Measurements of Higgs boson properties in bosonic final states at CMS

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on behalf of the CMS Collaboration

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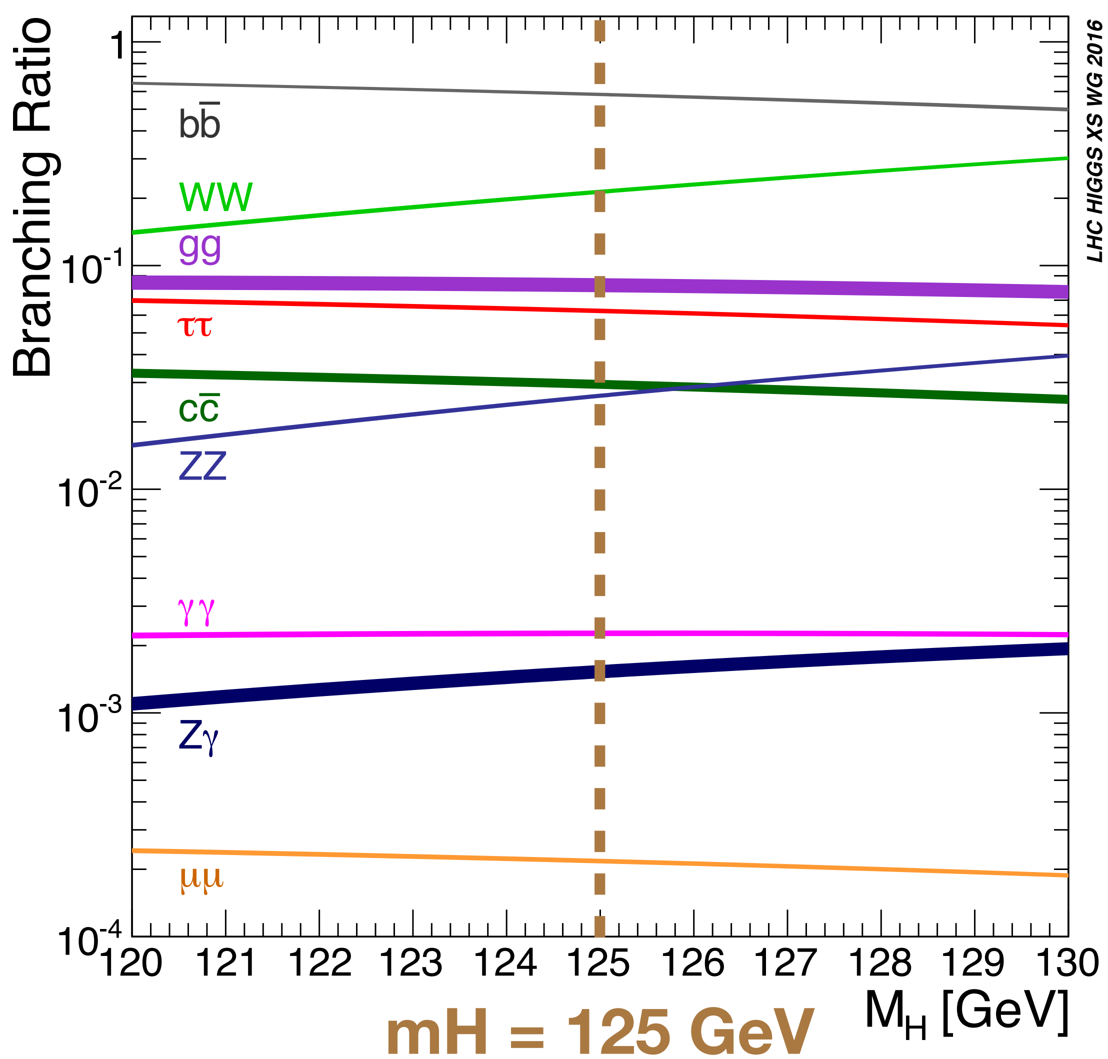
Overview

Higgs boson discovery was announced in 2012.
Since then, many efforts have been profused to study its properties.

This information could test for physics Beyond Standard Model.

This talk will focus on diboson decay channels:



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CMS

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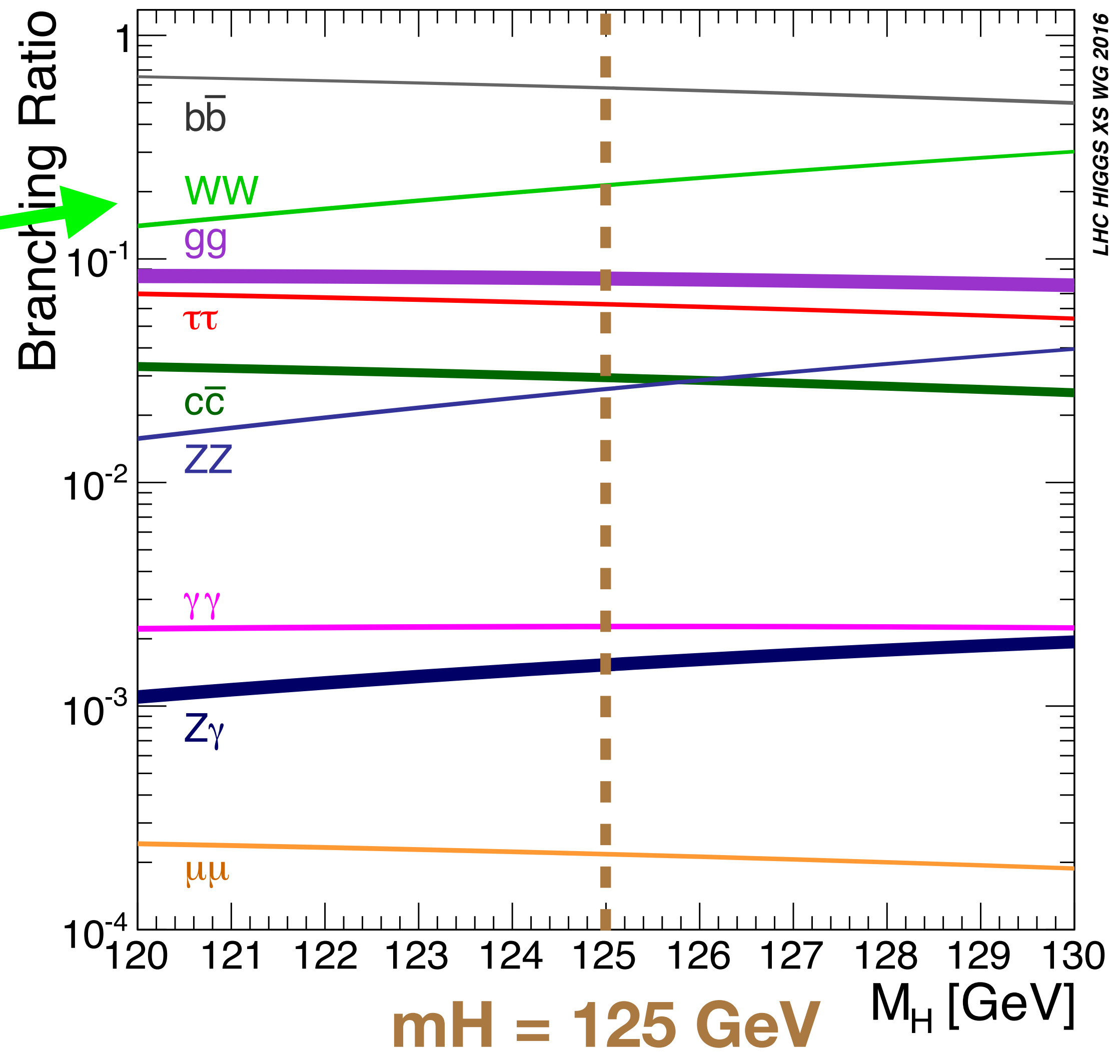
- **H —> WW:** second dominating branching ratio (21.4% @ 125 GeV). The neutrino in the leptonic decay prevents the full reconstruction of the Higgs boson mass.



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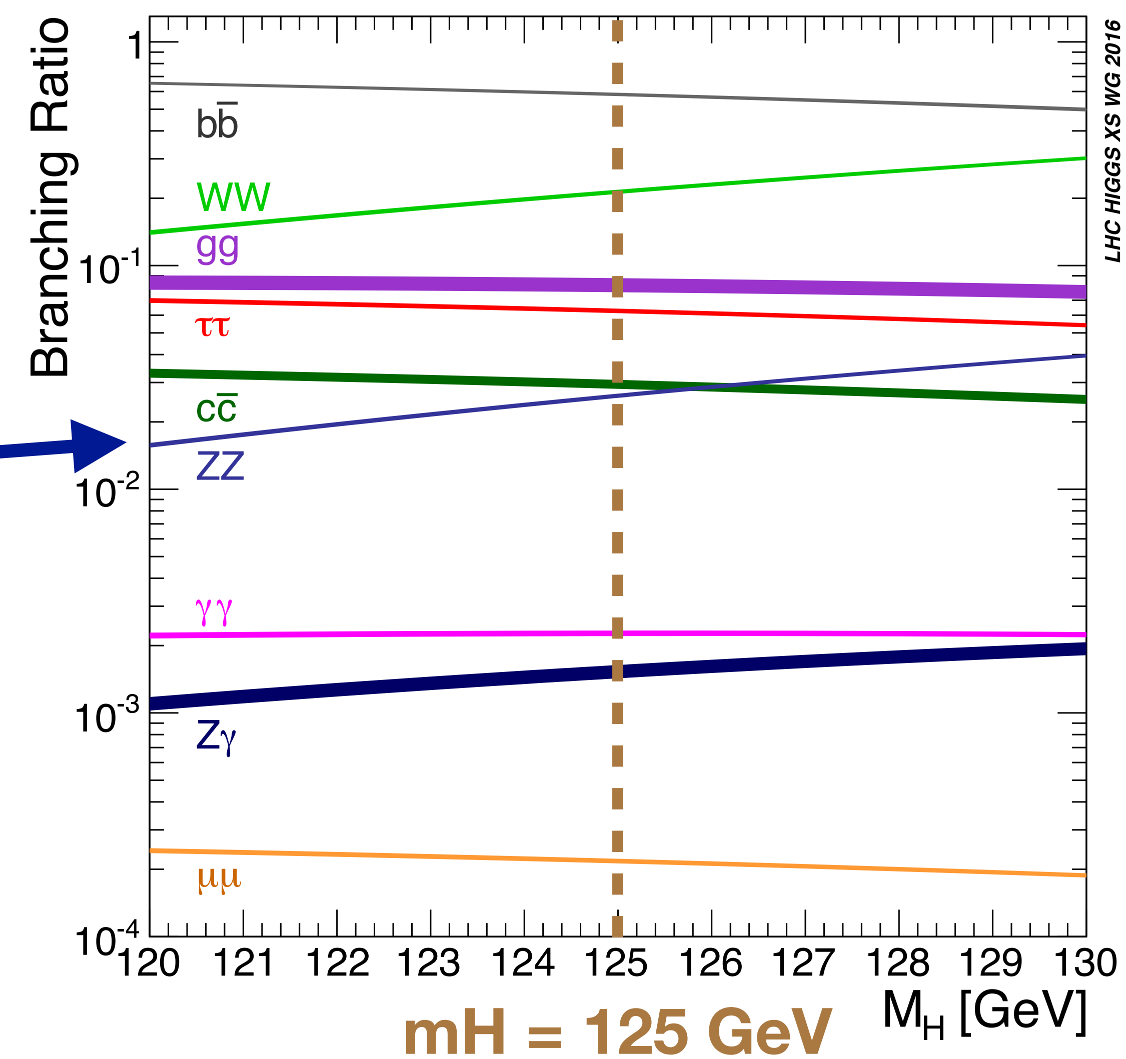
- **H —> WW**
- **H —> ZZ:** has large signal-to - background ratio due to the complete reconstruction of the final state decay products



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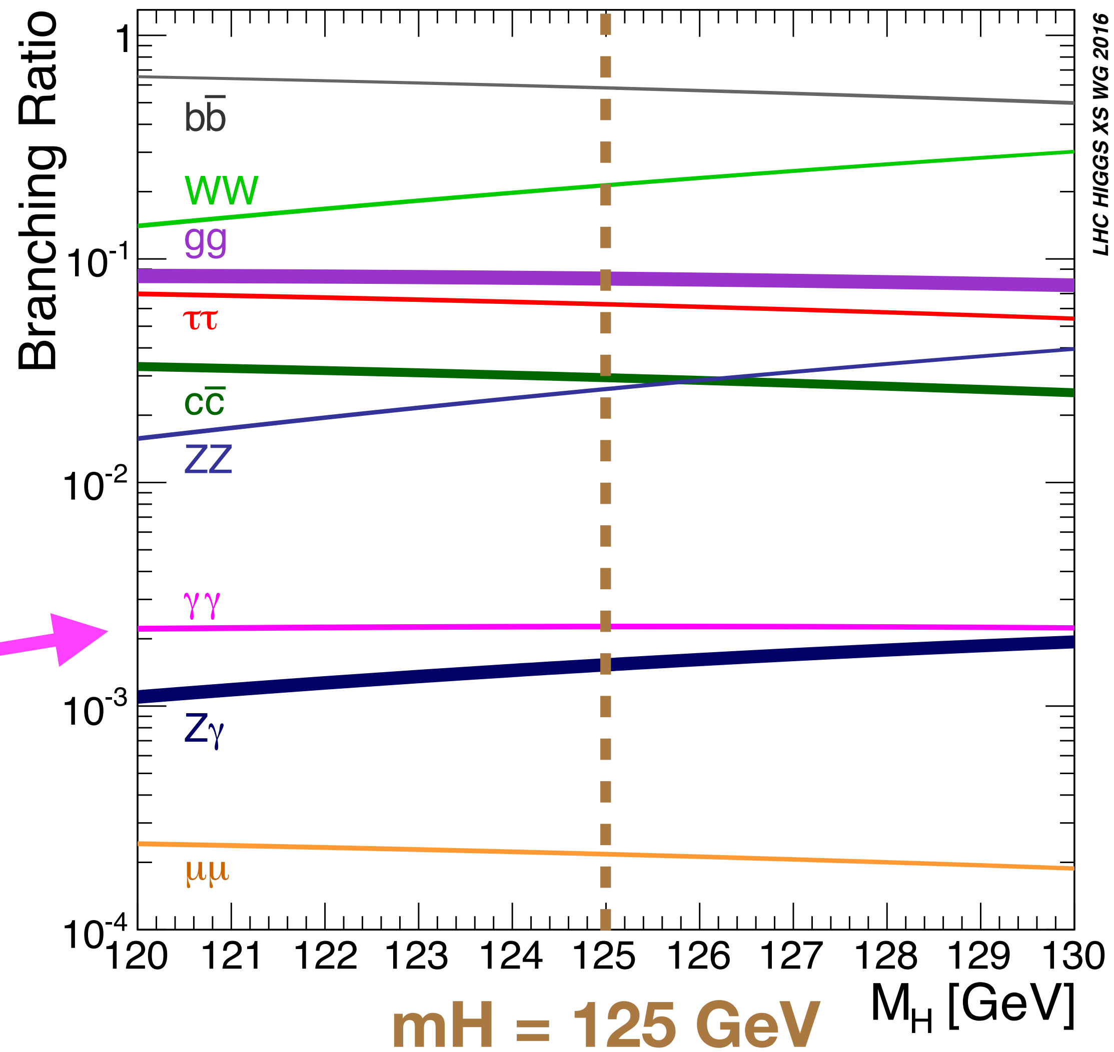
- **H —> WW**
- **H —> ZZ**
- **H —> γγ:** small branching ratio (0.2% @ 125 GeV) but profits by the clean signature and the high precision in reconstructing the diphoton invariant mass



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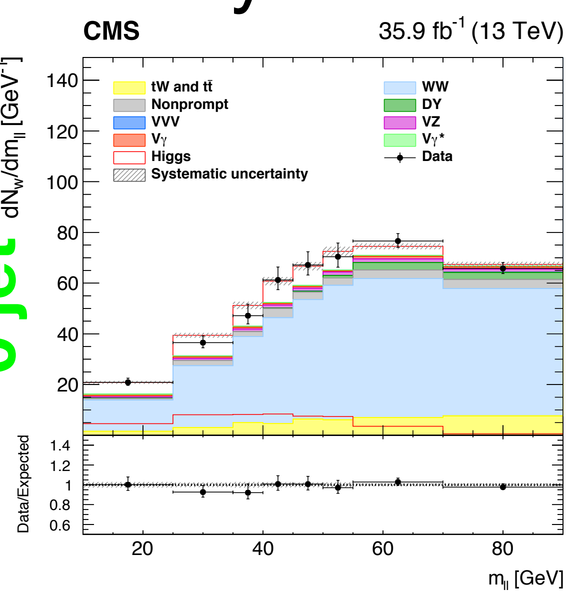
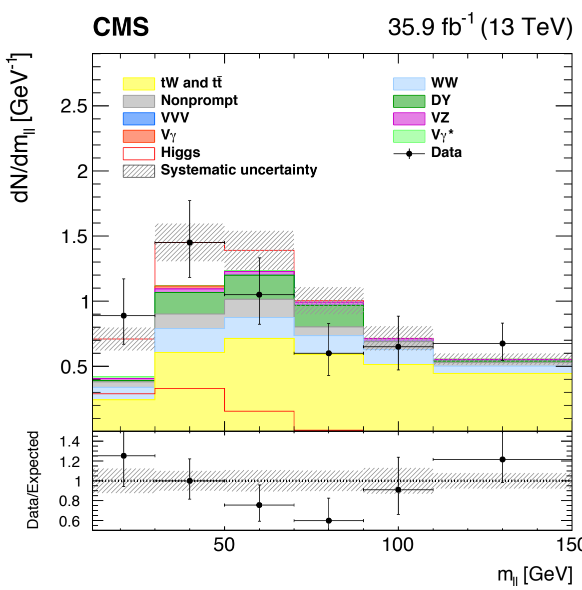
- H —> γγ

0 jet





$400<m_{jj}<700$

- Events categorised to enhance VBF and VH production mechanisms sensitivity.
- Non-resonant production of W boson pair is the **main (irreducible) background**. It is followed by the top quark contribution. Both backgrounds are evaluated from simulation and normalized from control regions in data
- The Drell-Yan contribution is relevant in ee and μμ final state but it is subdominant in the eμ

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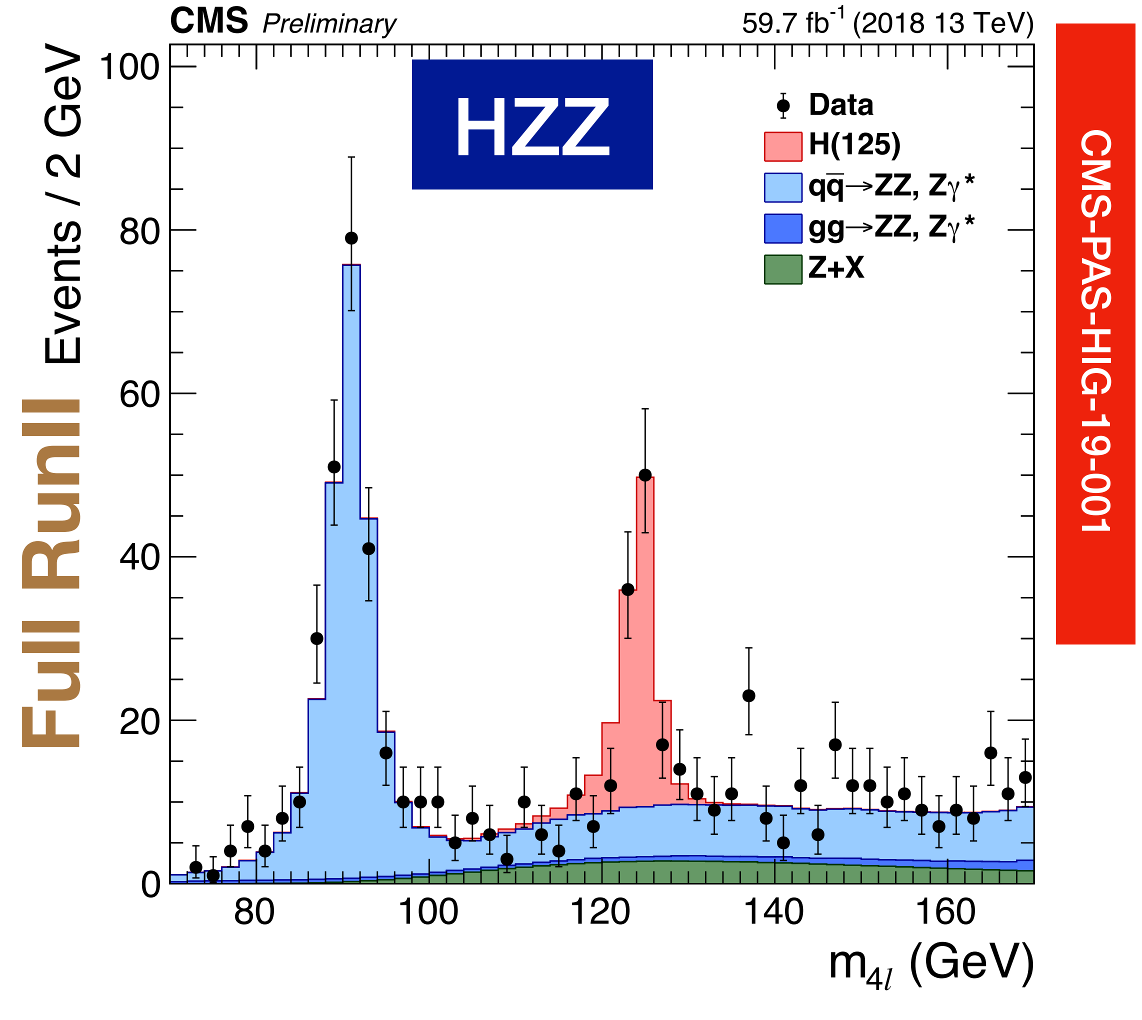
- H —> γγ

- Main (**irreducible**) background: **ZZ**
  Estimated using **simulation**

- Leptons produced by heavy-flavour jet or **jets** misidentified as leptons: Z + X
  Estimated from data



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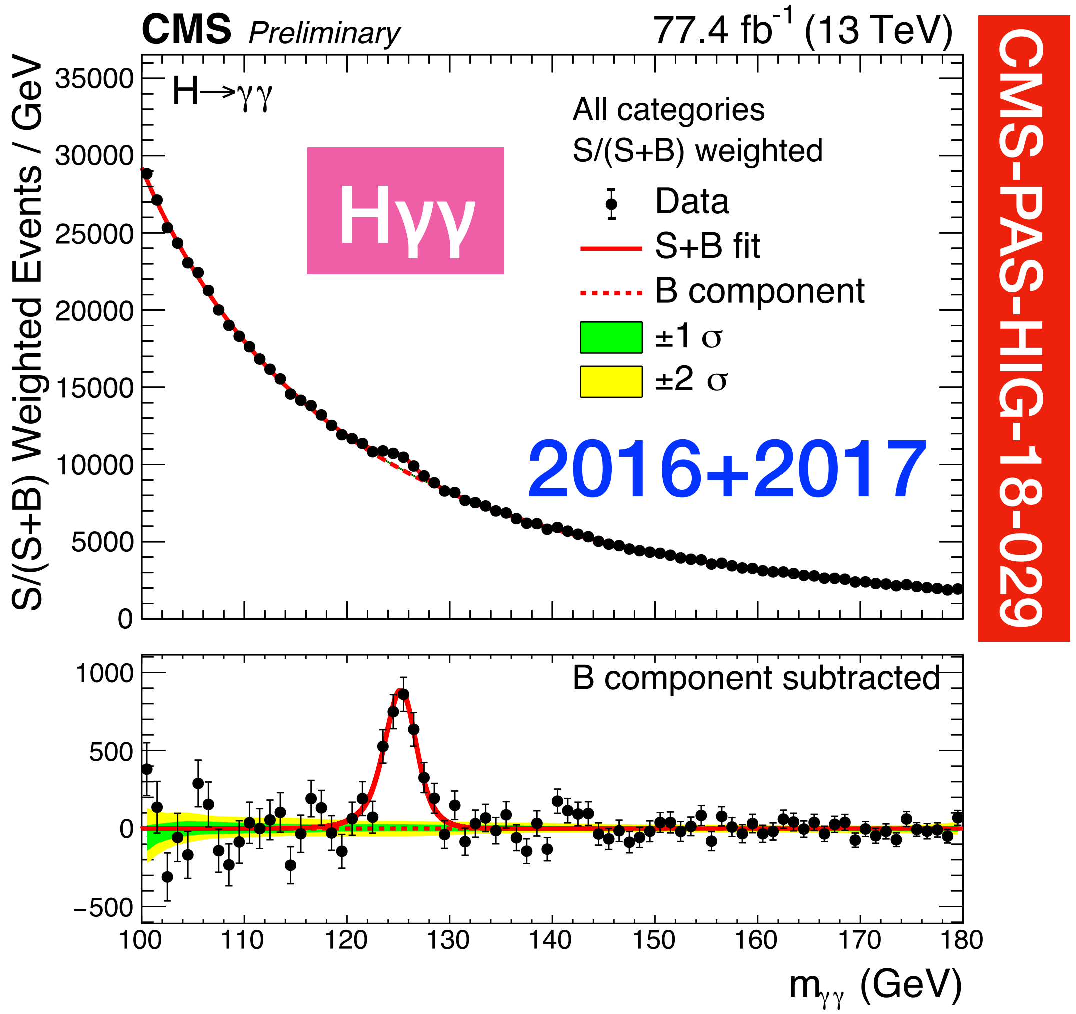
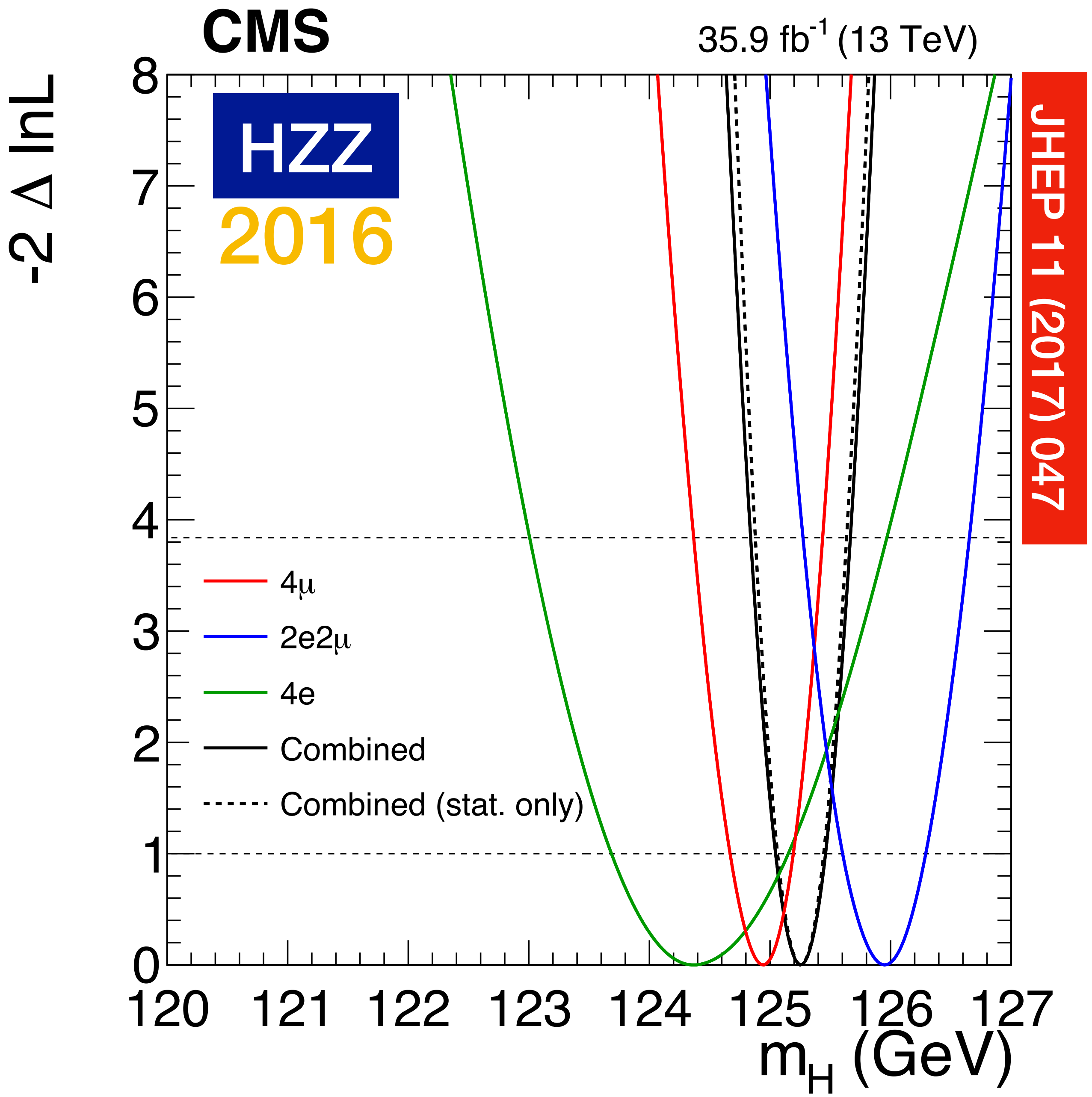


- Events classified targeting different production modes to improve sensitivity.
- Background modelled from data using analytical functions

1. Higgs mass



Latest mass measurement performed in the **HZZ** channel using 2016 dataset (35.9 /fb).

3D maximum likelihood fit has been implemented using:

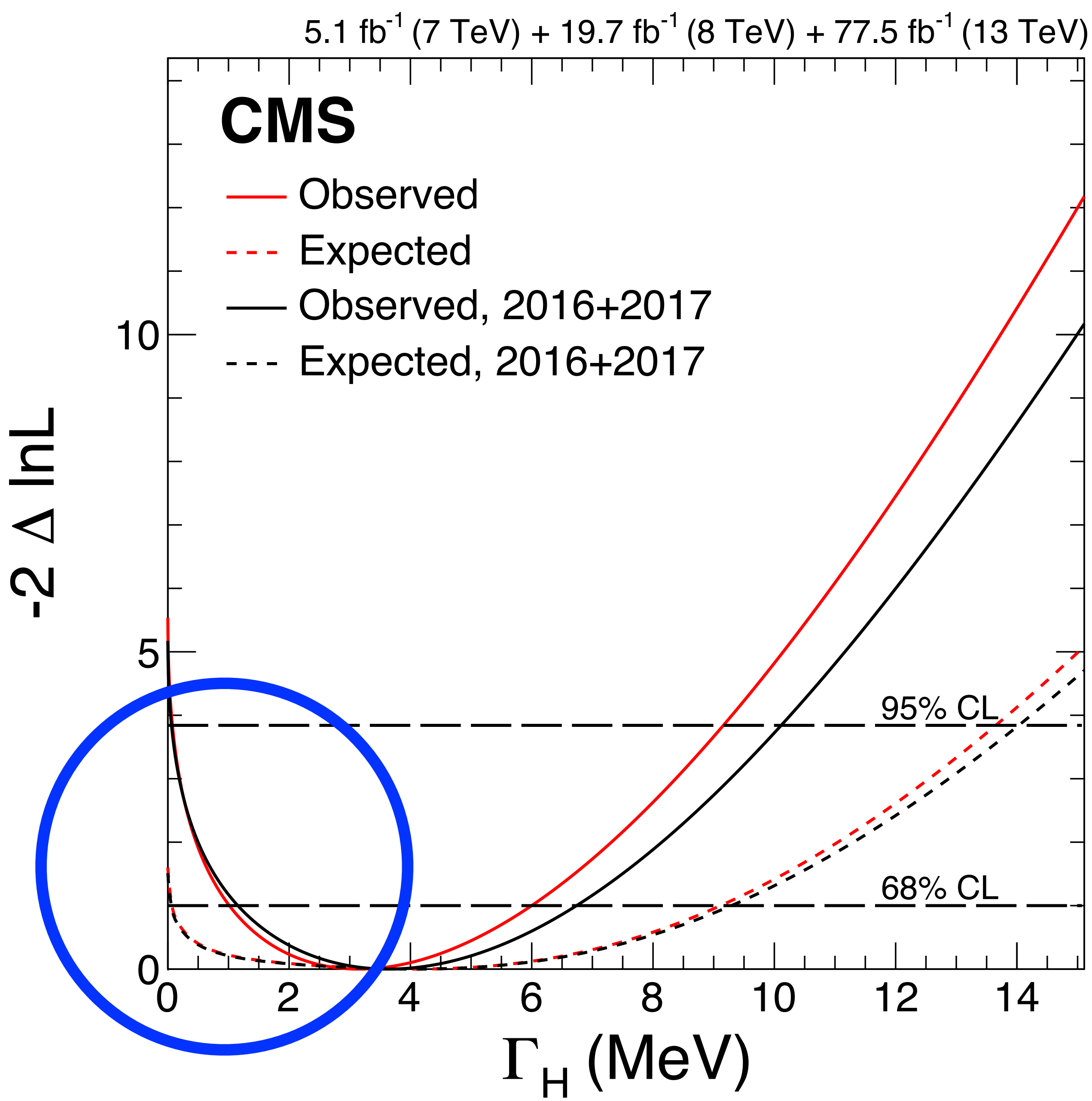
- four lepton mass ($m_{4\ell}$)
- event-by-event mass uncertainty
- kinematic discriminant

A mass constraint on the intermediate Z resonance has been exploited in order to improve $m_{4\ell}$ resolution

Best result up to now:

$$m_H = 125.26 \pm 0.21\ [0.20(stat) \pm 0.08(syst)]\ GeV$$

2. Higgs width



Phys. Rev. D 99, 112003 (2019)

Difficulties in directly measuring the width (4.07 MeV) due to detector resolution.

Measured in the H to 4ℓ channel, combining 2016-2017 data with RunI, comparing on-shell and off-shell production:

$$\frac{\sigma^{\text{on-shell}}_{gg\to H\to ZZ^*} \sim \frac{g^2_{ggH} g^2_{HZZ}}{m_H \Gamma_H}}{\sigma^{\text{off-shell}}_{gg\to H^*\to ZZ} \sim \frac{g^2_{ggH} g^2_{HZZ}}{(2m_Z)^2}}$$

Set a lower bound for the first time

Best result up to now:

$$\Gamma_H < 9.16 \ (exp\ 13.7)\ MeV\ @95\%\ C.L.$$

3. Higgs signal strength modifier

Signal strength modifier (μ) is defined as the ratio between the measured signal cross section and the SM expectation.

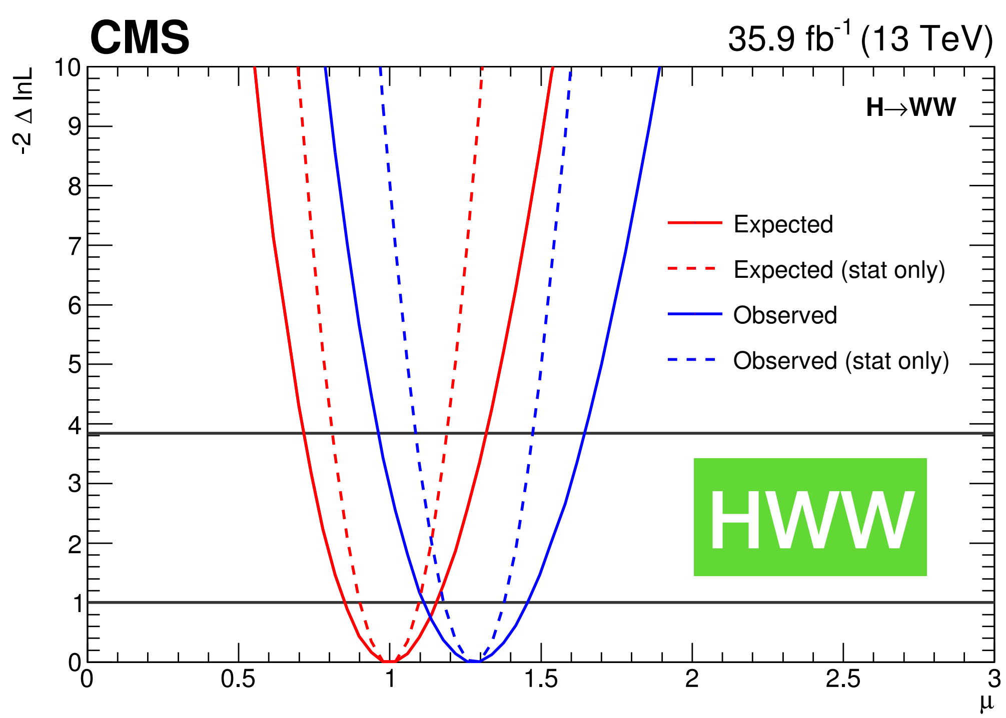
Full RunII 137/fb

HZZ

CMS-PAS-HIG-19-001

$$\mu_{HZZ} = 0.94 \,^{+0.07}_{-0.07}\,(stat)\,^{+0.08}_{-0.07}\,(syst)$$

2016



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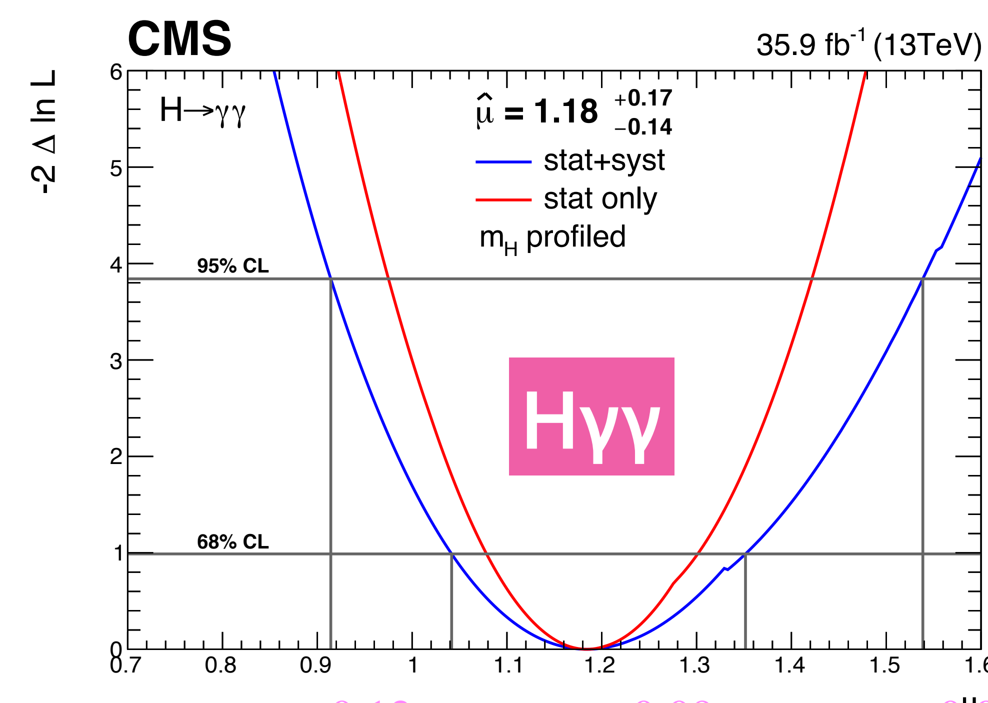
$$\mu_{HWW} = 1.28 \pm 0.10\,(stat) \pm 0.11\,(syst)\,^{+0.10}_{-0.07}\,(theo)$$



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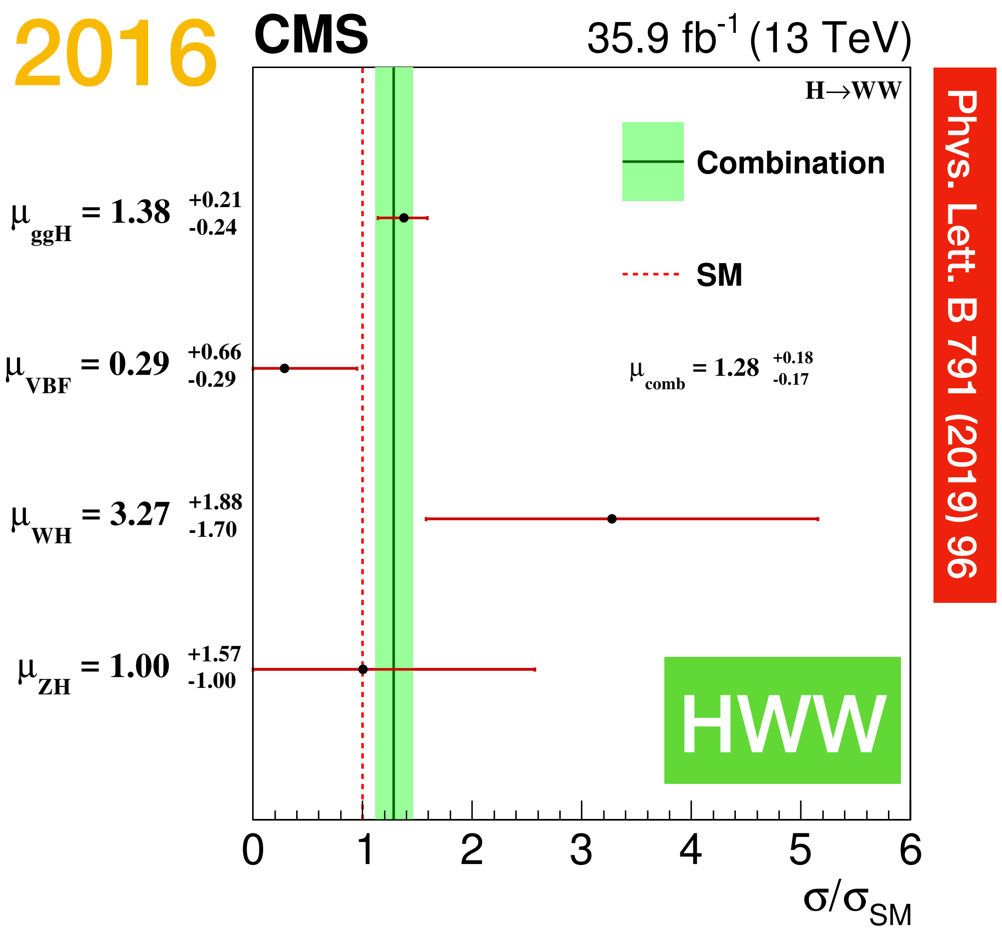
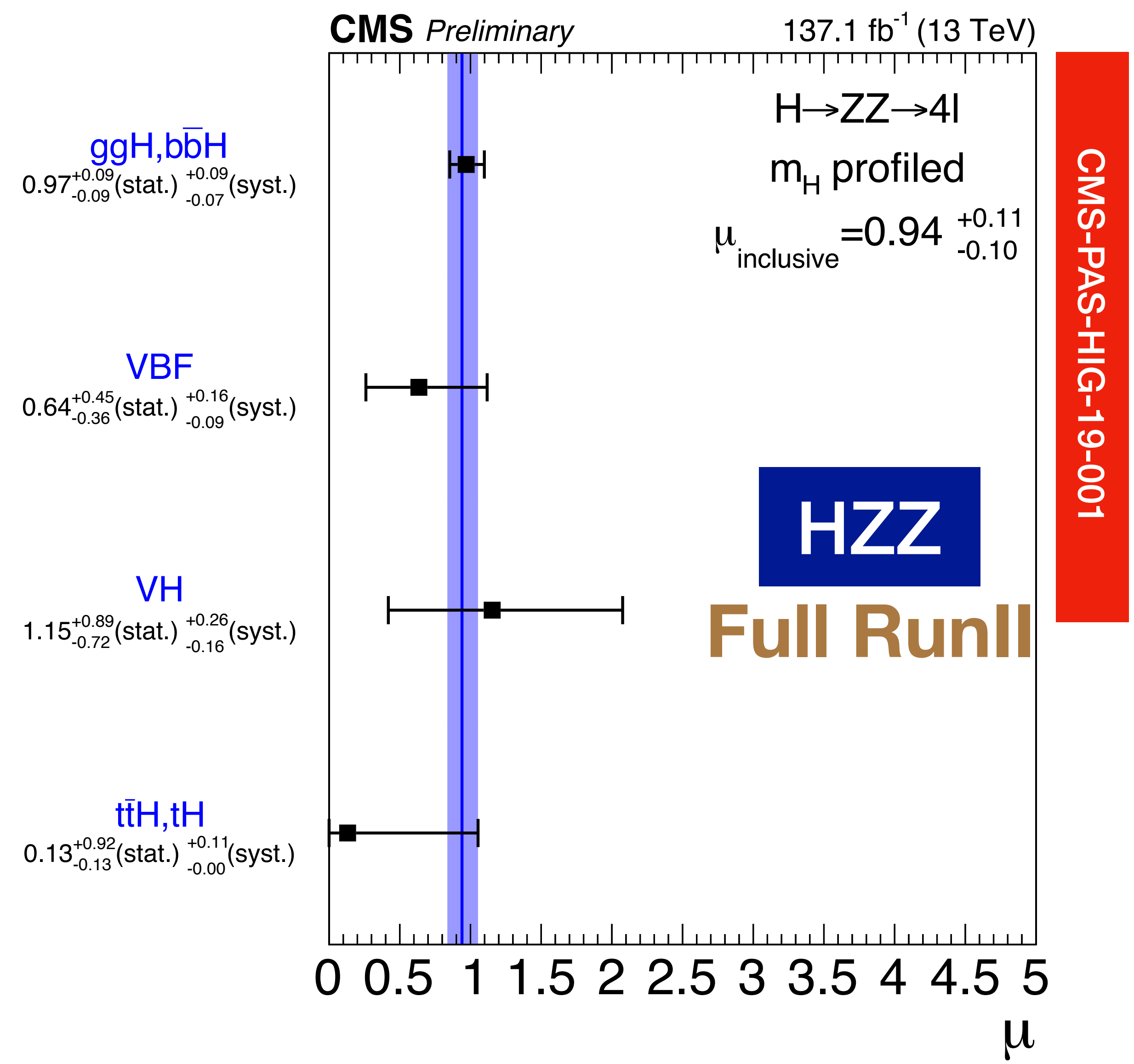
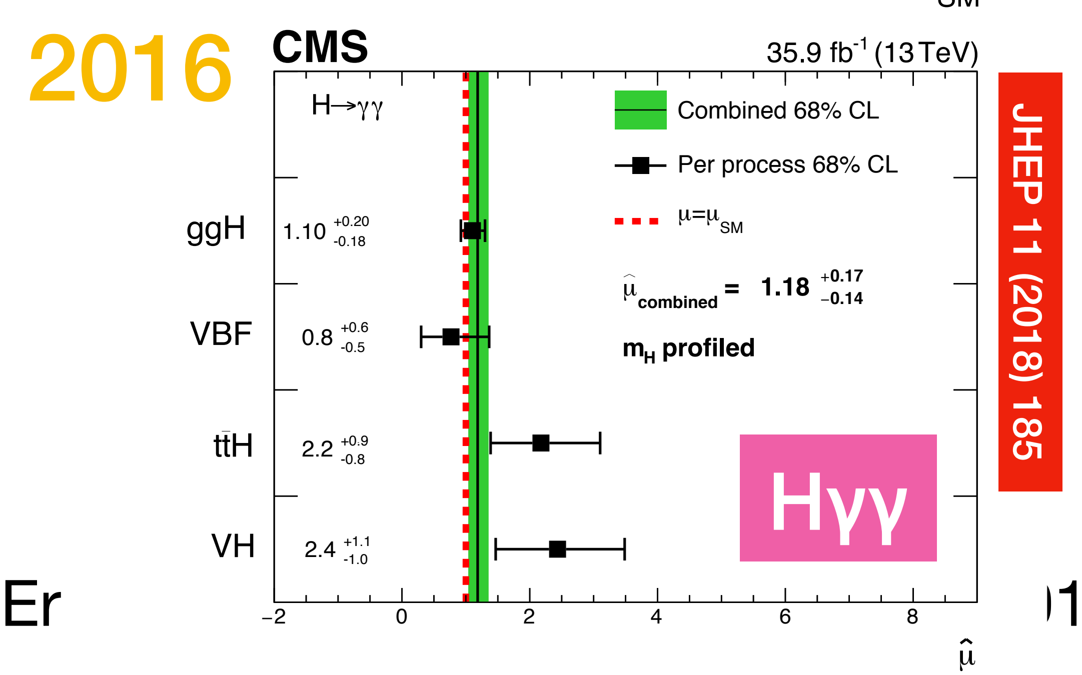
$$\mu_{H\gamma\gamma} = 1.18\,^{+0.12}_{-0.11}\,(stat)\,^{+0.09}_{-0.07}\,(syst)\,^{+0.07}_{-0.06}\,(theo)$$

3. μ by production modes

Signal strength modifier (μ) is defined as the ratio between the measured signal cross section and the SM expectation.







All signal strengths are in **agreement** with the SM prediction

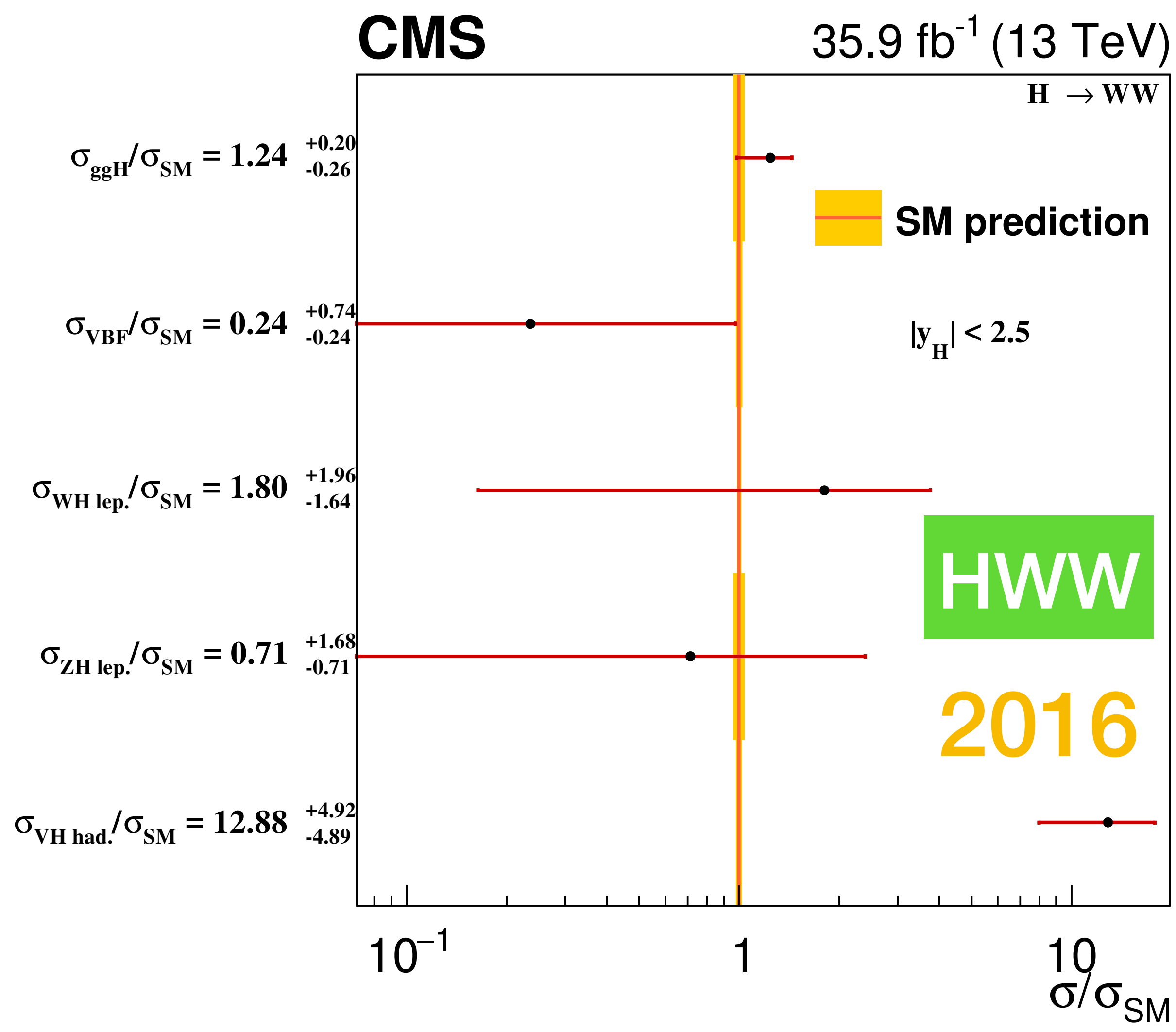
4. Simplified template cross sections

The simplified template cross section (STXS) tries to maximise the sensitivity of the measurement, minimising the dependence on the theory predictions, defining several kinematic regions using generator level information.

Different stages have been defined:
Stage 0: regions are equivalent to the different production modes

↓ Stage 1

Stage 1.1: other regions at high p_T or high mass have been introduced to study BSM physics.



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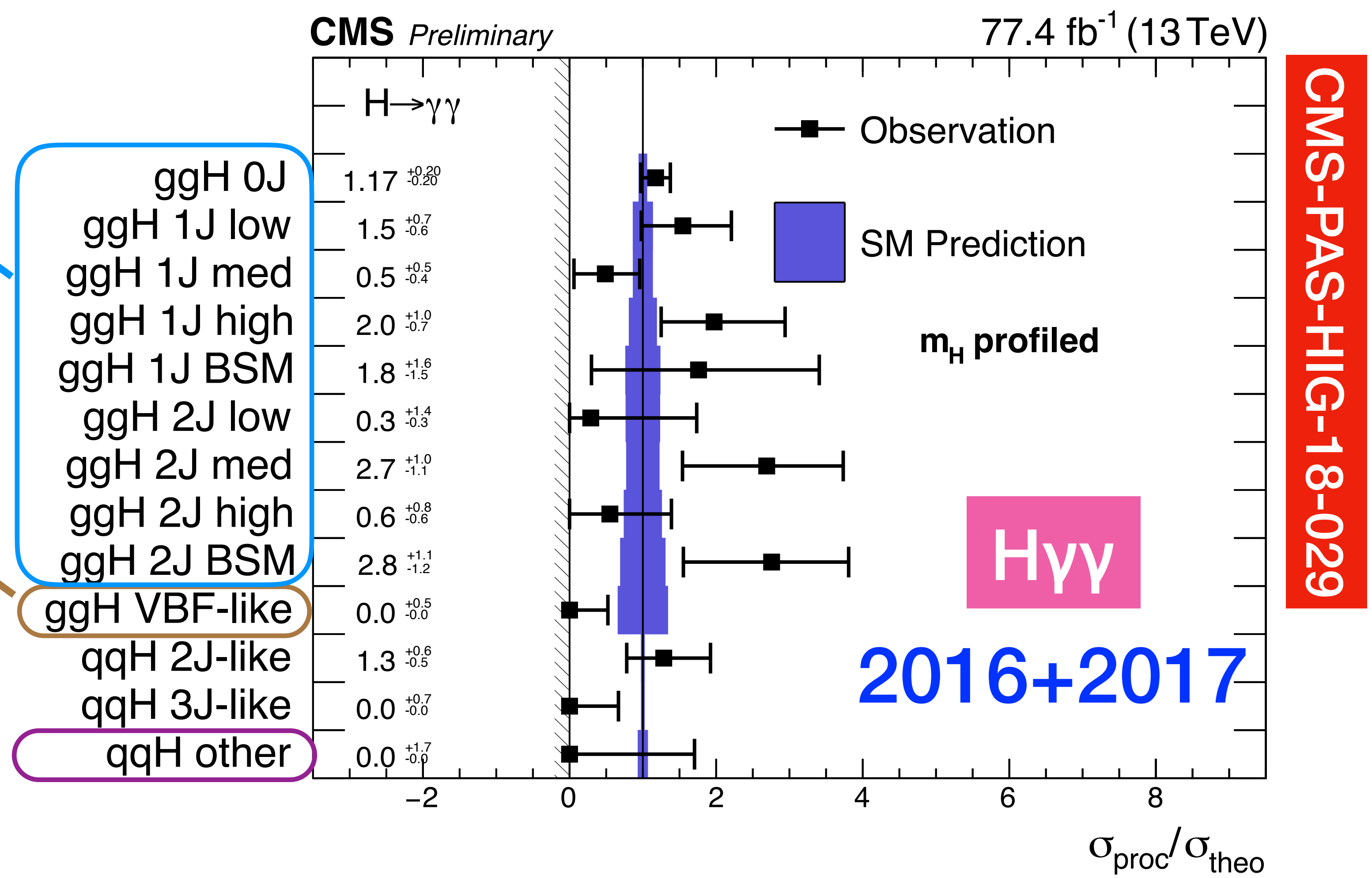
4. Simplified template cross sections

ggH (Stage 0)

Include the two VBF-like ggH bins (jets >= 2 & pT$_H$ < 200 GeV)

Contains VBF, VH-like, BSM-like and “rest” bins



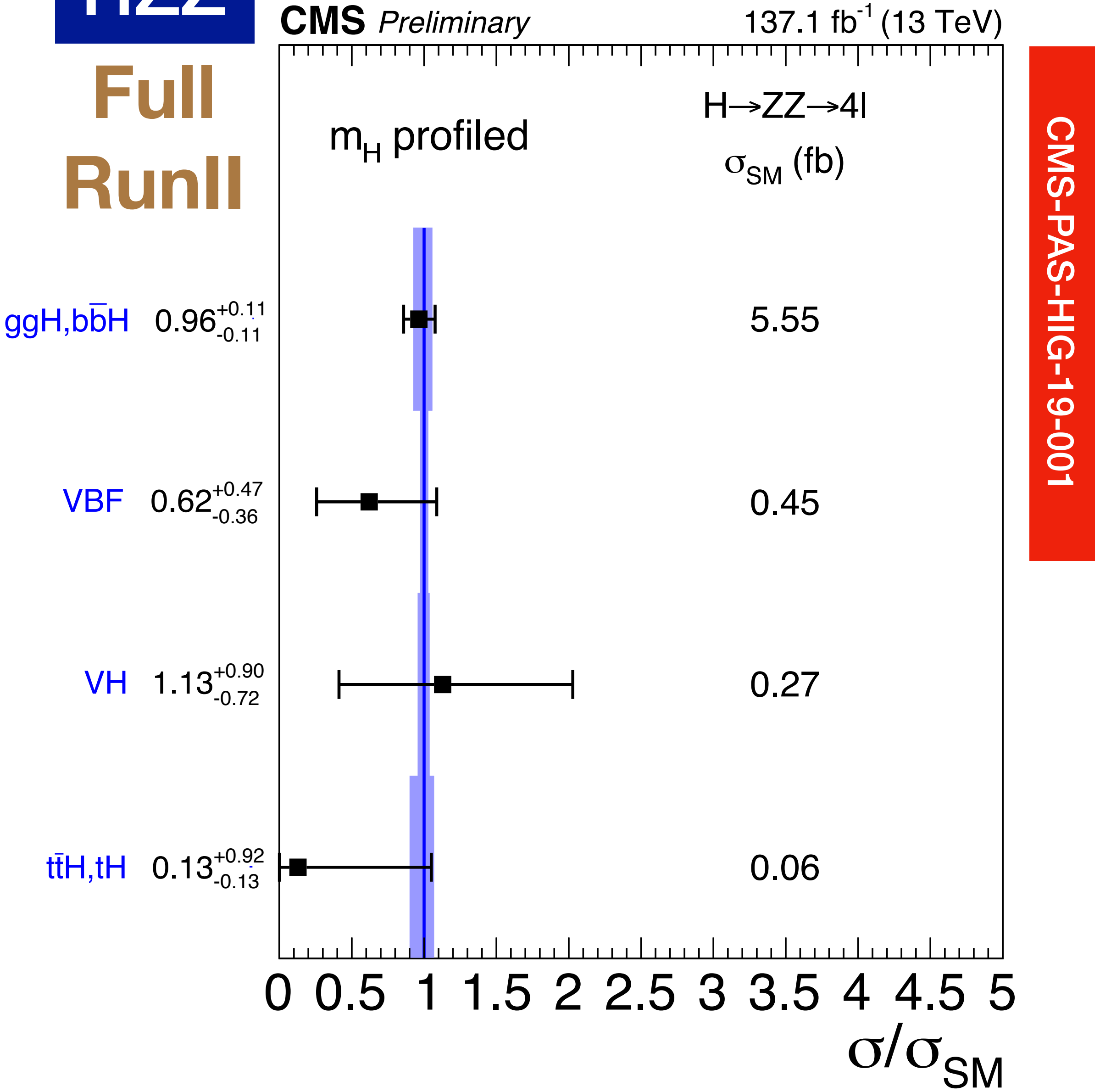
Due to large stat. uncertainties, some bins are merged trying to keep the most possible granularity.

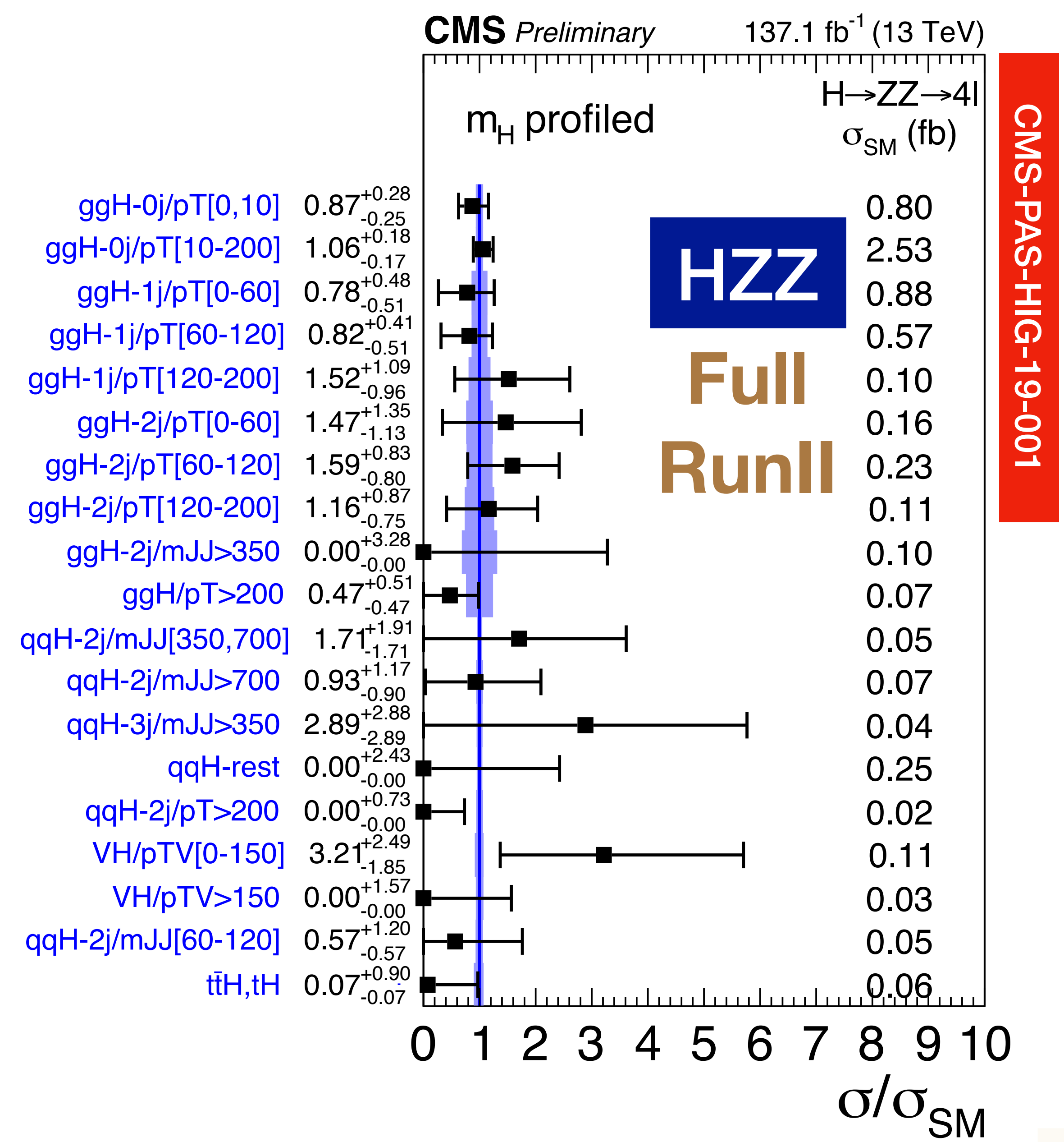
4. Simplified template cross sections

With more data (Full RunII, ~137 /fb), it is possible to have a finer split in the bins and test different regions.

STXS Stage 0 → STXS Stage 1.1

HZZ
Full RunII





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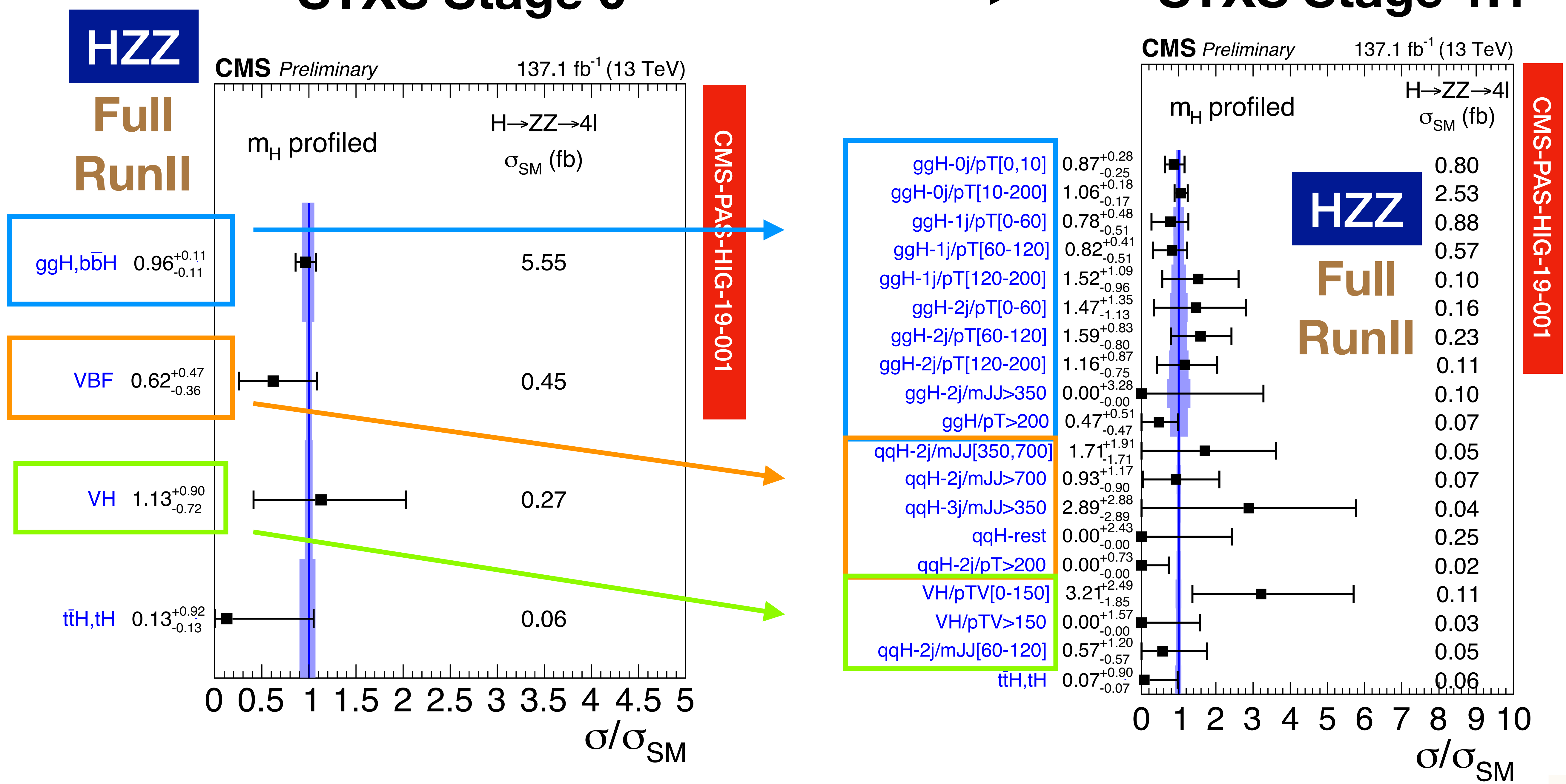

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5. Fiducial cross sections

- Cross section defined in a **fiducial phase space**.
- Volume defined by a set of **selection criteria at generator level** based on kinematic, geometrical variables and on the topology of the event.
- The idea is to **minimise the dependence on theoretical uncertainties**.

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HZZ fiducial volume

unique definition independent from the observable under study. Based on lepton kinematic cuts and isolation requirements with some restrictions on the dilepton and four-lepton system.

Hγγ fiducial volume

baseline defined for all the observables considering γ-p_T and diphoton mass, η and isolation requirement. On top of these, **other cuts** are imposed depending on the observable under study.

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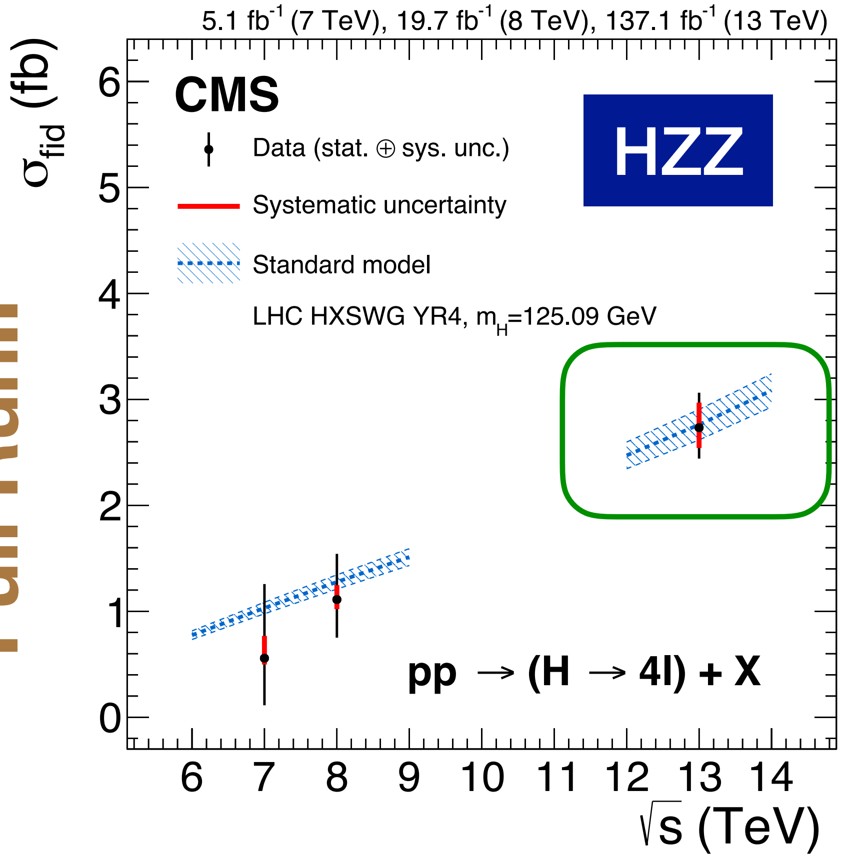
- Fiducial (differential) cross section obtained by performing a **maximum likelihood fit of the invariant mass spectrum** $m_{4\ell}$ or $m_{2\gamma}$

5. Fiducial cross sections

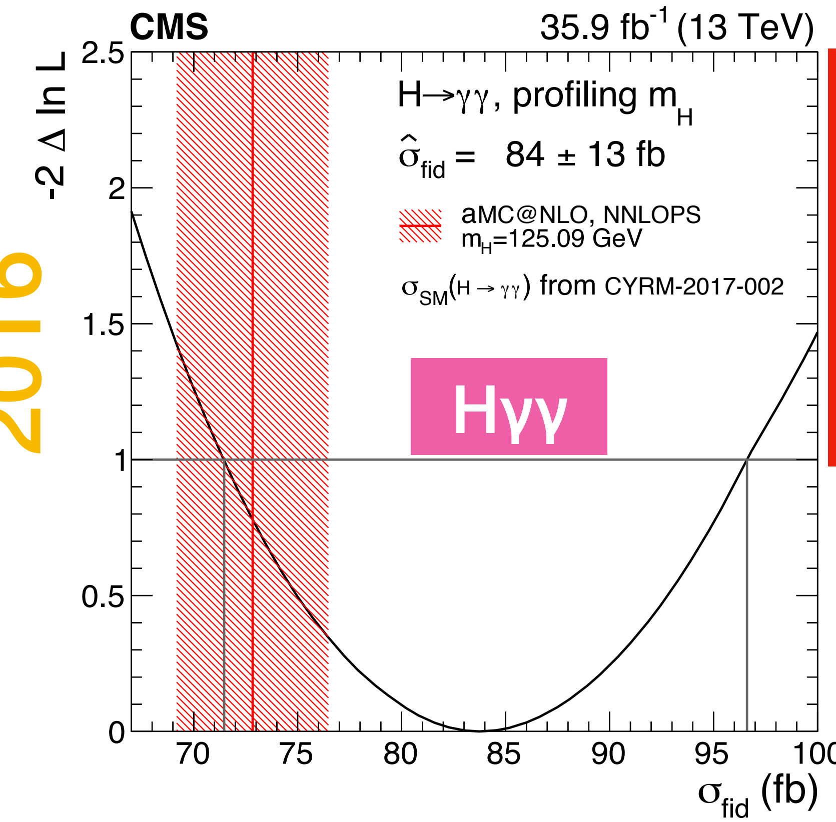
Full RunII



CMS-PAS-HIG-19-001

$$\sigma_{fid} = 2.73^{+0.30}_{-0.29}\ fb \qquad \sigma_{fid}^{theo} = 2.76 \pm 0.14\ fb$$

2016



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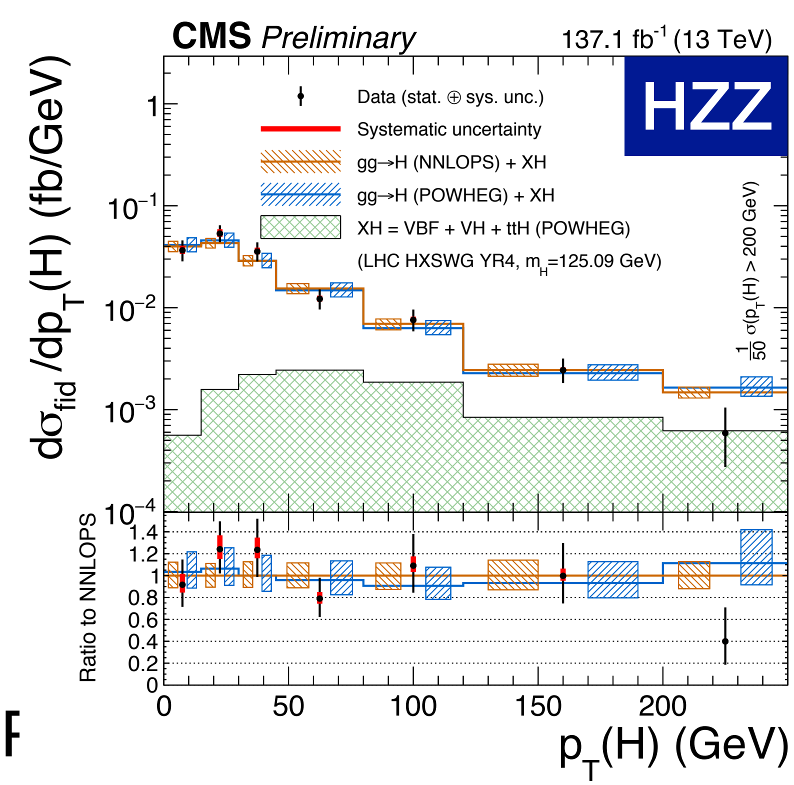
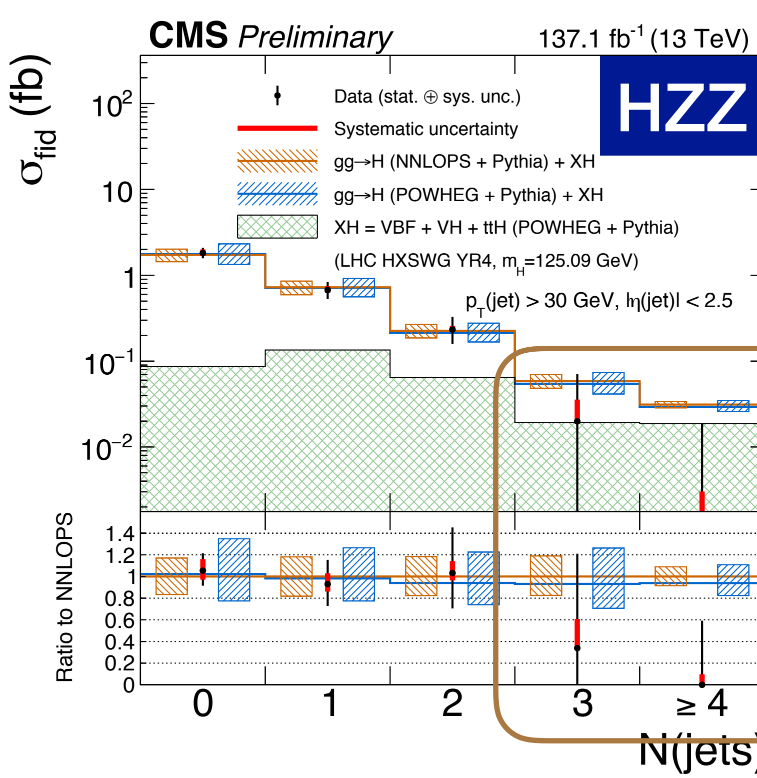
$$\sigma_{fiducial} = 84 \pm 13\ fb$$

$$\sigma_{fiducial}^{theory} = 73 \pm 4\ fb$$

Full RunII



CMS-PAS-HIG-19-001



CMS-PAS-HIG-19-001

Even with full RunII data, there are large stat. uncertainties

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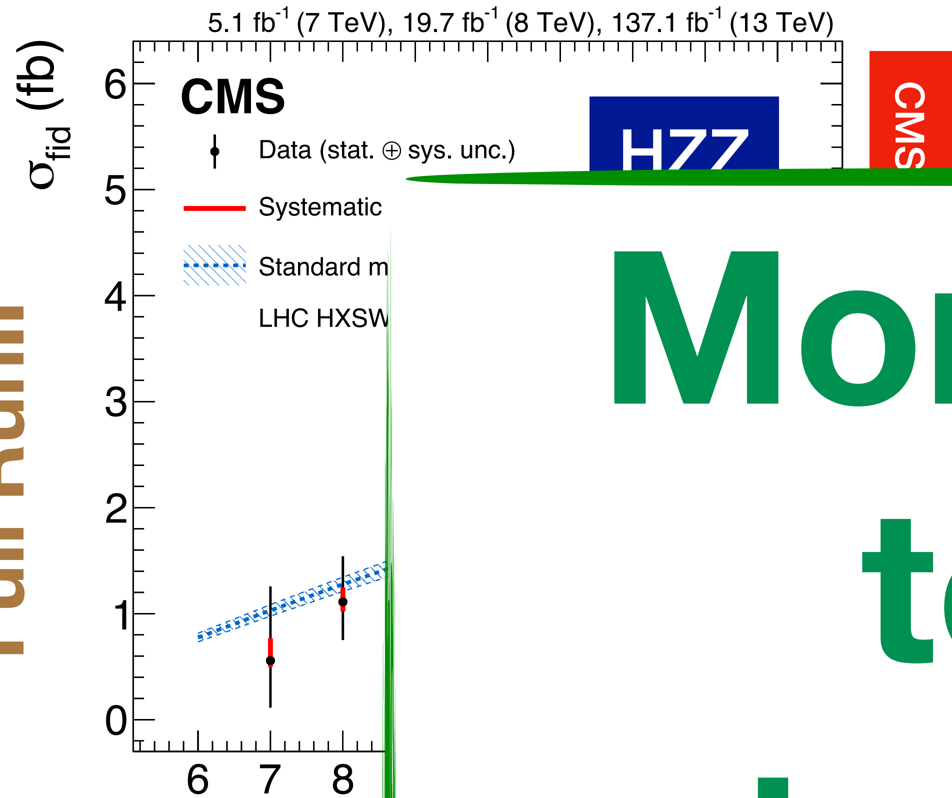
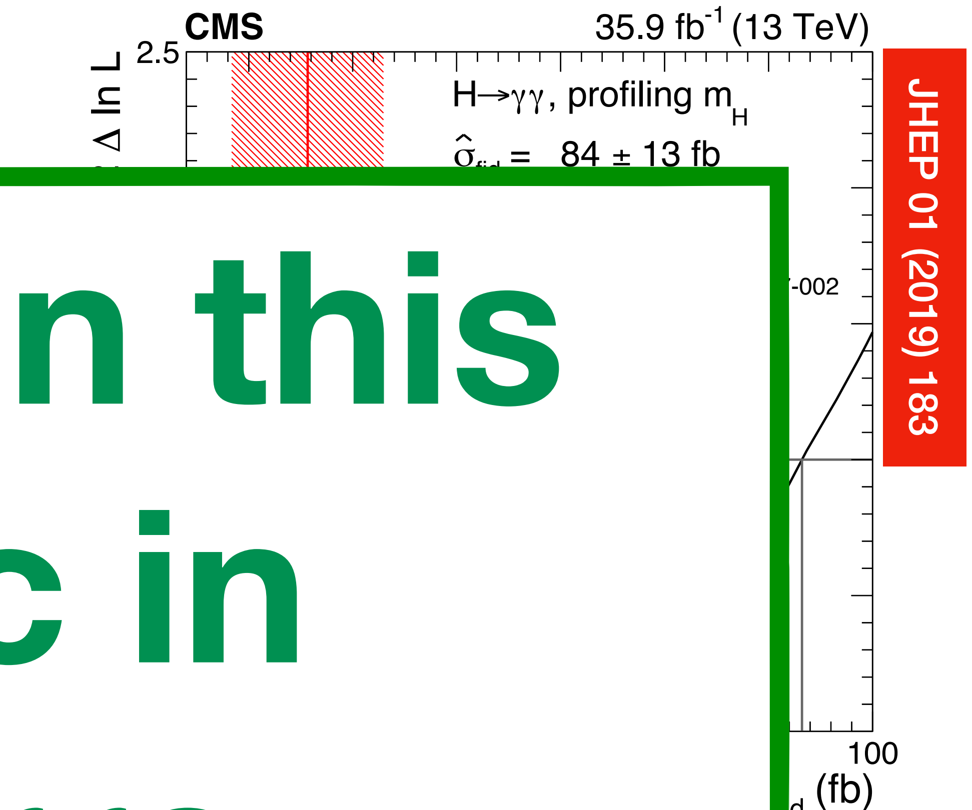
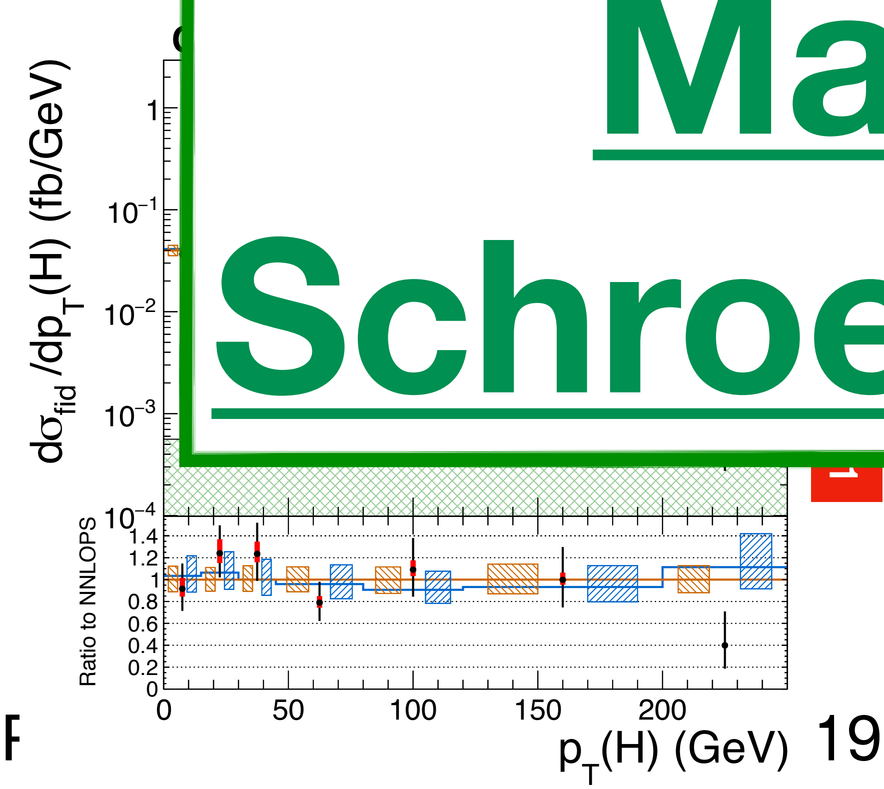


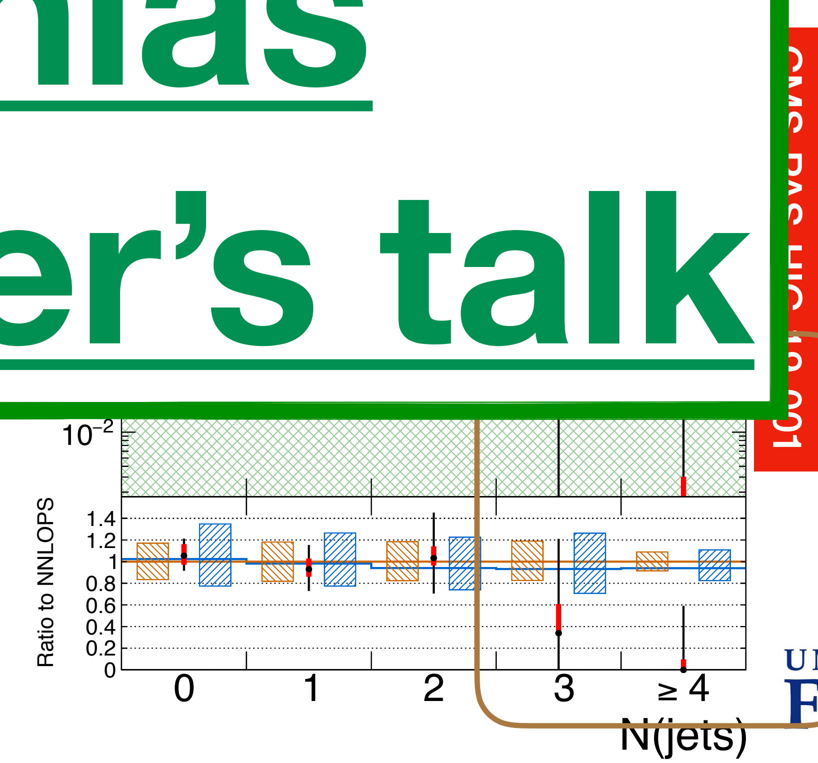


$\sigma_{fid} = 2.73^{+0.}_{-0.}$ ... fb

More on this topic in tomorrow <u>Matthias Schroeder's talk</u>

Full RunII





Even with full RunII data, there are large stat. uncertainties

Summary

Higgs boson properties, measured in bosonic final states at CMS, have been presented.

- VV (V = **W** or **Z**) and $\gamma\gamma$ decay channels have been considered.
- Best results up to now:
  - ★ mass m_H = 125.26 ± 0.21 GeV
  - ★ width Γ_H < 9.16 MeV @ 95% C.L.
- Latest CMS results:
  - ✤ STXS using **full Run II** data in **HZZ**, the combination of 2016 + 2017 data in **H$\gamma\gamma$** and 2016-only data in **HWW**
  - ✤ fiducial (differential) cross section using **full Run II** data in **HZZ** and 2016-only data in **H$\gamma\gamma$**
- No deviations from SM expectations have been observed.
- Looking forward to analyse (and collect) more data to test BSM physics.

Thanks for the attention

To further discuss about the content of this presentation, please contact me at
filippo.errico@cern.ch

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CMS

Backup

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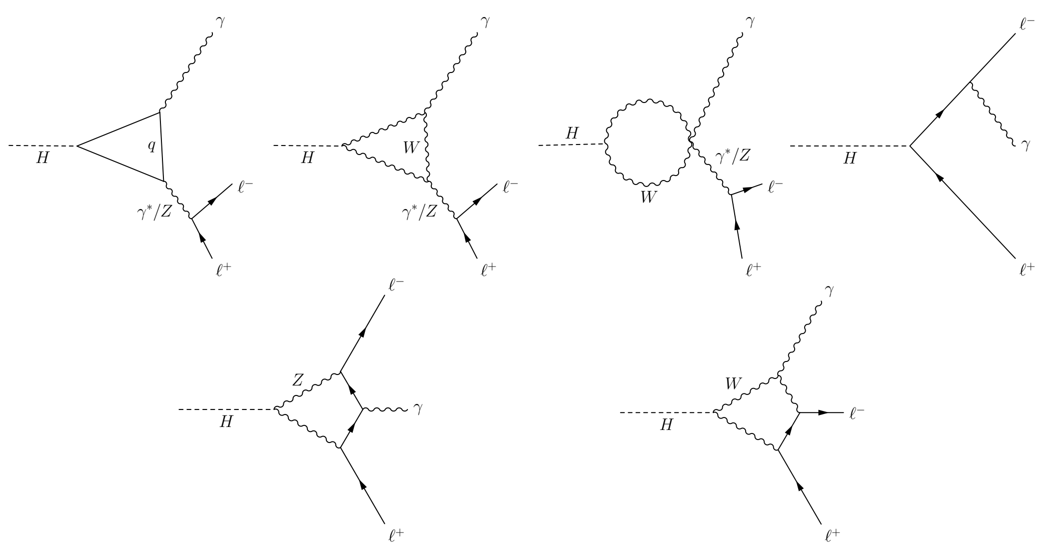
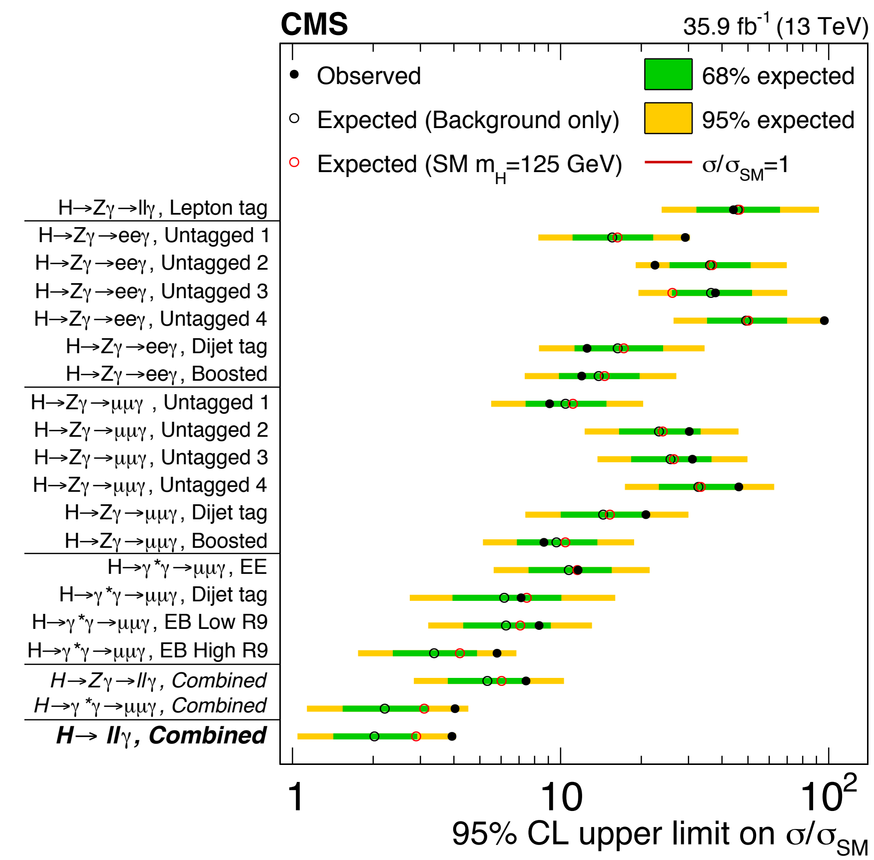
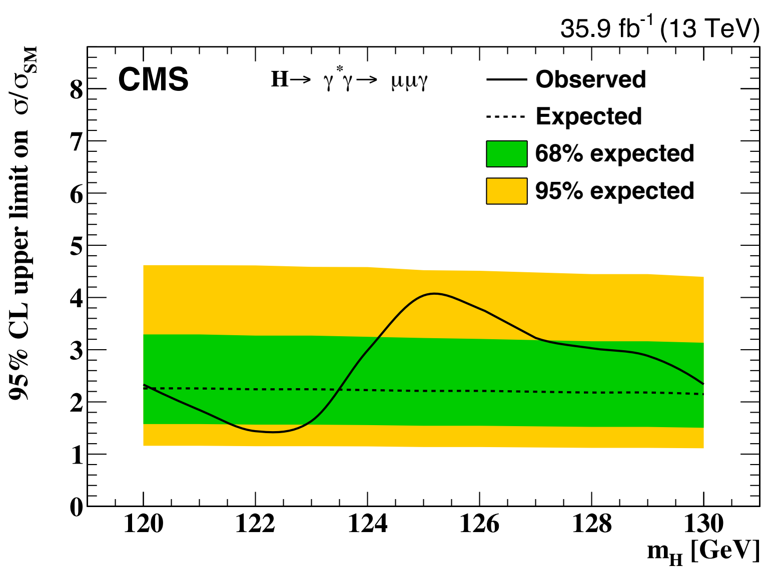
H —> Zγ

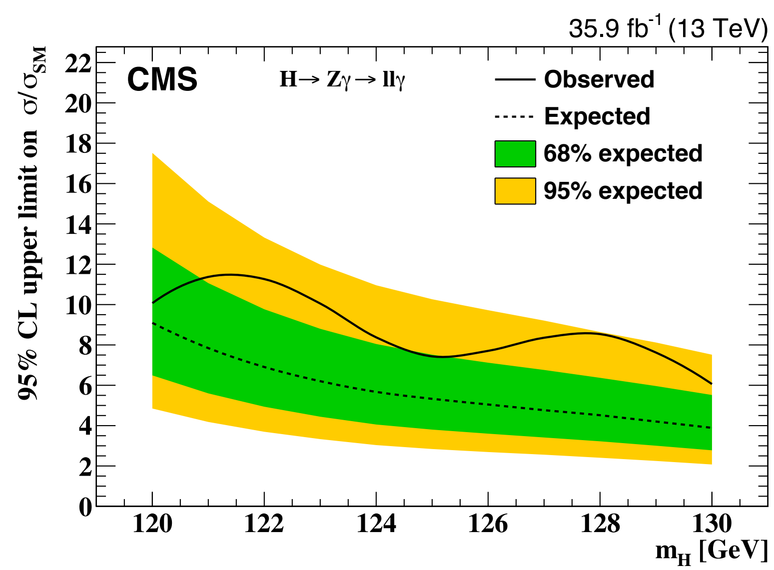
2016



Dominant Feynman diagrams contributing to the H—> ℓℓγ process







Combination:
Exp (obs) limits: 2.0 (3.9) times the SM XS at 125 GeV @ 95% C.L.

pValue Exp(obs) = 0.02 (0.16) corresponding to ~2σ (~1σ)

H—>γ*γ—> μμγ

Exp (obs) limits: 2.1 - 2.3 (1.4 - 4.0) times the SM XS

H—>Zγ—> ℓℓγ

Exp (obs) limits: 3.9 - 9.1 (6.1 - 11.4) times the SM XS

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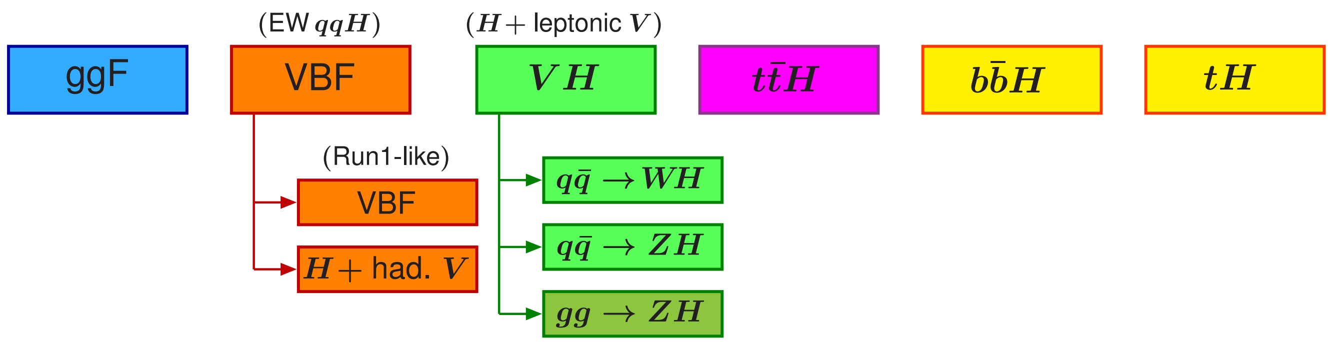
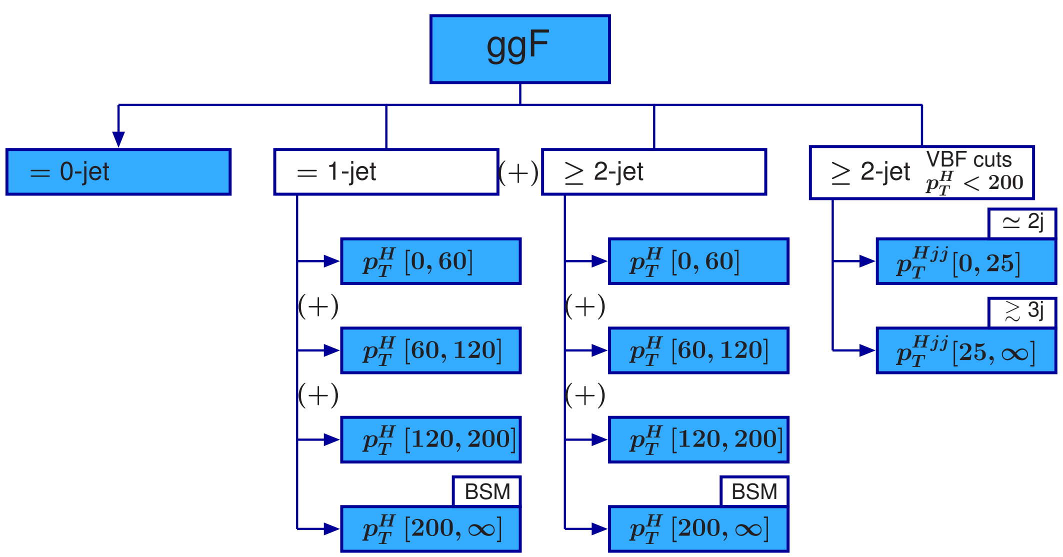
STXS

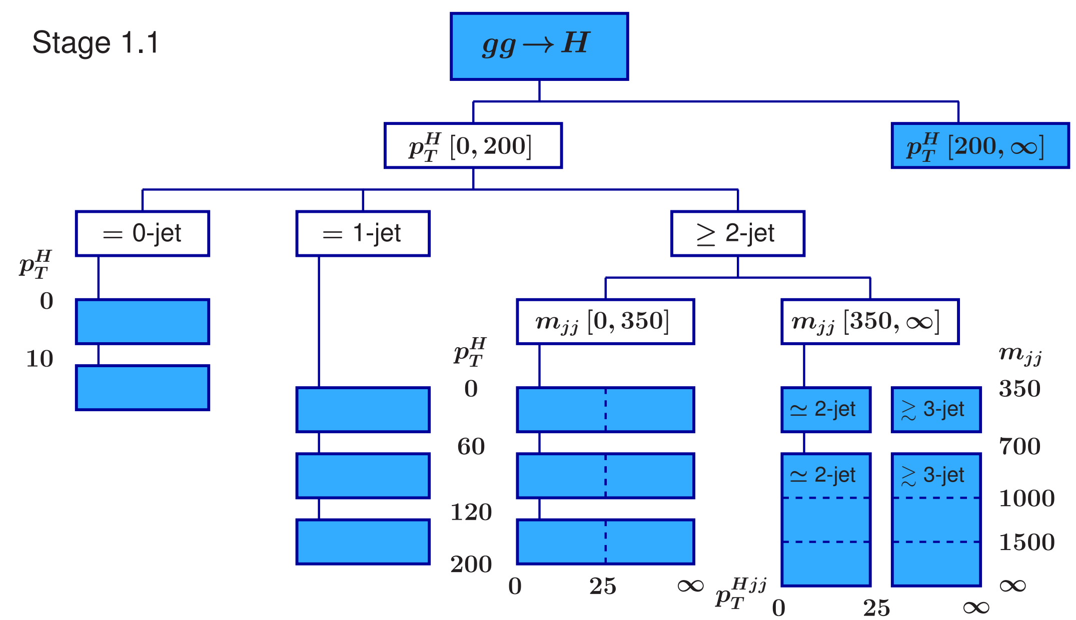


Stage 0

ggF: Stage 1

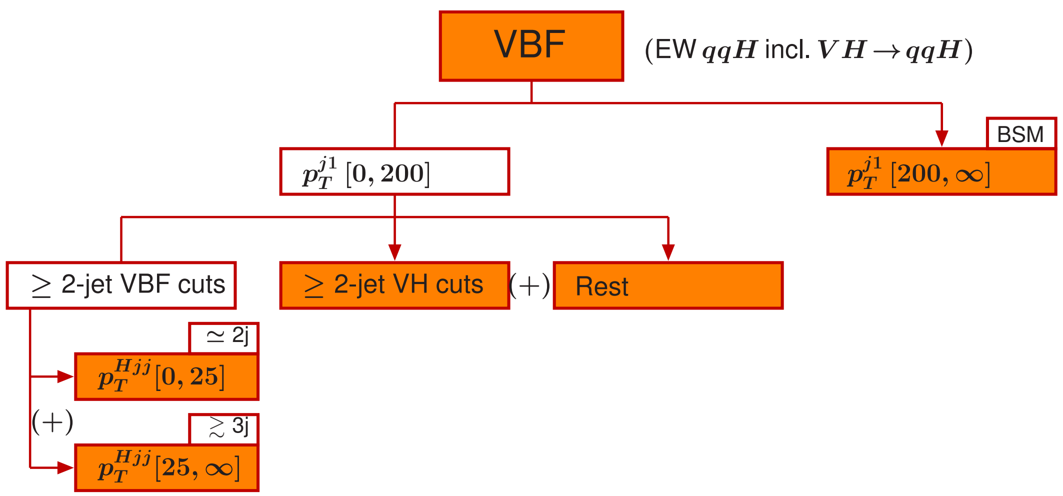


ggF: Stage 1.1

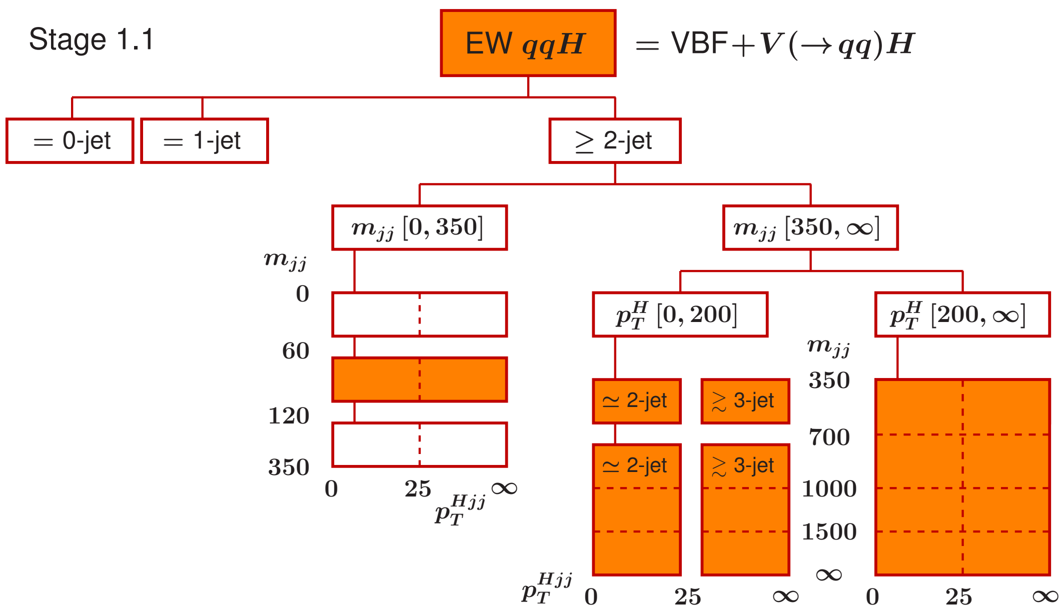


STXS

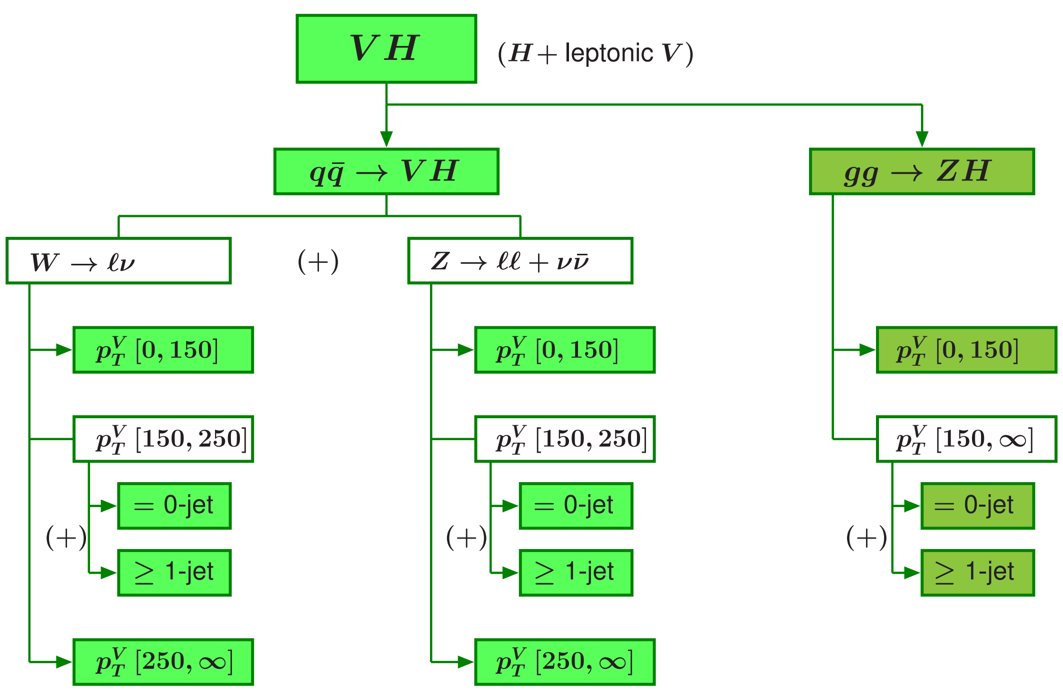
VBF: Stage 1



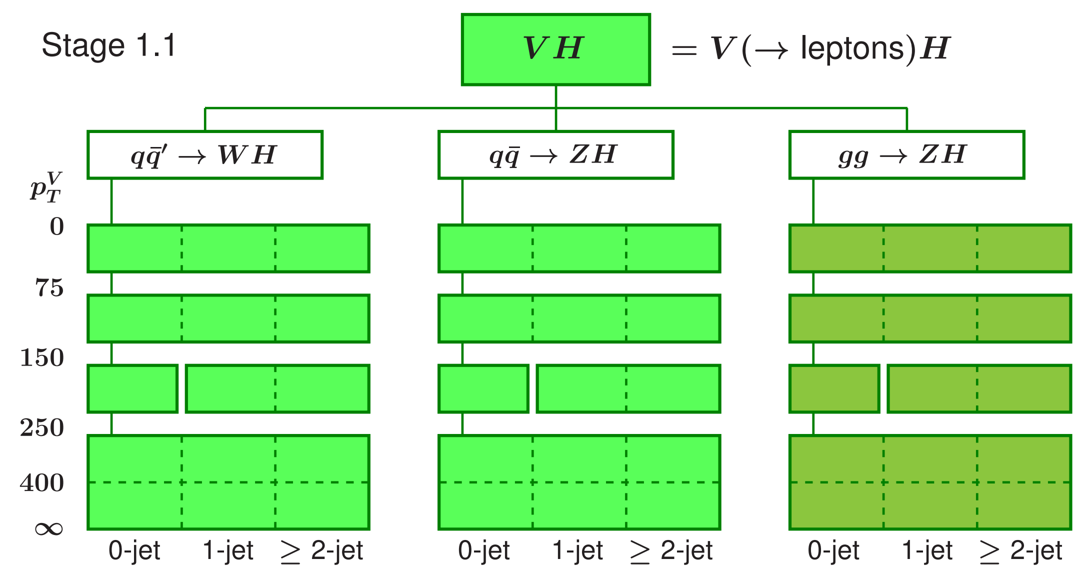
VBF: Stage 1.1



VH: Stage 1



VH: Stage 1.1



Fiducial phase space

Hγγ

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Phase space	Observable	Bin boundaries								
Baseline $p_T^{\gamma_1}/m_{\gamma\gamma} > 1/3$ $p_T^{\gamma_2}/m_{\gamma\gamma} > 1/4$ $\lvert\eta^\gamma\rvert < 2.5$ $\mathrm{Iso}_{\mathrm{gen}}^{\gamma} < 10\,\mathrm{GeV}$	$p_T^{\gamma\gamma}$ (GeV)	0	15	30	45	80	120	200	350	∞
	N_{jet}	0	1	2	3	4	∞			
	$\lvert y^{\gamma\gamma}\rvert$	0	0.15	0.3	0.6	0.9	2.5			
	$\lvert\cos(\theta^*)\rvert$	0	0.1	0.25	0.35	0.55	1			
	$p_T^{\gamma\gamma}$ (GeV), $N_{\mathrm{jet}} = 0$	0	20	60	∞					
	$p_T^{\gamma\gamma}$ (GeV), $N_{\mathrm{jet}} = 1$	0	60	120	∞					
	$p_T^{\gamma\gamma}$ (GeV), $N_{\mathrm{jet}} > 1$	0	150	300	∞					
	$N_{\mathrm{jet}}^{\mathrm{b}}$	0	1	2	∞					
	N_{lepton}	0	1	2	∞					
	p_T^{miss} (GeV)	0	100	200	∞					
1-jet Baseline + $\geq$1 jet $p_T^j > 30\,\mathrm{GeV}$, $\lvert\eta^j\rvert < 2.5$	$p_T^{j_1}$ (GeV)	0	45	70	110	200	∞			
	$\lvert y^{j_1}\rvert$	0	0.5	1.2	2	2.5				
	$\lvert\Delta\phi^{\gamma\gamma,j_1}\rvert$	0	2.6	2.9	3.03	π				
	$\lvert\Delta y^{\gamma\gamma,j_1}\rvert$	0	0.6	1.2	1.9	∞				
2-jets Baseline + $\geq$2 jets $p_T^j > 30\,\mathrm{GeV}$, $\lvert\eta^j\rvert < 4.7$	$p_T^{j_2}$ (GeV)	0	45	90	∞					
	$\lvert y^{j_2}\rvert$	0	1.2	2.5	4.7					
	$\lvert\Delta\phi^{j_1,j_2}\rvert$	0	0.9	1.8	π					
	$\lvert\Delta\phi^{\gamma\gamma,j_1j_2}\rvert$	0	2.9	3.05	π					
	$\lvert\overline{\eta}_{j_1j_2} - \eta_{\gamma\gamma}\rvert$	0	0.5	1.2	∞					
	$m^{j_1j_2}$ (GeV)	0	100	150	450	1000	∞			
	$\lvert\Delta\eta^{j_1,j_2}\rvert$	0	1.6	4.3	∞					
VBF-enriched 2-jets + $\lvert\Delta\eta^{j_1,j_2}\rvert > 3.5$, $m^{j_1j_2} > 200\,\mathrm{GeV}$	$p_T^{j_2}$ (GeV)	0	45	90	∞					
	$\lvert\Delta\phi^{j_1,j_2}\rvert$	0	0.9	1.8	π					
	$\lvert\Delta\phi^{\gamma\gamma,j_1j_2}\rvert$	0	2.9	3.05	π					

HZZ

CMS-PAS-HIG-19-001

Requirements for the $\mathrm{H} \to 4\ell$ fiducial phase space	
Lepton kinematics and isolation	
Leading lepton p_T	$p_T > 20$ GeV
Next-to-leading lepton p_T	$p_T > 10$ GeV
Additional electrons (muons) p_T	$p_T > 7(5)$ GeV
Pseudorapidity of electrons (muons)	$\lvert\eta\rvert < 2.5(2.4)$
Sum of scalar p_T of all stable particles within $\Delta R < 0.3$ from lepton	$< 0.35 \cdot p_T$
Event topology	
Existence of at least two same-flavor OS lepton pairs, where leptons satisfy criteria above	
Inv. mass of the Z_1 candidate	$40\,\mathrm{GeV} < m_{Z_1} < 120\,\mathrm{GeV}$
Inv. mass of the Z_2 candidate	$12\,\mathrm{GeV} < m_{Z_2} < 120\,\mathrm{GeV}$
Distance between selected four leptons	$\Delta R(\ell_i, \ell_j) > 0.02$ for any $i \neq j$
Inv. mass of any opposite sign lepton pair	$m_{\ell^+\ell'^-} > 4\,\mathrm{GeV}$
Inv. mass of the selected four leptons	$105\,\mathrm{GeV} < m_{4\ell} < 140\,\mathrm{GeV}$

HZZ: fiducial cross sections

Fiducial (differential) cross section obtained performing a maximum likelihood fit of the signal and background parameterisations to the observed $m_{4\ell}$ distribution, $N_{obs}(m_{4\ell})$

$$N^{f,i}_{obs}(m_{4\ell}) = N^{f,i}_{fid}(m_{4\ell}) + N^{f,i}_{nonfid}(m_{4\ell}) + N^{f,i}_{nonres}(m_{4\ell}) + N^{f,i}_{bkg}(m_{4\ell})$$
$$= \epsilon^{f}_{i,j} \cdot \left(1 + f^{f,i}_{nonfid}\right) \cdot \sigma^{f,j}_{fid} \cdot \mathcal{L} \cdot \mathcal{P}_{res}(m_{4\ell})$$
$$+ N^{f,i}_{nonres} \mathcal{P}_{nonres}(m_{4\ell}) + N^{f,i}_{bkg} \cdot \mathcal{P}_{bkg}(m_{4\ell}),$$

Detector response matrix

DSCB to model the resonant signal contribution

Contribution due to events accepted but do not originate from the fiducial phase space (different between GEN and RECO

Landau to describe the contribution due to VH and ttH where a lepton from H is lost.

Acceptance

CMS-PAS-HIG-19-001

Signal process	$\mathcal{A}_{fid}$	ϵ	f_{nonfid}	$(1 + f_{nonfid})\epsilon$
Individual Higgs boson production modes				
gg→H (POWHEG)	0.402 ± 0.001	0.592 ± 0.002	0.053 ± 0.001	0.624 ± 0.002
VBF (POWHEG)	0.444 ± 0.002	0.605 ± 0.003	0.043 ± 0.001	0.631 ± 0.003
WH (POWHEG+MINLO)	0.325 ± 0.002	0.588 ± 0.003	0.075 ± 0.002	0.632 ± 0.004
ZH (POWHEG+MINLO)	0.340 ± 0.003	0.594 ± 0.005	0.081 ± 0.004	0.643 ± 0.006
ttH (POWHEG)	0.314 ± 0.003	0.585 ± 0.006	0.169 ± 0.006	0.684 ± 0.007

Hγγ: fiducial cross sections

Fiducial (differential) cross section obtained performing a maximum likelihood fit of the diphoton invariant mass spectrum $m_{2\gamma}$

$$\mathcal{L}_{ij}(\text{data}|\Delta\vec{\sigma}^{\text{fid}},\vec{n}_{\text{bkg}},\vec{\theta}_{\text{S}},\vec{\theta}_{\text{B}}) = \prod_{l=1}^{n_{m_{\gamma\gamma}}} \left(\frac{\sum_{k=1}^{n_b} \Delta\sigma_k^{\text{fid}} K_k^{ij}(\vec{\theta}_{\text{S}}) S_k^{ij}(m^l_{\gamma\gamma}|\vec{\theta}_{\text{S}}) L + n^{ij}_{\text{OOA}} S^{ij}_{\text{OOA}}(m^l_{\gamma\gamma}|\vec{\theta}_{\text{S}}) + n^{ij}_{\text{bkg}} B^{ij}(m^l_{\gamma\gamma}|\vec{\theta}_{\text{B}})}{n^{ij}_{\text{sig}} + n^{ij}_{\text{bkg}}} \right)^{n_{\text{ev}}^{lij}}$$

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Signal PDF (gaussian)

Bkg PDF
(used discrete profiling method to choice the function)

vector of fid. XS being measured, times BR of the diphoton decay channel

Matrix represent the efficiency between GEN and RECo category for a given event

Out-of-Acceptance contribution (it is approximately ~1%)

$n_{m\gamma\gamma}$, n_b = number of bins for the diphoton mass and observable under study

n_{ev}, n_{sig}, n_{bkg} = number of observed, signal and background events in a given reconstruction bin-category

$\theta_{S(B)}$ = nuisance parameters associated with signal (background)

HZZ

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$$\mathcal{D}^{\text{kin}}_{\text{bkg}} = \left[1 + \frac{\mathcal{P}^{q\bar{q}}_{\text{bkg}}(\vec{\Omega}^{\text{H}\to 4\ell}|m_{4\ell})}{\mathcal{P}^{\text{gg}}_{\text{sig}}(\vec{\Omega}^{\text{H}\to 4\ell}|m_{4\ell})}\right]^{-1}$$

No $m(\text{Z}_1)$ constraint	3D: $\mathcal{L}(m_{4\ell}, \mathcal{D}_{\text{mass}}, \mathcal{D}^{\text{kin}}_{\text{bkg}})$	2D: $\mathcal{L}(m_{4\ell}, \mathcal{D}_{\text{mass}})$	1D: $\mathcal{L}(m_{4\ell})$
Expected m_{H} uncertainty change	+8.1%	+11%	+21%
Observed m_{H} (GeV)	125.28±0.22	125.36±0.24	125.39±0.25
With $m(\text{Z}_1)$ constraint	3D: $\mathcal{L}(m'_{4\ell}, \mathcal{D}'_{\text{mass}}, \mathcal{D}^{\text{kin}}_{\text{bkg}})$	2D: $\mathcal{L}(m'_{4\ell}, \mathcal{D}'_{\text{mass}})$	1D: $\mathcal{L}(m'_{4\ell})$
Expected m_{H} uncertainty change	—	+3.2%	+11%
Observed m_{H} (GeV)	125.26±0.21	125.30±0.21	125.34±0.23

Event	Signal							Total	Background			Total	Observed
category	ggH	VBF	WH	ZH	ttH	bbH	tqH	signal	$q\bar{q} \to ZZ$	$gg \to ZZ$	Z + X	expected	
ggH-0j/pT[0,10]	25.3	0.08	0.02	0.02	0.00	0.14	0.00	25.6	26.5	0.97	1.19	54.2	61
ggH-0j/pT[10-200]	86.8	1.69	0.54	0.86	0.00	0.90	0.00	90.8	35.4	3.79	15.5	145	153
ggH-1j/pT[0-60]	26.2	1.43	0.50	0.45	0.01	0.43	0.01	29.1	10.3	1.19	5.54	46.1	40
ggH-1j/pT[60-120]	12.4	1.24	0.45	0.47	0.01	0.10	0.01	14.6	2.76	0.16	3.21	20.8	17
ggH-1j/pT[120-200]	3.31	0.62	0.17	0.26	0.00	0.02	0.00	4.38	0.38	0.00	0.52	5.28	6
ggH-2j/pT[0-60]	3.68	0.29	0.14	0.14	0.06	0.09	0.02	4.42	0.97	0.15	2.07	7.60	9
ggH-2j/pT[60-120]	5.17	0.54	0.22	0.22	0.09	0.04	0.02	6.30	0.84	0.07	1.86	9.06	12
ggH-2j/pT[120-200]	2.90	0.40	0.15	0.17	0.07	0.01	0.02	3.71	0.26	0.00	0.40	4.37	5
ggH/pT>200	2.72	0.65	0.21	0.24	0.06	0.01	0.02	3.91	0.16	0.00	0.21	4.28	2
ggH-2j/mJJ>350	0.82	0.17	0.06	0.05	0.04	0.01	0.01	1.16	0.16	0.02	0.65	1.98	3
VBF-1j	14.2	2.94	0.20	0.18	0.00	0.12	0.01	17.6	2.37	0.43	1.05	21.5	20
VBF-2j/mJJ[350,700]	0.80	1.11	0.01	0.01	0.00	0.01	0.00	1.95	0.08	0.02	0.04	2.09	2
VBF-2j/mJJ>700	0.43	1.80	0.00	0.00	0.00	0.00	0.00	2.25	0.02	0.01	0.03	2.31	2
VBF-3j/mJJ>350	2.43	2.15	0.06	0.07	0.02	0.03	0.05	4.81	0.24	0.06	0.96	6.07	6
VBF-2j/pT>200	0.42	0.76	0.01	0.01	0.01	0.00	0.01	1.22	0.01	0.00	0.03	1.26	0
VBF-rest	2.40	0.87	0.11	0.10	0.03	0.04	0.01	3.56	0.34	0.06	0.74	4.70	2
VH-lep/pTV[0-150]	0.24	0.04	0.71	0.25	0.08	0.02	0.02	1.37	0.82	0.14	0.40	2.72	5
VH-lep/pTV>150	0.02	0.01	0.21	0.08	0.04	0.00	0.01	0.36	0.01	0.00	0.02	0.40	0
VH-had/mJJ[60-120]	4.11	0.25	1.01	1.20	0.11	0.07	0.02	6.77	0.70	0.05	1.36	8.89	8
VH-rest	0.56	0.04	0.08	0.07	0.03	0.00	0.00	0.77	0.08	0.00	0.15	1.01	1
ttH-had	0.19	0.05	0.03	0.06	0.82	0.01	0.03	1.19	0.01	0.00	0.45	1.66	2
ttH-lep	0.02	0.00	0.02	0.02	0.60	0.00	0.03	0.70	0.03	0.00	0.12	0.85	0

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HWW

0 - 1 jet

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	Category							
	0-jet DF ggH-tagged		1-jet DF ggH-tagged		0-jet SF ggH-tagged		1-jet SF ggH-tagged	
ggH	483.1	(642.1)	269.1	(339.3)	231.2	(324.6)	82.0	(92.8)
VBF	5.6	(7.4)	22.1	(29.4)	1.5	(2.5)	5.9	(9.3)
WH	12.4	(16.4)	15.8	(20.6)	3.3	(4.3)	2.9	(3.8)
ZH	5.2	(6.9)	5.0	(6.7)	2.6	(3.4)	1.4	(1.8)
$t\bar{t}H$	<0.1	(<0.1)	0.2	(0.2)	<0.1	(<0.1)	<0.1	(<0.1)
$b\bar{b}H$	3.4	(4.4)	1.5	(2.0)	1.7	(2.3)	0.5	(0.7)
Signal	509	(677)	313	(398)	240	(337)	93	(108)
±total unc.		(±31)		(±19)		(±24)		(±13)
WW	7851	(9088)	3553	(3727)	1596	(1805)	373	(365)
Top quark	2505	(2422)	5395	(5224)	334	(339)	452	(443)
Nonprompt	1555	(1006)	781	(482)	301	(260)	111	(97)
DY	154	(154)	283	(302)	437	(459)	178	(216)
$VZ/V\gamma^*$	368	(385)	327	(338)	101	(104)	43	(43)
$V\gamma$	213	(210)	137	(128)	23	(26)	17	(19)
Other diboson	5.1	(5.3)	3.5	(3.7)	9.3	(9.4)	2.0	(2.1)
Triboson	9.3	(9.6)	16	(17)	1.2	(1.2)	1.3	(1.3)
Background	12660	(13280)	10496	(10222)	2803	(3004)	1177	(1186)
±total unc.		(±141)		(±178)		(±97)		(±83)
Data	13964		10591		3364		1308	

At least 2 jets

	Category									
	2-jet DF ggH-tagged		2-jet DF VBF-tagged		2-jet DF VH-tagged		3-lepton WH-tagged		4-lepton ZH-tagged	
ggH	80.4	(100.6)	11.6	(14.6)	13.9	(17.4)	<0.1	(<0.1)	<0.1	(<0.1)
VBF	10.3	(13.3)	19.2	(24.5)	0.4	(0.6)	<0.1	(<0.1)	<0.1	(<0.1)
WH	7.2	(9.3)	0.2	(0.2)	3.6	(4.6)	5.4	(7.2)	<0.1	(<0.1)
ZH	3.3	(4.3)	<0.1	(<0.1)	1.5	(2.1)	0.2	(0.2)	2.7	(3.5)
$t\bar{t}H$	1.6	(2.1)	<0.1	(<0.1)	0.1	(0.2)	<0.1	(<0.1)	<0.1	(<0.1)
$b\bar{b}H$	0.6	(0.7)	<0.1	(0.1)	<0.1	(<0.1)	<0.1	(<0.1)	<0.1	(<0.1)
Signal	103	(130)	31	(40)	20	(25)	5.6	(7.4)	2.7	(3.5)
±total unc.		(±16)		(±3)		(±3)		(±0.7)		(±0.3)
WW	1048	(860)	69	(46)	52	(34)	<0.1	(<0.1)	<0.1	(<0.1)
Top quark	5197	(5187)	157	(158)	230	(229)	<0.1	(<0.1)	0.3	(0.3)
Nonprompt	359	(305)	30	(20)	42	(37)	19	(21)	<0.1	(<0.1)
DY	110	(112)	20	(19)	29	(30)	<0.1	(<0.1)	<0.1	(<0.1)
$VZ/V\gamma^*$	136	(137)	7.1	(6.9)	11	(10)	<0.1	(<0.1)	<0.1	(<0.1)
$V\gamma$	59	(53)	2.8	(2.8)	4.2	(4.6)	3.8	(9.6)	<0.1	(<0.1)
Other diboson	2.1	(2.3)	0.3	(0.3)	1.2	(1.3)	32	(37)	13	(13)
Triboson	15	(15)	0.3	(0.3)	2.0	(2.0)	2.1	(2.1)	0.4	(0.4)
Background	6926	(6671)	287	(253)	371	(348)	57	(70)	13.7	(13.7)
±total unc.		(±502)		(±17)		(±37)		(±7)		(±0.6)
Data	6802		285		386		85		15	