Pile-up background estimation in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS Detector

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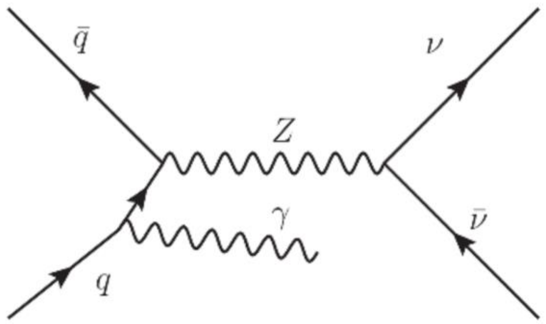
Motivation And Goals

Motivation:

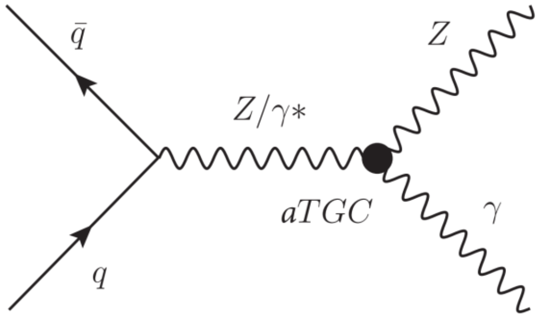
- To measure the parameters of the Standard Model (SM) to very high precision;
- The search of new physics predicted by the beyond SM (BSM) theories;
- Precise measurements of triple and quartic gauge couplings sensitive to BSM physics. One of the sensitive processes is $Z(\nu\nu)\gamma$ process.



(a) SM

Goal:

- To calculate integral and differential cross-sections for the main kinematic observables and compare the results with the theory predictions;
- To obtain the strongest up-to-date limits on anomalous neutral triple gauge-boson couplings (aTGCs).



(b) Beyond SM

Purpose of the current study:

- The background estimation procedure is extremely important. One of the backgrounds is the so-called pile-up background. The data-driven method* for estimating the pile-up background has several significant drawbacks, therefore an alternative overlay Monte-Carlo approach is considered.

*(more in back-up)

Phase Space Definition

Signal: Z(νν)γ

Backgrounds: γ+jets, W(→lν)γ, e → γ, jet → γ, Z(ll)γ, ttγ

- **Event selection criteria for Zγ candidate events:**

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

Studied background:

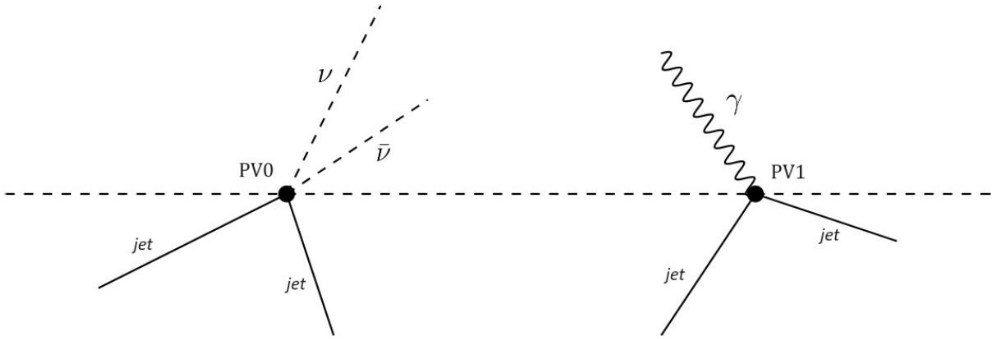
The background due to multiple pp interactions occurring within one intersection of bunches, *the so-called* *pile-up background*, *is the source of events in which the Z boson can be associated with a photon from another pp collision.*

- **FixedCutLoose isolation working point is chosen:**

FixedCutLoose working point	
Isolation	$E_{\mathrm{T}}^{\mathrm{cone20}} - 0.065 \cdot p_{\mathrm{T}}^{\mathrm{cone20}} < 0$ GeV
Track isolation	$p_{\mathrm{T}}^{\mathrm{cone20}} / p_{\mathrm{T}}^{\gamma} < 0.05$

⇨ Signal region (SR): events pass selections and have a leading photon candidate that is isolated.

Overlay Monte-Carlo (OMC) Method



Strategy:

1. To estimate the number of pile-up events (referred to as A+B) in the diboson production (referred to as AB) the overlay Monte-Carlo (OMC) method uses separate A and B samples at the particle-level.

2. The overlay of B over A is performed by adding objects (photons, jets, etc.) from B into A;

3. The variables that define the AB final state are calculated in order to form a valid combined A+B event (referred to as OMC event). These variables are used to be checked against analysis selections;

4. The weight of the combined A+B event is determined as:

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

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

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

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

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

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

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

Method Application

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

Definition of the fiducial region:

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

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

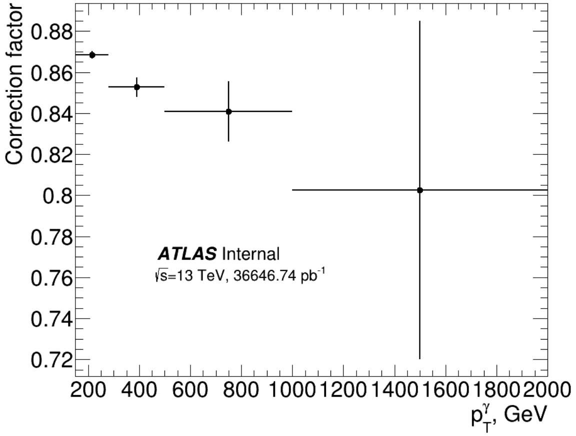
$$w_{Z+\gamma} = \frac{w_Z w_\gamma}{\langle w_Z\rangle\langle w_\gamma\rangle}\frac{L\sigma_{Z+\gamma}}{N_{\mathrm{OMC}}}$$

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

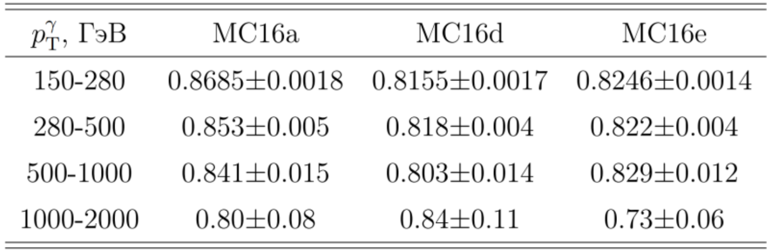
Correction Factor

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

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



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



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

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

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

The statistical uncertainties come from:

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

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

Summary

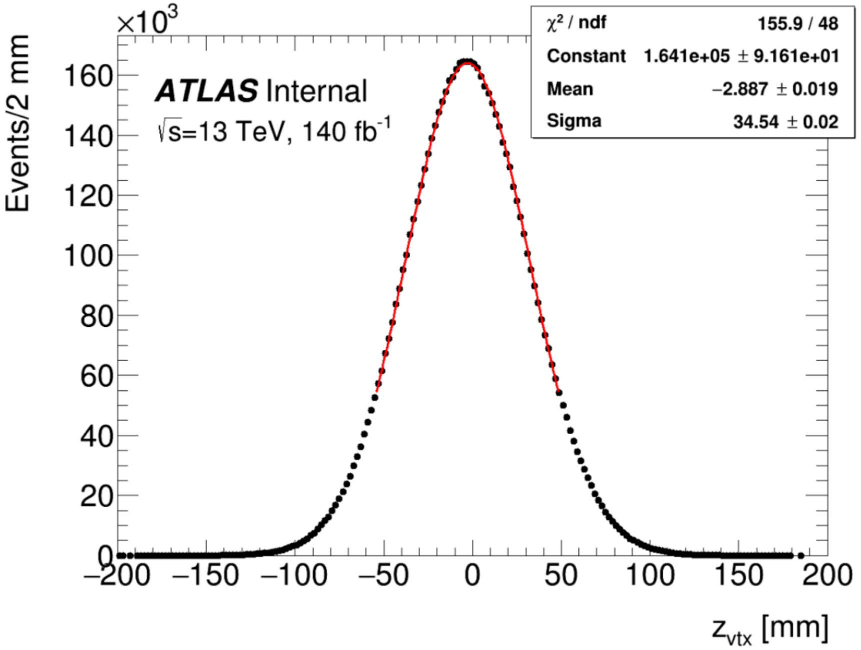
- As a result the overlay Monte-Carlo method for the estimation of pile-up background in Z(νν)γ production was developed. The resulting estimate of the number of pile-up background events was derived using MC-simulated Zj and γ+j samples;
- In case of Z(νν)γ study the OMC method provides the estimate of the number of pile-up background events with more statistical accuracy than the data-driven approach;
- The fraction of pile-up events in relation to the data obtained using the OMC method is (0.01257 ± 0.00011)%;
- Thereby, the pile-up background looks negligible for Z(νν)γ production in the SR.

Thank you for your attention!

BACK-UP

Data-Driven Method Considered Scale-Factors

- The estimation of the background is based on the distribution of the longitudinal spacing $\Delta z = z_\gamma - z_{vtx}$ between the identified primary vertex position z_{vtx} and the position z_γ of the photon candidate;
- The shape for the pile-up component is obtained by assuming that the distributions of z_{vtx} and z_γ are identical and uncorrelated;
- The z_{vtx} and z_γ distributions are described by a Gaussian distribution with $\sigma=35$ mm. Thus $\Delta z = z_\gamma - z_{vtx}$ also has a Gaussian distribution, with $\sigma\sim50$ mm;
- The estimation of the pile-up background is performed in the tails of the Δz distribution (32% of pile-up events have $|\Delta z|>50$ mm);



- The fraction of pile-up:

$$f_{\rm PU} = \frac{N_{\rm data}^{|\Delta z|>50mm} - N_{\rm single\ pp}^{|\Delta z|>50mm}}{0.32 \times N_{\rm data}}$$

$$N_{\rm single\ pp}^{|\Delta z|>50mm} = {\rm SF}_1 \times {\rm SF}_2 \times N_{\rm MC}^{|\Delta z|>50mm}$$

- Increased area:

$$f_{\rm PU} = \frac{N_{\rm data}^{|\Delta z|>15mm} - {\rm SF}_1 \times {\rm SF}_2 \times N_{\rm MC}^{|\Delta z|>15mm}}{0.76 \times N_{\rm data}}$$

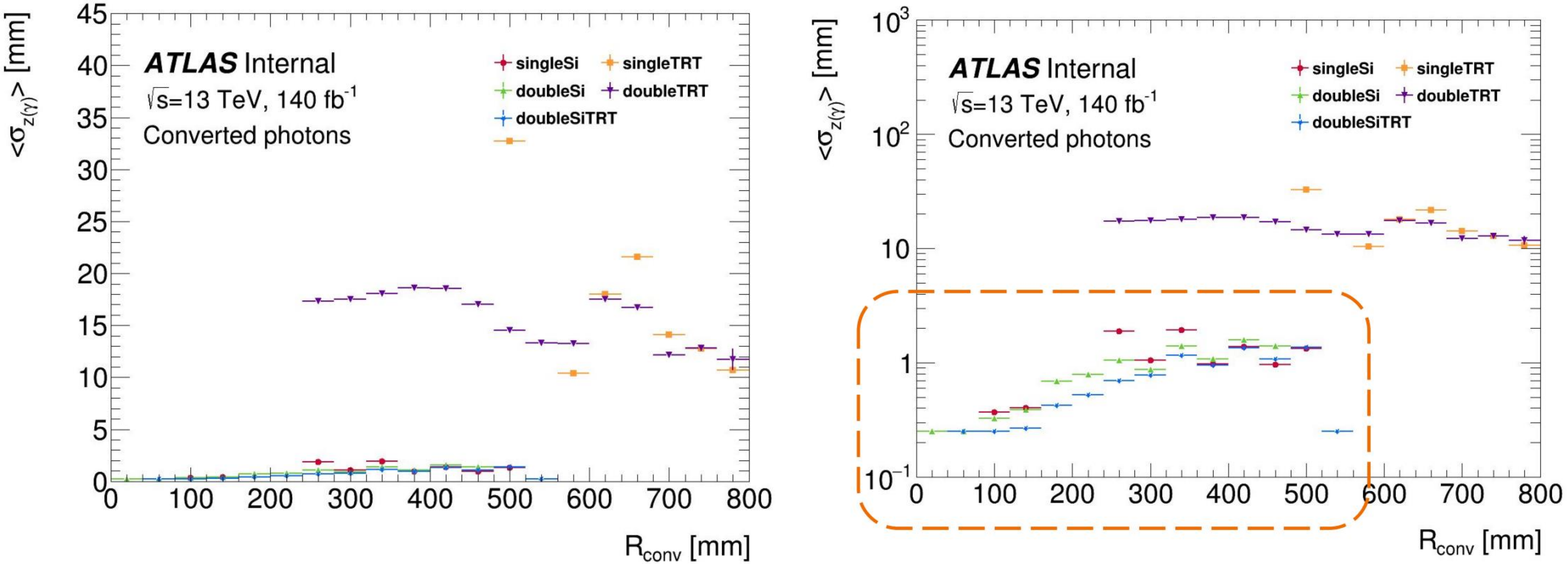
SF$_1$ – the ratio of events in data to events in Sherpa MC sample in the region of $|\Delta z|<10$ mm;

SF$_2$ = 1.48 ± 0.26 in the region of $|\Delta z|>50$ mm;

SF$_2$ = 1.27 ± 0.07 in the region of $|\Delta z|>15$ mm.

Requirement On Photons In Data-Driven Method

- The longitudinal point of origin of the reconstructed photon z_γ is not well measured in the most events. The uncertainty on z_γ in this case is much greater than the average longitudinal spacing between the primary vertices of independent processes



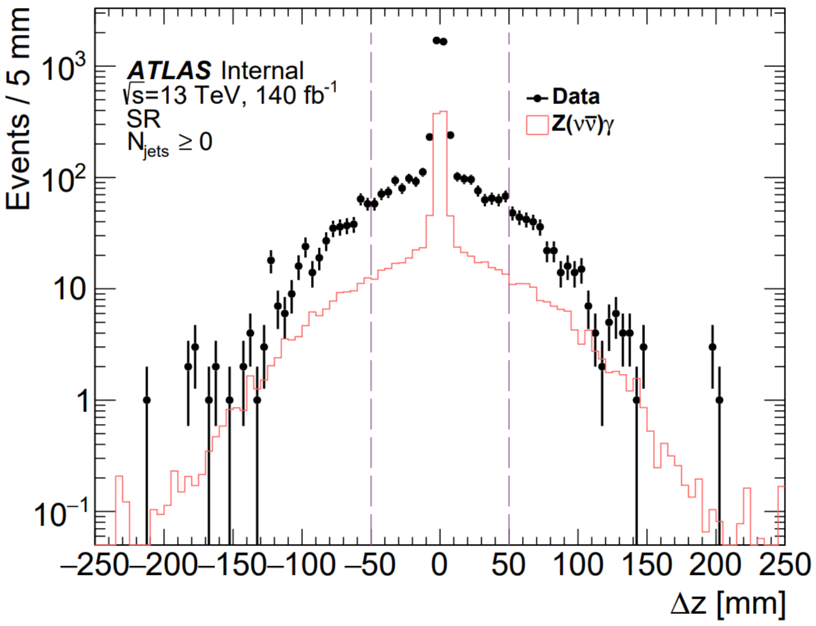
- To increase the accuracy of the recovered z_γ, converted photons associated with at least one track in a silicon detector are used : singleSi, doubleSi, doubleSiTRT.

Results For $N_{jets} \geq 0$

- SF1= 4.46 ± 0.08
- $|\Delta z|$>15 mm: f_{PU}=(-15±3)%
- $|\Delta z|$>50 mm: f_{PU}=(-34±13)%

	$N_{\text{jets}} \geq 0$	$N_{\text{jets}} > 0$	$N_{\text{jets}} > 1$	$N_{\text{jets}} = 0$
$f_{PU}^{\lvert\Delta z\rvert>15\text{mm}}, \%$	-15 ± 3	13.0 ± 1.7	17 ± 3	-29 ± 5
$f_{PU}^{\lvert\Delta z\rvert>50\text{mm}}, \%$	-34 ± 13	12 ± 3	12 ± 4	-56 ± 19

- Δz distribution in data compared to Z(vv)γ QCD LO sample:



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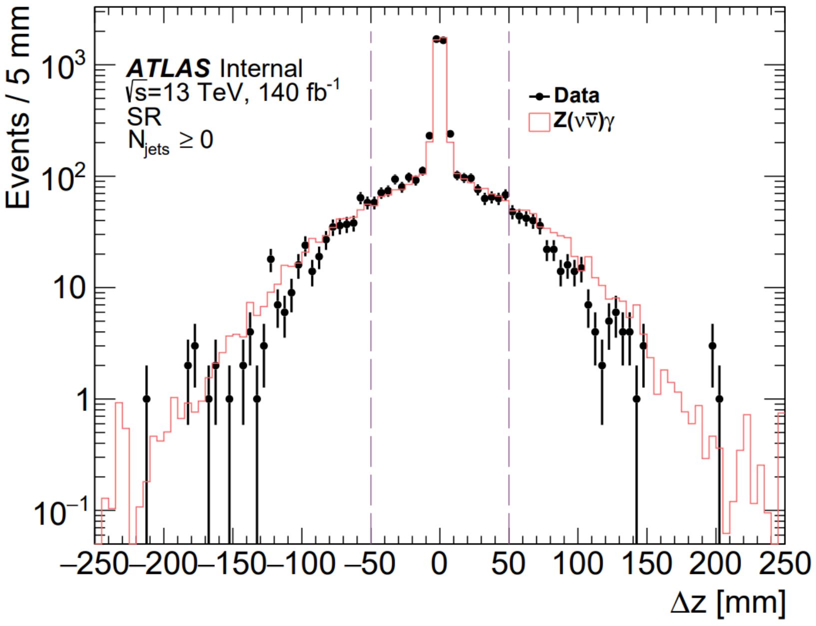
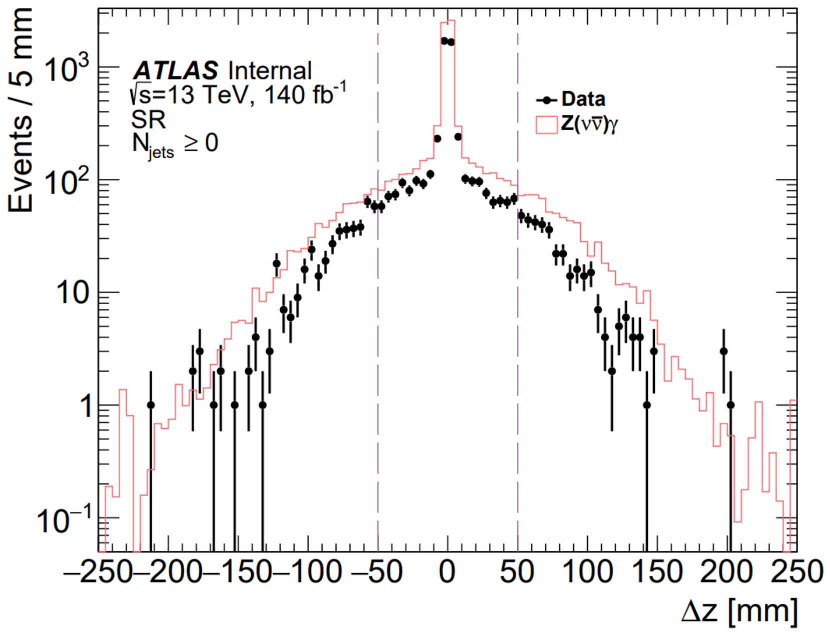


SF_1



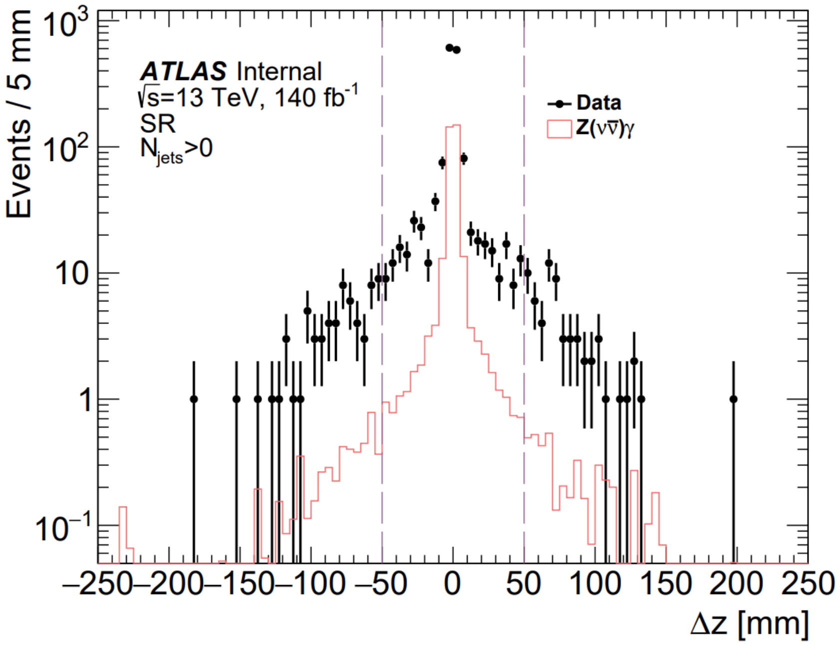
$SF_1 * SF_2$

Results For $N_{jets} > 0$

- SF1= 4.24 ± 0.12
- |Δz|>15 mm: f_{PU}=(13.0±1.7)%
- |Δz|>50 mm: f_{PU}=(12±3)%

	$N_{\text{jets}} \geqslant 0$	$N_{\text{jets}} > 0$	$N_{\text{jets}} > 1$	$N_{\text{jets}} = 0$
$f_{PU}^{\lvert\Delta z\rvert>15\text{mm}}, \%$	-15 ± 3	13.0 ± 1.7	17 ± 3	-29 ± 5
$f_{PU}^{\lvert\Delta z\rvert>50\text{mm}}, \%$	-34 ± 13	12 ± 3	12 ± 4	-56 ± 19

- Δz distribution in data compared to Z(νν)γ QCD LO sample:



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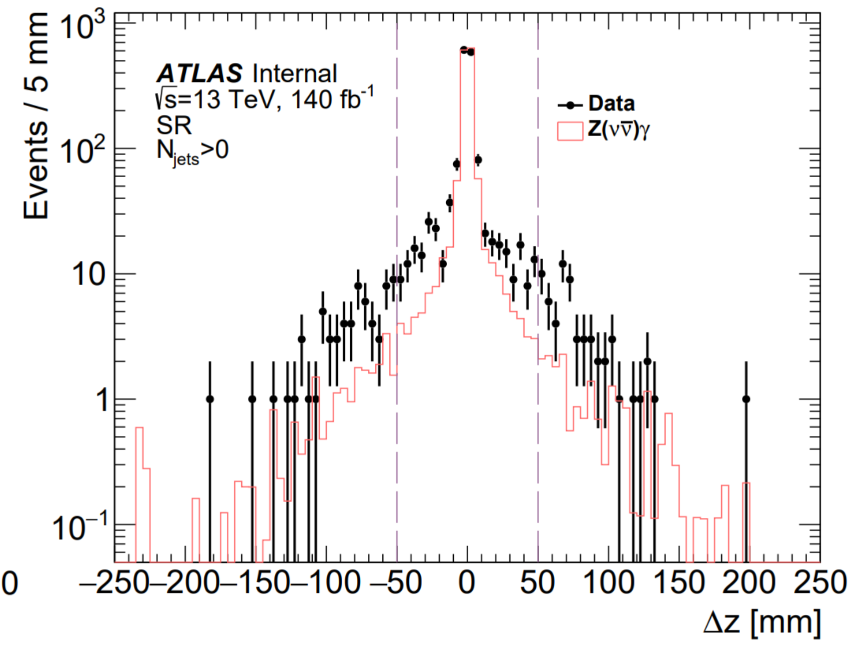
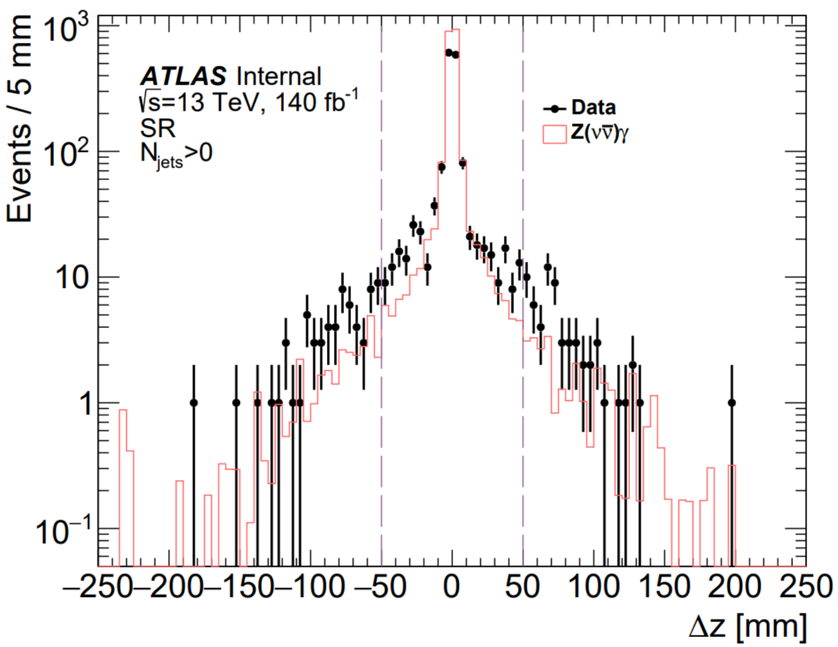


SF_1



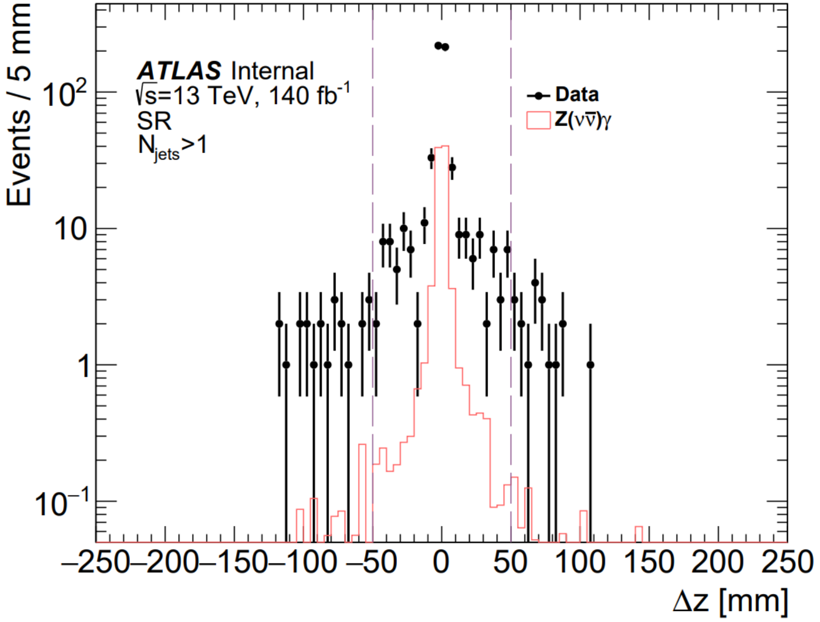
SF_1 * SF_2

Results For N_{jets}> 1

- SF1= 5.7 ± 0.3
- |Δz|>15 mm: f_{PU}=(17±3)%
- |Δz|>50 mm: f_{PU}=(12±4)%

	$N_{\text{jets}} \geqslant 0$	$N_{\text{jets}} > 0$	$N_{\text{jets}} > 1$	$N_{\text{jets}} = 0$
$f_{PU}^{\lvert\Delta z\rvert>15\text{mm}}$,%	-15 ± 3	13.0 ± 1.7	17 ± 3	-29 ± 5
$f_{PU}^{\lvert\Delta z\rvert>50\text{mm}}$,%	-34 ± 13	12 ± 3	12 ± 4	-56 ± 19

- Δz distribution in data compared to Z(νν)γ QCD LO sample:



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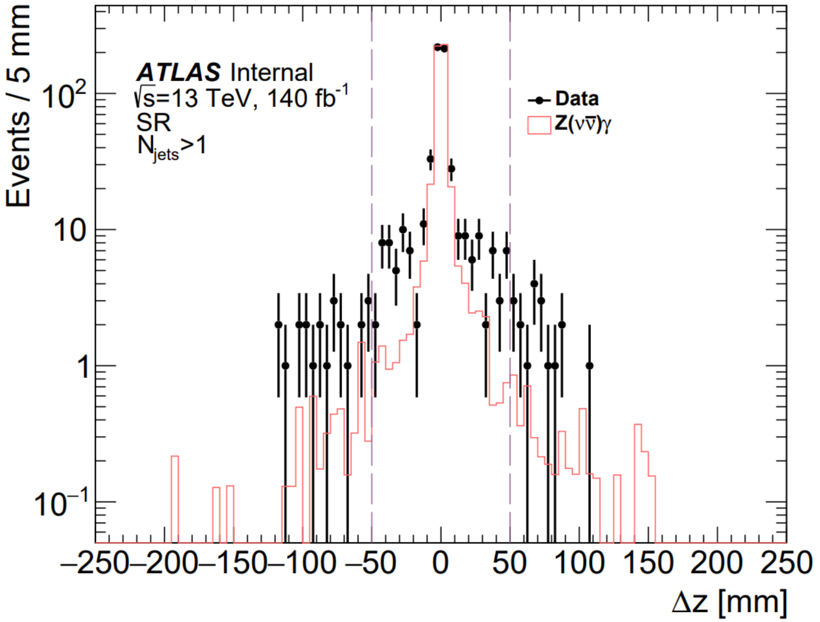
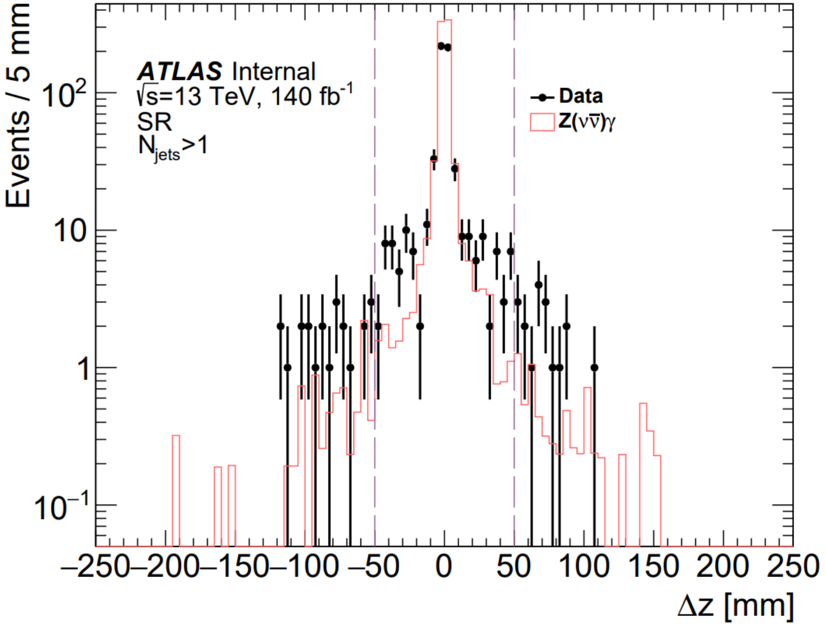


SF_1



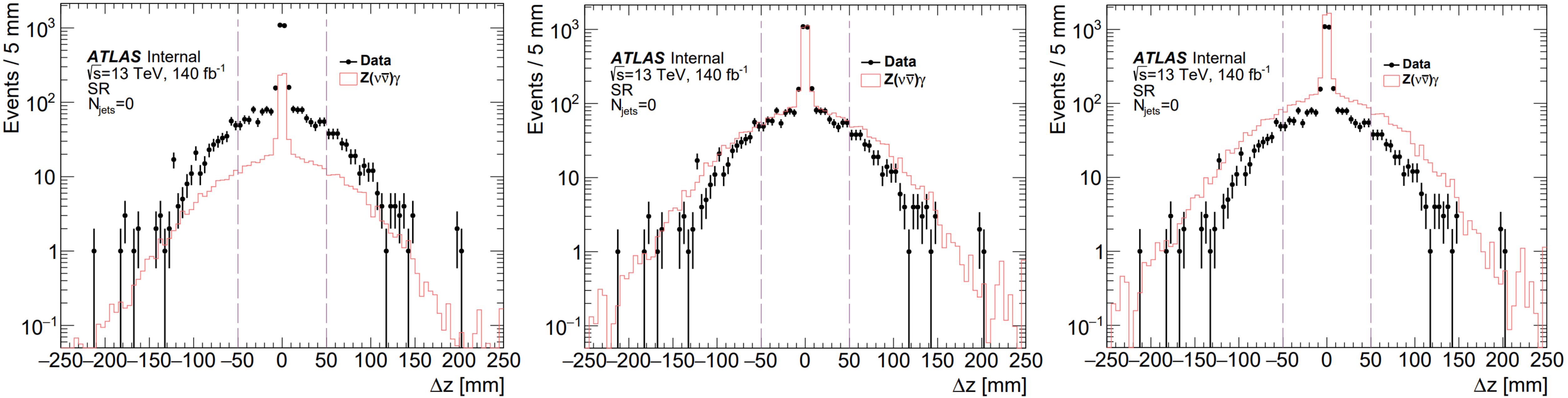
SF_1 * SF_2

Results For $N_{jets} = 0$

- SF1= 4.593 ± 0.010
- $|\Delta z| > 15$ mm: $f_{PU} = (-29 \pm 5)\%$
- $|\Delta z| > 50$ mm: $f_{PU} = (-56 \pm 19)\%$

	$N_{\text{jets}} \geqslant 0$	$N_{\text{jets}} > 0$	$N_{\text{jets}} > 1$	$N_{\text{jets}} = 0$
$f_{PU}^{\|\Delta z\|>15\text{mm}}, \%$	-15 ± 3	13.0 ± 1.7	17 ± 3	-29 ± 5
$f_{PU}^{\|\Delta z\|>50\text{mm}}, \%$	-34 ± 13	12 ± 3	12 ± 4	-56 ± 19

- Δz distribution in data compared to $Z(\nu\nu)\gamma$ QCD LO sample:



Unnormalized

SF_1

$SF_1 * SF_2$

Data-Driven Method

The fraction of pile-up:

$$f_{\text{PU}} = \frac{N^{|\Delta z|>50\text{mm}}_{\text{data excl. bkg}} - N^{|\Delta z|>50\text{mm}}_{\text{MC}}}{N_{\text{data}} \times 0.32}$$

- $N^{|\Delta z|>50mm}_{\text{data excl. bkg}}$ and N_{data} are the numbers of data excluding expected background events with $|\Delta z|$ > 50 mm and without any requirements on $|\Delta z|$ respectively.

Similarly for Increased area:

$$f_{\text{PU}} = \frac{N^{|\Delta z|>15\text{mm}}_{\text{data excl. bkg}} - N^{|\Delta z|>15\text{mm}}_{\text{MC}}}{N_{\text{data}} \times 0.76}$$

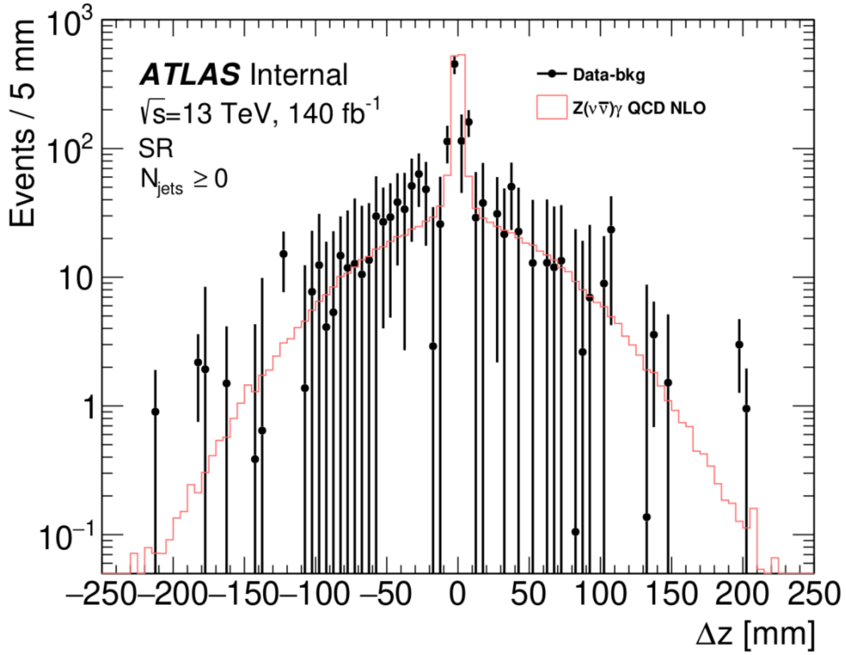
- Event yields for data, signal and expected background events without any requirements on $|\Delta z|$ used in pile-up background estimation.

Данные	$Z(\nu\bar{\nu})\gamma$	$W\gamma$, $tt\gamma$	$e \to \gamma$	$jet \to \gamma$	γ+jet	$Z(ll)\gamma$
5920 ± 80	1884 ± 4	749 ± 11	1989 ± 9	890 ± 180	780 ± 80	55.1 ± 1.9

- The fraction of pile-up photons in data using the data-driven approach is found to be:

Region	Data excl. bkg.	$Z(\nu\bar{\nu})\gamma$	f_{PU},%
$\|\Delta z\| > 15$	560 ± 170	633 ± 2	-2 ± 4
$\|\Delta z\| > 50$	200 ± 130	302.6 ± 1.4	-5 ± 7

Δz distribution in data excluding expected background events for events containing silicon conversions compared to Z(νν)γ QCD NLO sample:



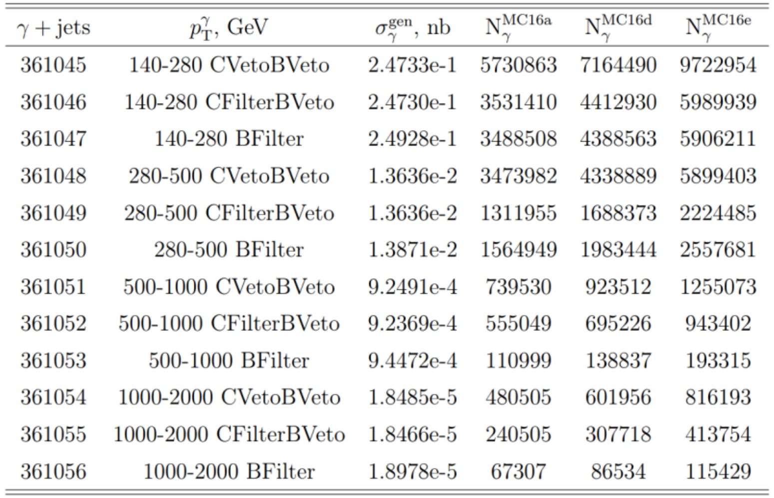
Its contribution looks negligible for Z(νν)γ SR events

Nevertheless, the result is statistically poor!

γ+j And Z+j Samples In The OMC Method

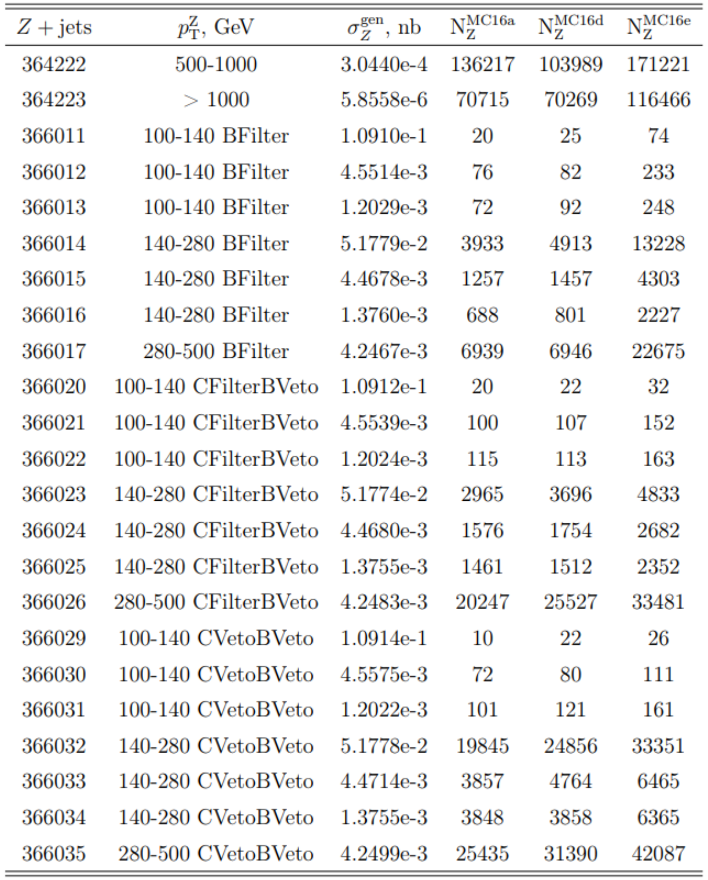
- The generator cross sections and the number of events pass the FR selections for the objects of the γ+jets and Zj processes in each of the campaigns

γ+jets



$\gamma+$jets	p_T^γ, GeV	$\sigma_\gamma^{\text{gen}}$, nb	$\text{N}_\gamma^{\text{MC16a}}$	$\text{N}_\gamma^{\text{MC16d}}$	$\text{N}_\gamma^{\text{MC16e}}$
361045	140-280 CVetoBVeto	2.4733e-1	5730863	7164490	9722954
361046	140-280 CFilterBVeto	2.4730e-1	3531410	4412930	5989939
361047	140-280 BFilter	2.4928e-1	3488508	4388563	5906211
361048	280-500 CVetoBVeto	1.3636e-2	3473982	4338889	5899403
361049	280-500 CFilterBVeto	1.3636e-2	1311955	1688373	2224485
361050	280-500 BFilter	1.3871e-2	1564949	1983444	2557681
361051	500-1000 CVetoBVeto	9.2491e-4	739530	923512	1255073
361052	500-1000 CFilterBVeto	9.2369e-4	555049	695226	943402
361053	500-1000 BFilter	9.4472e-4	110999	138837	193315
361054	1000-2000 CVetoBVeto	1.8485e-5	480505	601956	816193
361055	1000-2000 CFilterBVeto	1.8466e-5	240505	307718	413754
361056	1000-2000 BFilter	1.8978e-5	67307	86534	115429

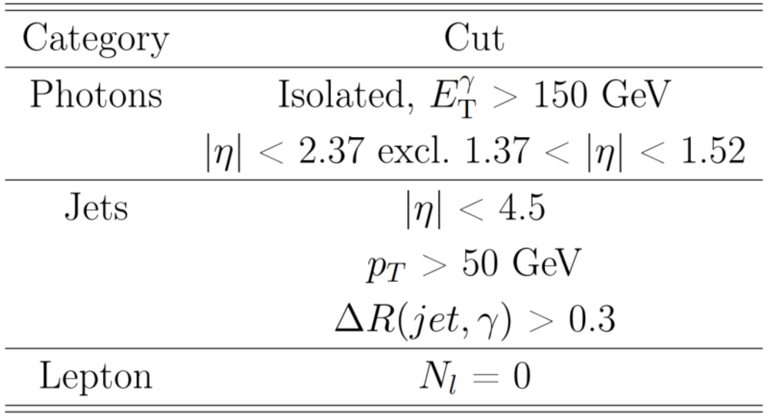
Zj



$Z+$jets	p_T^Z, GeV	σ_Z^{gen}, nb	$\text{N}_\text{Z}^{\text{MC16a}}$	$\text{N}_\text{Z}^{\text{MC16d}}$	$\text{N}_\text{Z}^{\text{MC16e}}$
364222	500-1000	3.0440e-4	136217	103989	171221
364223	>1000	5.8558e-6	70715	70269	116466
366011	100-140 BFilter	1.0910e-1	20	25	74
366012	100-140 BFilter	4.5514e-3	76	82	233
366013	100-140 BFilter	1.2029e-3	72	92	248
366014	140-280 BFilter	5.1779e-2	3933	4913	13228
366015	140-280 BFilter	4.4678e-3	1257	1457	4303
366016	140-280 BFilter	1.3760e-3	688	801	2227
366017	280-500 BFilter	4.2467e-3	6939	6946	22675
366020	100-140 CFilterBVeto	1.0912e-1	20	22	32
366021	100-140 CFilterBVeto	4.5539e-3	100	107	152
366022	100-140 CFilterBVeto	1.2024e-3	115	113	163
366023	140-280 CFilterBVeto	5.1774e-2	2965	3696	4833
366024	140-280 CFilterBVeto	4.4680e-3	1576	1754	2682
366025	140-280 CFilterBVeto	1.3755e-3	1461	1512	2352
366026	280-500 CFilterBVeto	4.2483e-3	20247	25527	33481
366029	100-140 CVetoBVeto	1.0914e-1	10	22	26
366030	100-140 CVetoBVeto	4.5575e-3	72	80	111
366031	100-140 CVetoBVeto	1.2022e-3	101	121	161
366032	140-280 CVetoBVeto	5.1778e-2	19845	24856	33351
366033	140-280 CVetoBVeto	4.4714e-3	3857	4764	6465
366034	140-280 CVetoBVeto	1.3755e-3	3848	3858	6365
366035	280-500 CVetoBVeto	4.2499e-3	25435	31390	42087

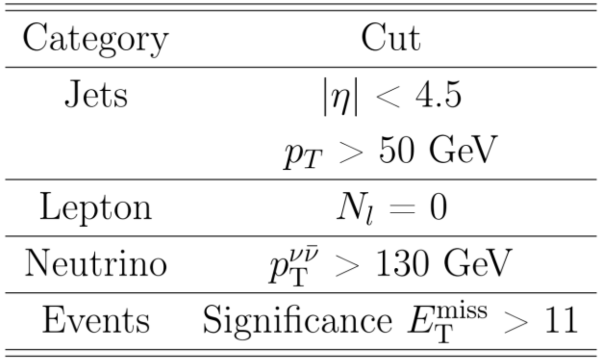
The required cuts:

γ+jets:



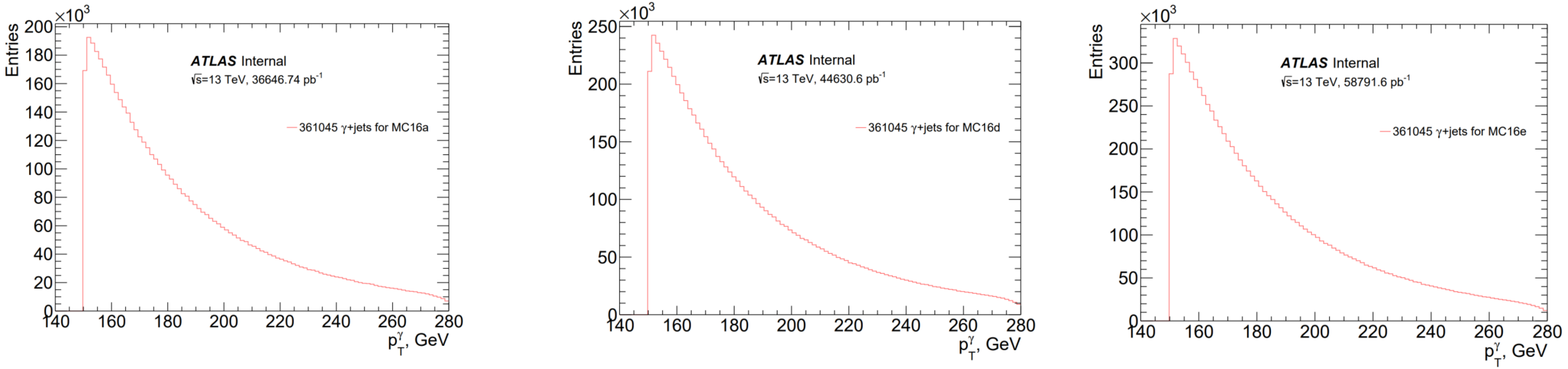
Category	Cut
Photons	Isolated, $E_\text{T}^\gamma > 150$ GeV
	$\|\eta\| < 2.37$ excl. $1.37 < \|\eta\| < 1.52$
Jets	$\|\eta\| < 4.5$
	$p_T > 50$ GeV
	$\Delta R(jet,\gamma) > 0.3$
Lepton	$N_l = 0$

Zj:

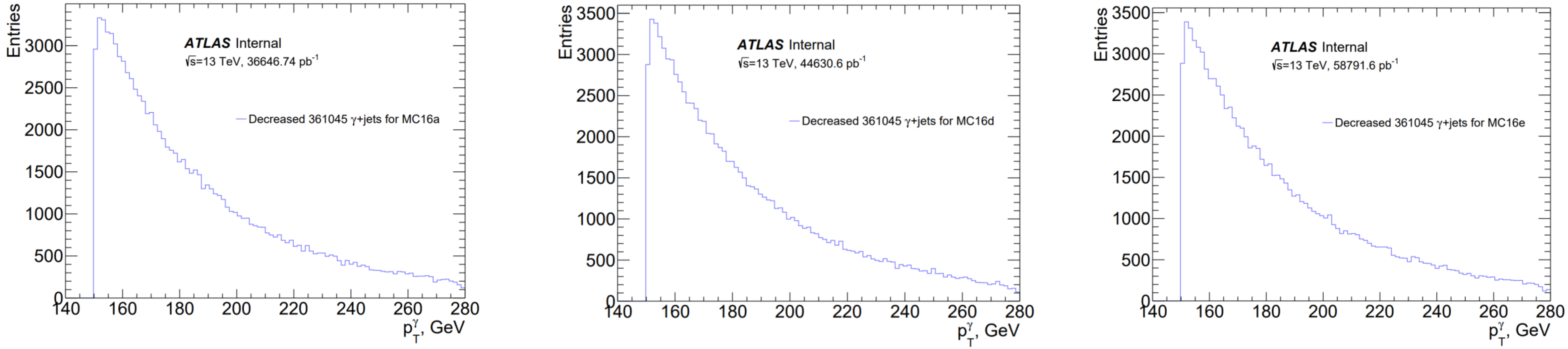


Category	Cut
Jets	$\|\eta\| < 4.5$
	$p_T > 50$ GeV
Lepton	$N_l = 0$
Neutrino	$p_\text{T}^{\nu\bar{\nu}} > 130$ GeV
Events	Significance $E_\text{T}^{\text{miss}} > 11$

The Representativeness Of The γ+jets Samples



Distribution of the number of events pass the required cuts for the 361045 γ+jets sample within MC16a/d/e

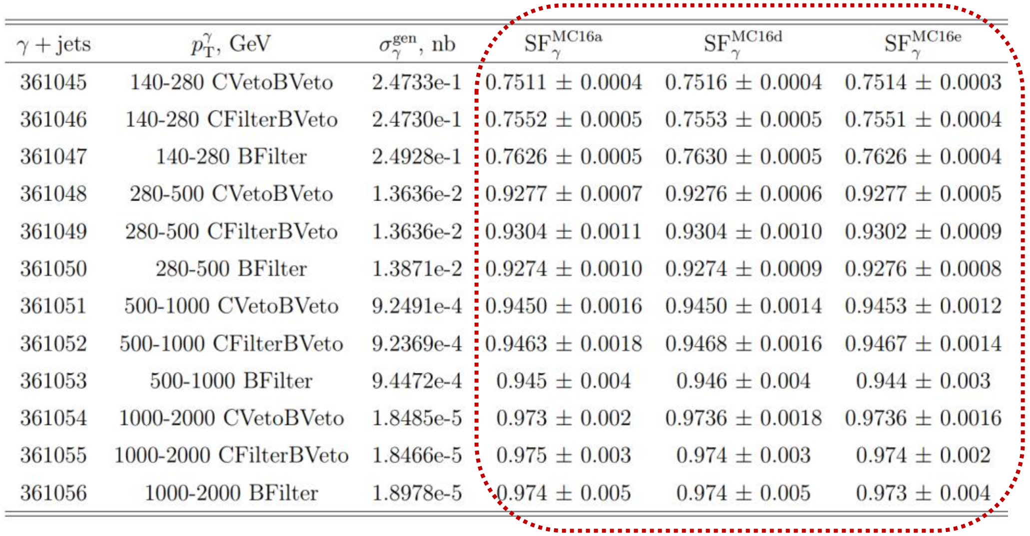


Distribution of the 100k events pass the required cuts for the 361045 γ+jets sample within MC16a/d/e

Scale Factors

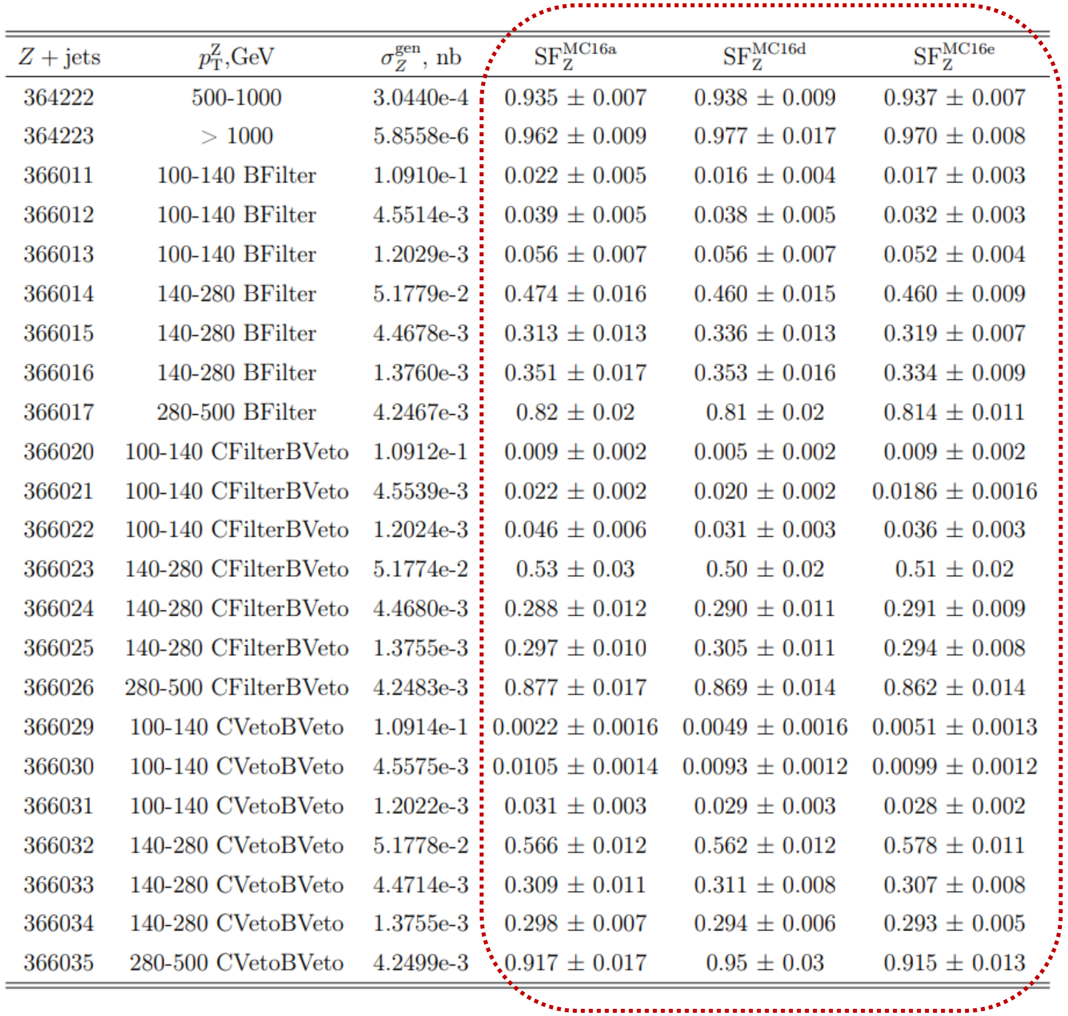
- To obtain cross sections within the certain phase space region, the scale factors SF_Z and SF_γ are applied to σ_Z and σ_γ respectively;
- Scale factor is defined as the number of the γ+j (Zj) events passing the required cuts divided by the number of events in the sample.

γ+jets



$\gamma + $jets	p_T^γ, GeV	σ_γ^{gen}, nb	SF_γ^{MC16a}	SF_γ^{MC16d}	SF_γ^{MC16e}
361045	140-280 CVetoBVeto	2.4733e-1	0.7511 ± 0.0004	0.7516 ± 0.0004	0.7514 ± 0.0003
361046	140-280 CFilterBVeto	2.4730e-1	0.7552 ± 0.0005	0.7553 ± 0.0005	0.7551 ± 0.0004
361047	140-280 BFilter	2.4928e-1	0.7626 ± 0.0005	0.7630 ± 0.0005	0.7626 ± 0.0004
361048	280-500 CVetoBVeto	1.3636e-2	0.9277 ± 0.0007	0.9276 ± 0.0006	0.9277 ± 0.0005
361049	280-500 CFilterBVeto	1.3636e-2	0.9304 ± 0.0011	0.9304 ± 0.0010	0.9302 ± 0.0009
361050	280-500 BFilter	1.3871e-2	0.9274 ± 0.0010	0.9274 ± 0.0009	0.9276 ± 0.0008
361051	500-1000 CVetoBVeto	9.2491e-4	0.9450 ± 0.0016	0.9450 ± 0.0014	0.9453 ± 0.0012
361052	500-1000 CFilterBVeto	9.2369e-4	0.9463 ± 0.0018	0.9468 ± 0.0016	0.9467 ± 0.0014
361053	500-1000 BFilter	9.4472e-4	0.945 ± 0.004	0.946 ± 0.004	0.944 ± 0.003
361054	1000-2000 CVetoBVeto	1.8485e-5	0.973 ± 0.002	0.9736 ± 0.0018	0.9736 ± 0.0016
361055	1000-2000 CFilterBVeto	1.8466e-5	0.975 ± 0.003	0.974 ± 0.003	0.974 ± 0.002
361056	1000-2000 BFilter	1.8978e-5	0.974 ± 0.005	0.974 ± 0.005	0.973 ± 0.004

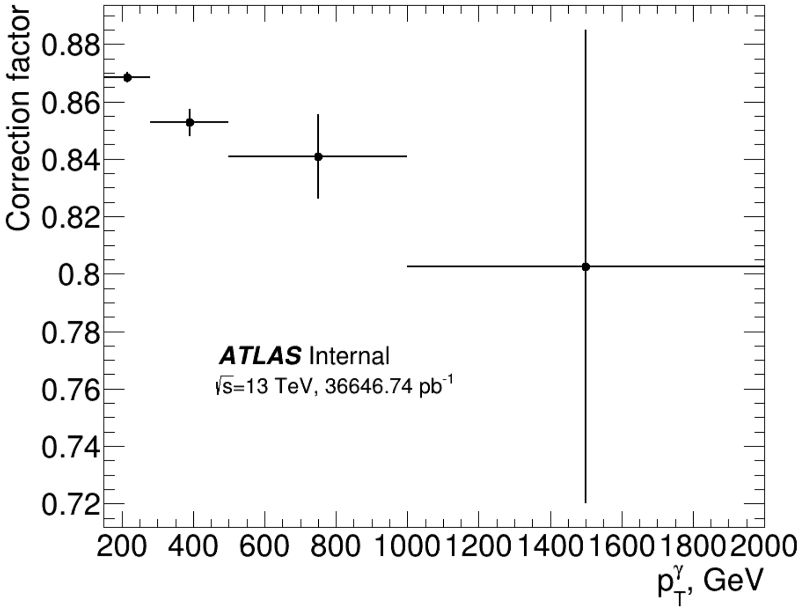
Zj

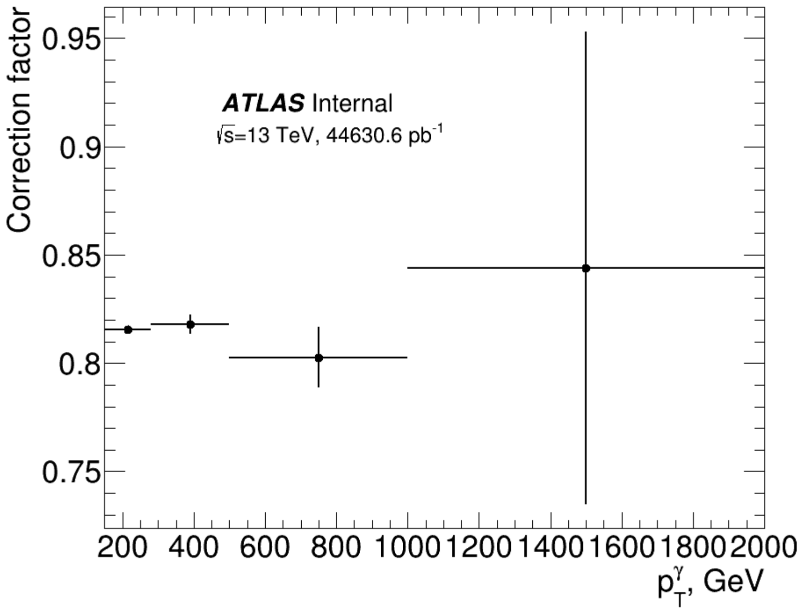


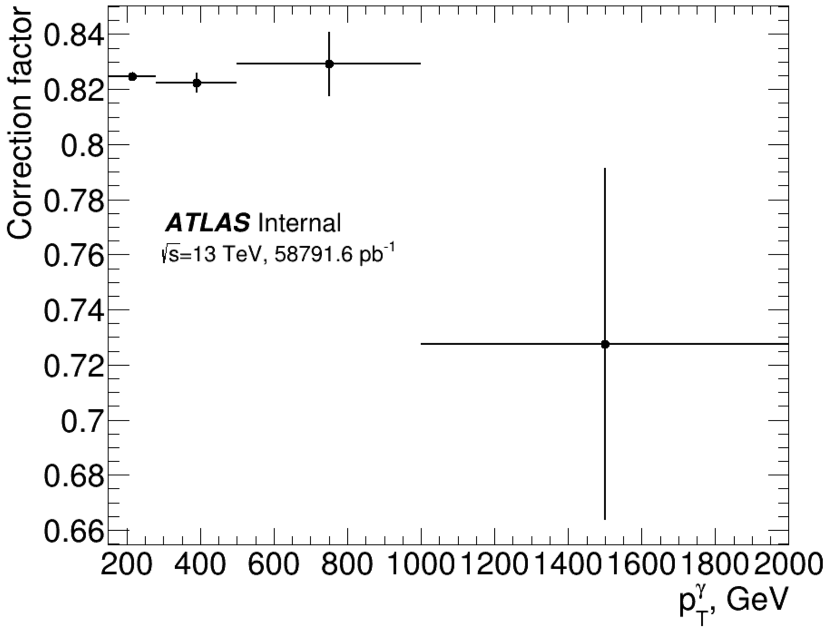
$Z + $jets	p_T^Z,GeV	σ_Z^{gen}, nb	SF_Z^{MC16a}	SF_Z^{MC16d}	SF_Z^{MC16e}
364222	500-1000	3.0440e-4	0.935 ± 0.007	0.938 ± 0.009	0.937 ± 0.007
364223	> 1000	5.8558e-6	0.962 ± 0.009	0.977 ± 0.017	0.970 ± 0.008
366011	100-140 BFilter	1.0910e-1	0.022 ± 0.005	0.016 ± 0.004	0.017 ± 0.003
366012	100-140 BFilter	4.5514e-3	0.039 ± 0.005	0.038 ± 0.005	0.032 ± 0.003
366013	100-140 BFilter	1.2029e-3	0.056 ± 0.007	0.056 ± 0.007	0.052 ± 0.004
366014	140-280 BFilter	5.1779e-2	0.474 ± 0.016	0.460 ± 0.015	0.460 ± 0.009
366015	140-280 BFilter	4.4678e-3	0.313 ± 0.013	0.336 ± 0.013	0.319 ± 0.007
366016	140-280 BFilter	1.3760e-3	0.351 ± 0.017	0.353 ± 0.016	0.334 ± 0.009
366017	280-500 BFilter	4.2467e-3	0.82 ± 0.02	0.81 ± 0.02	0.814 ± 0.011
366020	100-140 CFilterBVeto	1.0912e-1	0.009 ± 0.002	0.005 ± 0.002	0.009 ± 0.002
366021	100-140 CFilterBVeto	4.5539e-3	0.022 ± 0.002	0.020 ± 0.002	0.0186 ± 0.0016
366022	100-140 CFilterBVeto	1.2024e-3	0.046 ± 0.006	0.031 ± 0.003	0.036 ± 0.003
366023	140-280 CFilterBVeto	5.1774e-2	0.53 ± 0.03	0.50 ± 0.02	0.51 ± 0.02
366024	140-280 CFilterBVeto	4.4680e-3	0.288 ± 0.012	0.290 ± 0.011	0.291 ± 0.009
366025	140-280 CFilterBVeto	1.3755e-3	0.297 ± 0.010	0.305 ± 0.011	0.294 ± 0.008
366026	280-500 CFilterBVeto	4.2483e-3	0.877 ± 0.017	0.869 ± 0.014	0.862 ± 0.014
366029	100-140 CVetoBVeto	1.0914e-1	0.0022 ± 0.0016	0.0049 ± 0.0016	0.0051 ± 0.0013
366030	100-140 CVetoBVeto	4.5575e-3	0.0105 ± 0.0014	0.0093 ± 0.0012	0.0099 ± 0.0012
366031	100-140 CVetoBVeto	1.2022e-3	0.031 ± 0.003	0.029 ± 0.003	0.028 ± 0.002
366032	140-280 CVetoBVeto	5.1778e-2	0.566 ± 0.012	0.562 ± 0.012	0.578 ± 0.011
366033	140-280 CVetoBVeto	4.4714e-3	0.309 ± 0.011	0.311 ± 0.008	0.307 ± 0.008
366034	140-280 CVetoBVeto	1.3755e-3	0.298 ± 0.007	0.294 ± 0.006	0.293 ± 0.005
366035	280-500 CVetoBVeto	4.2499e-3	0.917 ± 0.017	0.95 ± 0.03	0.915 ± 0.013

Correction Factor

The C-factor is parameterized by the transverse momentum of the photon.

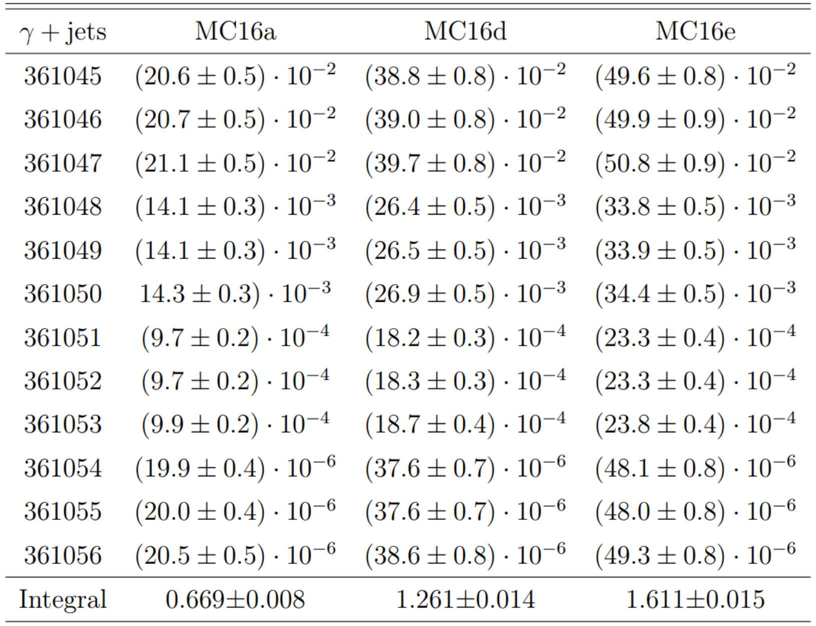






The estimates of correction factor obtained with Z(νν)γ MC signal for 4 intervals of the transverse momentum of the photon [150; 280; 500; 1000; 2000] GeV for MC16a/d/e.

Results for each slice of p_T^γ

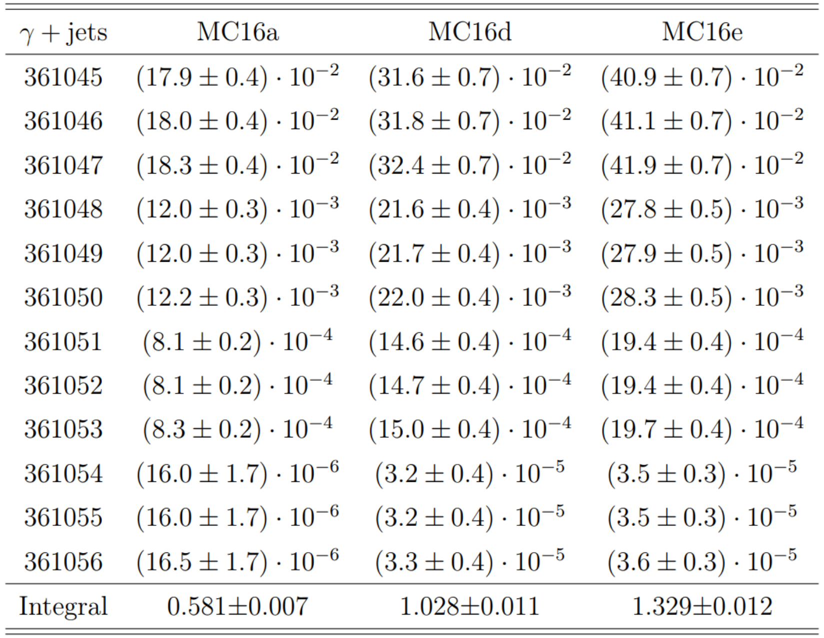


γ + jets	MC16a	MC16d	MC16e
361045	$(20.6 \pm 0.5) \cdot 10^{-2}$	$(38.8 \pm 0.8) \cdot 10^{-2}$	$(49.6 \pm 0.8) \cdot 10^{-2}$
361046	$(20.7 \pm 0.5) \cdot 10^{-2}$	$(39.0 \pm 0.8) \cdot 10^{-2}$	$(49.9 \pm 0.9) \cdot 10^{-2}$
361047	$(21.1 \pm 0.5) \cdot 10^{-2}$	$(39.7 \pm 0.8) \cdot 10^{-2}$	$(50.8 \pm 0.9) \cdot 10^{-2}$
361048	$(14.1 \pm 0.3) \cdot 10^{-3}$	$(26.4 \pm 0.5) \cdot 10^{-3}$	$(33.8 \pm 0.5) \cdot 10^{-3}$
361049	$(14.1 \pm 0.3) \cdot 10^{-3}$	$(26.5 \pm 0.5) \cdot 10^{-3}$	$(33.9 \pm 0.5) \cdot 10^{-3}$
361050	$14.3 \pm 0.3) \cdot 10^{-3}$	$(26.9 \pm 0.5) \cdot 10^{-3}$	$(34.4 \pm 0.5) \cdot 10^{-3}$
361051	$(9.7 \pm 0.2) \cdot 10^{-4}$	$(18.2 \pm 0.3) \cdot 10^{-4}$	$(23.3 \pm 0.4) \cdot 10^{-4}$
361052	$(9.7 \pm 0.2) \cdot 10^{-4}$	$(18.3 \pm 0.3) \cdot 10^{-4}$	$(23.3 \pm 0.4) \cdot 10^{-4}$
361053	$(9.9 \pm 0.2) \cdot 10^{-4}$	$(18.7 \pm 0.4) \cdot 10^{-4}$	$(23.8 \pm 0.4) \cdot 10^{-4}$
361054	$(19.9 \pm 0.4) \cdot 10^{-6}$	$(37.6 \pm 0.7) \cdot 10^{-6}$	$(48.1 \pm 0.8) \cdot 10^{-6}$
361055	$(20.0 \pm 0.4) \cdot 10^{-6}$	$(37.6 \pm 0.7) \cdot 10^{-6}$	$(48.0 \pm 0.8) \cdot 10^{-6}$
361056	$(20.5 \pm 0.5) \cdot 10^{-6}$	$(38.6 \pm 0.8) \cdot 10^{-6}$	$(49.3 \pm 0.8) \cdot 10^{-6}$
Integral	0.669±0.008	1.261±0.014	1.611±0.015

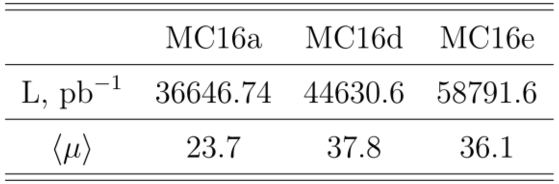
The estimates of the number of pile-up events at the particle-level for each γ+jets sample, obtained by sequential combination with each Zj sample.

The values of the integrated luminosity L and <μ> the average number of pp inelastic collisions per bunch crossing for each campaign:

- The reconstruction level:



γ + jets	MC16a	MC16d	MC16e
361045	$(17.9 \pm 0.4) \cdot 10^{-2}$	$(31.6 \pm 0.7) \cdot 10^{-2}$	$(40.9 \pm 0.7) \cdot 10^{-2}$
361046	$(18.0 \pm 0.4) \cdot 10^{-2}$	$(31.8 \pm 0.7) \cdot 10^{-2}$	$(41.1 \pm 0.7) \cdot 10^{-2}$
361047	$(18.3 \pm 0.4) \cdot 10^{-2}$	$(32.4 \pm 0.7) \cdot 10^{-2}$	$(41.9 \pm 0.7) \cdot 10^{-2}$
361048	$(12.0 \pm 0.3) \cdot 10^{-3}$	$(21.6 \pm 0.4) \cdot 10^{-3}$	$(27.8 \pm 0.5) \cdot 10^{-3}$
361049	$(12.0 \pm 0.3) \cdot 10^{-3}$	$(21.7 \pm 0.4) \cdot 10^{-3}$	$(27.9 \pm 0.5) \cdot 10^{-3}$
361050	$(12.2 \pm 0.3) \cdot 10^{-3}$	$(22.0 \pm 0.4) \cdot 10^{-3}$	$(28.3 \pm 0.5) \cdot 10^{-3}$
361051	$(8.1 \pm 0.2) \cdot 10^{-4}$	$(14.6 \pm 0.4) \cdot 10^{-4}$	$(19.4 \pm 0.4) \cdot 10^{-4}$
361052	$(8.1 \pm 0.2) \cdot 10^{-4}$	$(14.7 \pm 0.4) \cdot 10^{-4}$	$(19.4 \pm 0.4) \cdot 10^{-4}$
361053	$(8.3 \pm 0.2) \cdot 10^{-4}$	$(15.0 \pm 0.4) \cdot 10^{-4}$	$(19.7 \pm 0.4) \cdot 10^{-4}$
361054	$(16.0 \pm 1.7) \cdot 10^{-6}$	$(3.2 \pm 0.4) \cdot 10^{-5}$	$(3.5 \pm 0.3) \cdot 10^{-5}$
361055	$(16.0 \pm 1.7) \cdot 10^{-6}$	$(3.2 \pm 0.4) \cdot 10^{-5}$	$(3.5 \pm 0.3) \cdot 10^{-5}$
361056	$(16.5 \pm 1.7) \cdot 10^{-6}$	$(3.3 \pm 0.4) \cdot 10^{-5}$	$(3.6 \pm 0.3) \cdot 10^{-5}$
Integral	0.581±0.007	1.028±0.011	1.329±0.012



	MC16a	MC16d	MC16e
L, pb^{-1}	36646.74	44630.6	58791.6
$\langle\mu\rangle$	23.7	37.8	36.1

- The inelastic cross section σ_{inel} = 80 mb

- The bottom line corresponds to the total values of the number of pile-up events at the particle-level and at the reconstruction level within the MC16a/d/e campaigns