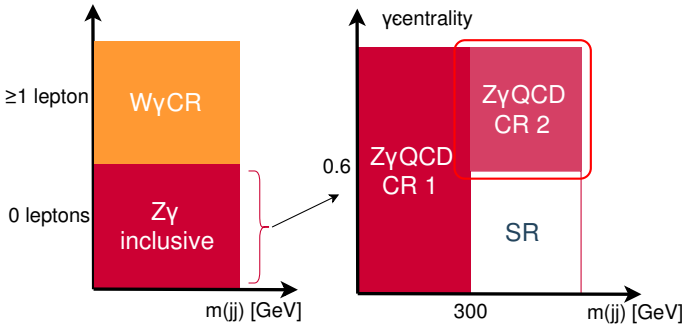
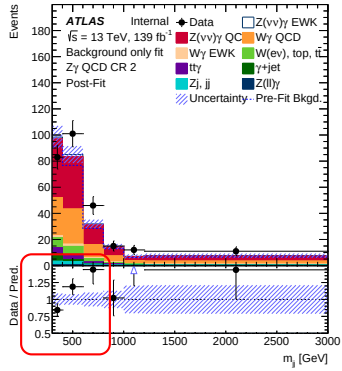
The issue





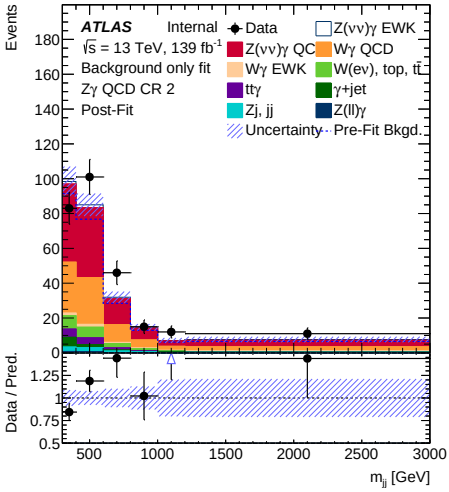
Silvia

After fit there is still present a trend of data/pred. in the first 3 bins. Is this understood?

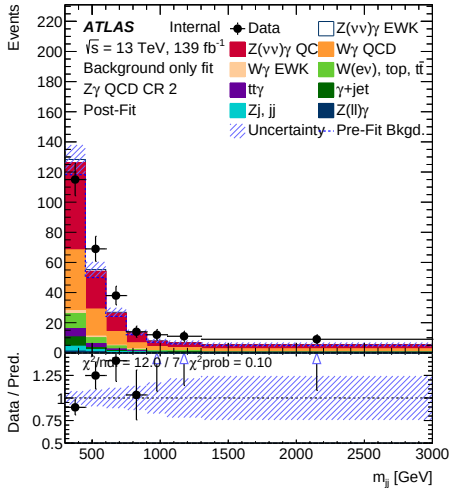
This is an issue since this m_{jj} mismodelling could be present in the SR and affect the measured signal process cross-section and its significance.

Rebinning

Old binning

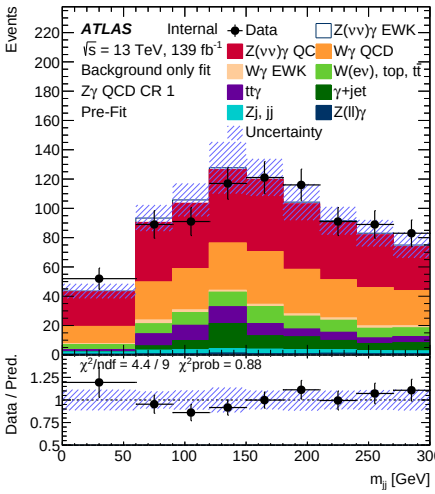


New binning

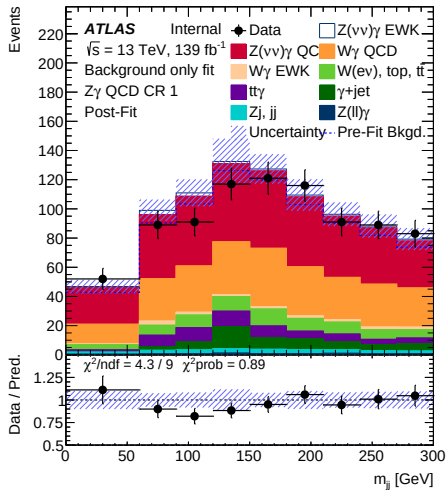


χ^2 tests, $Z\gamma$ QCD CR1

Old binning

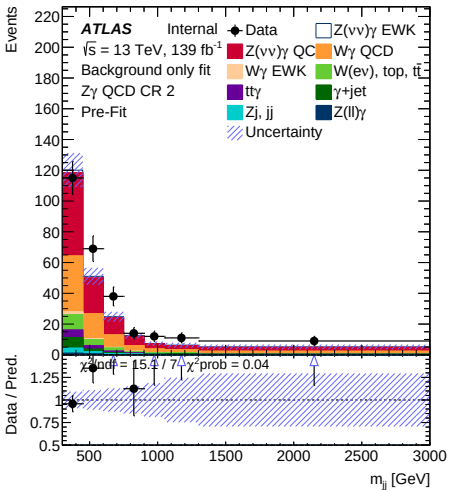


New binning

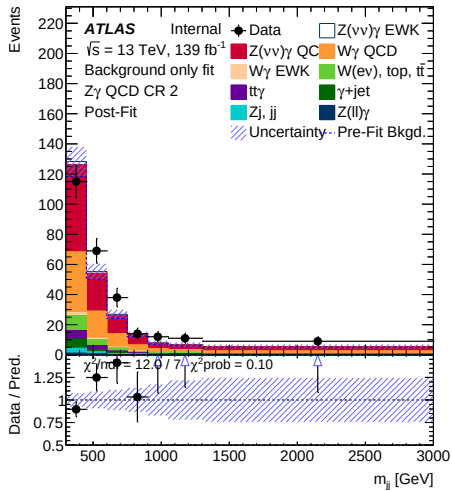


χ^2 tests, $Z\gamma$ QCD CR2

Old binning

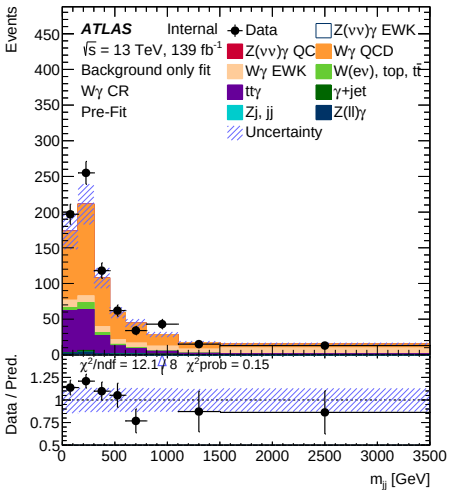


New binning

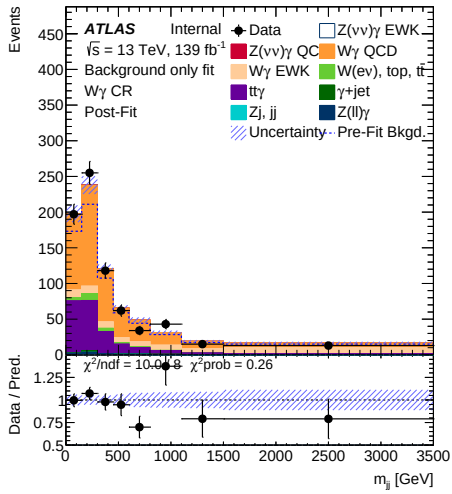


χ^2 tests, $W\gamma$ QCD CR

Old binning

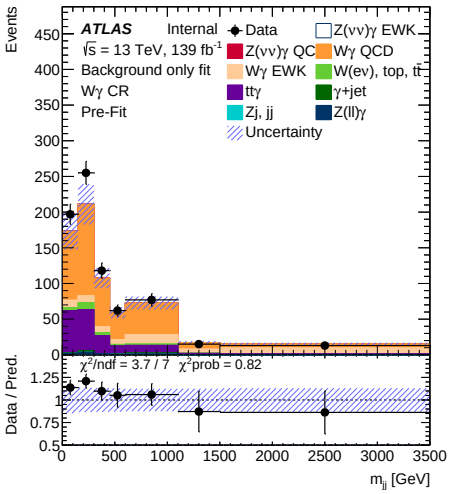


New binning

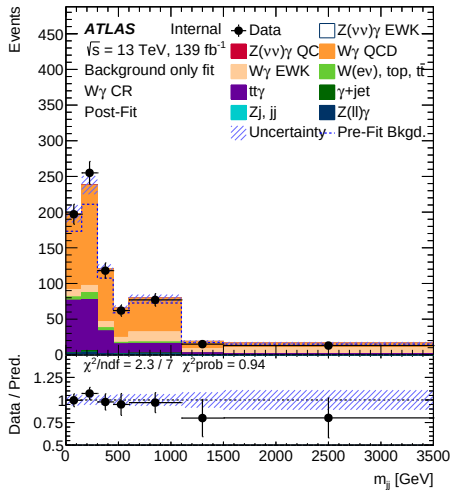


χ^2 tests, $W\gamma$ QCD CR, merged bins

Old binning



New binning



Idea — $Z\gamma$ QCD reweighting

$Z\gamma$ QCD process accounts for almost half of events in the $Z\gamma$ QCD CR2 and is known for poor m_{jj} shape modelling at high values.

Idea:

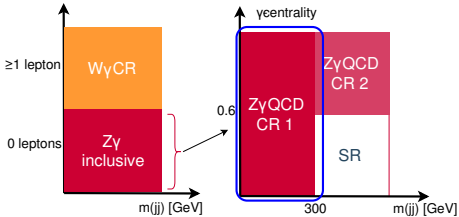
1. Fit the data/prediction discrepancy in the ($Z\gamma$ inc. + γ-cent. > 0.6) region the using some $f(m_{jj})$ function.
2. Scale the $Z\gamma$ QCD sample in both $Z\gamma$ QCD CR2 and SR.

Checks were done using `Sherpa` (nominal) and `MadGraph` (alternative) $Z\gamma$ QCD samples.

$Z\gamma$ QCD CR2, before background-only fit

Sample	% of pred. events
$Z\gamma$, QCD	45.41
$W\gamma$, QCD	30.74
$W(e\nu)$, top, $t\bar{t}$	7.88
jet+γ	4.45
$tt\gamma$	3.81
Zj, jj	2.76
$Z\gamma$, EWK	2.12
$W\gamma$, EWK	1.94
$Z(\ell\ell)\gamma$	0.89

$Z\gamma$ QCD reweighting. Feasibility check



To see if the proposed method is feasible $Z\gamma$ QCD CR1 was used. Though it only has $m_{jj} \in [0; 300]$ GeV, it has both prediction and unblinded data for full γ-centrality range.
It was split into two sub-regions: γ-cent. < 0.6 (SR-like) and γ-cent. > 0.6 ($Z\gamma$ QCD CR2-like)

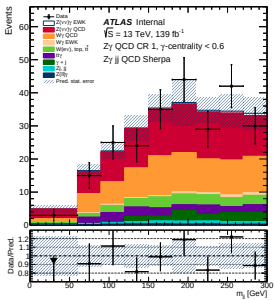
The following checks were performed:

1. Check data/prediction comparison for both sub-regions.
2. Distribution comparison between two sub-regions.
3. Correlation coefficients comparison.

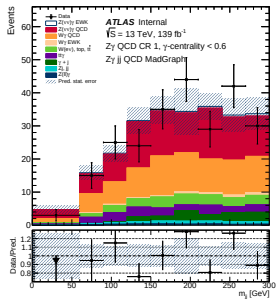
Data/prediction comparison for $Z\gamma$ QCD CR1 sub-regions

γ-centrality < 0.6

Sherpa $Z\gamma$QCD

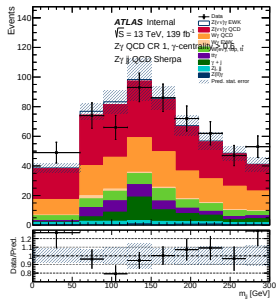


MadGraph $Z\gamma$QCD

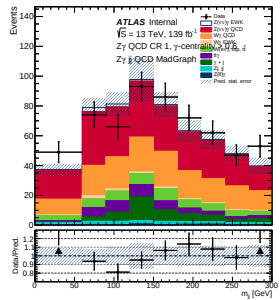


γ-centrality > 0.6

Sherpa $Z\gamma$QCD



MadGraph $Z\gamma$QCD

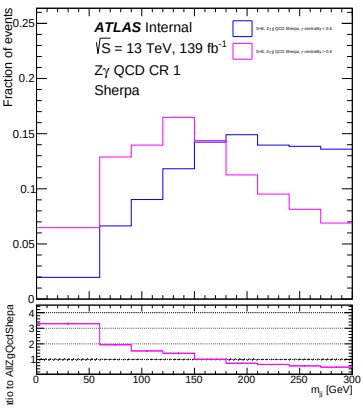


The data is in agreement with the prediction for all sub-regions and $Z\gamma$ QCD samples.

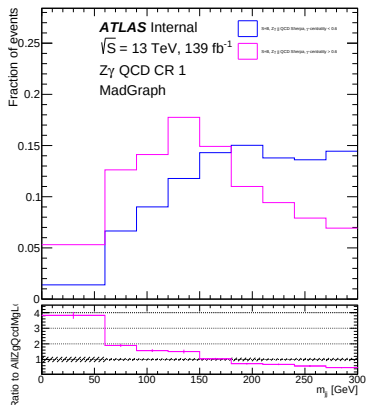
Distribution comparison between two $Z\gamma$ QCD CR1 sub-regions

Blue histogram — γ-centrality < 0.6
Magenta histogram — γ-centrality > 0.6

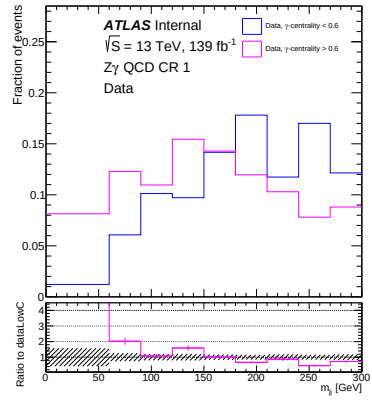
Sum of prediction, Sherpa $Z\gamma$QCD



Sum of prediction, MadGraph $Z\gamma$QCD



Data



Same trends are observed for both $Z\gamma$ QCD samples and the data.

m_{jj} and γ-centrality correlation in $Z\gamma$QCD CR 1

γ-centrality selection	Sherpa $Z\gamma$ QCD	MadGraph $Z\gamma$ QCD	Data
< 0.6	-0.03	-0.02	-0.03
> 0.6	0.03	-0.01	-0.07

m_{jj} and γ-centrality appear not to be correlated.

$Z\gamma$ QCD fit setup

Since the checks have not shown any obstructions for the proposed method we've proceeded with the fit.

Region

The fit was done in the $Z\gamma$ inclusive region with the following cuts:

- $m_{jj} > 200$ GeV (compare to $m_{jj} > 300$ GeV for $Z\gamma$ QCD CR2);
- γ-centrality > 0.6 (same as $Z\gamma$ QCD CR2)

The m_{jj} range was extended beyond the $Z\gamma$ QCD CR2 for modelling of low m_{jj} values.

Distribution

$$\frac{\text{Data} - \text{Non. } Z\gamma \text{ QCD background}}{Z\gamma\text{QCD}}$$

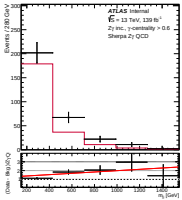
Functions

- $A + Bx$
- $A + Bx + Cx^2$
- e^{A+Bx}

Fitting the $Z\gamma$ QCD m_{jj} distribution in the $Z\gamma$ QCD CR2

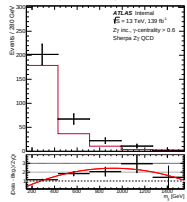
Sherpa $Z\gamma$ QCD

$A + Bx$



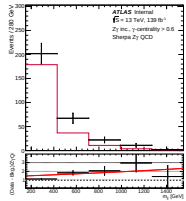
$\chi^2/N_{\text{df}} = 9.20/3$

$A + Bx + Cx^2$



$\chi^2/N_{\text{df}} = 1.63/2$

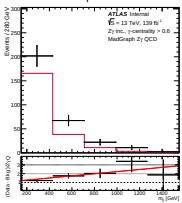
e^{A+Bx}



$\chi^2/N_{\text{df}} = 14.24/3$

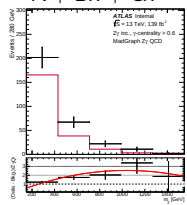
MadGraph $Z\gamma$ QCD

$A + Bx$



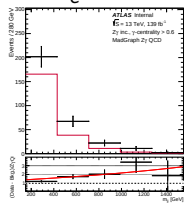
$\chi^2/N_{\text{df}} = 2.49/3$

$A + Bx + Cx^2$



$\chi^2/N_{\text{df}} = 2.50/2$

e^{A+Bx}



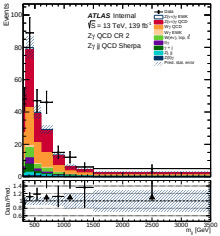
$\chi^2/N_{\text{df}} = 5.98/2$

Highlighted results were used for $Z\gamma$ QCD reweighting in $Z\gamma$ QCD CR 2 and SR.

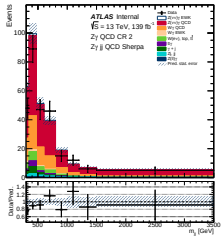
Applying the fitted function

Sherpa $Z\gamma$ QCD

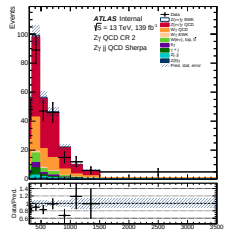
Initial



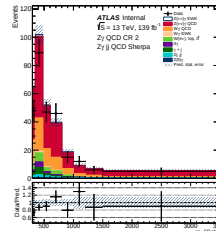
$A + Bx$



$A + Bx + Cx^2$

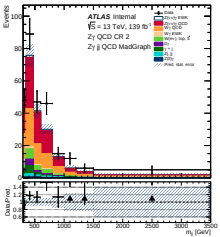


e^{A+Bx}

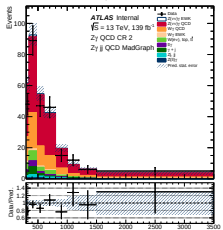


MadGraph $Z\gamma$ QCD

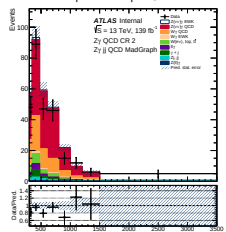
Initial



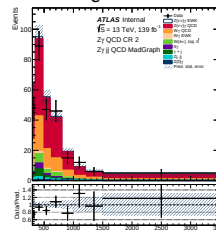
$A + Bx$



$A + Bx + Cx^2$



e^{A+Bx}



Highlighted results were later used for $Z\gamma$ QCD reweighting in $Z\gamma$ QCD CR 2 and SR and cross-section measurement.

Using the reweighted $Z\gamma$ QCD in the cross-section measurement fit

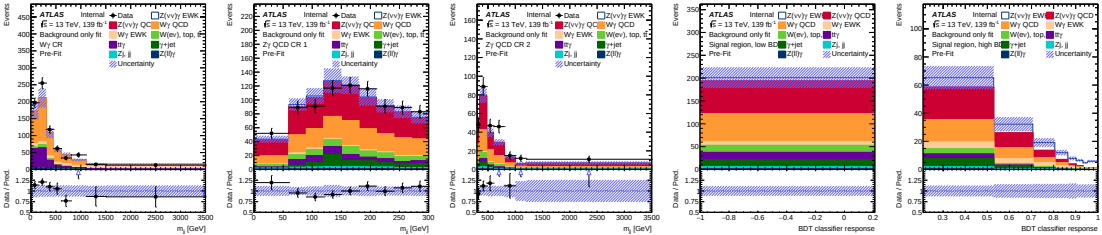
$A + Bx$ and e^{A+Bx} function had shown good results for the reweighting in the $Z\gamma$ QCD CR2.

Since the results were the same for both `Sherpa` and `MadGraph` $Z\gamma$ QCD samples only the `Sherpa` one was used for the measurement.

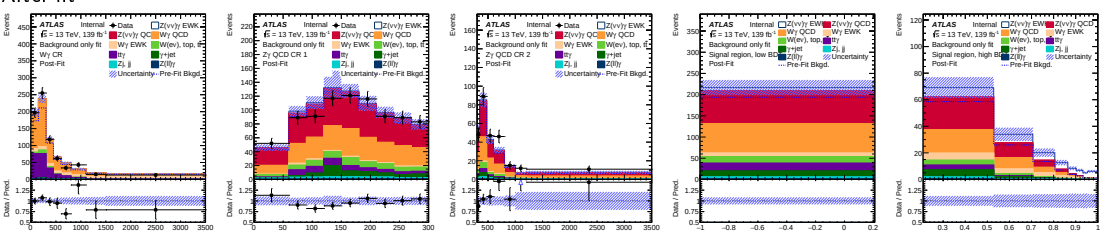
The reweighting function were used to change the weights of the $Z\gamma$ QCD events in the SR based on their m_{jj} value.

Background only fit, no reweighting

Before fit

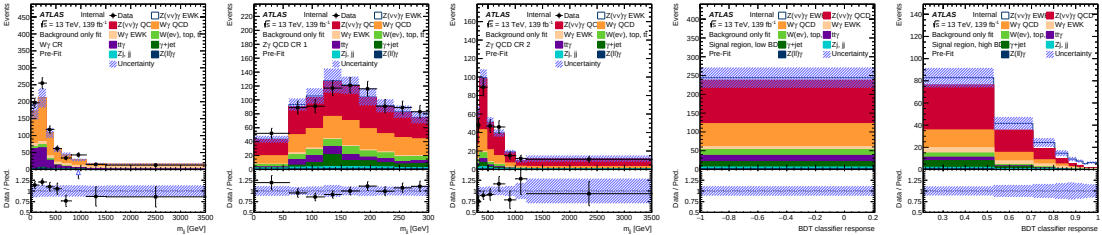


After fit

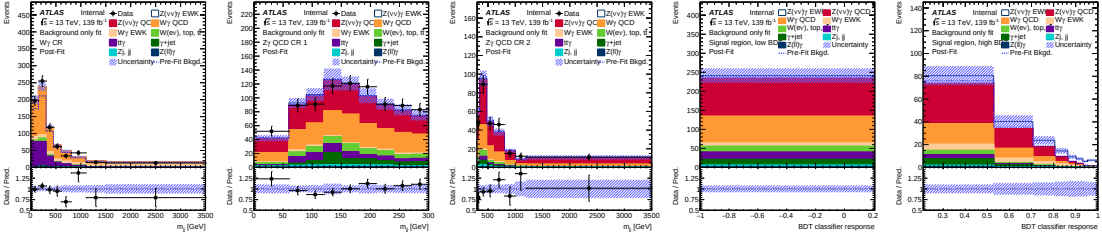


Background only fit, $A + Bx$ reweighting

Before fit

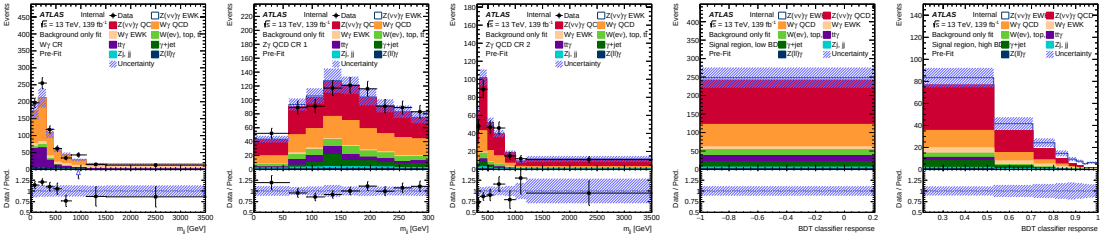


After fit

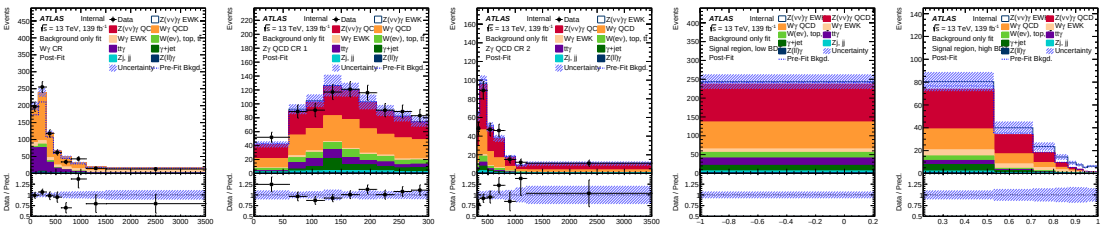


Background only fit, e^{A+Bx} reweighting

Before fit



After fit



Asimov data fit results

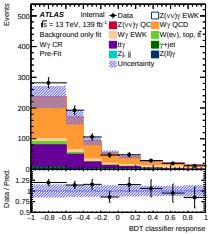
Initial $Z\gamma$ QCD		$A + Bx$ $Z\gamma$ QCD reweighting		e^{A+Bx} $Z\gamma$ QCD reweighting	
$\mu_{Z\gamma\text{EWK}}$	$1.00^{+0.27}_{-0.25}(\text{stat})^{+0.24}_{-0.17}(\text{syst})$	$\mu_{Z\gamma\text{EWK}}$	$1.00^{+0.29}_{-0.27}(\text{stat})^{+0.28}_{-0.21}(\text{syst})$	$\mu_{Z\gamma\text{EWK}}$	$1.00^{+0.29}_{-0.27}(\text{stat})^{+0.27}_{-0.20}(\text{syst})$
$\mu_{Z\gamma\text{QCD}}$	$1.05 \pm 0.08(\text{stat})^{+0.15}_{-0.16}(\text{syst})$	$\mu_{Z\gamma\text{QCD}}$	$0.85 \pm 0.06(\text{stat}) \pm 0.12(\text{syst})$	$\mu_{Z\gamma\text{QCD}}$	$0.83 \pm 0.06(\text{stat}) \pm 0.12(\text{sys}$
$\mu_{W\gamma}$	$1.08 \pm 0.04(\text{stat})^{+0.19}_{-0.13}(\text{syst})$	$\mu_{W\gamma}$	$1.10 \pm 0.04(\text{stat})^{+0.19}_{-0.14}(\text{syst})$	$\mu_{W\gamma}$	$1.11 \pm 0.04(\text{stat})^{+0.19}_{-0.15}(\text{syst}$
Expected median cross-section measurement significance 3.81σ		Expected median cross-section measurement significance 3.33σ		Expected median cross-section measurement significance 3.36σ	

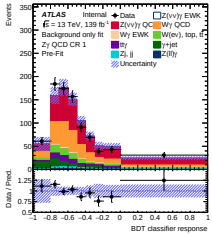
Result: reweighting allows for a better data/prediction agreement in the $Z\gamma$ QCD CR2 and potentially improves m_{jj} modelling in the SR, but lowers the expected significance.

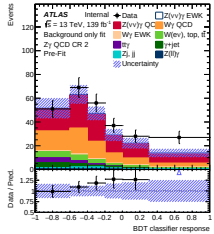
In order to increase the expected significance we've tried to use the BDT classifier response distributions in the control regions.

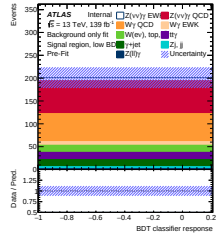
Background only fit, no reweighting

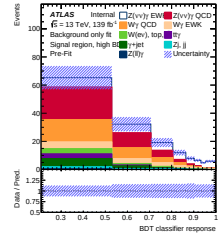
Before fit



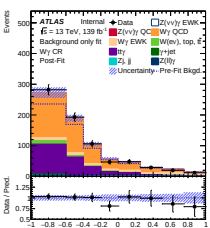


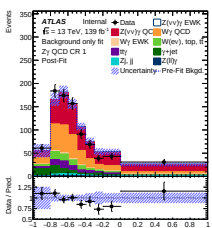


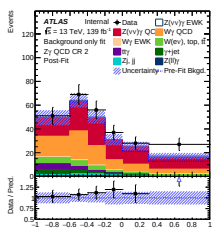


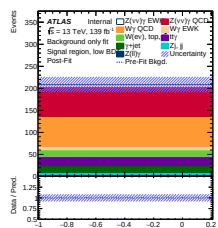


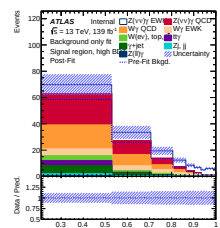
After fit





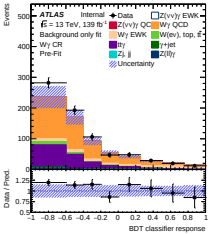


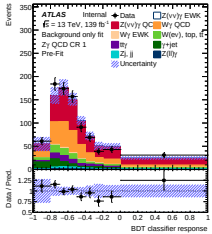


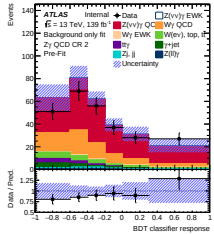


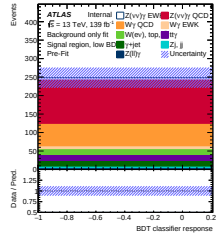
Background only fit, e^{A+Bx} reweighting

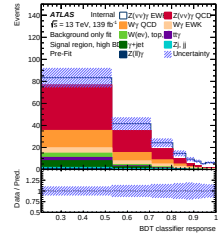
Before fit



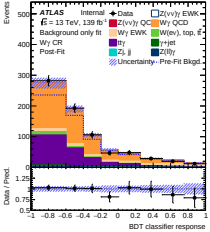


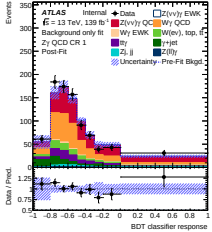


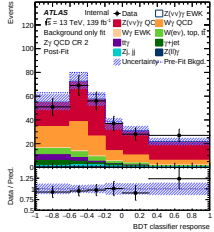


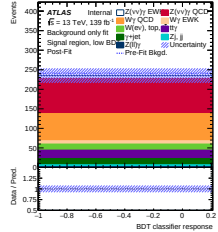


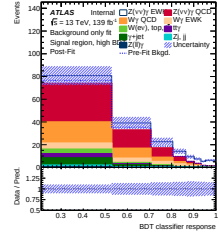
After fit











Asimov data fit results

BDT classifier response in the control regions

Initial $Z\gamma$ QCD

$\mu_{Z\gamma\text{EWK}}$	$1.00^{+0.27}_{-0.25}(\text{stat})^{+0.24}_{-0.17}(\text{syst})$
$\mu_{Z\gamma\text{QCD}}$	$1.05 \pm 0.08(\text{stat})^{+0.15}_{-0.16}(\text{syst})$
$\mu_{W\gamma}$	$1.08 \pm 0.04(\text{stat})^{+0.19}_{-0.13}(\text{syst})$

Expected median cross-section measurement significance
3.81σ

e^{A+Bx} $Z\gamma$ QCD reweighting

$\mu_{Z\gamma\text{EWK}}$	$1.00^{+0.29}_{-0.26}(\text{stat})^{+0.27}_{-0.20}(\text{syst})$
$\mu_{Z\gamma\text{QCD}}$	$0.82 \pm 0.06(\text{stat}) \pm 0.11(\text{syst})$
$\mu_{W\gamma}$	$1.09 \pm 0.04(\text{stat})^{+0.17}_{-0.14}(\text{syst})$

Expected median cross-section measurement significance
3.39σ

m_{jj} in the control regions

Initial $Z\gamma$ QCD

$\mu_{Z\gamma\text{EWK}}$	$1.00^{+0.27}_{-0.25}(\text{stat})^{+0.24}_{-0.17}(\text{syst})$
$\mu_{Z\gamma\text{QCD}}$	$1.05 \pm 0.08(\text{stat})^{+0.15}_{-0.16}(\text{syst})$
$\mu_{W\gamma}$	$1.08 \pm 0.04(\text{stat})^{+0.19}_{-0.13}(\text{syst})$

Expected median cross-section measurement significance
3.81σ

e^{A+Bx} $Z\gamma$ QCD reweighting

$\mu_{Z\gamma\text{EWK}}$	$1.00^{+0.29}_{-0.27}(\text{stat})^{+0.27}_{-0.20}(\text{syst})$
$\mu_{Z\gamma\text{QCD}}$	$0.83 \pm 0.06(\text{stat}) \pm 0.12(\text{syst})$
$\mu_{W\gamma}$	$1.11 \pm 0.04(\text{stat})^{+0.19}_{-0.15}(\text{syst})$

Expected median cross-section measurement significance
3.36σ

Change from m_{jj} to BDT classifier response in the control regions yields no improvement.

Final results

$Z\gamma$ QCD sample reweighting allows for a better data/prediction agreement in the $Z\gamma$ QCD CR2 and potentially improves m_{jj} modelling in the SR, but lowers the expected significance from 3.8σ to 3.3σ.

Change from m_{jj} distribution to BDT classifier response distribution in the control regions yields no improvement for the expected significance.

We're planning to use this reweighing for the final measurement and proposing using the difference between $A + Bx$ and e^{A+Bx} reweighting functions as the systematic uncertainty.