CLHCP 2018 - Wuhan

20 December 2018

Low-Mass Diphoton Resonances Search With the ATLAS Detector at 13 TeV

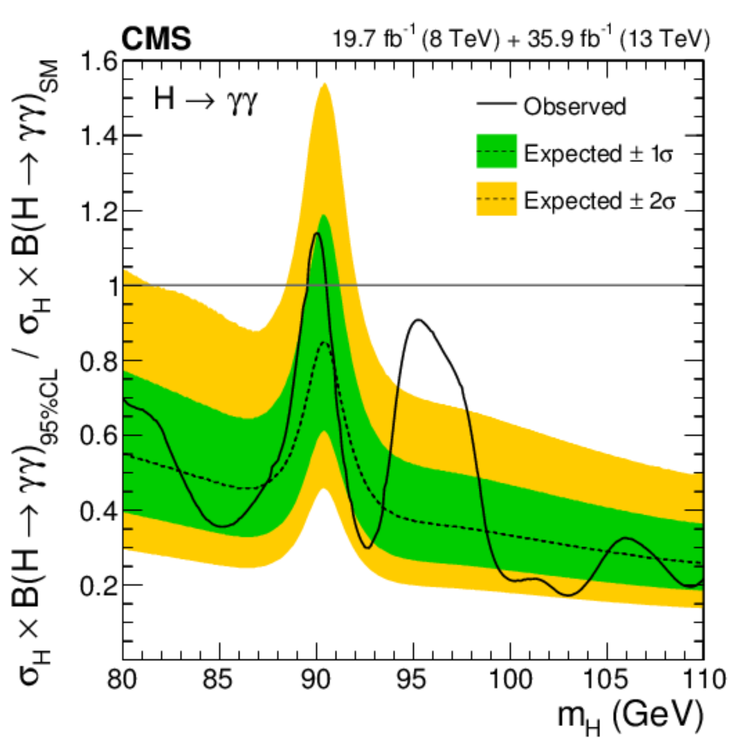
Asma Hadef

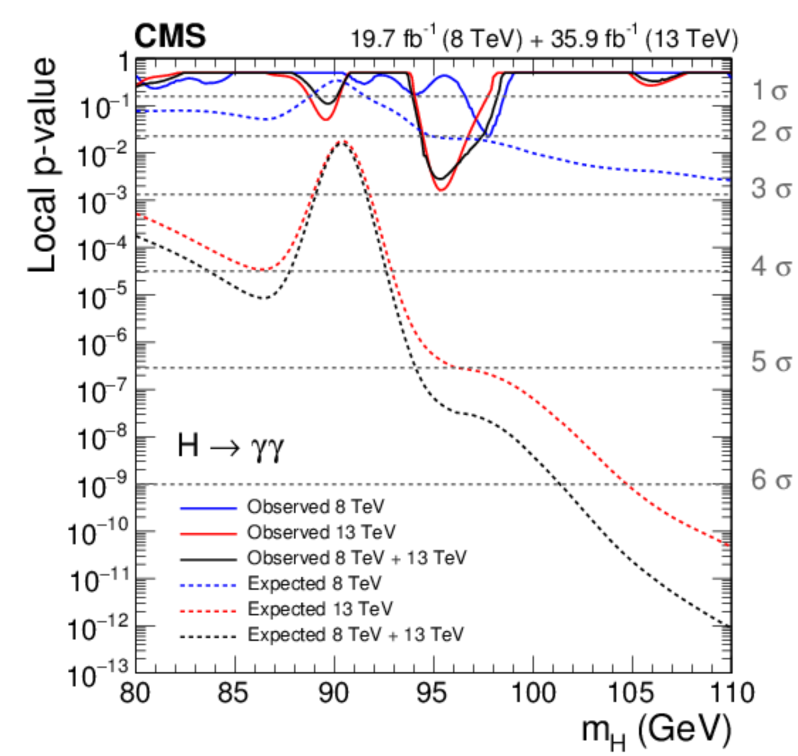
- University of Science and Technology of China -

On behalf of ATLAS collaboration

Motivation

- Several models predict new resonances below the Higgs mass
  - Additional scalar in 2HDM [arXiv:1106.0034]
  - Axion-like particles [arXiv:1710.01743]
- **Small excess seen at 95.3 GeV at CMS: 2.8σ local, 1.3σ global (8 + 13 TeV).**
  - [arXiv:1811.08459]

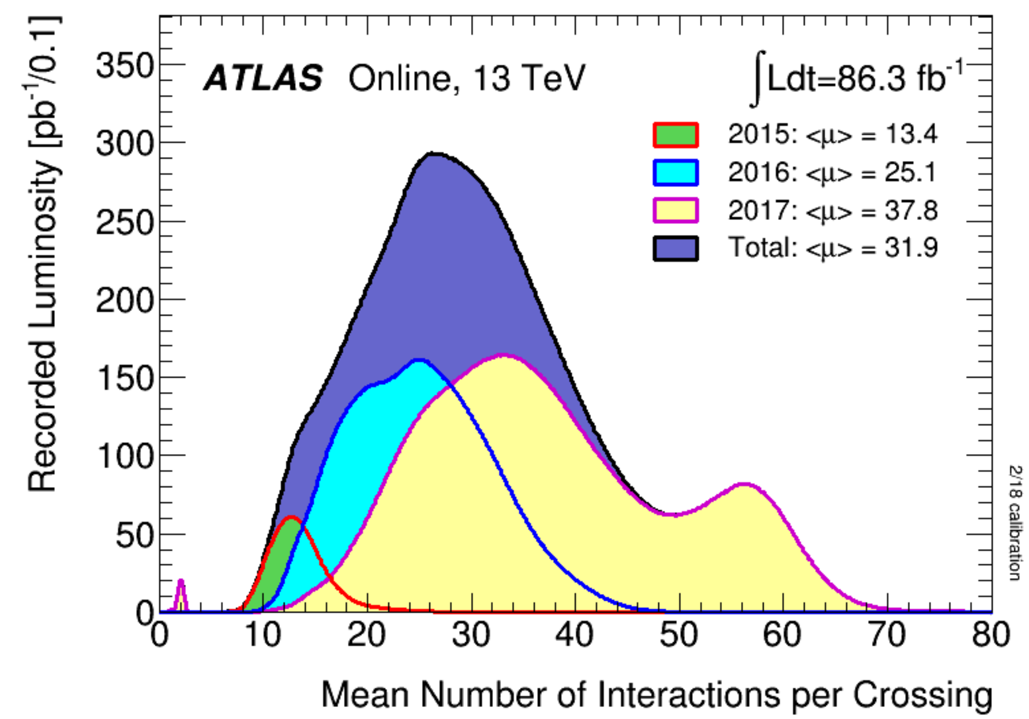




- **In this talk:**
  - Search for narrow spin-0 resonances between 65 and 110 GeV with 80 fb^{-1} @13TeV at ATLAS (ATLAS-CONF-2018-025)

Signal Selection

- **Trigger selection:**
  - The 2015-2017 data were recorded using diphoton triggers that required two electromagnetic clusters with transverse energies p_T above 20 GeV (22 in 2016) + satisfying identification criteria based on variables describing the shape of the electromagnetic showers in the calorimeter
  - In 2017 a requirement on calorimeter isolation transverse energy at the trigger level is added to lower the pT threshold back to 20 GeV



a new trigger is developed for this analysis to cope with the higher pile-up in 2017

- **Requirements on leading and sub-leading photons:**
  - Kinematics: $p_T > 22$ GeV, $|\eta| < 2.37$ excluding the transition region $1.37 < |\eta| < 1.52$
  - 2 isolated photons using both calorimeter and tracking detector information.
  - Tight identification criteria
  - $60 < m_{\gamma\gamma} < 120$ GeV

- **Categorisation:**
  - 0-conversions: 2 unconverted photons **UU (50%)**
  - 1-conversion: one converted photon only **CU (42%)**
  - 2-conversion: 2 converted photons **CC (8%)**

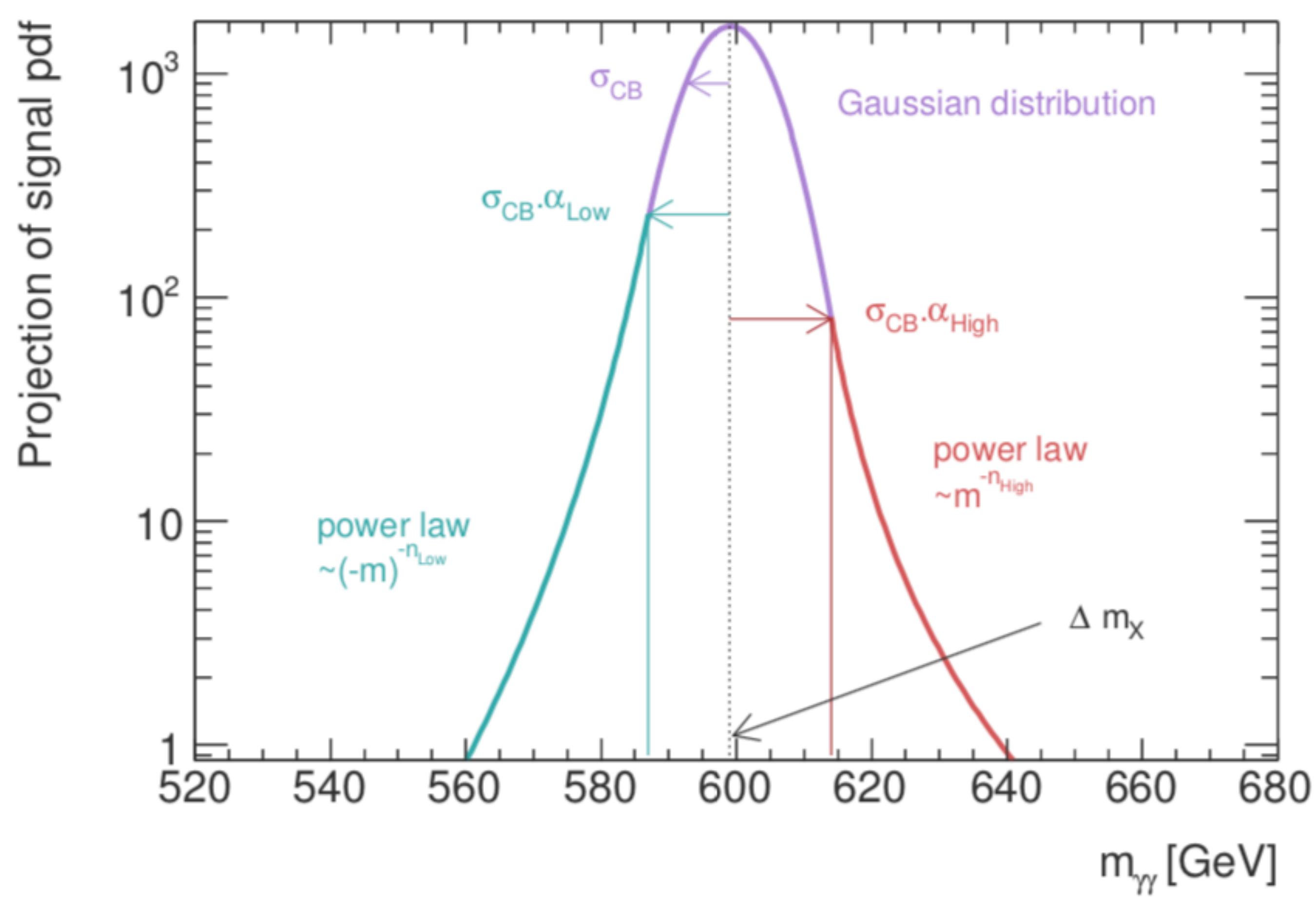
the probability of a photon to be converted varies between 20% to 50% depending on p_T and η ranges.

Signal Modelling

- Signal consists of:
  - a gaussian core + asymmetric non-gaussian tails
- Double-side Crystal Ball function (DSCB):

non-linear energy leakage effects and FSR processes

$$N \cdot \begin{cases} e^{-t^2/2} & \text{if } -\alpha_{\text{low}} \le t \le \alpha_{\text{high}} \\ \dfrac{e^{-0.5\alpha_{\text{low}}^2}}{\left[\frac{\alpha_{\text{low}}}{n_{\text{low}}}\left(\frac{n_{\text{low}}}{\alpha_{\text{low}}} - \alpha_{\text{low}} - t\right)\right]^{n_{\text{low}}}} & \text{if } t < -\alpha_{\text{low}} \\ \dfrac{e^{-0.5\alpha_{\text{high}}^2}}{\left[\frac{\alpha_{\text{high}}}{n_{\text{high}}}\left(\frac{n_{\text{high}}}{\alpha_{\text{high}}} - \alpha_{\text{high}} + t\right)\right]^{n_{\text{high}}}} & \text{if } t > \alpha_{\text{high}}, \end{cases}$$



$t = (m-\mu)/\sigma$; σ: CB width;

m: diphoton mass; μ: CB peak.

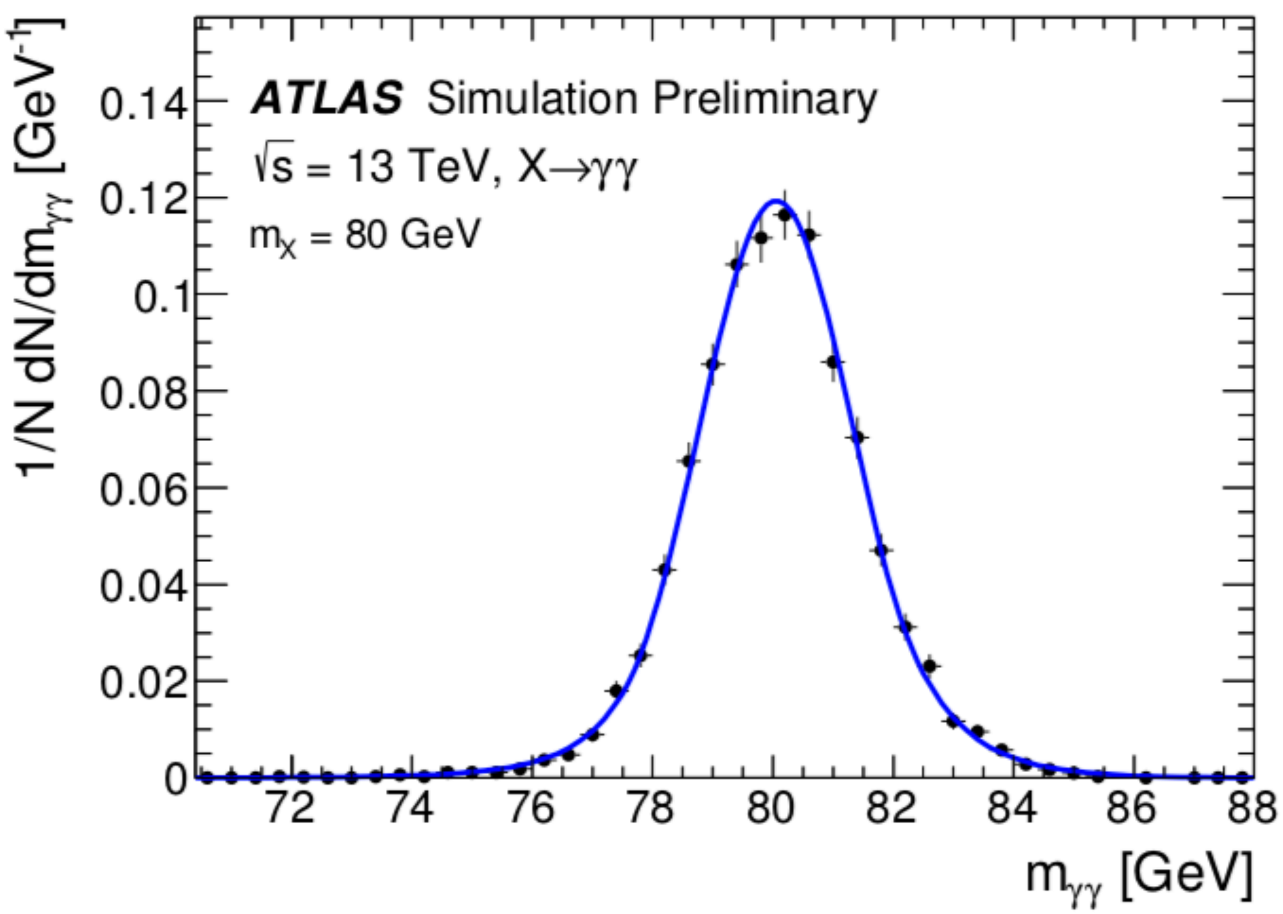
➤ 6 parameters: μ, σ, α_{low}, α_{high}, n_{low}, n_{high}

power law

exponent of power law

Signal Modelling - Parameterisation

- Parametrise the six signal parameters (correlated and mass dependent):
  - μ, σ, α_{low}, α_{high}: extracted as a function of m_X (1st order poly)
  - n_{low}, n_{high}: are constrained (mass independent)



Fitting multiple mass point simultaneously in [60-200] GeV with nominal ggF samples.

Since $n_{low/high}$ and $a_{low/high}$ are correlated, multiple fit will find the best combination taking into account various m_X hypothesis.

- Parameterisation validation with single mass points (concrete values of the six parameters of the DSCB)

Background Decomposition

- **Continuum**
  - Irreducible background (γγ)

    –> Simulation, Sherpa @ NLO QCD
  - Reducible background (γ*j*, *jj*)

    –> Shape from data CR, normalisation from data-driven decomposition
- **Resonant**
  - Drell-Yan background (Z->ee)

    –> data-driven method: shape from e ->γ transformation, normalisation from e ->γ rates
  - SM Higgs @ 125 GeV

    –> Simulation, negligible below 110 GeV

2x2D "sideband" decomposition method

Category	UU	CU	CC
N_{data}	1204889	1025072	234166
$N_{\mathrm{DY}}^{\mathrm{exp}}$	5000 ± 1100	18800 ± 2000	22300 ± 2600
$f_{\gamma\gamma}$	$0.688^{+0.021}_{-0.048}$	$0.661^{+0.029}_{-0.034}$	$0.654^{+0.045}_{-0.027}$
$f_{\gamma \mathrm{j}}$	$0.175^{+0.037}_{-0.026}$	$0.181^{+0.029}_{-0.025}$	$0.179^{+0.051}_{-0.044}$
$f_{\mathrm{j}\gamma}$	$0.080^{+0.027}_{-0.017}$	$0.093^{+0.031}_{-0.025}$	$0.093^{+0.035}_{-0.048}$
f_{jj}	$0.057^{+0.023}_{-0.028}$	$0.065^{+0.029}_{-0.034}$	$0.074^{+0.043}_{-0.050}$

γγ Purity ~65% –> cannot ignore reducible component

Continuum Background

- **Reducible**
  - **Shape**: reweighted MC γγ continuum to match the data in a CR with one photon failing the tight ID.
  - **Normalisation**: to data using the fractions measured with the 2x2D sideband method. γγ /γj(jγ) ratio fitted with a 1st or 2nd order polynomial, depending on the category.

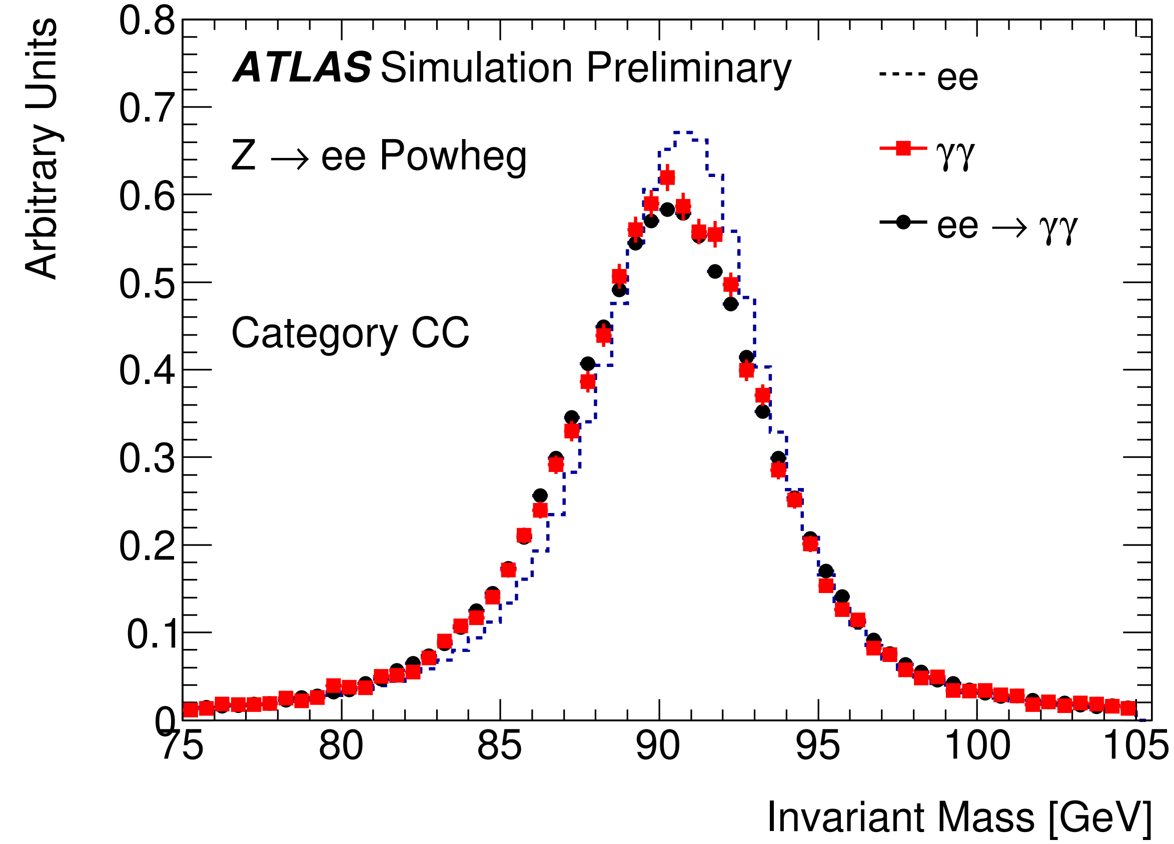
- **Reducible + irreducible modelling:** Continuum background is fitted on data with a selected model with free parameters of shape and normalisation, using **spurious signal method**
  - **spurious signal method:** Different models are chosen for the different categories to achieve a good compromise between limiting the size of a potential bias (*spurious signal*) while retaining good statistical power.
  - The spurious signal is required to be less than 30% of background uncertainty

we would need a factor 100 to have small statistical fluctuations of the Spurious Signal (but we have already half a billion of events!)

—> we expect large fluctuations of the Spurious Signal.

Z ->ee Background

- Fake photons from bremsstrahlung electrons
- Both electrons are misidentified as photons –> electron background
- Modeled using a DSCB function
- Estimated by data-driven method:
    - **CR**: reconstructed di-electron in data passing same diphoton signal selection except isolation + $\Delta R_{e\gamma}>0.1$
    - **Shape**: Transform the kinematics distributions of the electrons inv. mass to match those of the fake photons using MC
    - **Normalisation**: electron to photon fake rates



$$N_{\gamma\gamma}^{DY} = \alpha \cdot \boxed{\rho_1 \cdot \rho_2} \cdot N_{ee}^{DY}$$

correlation correction factor

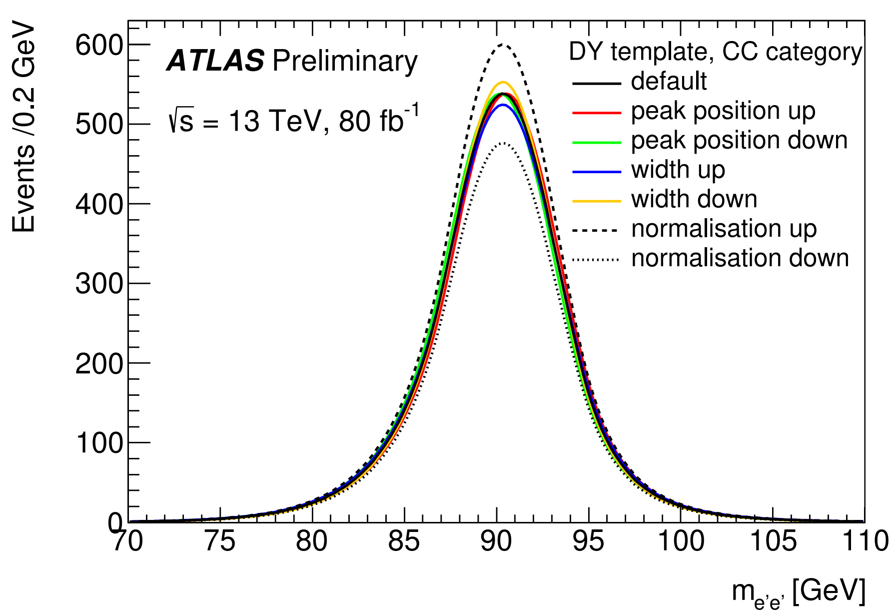
(Sub)leading fake rates

Drell-Yan events, continuum subtracted

$$\rho_1 = N_{\gamma e}/N_{e'e}$$

$$\rho_2 = N_{e\gamma}/N_{ee'}$$

Computed in data



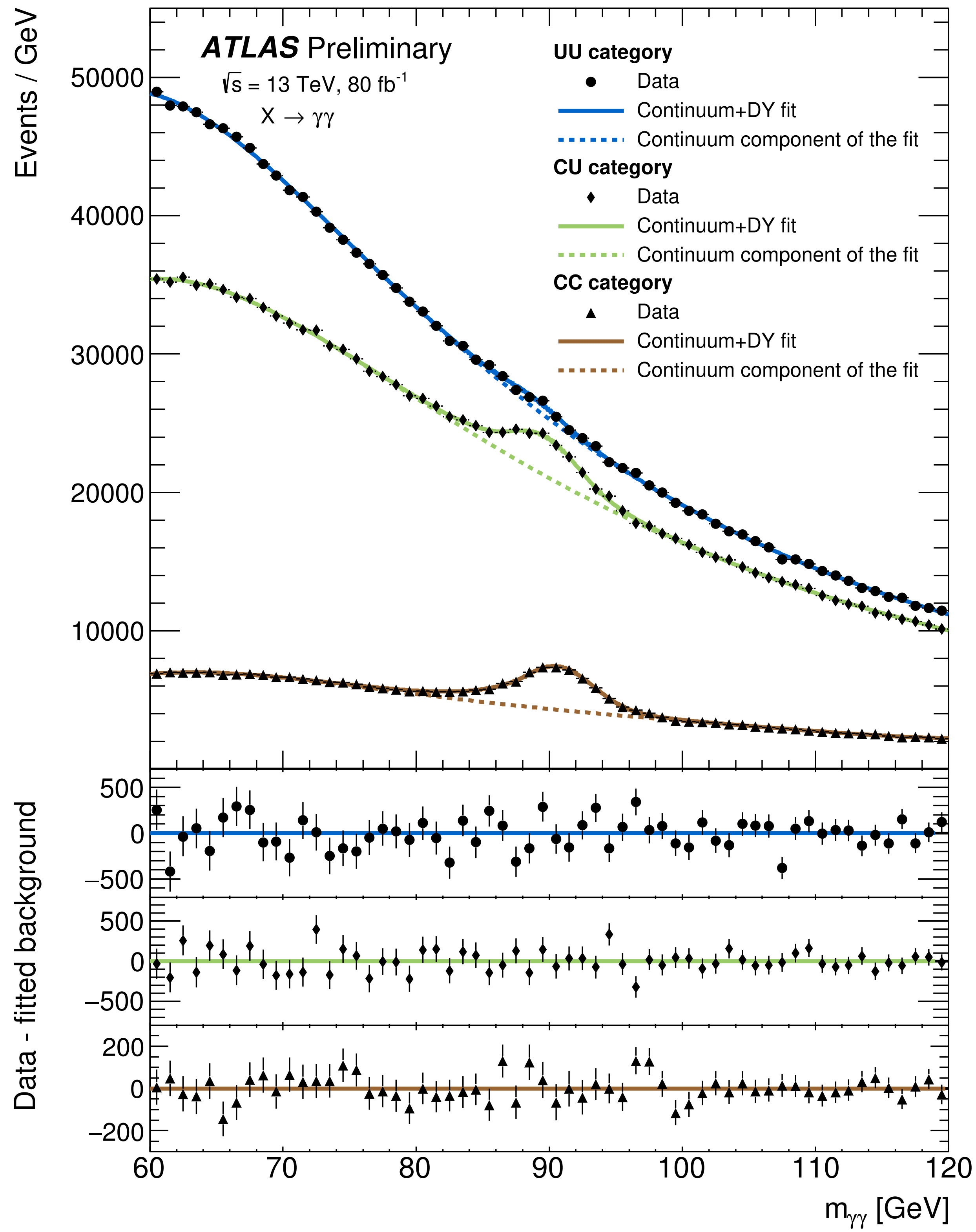
both shape and normalisation are fitted but constrained

Systematics

Source	Uncertainty [%]	Remarks
Signal yield		
Luminosity	±2	
Trigger eff.	±1.4 – 1.7	m_X-dependent
Photon identification eff.	±1.5 – 2.3	m_X-dependent
Isolation eff.	±4	
Photon energy scale	±0.13 – 0.49	m_X-dependent
Photon energy resolution	±0.053 – 0.28	m_X-dependent
Pile-up	±1.8 – 4.1	m_X-dependent
Production mode	±2.4 – 25	m_X-dependent
Signal modeling		
Photon energy scale	±0.3 – 0.5	m_X- and category–dependent
Photon energy resolution	±2 – 8	m_X- and category-dependent
Migration between categories		
Material	−2.0 / +1.0 / +4.1	category-dependent (UU/CU/CC)
Non-resonant Background		
Spurious Signal	128 / 104 / 79	ratio to the expected spurious signal uncertainty
	(604 / 496 / 181 events)	(category-dependent)
DY Background modeling		
Peak position	±0.1 – 0.2	category-dependent
Peak width	±2 – 3	category-dependent
Normalization	±9 – 21	category-dependent

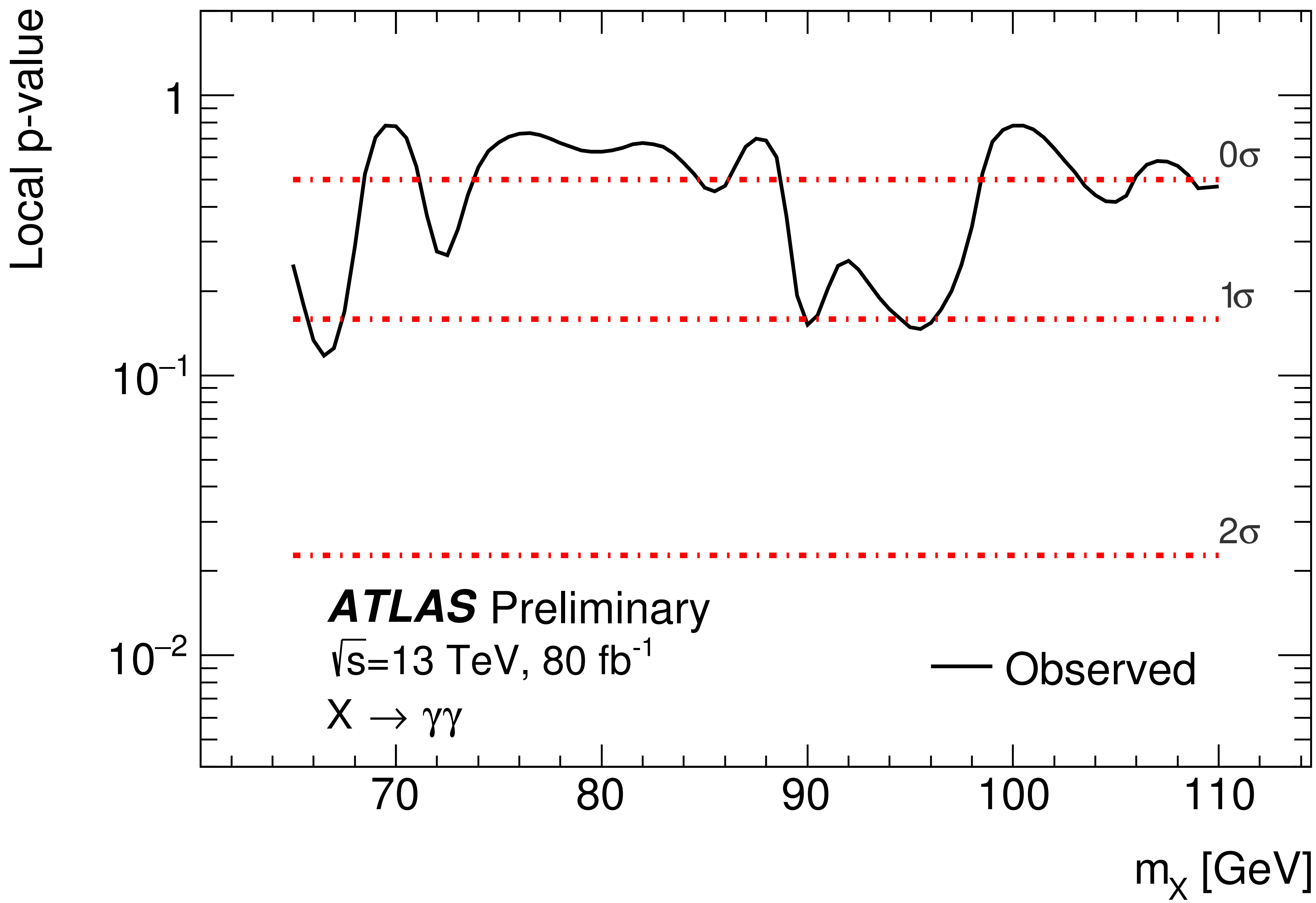
Results - Post-fit Mass Spectra

The DY peak is clearly visible and no structure is seen in the residuals



Results - p_0 Scan

The compatibility of the observed diphoton mass spectra with the background-only hypothesis, for a given signal hypothesis X, is determined with a local p-value based on the profile-likelihood-ratio-test statistic



- 3 largest deviations are at 1 sigma level (~67,90,95 GeV)

Results - Limit

$$\sigma_{fid} \cdot \beta = \frac{N_s}{C_X \mathcal{L}}$$

fitted number of signal events in data

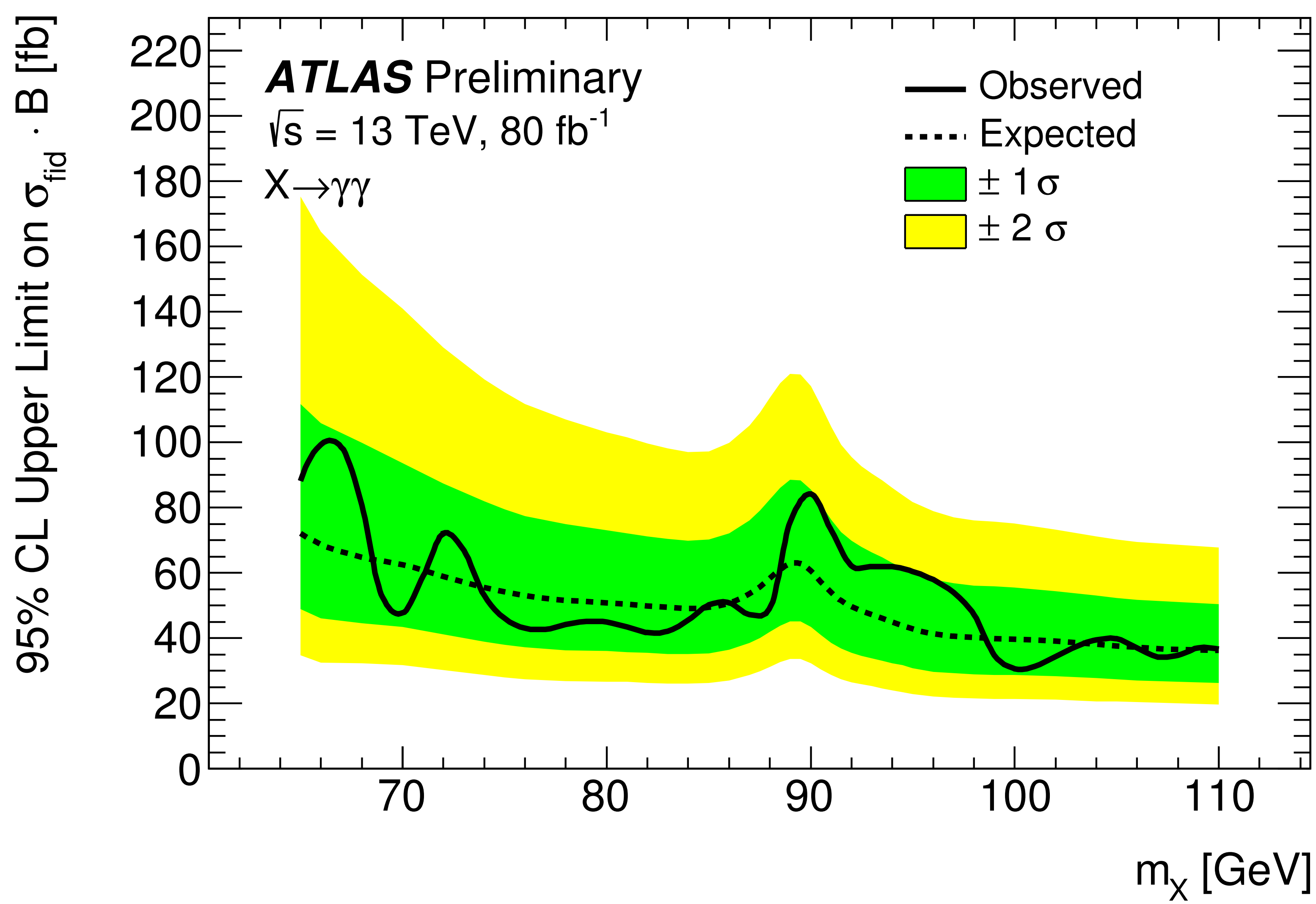
Efficiency correction factor

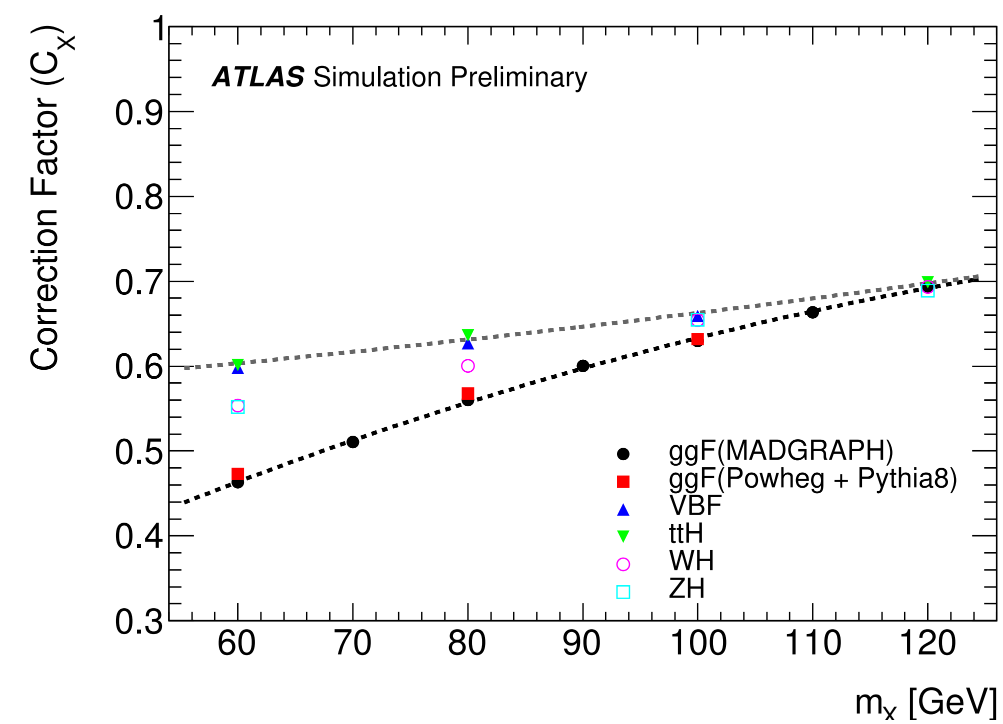
integrated luminosity

$$C_X = \frac{N_{MC}^{det}}{N_{MC}^{fid}}$$

number of simulated events passing the detector-level selection criteria

number of simulated events MC passing the particle-level selection

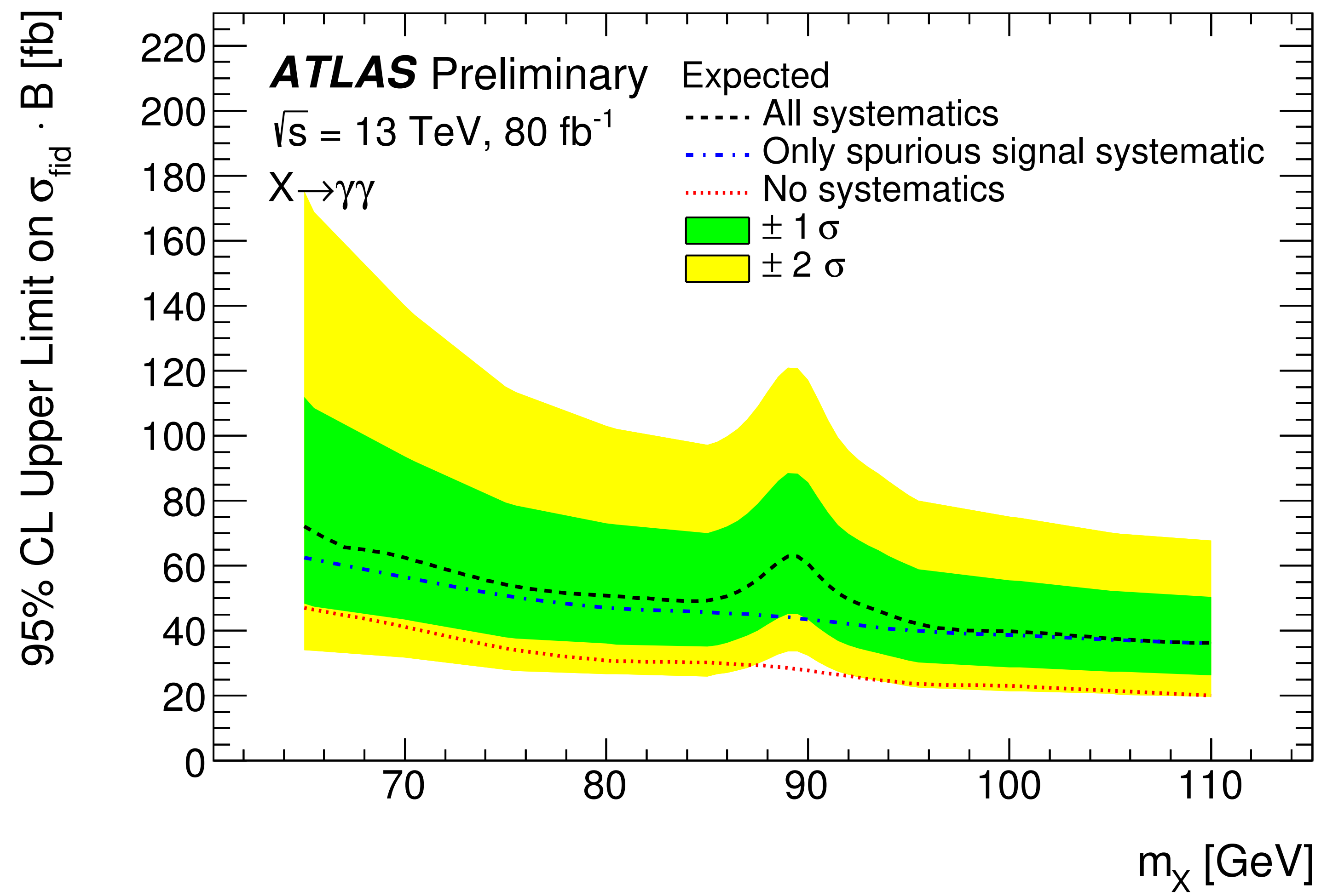




The limit is similar to the Run-1 one (would be better without the large Spurious Signal…) but we have to keep in mind that a signal would have a 1.5-2 larger cross-section so in the end we are more sensitive than Run1.

Results - Systematics Effect

- Spurious signal systematics has big impact on the limit –> major constraint of the analysis
- The impact of C_X factor (the dominant systematics on the signal) will be the next challenge –> The signal modelling strategy could be changed in the future

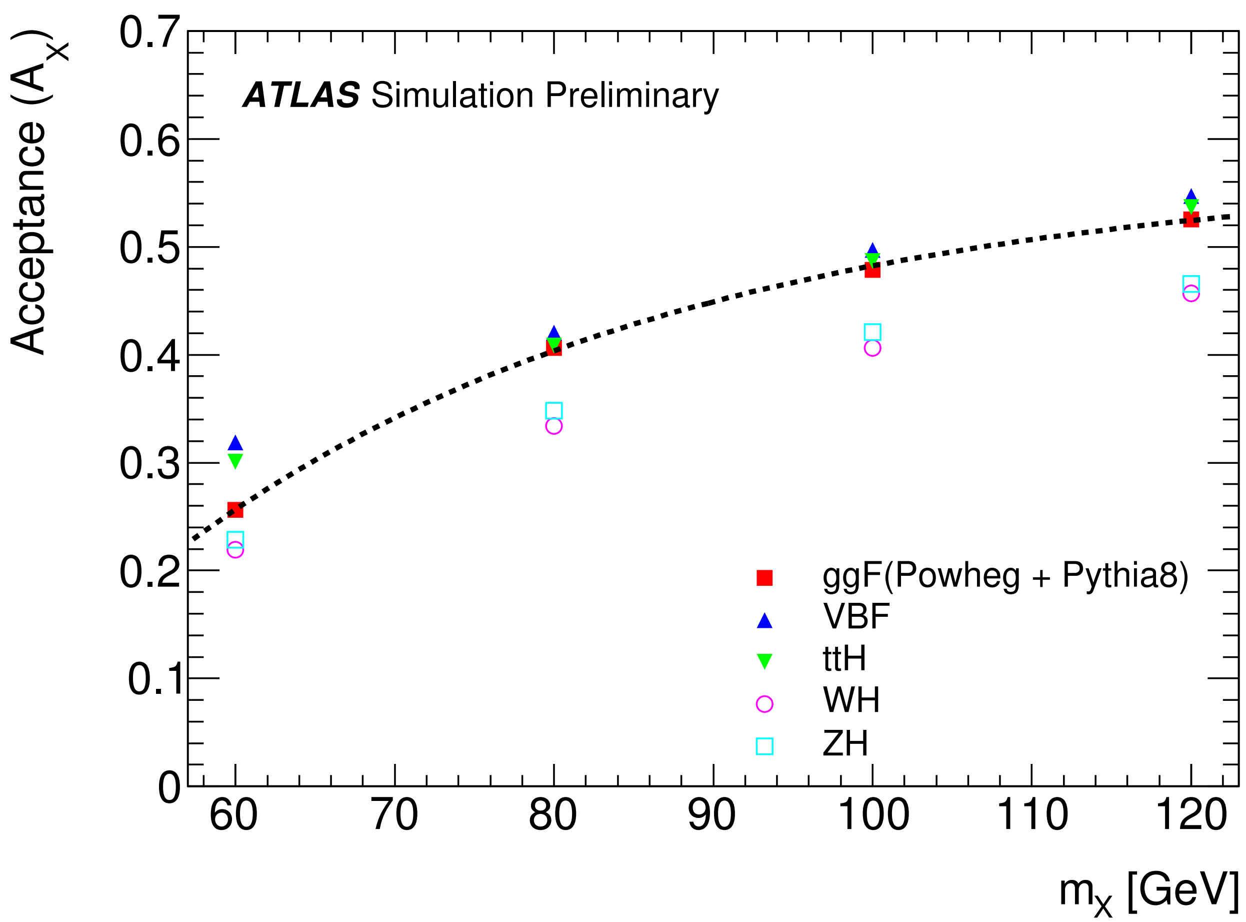


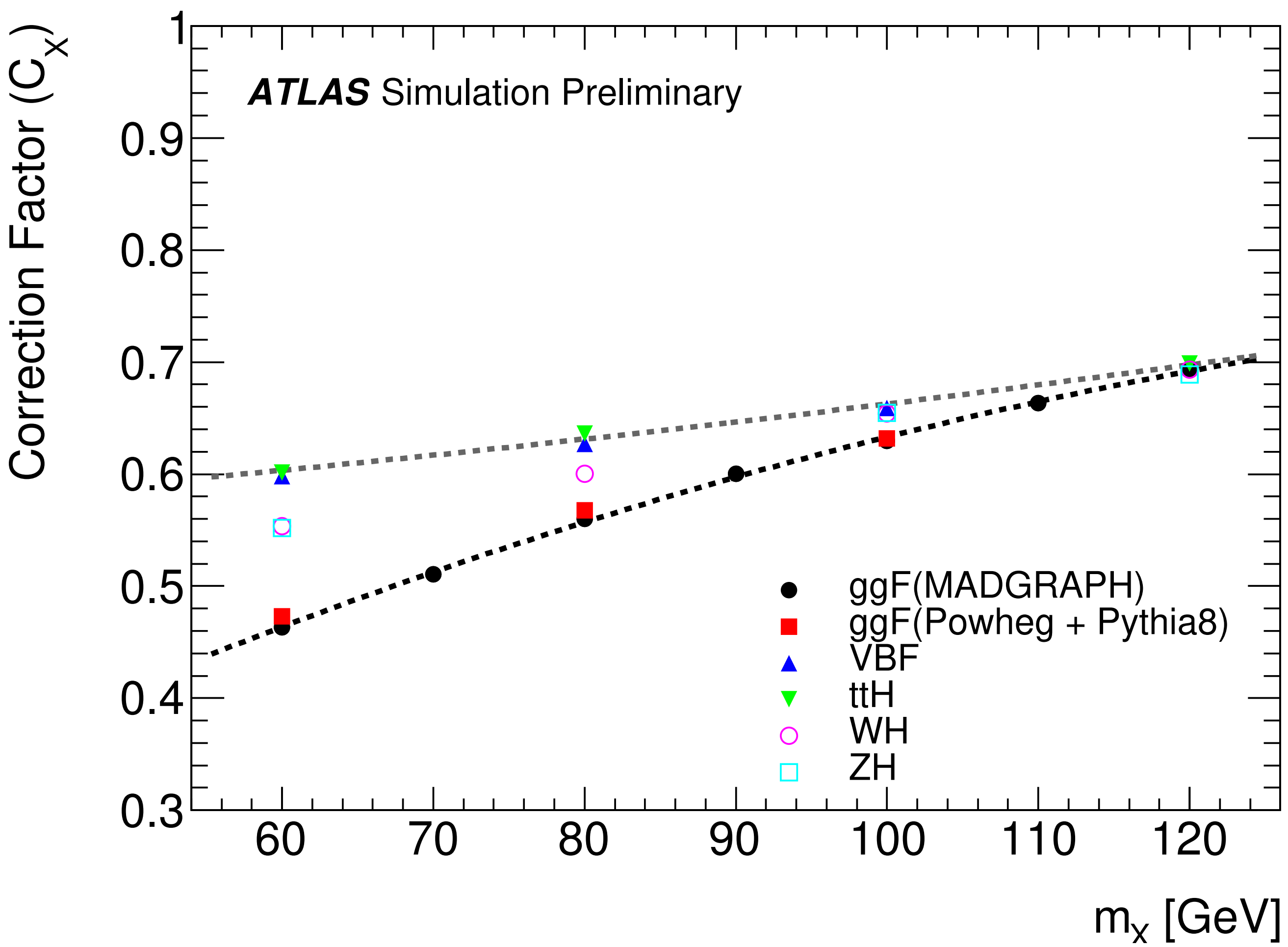
Conclusion

- A search was performed for a narrow scalar resonance decaying to two photons in the range 65-110 GeV with 80 fb^{-1} @ 13 TeV
- Cross-sections above 30 to 101 fb are excluded at the 95% CL, depending on the diphoton invariant mass
- the systematic limitation comes from the uncertainty on the continuum background modelling, arising from limited MC statistics.
- No excess is observed.
- Current effort is to reduce systematics coming mainly from spurious signal method and extending the search range to very low masses (below 65 GeV) and very high masses (as much as the data allows)..

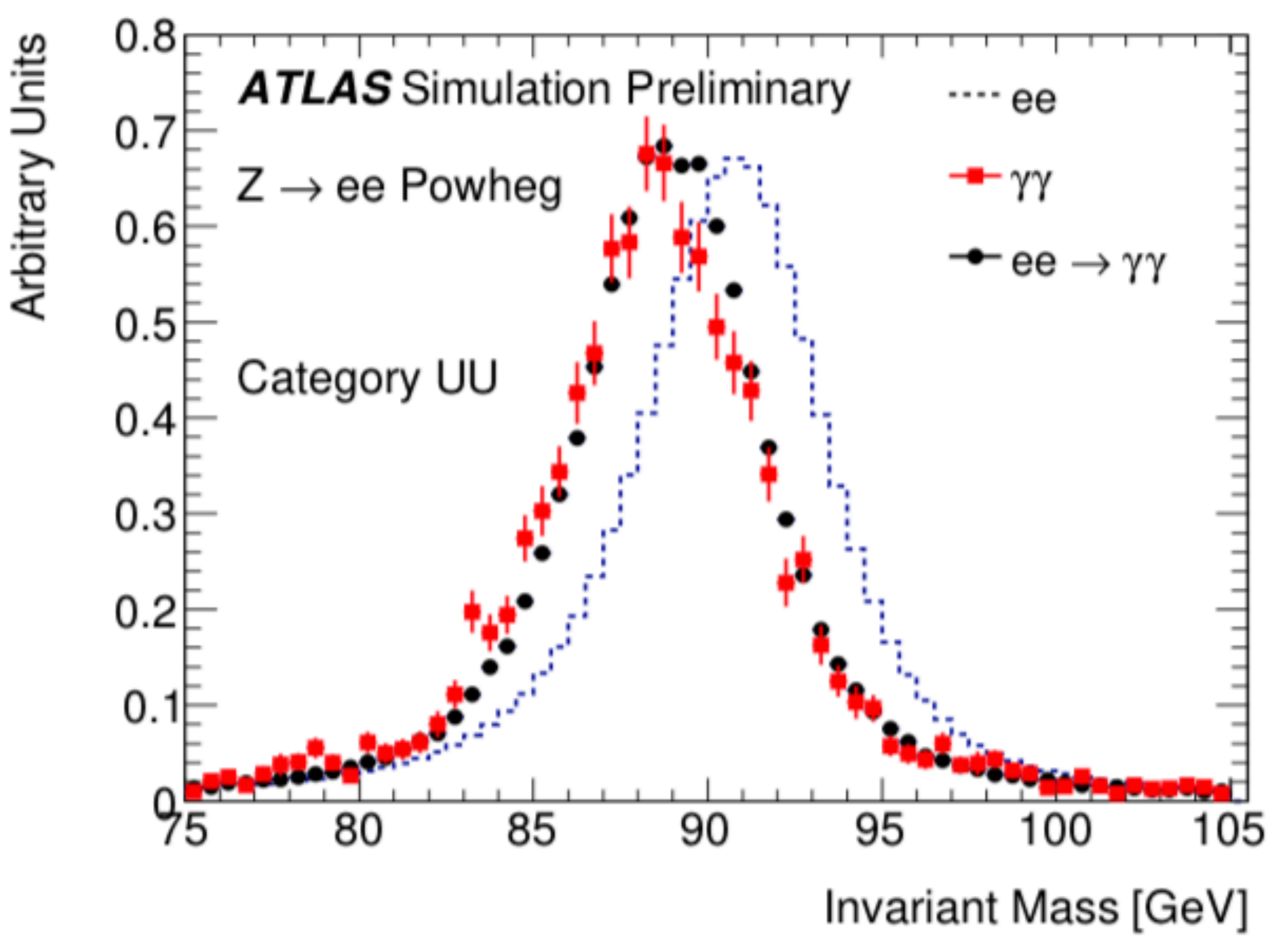
Back Up

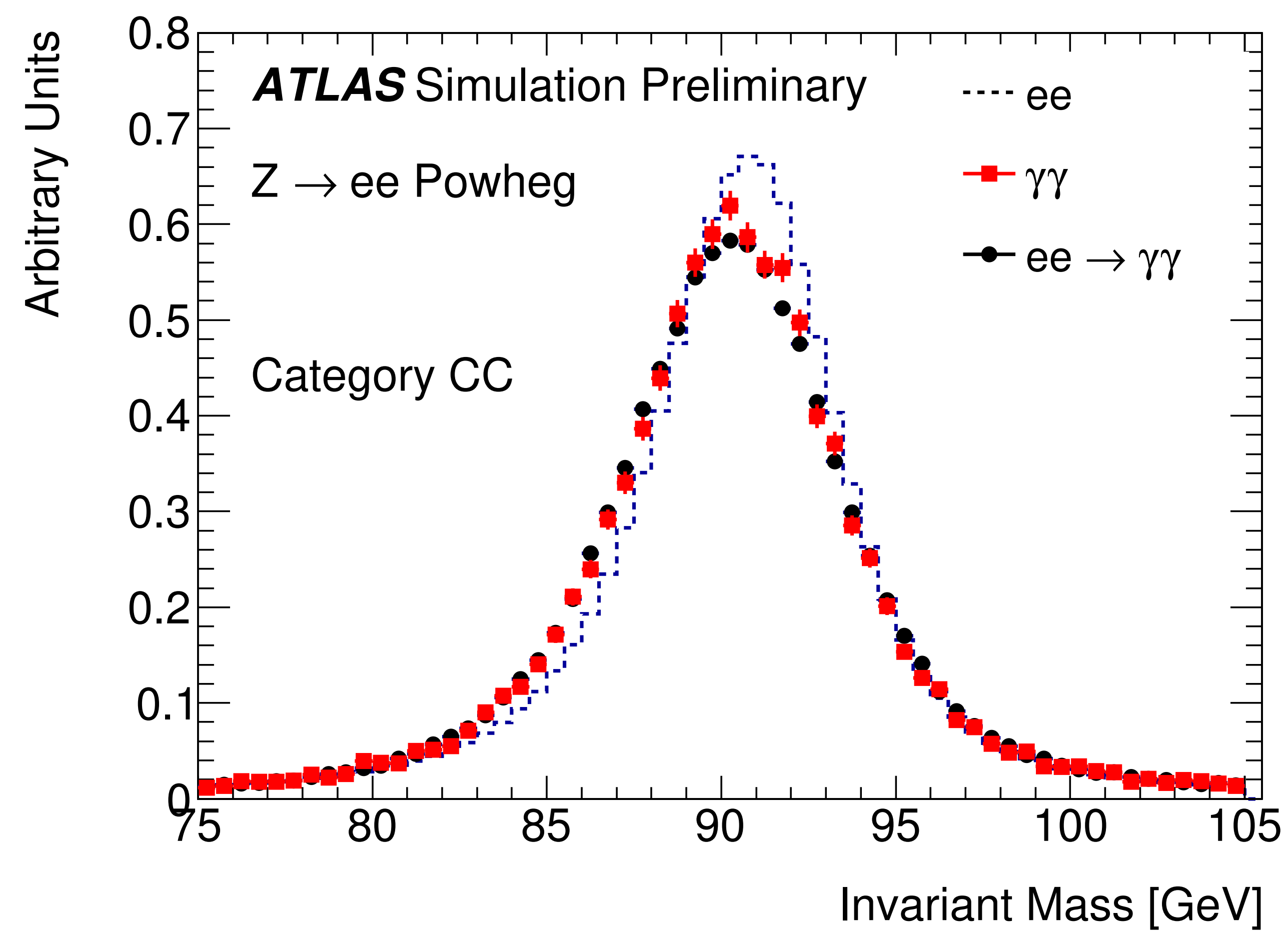
Acceptance and efficiency correction factors





DY background





- electrons reconstructed as unconverted photons are more affected by bremsstrahlung —> the UU events are more shifted to lower invariant masses than CC events.

2x2D sideband decomposition method

- Two requirements of the signal selection are loosened:
    - the isolation criteria are dropped
    - the photons must pass the Loose' identification criteria selection instead of the Tight one. The Loose' selections consists of removing cuts on some shower shapes in the first layer of the calorimeter
- This sample is then divided into 16 orthogonal subsamples, in which the photons either pass or fail the tight identification criteria and either pass or fail the isolation selection.

$$\underbrace{W_{\text{tot}}^{\text{L}'\text{L}'}}_{\text{observed yield}} = \underbrace{W_{\gamma\gamma}^{\text{L}'\text{L}'}}_{\text{(unknown) di-photon signal yield}} + \underbrace{W_{\gamma\text{j}}^{\text{L}'\text{L}'} + W_{\text{j}\gamma}^{\text{L}'\text{L}'} + W_{\text{jj}}^{\text{L}'\text{L}'}}_{\text{(unknown) background yields}} .$$

$$\begin{aligned} N_{\text{TITI}} = {} & W_{\gamma\gamma}^{\text{L}'\text{L}'} \epsilon_{I1}\epsilon_{T1}\epsilon_{I2}\epsilon_{T2} \\ & + W_{\gamma\text{j}}^{\text{L}'\text{L}'} \epsilon_{I1}\epsilon_{T1} f_{I2} f_{T2} \\ & + W_{\text{j}\gamma}^{\text{L}'\text{L}'} f_{I1} f_{T1} \epsilon_{I2}\epsilon_{T2} \\ & + W_{\text{jj}}^{\text{L}'\text{L}'} f'_{I1} f'_{T1} f'_{I2} f'_{T2} \xi_{Ijj} , \end{aligned}$$

- ϵ_{I1} and ϵ_{I2} are the efficiencies of the isolation criteria of one of the six analysis under study for the leading and subleading photons respectively. They are determined from the di-photon simulation;
- ϵ_{T1} and ϵ_{T2} are the Tight identification efficiencies for the leading and subleading photons respectively, also determined from the di-photon simulation;
- f_{I1} and f_{I2} are the isolation fake rates for the γj and jγ events, fitted directly on data;
- f_{T1} and f_{T2} are the Tight identification fake rates for the γj and jγ events, fitted directly on data;
- f'_{I1} and f'_{I2} are the isolation fake rates for the jj events, fitted directly on data;
- f'_{T1} and f'_{T2} are the Tight identification fake rates for the jj events, fitted directly on data or forced to be equal to f_{T1} and f_{T2} (see text below);
- ξ_{Ijj} is the isolation correlation factor between the jets in the jj events, fitted directly on data.

More Information on Signal Selection

Year	2015	2016 up to D3	2016 from D3	2017
HLT item	2g20_tight	2g20_tight	2g22_tight	2g20_tight_icalovloose
luminosity [fb^{-1}]	3.2 fb^{-1}	11.5	21.5	43.6 fb^{-1}

- Photon Isolation requirement : Fixed Cut Loose (topo $E_T^{cone20} < 0.065 * E_T$ & $p_T^{cone20} < 0.05 * p_T$)
- Identification: Tight ID

Signal Samples

Process	Generator	Mass [GeV]	Nevents ($\times 10^3$)		width
			mc16a	mc16d	
ggF	MadGraph	40-50-60-70-80-90-100-110-120-140-160-180	30	40	NWA
		60	30	40	5%
ggF	PowHeg+Pythia8	40-60-80-100-120	30	40	NWA
VBF	PowHeg+Pythia8	40-60-80-100-120	30	40	NWA
WH	Pythia8	40-60-80-100-120	30	40	NWA
ZH	Pythia8	40-60-80-100-120	30	40	NWA
$t\bar{t}$ H	Pythia8	40-60-80-100-120	30	40	NWA

Background Samples

Generator	$m_{\gamma\gamma}$ range [GeV]	Cross section [pb]	Filter efficiency	Nevents ($\times 10^6$)		Reconstruction
	–			mc16a	mc16d	
Sherpa LO	0 – 55	$1.4088 \cdot 10^{+2}$	$2.4335 \cdot 10^{-1}$	1.0	1.0	FS
	55 – 100	$1.4778 \cdot 10^{+2}$	$4.5670 \cdot 10^{-1}$	1.0	1.0	FS
	100 – 160	$3.9728 \cdot 10^{+1}$	$4.9730 \cdot 10^{-1}$	1.0	1.0	FS
Sherpa NLO	50 – 90	$1.3904 \cdot 10^{+2}$	1	91.7	130.0	AFII
	90 – 175	$5.1823 \cdot 10^{+1}$	1	114.7	162.7	AFII

Generator	m_{ee} range [GeV]	Filter	Cross section [pb]	Filter efficiency	Nevents ($\times 10^6$)	
	–				mc16a	mc16d
Powheg	–		$1.9012 \cdot 10^{+3}$	1	61.2	79.3
Sherpa	0 – 70	c-veto, b-veto	$1.9810 \cdot 10^{+3}$	0.82143	8.0	
	0 – 70	c-filter, b-veto	$1.9816 \cdot 10^{+3}$	0.11407	5.0	
	0 – 70	b-filter	$1.9821 \cdot 10^{+3}$	0.06576	8.0	
	70 – 140	c-veto, b-veto	$1.1063 \cdot 10^{+3}$	0.69432	6.0	
	70 – 140	c-filter, b-veto	$1.1045 \cdot 10^{+2}$	0.18697	2.0	
	70 – 140	b-filter	$1.1043 \cdot 10^{+2}$	0.11605	6.0	
	140 – 280	c-veto, b-veto	$4.0711 \cdot 10^{+1}$	0.61632	5.0	
	140 – 280	c-filter, b-veto	$4.0683 \cdot 10^{+1}$	0.23302	3.0	
	140 – 280	b-filter	$4.0671 \cdot 10^{+1}$	0.15319	12.4	
	280 – 500	c-veto, b-veto	$8.6711 \cdot 10^{+0}$	0.56328	2.0	
	280 – 500	c-filter, b-veto	$8.6597 \cdot 10^{+0}$	0.26640	2.0	
	280 – 500	b-filter	$8.6793 \cdot 10^{+0}$	0.17638	2.0	
	500 – 1000		$1.8096 \cdot 10^{+0}$	1	3.0	
	1000 – ∞		$1.4875 \cdot 10^{-1}$	1	1.0	