ)<0.4

Jet selection:

AntiKt4EMTopoJets, E_T>50 GeV, |η|<4.5, ΔR(jet,e/μ/γ)<0.4, JVT cut

Muon selection:

p_T>7 GeV, |η|<2.47, away from bad calo region, Medium ID, $|z_0 * \sin\theta|<0.5$mm, d_0-signif.<3, isolation LooseTrackOnly

Electron selection:

p_T>7 GeV, |η|<2.47, crack region excluded, cluster quality cut, LooseBL ID, $|z_0 * \sin\theta|<0.5$ mm, d_0-signif.<5, isolation LooseTrackOnly, ΔR(e,μ)<0.1

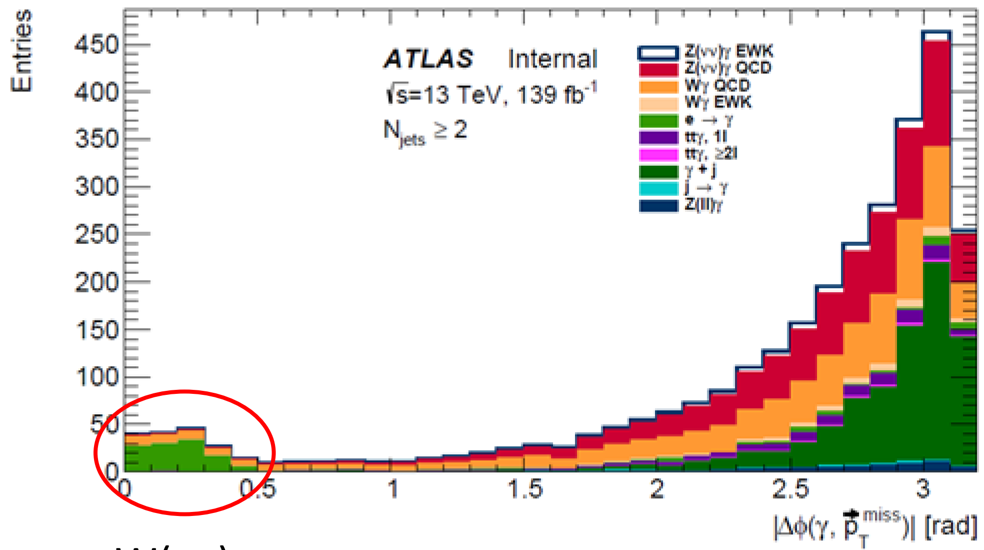
Photon FixedCutTight iso:

$E_T^{cone}40 < 0.022 p_T + 2.45$ [GeV];

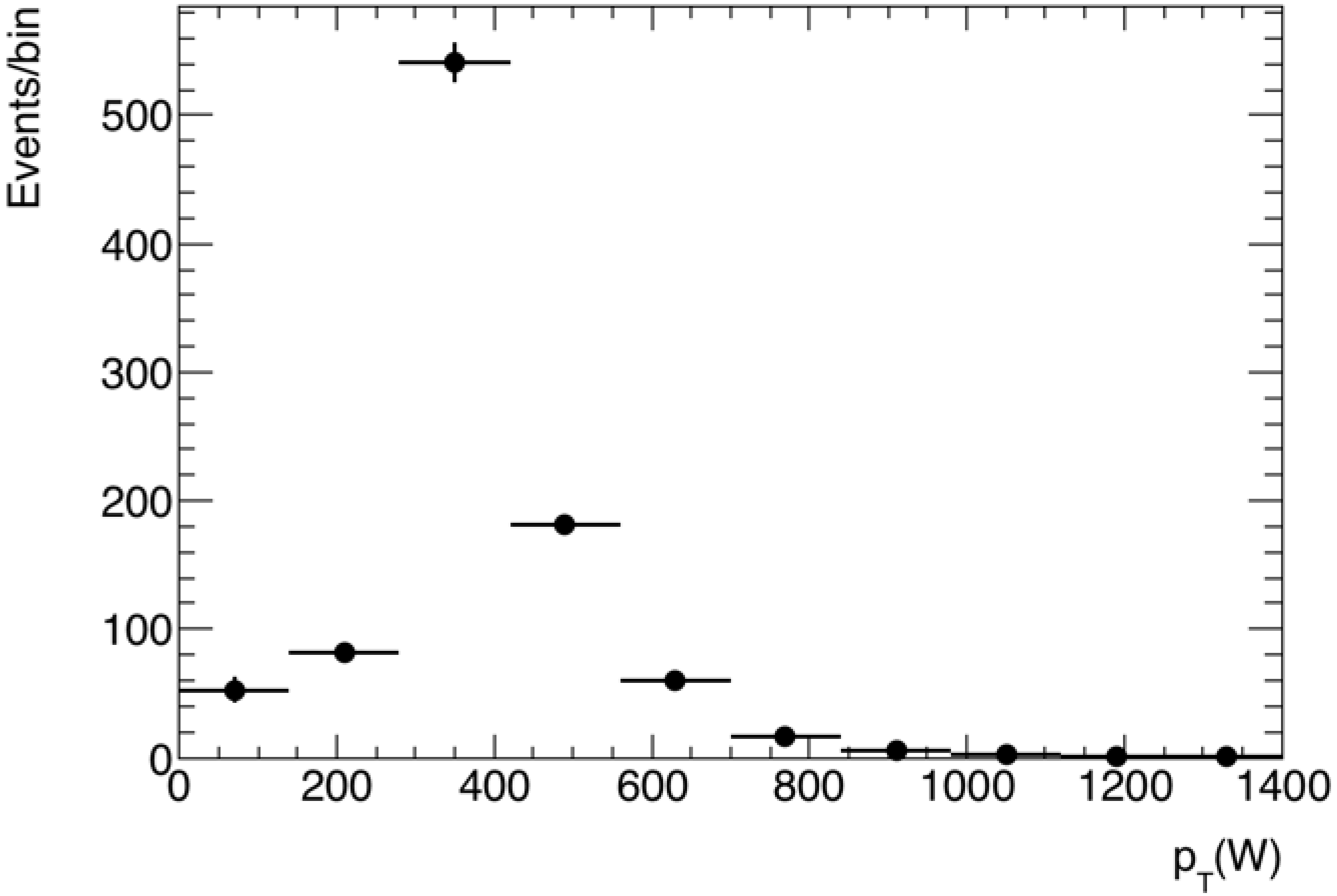
$p_T^{cone}20/p_T < 0.05$

Selection optimization

- $|\Delta\varphi[\gamma, p_T^{miss}]|$



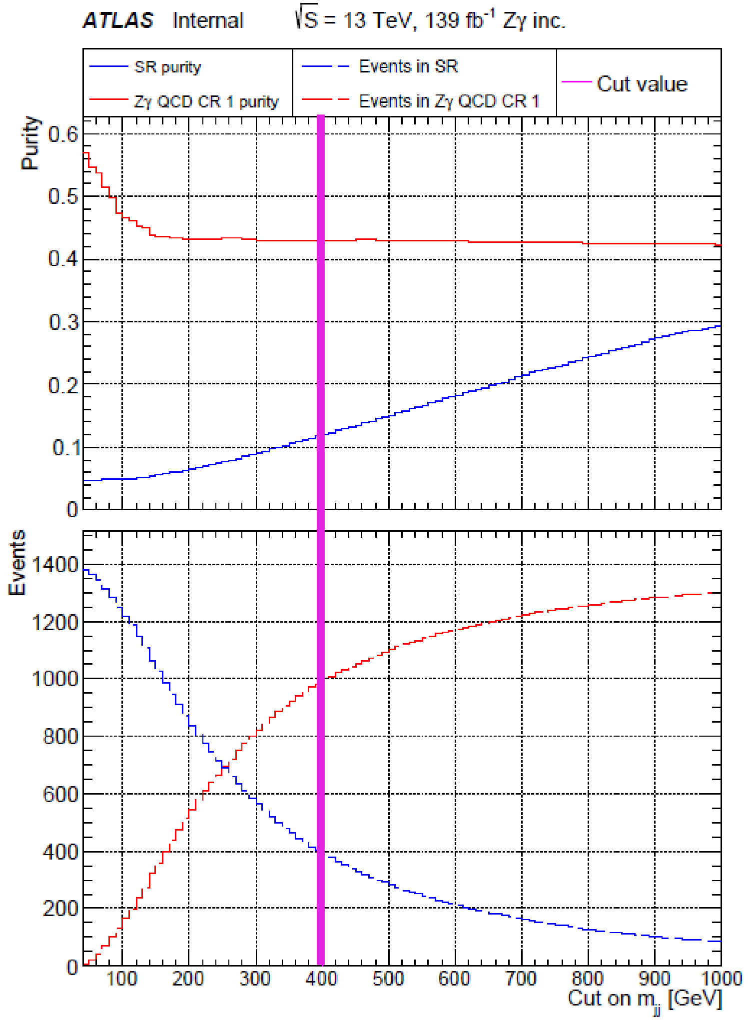
W(eν)



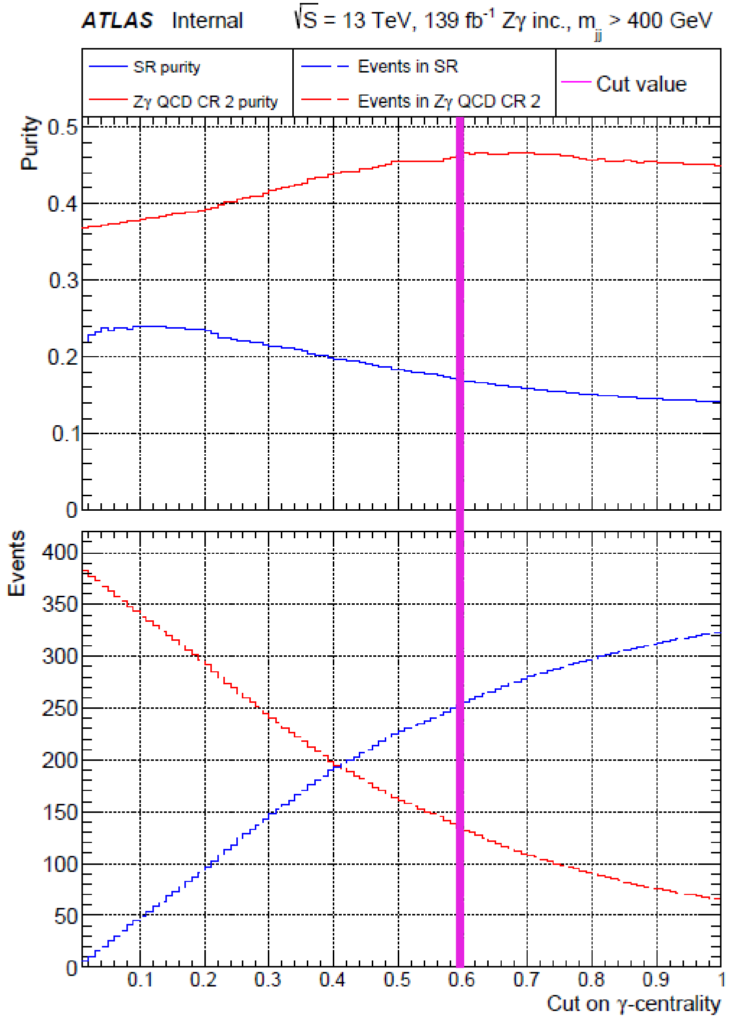
- W boson in most of events is very boosted.

Control regions selection optimization

- Optimizing cuts to create control regions
- m_{jj}

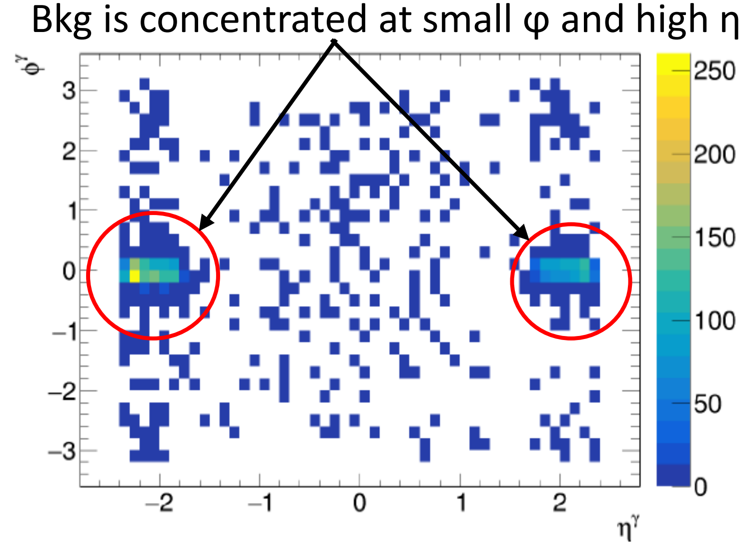


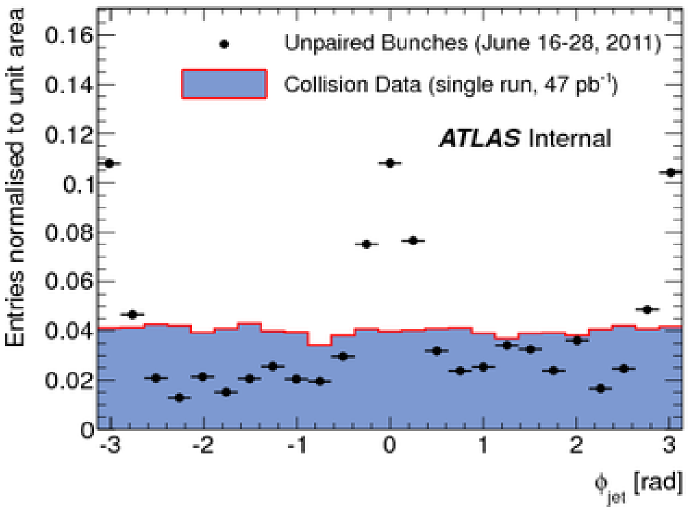
- γ-centrality



- The values of the cuts were chosen to maximize the number of events and the purity of the dedicated process in each region

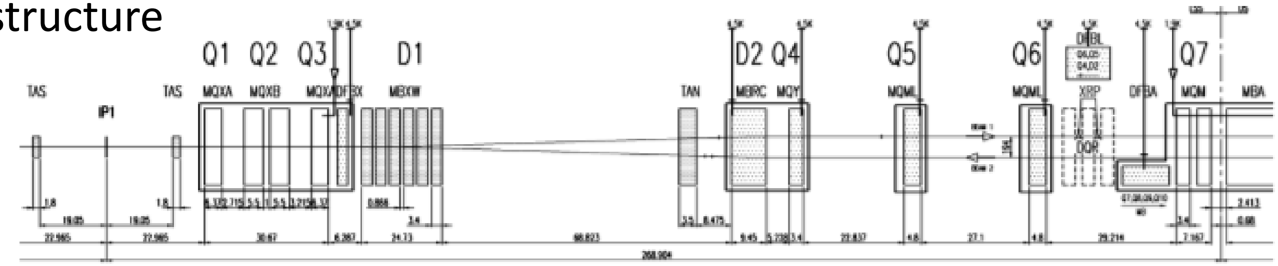
Beam-induced background (BIB)





Why? What is the origin?

- Beam induced background originates from three different beam-loss processes, mainly elastic/non-elastic collisions with gas in beam pipe, beam halo. **Non-elastic collisions are main part of BIB.**
- These collisions produces **high-energy muons**, originating mostly from pion and kaon decay in the hadronic showers induced by beam losses. These muons can deposit large amounts of energy in calorimeters through radiative processes. Such energy depositions, which are not associated with a hard scattering at the interaction point (IP), can be reconstructed as **fake jets**.
- It will be **isolated**, since it is a muon, not jet.
- Typical characteristic of the fake jets due to beam-induced backgrounds is the azimuthal structure

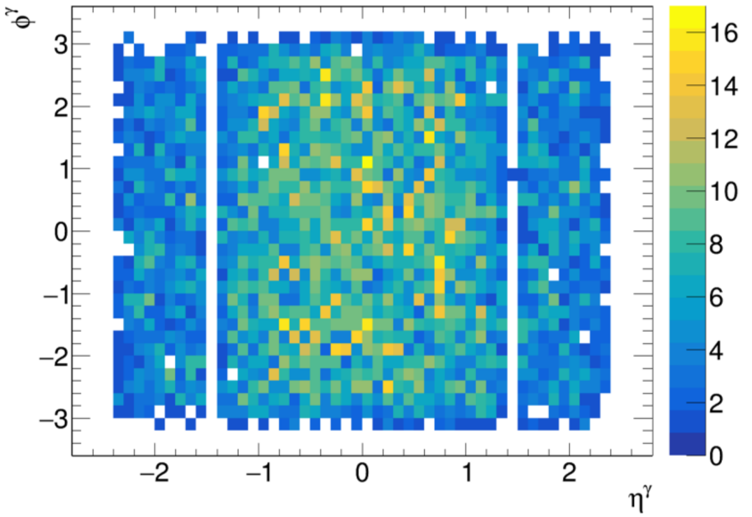


- The characteristic peaks at ±π and 0 are mainly due to the bending in the horizontal plane that occurs in the D1 and D2 dipoles and the LHC arc

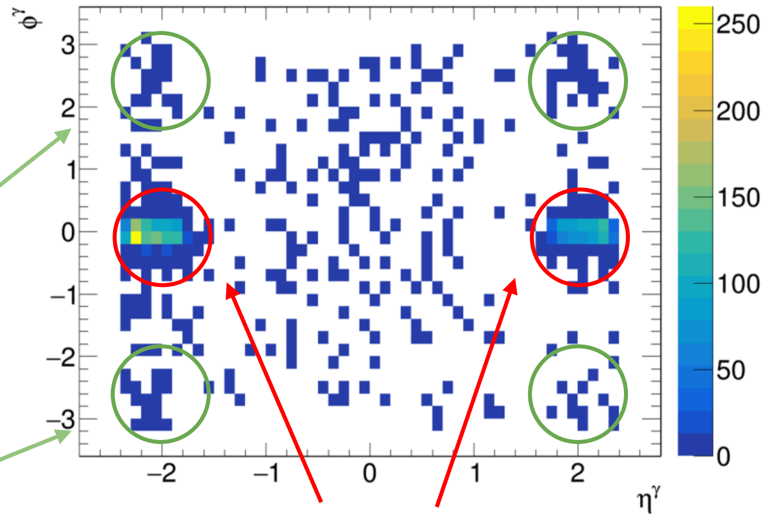
For details see: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/DAPR-2017-01/ (***JINST 13 (2018) P12006***)
https://cds.cern.ch/record/2261862/files/CERN-ACC-2017-0025.pdf https://iopscience.iop.org/article/10.1088/1748-0221/8/07/P07004/pdf
https://twiki.cern.ch/twiki/bin/viewauth/Atlas/BeamBackgroundIdentificationMethods

Beam-induced background

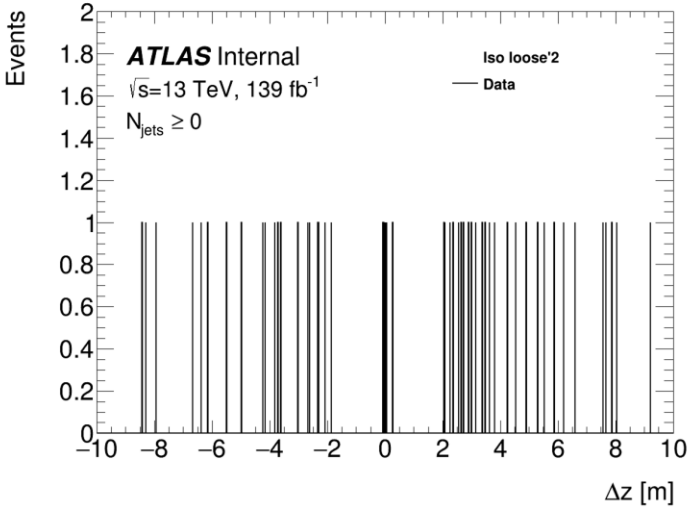
Distribution of photon ϕ versus photon η in the *tight* and isolated region.



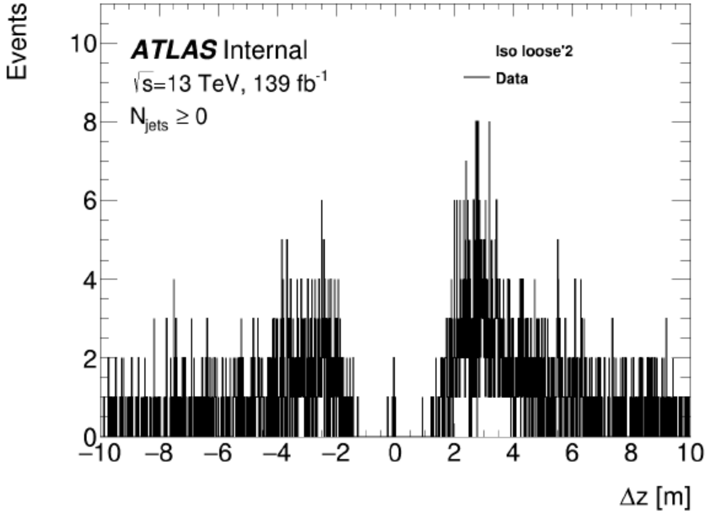
Distribution of photon ϕ versus photon η in the *loose'2* and isolated region.



Applying |φ|> 2.5, |η| > 1.7



Applying |φ| < 0.2, |η| > 1.7



jet→γ misID background

Event yields for the data and non jet → γ background processes considered in the ABCD method:

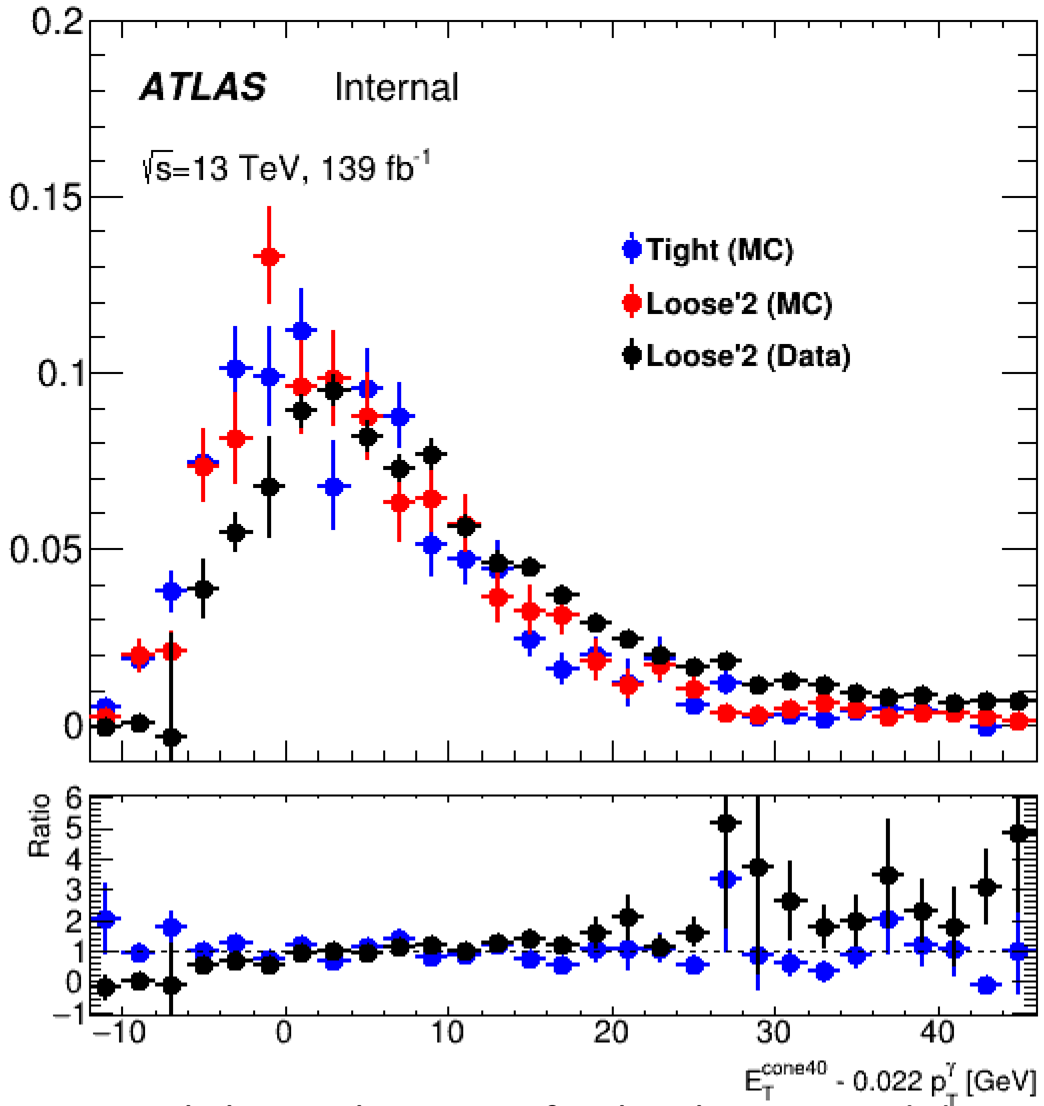
	Data	$Z(\nu\nu)\gamma$ QCD	$W\gamma$ QCD	$W\gamma$ EWK	$e \to \gamma$	γ+jet	$Z(ll)\gamma$	$tt\gamma, 1l$	$tt\gamma, \geq 2l$
A	1430 ± 40	569.5 ± 1.7	396 ± 6	41.6 ± 0.4	97 ± 3	112 ± 10	11.0 ± 0.8	60.6 ± 0.9	8.7 ± 0.4
B	101 ± 10	29.4 ± 0.4	16.1 ± 1.9	1.51 ± 0.08	3.7 ± 0.2	2.1 ± 1.1	0.5 ± 0.2	2.61 ± 0.18	0.24 ± 0.07
C	38 ± 6	5.08 ± 0.16	3.9 ± 0.6	0.42 ± 0.04	1.30 ± 0.14	0.8 ± 0.7	0.11 ± 0.05	0.58 ± 0.09	0.11 ± 0.03
D	27 ± 5	0.22 ± 0.03	0.14 ± 0.08	0.015 ± 0.007	0.4 ± 0.4	0.3 ± 0.3	0 ± 0	0.058 ± 0.019	0.007 ± 0.007

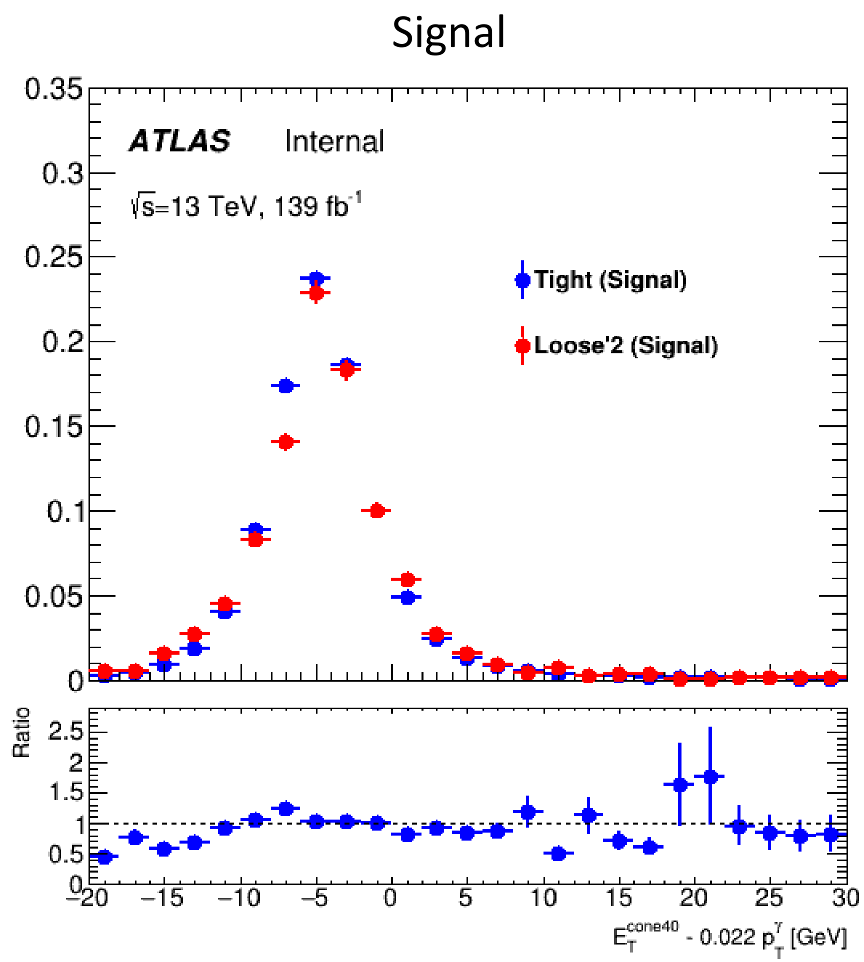
The differences between the different MC exist mostly due to the imperfect photon iso/ID modeling in them. Therefore, systematics can be derived from the iso/ID uncertainty on reconstruction photon efficiency $\delta^{eff}_{iso/ID}$ (relative). By definition, the photon isolation modeling only affects c_B and c_D, while the photon ID modeling only has effects on c_C and c_D, which gives the following σ for leakage parameters:

- $\sigma^{c_B}_{iso}(\text{relative}) = \delta^{eff}_{iso} * (c_B + 1)/c_B$
- $\sigma^{c_C}_{ID}(\text{relative}) = \delta^{eff}_{ID} * (c_C + 1)/c_C$
- $\sigma^{c_D}_{iso}(\text{relative}) = \delta^{eff}_{iso} * (c_B + 1)/c_B$
- $\sigma^{c_D}_{ID}(\text{relative}) = \delta^{eff}_{ID} * (c_C + 1)/c_C$

$\delta^{eff}_{iso} = 0.023$, $\delta^{eff}_{iso/ID} = 0.019$. The largest variation from this type of uncertainty is **10%**.

jet→γ misID background: iso distribution

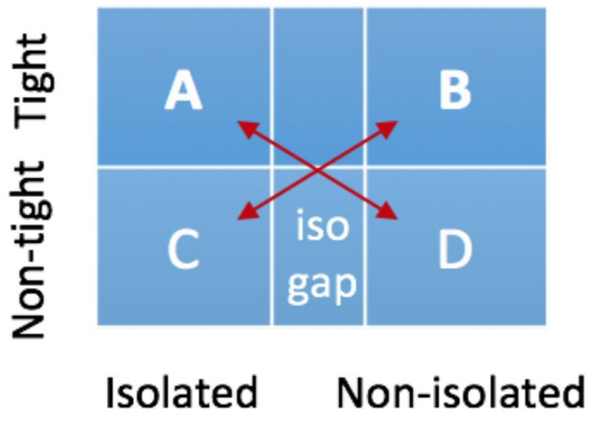




The bottom panel shows the ratio of tight photon candidates from Z+jets simulation and anti-tight photon candidates in data to the anti-tight photon candidates from Z+jets simulation.

jet→γ misID background

iso gap = 2 GeV



The number of events arising in each of the regions:

$$N_A = \boxed{N_A^{Z(\nu\bar{\nu})\gamma}} + N_A^{bkg} + \boxed{N_A^{jet\to\gamma}};$$
$$N_B = c_B N_A^{Z(\nu\bar{\nu})\gamma} + N_B^{bkg} + N_B^{jet\to\gamma};$$
$$N_C = c_C N_A^{Z(\nu\bar{\nu})\gamma} + N_C^{bkg} + N_C^{jet\to\gamma};$$
$$N_D = c_D N_A^{Z(\nu\bar{\nu})\gamma} + N_D^{bkg} + N_D^{jet\to\gamma};$$

$$\boxed{N_A^{jet\to\gamma}}$$

$N_i^{jet\to\gamma}$ — a number of jet → γ events;
$N_i^{Z(\nu\nu)\gamma}$ — a number of signal events;
N_i — a number of data events in each region;
N_i^{bkg} — a number of events for other than jet → γ backgrounds.

The signal leakage parameters:

$$c_B = \frac{N_B^{Z(\nu\bar{\nu})\gamma}}{N_A^{Z(\nu\bar{\nu})\gamma}} \quad c_C = \frac{N_C^{Z(\nu\bar{\nu})\gamma}}{N_A^{Z(\nu\bar{\nu})\gamma}} \quad c_D = \frac{N_D^{Z(\nu\bar{\nu})\gamma}}{N_A^{Z(\nu\bar{\nu})\gamma}}$$

MC

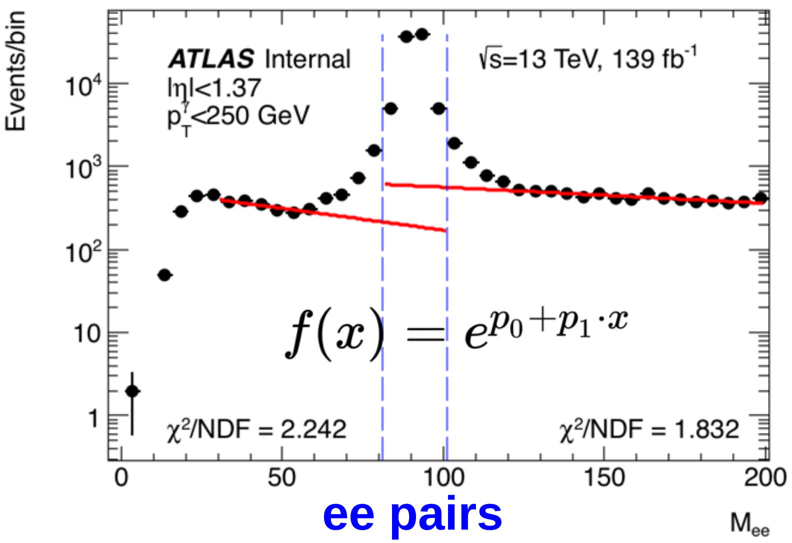
$$N_A^{Z(\nu\bar{\nu})\gamma} = \tilde{N}_A - (\tilde{N}_B - c_B N_A^{Z(\nu\bar{\nu})\gamma})\frac{\tilde{N}_C - c_C N_A^{Z(\nu\bar{\nu})\gamma}}{\tilde{N}_D - c_D N_A^{Z(\nu\bar{\nu})\gamma}}$$

($\tilde{N}_i$ - data with subtracted N_i^{bkg})

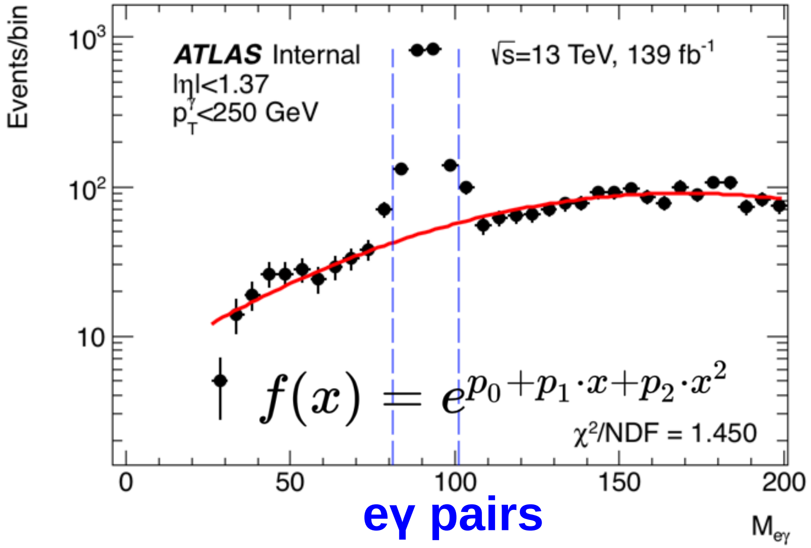
$$a = c_D - c_B c_C;$$
$$b = \tilde{N}_D + c_D\tilde{N}_A - (c_B\tilde{N}_C + c_C\tilde{N}_B);$$
$$c = \tilde{N}_D\tilde{N}_A - \tilde{N}_C\tilde{N}_B.$$

$$\boxed{N_A^{Z(\nu\bar{\nu})\gamma} = \frac{b - \sqrt{b^2 - 4ac}}{2a}}$$

e→γ background



ee pairs



eγ pairs

fit from left side in range (30,60)
fit from right side in range(120,200)

Background fit is extrapolated to Z peak mass window from both sides. Integrals under the fit function in this region give N_{min} and N_{max}

Average used as N_{ee}^{bkg} in fake-rate calculation: $N^{bkg}_{average} = \frac{N^{bkg}_{min}+N^{bkg}_{min}}{2}$

simultaneous fit in range (25,70)&&(110,200)
Range is safely extended to gain statistics.

Background fit is extrapolated to Z peak mass window after the fit. Integral of extrapolated function in Z peak mass window is used as $N_{e\gamma}^{bkg}$

Systematics on bkg estimation under the Z peak is 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 were 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 $N^{bkg}_{e\gamma}$ and N^{bkg}_{ee} is taken as systematics.

Details on uncertainty components for e→γ background

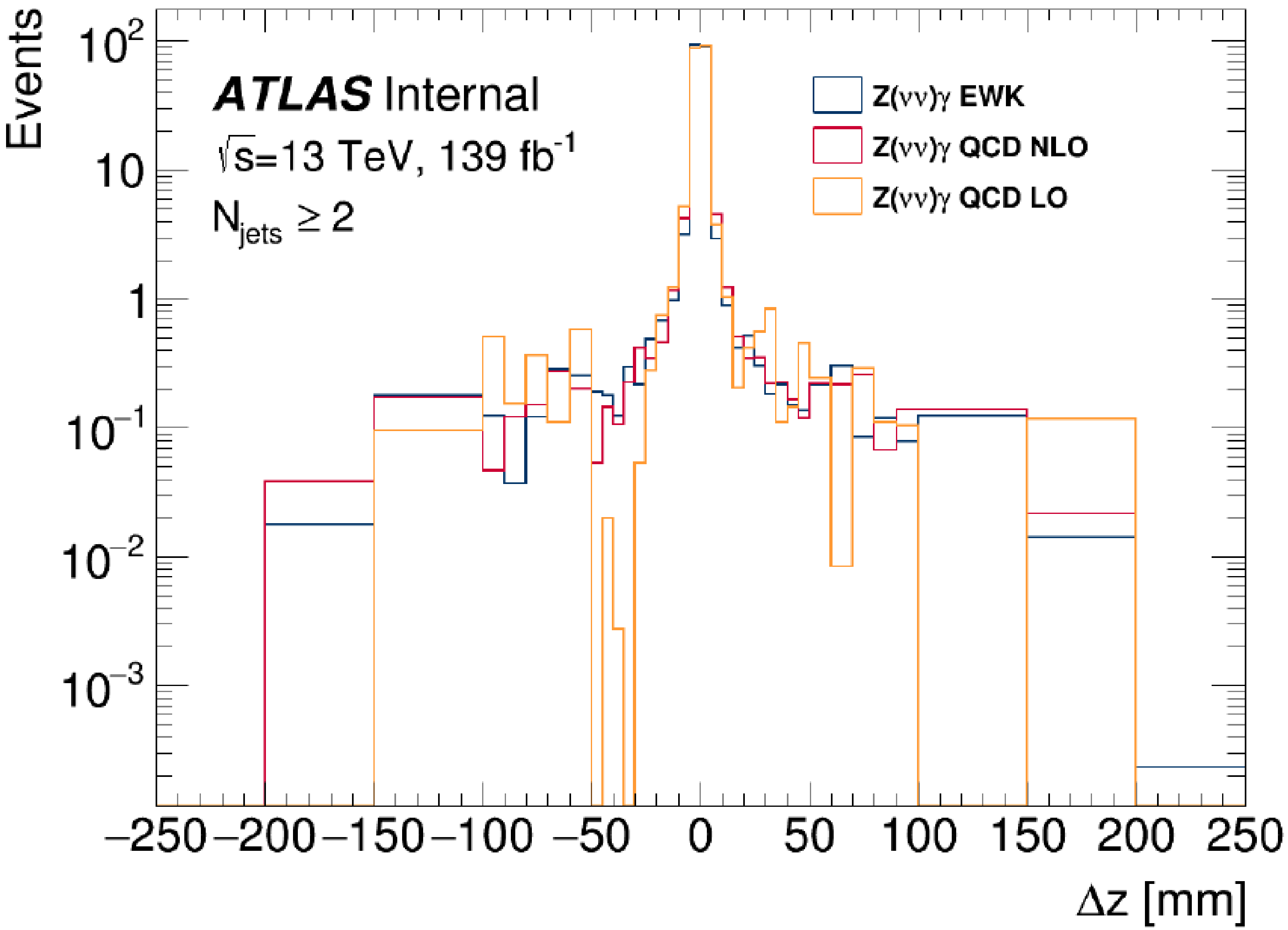
region	$150<E_T<250$ GeV, $0<\|\eta\|<1.37$			$E_T>250$ GeV, $0<\|\eta\|<1.37$			$1.52<\|\eta\|<2.37$		
stat. unc.	fake-rate stat.	region stat.	sum ⊕	fake-rate stat.	region stat.	sum ⊕	fake-rate stat.	region stat.	sum ⊕
Zγ incl.	2.62%	2.17%	3.40%	6.57%	3.46%	7.43%	2.87%	3.86%	4.81%
SR	2.62%	5.36%	5.97%	6.57%	8.48%	10.7%	2.87%	11.11%	11.5%

Total stat. unc. on the background is composed from sum ⊕ of absolute stat. unc. of each the region.

	$150 < E_T^\gamma < 250$ GeV $0 < \|\eta\| < 1.37$	$E_T^\gamma > 250$ GeV $0 < \|\eta\| < 1.37$	$1.52 < \|\eta\| < 2.37$
$Z(ee)$ MC tag-n-probe fake rate	0.0182 ± 0.0003	0.0175 ± 0.0005	0.0542 ± 0.0010
$Z(ee)$ MC mass window var. fake rate	0.0181 ± 0.0003	0.0176 ± 0.0005	0.0545 ± 0.0010
syst. from mass window var.:	0.4%	0.3%	0.6%
$Z(ee)$ MC real fake rate	0.018 ± 0.002	0.020 ± 0.002	0.059 ± 0.004
syst. from tag-n-probe and real f.r.:	3.1%	13.4%	8.7%
$W(e\nu)$ MC real fake rate	0.023 ± 0.003	0.020 ± 0.003	0.067 ± 0.012
syst. from real f.r. in $W(e\nu)$ and $Z(ee)$ MC:	29.2%	1.9%	14.0%
Background fit variation	3.7%	10.8%	3.3%
Total syst.:	29.6%	17.3%	16.5%

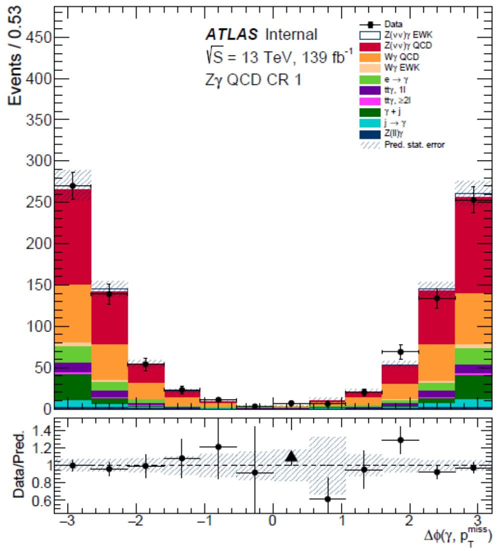
Table 18: Electron-to-photon fake rate systematics summary.

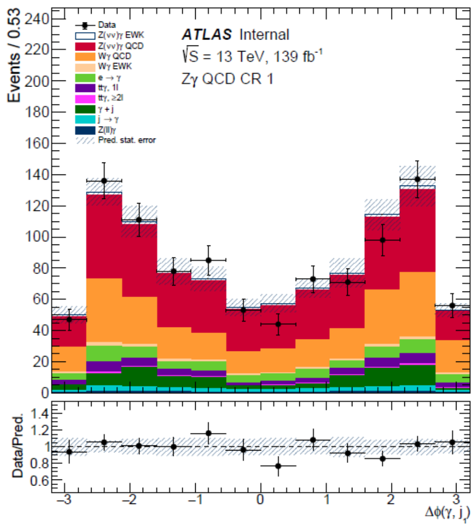
Pile-up background

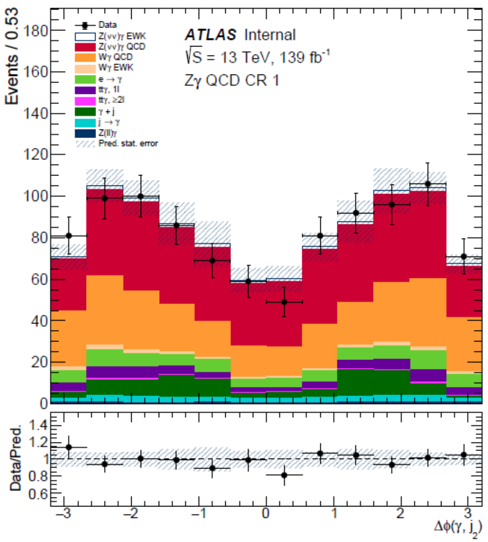


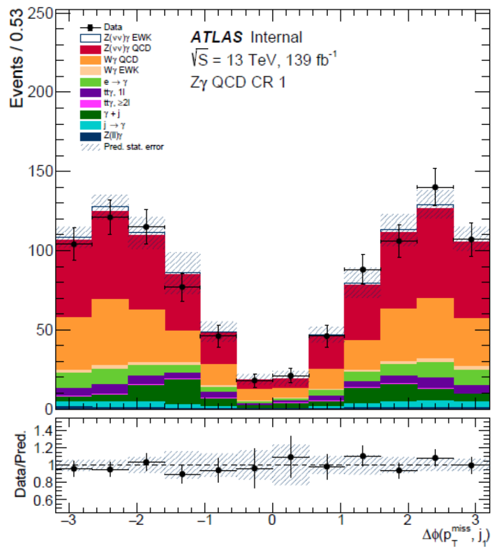
Possible pile-up background impact on shapes

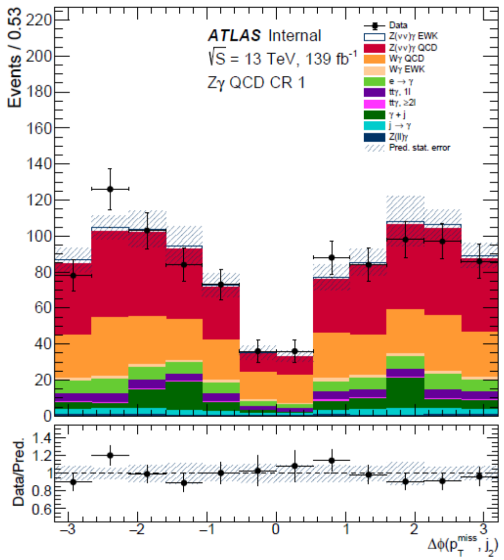
- Before fit

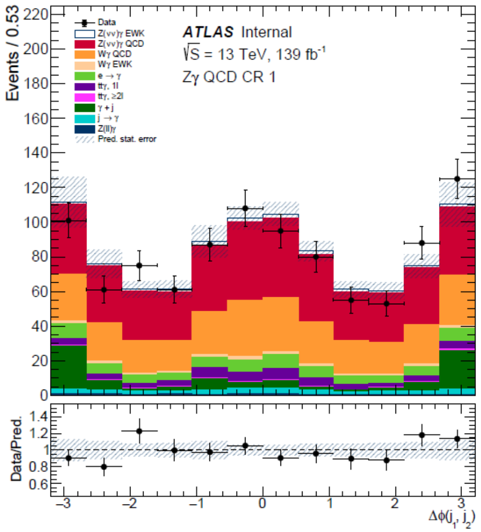






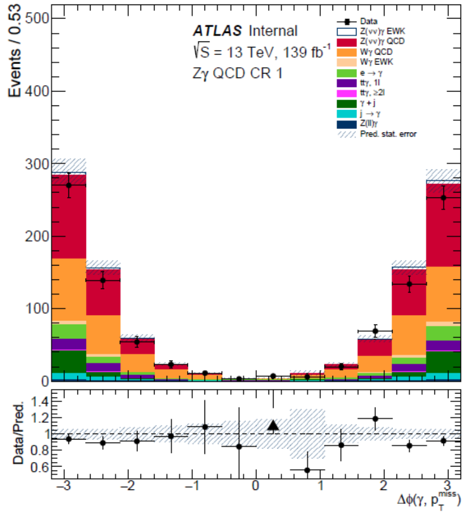


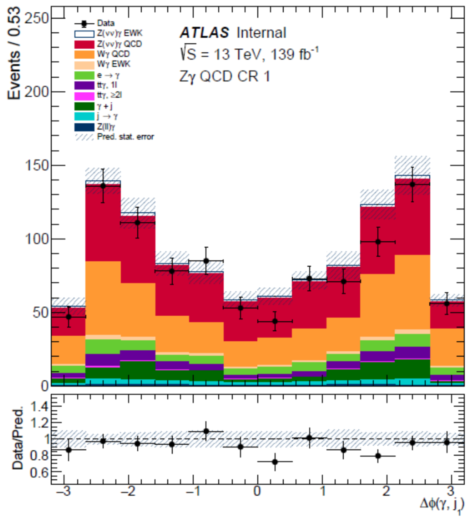


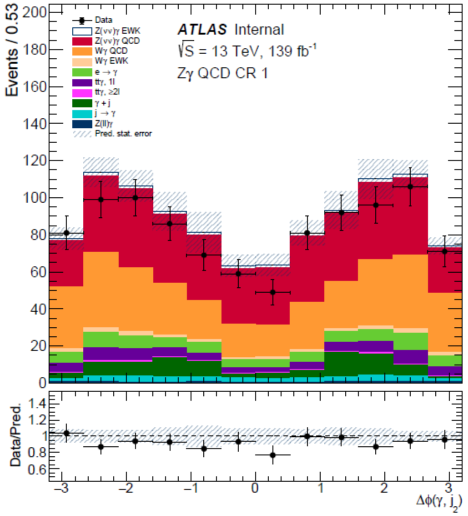


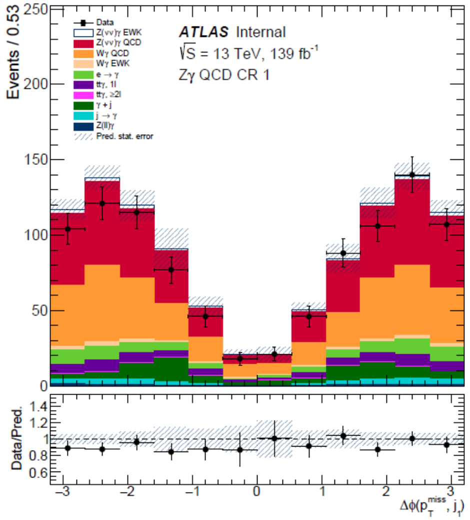
Possible pile-up background impact on shapes

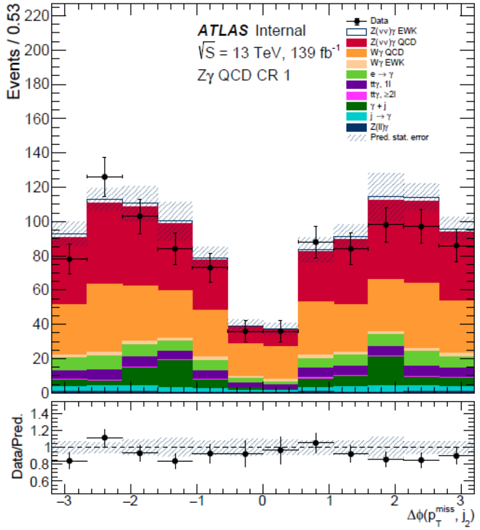
➢ After fit

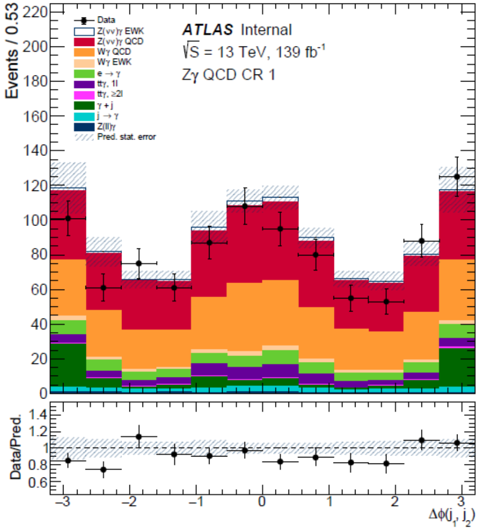












ttgamma classification at truth level

Strategy used for old ttgamma (407320.aMcAtNloPythia8EvtGen_MEN30NLO_A14N23LO_tta140):

leptons are chosen in a way from TruthMuons, TruthElectrons and TruthTaus:

status==1 (2 for tau) && barcode < 200000 && (classifierParticleOrigin ==10 || classifierParticleOrigin==12)

MCTruthClassifier (classifierParticleOrigin):
top = 10 (t->W->lν)
WBoson = 12

for 410389.MadGraphPythia8EvtGen_A14NNPDF23_ttgamma_nonallhadronic:

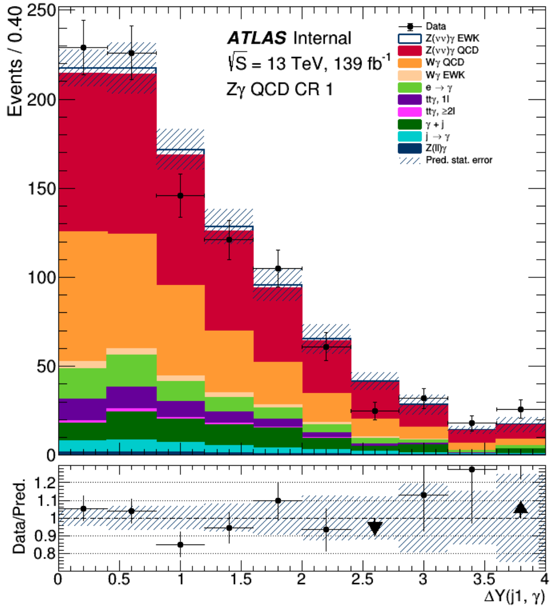
classifier is not working well, since classifierParticleOrigin is sometimes 0 - notDefined.
Therefore neutrino are used, because number of neutrino corresponds to the number of leptons

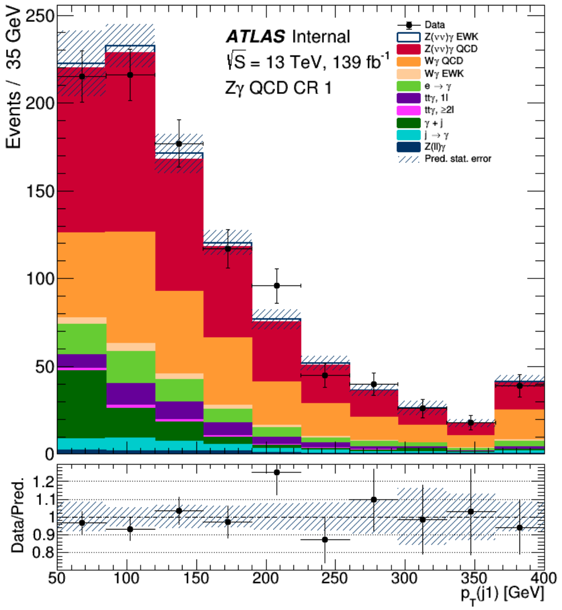
From TruthParticle container
(abs(pdgId)==12 || abs(pdgId)==14 || abs(pdgId)==16) && status==1 && barcode < 200000 &&
&& (parent->pdgId==pdgId || abs(parent->pdgId)==24 || abs(parent->pdgId)==6)

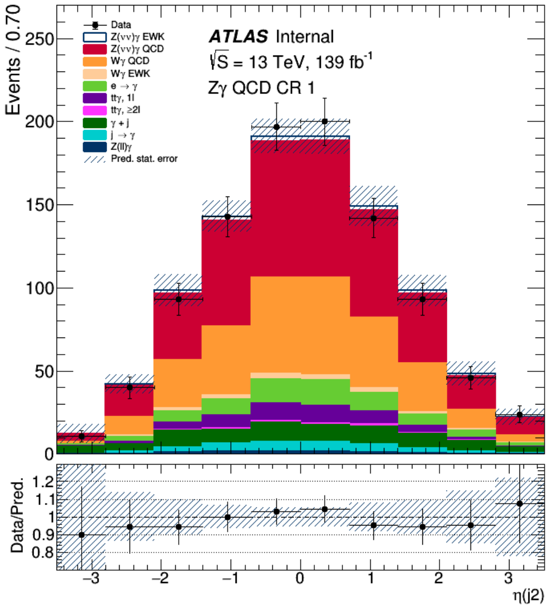
24 - WBozon, 6 - top

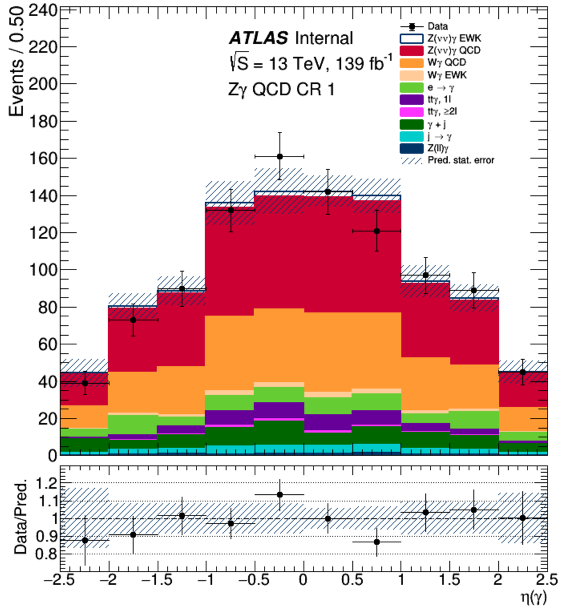
In both cases: n_{lep} == 1 - MC and $\mu_{W\gamma}$ applied, n_{lep}>1 - using MC without normalization

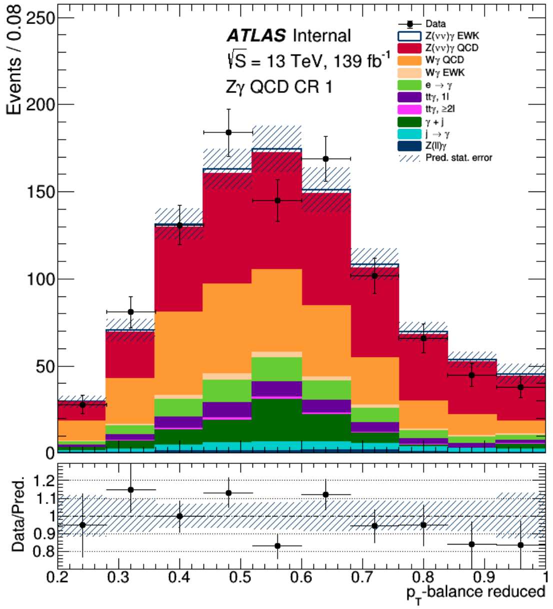
Control plots











BDT Classifier input variables

Selected:

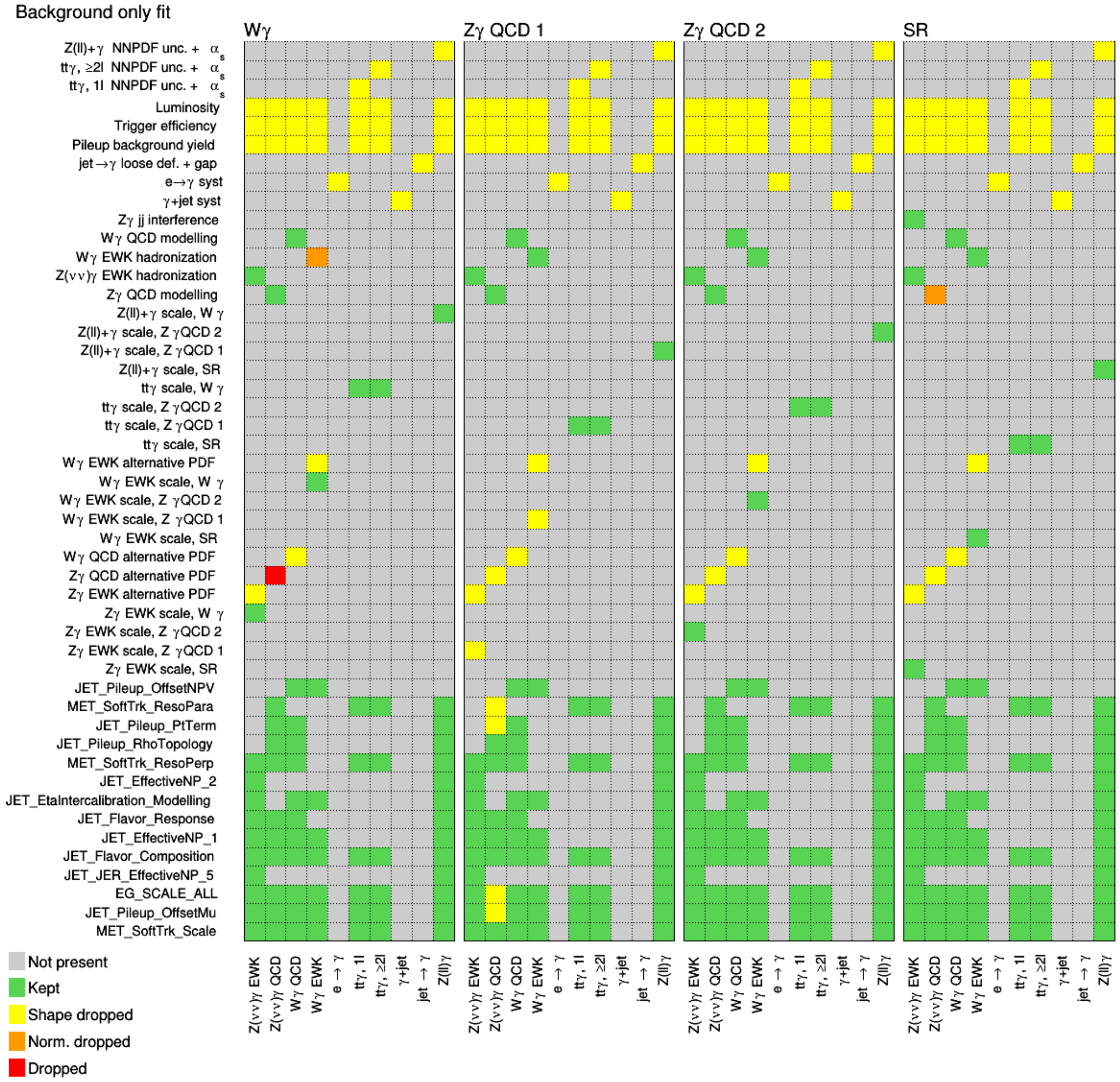
1. m_{jj};
2. $\Delta Y(j_1, j_2)$;
3. E_T^{miss}
4. p_T-balance $= = \frac{|\vec{p}_T^{\,\text{miss}} + \vec{p}_T^{\,\gamma} + \vec{p}_T^{\,j_1} + \vec{p}_T^{\,j_2}|}{E_T^{\text{miss}} + p_T^{\gamma} + p_T^{j_1} + p_T^{j_2}}$;
5. $\eta(j_2)$;
6. $p_T(j_1)$;
7. $\eta(\gamma)$;
8. p_T-balance(reduced)$= \frac{|\vec{p}_T^{\,\gamma} + \vec{p}_T^{\,j_1} + \vec{p}_T^{\,j_2}|}{p_T^{\gamma} + p_T^{j_1} + p_T^{j_2}}$;
9. N_{jets};
10. $\sin\left(\left|\frac{\Delta\varphi(j_1, j_2)}{2}\right|\right)$;
11. $\Delta Y(j_1, \gamma)$.

Considered:

- $\eta(j_1)\eta(j_2)$;
- $\Delta R(j_1, j_2)$;
- $\Delta R(j_1, \gamma)$;
- $\Delta p_T(j_1, j_2)$
- $\zeta_{\text{jets}} = \frac{p_T^{j_1} - p_T^{j_2}}{E^{j_1} + E^{j_2}}$;
- $\Delta R(j_1, \vec{p}_T^{\,\text{miss}})$;
- $\varphi(j_1)$;
- $\eta(j_1)$;
- $p_T(j_2)$;
- $\varphi(j_2)$;
- $p_T(\gamma)$;
- $\varphi(\gamma)$;
- $\varphi(\vec{p}_T^{\,\text{miss}})$
- $m_T(E_T^{\text{miss}}, \gamma)$

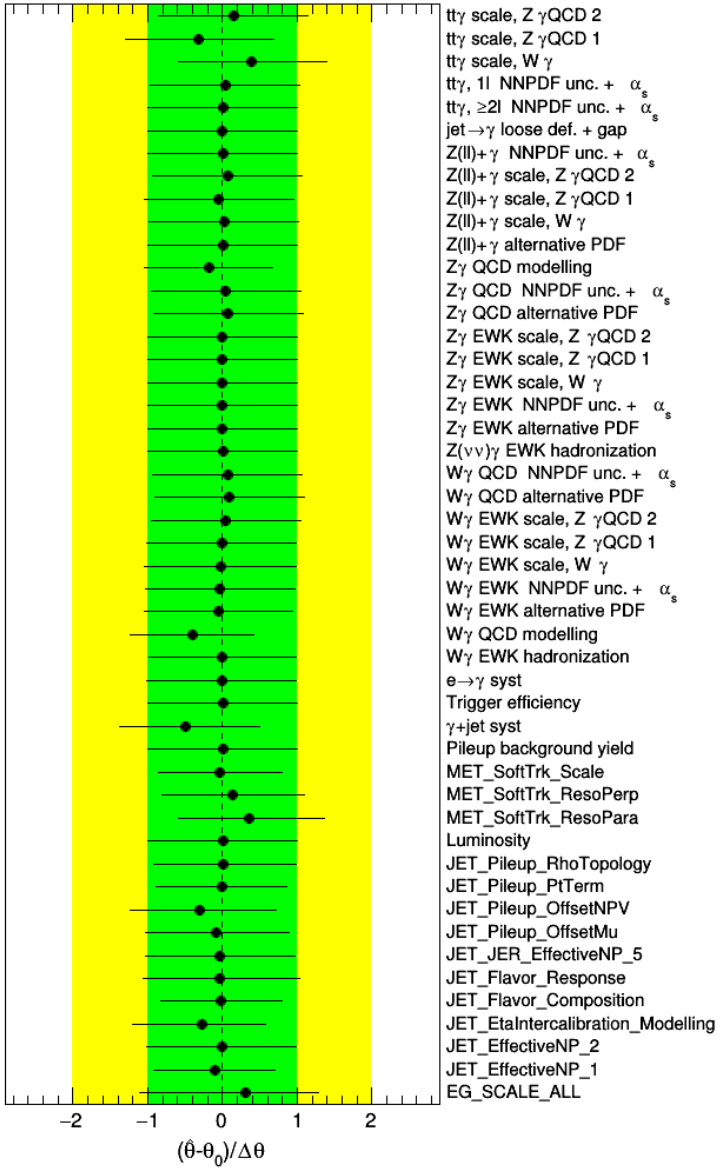
γ-centrality$= \left|\frac{y(\gamma) - \frac{y(j_1)+y(j_2)}{2}}{y(j_1) - y(j_2)}\right|$

Full systematics list



- Scale uncertainties are decorrelated between the regions
- Z(νν)γ QCD and Wγ QCD scale uncertainties are omitted because they have high correlations with the normalizations coefficients and had normalization effect only
- Z(νν)γ EWK has an interference uncertainty created with a truth level interference sample
- Wγ QCD modelling uncertainty is made using Z(νν)γ QCD modelling uncertainty as a template

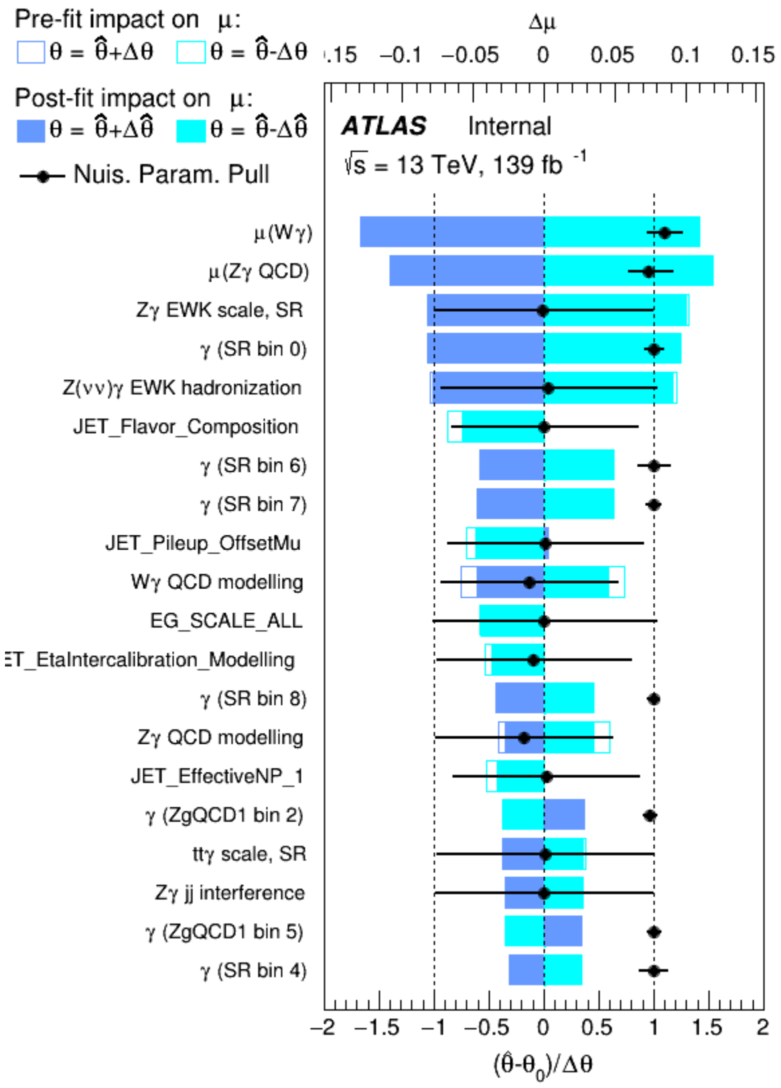
Background-only fit, systematics



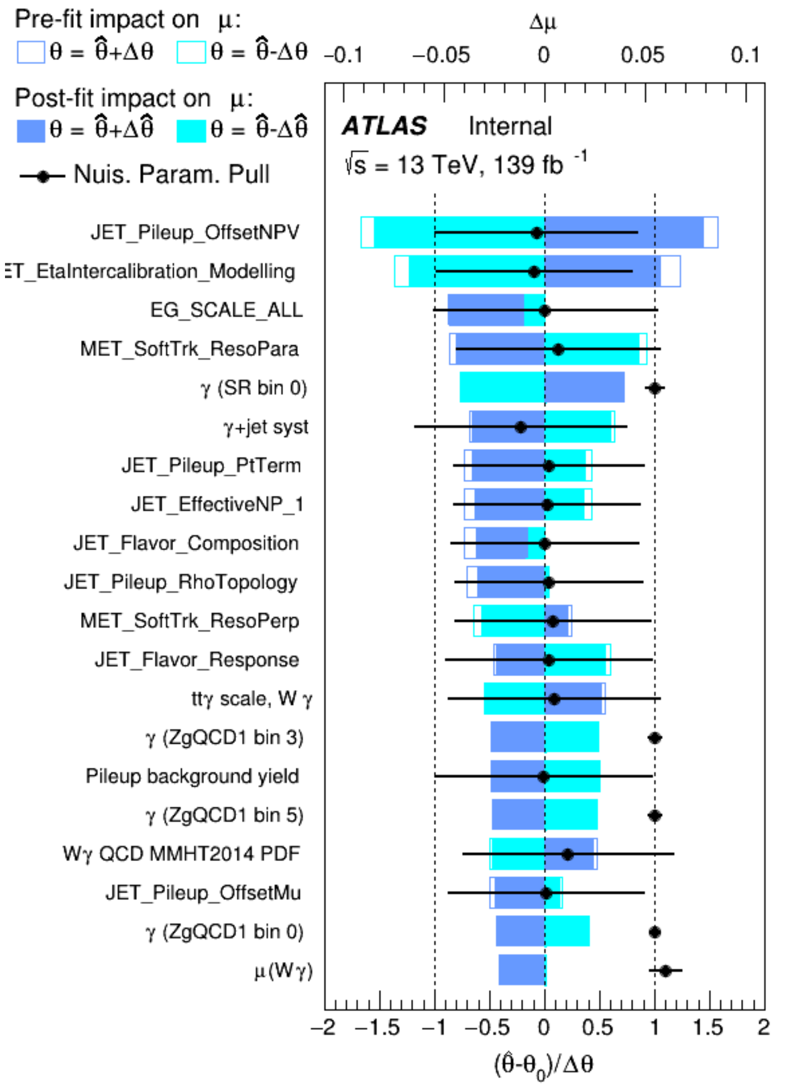
	EG_SCALE_ALL	JET_EffectiveNP_1	JET_EtaIntercalibration_Modelling	JET_Flavor_Composition	JET_Flavor_Response	JET_Pileup_OffsetMu	JET_Pileup_OffsetNPV	JET_Pileup_PtTerm	JET_Pileup_RhoTopology	MET_SoftTrk_ResoPara	MET_SoftTrk_ResoPerp	MET_SoftTrk_Scale	γ+jet syst	Wγ QCD modelling	Zγ QCD modelling	ttγ scale, W γ	μ(Zγ QCD)	μ(Wγ)
EG_SCALE_ALL	100.0	-4.4	-7.1	-5.8	-12.8	-6.4	-10.3	-8.2	-8.4	-1.2	-7.7	-5.7	0.1	3.9	-3.6	-1.1	-40.8	-53.4
JET_EffectiveNP_1	-4.4	100.0	-6.3	-5.3	-6.1	-4.5	-7.4	-1.9	-3.9	0.1	-2.5	-4.7	-0.0	-0.7	-2.3	2.3	-17.7	-10.8
JET_EtaIntercalibration_Modelling	-7.1	-6.3	100.0	-6.3	-6.4	-6.8	-9.5	-2.9	-4.3	-0.4	-4.2	-5.9	-0.0	-1.1	-2.3	0.6	18.2	-12.4
JET_Flavor_Composition	-5.8	-5.3	-6.3	100.0	-8.5	-3.7	-5.8	-3.5	-5.1	0.8	-2.0	-3.0	-0.5	-3.1	-4.2	1.5	-13.8	-16.3
JET_Flavor_Response	-12.8	-6.1	-6.4	-8.5	100.0	-8.3	-6.2	-7.8	-10.4	-3.1	-10.4	-8.7	-1.2	-1.6	-3.9	-2.0	-23.5	-6.8
JET_Pileup_OffsetMu	-6.4	-4.5	-6.8	-3.7	-8.3	100.0	-8.3	-5.0	-5.5	1.3	-3.1	-3.3	-1.1	3.4	-2.2	1.7	-23.6	-26.9
JET_Pileup_OffsetNPV	-10.3	-7.4	-9.5	-5.8	-6.2	-8.3	100.0	-4.8	-4.4	0.7	-7.7	-8.2	0.3	2.8	-0.5	2.3	24.8	-10.5
JET_Pileup_PtTerm	-8.2	-1.9	-2.9	-3.5	-7.8	-5.0	-4.8	100.0	-5.2	-2.1	-7.2	-4.7	0.2	1.9	-0.9	-1.7	-18.0	-7.0
JET_Pileup_RhoTopology	-8.4	-3.9	-4.3	-5.1	-10.4	-5.5	-4.4	-5.2	100.0	-2.3	-6.8	-5.7	-0.6	-0.5	-1.1	-1.2	-18.7	-7.5
MET_SoftTrk_ResoPara	-1.2	0.1	-0.4	0.8	-3.1	1.3	0.7	-2.1	-2.3	100.0	1.1	1.6	-0.4	1.8	-0.2	1.1	-26.0	-4.5
MET_SoftTrk_ResoPerp	-7.7	-2.5	-4.2	-2.0	-10.4	-3.1	-7.7	-7.2	-6.8	1.1	100.0	-3.2	0.6	5.4	-1.1	0.6	-10.5	-4.9
MET_SoftTrk_Scale	-5.7	-4.7	-5.9	-3.0	-8.7	-3.3	-8.2	-4.7	-5.7	1.6	-3.2	100.0	-0.0	2.2	-0.9	2.9	-17.4	-18.4
γ+jet syst	0.1	-0.0	-0.0	-0.5	-1.2	-1.1	0.3	0.2	-0.6	-0.4	0.6	-0.0	100.0	0.8	2.0	0.6	-8.7	0.0
Wγ QCD modelling	3.9	-0.7	-1.1	-3.1	-1.6	3.4	2.8	1.9	-0.5	1.8	5.4	2.2	0.8	100.0	-21.6	0.7	-5.7	-0.2
Zγ QCD modelling	-3.6	-2.3	-2.3	-4.2	-3.9	-2.2	-0.5	-0.9	-1.1	-0.2	-1.1	-0.9	2.0	-21.6	100.0	-0.6	16.3	9.7
ttγ scale, W γ	-1.1	2.3	0.6	1.5	-2.0	1.7	2.3	-1.7	-1.2	1.1	0.6	2.9	0.6	0.7	-0.6	100.0	5.4	-10.7
μ(Zγ QCD)	-40.8	-17.7	18.2	-13.8	-23.5	-23.6	24.8	-18.0	-18.7	-26.0	-10.5	-17.4	-8.7	-5.7	16.3	5.4	100.0	72.9
μ(Wγ)	-53.4	-10.8	-12.4	-16.3	-6.8	-26.9	-10.5	-7.0	-7.5	-4.5	-4.9	-18.4	0.0	-0.2	9.7	-10.7	72.9	100.0

Fit to Asimov data, ranking

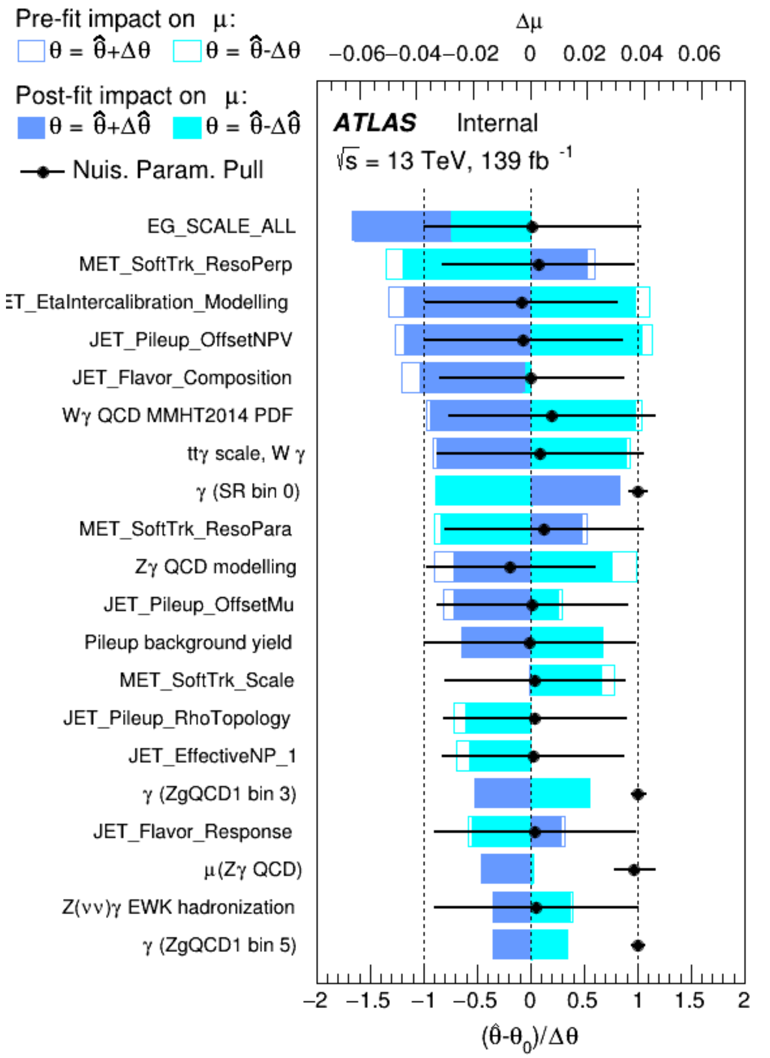
μ_{EWK}



μ_{QCD}

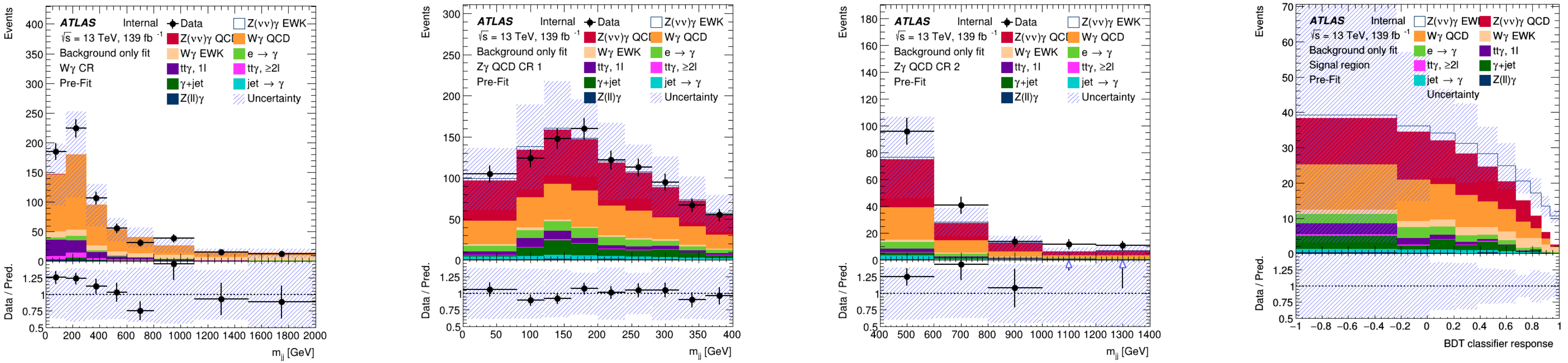


$\mu_{W\gamma}$

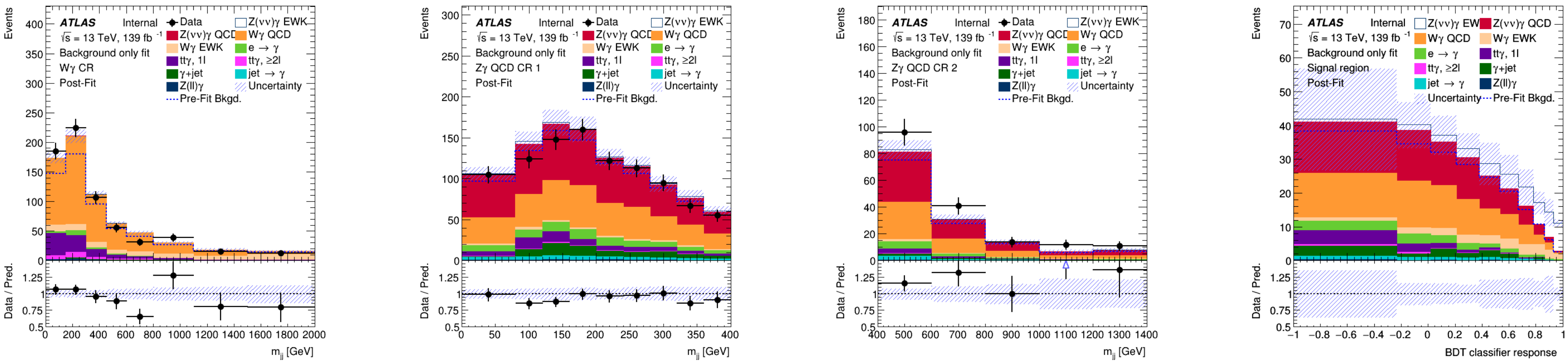


Background only fit, before and after

➢ Before fit



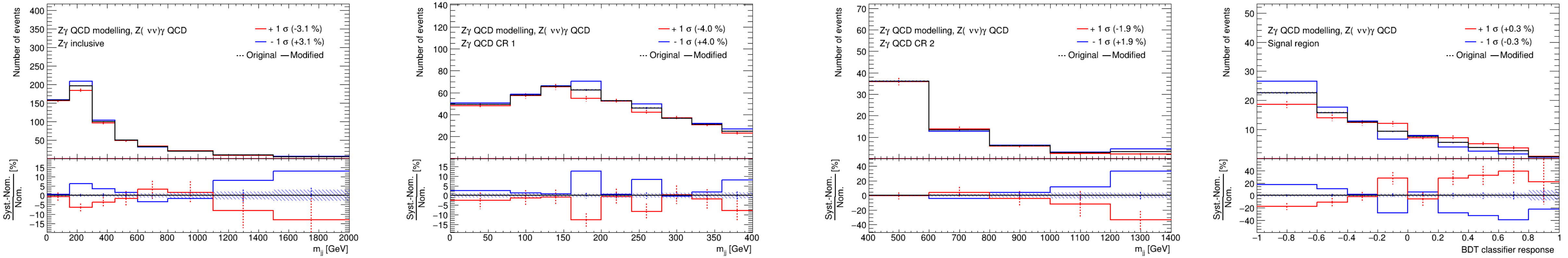
➢ After fit



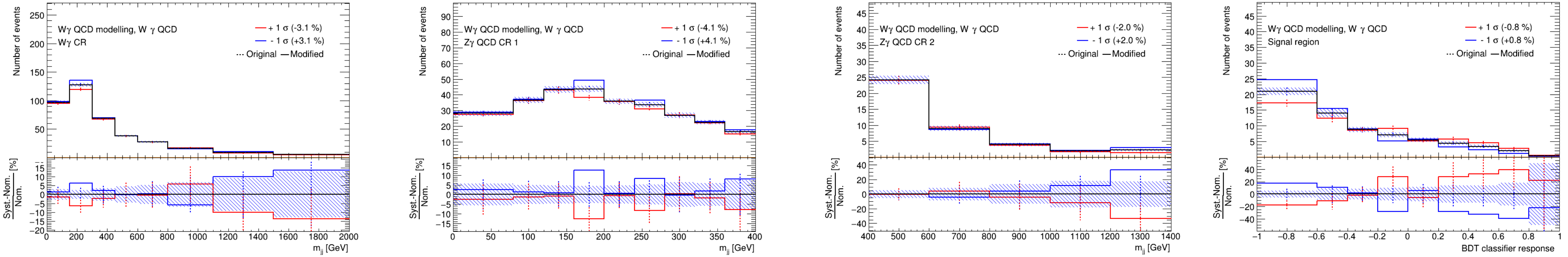
Wγ QCD modelling uncertainty

- Since there are no alternative samples for Wγ QCD, the modelling uncertainty was created by taking relative uncertainties of Z(νν)γ QCD Sherpa/Madgraph comparison in every region.
- Zγ inclusive region is used to model the uncertainty in the Wγ region, since Z(νν)γ QCD has low statistics and fluctuations as high as 1000% in Wγ region

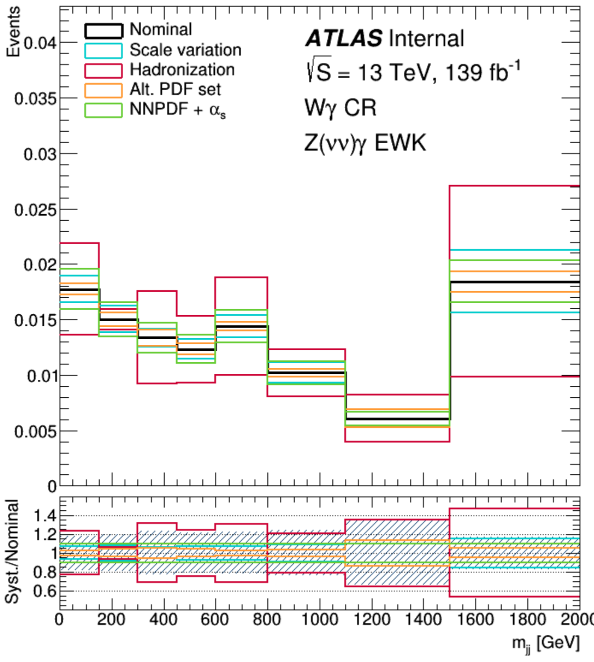
Z(νν)γ QCD template

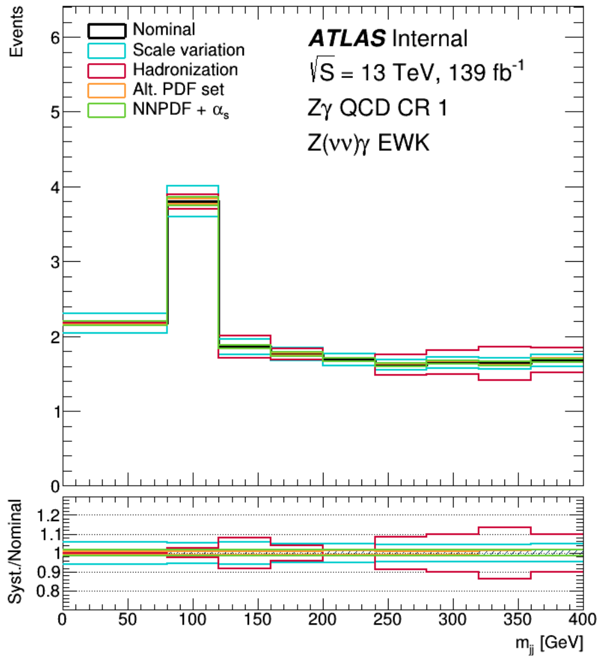


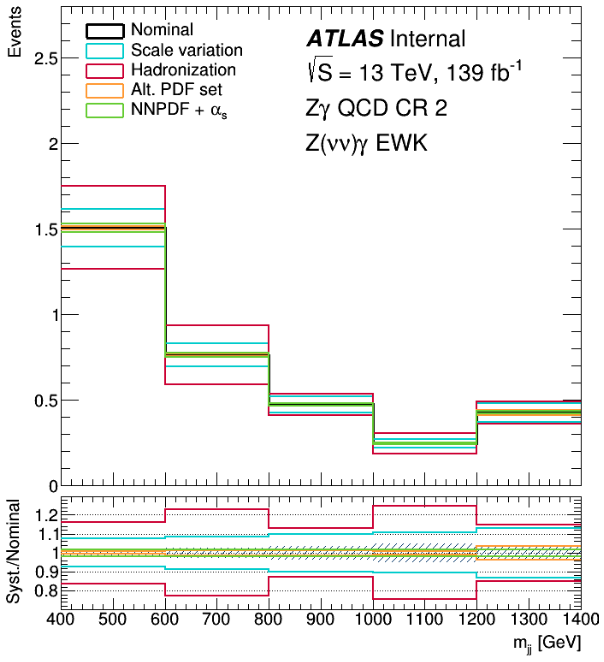
Wγ QCD derived uncertainty

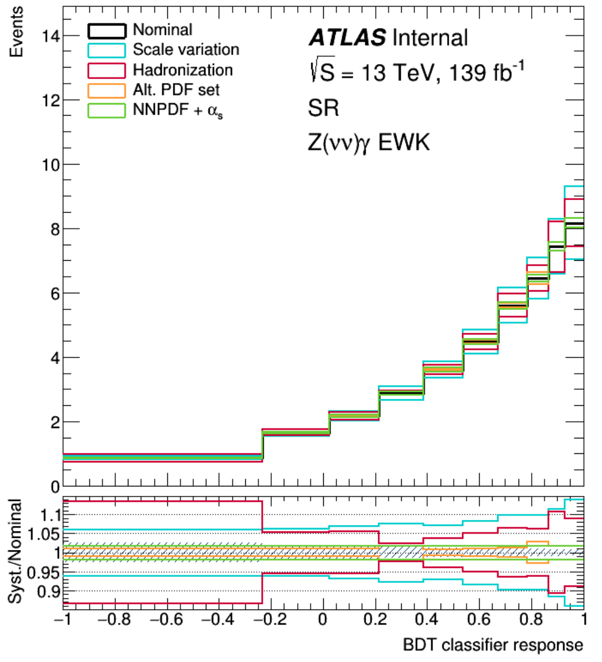


Z(νν)γ EWK theoretical uncertainties

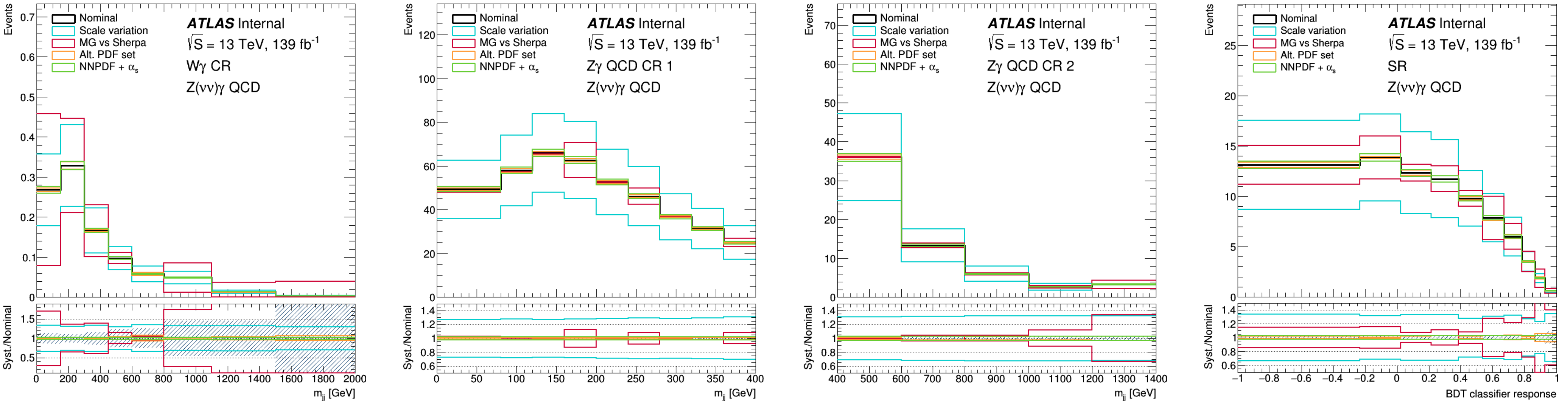




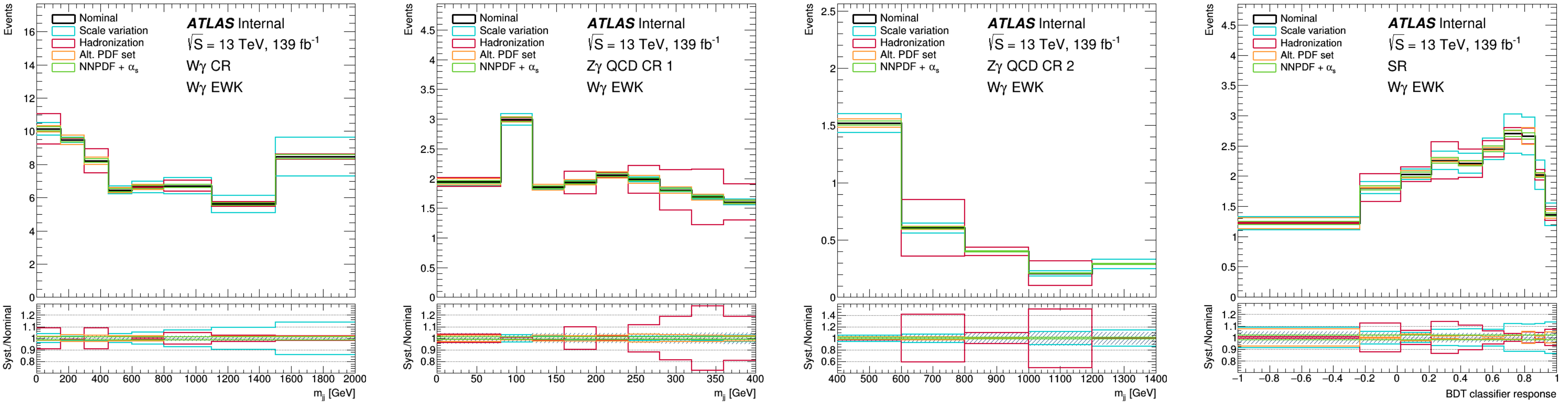




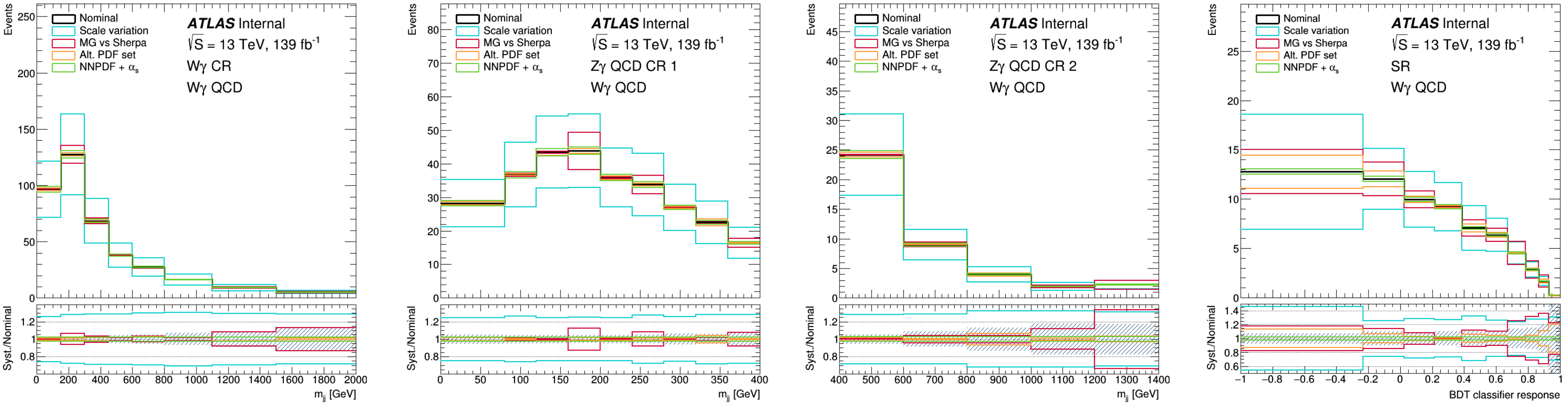
Z(νν)γ QCD theoretical uncertainties



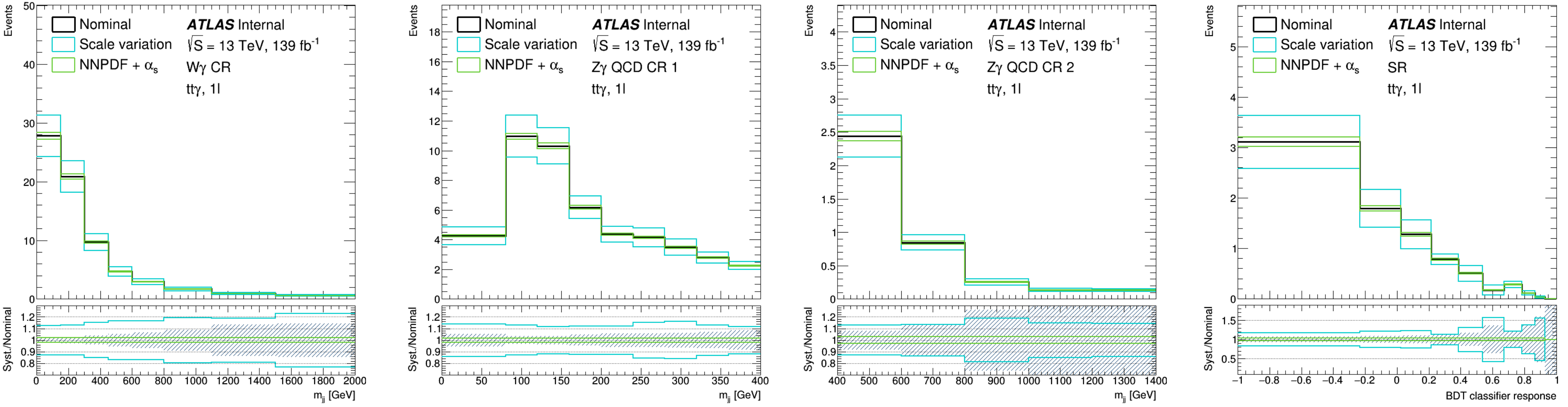
W(lν)γ EWK theoretical uncertainties



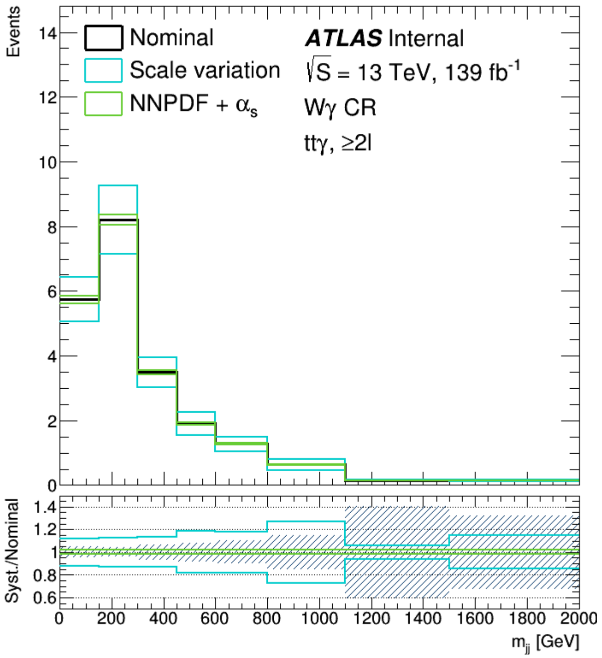
W(lν)γ QCD theoretical uncertainties

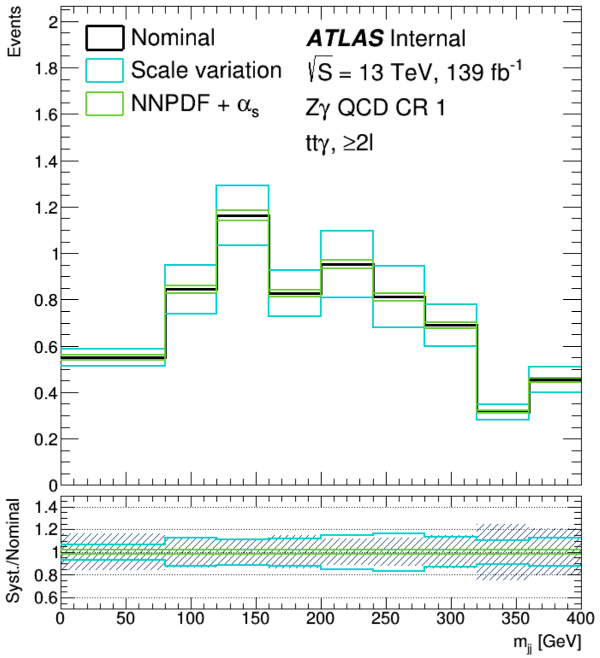


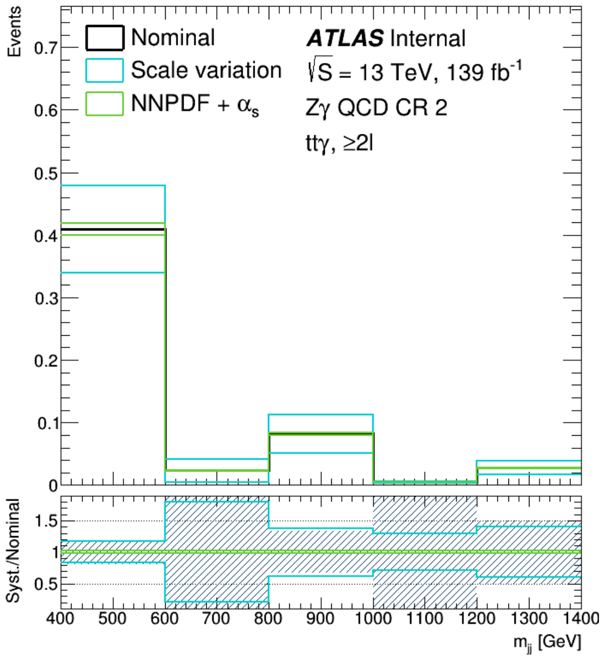
tty 1 lepton theoretical uncertainties

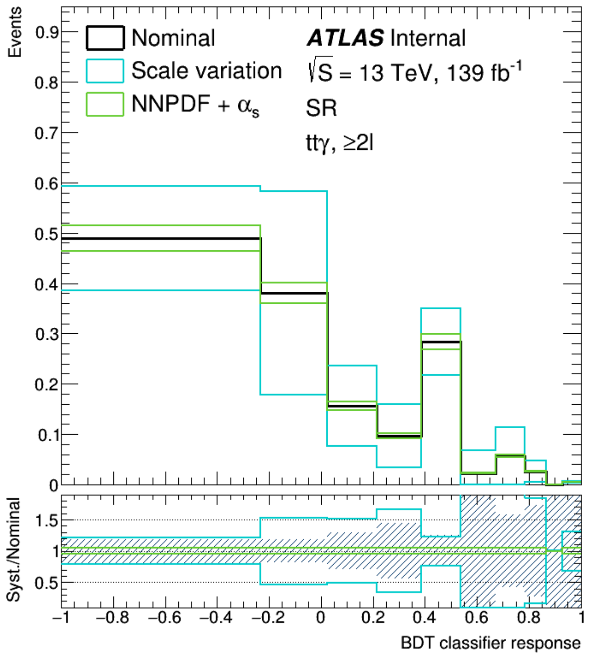


ttγ ≥2 leptons theoretical uncertainties

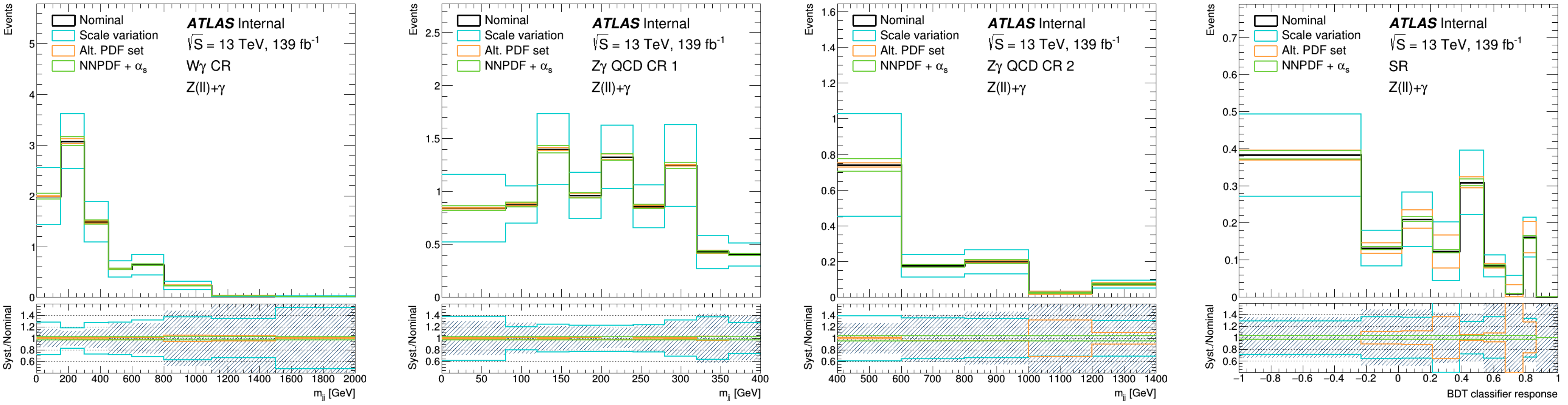




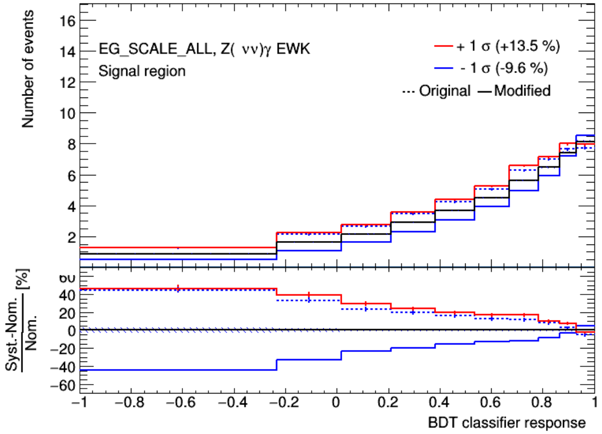


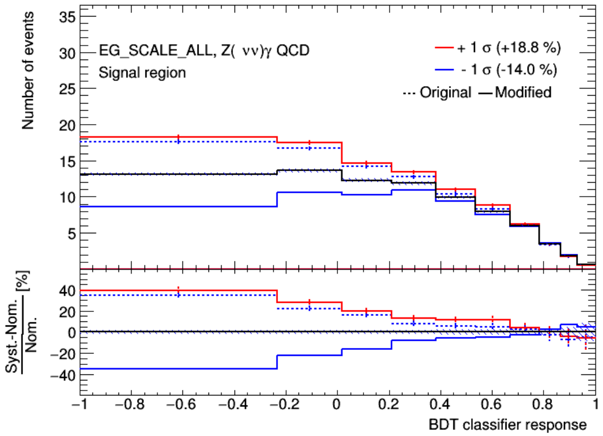


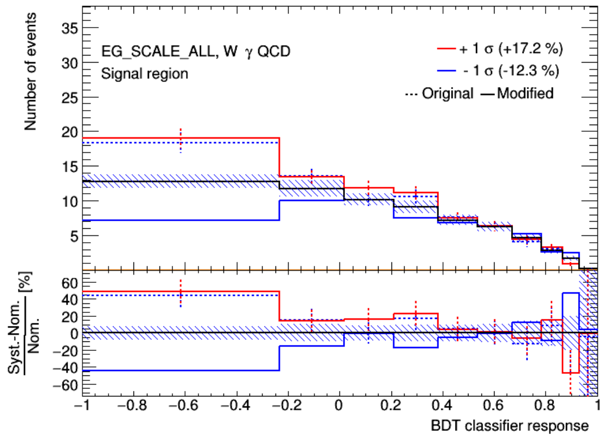
Z(ll)+γ theoretical uncertainties

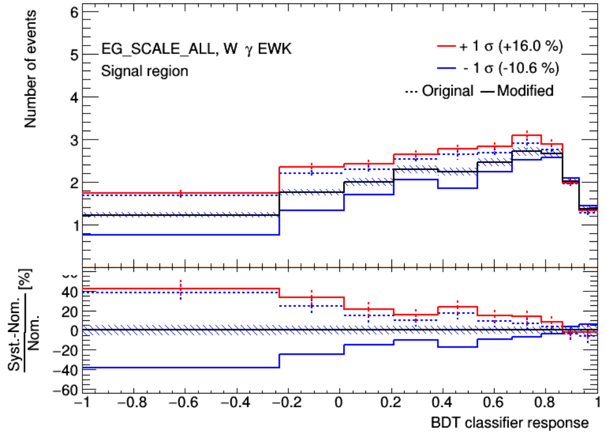


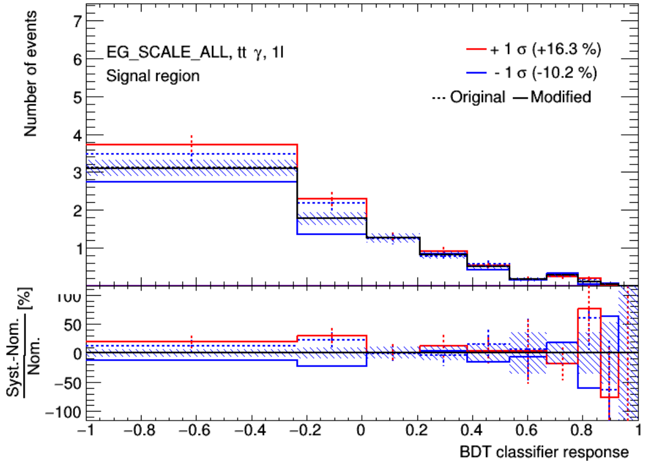
Experimental systematics: EG_SCALE_ALL

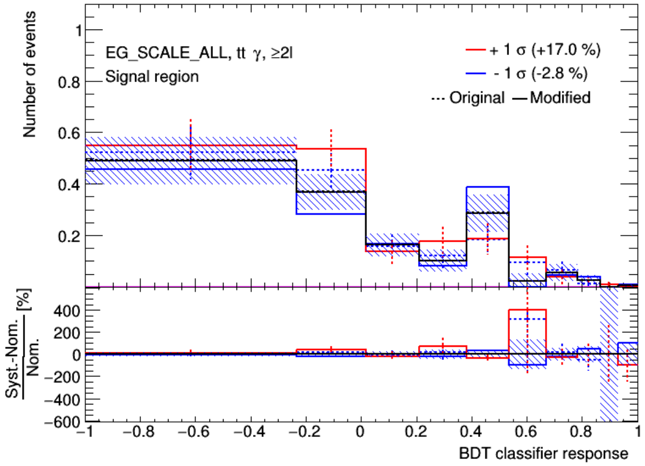


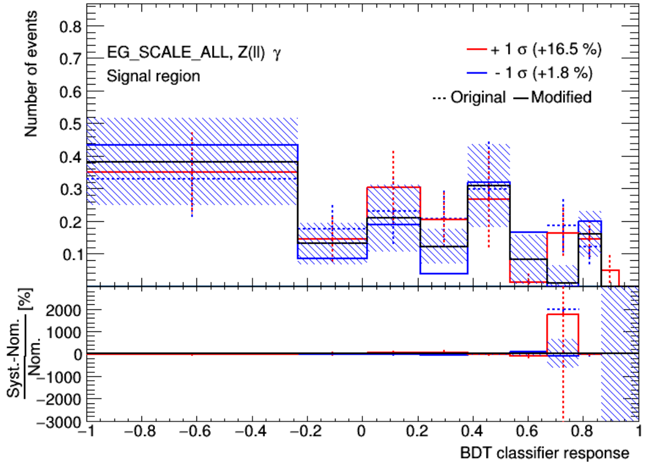




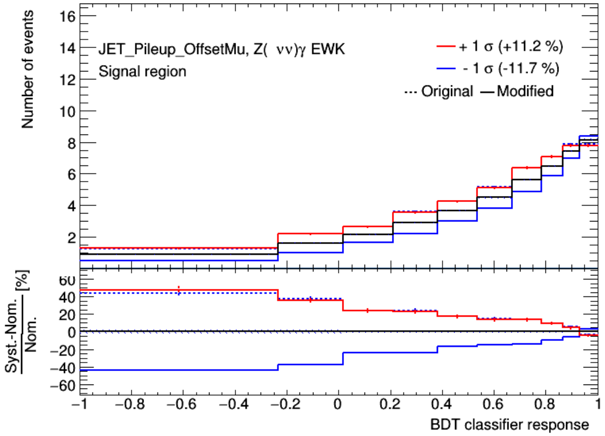


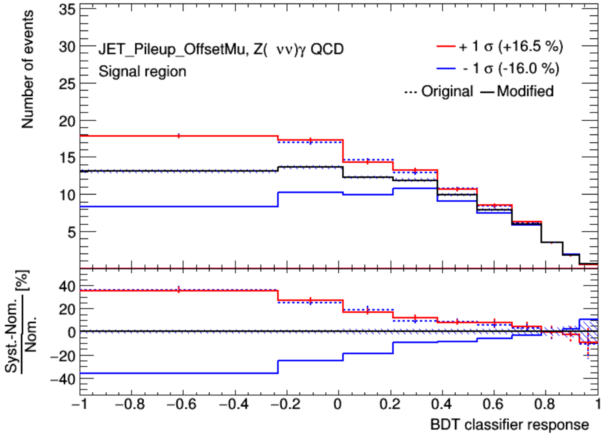


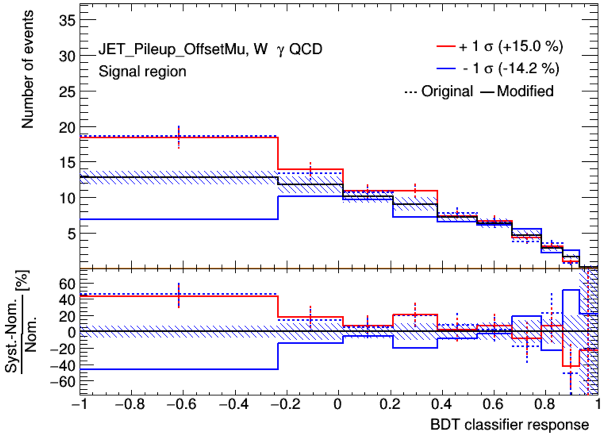


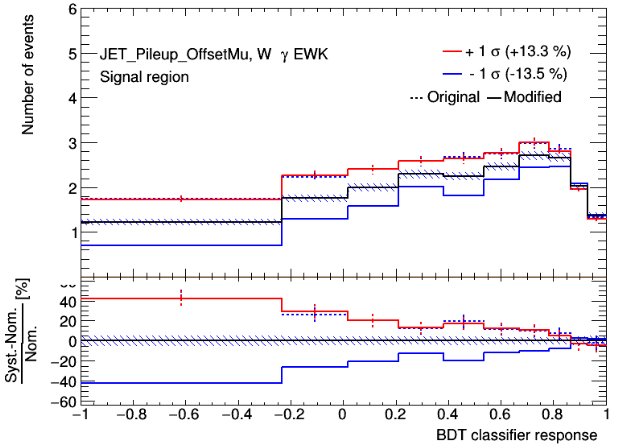


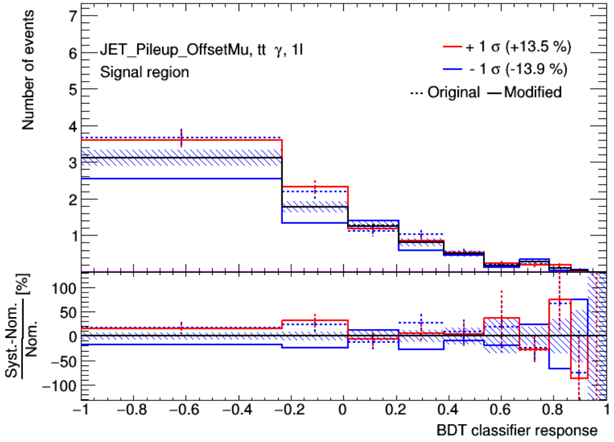
Experimental systematics: Jet_Pileup_OffsetMu

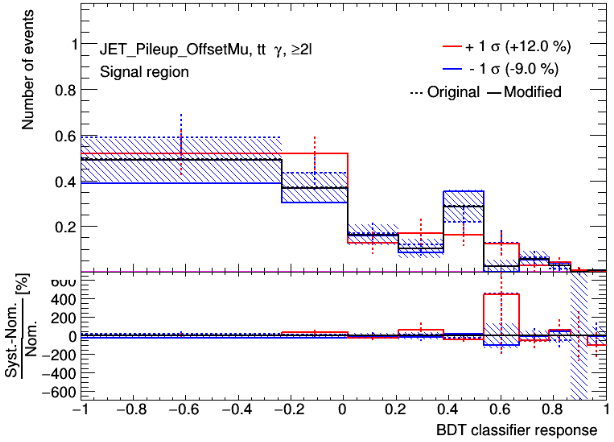


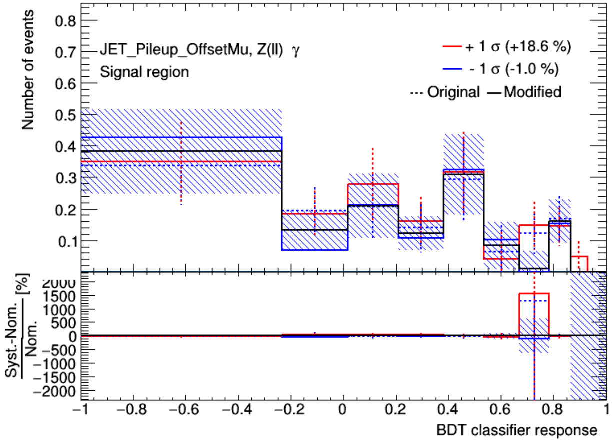










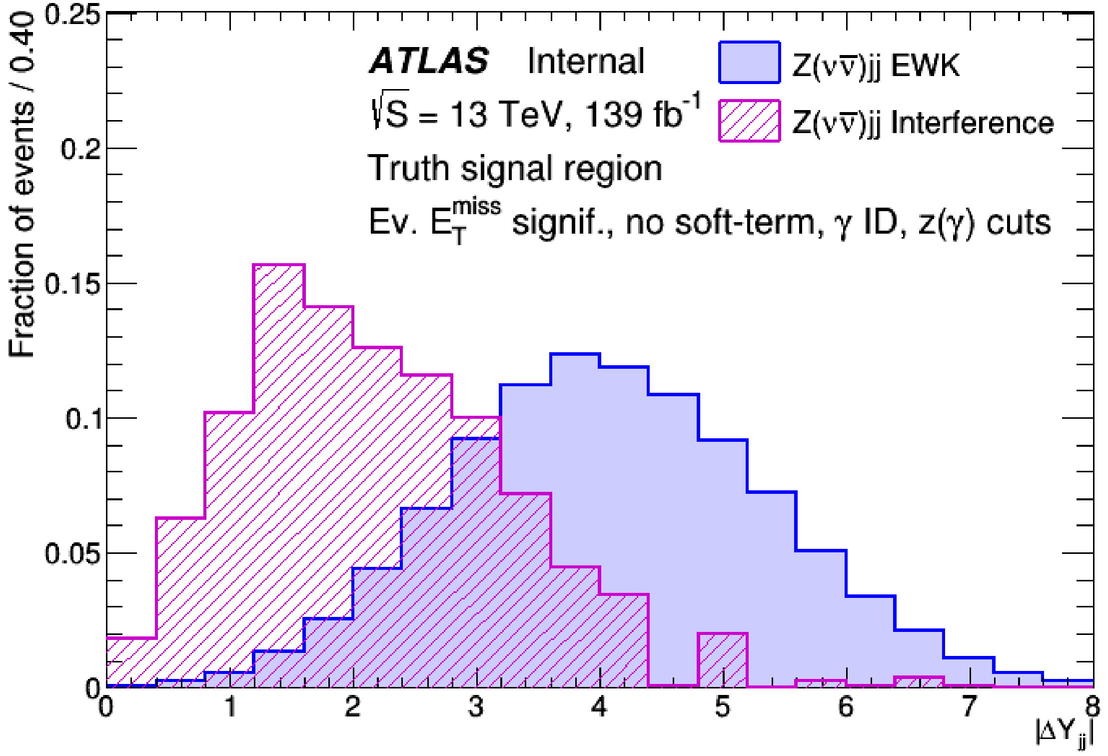


Z(νν)γ interference reweighting

<u>The idea:</u>

1. Use the truth-level ΔY_{jj} distribution of Z(νν)γ EWK and interference samples to create pseudo Z(νν)γ EWK + interference reco-sample (and do the same for all of the Z(νν)γ EWK systematics).
2. Use this sample in the fit instead of the Z(νν)γ EWK sample in the <u>fit to Asimov pseudodata</u> without Z(νν)γ EWK interference systematic.
3. Estimate the impact on the median expected significance.

ΔY_{jj} distribution



ΔY_{jj} distribution used for reweighting