Measurement of Higgs boson production in the diphoton decay channel with the ATLAS detector

2017 Division of Particles and Fields meeting

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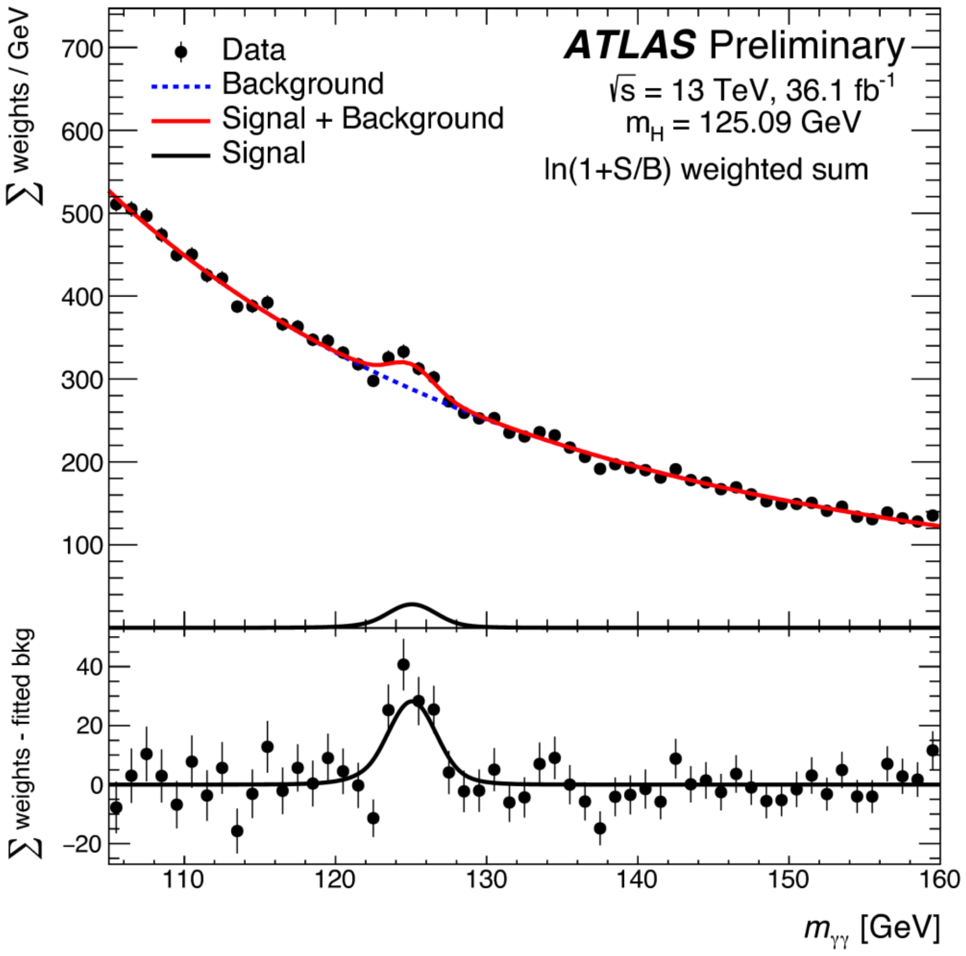
Introduction



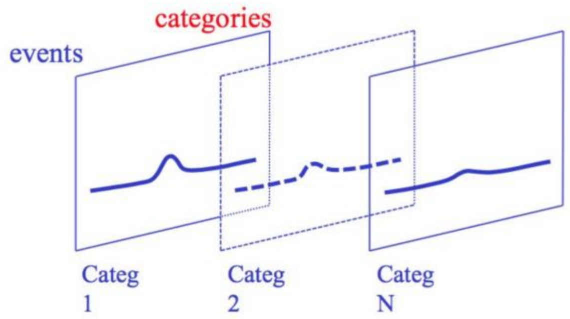
Mass spectrum (weighted by ln(1+S/B) in each category)

H→γγ analysis with full 2015+2016 data at 13 TeV collected by ATLAS:

- A clean signature and excellent invariant mass resolution in diphoton channel.
- Coupling analysis measures production rates and properties by splitting dataset into independent "categories" targeted for different production modes.

Production Mode Measurement:

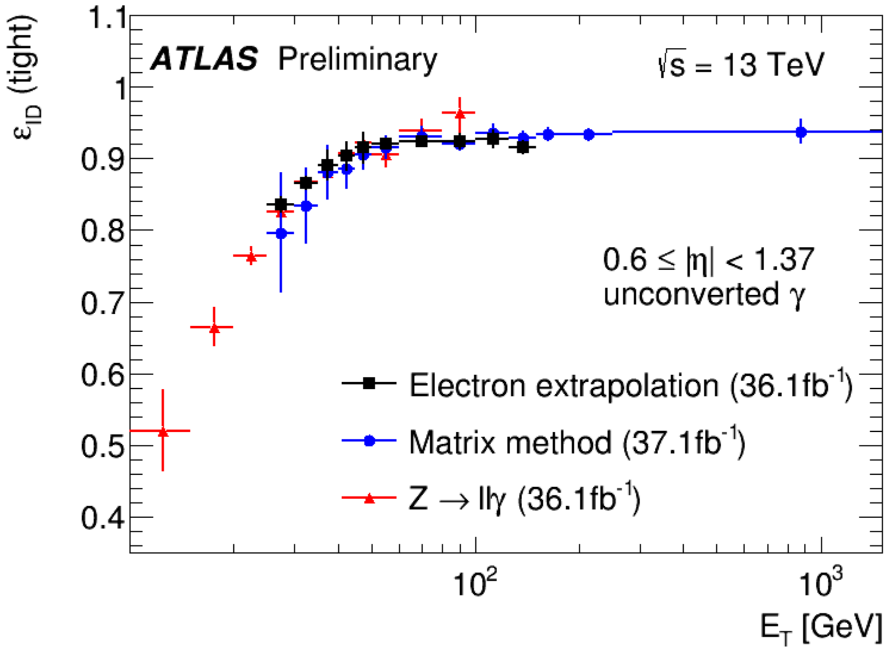
- Signal strengths
- Production cross section (XS)
- Simplified Template XS
- Coupling Strengths



EPS conf note: ATLAS-CONF-2017-045

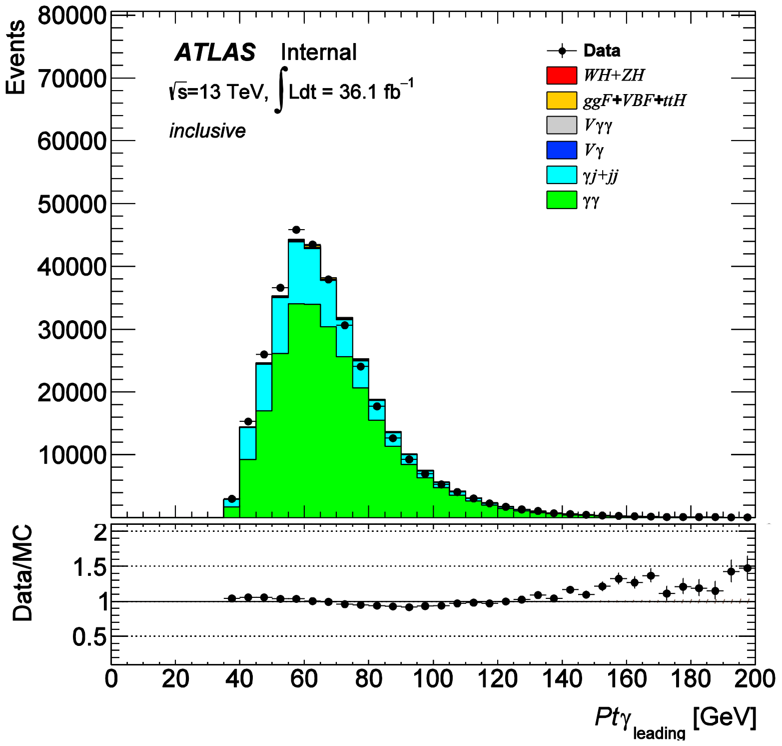
Inclusive event selection

- HLT g_35_loose_g25_loose trigger (photon p_{T} thresholds 35 GeV and 25 GeV)
- $|\eta_\gamma|$< 2.37, and excluding the crack region (1.37<$|\eta_\gamma|$<1.52)
- 2 tight identification and isolated photons
- Relative p_{T} cut: $p_{\mathrm{T}}/m_{\gamma\gamma}$> 0.35/0.25 (leading/subleading)
- Diphoton mass window cut: 105 < $m_{\gamma\gamma}$< 160 GeV

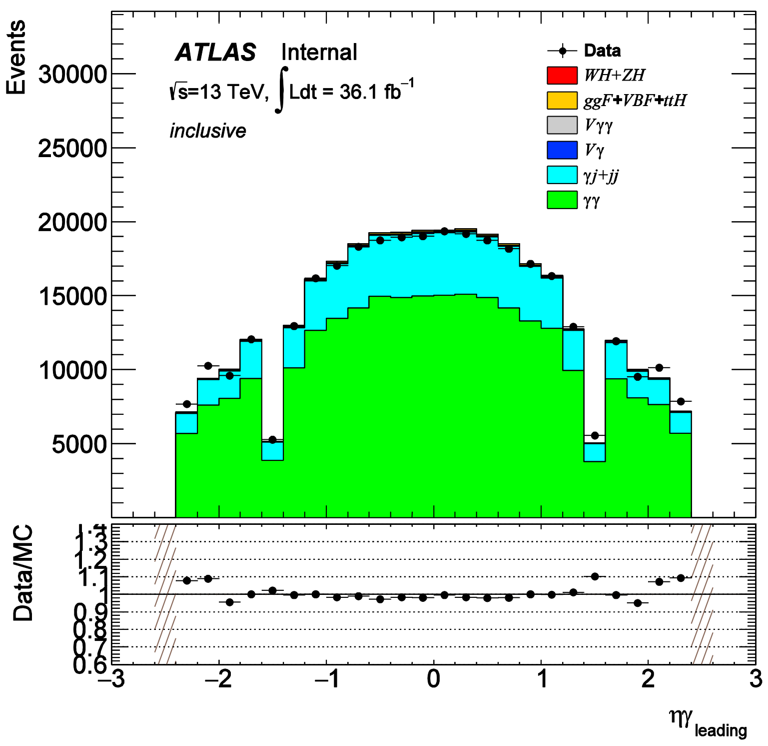


Photon identification efficiency as a function of $p_{\mathrm{T}\gamma}$ (ATL-COM-PHYS-2017-950)

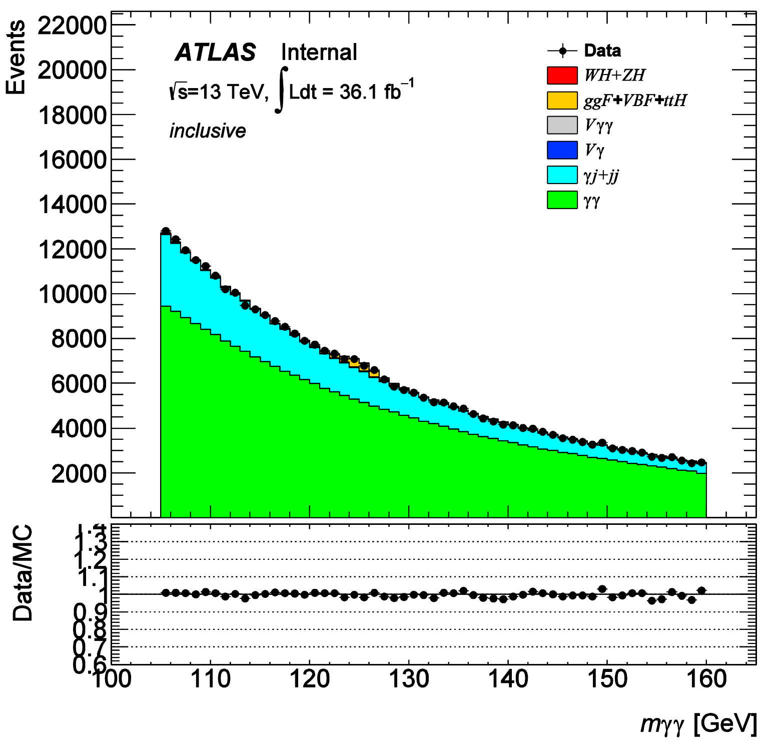
Data/MC comparison



$p_{T\gamma leading}$



$\eta_{\gamma leading}$



$m_{\gamma\gamma}$

irreducible background ($\gamma\gamma$) contributes 78.6%, **fake ($\gamma j + jj$)** contributes 21.4% of the continuum background in sideband (105-120,130-160GeV).

Categorization I

- In order to probe the Higgs production modes, 31 reconstructed categories are developed.
- Signal significance, purity and availability of statistic are all considered in category development.
- the sequence is made in order to test the categories from the most rare to the most frequent, to avoid contamination among categories.
- The remaining contamination is taken into account by the statistic model.

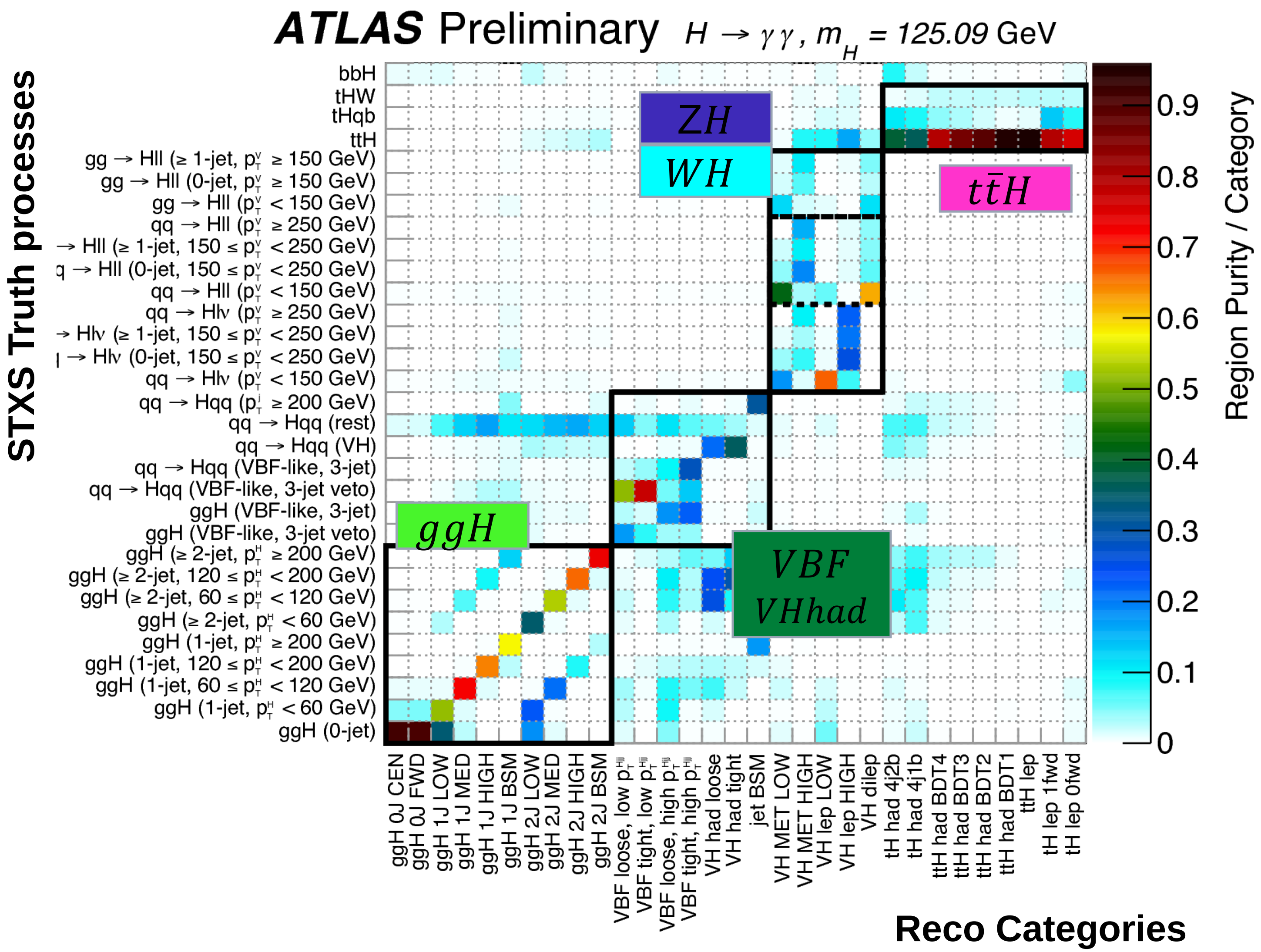
- ***t(t)H* categories:** 3 cut-based leptonic categories, 4 BDT hadronic categories and 2 cut-based hadronic categories.

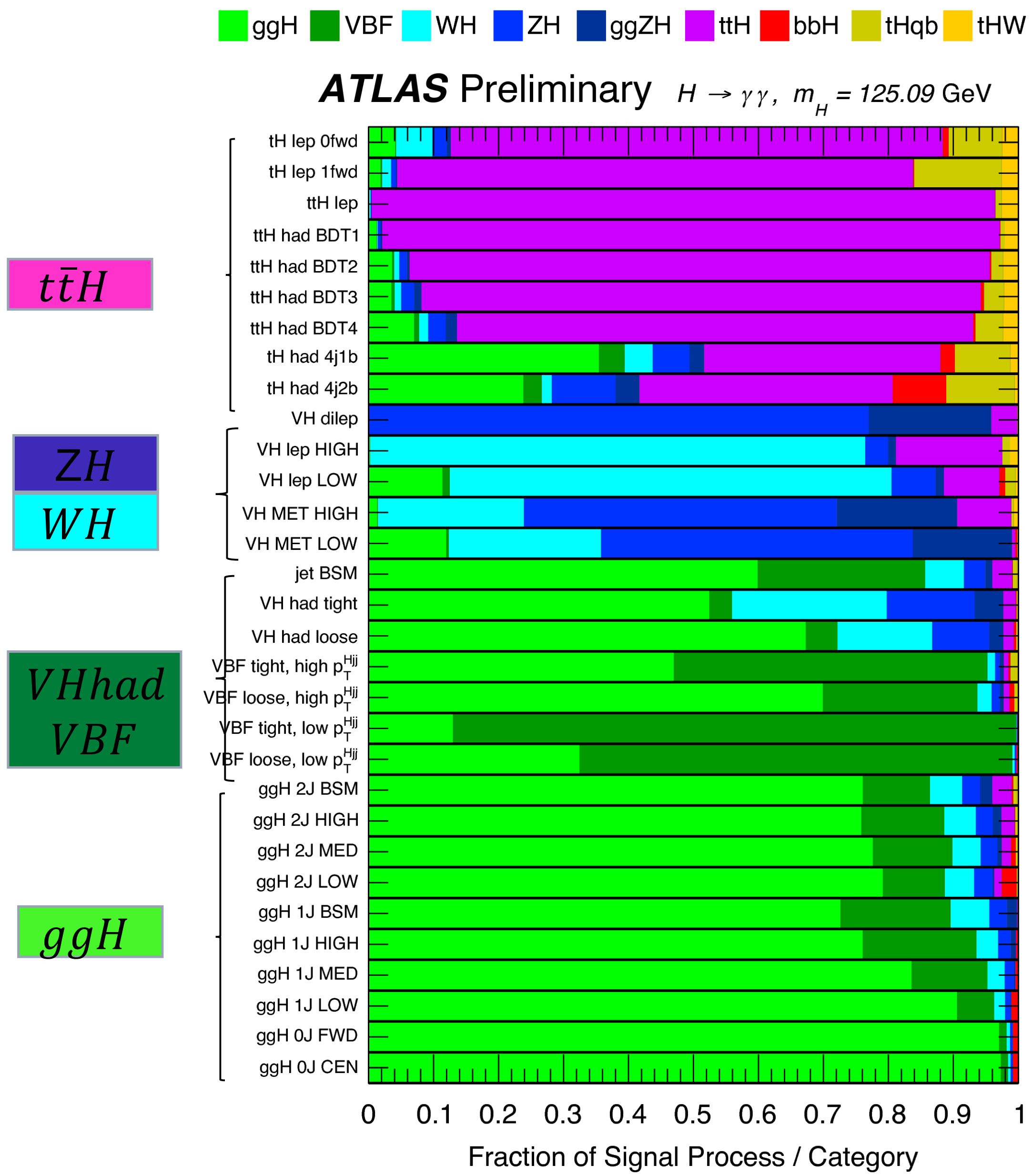
- ***VH* categories:** 5 cut-based leptonic and MET categories. 1 BSM category and 2 BDT hadronic categories

- **VBF categories:** 4 BDT categories.

- ***ggH* (untagged) categories:** 10 cut-based categories.

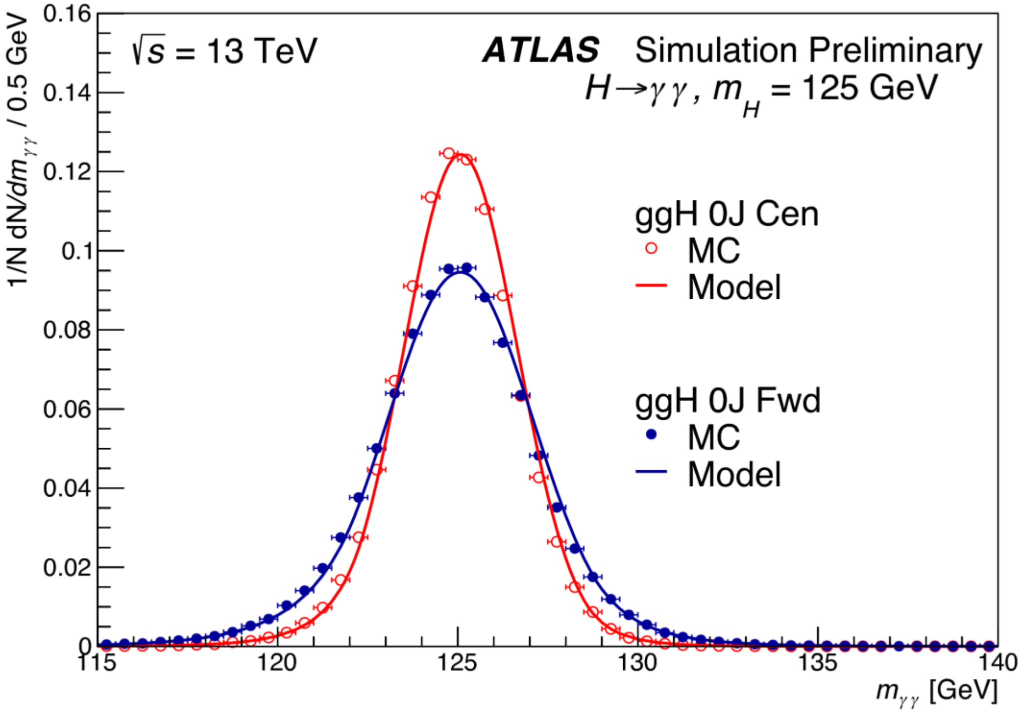
Categorization II





Signal/background Modeling

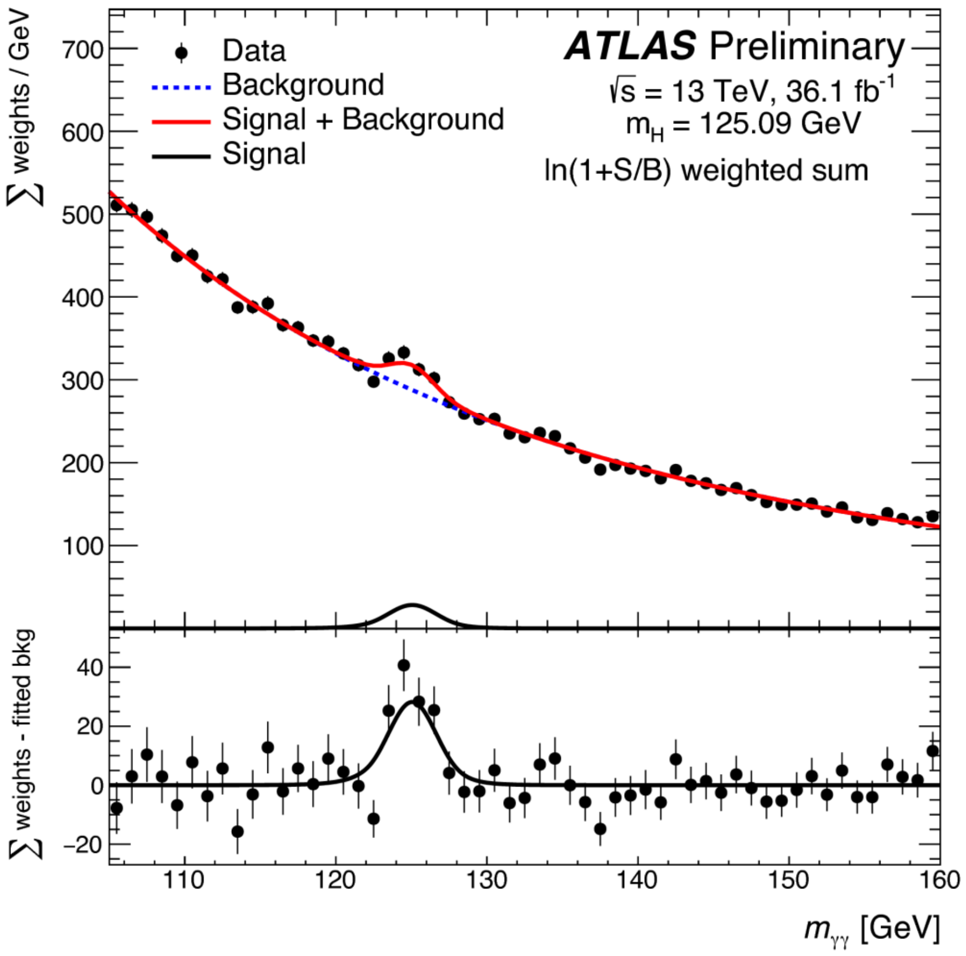
- Double Sided Crystal Ball functions is chosen to be the signal function form.
- Spurious signal method w/ S+B fit to BG MC templates is used to select background functional form and bias uncertainty



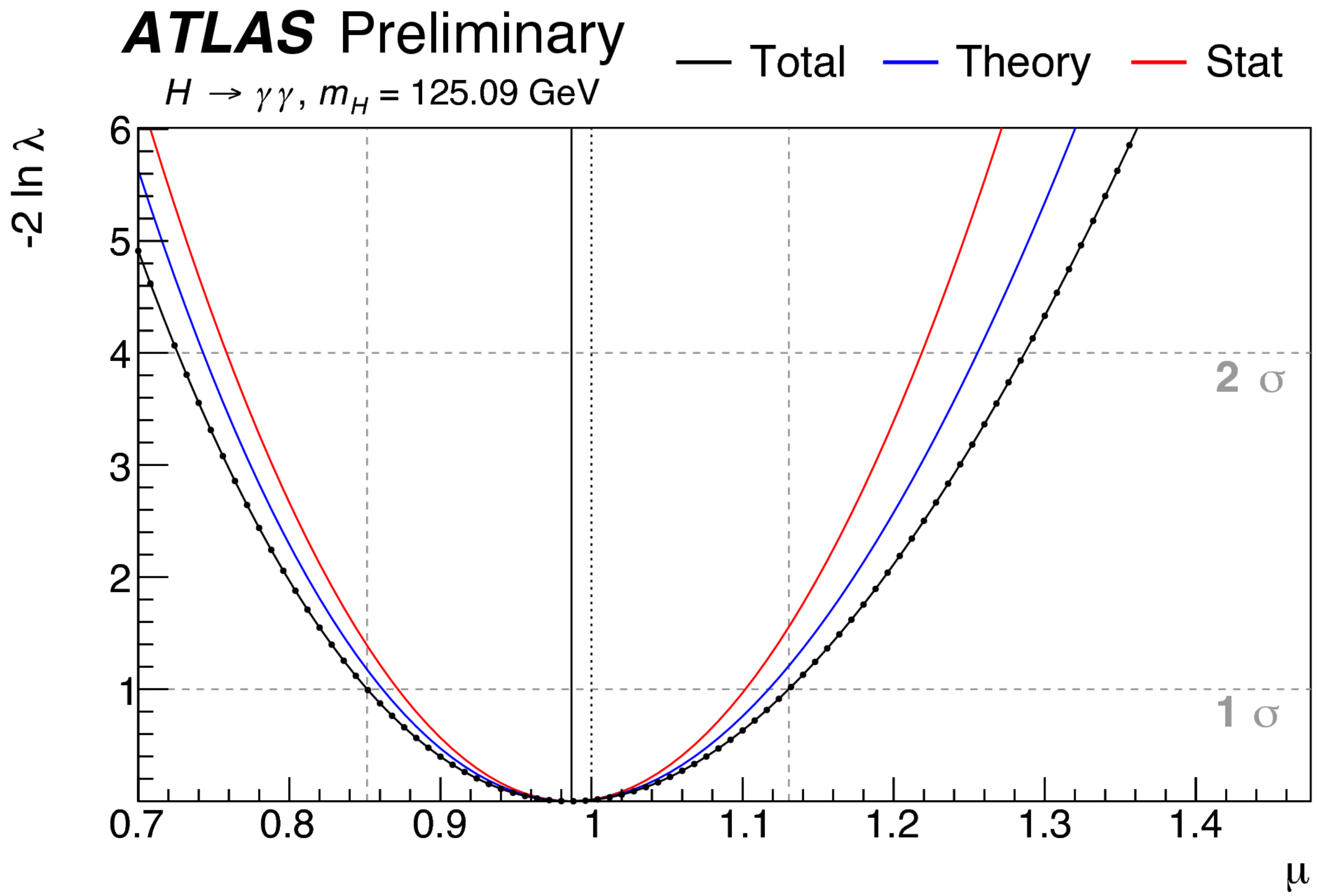
Categories with the best/worst resolution

Category	Form	Bkg Yield	p0	p1
GGH_0J_CEN	exp2	44860.6	-4.04	0.976
GGH_0J_FWD	exp2	122510	-3.97	0.962
GGH_1J_LOW	exp2	75481.9	-3.76	0.968
GGH_1J_MED	exp2	22456.6	-2.27	0.0308
GGH_1J_HIGH	pow	2148.37	-1.44	
GGH_1J_BSM	exp	65.72	-0.0127	
GGH_2J_LOW	exp2	33689.4	-3.55	0.712
GGH_2J_MED	exp2	14846.7	-2	-0.253
GGH_2J_HIGH	pow	2693.53	-2.07	
GGH_2J_BSM	pow	282.05	-0.00285	
VBF_HjjLO_loose	exp	1160.51	-0.0241	
VBF_HjjLO_tight	exp	141.5	-0.0102	
VBF_HjjHI_loose	exp	3235.05	-0.0277	
VBF_HjjHI_tight	exp	1348.81	-0.023	
VHhad_loose	exp	1971.13	-0.0238	
VHhad_tight	exp	492.2	-0.0143	
QQH_BSM	exp	3043.6	-0.015	
VHMET_LOW	exp	29.96	-0.0507	
VHMET_HIGH	exp	34.68	-0.0128	
VHlep_LOW	pow	389.64	-3.55	
VHlep_HIGH	exp	21.14	-0.0115	
VHdilep	pow	8.72	-4.81	
tHhad_4j2b	pow	54.91	-2.71	
tHhad_4j1b	pow	432.08	-3.33	
ttHhadBDT4	exp	136.7	-0.0217	
ttHhadBDT3	exp	24.47	-0.00306	
ttHhadBDT2	exp	38.85	-0.0204	
ttHhadBDT1	exp	20.76	-0.00128	
ttHlep	pow	27.12	-6.04	
tHlep_1fwd	pow	20.82	-0.402	
tHlep_0fwd	pow	39.61	-1.25	

Combined signal strength



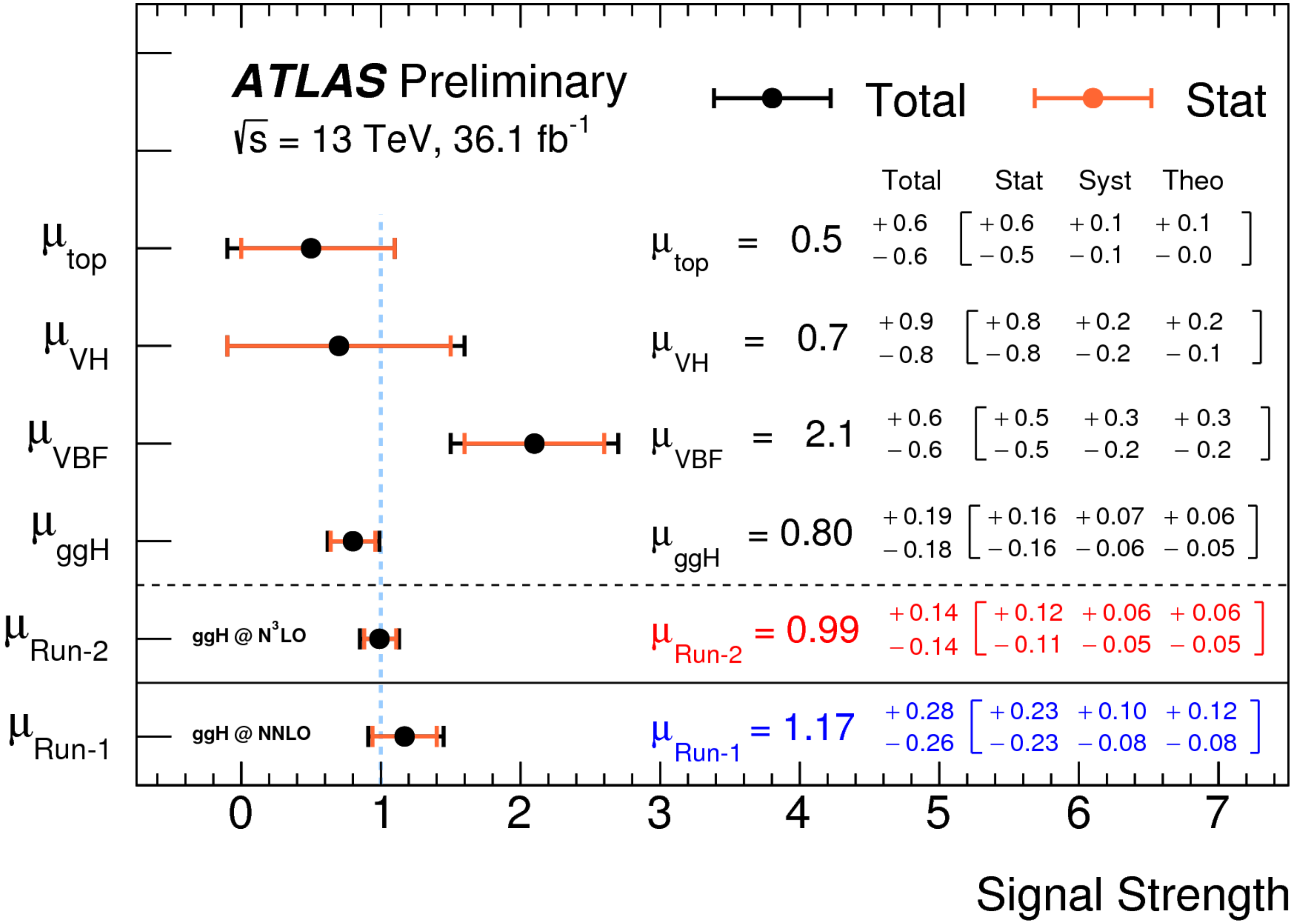
Mass spectrum (weighted by ln(1+S/B) in each category)

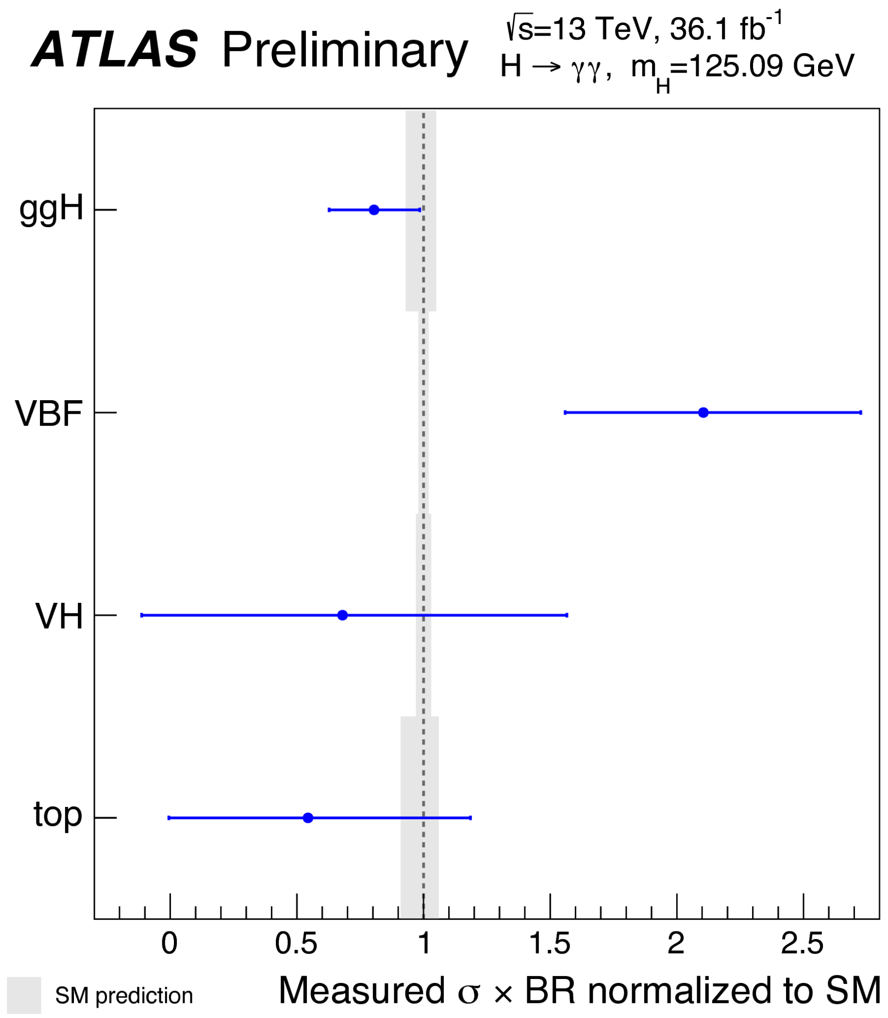


Expected: $\mu = 1.00^{+0.15}_{-0.14} = 1.00^{+0.12}_{-0.12}(\text{stat.})^{+0.07}_{-0.06}(\text{exp.})^{+0.06}_{-0.05}(\text{theory})$

Observed: $\mu = 0.99^{+0.15}_{-0.14} = 0.99^{+0.12}_{-0.12}(\text{stat.})^{+0.06}_{-0.05}(\text{exp.})^{+0.07}_{-0.05}(\text{theory})$

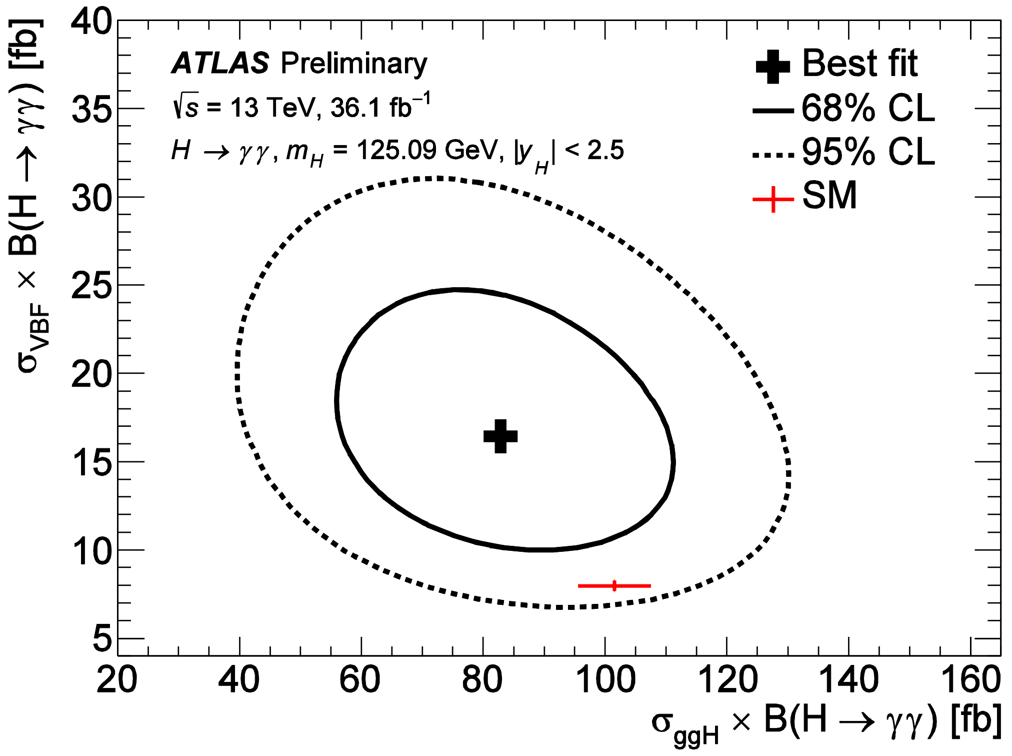
Production mode signal strength and cross sections





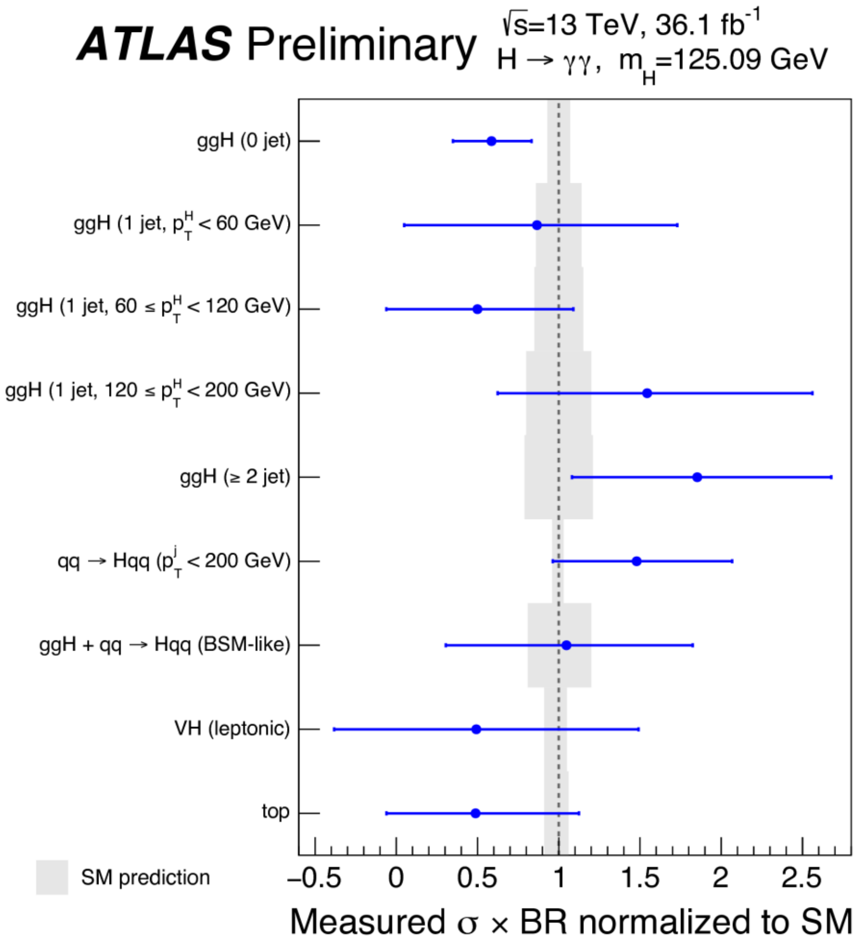
Cross section normalized to SM

Production mode signal strength and cross sections



Likelihood contours in the (σggH, σVBF) plane, compared to the Standard Model prediction

Simplified template XS results

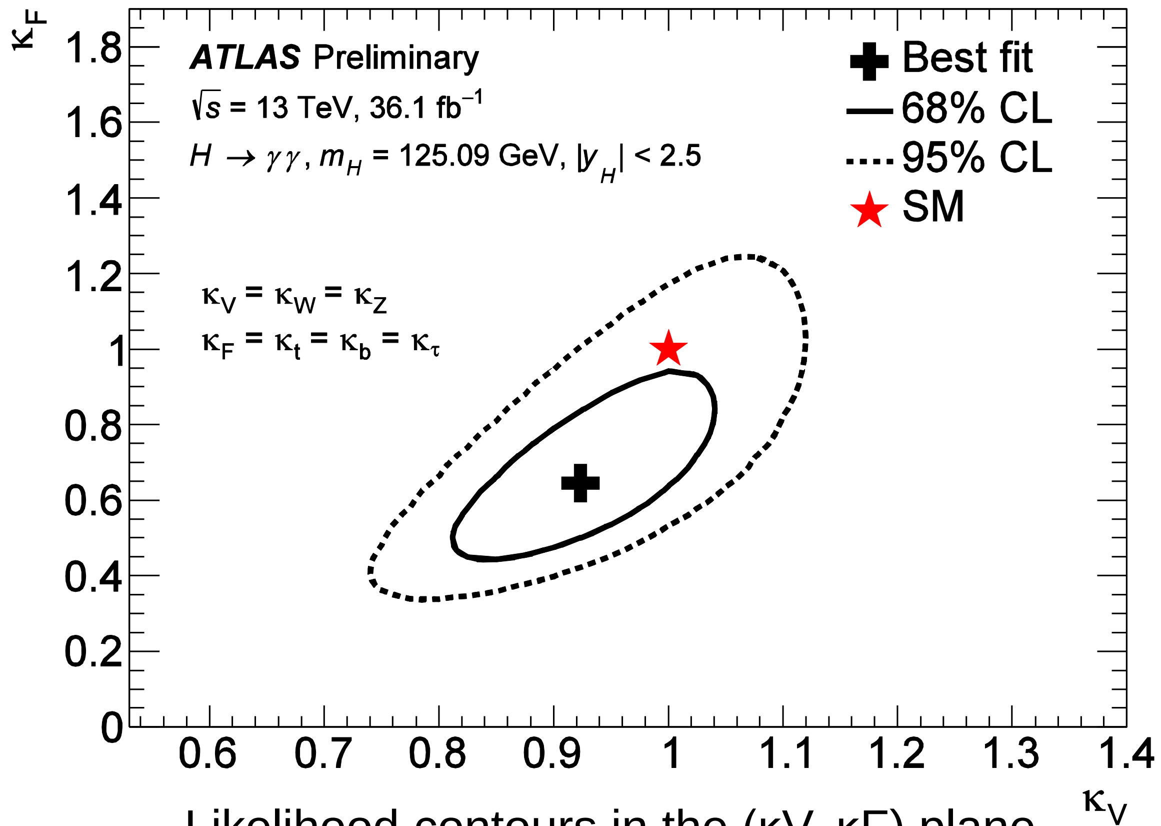


$$\sigma(ggH, 0\text{ jet}) \times \mathcal{B}(H \to \gamma\gamma) = 63\ ^{+17}_{-16}\ \text{fb}$$
$$= 63\ ^{+15}_{-15}\,(\text{stat.})\ ^{+8}_{-6}\,(\text{syst.})\ \text{fb}$$
$$\sigma(ggH, 1\text{ jet}, p_T^H < 60\ \text{GeV}) \times \mathcal{B}(H \to \gamma\gamma) = 15\ ^{+13}_{-12}\ \text{fb}$$
$$= 15\ ^{+12}_{-12}\,(\text{stat.})\ ^{+6}_{-4}\,(\text{syst.})\ \text{fb}$$
$$\sigma(ggH, 1\text{ jet}, 60 \le p_T^H < 120\ \text{GeV}) \times \mathcal{B}(H \to \gamma\gamma) = 10\ ^{+7}_{-6}\ \text{fb}$$
$$= 10\ ^{+6}_{-6}\,(\text{stat.})\ ^{+2}_{-1}\,(\text{syst.})\ \text{fb}$$
$$\sigma(ggH, 1\text{ jet}, 120 \le p_T^H < 200\ \text{GeV}) \times \mathcal{B}(H \to \gamma\gamma) = 1.7\ ^{+1.7}_{-1.6}\ \text{fb}$$
$$= 1.7\ ^{+1.6}_{-1.6}\,(\text{stat.})\ ^{+0.6}_{-0.4}\,(\text{syst.})\ \text{fb}$$
$$\sigma(ggH, \ge 2\text{ jet}) \times \mathcal{B}(H \to \gamma\gamma) = 11\ ^{+8}_{-8}\ \text{fb}$$
$$= 11\ ^{+8}_{-8}\,(\text{stat.})\ ^{+3}_{-2}\,(\text{syst.})\ \text{fb}$$
$$\sigma(qq \to Hqq, p_T^j < 200\ \text{GeV}) \times \mathcal{B}(H \to \gamma\gamma) = 10\ ^{+6}_{-5}\ \text{fb}$$
$$= 10\ ^{+5}_{-5}\,(\text{stat.})\ ^{+2}_{-1}\,(\text{syst.})\ \text{fb}$$
$$\sigma(ggH + qq \to Hqq, \text{BSM}-\text{like}) \times \mathcal{B}(H \to \gamma\gamma) = 1.8\ ^{+1.4}_{-1.4}\ \text{fb}$$
$$= 1.8\ ^{+1.3}_{-1.3}\,(\text{stat.})\ ^{+0.5}_{-0.5}\,(\text{syst.})\ \text{fb}$$
$$\sigma(\text{VH, leptonic}) \times \mathcal{B}(H \to \gamma\gamma) = 1.4\ ^{+1.4}_{-1.2}\ \text{fb}$$
$$= 1.4\ ^{+1.3}_{-1.2}\,(\text{stat.})\ ^{+0.3}_{-0.3}\,(\text{syst.})\ \text{fb}$$
$$\sigma(top) \times \mathcal{B}(H \to \gamma\gamma) = 1.3\ ^{+0.9}_{-0.8}\ \text{fb}$$
$$= 1.3\ ^{+0.9}_{-0.8}\,(\text{stat.})\ ^{+0.3}_{-0.1}\,(\text{syst.})\ \text{fb}$$

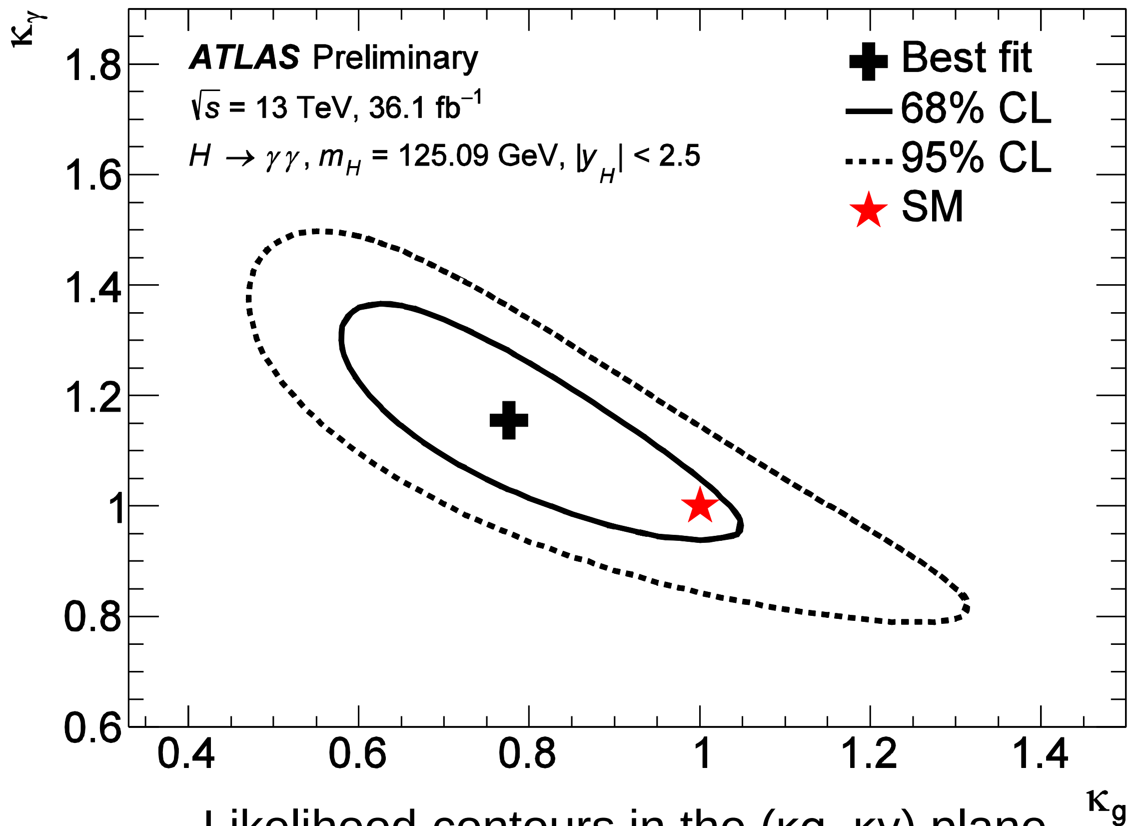
Higgs coupling strength result

- Introduce one scale factor κ per SM particle with observable “Higgs coupling” at the LHC: κW, κZ, κt, κb, κτ, κμ, κγ, κg, κH
- Use best available SM calculation for cross-section and BR, to look for deviations from the SM.
- Eg:

$$(\sigma \cdot \mathrm{BR})\,(\mathrm{gg} \to \mathrm{H} \to \gamma\gamma) \;=\; \sigma_{\mathrm{SM}}(\mathrm{gg} \to \mathrm{H}) \cdot \mathrm{BR}_{\mathrm{SM}}(\mathrm{H} \to \gamma\gamma) \cdot \frac{\kappa_{\mathrm{g}}^2 \cdot \kappa_{\gamma}^2}{\kappa_{\mathrm{H}}^2}$$



Likelihood contours in the (κV, κF) plane.



Likelihood contours in the (κg, κγ) plane.

Summary

- Latest results of the measurements of Higgs boson production in the diphoton decay channel with the ATLAS experiment corresponding to 2015+2016 data (36.1 fb^{-1}) were presented.
- Production mode and Simplified Template Cross Sections are measured.
- Higgs couplings are studied for 125.09 GeV Higgs.
- Measurements of Higgs properties in this channel are largely compatible with SM expectations.

Thanks

Backup

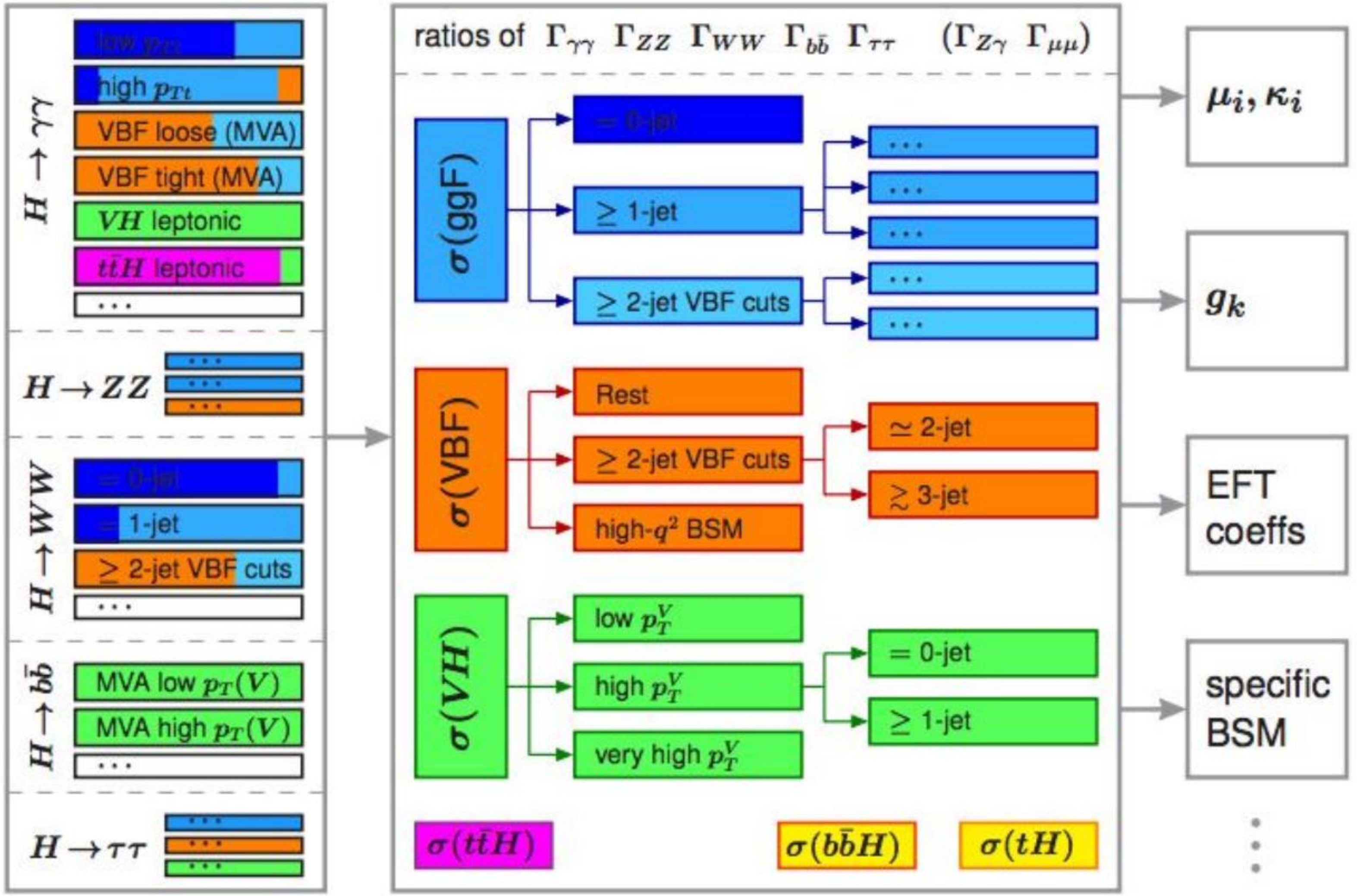
Simplified Template Cross Section

STXS (Simplified Template Cross-Section) takes reconstructed categories, but splits Higgs productions into exclusive kinematic regions at truth level.

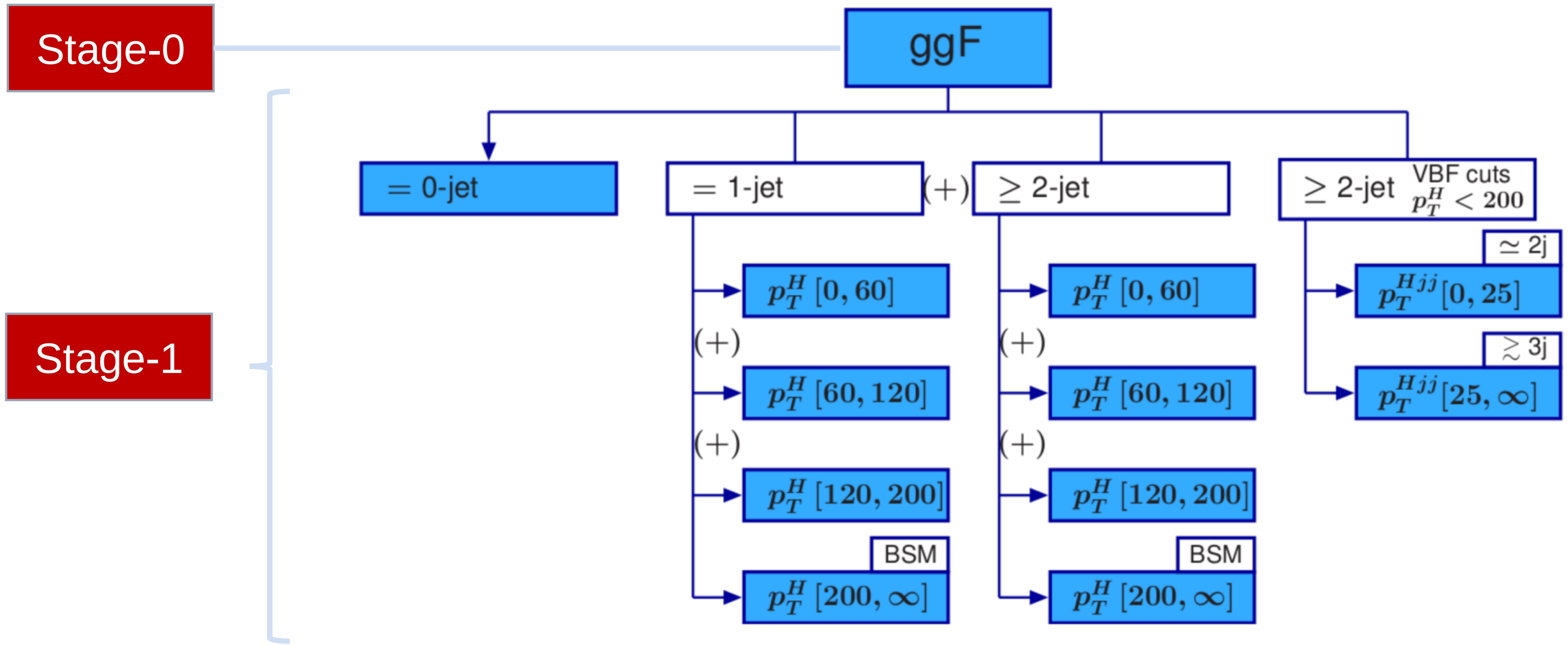
Compromise of analysis power and model independence

- Intended for combination of all decay channels
- Split of the measurement and interpretation

(the theoretical uncertainties are directly folded into the measurements)



STXS Stage-1 Split

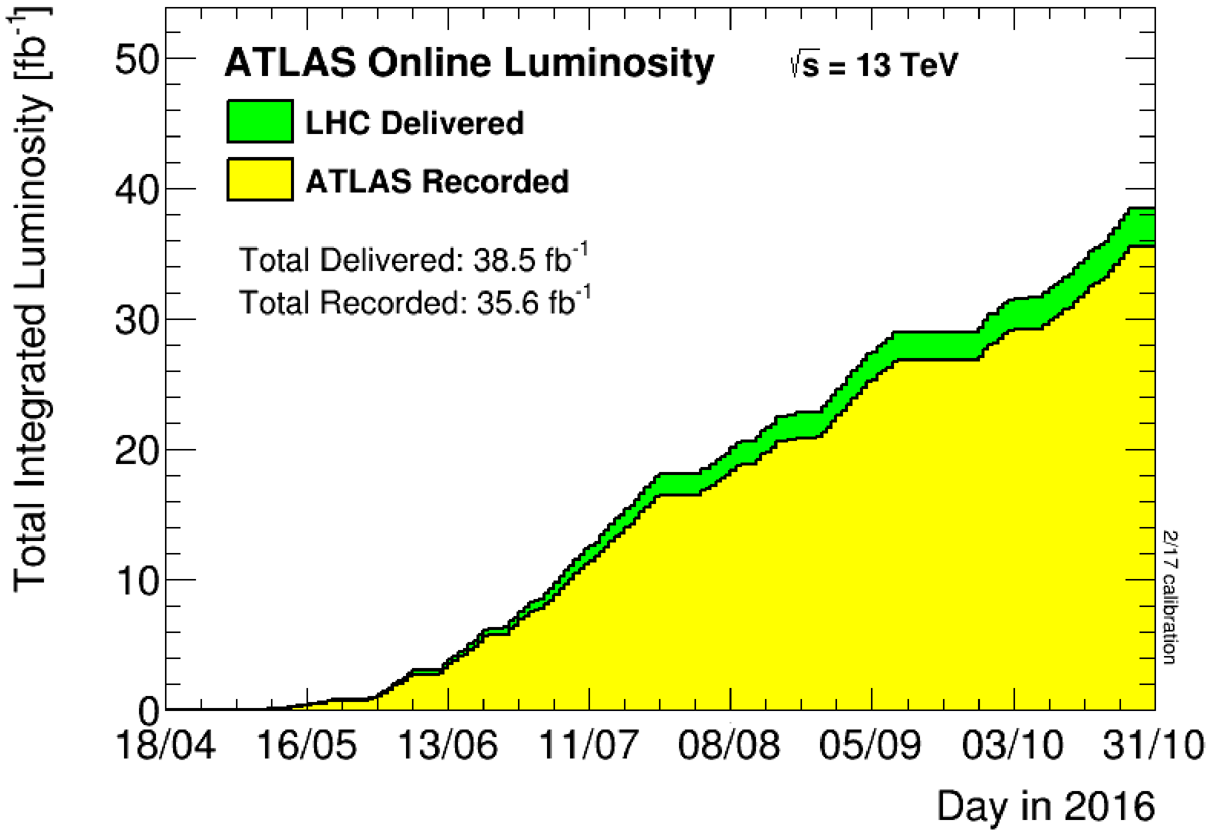


- Ideally, to measure each POI, reconstructed categories should match STXS truth bins.
- Adjacent bins will be merged if sensitivity is poor. ("+" means merge if there is insufficient statistics)

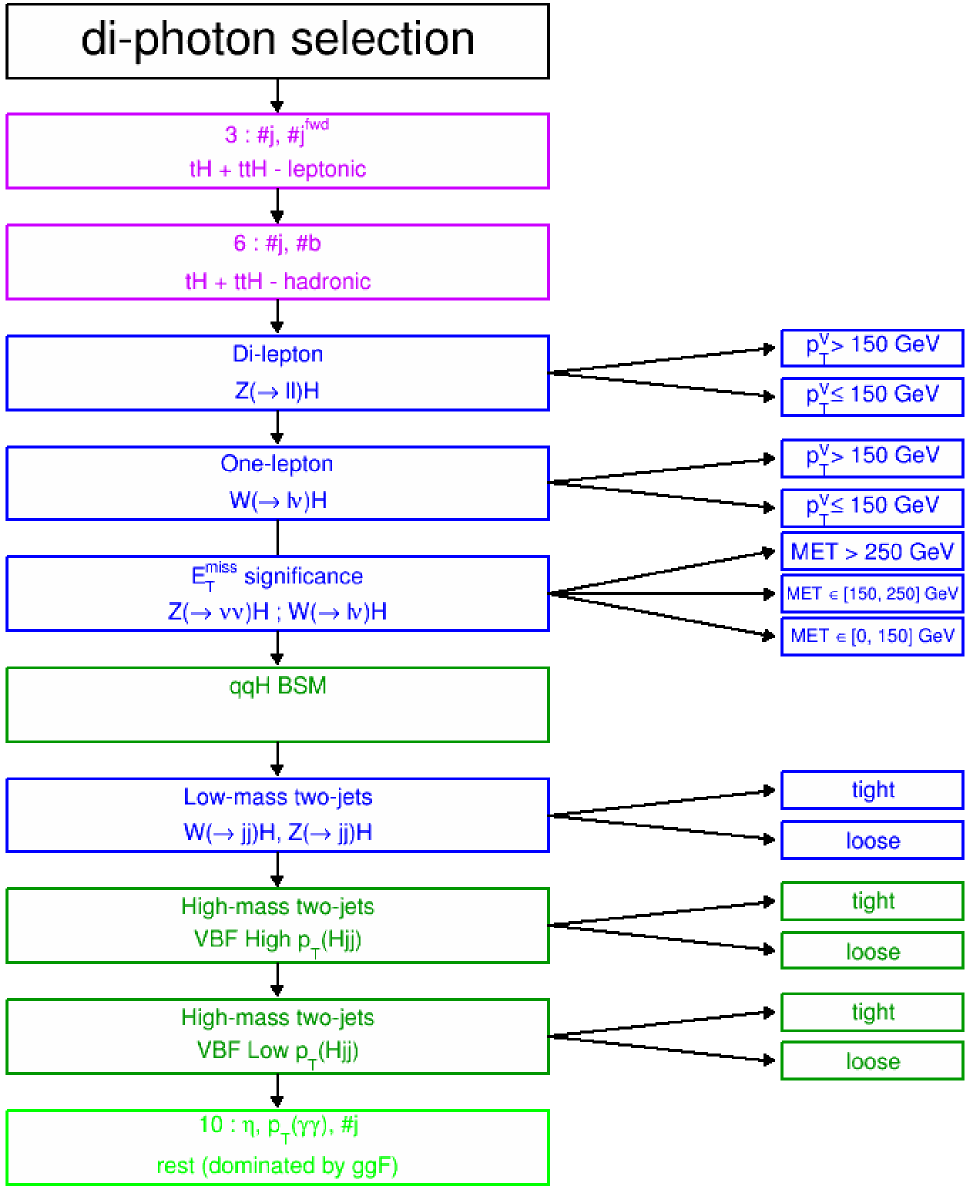
Dataset

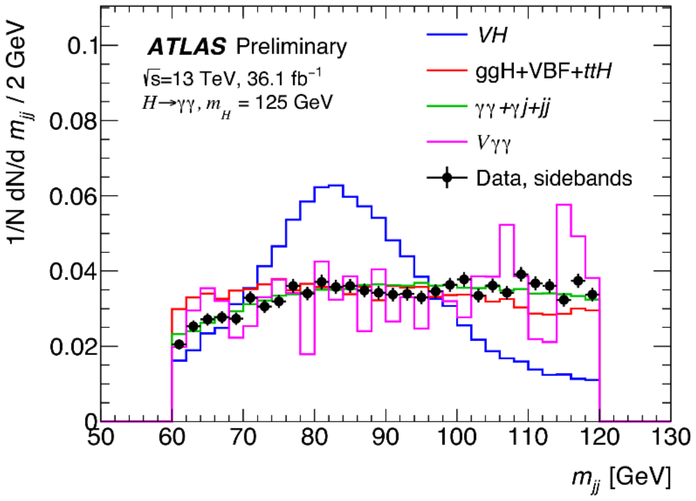
- ATLAS 2015+2016 dataset with 36.1 fb-1 after passing GRL

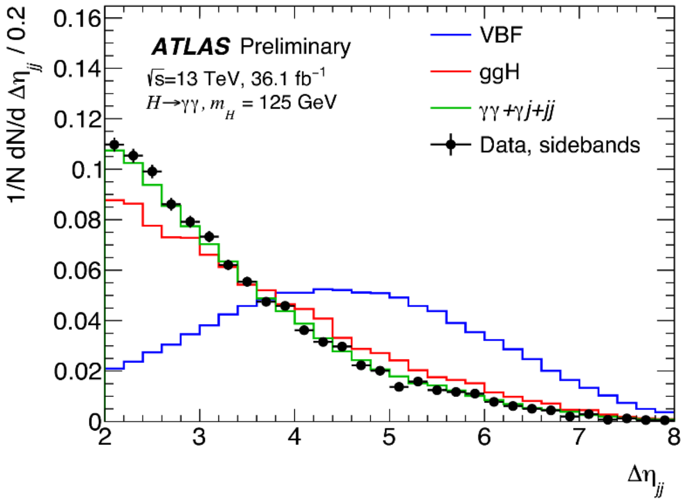
- Assign a common luminosity systematics 3.2 % for both 2015 and 2016 dataset.
- Trigger 99.0 ± 0.5% efficient



Categorization II







The normalised distributions of two example kinematic variables used for the selection of the VH hadronic and VBF categories. The signal process is marked with blue, which has different distributions from other background processes.

MC samples

Process	Generator	Pdf ME	Pdf PS	Simulation
ggF	Powheg+Pythia8	CT10	AZNLOCTEQ6L1	Full
VBF	Powheg+Pythia8	CT10	AZNLOCTEQ6L1	Full
WH	Pythia8	A14NNPDF23LO	A14NNPDF23LO	Full
ZH	Pythia8	A14NNPDF23LO	A14NNPDF23LO	Full
$t\bar{t}H$	aMC@NLO+Pythia8	NNPDF30	NNPDF23	Full
$b\bar{b}H\ yb2$	aMC@NLO+Pythia8	A14NNPDF23LO	A14NNPDF23LO	Full
$b\bar{b}H\ ybyt$	aMC@NLO+Pythia8	A14NNPDF23LO	A14NNPDF23LO	Full
$tHjb$	aMC@NLO(LO)+Pythia8	CT10	A14	Full
tWH	aMC@NLO+Herwig	CT10	UEEE5_CTEQ6L1	Full
$\gamma\gamma\ 0{-}3j$	Sherpa	CT10	CT10	AF2
$V\gamma$	Sherpa	CT10	CT10	Full
$V\gamma\gamma$	Sherpa	CT10	CT10	Full

- Samples generated at m_H = 125 GeV but normalized to m_H = 125.09 GeV
- MC Weights are also corrected for pile up, PID, isolation, fudge factors, etc.

Systematic uncertainties

		Syst. source	N_{NP}	Implementation
Yield	Theo.	Missing higher orders	6	$N_{\mathrm{S}}^{p}\, F_{\mathrm{LN}}(\sigma_i, \theta_i)$
		PDF	30	$N_{\mathrm{S}}^{p}\, F_{\mathrm{LN}}(\sigma_i, \theta_i)$
		$B(H \to \gamma\gamma)$	1	$N_{\mathrm{S}}^{\mathrm{tot}}\, F_{\mathrm{LN}}(\sigma_i, \theta_i)$
	Exp.	Heavy Flavor Content	1	$N_{\mathrm{S}}^{p}\, F_{\mathrm{LN}}(\sigma_i, \theta_i)$
		Luminosity	1	$N_{\mathrm{S}}^{\mathrm{tot}}\, F_{\mathrm{LN}}(\sigma_i, \theta_i)$
		Trigger	1	$N_{\mathrm{S}}^{\mathrm{tot}}\, F_{\mathrm{LN}}(\sigma_i, \theta_i)$
		Photon Identification	1	$N_{\mathrm{S}}^{p}\, F_{\mathrm{LN}}(\sigma_i, \theta_i)$
		Photon Isolation	2	$N_{\mathrm{S}}^{p}\, F_{\mathrm{LN}}(\sigma_i, \theta_i)$
Migrations	Theo.	ggH Theory	9	$N_{\mathrm{S}}^{\mathrm{ggH}}\, F_{\mathrm{LN}}(\sigma_i, \theta_i)$
		UE/PS	3	$N_{\mathrm{S}}^{p}\, F_{\mathrm{LN}}(\sigma_i, \theta_i)$
		PDF	30	$N_{\mathrm{S}}^{p}\, F_{\mathrm{LN}}(\sigma_i, \theta_i)$
		α_{S}	1	$N_{\mathrm{S}}^{p}\, F_{\mathrm{LN}}(\sigma_i, \theta_i)$
	Exp.	Flavor Tagging	14	$N_{\mathrm{S}}^{p}\, F_{\mathrm{LN}}(\sigma_i, \theta_i)$
		Jet	20	$N_{\mathrm{S}}^{p}\, F_{\mathrm{LN}}(\sigma_i, \theta_i)$
		Jet Flavor Composition	7	$N_{\mathrm{S}}^{p}\, F_{\mathrm{LN}}(\sigma_i, \theta_i)$
		Jet Flavor Response	7	$N_{\mathrm{S}}^{p}\, F_{\mathrm{LN}}(\sigma_i, \theta_i)$
		Electron	3	$N_{\mathrm{S}}^{p}\, F_{\mathrm{LN}}(\sigma_i, \theta_i)$
		Muon	11	$N_{\mathrm{S}}^{p}\, F_{\mathrm{LN}}(\sigma_i, \theta_i)$
		MET	3	$N_{\mathrm{S}}^{p}\, F_{\mathrm{LN}}(\sigma_i, \theta_i)$
		Pileup	1	$N_{\mathrm{S}}^{p}\, F_{\mathrm{LN}}(\sigma_i, \theta_i)$
		Photon Energy Scale	40	$N_{\mathrm{S}}^{p}\, F_{\mathrm{LN}}(\sigma_i, \theta_i)$
Mass		ATLAS-CMS m_H	1	$\mu_{\mathrm{CB}}\, F_{\mathrm{G}}(\sigma_i, \theta_i)$
		Photon Energy Scale	40	$\mu_{\mathrm{CB}}\, F_{\mathrm{G}}(\sigma_i, \theta_i)$
		Photon Energy Resolution	9	$\sigma_{\mathrm{CB}}\, F_{\mathrm{LN}}(\sigma_i, \theta_i)$
Background		Spurious signal	31	$N_{\mathrm{spur},c}\, \theta_{\mathrm{spur},c}$

Impact on combined signal strength

Uncertainty Group	$\sigma_{\mu}^{\mathrm{syst.}}$
Theory (yield)	0.03
Experimental (yield)	0.02
Luminosity	0.03
Theory (migrations)	0.05
Experimental (migrations)	0.01
Mass resolution	0.03
Mass scale	0.04
Background shape	0.03

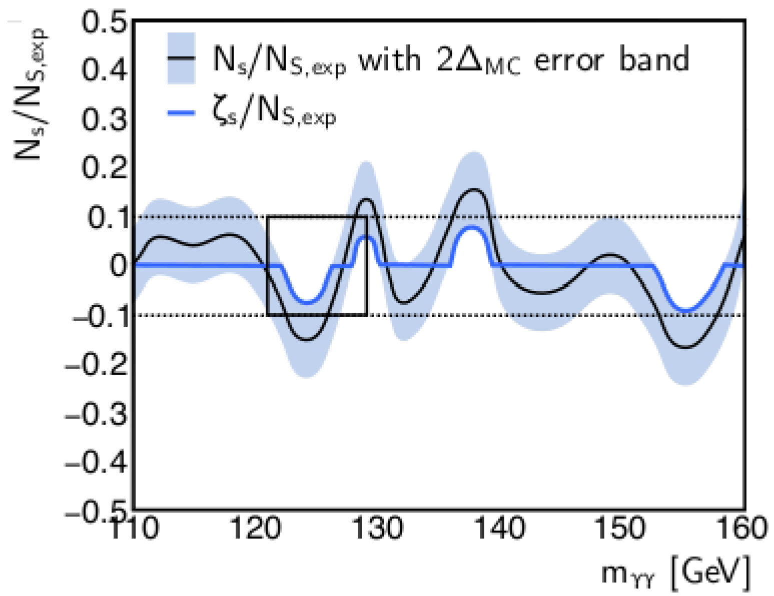
Signal MC samples

	New samples	Generator	PDF
ggH	yes	POWHEG+PYTHIA NLO → NNLOPS	NNPDF3.0 + PDF4LHC15_nlo_30_as
VBF	yes	POWHEG+PYTHIA NLO	NNPDF3.0 + PDF4LHC15_nlo_30_as
VH	yes	POWHEG+PYTHIA → VHJ MINLO	NNPDF3.0 + PDF4LHC15_nlo_30_as
gg → ZH	yes	POWHEG, LO	NNPDF3.0 +PDF4LHC15_nlo_30_as
ttH	no	aMC@NLO NLO	NNPDF3.0
bbH	yes	aMC@NLO or PYTHIA?	NNPDF3.0 + PDF4LHC15_nlo_30_as

- We may get some new generators for various samples. Samples for ggH and VBF with NNLOPS are high priority on this list. There are also investigations for NLO $q\bar{q} \rightarrow VH$ samples and possibly the inclusion of a $gg \rightarrow ZH$ sample. Powheg samples for ttH and bbH are also being considered.

Background Modeling

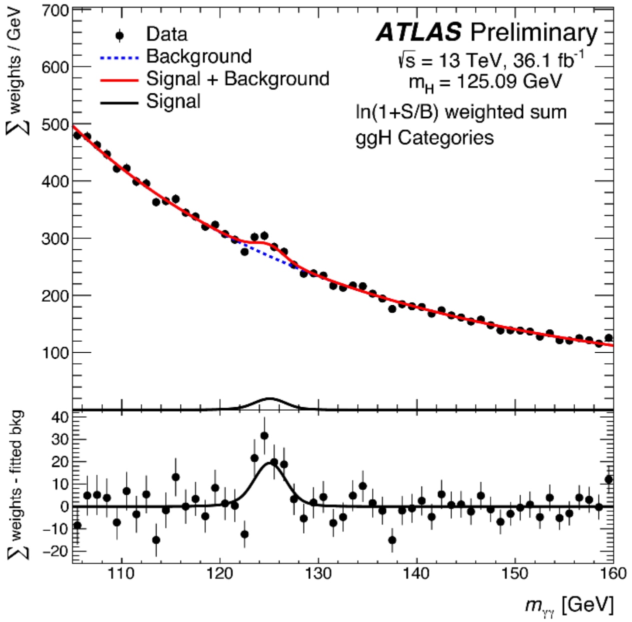
- Parameters of BG model for Asimov data found by fits to the data sideband
- Spurious signal method w/ S+B fit to BG MC templates is used to select background functional form and bias uncertainty
- Method is relaxed to allow a 2 sigma error band for functions to satisfy criteria, removing dependence from low MC stats



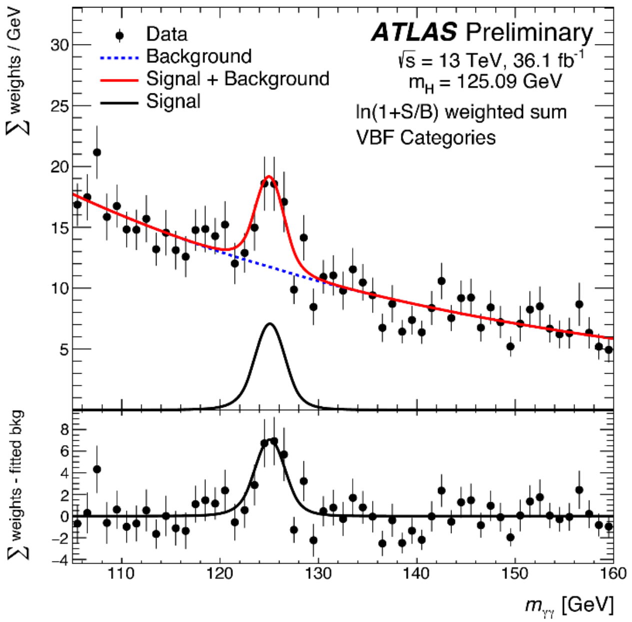
$$\zeta_s = \begin{cases} (N_s+2\Delta_{MC}), & N_s+2\Delta_{MC} < 0 \\ (N_s-2\Delta_{MC}), & N_s-2\Delta_{MC} > 0 \\ 0, & \text{otherwise} \end{cases}$$

- $\zeta_{sp} < 10\% \, N_{s,exp}$
- $\zeta_{sp} < 20\% \, \sigma_{bkg}$
- $p\text{-value}(\chi^2) > 1\%$

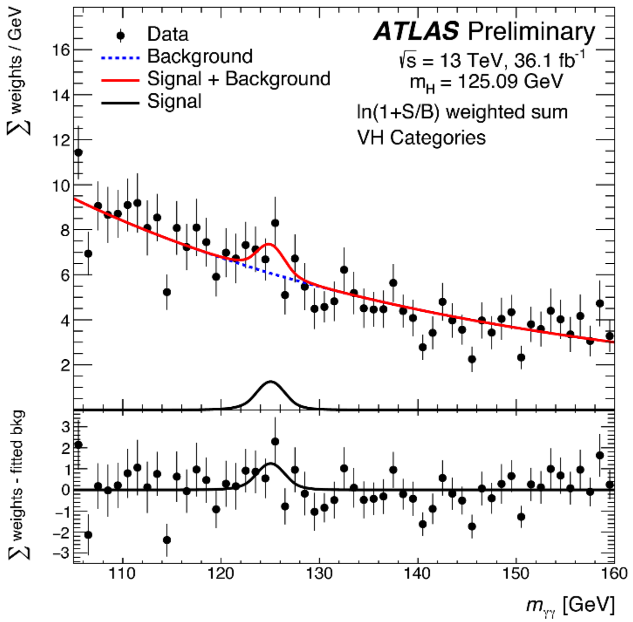
Production mode mass spectrum



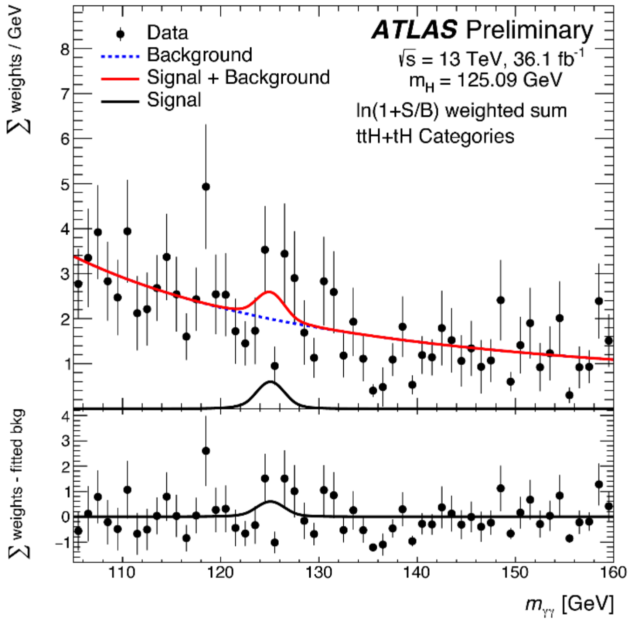
ggH categories mass spectrum



VBF categories mass spectrum



VH categories mass spectrum



t(t)H categories mass spectrum