H→γγ result from ATLAS

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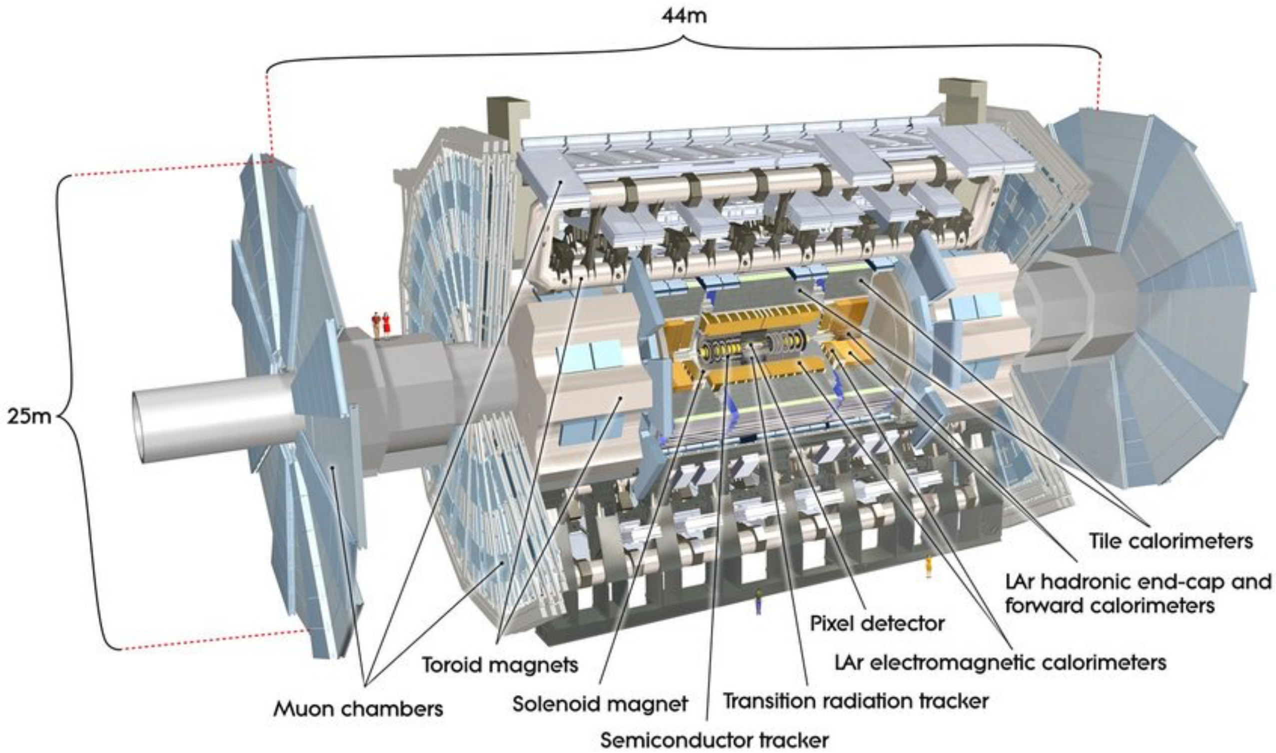
ATLAS EXPERIMENT

DESY

Introduction

ATLAS

I will try to compare some details to the latest CMS paper

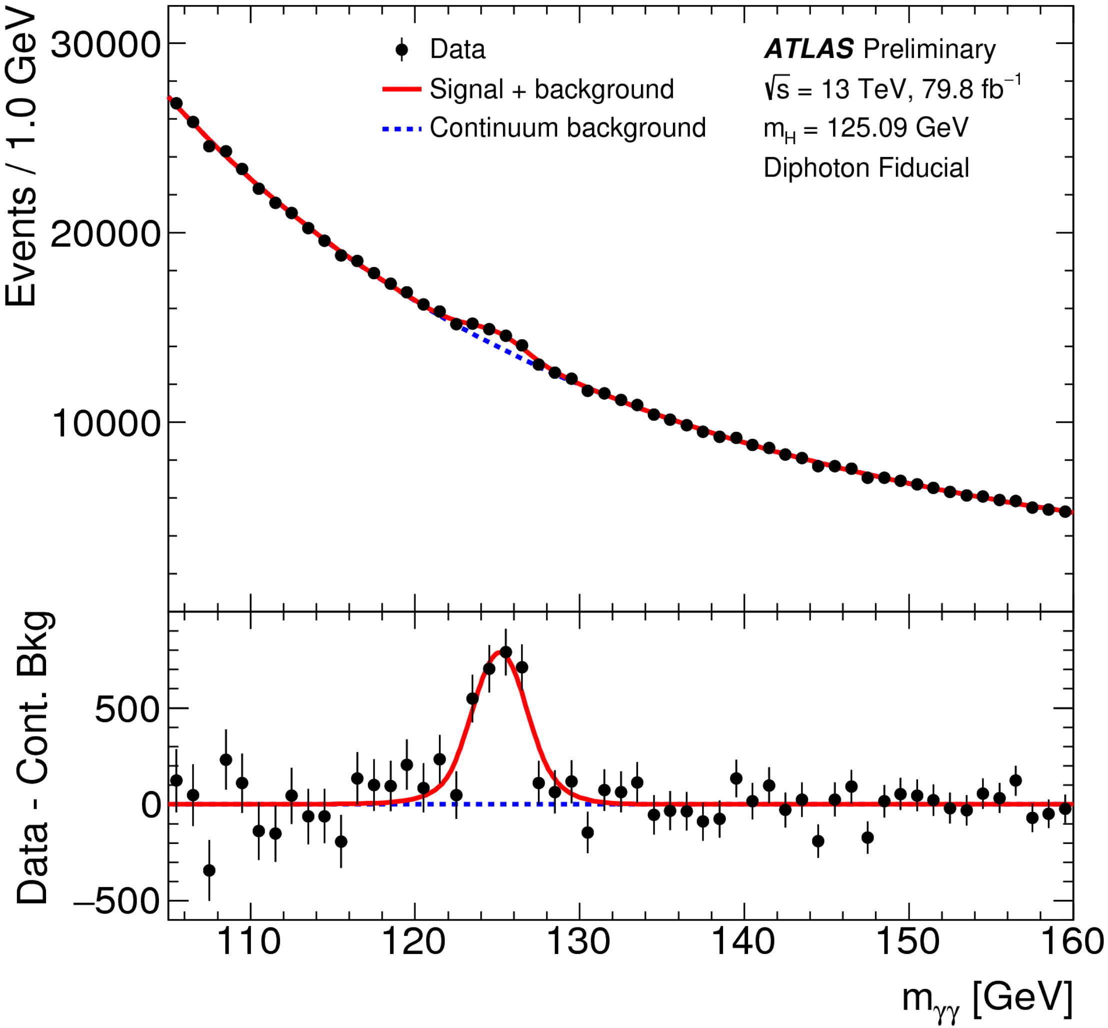


Introduction

$H \rightarrow \gamma\gamma$ summer result

ATLAS-CONF-2018-028,

79.8/fb of data, $\sqrt{s}$=13 TeV



So what did ATLAS publish?

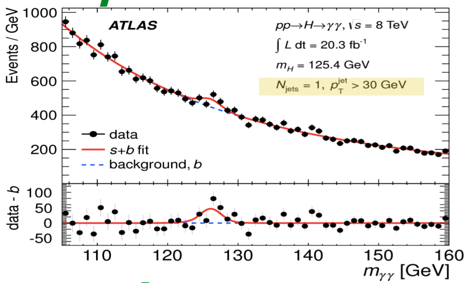
- Production-mode cross-sections: ggF, VBF, VH, top.
- Stage1 Simplified Template Cross-Sections (STXS) with strong merging. Fiducial cross-section measurement.
- Differential cross-sections: pT($\gamma\gamma$), |y($\gamma\gamma$)|, pT(j1), N(b-jets).

Reduced statistical uncertainties and additional differential measurements compared to arXiv:1802.04146 using 36.1/fb of data.

The 36/fb paper has comparable differential distributions to the latest CMS paper

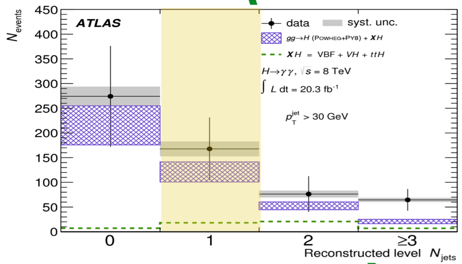
Analysis strategy

Detector



Event selection and categorisation
e.g. 1 jet

Signal yield (detector phase space)

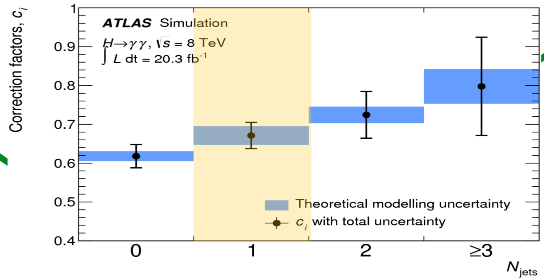


Signal + BG fits

$$\sigma_i = \frac{\boxed{\nu_i^{\mathrm{sig}}}}{\boxed{C_i} \cdot \mathcal{L}_{\mathrm{int}}}$$

Correction for detector effects (unfolding)

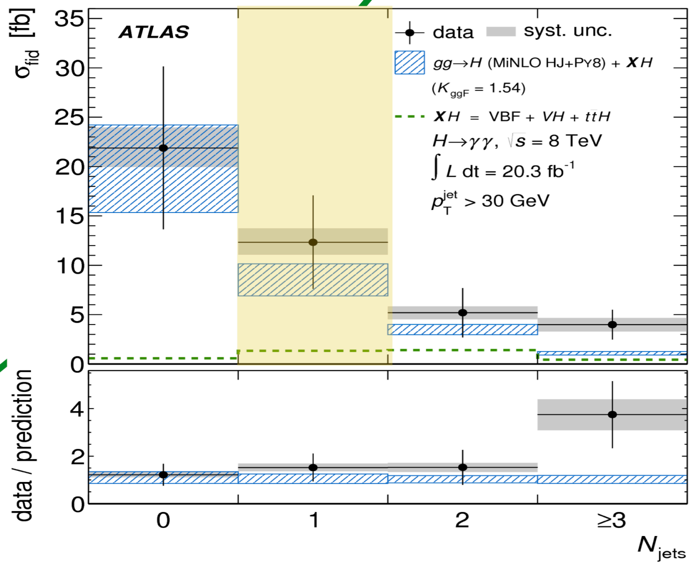
$$C_i = \frac{N^i_{reco}}{N^i_{true}}$$



Theory

Parton level (full phase space)

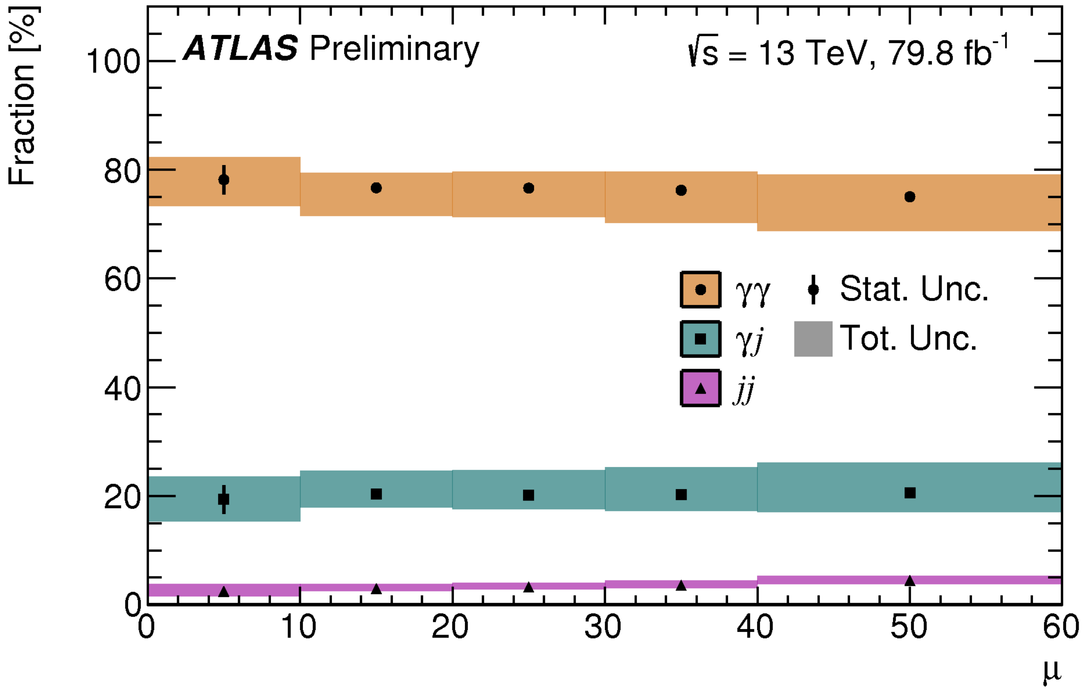
Particle level (fiducial phase space)



Purity

The purity of γγ events in the diphoton fiducial region

CMS uses a BDT for Photon ID, while ATLAS uses a cut-base method

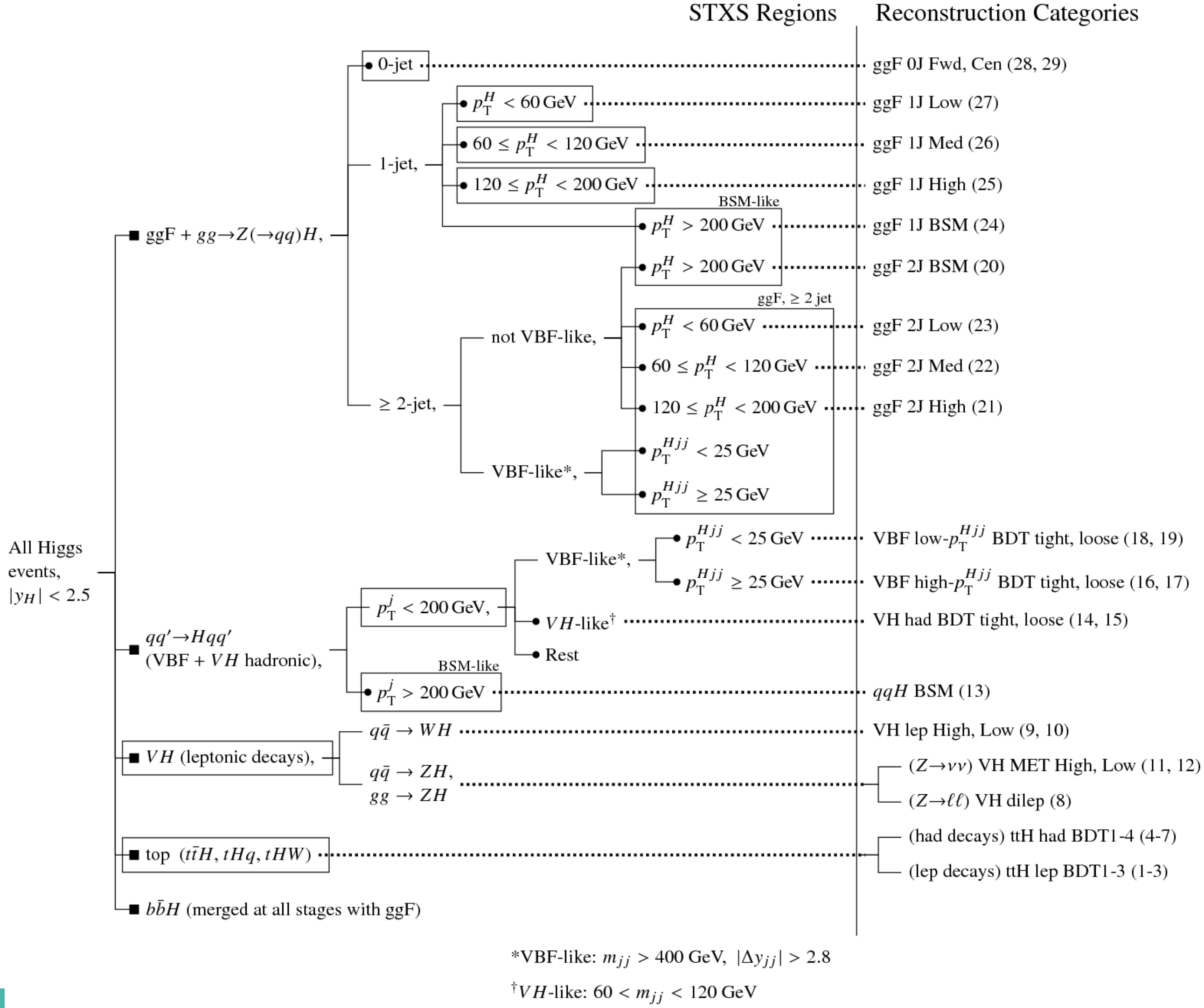


Event generators used

Process	Generator	Showering	PDF set	σ [pb] $\sqrt{s} = 13$ TeV	Order of σ calculation
ggF	Powheg NNLOPS	Pythia 8	PDF4LHC15	48.52	$\mathrm{N^3LO(QCD)+NLO(EW)}$
VBF	Powheg-Box	Pythia 8	PDF4LHC15	3.78	approximate-NNLO(QCD)+NLO(EW)
WH	Powheg-Box	Pythia 8	PDF4LHC15	1.37	NNLO(QCD)+NLO(EW)
$q\bar{q}' \to ZH$	Powheg-Box	Pythia 8	PDF4LHC15	0.76	NNLO(QCD)+NLO(EW)
$gg \to ZH$	Powheg-Box	Pythia 8	PDF4LHC15	0.12	NNLO(QCD)+NLO(EW)
$t\bar{t}H$	Powheg-Box	Pythia 8	PDF4LHC15	0.51	NNLO(QCD)+NLO(EW)
$b\bar{b}H$	Powheg-Box	Pythia 8	PDF4LHC15	0.49	NNLO(QCD)+NLO(EW)
tHq	MG5_aMC@NLO	Pythia 8	CT10	0.07	4FS(LO)
tHW	MG5_aMC@NLO	Herwig++	CT10	0.02	5FS(NLO)
$\gamma\gamma$	Sherpa	Sherpa	CT10		
$V\gamma\gamma$	Sherpa	Sherpa	CT10		
$t\bar{t}\gamma\gamma$	MG5_aMC@NLO	Pythia 8	PDF4LHC15		

STXS bins

- Stage-0 simplified template cross section regions are indicated with an adjacent square.
- stage-1 regions are denoted with a circle.
- Some stage-1 regions are omitted in cases where the data set lacks the sensitivity to resolve them



Kinematic regions in STXS stage-1

Two regions are indicated as BSM-like and are summed

Process	Measurement region	Stage-1 region
ggF + $gg \to Z(\to qq)H$	0-jet	0-jet
	1-jet, $p_T^H < 60\,GeV$	1-jet, $p_T^H < 60\,GeV$
	1-jet, $60 \leq p_T^H < 120\,GeV$	1-jet, $60 \leq p_T^H < 120\,GeV$
	1-jet, $120 \leq p_T^H < 200\,GeV$	1-jet, $120 \leq p_T^H < 200\,GeV$
	BSM-like* ($\geq$ 1-jet, $p_T^H > 200\,GeV$)	1-jet, $p_T^H > 200\,GeV$
		$\geq$ 2-jet, $p_T^H > 200\,GeV$
	$\geq$ 2 jet ($p_T^H < 200\,GeV$ or VBF-like)	$\geq$ 2-jet, $p_T^H < 60\,GeV$
		$\geq$ 2-jet, $60 \leq p_T^H < 120\,GeV$
		$\geq$ 2-jet, $120 \leq p_T^H < 200\,GeV$
		VBF-like, $p_T^{Hjj} < 25\,GeV$
		VBF-like, $p_T^{Hjj} \geq 25\,GeV$
$qq' \to Hqq'$ (VBF + VH hadronic)	$p_T^j < 200\,GeV$	$p_T^j < 200\,GeV$, VBF-like, $p_T^{Hjj} < 25\,GeV$
		$p_T^j < 200\,GeV$, VBF-like, $p_T^{Hjj} \geq 25\,GeV$
		$p_T^j < 200\,GeV$, VH-like
		$p_T^j < 200\,GeV$, Rest
	BSM-like* ($p_T^j > 200\,GeV$)	$p_T^j > 200\,GeV$
VH (leptonic decays)	VH leptonic	$q\bar{q} \to ZH$, $p_T^Z < 150$ GeV
		$q\bar{q} \to ZH$, 150 GeV $< p_T^Z <$ 250 GeV, 0-jet
		$q\bar{q} \to ZH$, 150 GeV $< p_T^Z <$ 250 GeV, $\geq$ 1-jet
		$q\bar{q} \to ZH$, $p_T^Z > 250$ GeV
		$q\bar{q} \to WH$, $p_T^W < 150$ GeV
		$q\bar{q} \to WH$, 150 GeV $< p_T^W <$ 250 GeV, 0-jet
		$q\bar{q} \to WH$, 150 GeV $< p_T^W <$ 250 GeV, $\geq$ 1-jet
		$q\bar{q} \to WH$, $p_T^W > 250$ GeV
		$gg \to ZH$, $p_T^Z < 150$ GeV
		$gg \to ZH$, $p_T^Z > 150$ GeV, 0-jet
		$gg \to ZH$, $p_T^Z > 150$ GeV, $\geq$ 1-jet
top-associated production	Top	$t\bar{t}H$
		tHW
		$tHqb$
$b\bar{b}H$	merged w/ ggF	$b\bar{b}H$

Reconstruction categories

Each event is assigned to the first category whose requirements are satisfied, using the descending order given in the table

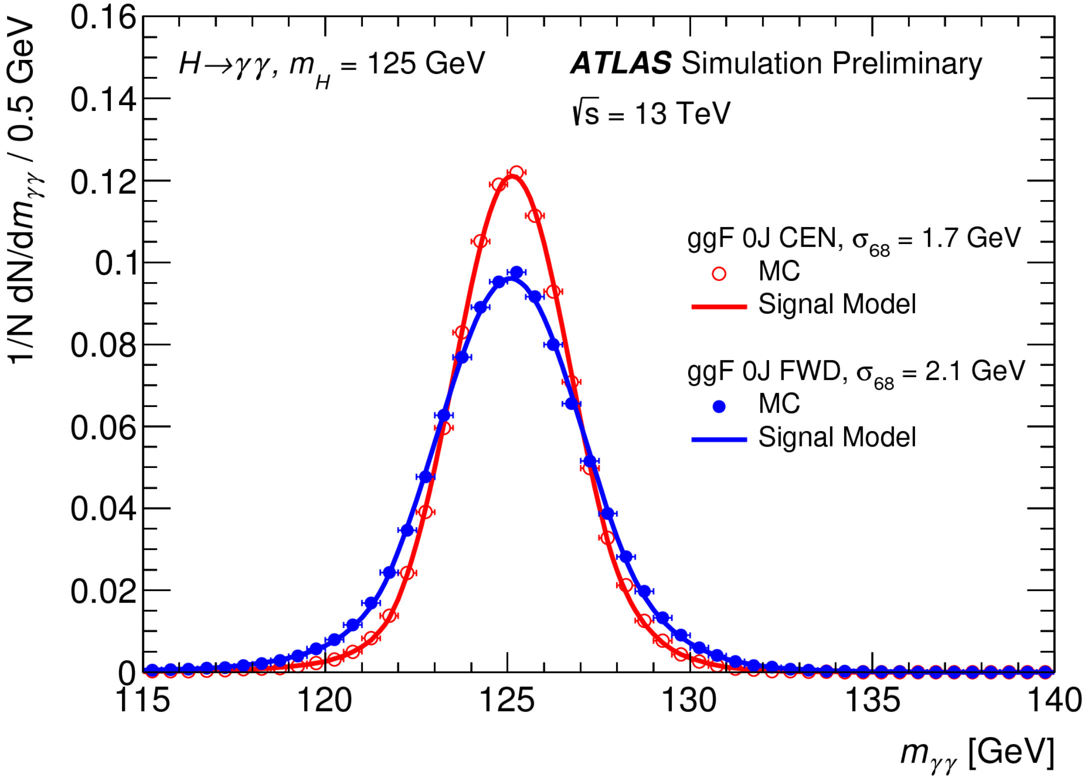
Horizontal lines based on the definitions of the stage-0 simplified template cross sections

Category label	Selection
ttH lep BDT1	$N_{\mathrm{lep}} \geq 1,\ N_{b-\mathrm{jet}} \geq 1,\ \mathrm{BDT}_{\mathrm{ttHlep}} > 0.987$
ttH lep BDT2	$N_{\mathrm{lep}} \geq 1,\ N_{b-\mathrm{jet}} \geq 1,\ 0.942 < \mathrm{BDT}_{\mathrm{ttHlep}} < 0.987$
ttH lep BDT3	$N_{\mathrm{lep}} \geq 1,\ N_{b-\mathrm{jet}} \geq 1,\ 0.705 < \mathrm{BDT}_{\mathrm{ttHlep}} < 0.942$
ttH had BDT1	$N_{\mathrm{lep}} = 0,\ N_{\mathrm{jets}} \geq 3,\ N_{b-\mathrm{jet}} \geq 1,\ \mathrm{BDT}_{\mathrm{ttHhad}} > 0.996$
ttH had BDT2	$N_{\mathrm{lep}} = 0,\ N_{\mathrm{jets}} \geq 3,\ N_{b-\mathrm{jet}} \geq 1,\ 0.991 < \mathrm{BDT}_{\mathrm{ttHhad}} < 0.996$
ttH had BDT3	$N_{\mathrm{lep}} = 0,\ N_{\mathrm{jets}} \geq 3,\ N_{b-\mathrm{jet}} \geq 1,\ 0.971 < \mathrm{BDT}_{\mathrm{ttHhad}} < 0.991$
ttH had BDT4	$N_{\mathrm{lep}} = 0,\ N_{\mathrm{jets}} \geq 3,\ N_{b-\mathrm{jet}} \geq 1,\ 0.911 < \mathrm{BDT}_{\mathrm{ttHhad}} < 0.971$
VH dilep	$N_{\mathrm{lep}} \geq 2,\ 70\,\mathrm{GeV} \leq m_{\ell\ell} \leq 110\,\mathrm{GeV}$
VH lep High	$N_{\mathrm{lep}} = 1,\ \lvert m_{e\gamma} - 89\,\mathrm{GeV}\rvert > 5\,\mathrm{GeV},\ p_{\mathrm{T}}^{\ell+E_{\mathrm{T}}^{\mathrm{miss}}} > 150\,\mathrm{GeV}$
VH lep Low	$N_{\mathrm{lep}} = 1,\ \lvert m_{e\gamma} - 89\,\mathrm{GeV}\rvert > 5\,\mathrm{GeV},\ p_{\mathrm{T}}^{\ell+E_{\mathrm{T}}^{\mathrm{miss}}} < 150\,\mathrm{GeV},\ E_{\mathrm{T}}^{\mathrm{miss}}$ significance > 1
VH MET High	$150\,\mathrm{GeV} < E_{\mathrm{T}}^{\mathrm{miss}} < 250\,\mathrm{GeV},\ E_{\mathrm{T}}^{\mathrm{miss}}$ significance > 9 or $E_{\mathrm{T}}^{\mathrm{miss}} > 250\,\mathrm{GeV}$
VH MET Low	$80\,\mathrm{GeV} < E_{\mathrm{T}}^{\mathrm{miss}} < 150\,\mathrm{GeV},\ E_{\mathrm{T}}^{\mathrm{miss}}$ significance > 8
qqH BSM	$N_{\mathrm{jets}} \geq 2,\ p_{\mathrm{T,j1}} > 200\,\mathrm{GeV}$
VH had BDT tight	$60\,\mathrm{GeV} < m_{\mathrm{jj}} < 120\,\mathrm{GeV},\ \mathrm{BDT}_{\mathrm{VH}} > 0.78$
VH had BDT loose	$60\,\mathrm{GeV} < m_{\mathrm{jj}} < 120\,\mathrm{GeV},\ 0.35 < \mathrm{BDT}_{\mathrm{VH}} < 0.78$
VBF high-p_{T}^{Hjj} BDT tight	$\lvert\Delta\eta_{jj}\rvert > 2,\ \lvert\eta_{\gamma\gamma} - 0.5(\eta_{\mathrm{j1}} + \eta_{\mathrm{j2}})\rvert < 5,\ p_{\mathrm{T}}^{Hjj} > 25\,\mathrm{GeV},\ \mathrm{BDT}_{\mathrm{VBF}}^{\mathrm{high}} > 0.47$
VBF high-p_{T}^{Hjj} BDT loose	$\lvert\Delta\eta_{jj}\rvert > 2,\ \lvert\eta_{\gamma\gamma} - 0.5(\eta_{\mathrm{j1}} + \eta_{\mathrm{j2}})\rvert < 5,\ p_{\mathrm{T}}^{Hjj} > 25\,\mathrm{GeV},\ -0.32 < \mathrm{BDT}_{\mathrm{VBF}}^{\mathrm{high}} < 0.47$
VBF low-p_{T}^{Hjj} BDT tight	$\lvert\Delta\eta_{jj}\rvert > 2,\ \lvert\eta_{\gamma\gamma} - 0.5(\eta_{\mathrm{j1}} + \eta_{\mathrm{j2}})\rvert < 5,\ p_{\mathrm{T}}^{Hjj} < 25\,\mathrm{GeV},\ \mathrm{BDT}_{\mathrm{VBF}}^{\mathrm{low}} > 0.87$
VBF low-p_{T}^{Hjj} BDT loose	$\lvert\Delta\eta_{jj}\rvert > 2,\ \lvert\eta_{\gamma\gamma} - 0.5(\eta_{\mathrm{j1}} + \eta_{\mathrm{j2}})\rvert < 5,\ p_{\mathrm{T}}^{Hjj} < 25\,\mathrm{GeV},\ 0.26 < \mathrm{BDT}_{\mathrm{VBF}}^{\mathrm{low}} < 0.87$
ggF 2J BSM	$N_{\mathrm{jets}} \geq 2,\ p_{\mathrm{T}}^{\gamma\gamma} \geq 200\,\mathrm{GeV}$
ggF 2J High	$N_{\mathrm{jets}} \geq 2,\ p_{\mathrm{T}}^{\gamma\gamma} \in [120, 200]$ GeV
ggF 2J Med	$N_{\mathrm{jets}} \geq 2,\ p_{\mathrm{T}}^{\gamma\gamma} \in [60, 120]$ GeV
ggF 2J Low	$N_{\mathrm{jets}} \geq 2,\ p_{\mathrm{T}}^{\gamma\gamma} \in [0, 60]$ GeV
ggF 1J BSM	$N_{\mathrm{jets}} = 1,\ p_{\mathrm{T}}^{\gamma\gamma} \geq 200\,\mathrm{GeV}$
ggF 1J High	$N_{\mathrm{jets}} = 1,\ p_{\mathrm{T}}^{\gamma\gamma} \in [120, 200]$ GeV
ggF 1J Med	$N_{\mathrm{jets}} = 1,\ p_{\mathrm{T}}^{\gamma\gamma} \in [60, 120]$ GeV
ggF 1J Low	$N_{\mathrm{jets}} = 1,\ p_{\mathrm{T}}^{\gamma\gamma} \in [0, 60]$ GeV
ggF 0J Fwd	$N_{\mathrm{jets}} = 0$, one photon with $\lvert\eta\rvert > 0.95$
ggF 0J Cen	$N_{\mathrm{jets}} = 0$, two photons with $\lvert\eta\rvert \leq 0.95$

Fitted signal parametrisation

Best and Worst mass resolutions

Using slightly different diphoton mass ranges;
ATLAS: 105-160 GeV
CMS: 100-180 GeV



Signal composition

Jet p_T cut;

ATLAS: 25/30GeV central/Forward

CMS: 30GeV everywhere

b-tagging working point;

ATLAS: 70%

- 380x light quark rejection

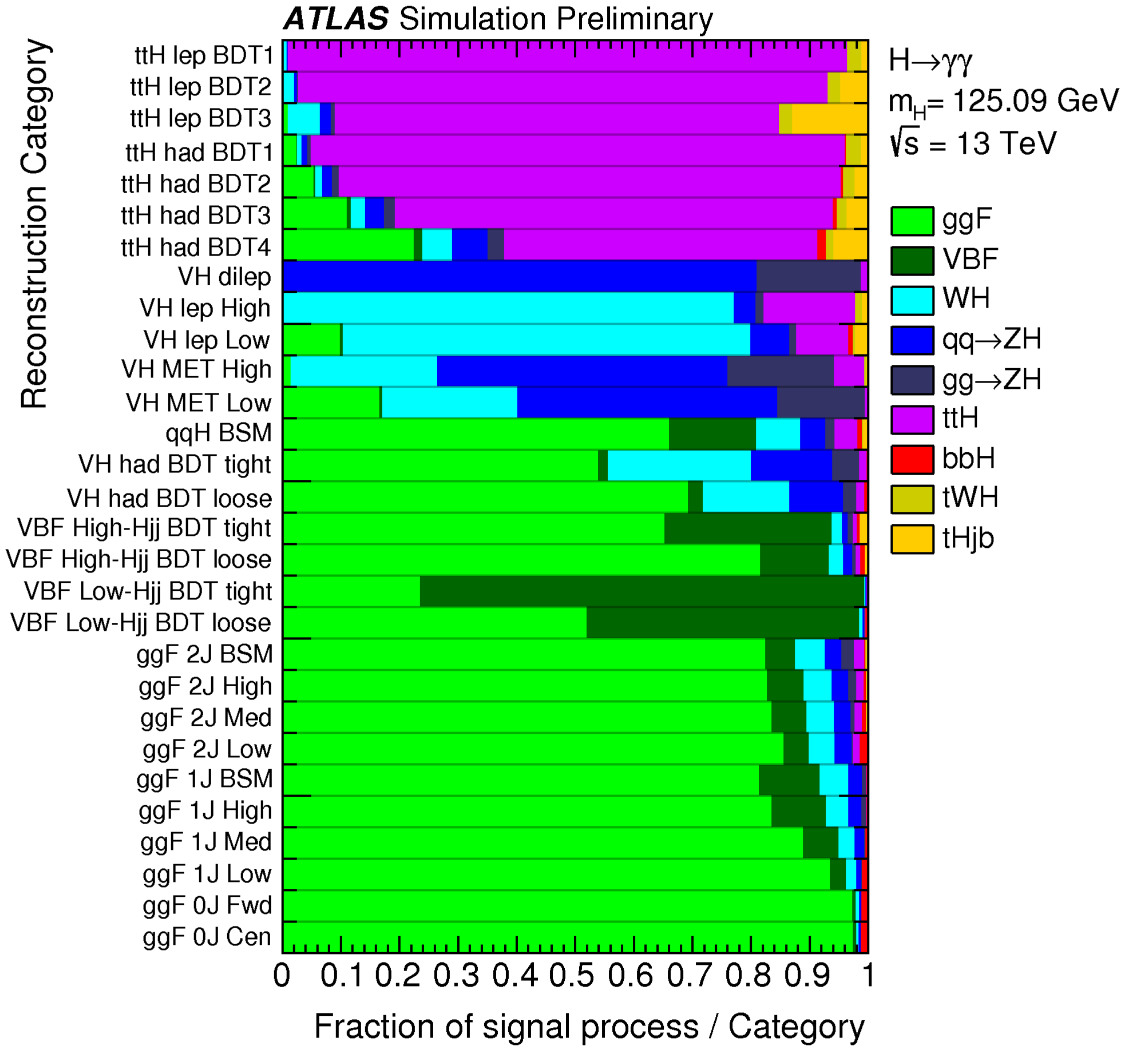
CMS: 55%

- 1000x light quark rejection

Leptons;

ATLAS: 15 GeV + loose isolation

CMS: 20 GeV



Particle level object definition

Objects	Definition
Photons	$\lvert\eta\rvert < 1.37$ or $1.52 < \lvert\eta\rvert < 2.37$, $\quad p_{\mathrm{T}}^{\mathrm{iso},0.2}/p_{\mathrm{T}}^{\gamma} < 0.05$
Jets	anti-k_t, $R = 0.4$, $\quad p_{\mathrm{T}} > 30\,\mathrm{GeV}$, $\quad \lvert y\rvert < 4.4$
– Central jets	$\lvert y\rvert < 2.5$
– b-jets	$\lvert y\rvert < 2.5$, $\Delta R(\mathrm{jet}, b\text{-hadron}) < 0.4$ for b-hadrons with $p_{\mathrm{T}} > 5$ GeV
Leptons, $\ell = e$ or μ	electrons: $p_{\mathrm{T}} > 10\,\mathrm{GeV}$, $\quad \lvert\eta\rvert < 2.47$ (excluding $1.37 < \lvert\eta\rvert < 1.52$)
	muons: $p_{\mathrm{T}} > 10\,\mathrm{GeV}$, $\lvert\eta\rvert < 2.7$

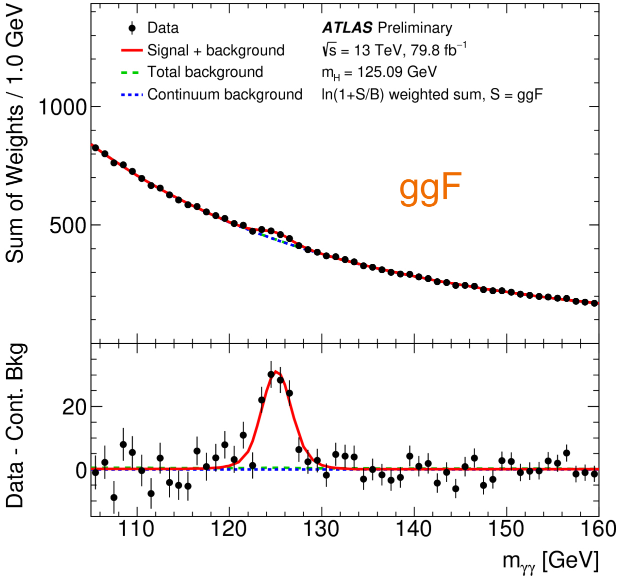
Fiducial region	Definition
Diphoton fiducial	$N_{\gamma} \geq 2$, $\quad p_{\mathrm{T}}^{\gamma_1} > 0.35 \cdot m_{\gamma\gamma}$, $\quad p_{\mathrm{T}}^{\gamma_2} > 0.25 \cdot m_{\gamma\gamma}$
$N_{b\text{-jets}}$ measurement	Diphoton fiducial, $N_{\mathrm{jets}}^{\mathrm{Cen}} \geq 1$, $N_{\mathrm{leptons}} = 0$

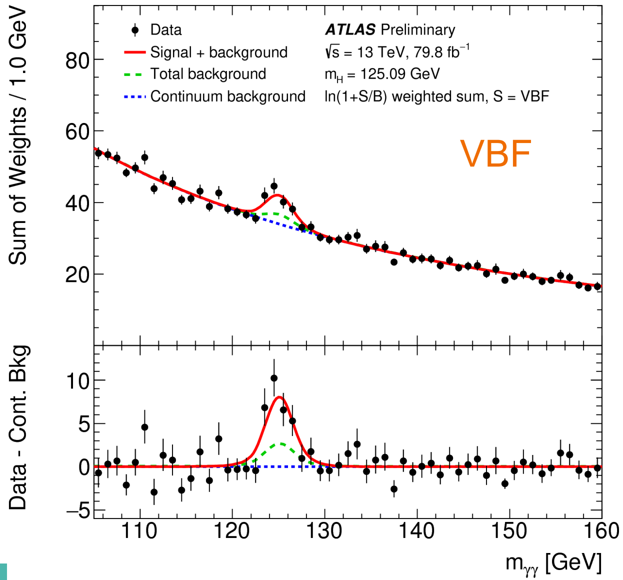
Diphoton invariant mass spectrum

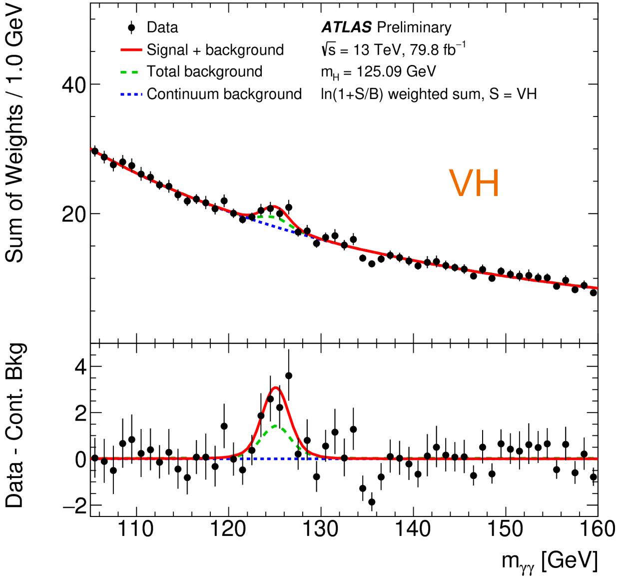
Signal Modelling;

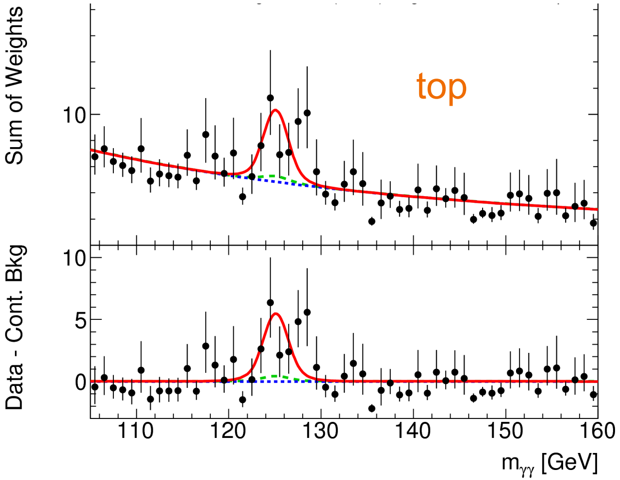
ATLAS: DSCB+Gaussian

CMS: Sum of 5 Gaussians





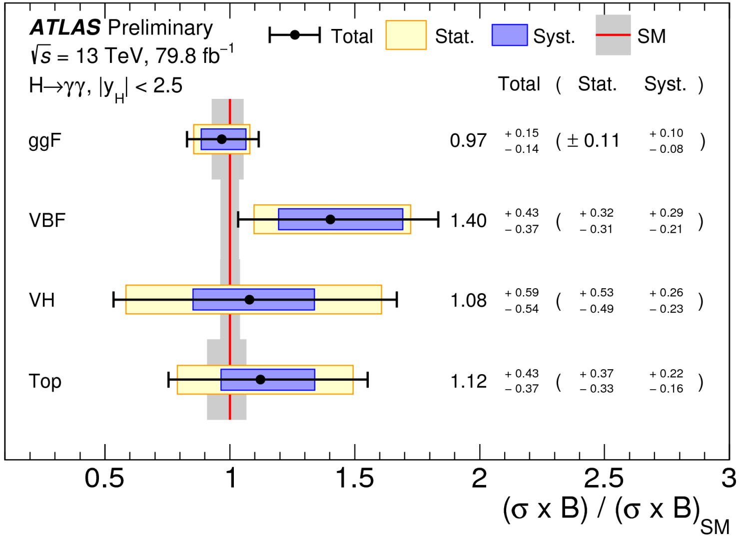




Diphoton invariant mass spectrum

Background model from Sherpa with spurious signal tests

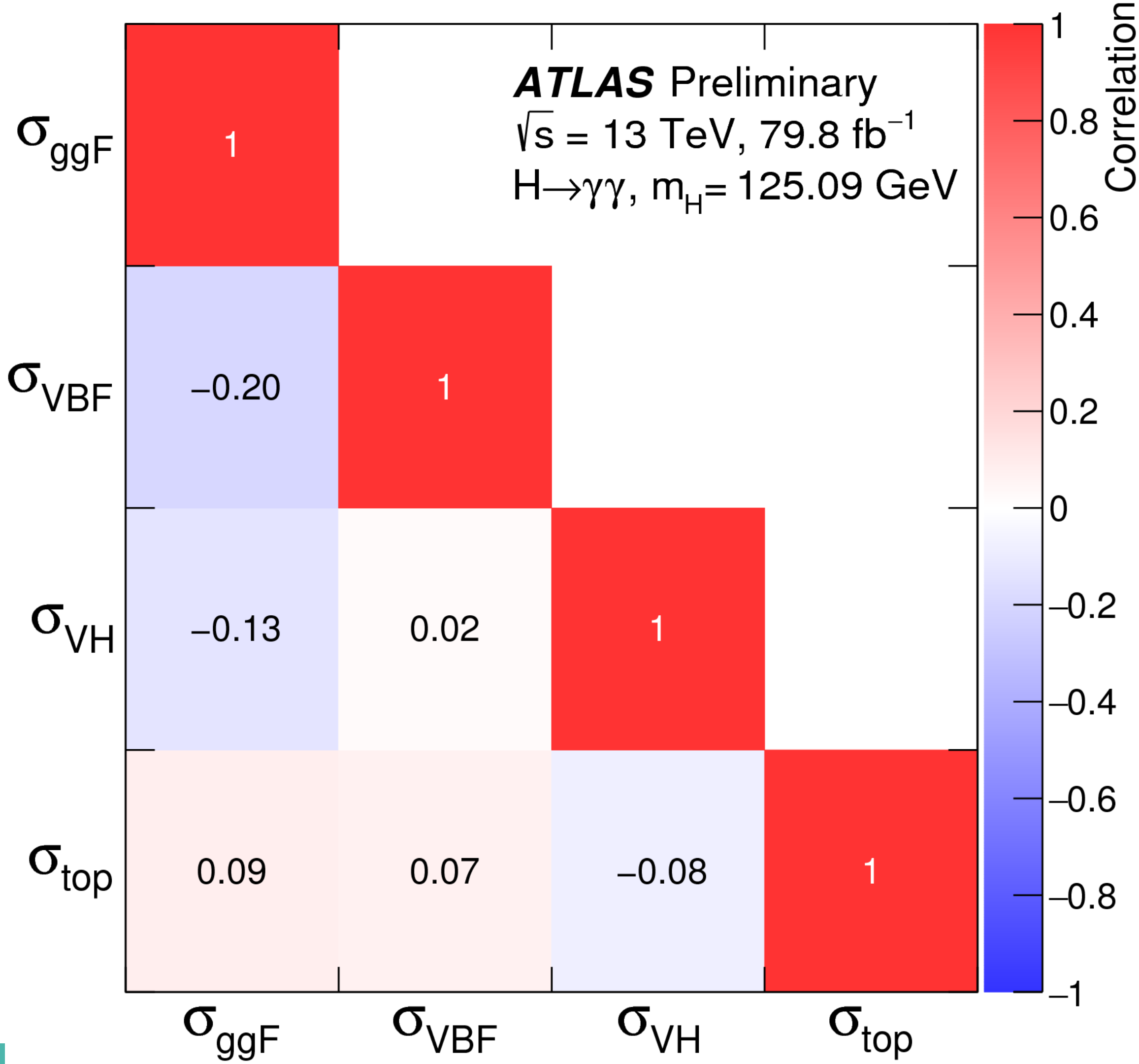
CMS includes background model directly in Likelihood model



Process ($\|y_H\| < 2.5$)	Result [fb]	Uncertainty [fb] Total	(Stat.	Exp.	Theo.)	SM prediction [fb]
ggF	98	$^{+15}_{-14}$	± 11	$^{+9}_{-8}$	$^{+4}_{-3}$	$102\ ^{+5}_{-7}$
VBF	11.2	$^{+3.4}_{-3.0}$	$^{+2.6}_{-2.4}$	$^{+1.3}_{-1.2}$	$^{+1.9}_{-1.1}$	8.0 ± 0.2
VH	4.9	$^{+2.7}_{-2.5}$	$^{+2.4}_{-2.2}$	$^{+1.0}_{-0.9}$	$^{+0.6}_{-0.5}$	4.5 ± 0.2
Top	1.5	$^{+0.6}_{-0.5}$	$^{+0.5}_{-0.4}$	± 0.2	$^{+0.2}_{-0.1}$	1.3 ± 0.1

Production mode correlations

Small correlations between the different production modes

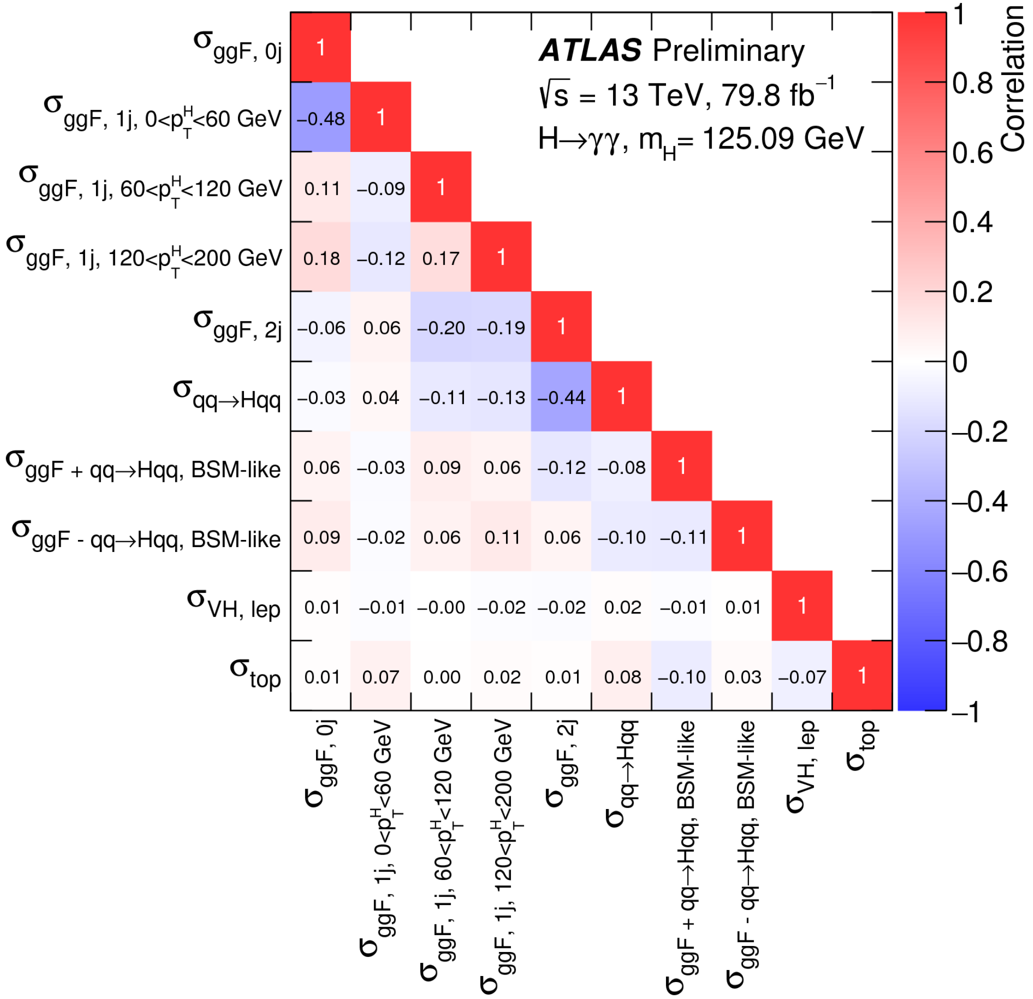


STXS cross-sections

Measurement region ($\lvert y_H \rvert < 2.5$)	Result [fb]	Uncertainty [fb] Total	Stat.	Exp.	Theo.	SM prediction [fb]
ggF, 0 jet	58	$^{+15}_{-14}$	± 11	$^{+10}_{-8}$	$^{+2}_{-1}$	63 ± 5
ggF, 1 jet, $p_T^H < 60$ GeV	18	$^{+10}_{-9}$	± 8	$^{+6}_{-5}$	$^{+1}_{-1}$	15 ± 2
ggF, 1 jet, $60 \leq p_T^H < 120$ GeV	9	± 5	± 4	$^{+3}_{-2}$	$^{+1}_{-0}$	10 ± 2
ggF, 1 jet, $120 \leq p_T^H < 200$ GeV	2.6	$^{+1.5}_{-1.3}$	± 1.2	$^{+0.8}_{-0.6}$	$^{+0.3}_{-0.1}$	1.7 ± 0.3
ggF, ≥ 2 jet	7	± 6	± 5	$^{+3}_{-2}$	± 2	11 ± 2
$qq \rightarrow Hqq$, $p_T^j < 200$ GeV	15	$^{+5}_{-4}$	± 4	± 2	± 2	10 ± 0.5
ggF + $qq \rightarrow Hqq$, BSM-like	1.4	± 0.9	± 0.8	± 0.4	± 0.2	1.8 ± 0.4
VH, leptonic	2.0	$^{+1.1}_{-1.0}$	$^{+1.0}_{-0.9}$	± 0.4	± 0.1	1.4 ± 0.1
Top	1.5	$^{+0.6}_{-0.5}$	± 0.5	± 0.2	± 0.2	1.3 ± 0.1

STXS correlations

Mostly small correlations



Breakdown of the uncertainties

Systematic uncertainties including PER, Photon ID and spurious signal

CMS does not include additional background model uncertainties beyond terms in Likelihood

Statistical component dominates in differential regions

Experimental uncertainties on signal and background modelling

Experimental uncertainties on the correction factor

Theoretical uncertainties

Experimental uncertainties on the correction factor

Source	Uncertainty (%)
Fit (stat.)	10
Fit (syst.)	8.3
Photon energy scale & resolution	4.0
Background modeling (spurious signal)	7.3
Correction factor	5.2
Photon isolation efficiency	4.6
Pileup	1.9
Photon ID efficiency	1.3
Trigger efficiency	0.7
Dalitz Decays	0.4
Theoretical modeling	$^{+0.3}_{-0.4}$
Diphoton vertex selection	0.1
Photon energy scale & resolution	0.1
Luminosity	2.0
Total	14

Intermezzo: Unfolding Idea

Modelling detector response versus unfolding

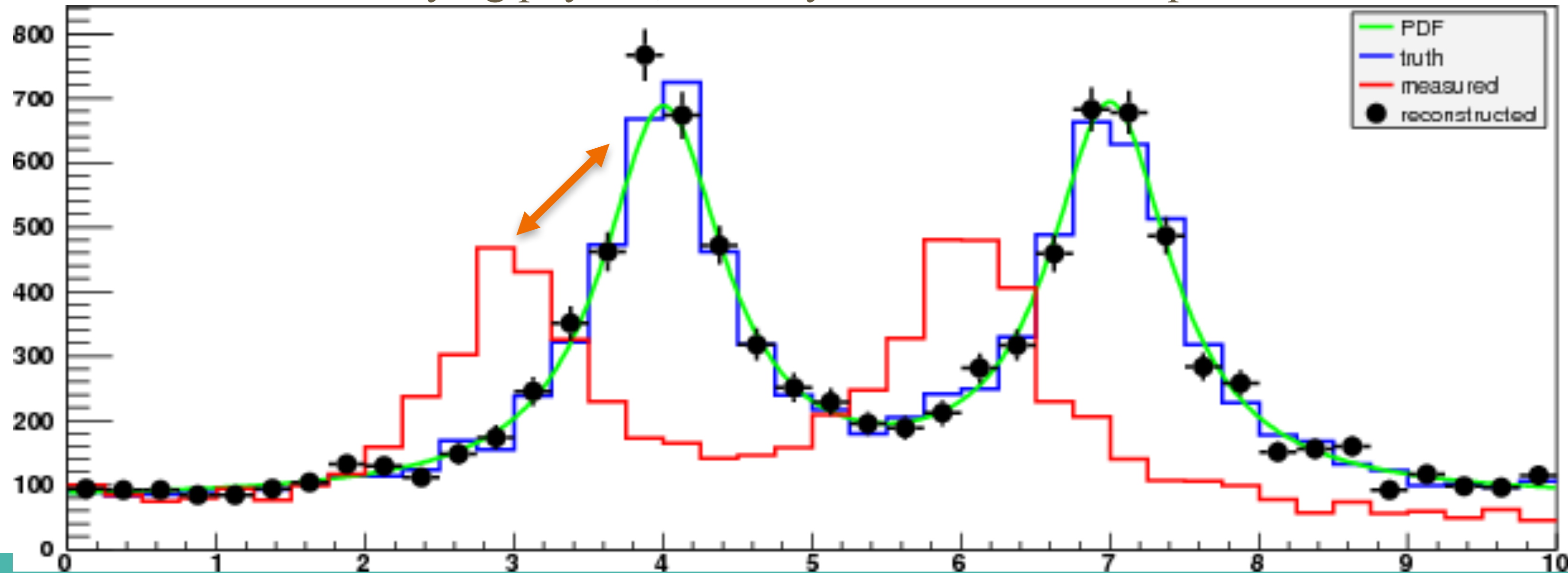
Theory

Model detector response

Unfold

Data

You want to know the underlying physics, not only if it matches with predictions



Intermezzo: Unfolding mathematically

The forward model can be described by a smoothing matrix

- Limited detector resolution throws information away

In reverse mode (unfolding) matrix has to recreate sharp points

- Regularisation used to enforce a degree of smoothness on the reconstructed distribution

$$\begin{array}{ccc} & \text{Model detector response} & \\ \text{Theory} & \begin{array}{c}\longrightarrow \\ \longleftarrow\end{array} & \text{Data} \\ & \text{Unfold} & \end{array}$$

Comparison with Maximum Likelihood Estimate

MLE is unbiased, but has large variance

Unfolding deliberately adds a small bias to produce a solution with a much smaller variance

Note: Normally a pseudo inverse of the matrix is used based on a maximum Likelihood fit

Intermezzo: Choosing Unfolding Method

For each bin

$$b_i < \sigma_{stat,i}$$

$$\frac{|b_i|}{\sigma_{i,stat}} \qquad \frac{\sigma_{i,stat}^{unf.}}{\sigma_{i,stat}^{data}} < 1$$

- Biases (b_i) should be small compared to statistical uncertainties
- Unfolding should not greatly alter the statistical uncertainty

For each distribution there are different figures of merit

- Total statistical uncertainty $\sqrt{\Sigma_i^{Nbin} \sigma_{stat,i}^2}$
- Sum of biases (b_i) $\Sigma_i^{Nbin} b_i$
- Absolute sum of biases (b_i) $\Sigma_i^{Nbin} |b_i|$
- Total stat. error, including correlations $\sqrt{Cov_{i,j}(stat)}$
- Bias divided by total stat error $\frac{\Sigma_i^{Nbin} |b_i|}{\sqrt{Cov_{i,j}(stat)}}$
- Ratio of total stat error of the method w.r.t. bin-by-bin $\left| \frac{\sqrt{Cov_{i,j}^{stat}(method)}}{\sqrt{Cov_{i,j}^{stat}(bbb)}} \right|$
- Shape via $\chi 2$ $\chi^2 = (\vec{\mu}_{SM} - \vec{\mu}_{bias})\, Cov_{Stat+b}^{-1}\, (\vec{\mu}_{SM} - \vec{\mu}_{bias})^T$

Unfolding

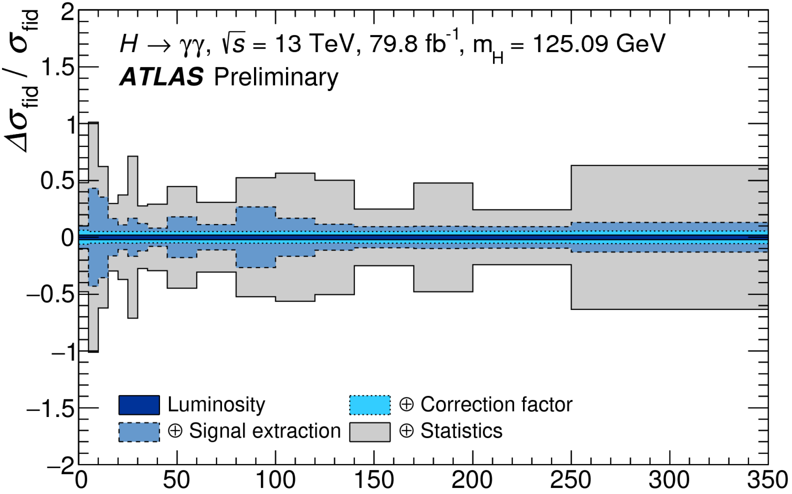
Bin-by-bin method $\sigma = \frac{N_{sig}}{c\mathcal{L}_{\text{int}}}$, c is the correction factor

- Derived from simulations
- Inclusive diphoton fiducial region: c = 0.73 ± 0.04
- Differential cross-sections: c ~ 0.7 − 0.8 (except a couple of bins)
- Largest impact: photon identification efficiencies

Reasons for choosing bin-by-bin

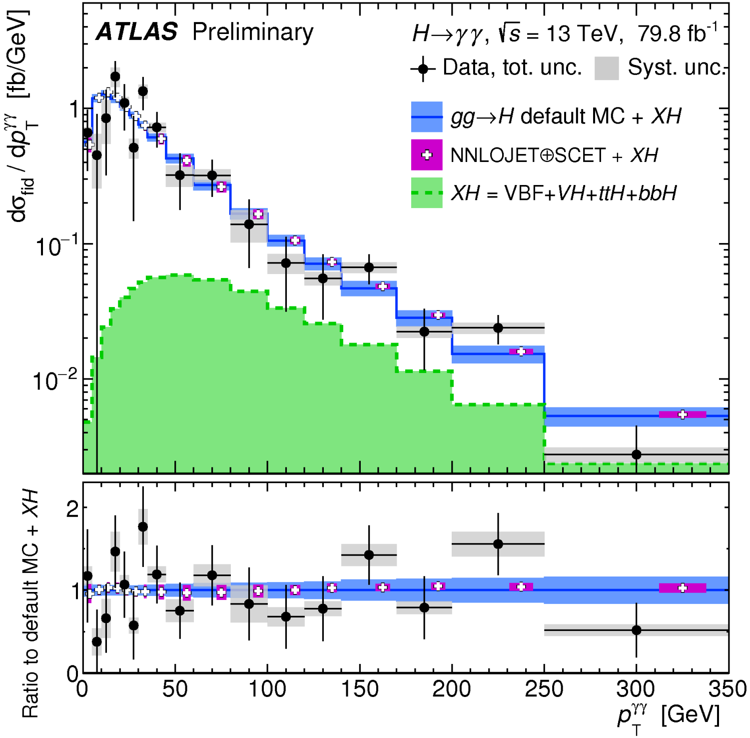
- Introduces minimal bias
- Performance acceptable given statistical limits of this measurement

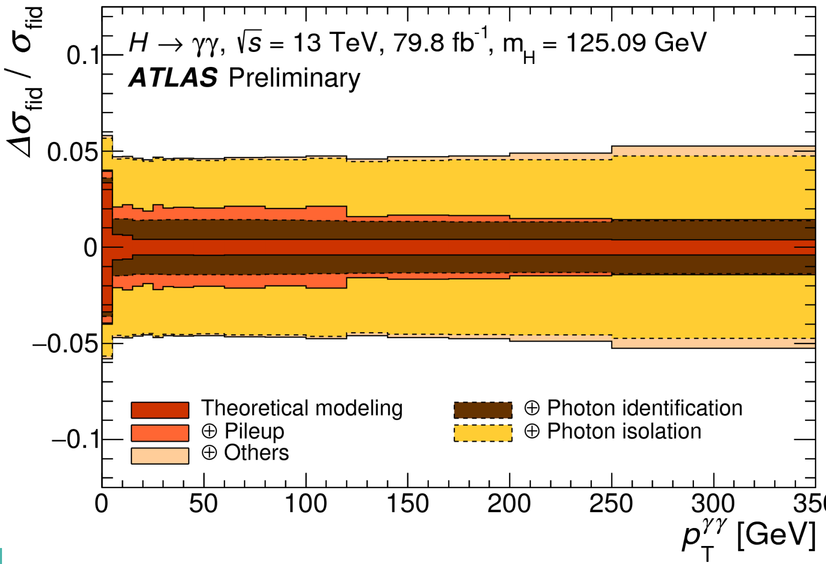
CMS: Unfolding matrices directly in the Likelihood with no regularisation (wide enough bins)



$p_T^{\gamma\gamma}$

$P(\chi^2) = 31\%$

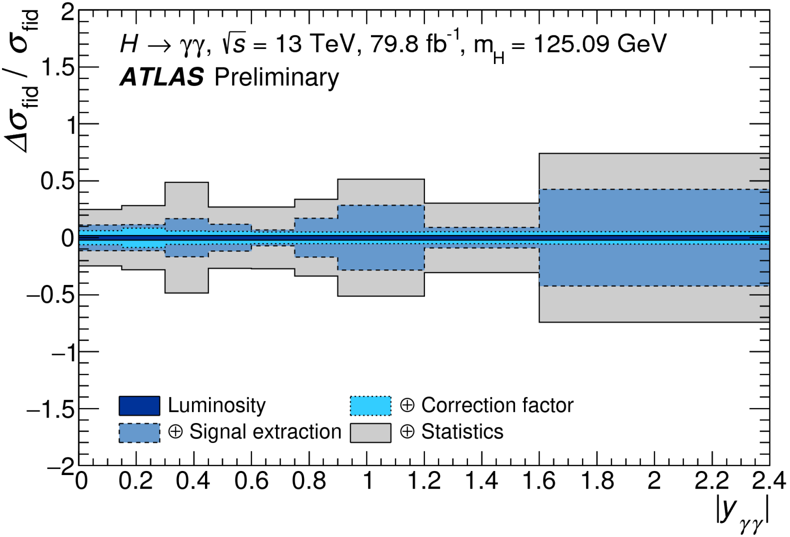




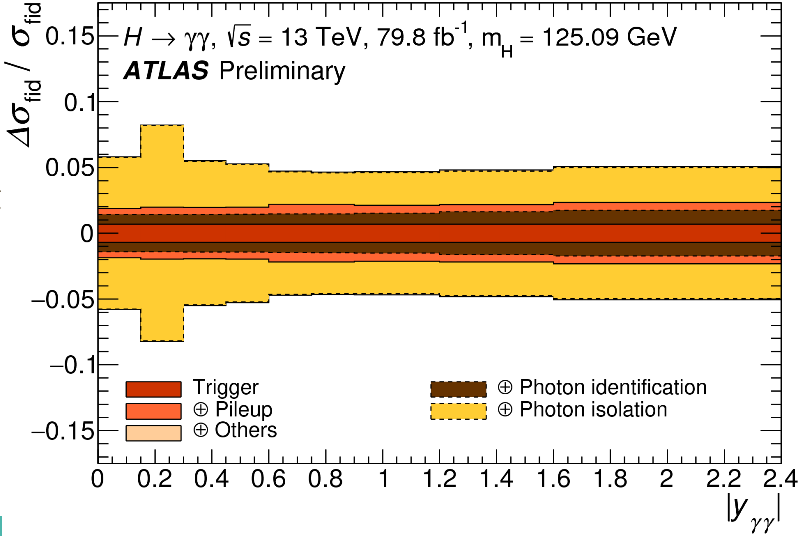
Default MC: Powheg NNLOPS, normalization: N3LO(QCD) and NLO(EW)

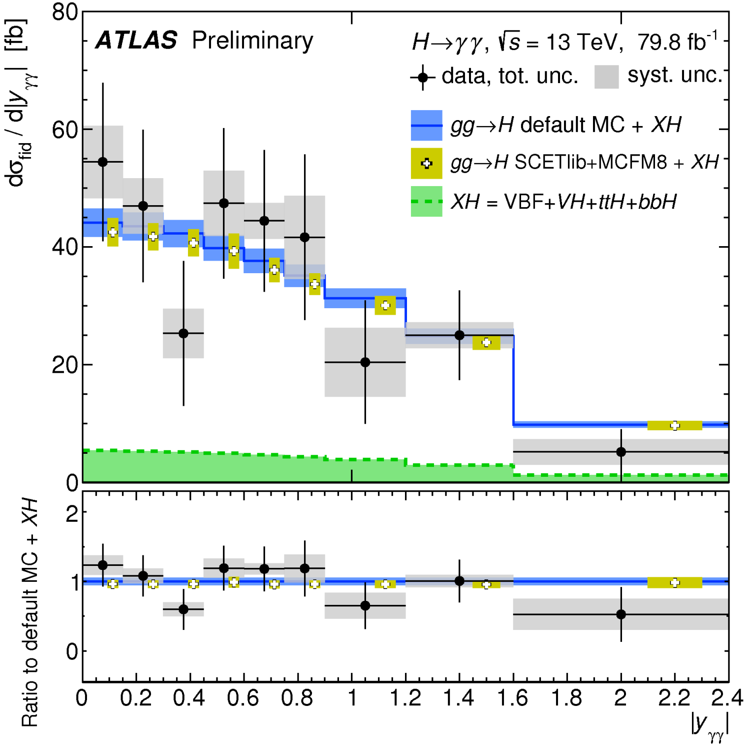
Additionally: NNLOjet+SCETL NNLO+N3LL resummation

$|y_{\gamma\gamma}|$



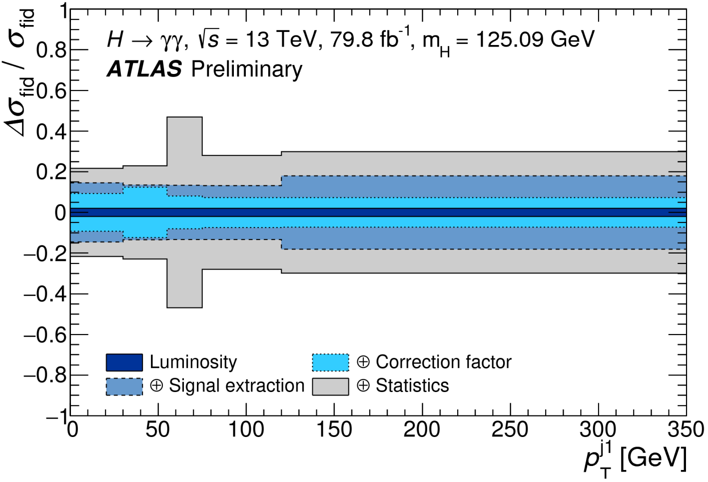
$P(\chi^2) = 56\%$





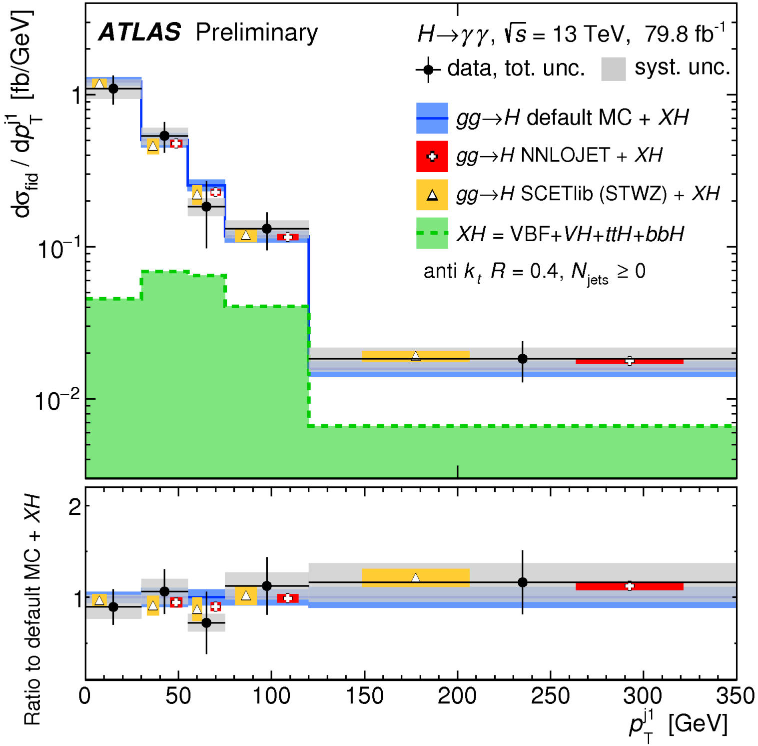
Default MC: Powheg NNLOPS, normalization: N3LO(QCD) and NLO(EW)

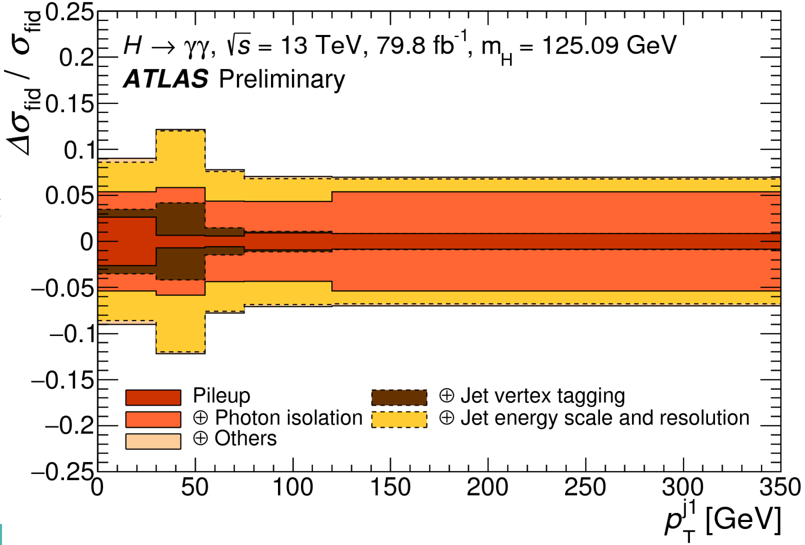
Additionally compared to SCETlib+MCFM8



p_T^{j1}

$$P(\chi^2) = 88\%$$





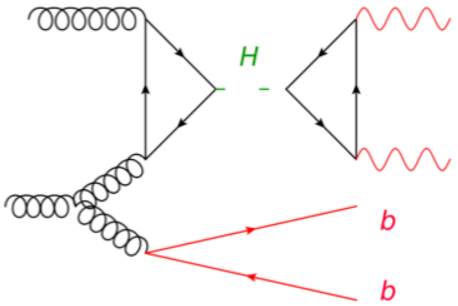
Default MC: Powheg NNLOPS, normalization: N3LO(QCD) and NLO(EW)

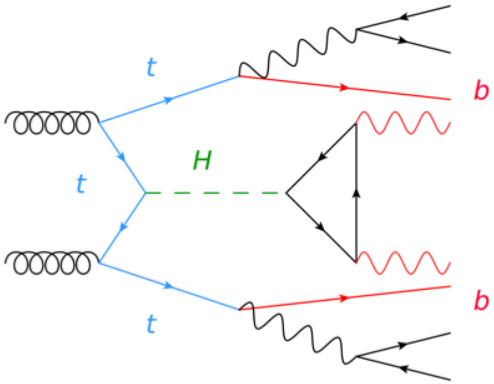
Additionally compared to NNLOJET and SCETlib(STWZ)

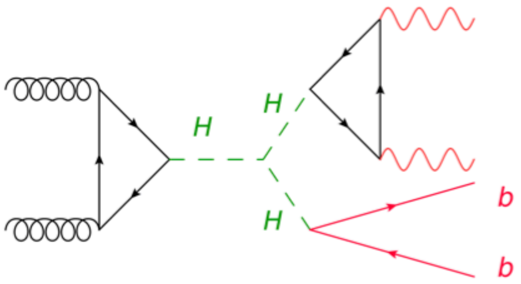
Higgs with Heavy flavour

Measurement of the number of b-jets

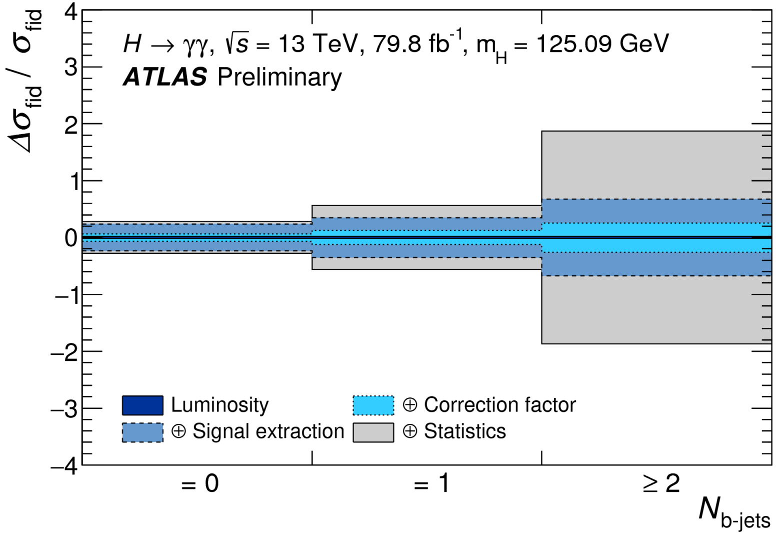
- Higgs with heavy flavour poorly constrained theoretically for ttH and hh
- Veto on electrons and muons to reduce ttH contribution
- H+HF best probed for $N_{b\text{-jet}}$=1
- Associated HF production: QCD splitting



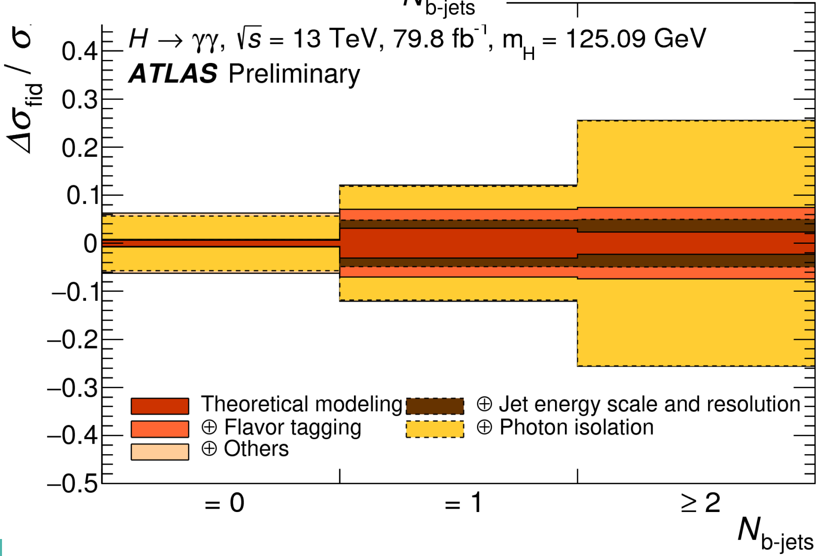


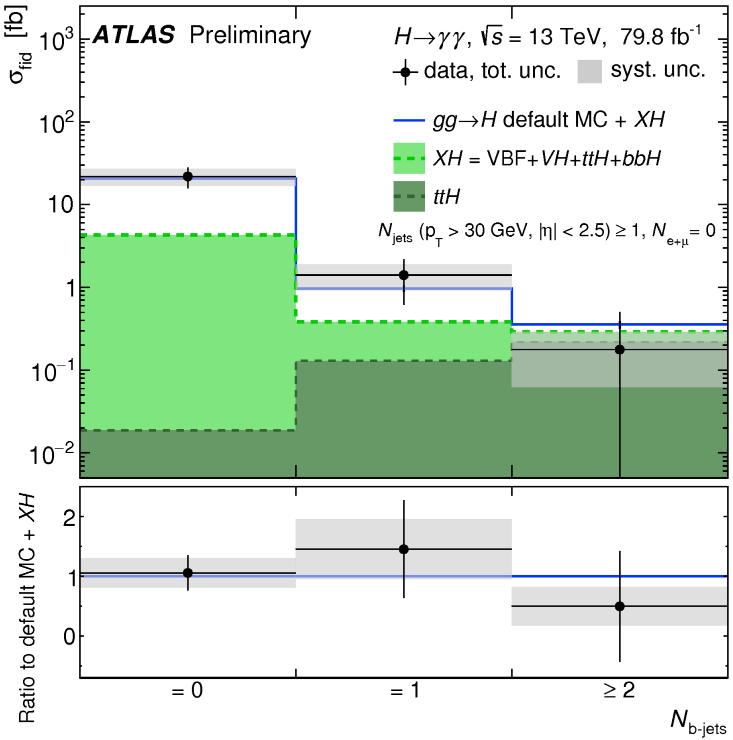


$N_{\text{b-jet}}$



$P(\chi^2) = 84\%$





Default MC: Powheg NNLOPS, normalization: N3LO(QCD) and NLO(EW)

Conclusions

Statistical improvement from 36/fb to 80/fb: 16% → 10%

- Will improve further with full Run 2 dataset

Excellent agreement with the SM in all regions

- Will try to reduce systematics further for full Run 2 dataset

Bin-by-bin unfolding

- Will need to update unfolding method for full Run 2 dataset

Start made on Higgs with heavy flavour

- Will created fiducial region for full Run 2 dataset using continuous b-tagging method

Back-up

Signal efficiencies

Category	N_{H}	Efficiency [%]								
		ggF	VBF	WH	$q\bar{q}'\to ZH$	$gg\to ZH$	$t\bar{t}H$	$b\bar{b}H$	tHq	tHW
ggF 0J Cen	700	8.5	1.2	1.5	2.0	0.8	nil	10.2	nil	0.1
ggF 0J Fwd	1200	14.9	2.3	3.2	4.0	1.3	nil	16.8	0.1	0.1
ggF 1J Low	620	7.1	5.5	4.9	4.6	1.2	0.1	7.5	0.5	0.2
ggF 1J Med	330	3.4	6.1	4.1	4.1	2.6	0.1	1.9	0.7	0.3
ggF 1J High	69	0.7	1.9	1.1	1.1	2.3	0.1	0.2	0.3	0.1
ggF 1J BSM	18	0.2	0.6	0.4	0.3	0.5	nil	0.1	0.1	0.1
ggF 2J Low	180	1.8	2.6	3.5	4.0	1.9	1.9	2.3	4.2	1.9
ggF 2J Med	150	1.5	3.0	3.2	3.3	4.3	1.9	1.0	4.9	2.1
ggF 2J High	64	0.6	1.3	1.3	1.3	3.8	0.8	0.2	2.0	1.2
ggF 2J BSM	16	0.1	0.3	0.3	0.3	1.5	0.3	nil	0.5	0.6
VBF low-p_{T}^{Hjj} BDT loose	41	0.2	4.2	0.1	0.1	0.1	nil	0.1	0.4	nil
VBF low-p_{T}^{Hjj} BDT tight	29	nil	4.0	nil	nil	0.1	nil	nil	0.3	nil
VBF high-p_{T}^{Hjj} BDT loose	38	0.3	1.4	0.4	0.4	1.0	0.2	0.3	1.8	0.4
VBF high-p_{T}^{Hjj} BDT tight	46	0.3	3.4	0.3	0.3	1.3	0.3	0.2	4.3	0.4
VH had BDT loose	34	0.3	0.3	2.3	2.5	3.6	0.4	0.2	0.7	0.7
VH had BDT tight	26	0.2	0.1	2.8	2.8	5.2	0.3	0.1	0.3	0.7
qqH BSM	42	0.3	1.8	1.3	1.3	2.7	1.4	0.3	2.8	3.2
VH MET Low	1.4	nil	nil	0.2	0.5	1.0	nil	nil	nil	nil
VH MET High	2.7	nil	nil	0.3	1.1	2.3	0.1	nil	0.1	0.4
VH lep Low	12	nil	nil	4.0	0.7	0.7	1.1	0.1	2.3	2.0
VH lep High	3.1	nil	nil	1.1	0.1	0.2	0.5	nil	0.3	1.3
VH dilep	1.8	nil	nil	nil	1.2	1.5	nil	nil	nil	nil
ttH had BDT4	6.6	nil	nil	0.2	0.4	0.9	3.7	0.1	3.5	3.2
ttH had BDT3	7.2	nil	nil	0.1	0.2	0.7	5.8	0.1	2.5	4.7
ttH had BDT2	4.5	nil	nil	nil	0.1	0.3	4.3	nil	1.0	3.7
ttH had BDT1	5.2	nil	nil	nil	nil	0.2	5.3	nil	0.7	5.5
ttH lep BDT3	1.2	nil	nil	nil	nil	nil	1.0	nil	1.5	1.1
ttH lep BDT2	2.8	nil	nil	nil	nil	nil	2.8	nil	1.2	2.5
ttH lep BDT1	5.3	nil	nil	nil	nil	nil	5.6	nil	0.6	5.3
Total efficiency [%]		40.4	39.9	36.6	36.7	42.0	38.0	41.8	37.7	41.8

Higgs composition

Category	N_{H}	Composition [%]								
		ggF	VBF	WH	$q\bar{q}'\to ZH$	$gg\to ZH$	$t\bar{t}H$	$b\bar{b}H$	tHq	tHW
ggF 0J Cen	700	97.3	0.5	0.5	0.3	nil	nil	1.4	nil	nil
ggF 0J Fwd	1200	97.2	0.6	0.5	0.4	nil	nil	1.3	nil	nil
ggF 1J Low	620	93.4	2.7	1.7	0.9	nil	nil	1.2	nil	nil
ggF 1J Med	330	88.8	6.0	2.8	1.6	0.2	nil	0.6	nil	nil
ggF 1J High	69	83.4	9.2	3.9	2.2	0.8	0.1	0.3	0.1	nil
ggF 1J BSM	18	81.3	10.3	4.9	2.3	0.7	0.1	0.3	0.1	nil
ggF 2J Low	180	85.4	4.4	4.4	2.9	0.2	1.1	1.3	0.3	nil
ggF 2J Med	150	83.4	6.0	4.7	2.8	0.6	1.3	0.7	0.4	nil
ggF 2J High	64	82.5	6.3	4.8	2.8	1.4	1.3	0.4	0.4	0.1
ggF 2J BSM	16	82.3	5.1	5.1	2.8	2.1	1.8	0.2	0.4	0.1
VBF low-p_{T}^{Hjj} BDT loose	41	51.8	46.5	0.6	0.4	0.1	0.1	0.4	0.2	nil
VBF low-p_{T}^{Hjj} BDT tight	29	23.4	75.8	0.2	0.1	0.1	nil	0.1	0.3	nil
VBF high-p_{T}^{Hjj} BDT loose	38	81.5	11.7	2.4	1.5	0.7	0.7	0.8	0.7	nil
VBF high-p_{T}^{Hjj} BDT tight	46	65.1	28.6	1.7	1.0	0.8	0.7	0.5	1.6	nil
VH had BDT loose	34	69.2	2.5	14.8	9.2	2.3	1.3	0.4	0.3	0.1
VH had BDT tight	26	53.8	1.7	24.3	13.9	4.5	1.3	0.2	0.2	0.1
qqH BSM	42	65.9	14.8	7.5	4.3	1.6	3.9	0.8	1.0	0.2
VH MET Low	1.4	16.4	0.5	23.1	44.3	15.0	0.5	nil	0.2	nil
VH MET High	2.7	1.3	nil	25.0	49.5	18.2	5.2	nil	0.4	0.4
VH lep Low	12	9.7	0.5	69.6	6.6	1.2	8.9	0.7	2.3	0.4
VH lep High	3.1	0.1	0.1	76.8	3.7	1.4	15.6	nil	1.2	1.2
VH dilep	1.8	nil	nil	nil	80.8	17.8	1.4	nil	nil	nil
ttH had BDT4	6.6	22.3	1.5	5.1	6.0	2.8	53.5	1.5	6.1	1.2
ttH had BDT3	7.2	10.9	0.6	2.5	3.2	1.9	74.7	0.7	3.8	1.6
ttH had BDT2	4.5	5.2	0.3	1.2	1.7	1.1	85.7	0.4	2.4	2.0
ttH had BDT1	5.2	2.2	0.1	0.7	1.0	0.6	91.2	0.2	1.4	2.6
ttH lep BDT3	1.2	0.8	nil	5.4	1.9	0.7	75.7	0.1	13.1	2.2
ttH lep BDT2	2.8	nil	nil	1.8	0.5	0.2	90.3	nil	4.9	2.2
ttH lep BDT1	5.3	0.1	nil	0.5	0.2	0.1	95.4	nil	1.3	2.5

Effective signal mass resolution

Category	σ_{68} [GeV]	σ_{90} [GeV]	S_{90}	B_{90}	f_{90}	Z_{90}
ggF 0J Cen	1.7	3.0	630	13 000	0.1	5.6
ggF 0J Fwd	2.1	3.8	1100	46 000	0.0	5.2
ggF 1J Low	1.9	3.6	560	19 000	0.0	4.0
ggF 1J Med	1.8	3.4	300	6900	0.0	3.6
ggF 1J High	1.7	3.1	62	640	0.1	2.4
ggF 1J BSM	1.4	2.7	16	80	0.2	1.8
ggF 2J Low	2.0	3.6	160	7700	0.0	1.9
ggF 2J Med	1.9	3.4	140	4100	0.0	2.1
ggF 2J High	1.7	3.1	57	690	0.1	2.2
ggF 2J BSM	1.5	2.8	14	61	0.2	1.7
VBF low-p_{T}^{Hjj} BDT loose	1.9	3.5	37	280	0.1	2.2
VBF low-p_{T}^{Hjj} BDT tight	1.7	3.1	26	35	0.4	4.0
VBF high-p_{T}^{Hjj} BDT loose	1.8	3.5	34	690	0.1	1.3
VBF high-p_{T}^{Hjj} BDT tight	1.7	3.2	41	320	0.1	2.3
VH had BDT loose	1.8	3.2	31	470	0.1	1.4
VH had BDT tight	1.6	2.9	23	110	0.2	2.1
qqH BSM	1.5	2.8	38	610	0.1	1.5
VH MET Low	1.9	3.6	1.3	9.8	0.1	0.4
VH MET High	1.6	3.0	2.4	6.5	0.3	0.9
VH lep Low	1.9	3.4	11	95	0.1	1.1
VH lep High	1.5	3.0	2.8	5.3	0.3	1.1
VH dilep	1.7	3.2	1.6	2.6	0.4	0.9
ttH had BDT4	1.7	3.2	6.1	55	0.1	0.8
ttH had BDT3	1.7	3.2	6.7	33	0.2	1.1
ttH had BDT2	1.6	3.1	4.1	8.2	0.3	1.4
ttH had BDT1	1.4	2.7	4.8	1.4	0.8	3.0
ttH lep BDT3	1.9	3.5	1.1	4.7	0.2	0.5
ttH lep BDT2	1.8	3.3	2.5	4.9	0.3	1.1
ttH lep BDT1	1.6	3.0	4.8	2.2	0.7	2.6

Expected correlations