Higgs cross-section and properties at CMS and ATLAS

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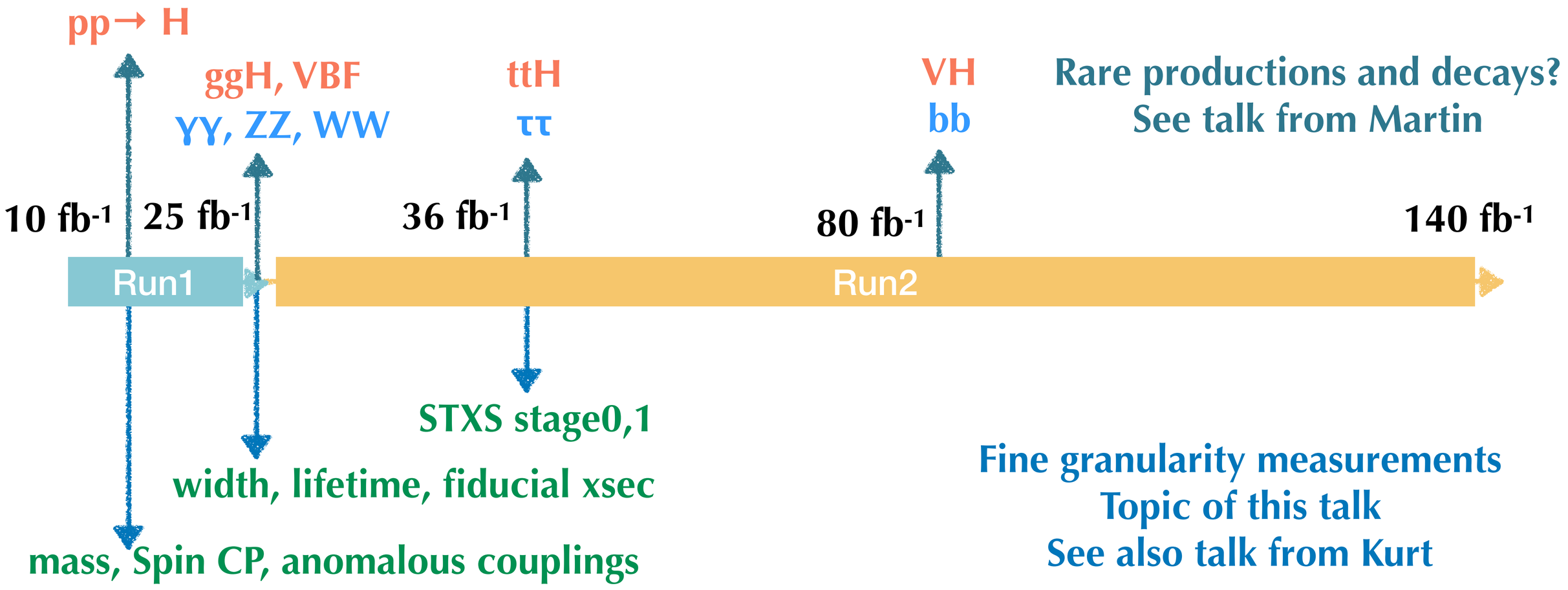
Mar 24th, 2019, Moriond QCD

Higgs story at the LHC

Main production: ggH, VBF, VH, ttH
Main decay: γγ, ZZ, WW, ττ, bb



Measurements in the talk

80 fb^{-1}, 2016+17+(15) data coupling modifiers, STXS stage1

- H→ γγ, CMS NEW!
- H→ ττ, CMS NEW!
- H combination (γγ, ZZ, WW, ττ, bb), ATLAS, 2015+16+17 NEW!

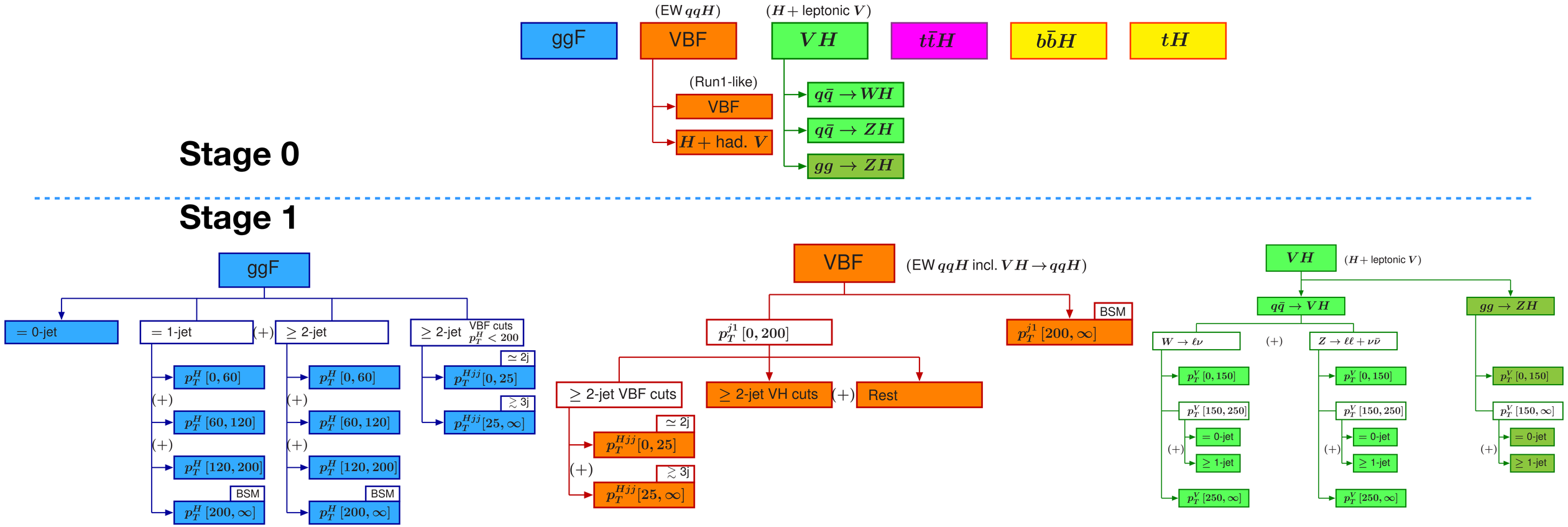
137 fb^{-1}, 2016+17+18 data fiducial xsec, STXS stage1.1

- H→ ZZ, CMS NEW!

Simplified template cross-sections (STXS)

arXiv:1610.07922

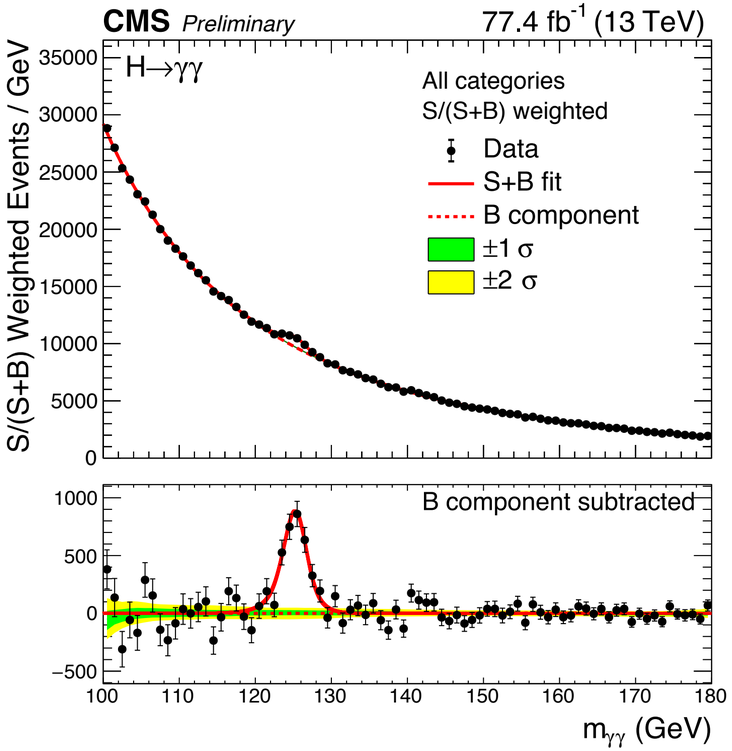
- STXS: defines xsec in exclusive fiducial regions
  - minimize theory dependence, maximize experimental sensitivity

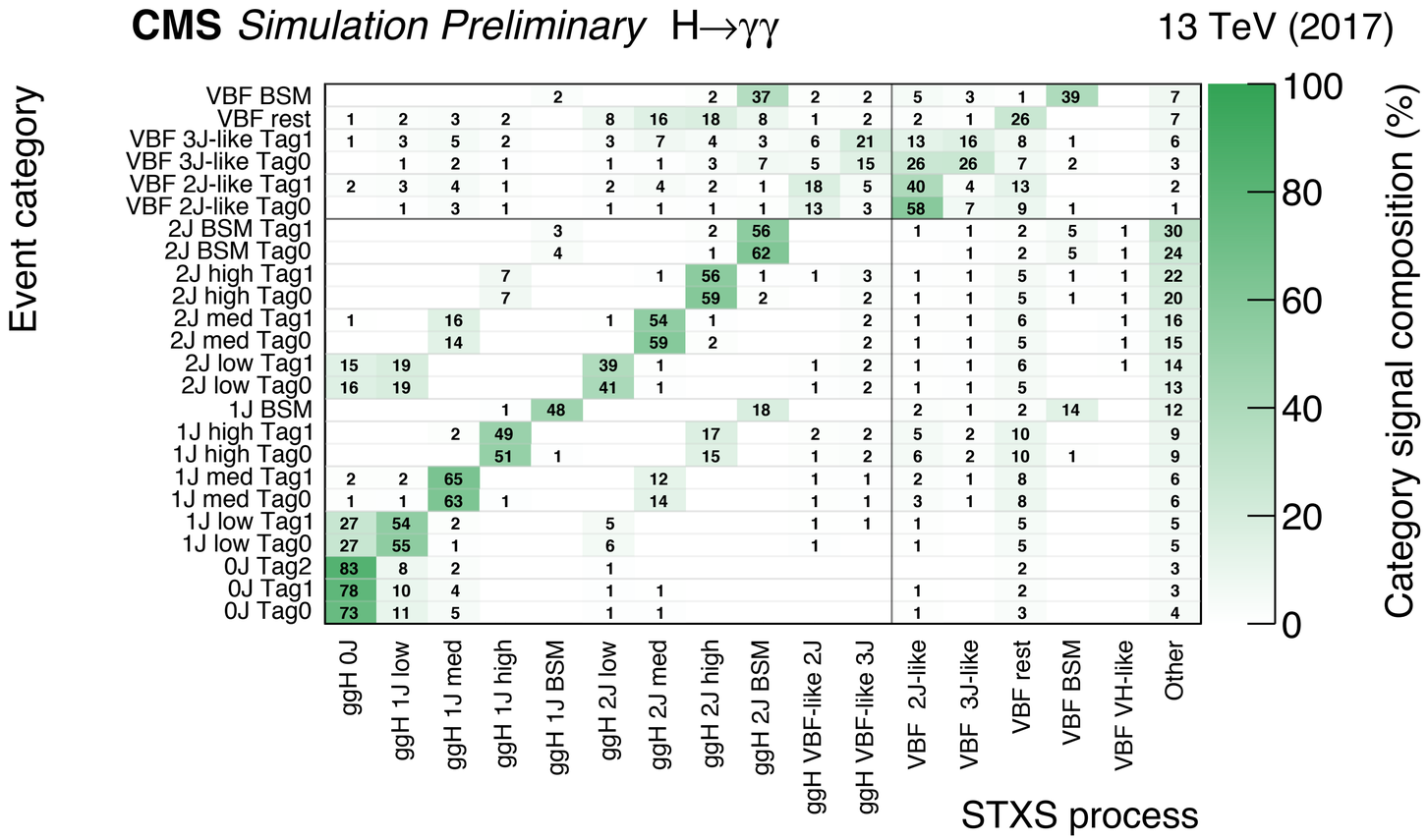


H→ γγ, 2016+17, CMS

CMS-PAS-HIG-18-029

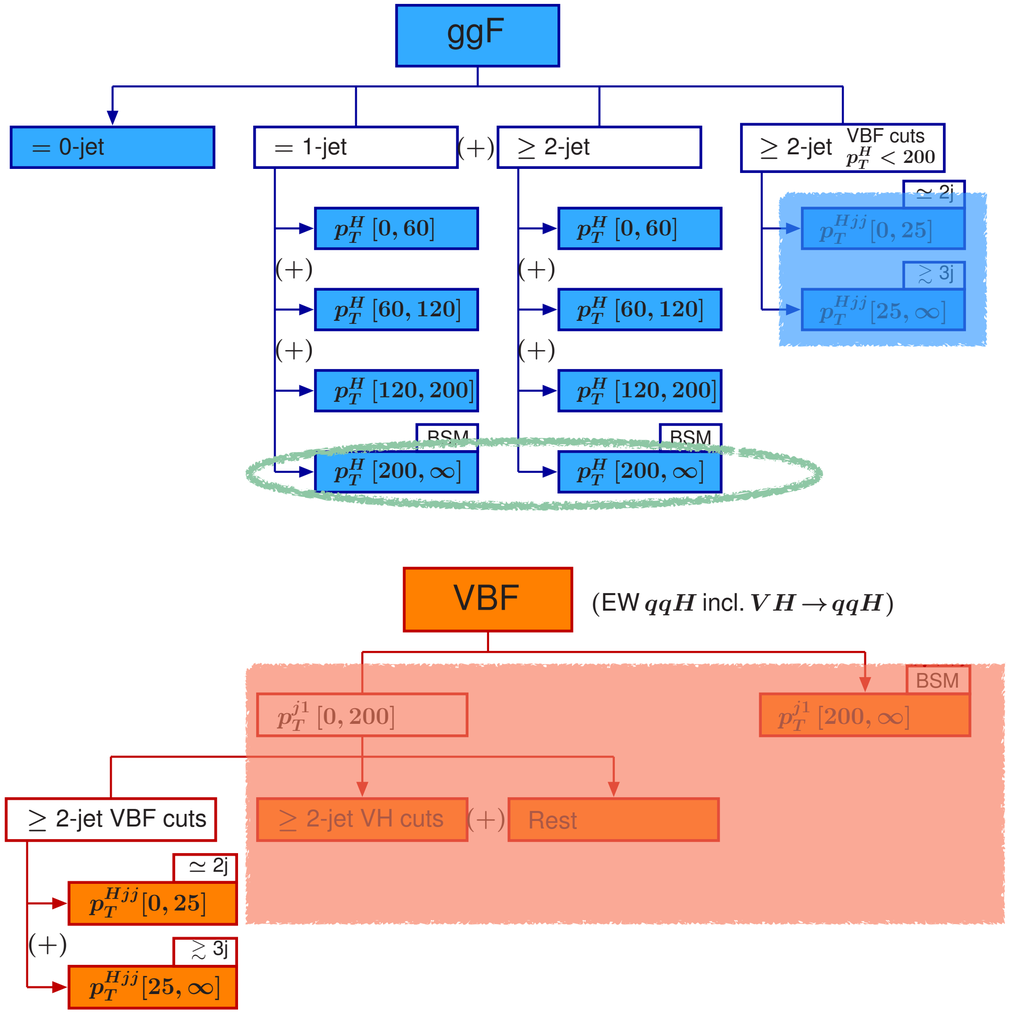
- Target ggH & VBF production modes
- VBF and ggH categories => split to match stage1 bins => split to improve S/B

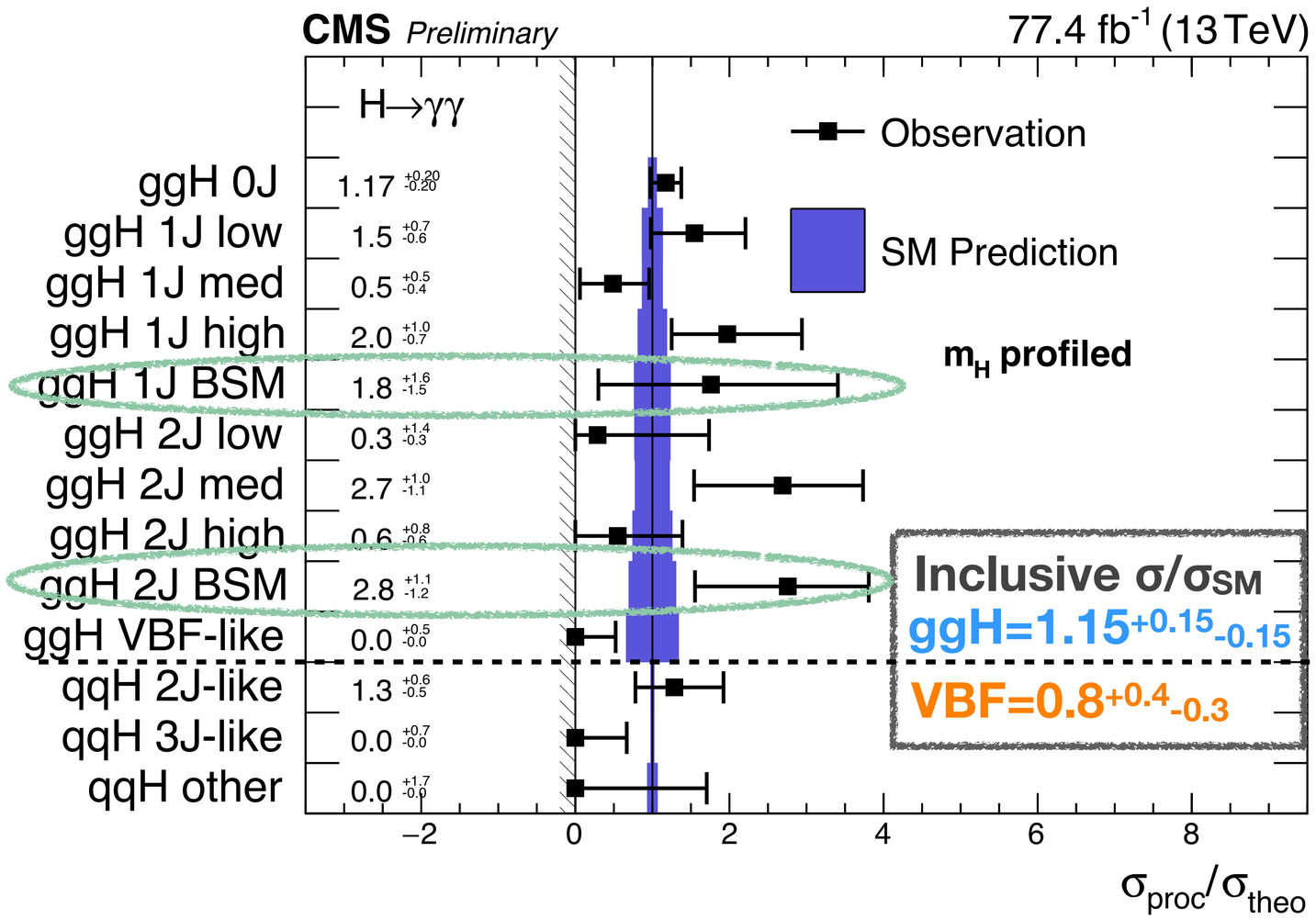




H→ γγ, 2016+17, CMS

CMS-PAS-HIG-18-029



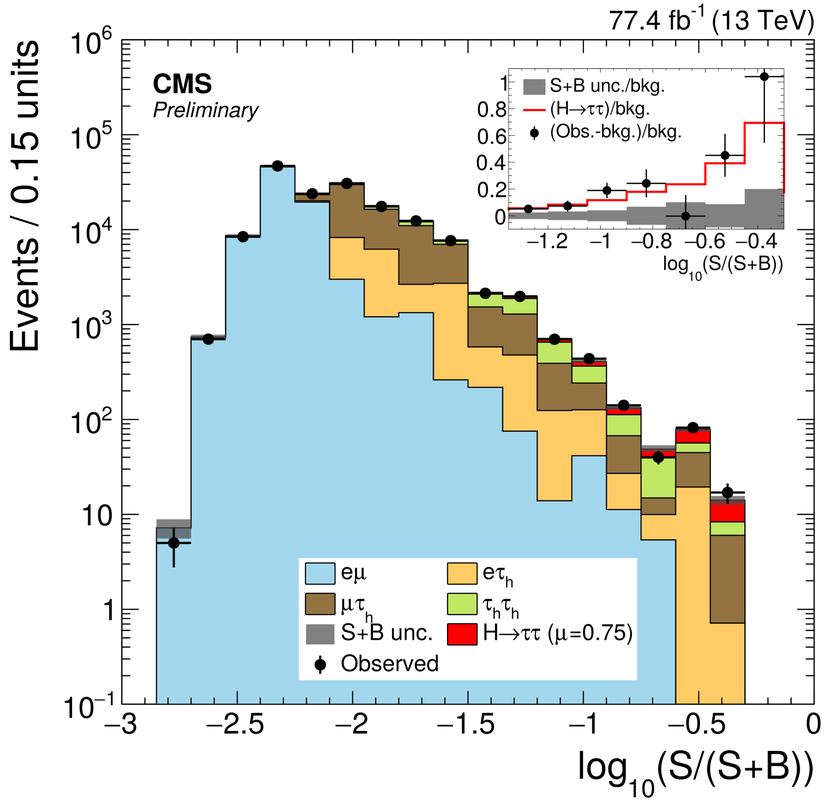


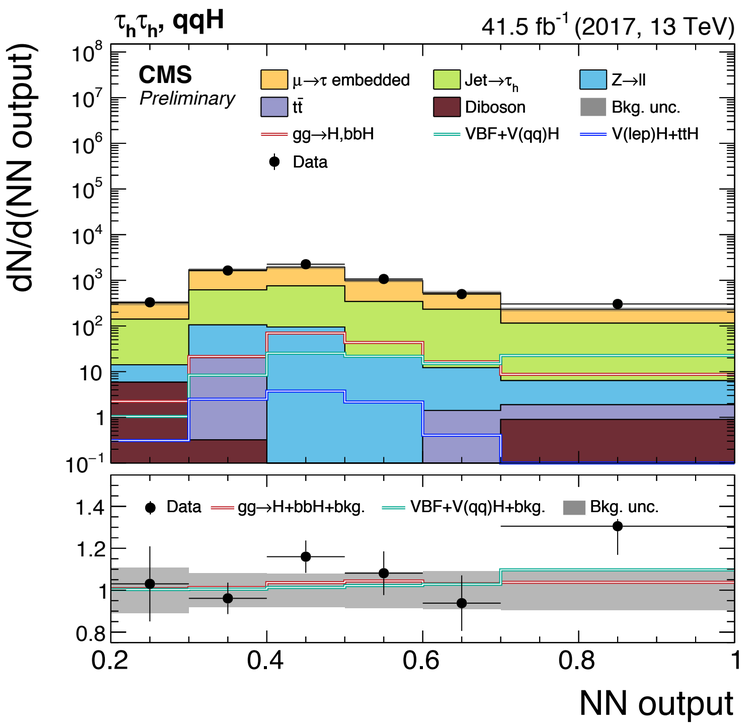
Earlier results of 36 fb^{-1} data: ggH=1.10$^{+0.20}_{-0.18}$, VBF=0.8$^{+0.6}_{-0.5}$

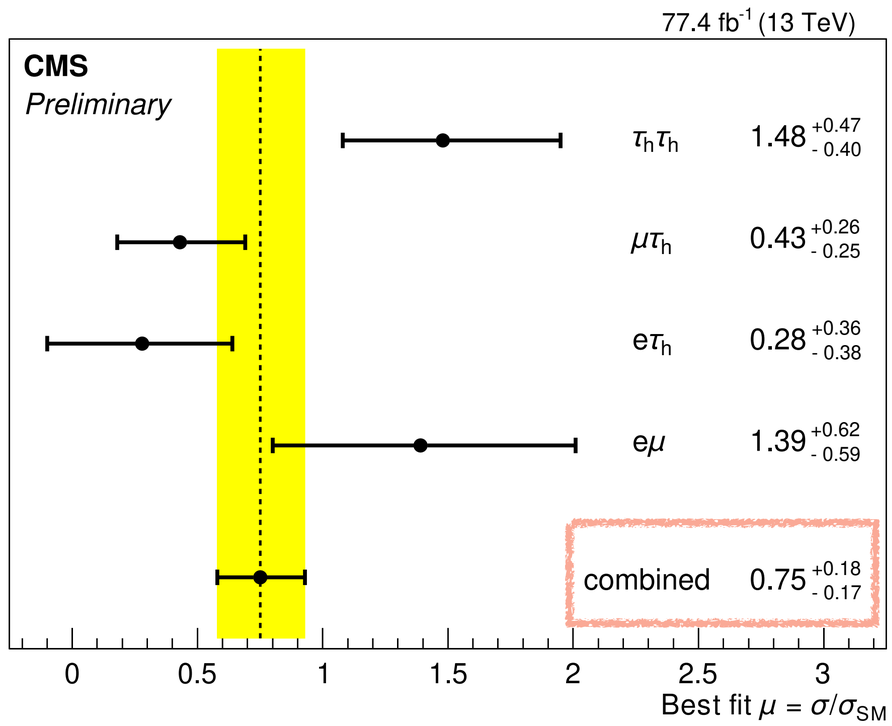
H→ $\tau\tau$, 2016+17, CMS

CMS-PAS-HIG-18-032

- Target ggH & VBF production modes
- After observation on 2016 data, new techniques applied on 2016 + 17 data
  - Multi-class Neural Network: one category per process (ggH, VBF, each bkg), 10% improvement
  - Improved background modeling for genuine taus (embedding) and reducible background (fake rate method)



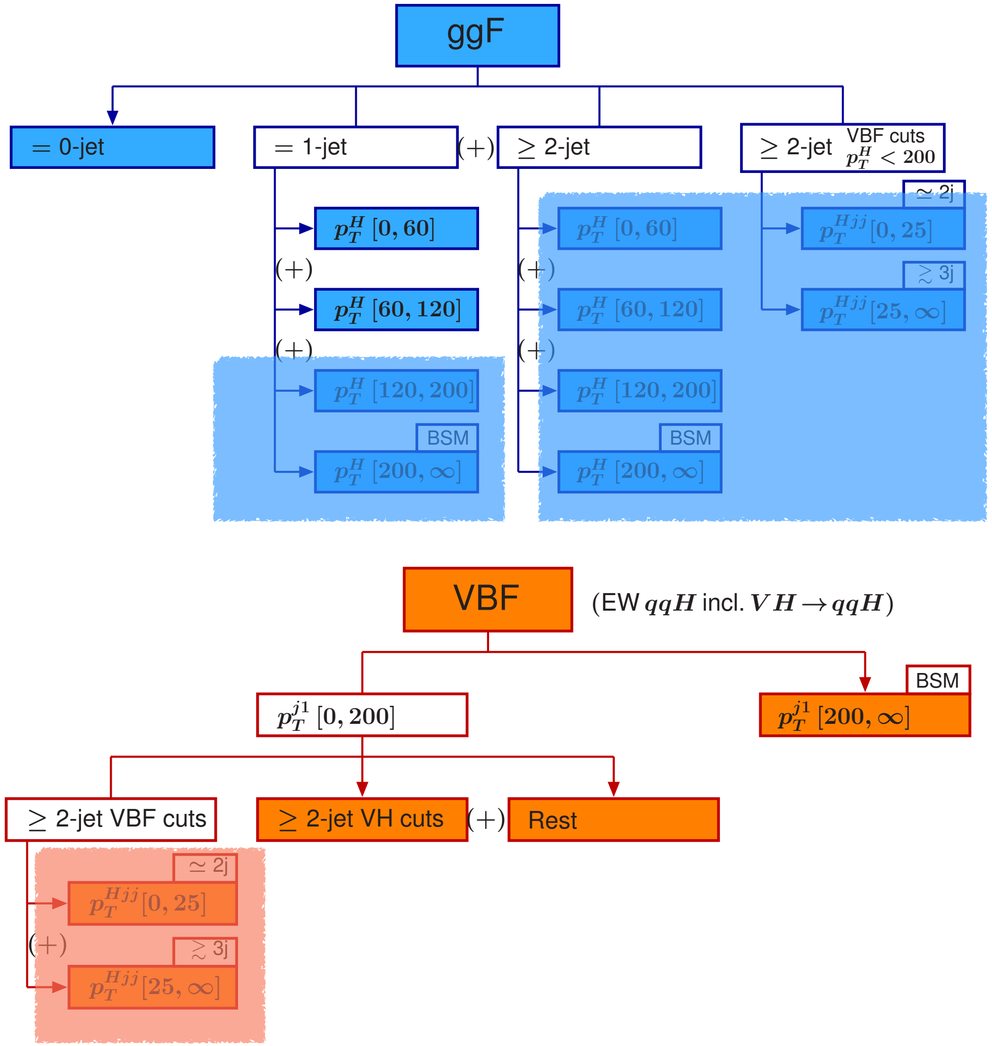


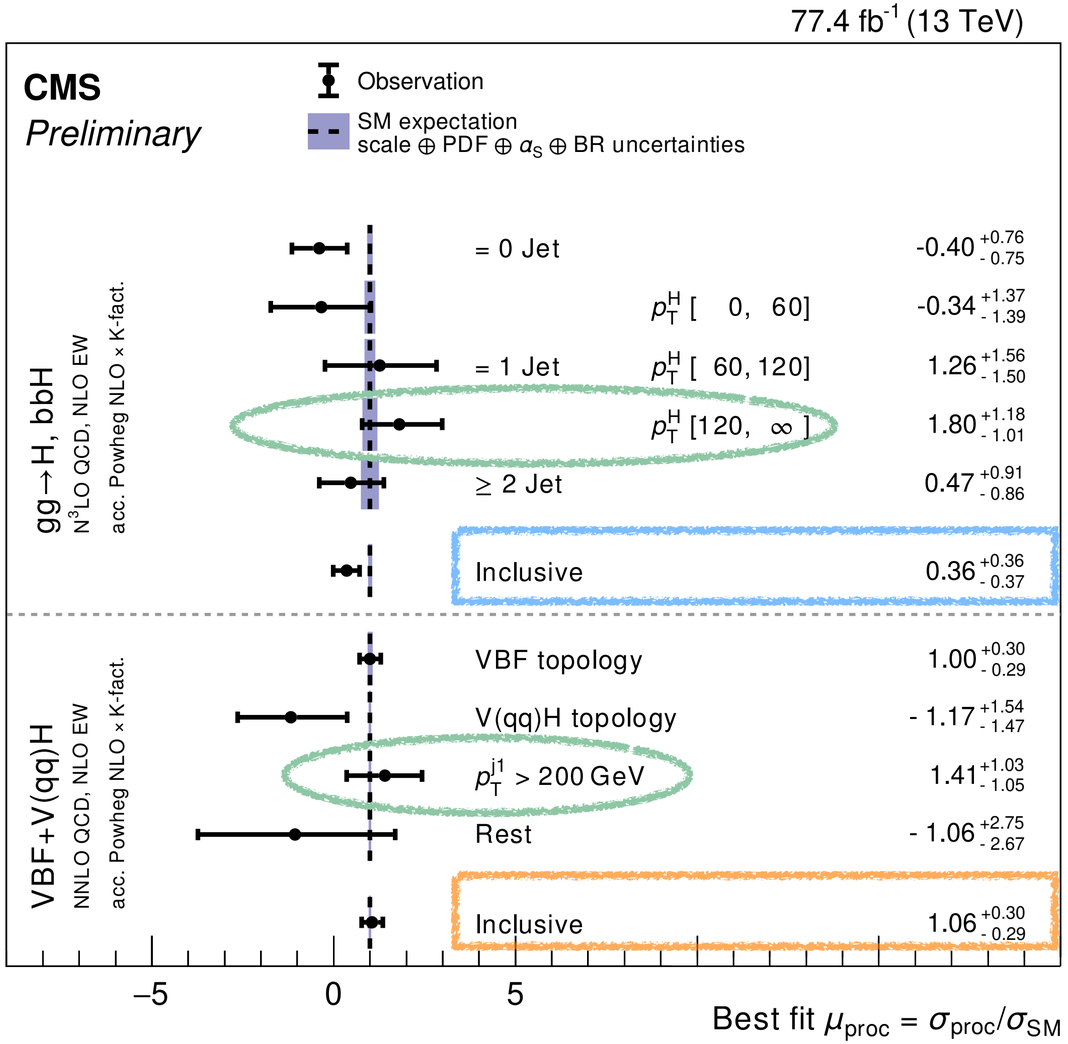


Earlier results of 36 fb^{-1} data: μ = 1.09 $^{+0.27}_{-0.26}$

H→ $\tau\tau$, 2016+17, CMS

CMS-PAS-HIG-18-032





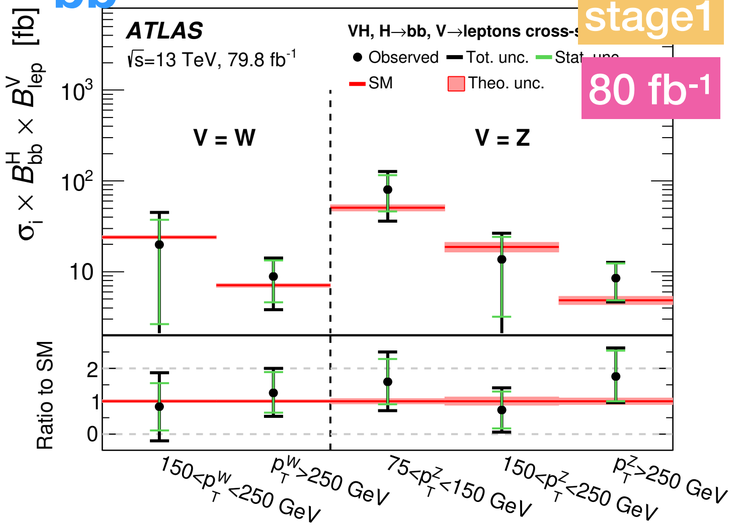
First stage1 H→ $\tau\tau$ measurement in multiple ggH & VBF bins

H combination, 2015+16+17, ATLAS

ATLAS-CONF-2019-005

A combination of major 5 decay modes + ttH + H invisible analyses

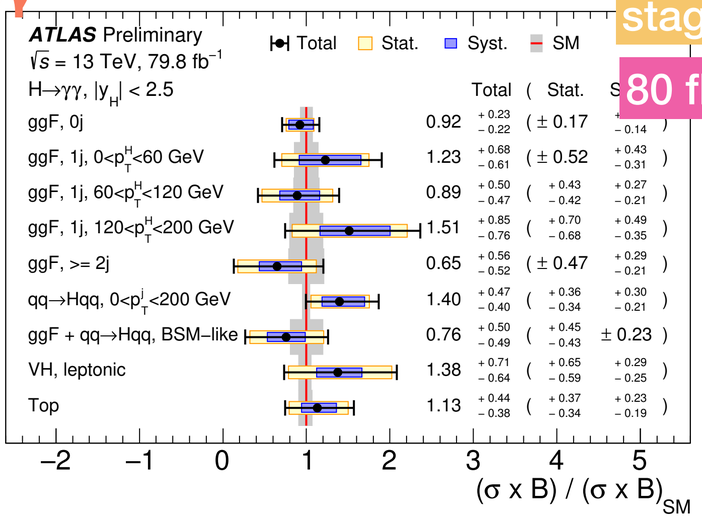
bb



stage1

80 fb-1

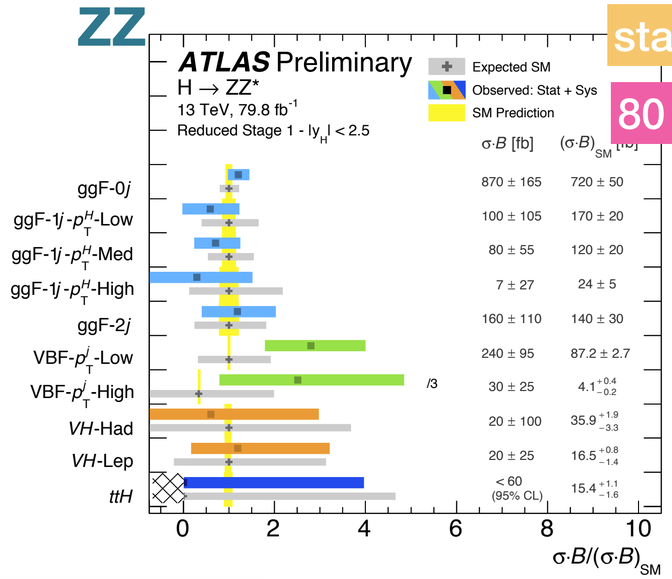
γγ



stage1

80 fb-1

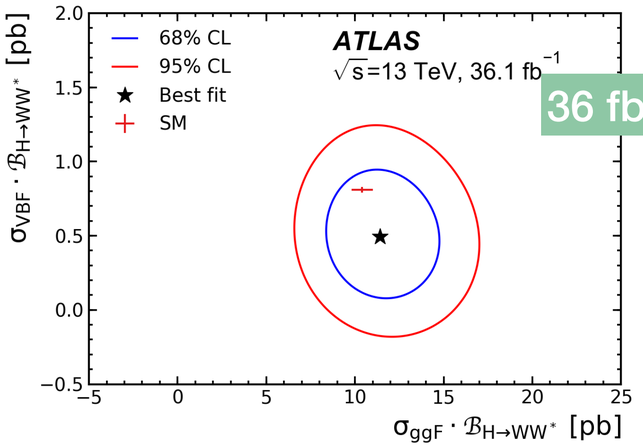
ZZ



stage1

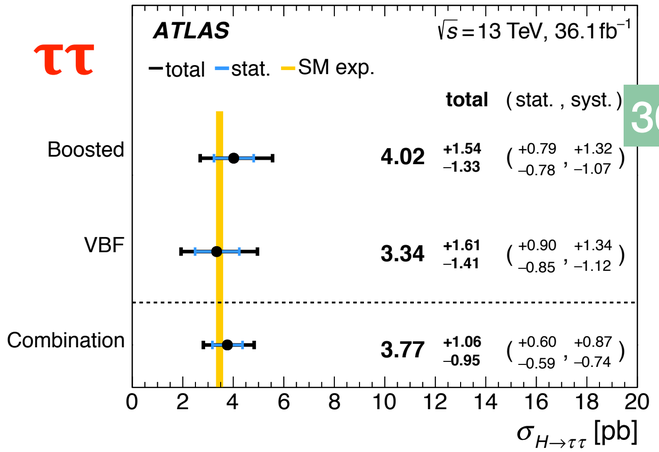
80 fb-1

WW



36 fb-1

ττ



36 fb-1

H combination, 2015+16+17, ATLAS

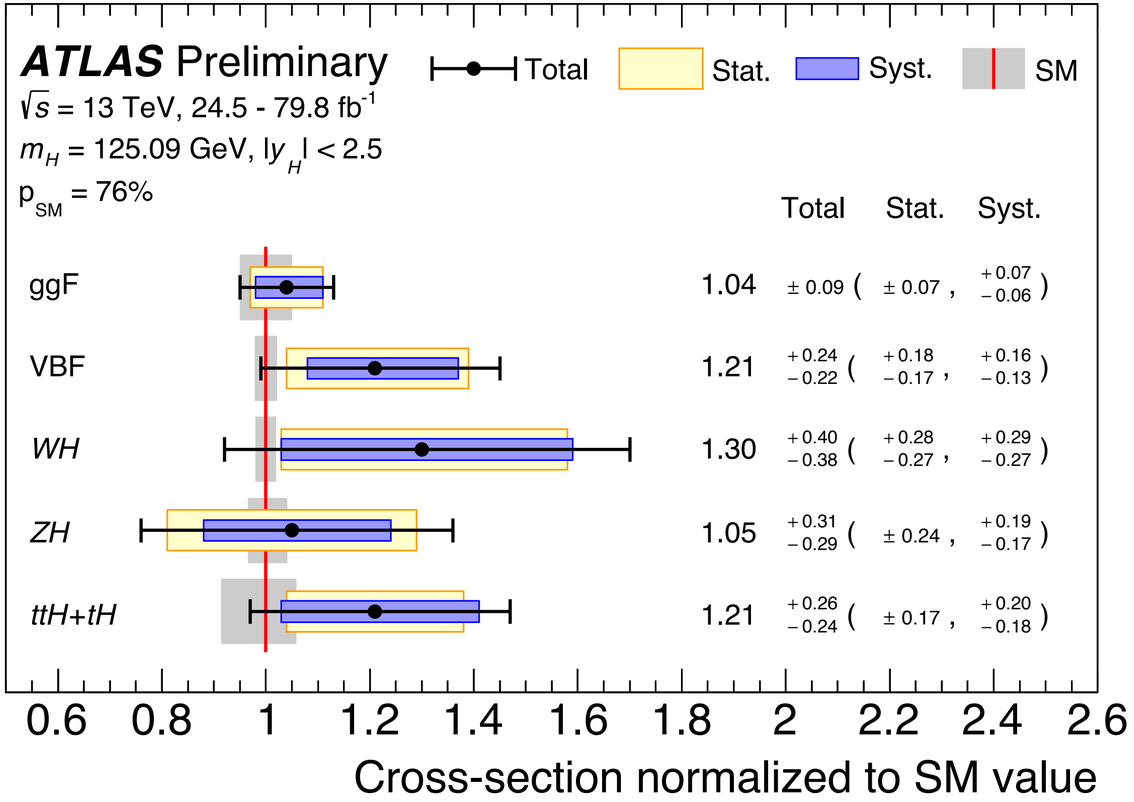
ATLAS-CONF-2019-005

All 4 production modes observed significance > 5σ

$$\mu = 1.11^{+0.09}_{-0.08} = 1.11 \pm 0.05(\text{stat.})^{+0.05}_{-0.04}(\text{exp.})^{+0.05}_{-0.04}(\text{sig. th.})^{+0.03}_{-0.03}(\text{bkg. th.})$$

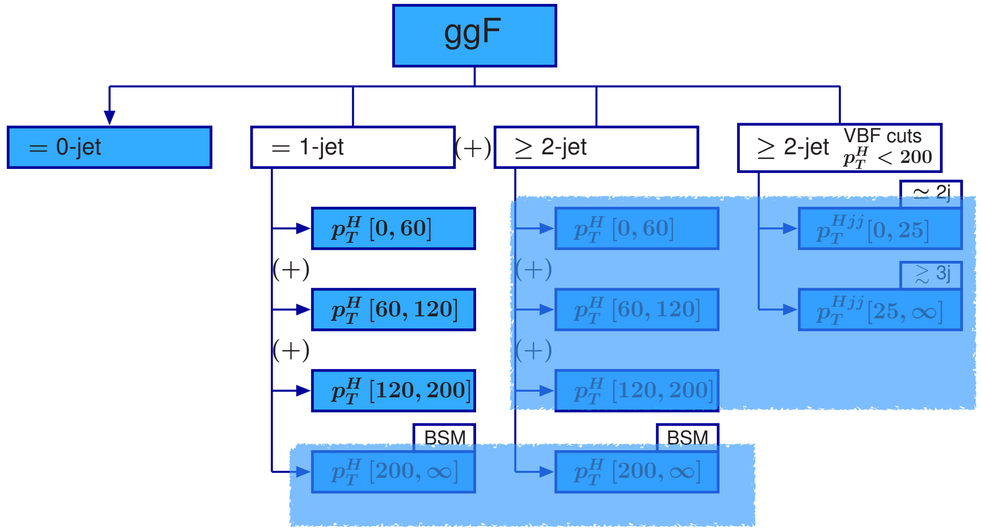
Overall μ uncertainty: 10%

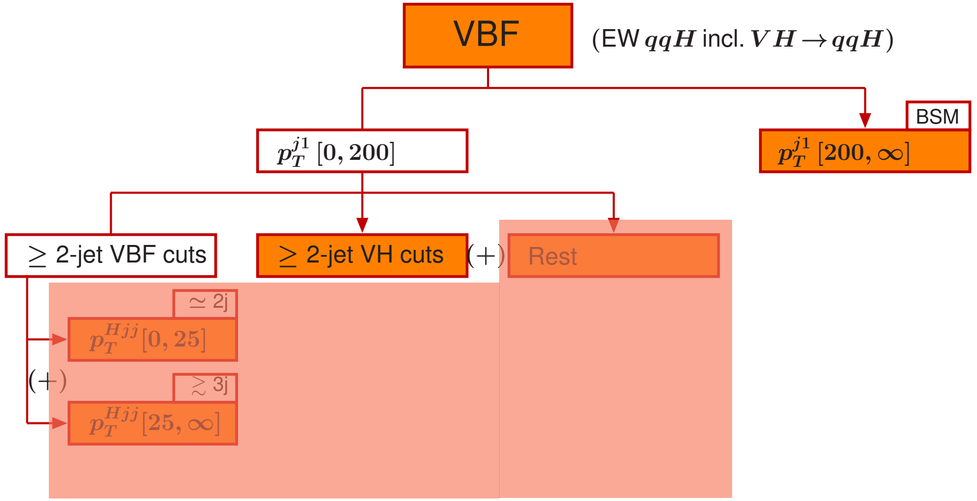
earlier 36.5 fb^{-1} combination (4l+γγ): μ =1.09 ± 0.12

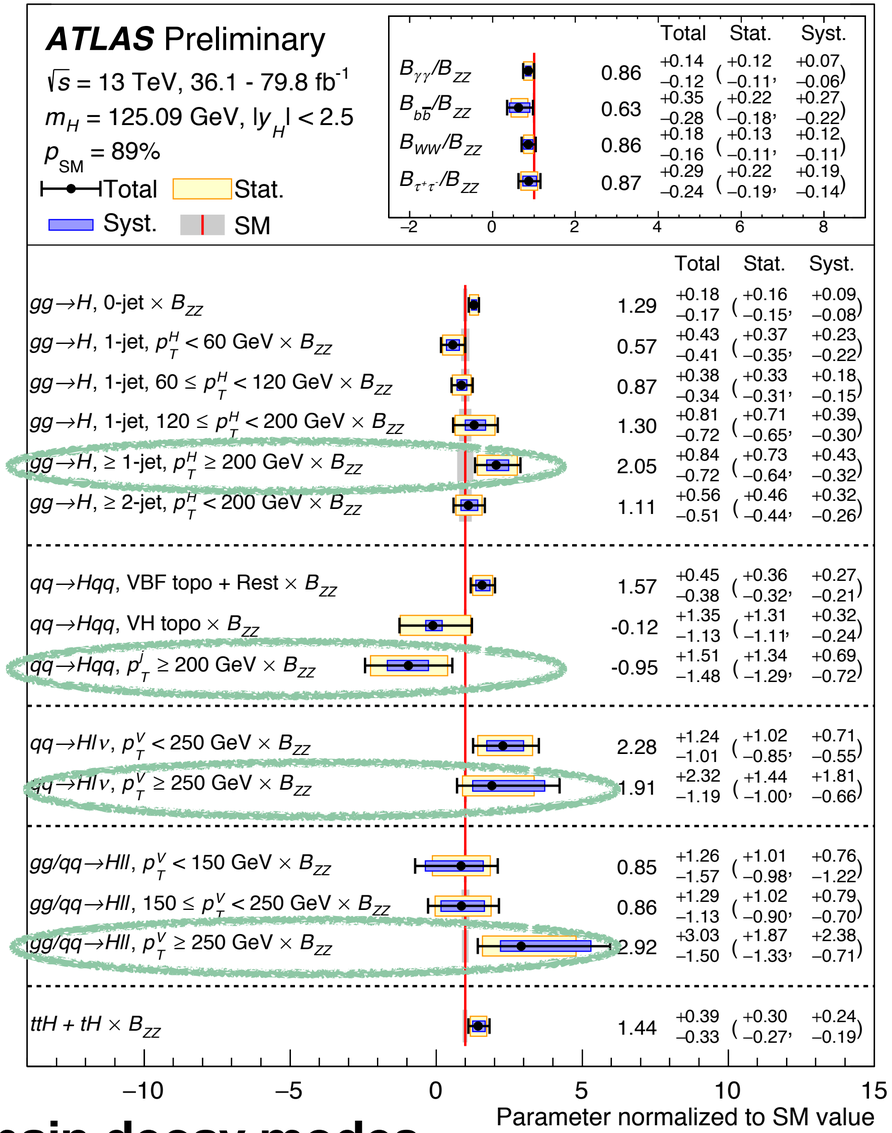


H combination, 2015+16+17, ATLAS

ATLAS-CONF-2019-005







First stage1 combination result with 5 main decay modes

H combination, 2015+16+17, ATLAS

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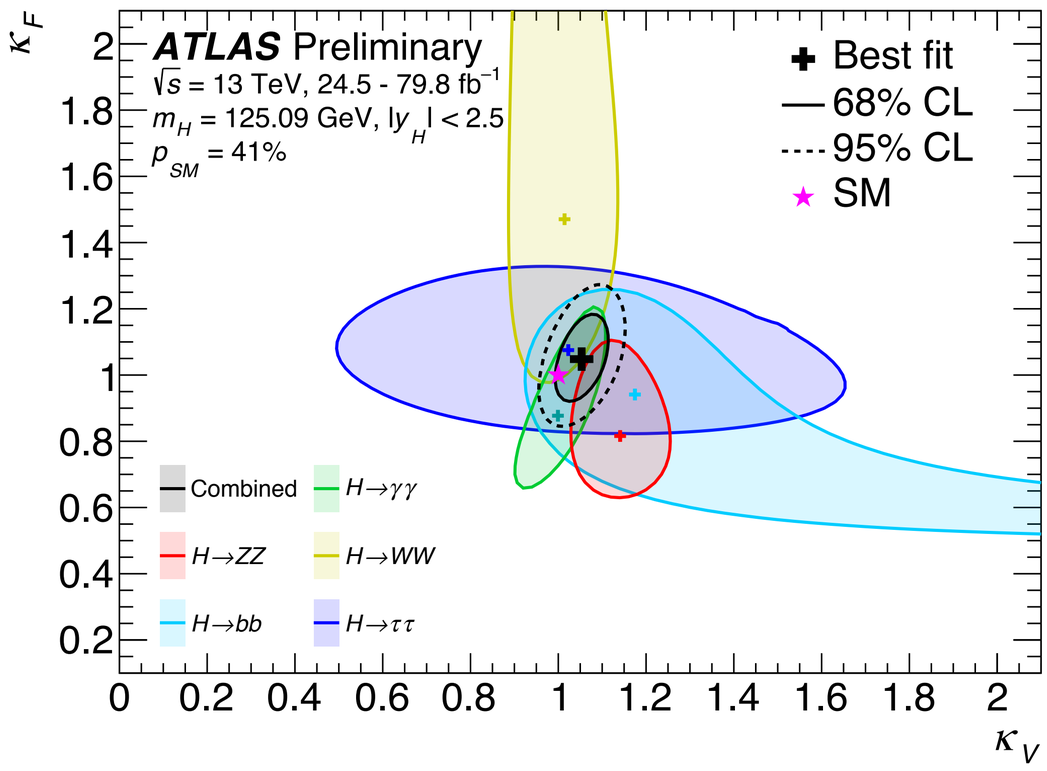
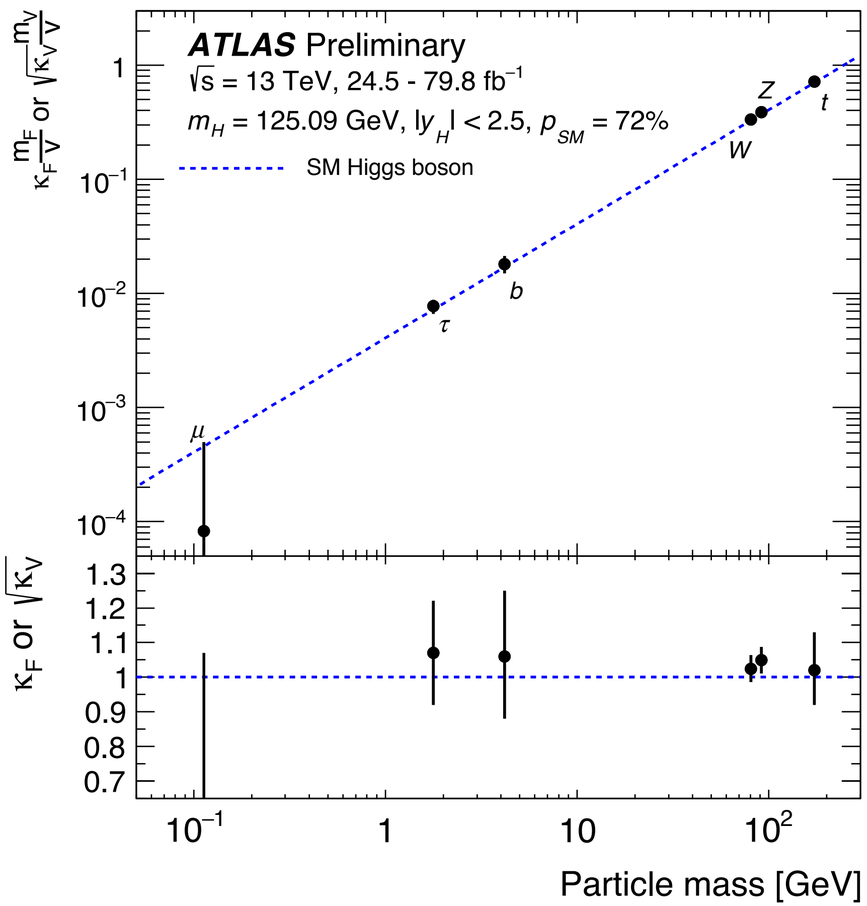
$$\kappa^2 = \sigma/\sigma^{\mathrm{SM}} = \Gamma/\Gamma^{\mathrm{SM}}$$

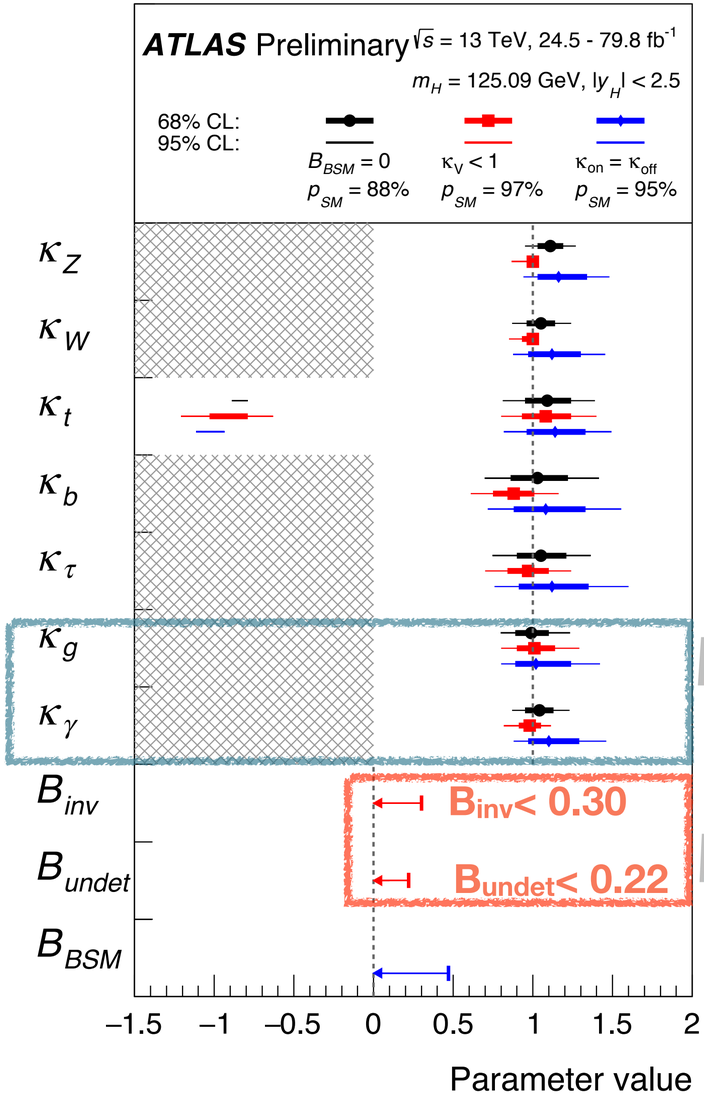




Assuming no new particles in the loop

H combination, 2015+16+17, ATLAS

ATLAS-CONF-2018-054
ATLAS-CONF-2019-005



Probe BSM

Loop effective coupling κ_g, κ_γ with or without B_{inv}, B_{undet}

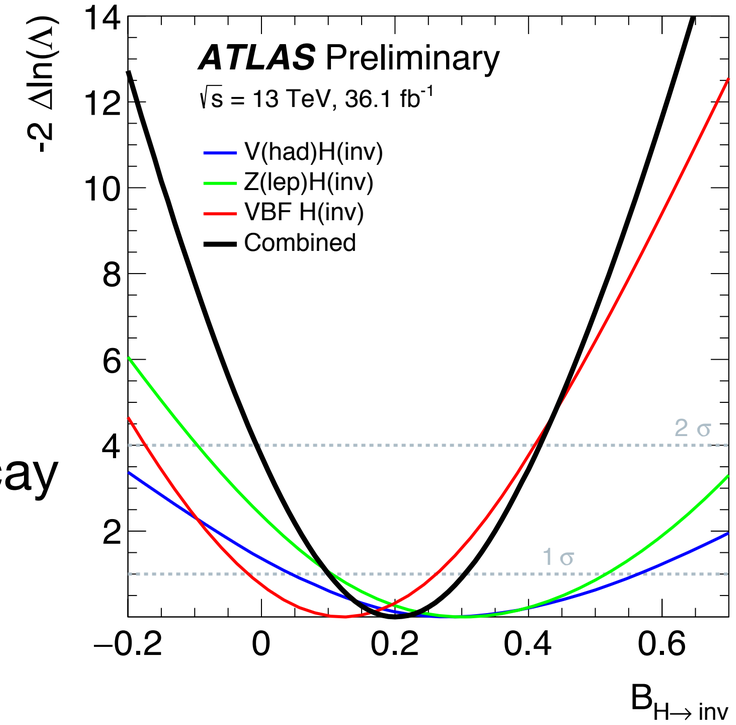
BSM invisible & undetected decay

$$\Gamma(1 - B_{inv} - B_{undet}) = \kappa_H^2(\kappa)\ \Gamma_H^{SM}$$

H→ invisible search, combines V(had)H, Z(lep)H, VBFH

Assuming SM xsec

$B_{inv} < 0.38$, Run2;
$B_{inv} < 0.26$, Run1+Run2



H combination, 2015+16+17, ATLAS

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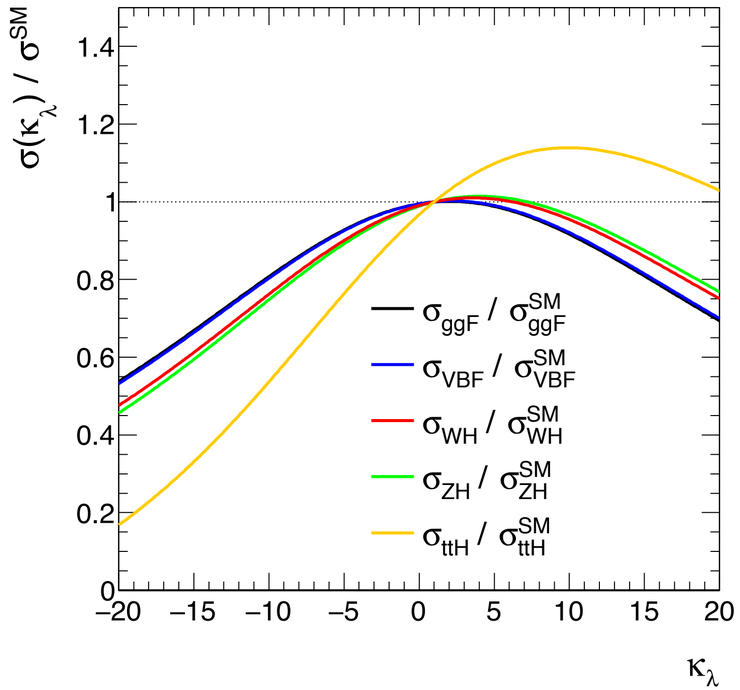
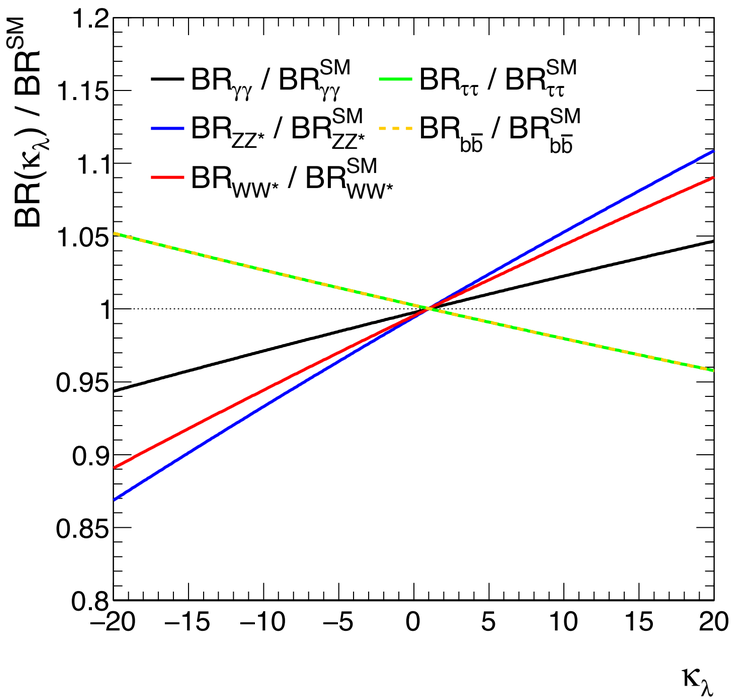
Higgs self coupling λ_{HHH} gives NLO EW corrections on

Higgs production rates



Higgs decay branching fractions



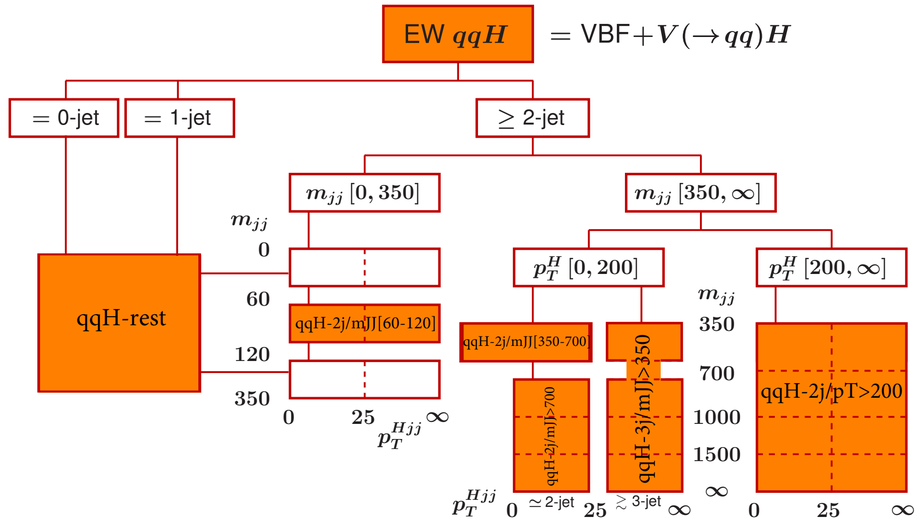
Higgs kinematics

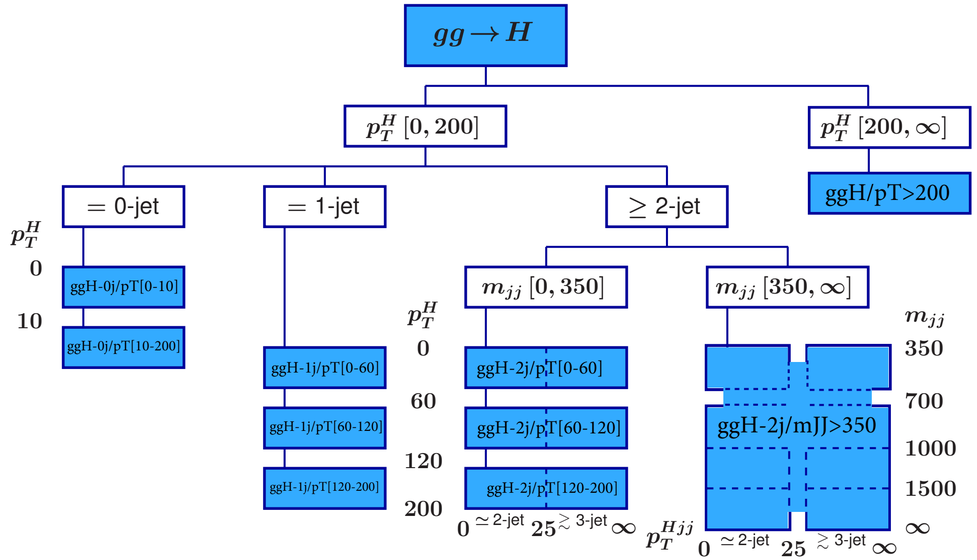
STXS region		VBF	WH	ZH
		$C_1^i \times 100$		
$VBF + V(\mathrm{had})H$	VBF-cuts $+ p_T^{j1} < 200$ GeV, $\leq 2j$	0.63	0.91	1.07
	VBF-cuts $+ p_T^{j1} < 200$ GeV, $\geq 3j$	0.61	0.85	1.04
	VH-cuts $+ p_T^{j1} < 200$ GeV	0.64	0.89	1.10
	no VBF/VH-cuts, $p_T^{j1} < 200$ GeV	0.65	1.13	1.28
	$p_T^{j1} > 200$ GeV	0.39	0.23	0.28
$qq \to H\ell\nu$	$p_T^V < 150$ GeV		1.15	
	$150 < p_T^V < 250$ GeV, $0j$		0.18	
	$150 < p_T^V < 250$ GeV, $\geq 1j$		0.33	
	$p_T^V > 250$ GeV		0	
$qq \to H\ell\ell$	$p_T^V < 150$ GeV			1.33
	$150 < p_T^V < 250$ GeV, $0j$			0.20
$qq \to H\nu\nu$	$150 < p_T^V < 250$ GeV, $\geq 1j$			0.39
	$p_T^V > 250$ GeV			0

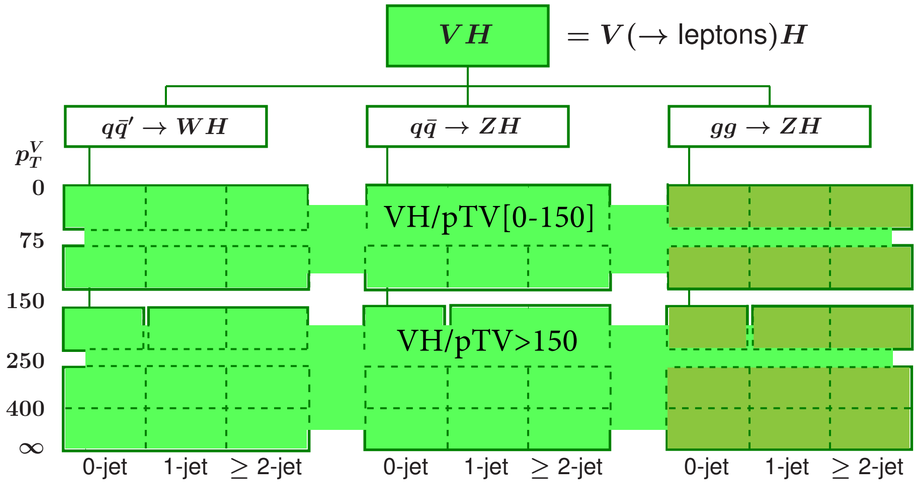
Combine 5 decay modes at stage1 and κ=1 $\kappa_\lambda = \lambda_{\mathrm{HHH}}/\lambda_{\mathrm{HHH}}^{\mathrm{SM}} = 4.0^{+4.3}_{-4.1}$; $-3.2 < \kappa_\lambda < 11.9$ at 95 % CL

H→ 4l, 2016+17+18, CMS

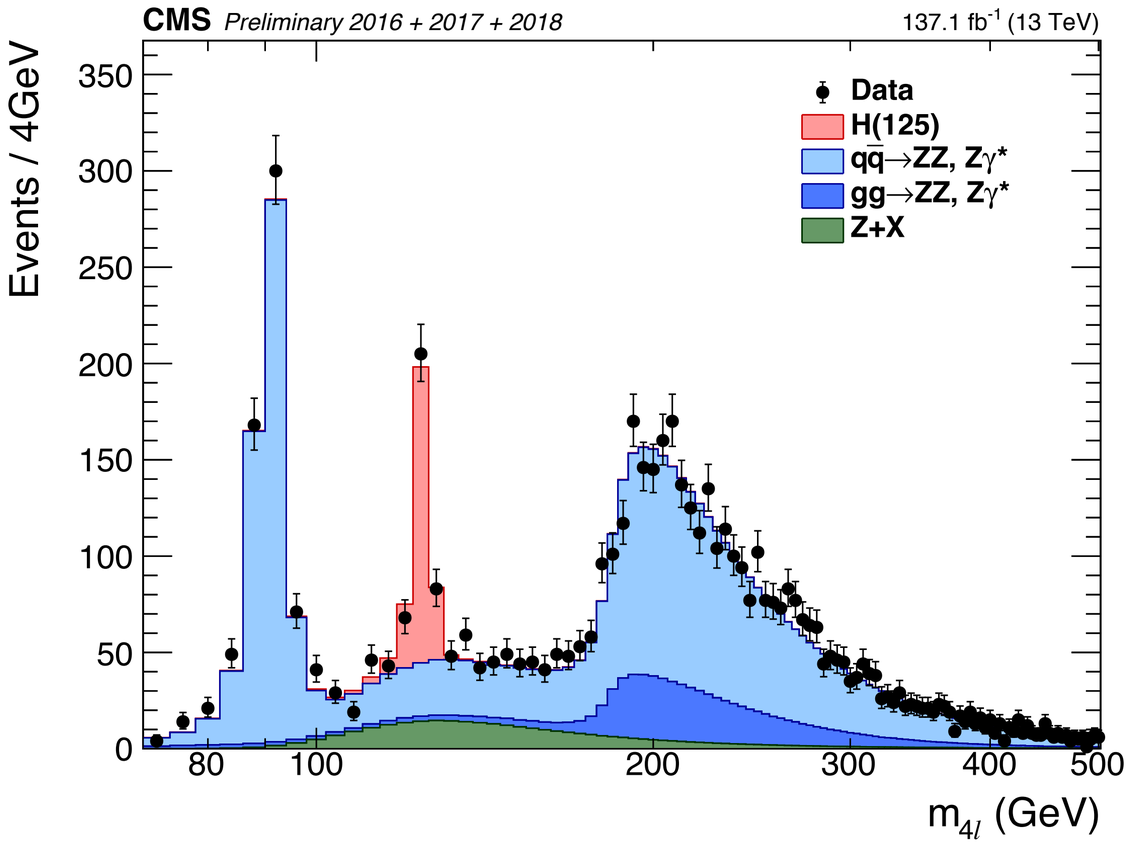
- First result with new STXS definition (stage 1.1)
  - Revised categorization on high p_T and VBF-like events
- Targeting all production modes: ggH, VBF, VH, ttH
  - 7 production mode categories => 22 categories targeting stage 1.1 bins



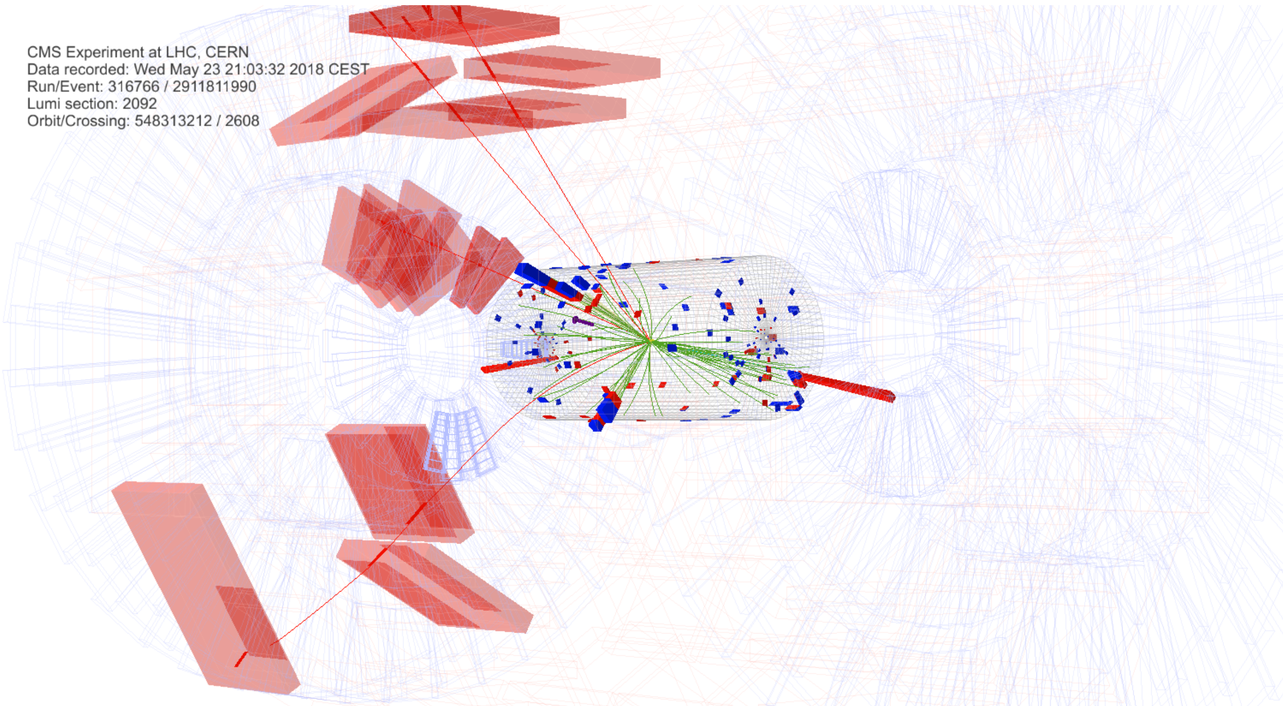




H→ 4l, 2016+17+18, CMS



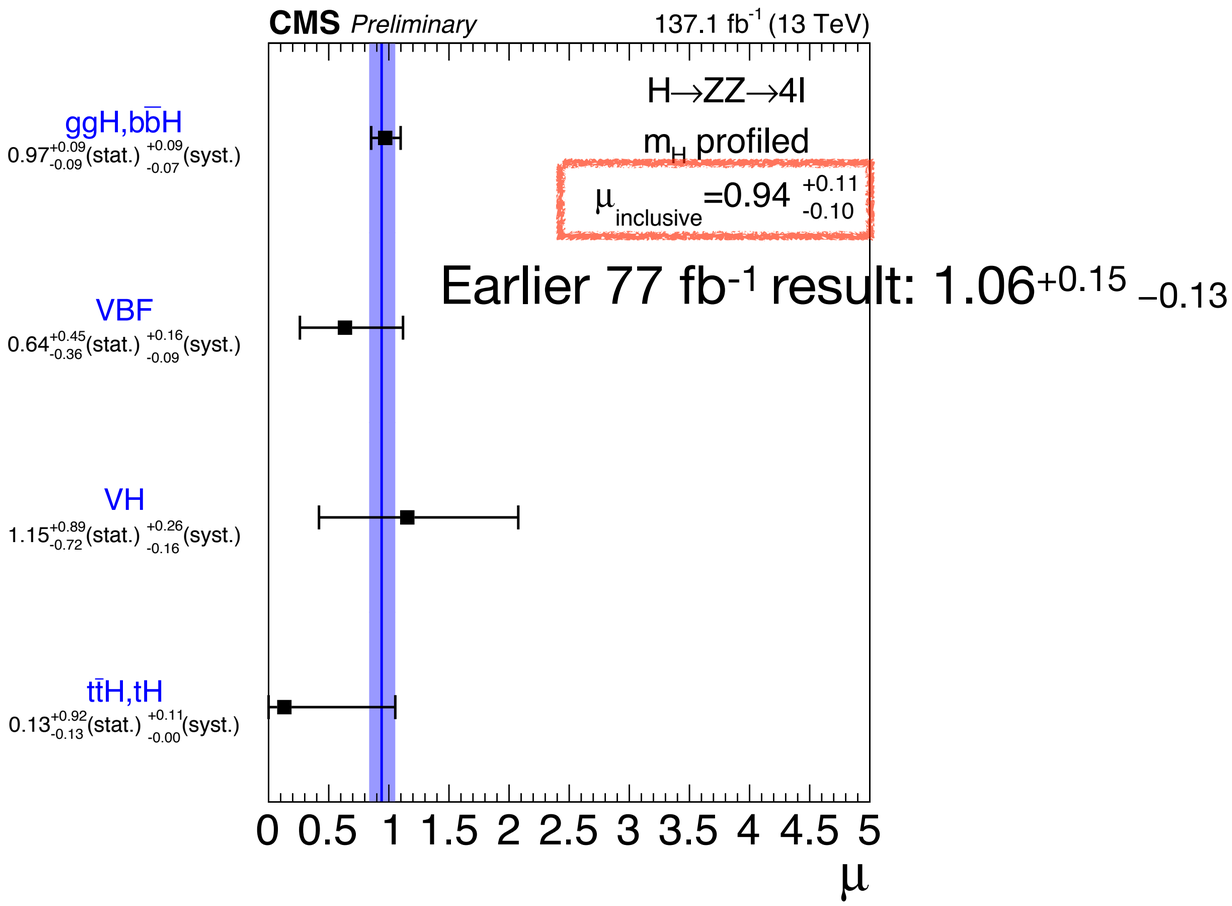
The first ttH candidate event seen in 4l final state

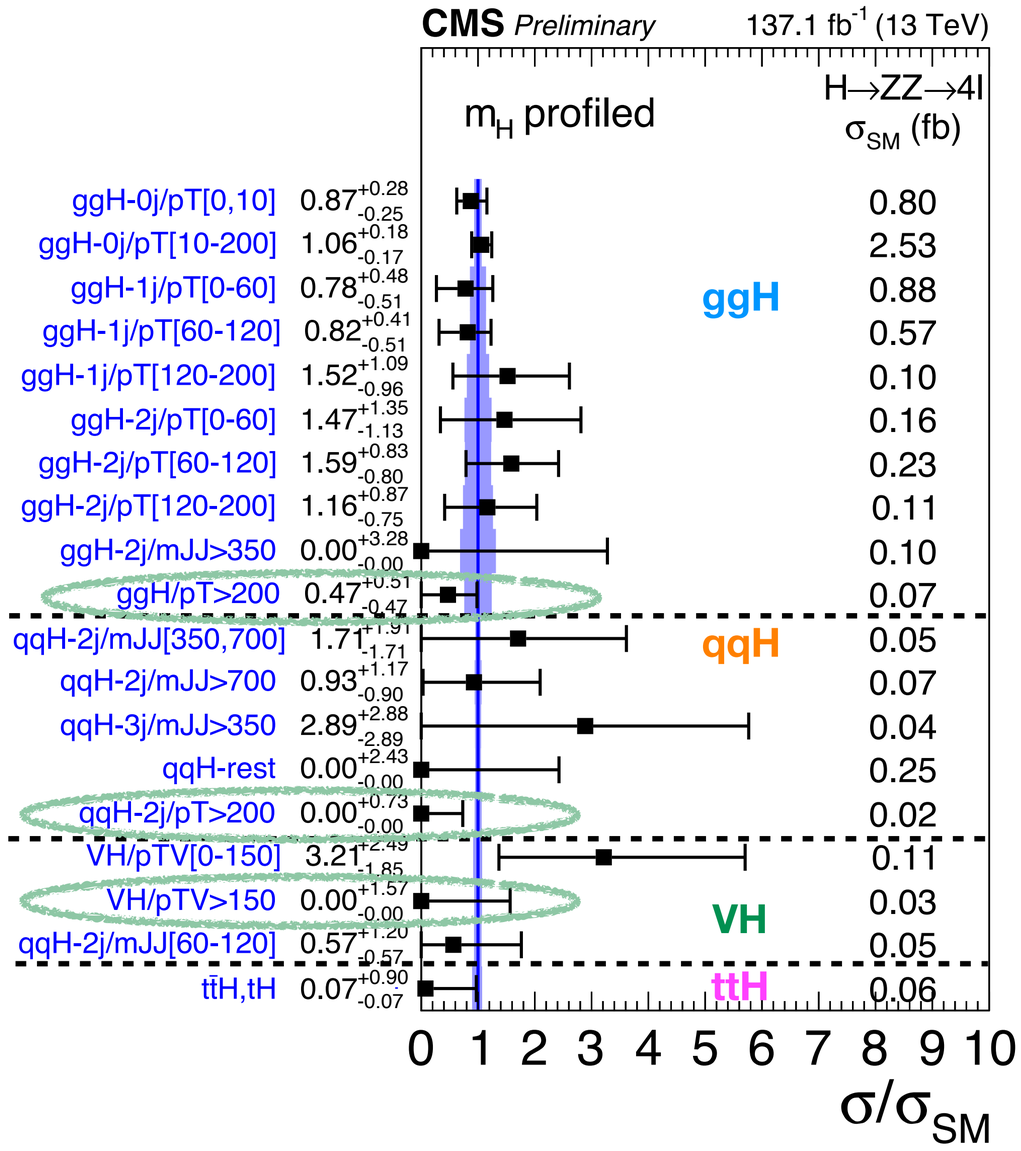


$m_{4\mu}$ = 123.8 GeV
Background suppression discriminant D_{bkg}^{kin} = 0.75
4 jets with pT> 30 GeV, 1 b-tagged

H→ 4l, 2016+17+18, CMS

Overall signal strength uncertainty: 10%



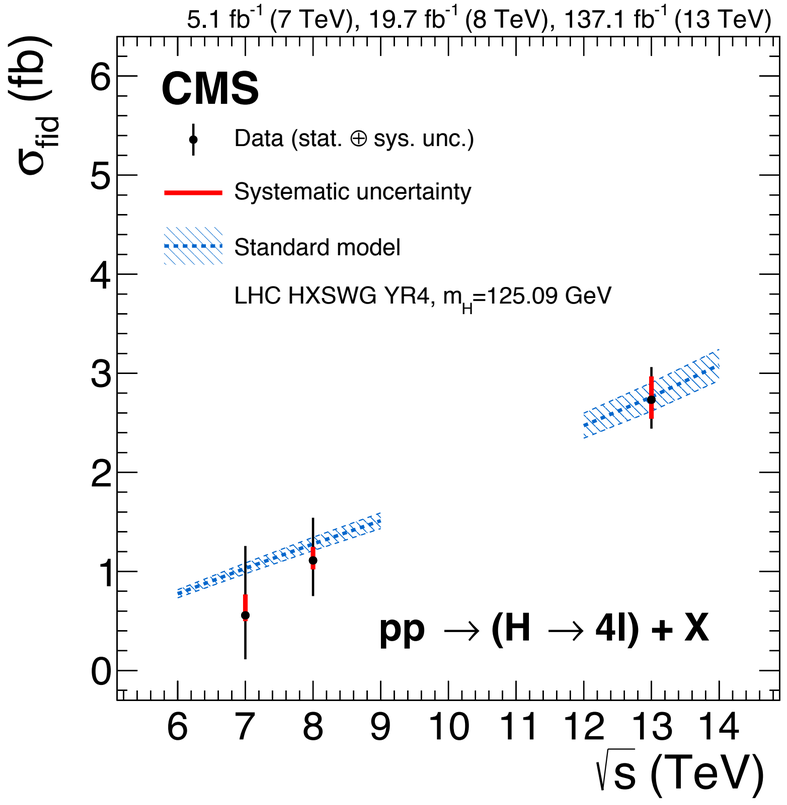


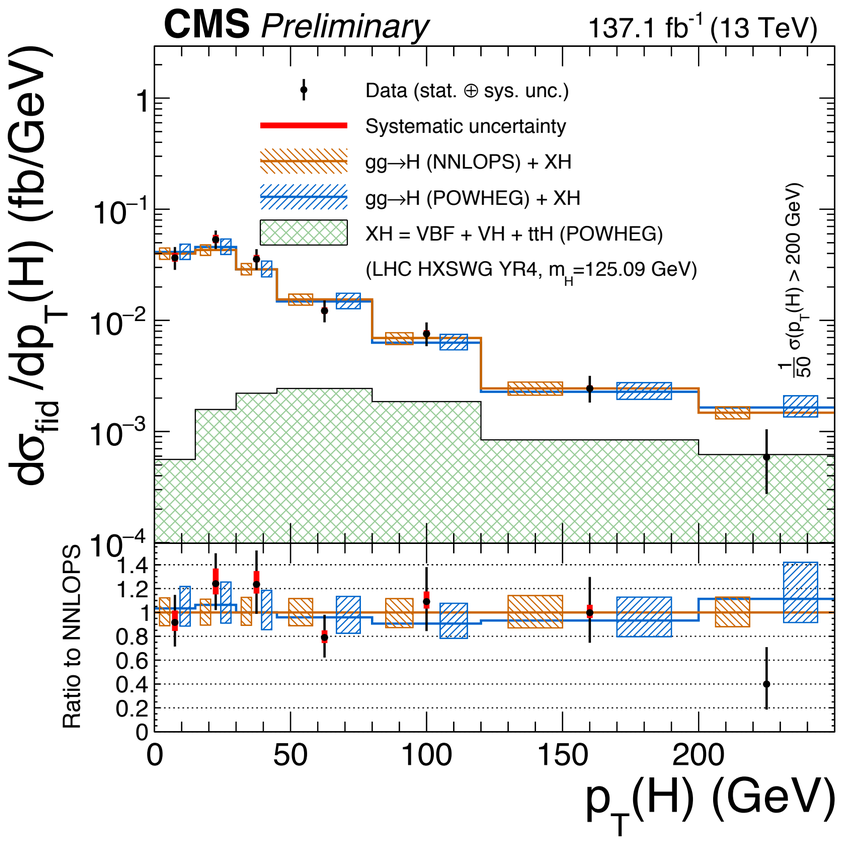
$\mu_{\mathrm{ggH,b\bar{b}H,t\bar{t}H,tH}} = 0.96^{+0.11}_{-0.12}$ $\mu_{\mathrm{VBF,VH}} = 0.83^{+0.29}_{-0.35}$

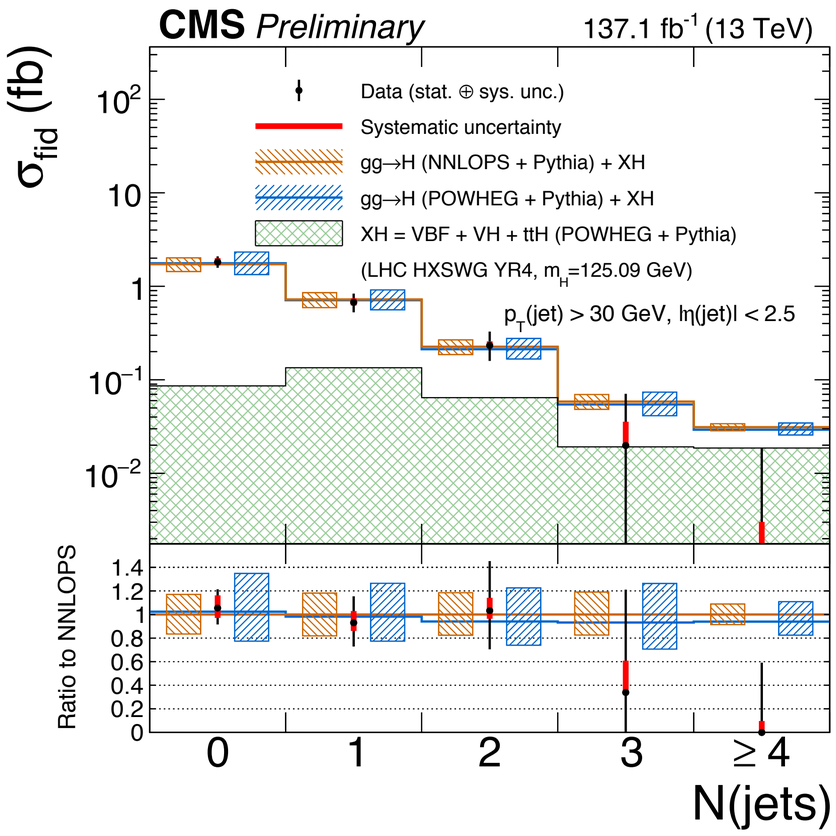
H→ 4l, fiducial xsec, 2016+17+18, CMS

$$\sigma_{fid} = 2.73^{+0.23}_{-0.22}(\text{stat.})^{+0.24}_{-0.19}(\text{syst.})\ \text{fb}$$

σ_{SM} = 2.76 ± 0.14 fb



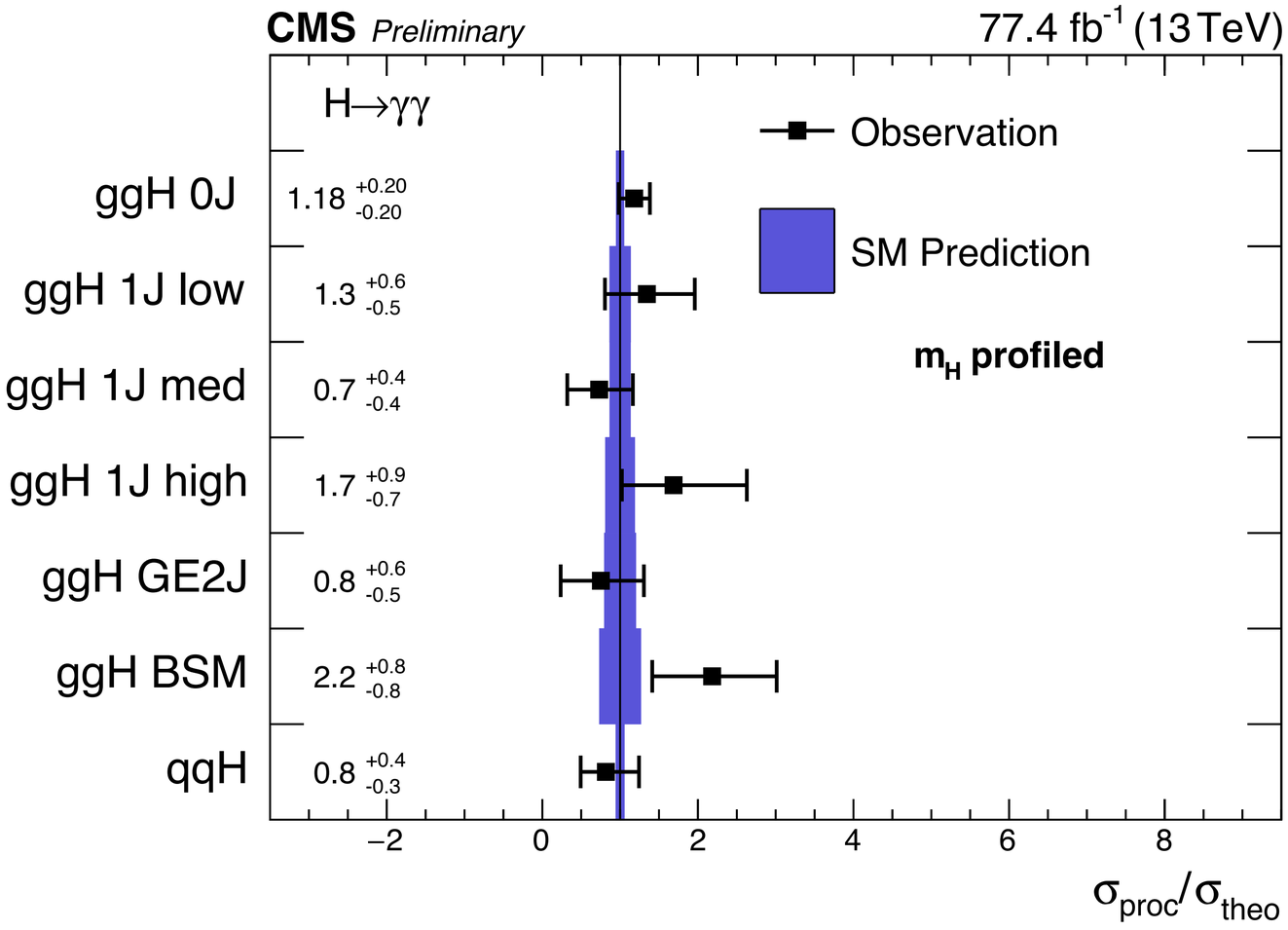


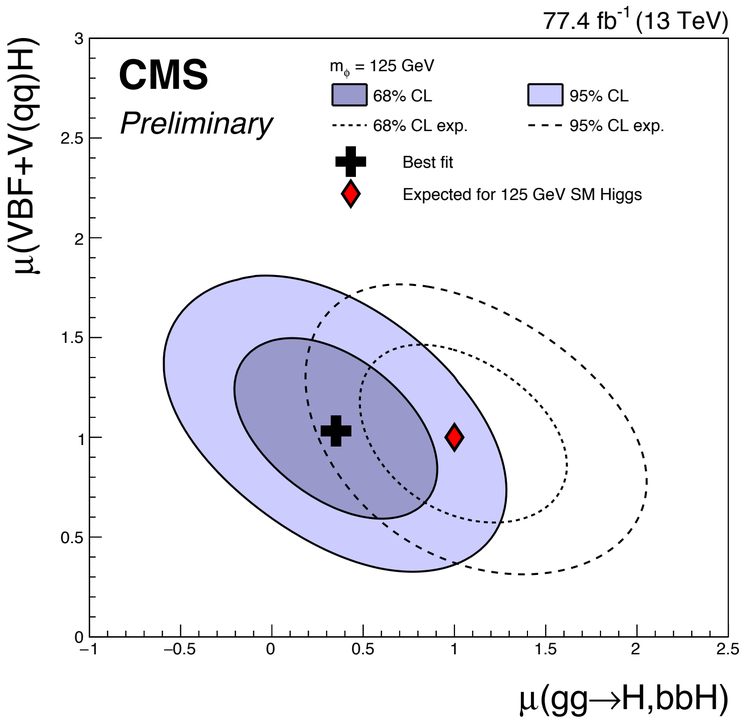


Summary

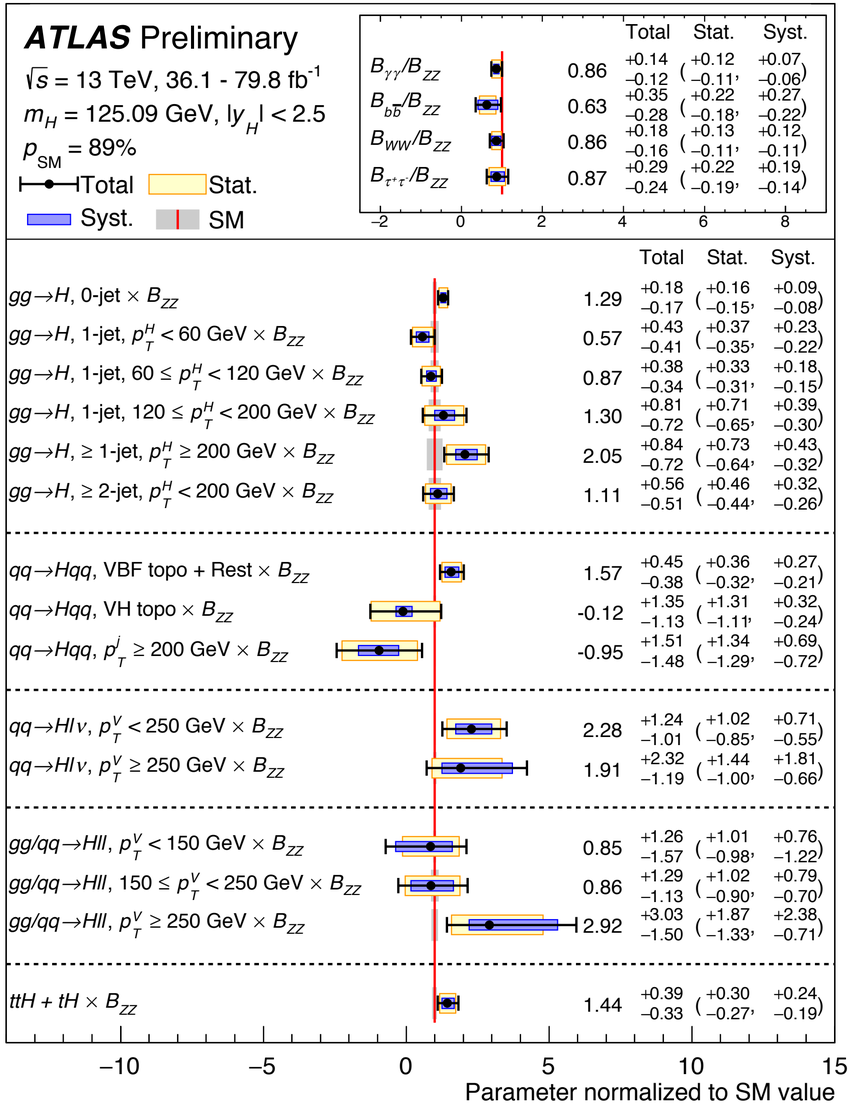
- Many new Higgs measurement results for Moriond, in this talk
  - 80 fb^{-1} data: STXS stage1 in $H\rightarrow\gamma\gamma$, $H\rightarrow\tau\tau$, CMS
  - 80 fb^{-1} data: H combination on couplings and STXS stage1, ATLAS
  - 137 fb^{-1} data: STXS stage1.1 in $H\rightarrow ZZ\rightarrow 4l$, CMS
- Improved precision in Higgs measurements
  - inclusive quantities: ~ 10%
  - ever finer granularity to probe deviations from the SM, some limited by statistics
- Looking forward to further improvements from more analyses on full Run2 and beyond

More plots


CMS Preliminary
77.4 fb-1 (13 TeV)
H→γγ
Observation
SM Prediction
mH profiled
ggH 0J
1.18 +0.20 -0.20
ggH 1J low
1.3 +0.6 -0.5
ggH 1J med
0.7 +0.4 -0.4
ggH 1J high
1.7 +0.9 -0.7
ggH GE2J
0.8 +0.6 -0.5
ggH BSM
2.2 +0.8 -0.8
qqH
0.8 +0.4 -0.3
−2
0
2
4
6
8
σproc/σtheo

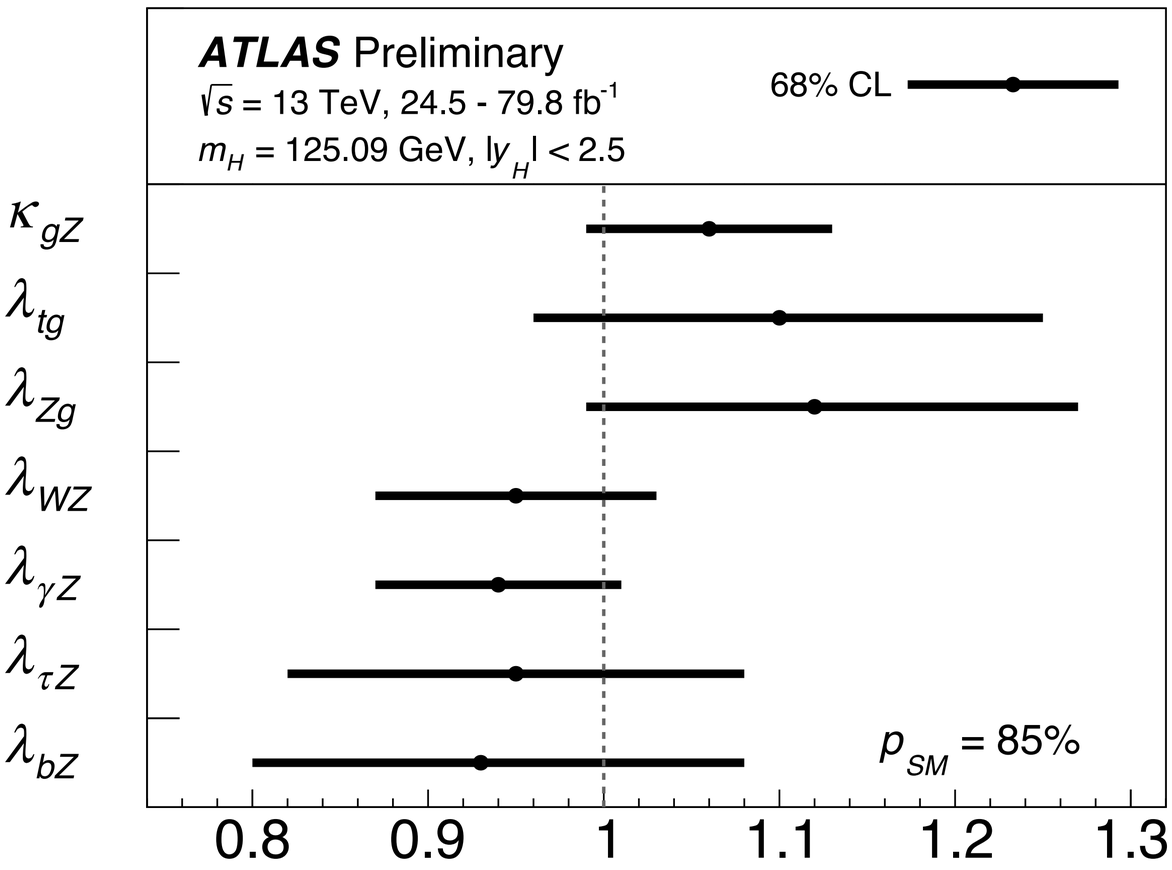

77.4 fb^{-1} (13 TeV)
CMS
Preliminary
m_ϕ = 125 GeV
68% CL
95% CL
68% CL exp.
95% CL exp.
Best fit
Expected for 125 GeV SM Higgs
μ(VBF+V(qq)H)
μ(gg→H,bbH)
3
2.5
2
1.5
1
0.5
0
−1
−0.5
0
0.5
1
1.5
2
2.5

- ggH 0-jet and 1-jet <60 GeV: WW > γγ > 4l
- ggH 1-jet > 60: γγ > 4l
- ggH + qqH: γγ
- qqH BSM: $\tau\tau$
- VH lep: bb
- ttH, multilepton and γγ

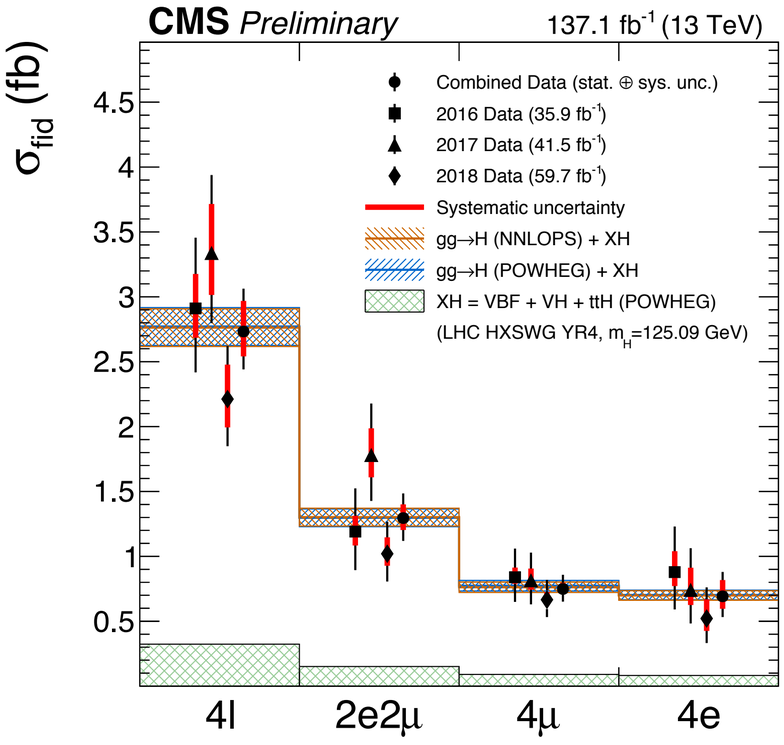


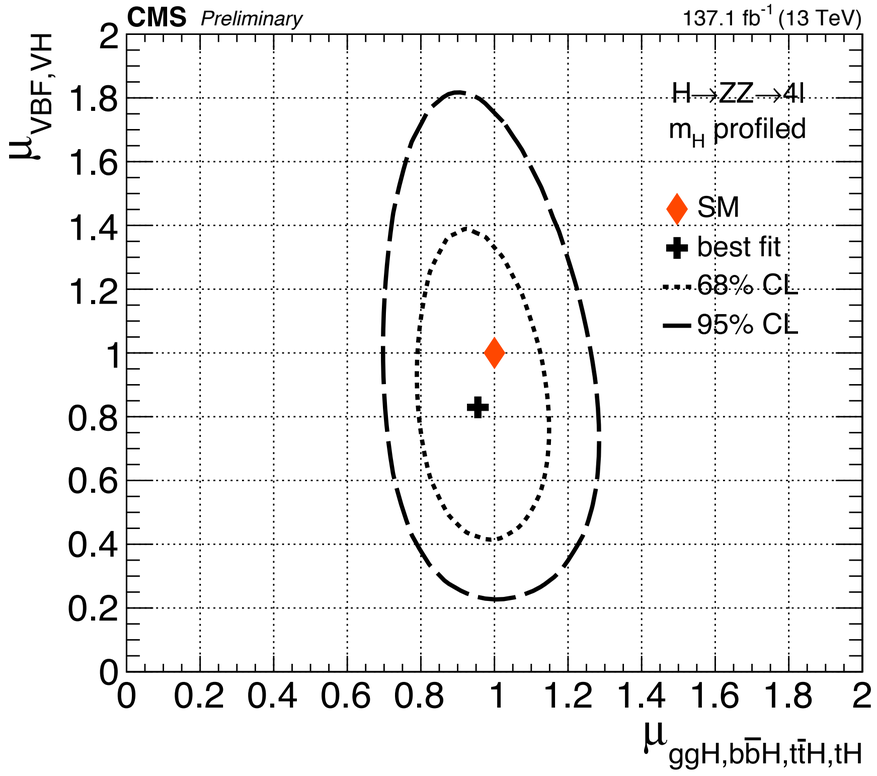
	$H\to\gamma\gamma$	$H\to ZZ^*$	$H\to WW^*$	$H\to\tau\tau$	$H\to b\bar{b}$
$t\bar{t}H$	$t\bar{t}H$ leptonic (3 categories) $t\bar{t}H$ hadronic (4 categories)	$t\bar{t}H$ multilepton 1 ℓ + 2 $\tau_{\rm had}$ $t\bar{t}H$ multilepton 2 opposite-sign ℓ + 1 $\tau_{\rm had}$ $t\bar{t}H$ multilepton 2 same-sign ℓ (categories for 0 or 1 $\tau_{\rm had}$) $t\bar{t}H$ multilepton 3 ℓ (categories for 0 or 1 $\tau_{\rm had}$) $t\bar{t}H$ multilepton 4 ℓ (except $H\to ZZ^*\to 4\ell$) $t\bar{t}H$ leptonic, $H\to ZZ^*\to 4\ell$ $t\bar{t}H$ hadronic, $H\to ZZ^*\to 4\ell$			$t\bar{t}H$ 1 ℓ, boosted $t\bar{t}H$ 1 ℓ, resolved (11 categories) $t\bar{t}H$ 2 ℓ (7 categories)
VH	VH 2 ℓ VH 1 ℓ, $p_{\rm T}^{\ell+E_{\rm T}^{\rm miss}}$ $\geq$ 150 GeV VH 1 ℓ, $p_{\rm T}^{\ell+E_{\rm T}^{\rm miss}}$ <150 GeV VH $E_{\rm T}^{\rm miss}$, $E_{\rm T}^{\rm miss}$ $\geq$ 150 GeV VH $E_{\rm T}^{\rm miss}$, $E_{\rm T}^{\rm miss}$ <150 GeV VH+VBF $p_{\rm T}^{j1}$ $\geq$ 200 GeV VH hadronic (2 categories)	VH leptonic 0-jet, $p_{\rm T}^{4\ell}\geq 100\ GeV$ 2-jet, $m_{jj}<120\ GeV$			2 ℓ, $75\leq p_{\rm T}^{V}<150\ GeV$, $N_{\rm jets}=2$ 2 ℓ, $75\leq p_{\rm T}^{V}<150\ GeV$, $N_{\rm jets}\geq 3$ 2 ℓ, $p_{\rm T}^{V}\geq 150\ GeV$, $N_{\rm jets}=2$ 2 ℓ, $p_{\rm T}^{V}\geq 150\ GeV$, $N_{\rm jets}\geq 3$ 1 ℓ $p_{\rm T}^{V}\geq 150\ GeV$, $N_{\rm jets}=2$ 1 ℓ $p_{\rm T}^{V}\geq 150\ GeV$, $N_{\rm jets}=3$ 0 ℓ, $p_{\rm T}^{V}\geq 150\ GeV$, $N_{\rm jets}=2$ 0 ℓ, $p_{\rm T}^{V}\geq 150\ GeV$, $N_{\rm jets}=3$
VBF	VBF, $p_{\rm T}^{\gamma\gamma jj}\geq 25$ GeV (2 categories) VBF, $p_{\rm T}^{\gamma\gamma jj}$<25 GeV (2 categories)	2-jet VBF, $p_{\rm T}^{j1}\geq 200\ GeV$ 2-jet VBF, $p_{\rm T}^{j1}$<200 GeV	2-jet VBF	VBF $p_{\rm T}^{\tau\tau}>140\ GeV$ ($\tau_{\rm had}\tau_{\rm had}$ only) VBF high-m_{jj} VBF low-m_{jj}	VBF, two central jets VBF, four central jets VBF $+\gamma$
ggF	2-jet, $p_{\rm T}^{\gamma\gamma}\geq 200$ GeV 2-jet, 120 GeV $\leq p_{\rm T}^{\gamma\gamma}$¡200 GeV 2-jet, 60 GeV $\leq p_{\rm T}^{\gamma\gamma}$¡120 GeV 2-jet, $p_{\rm T}^{\gamma\gamma}$ < 60 GeV 1-jet, $p_{\rm T}^{\gamma\gamma}\geq 200$ GeV 1-jet, 120 GeV $\leq p_{\rm T}^{\gamma\gamma}$¡200 GeV 1-jet, 60 GeV $\leq p_{\rm T}^{\gamma\gamma}$¡120 GeV 1-jet, $p_{\rm T}^{\gamma\gamma}$ < 60 GeV 0-jet (2 categories)	1-jet, $p_{\rm T}^{4\ell}\geq 120\ GeV$ 1-jet, 60 GeV$\leq p_{\rm T}^{4\ell}$¡120 GeV 1-jet, $p_{\rm T}^{4\ell}<60\ GeV$ 0-jet, $p_{\rm T}^{4\ell}<100\ GeV$	1-jet, $m_{\ell\ell}<30\ GeV$, $p_{\rm T}^{\ell_2}<20\ GeV$ 1-jet, $m_{\ell\ell}<30\ GeV$, $p_{\rm T}^{\ell_2}\geq 20\ GeV$ 1-jet, $m_{\ell\ell}\geq 30\ GeV$, $p_{\rm T}^{\ell_2}<20\ GeV$ 1-jet, $m_{\ell\ell}\geq 30\ GeV$, $p_{\rm T}^{\ell_2}\geq 20\ GeV$ 0-jet, $m_{\ell\ell}<30\ GeV$, $p_{\rm T}^{\ell_2}<20\ GeV$ 0-jet, $m_{\ell\ell}<30\ GeV$, $p_{\rm T}^{\ell_2}\geq 20\ GeV$ 0-jet, $m_{\ell\ell}\geq 30\ GeV$, $p_{\rm T}^{\ell_2}<20\ GeV$ 0-jet, $m_{\ell\ell}\geq 30\ GeV$, $p_{\rm T}^{\ell_2}\geq 20\ GeV$	Boosted, $p_{\rm T}^{\tau\tau}>140\ GeV$ Boosted, $p_{\rm T}^{\tau\tau}\leq 140\ GeV$	

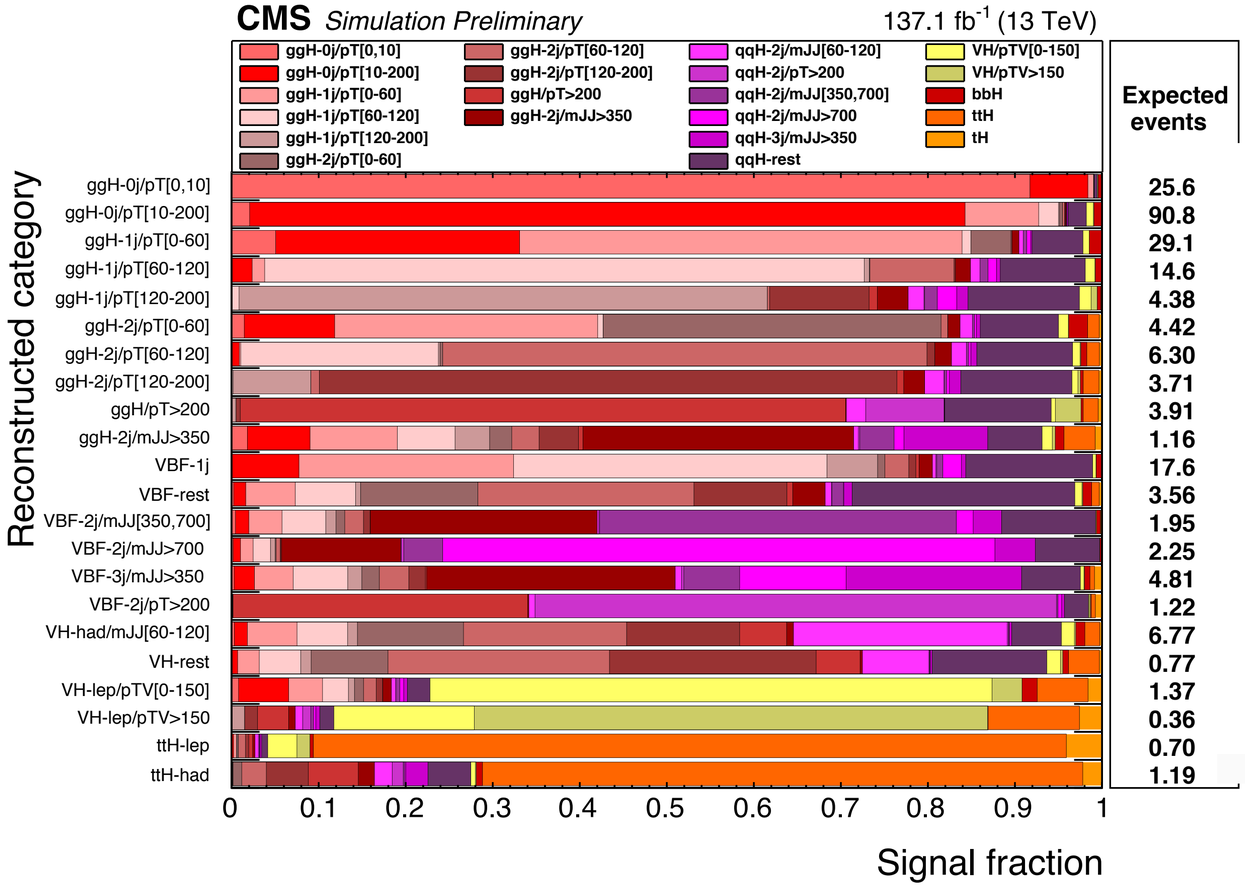
Uncertainty source	$\frac{\Delta\sigma_{\mathrm{ggF}}}{\sigma_{\mathrm{ggF}}}$ [%]	$\frac{\Delta\sigma_{\mathrm{VBF}}}{\sigma_{\mathrm{VBF}}}$ [%]	$\frac{\Delta\sigma_{WH}}{\sigma_{WH}}$ [%]	$\frac{\Delta\sigma_{ZH}}{\sigma_{ZH}}$ [%]	$\frac{\Delta\sigma_{t\bar{t}H+tH}}{\sigma_{t\bar{t}H+tH}}$ [%]
Statistical uncertainties	6.4	15	21	23	14
Systematic uncertainties	6.2	12	22	17	15
Theory uncertainties	3.4	9.2	14	14	12
Signal	2.0	8.7	5.8	6.7	6.3
Background	2.7	3.0	13	12	10
Experimental uncertainties (excl. MC stat.)	5.0	6.5	9.9	9.6	9.2
Luminosity	2.1	1.8	1.8	1.8	3.1
Background modeling	2.5	2.2	4.7	2.9	5.7
Jets, $E_{\mathrm{T}}^{\mathrm{miss}}$	0.9	5.4	3.0	3.3	4.0
Flavour tagging	0.9	1.3	7.9	8.0	1.8
Electrons, photons	2.5	1.7	1.8	1.5	3.8
Muons	0.4	0.3	0.1	0.2	0.5
τ-lepton	0.2	1.3	0.3	0.1	2.4
Other	2.5	1.2	0.3	1.1	0.8
MC statistical uncertainties	1.6	4.8	8.8	7.9	4.4
Total uncertainties	8.9	19	30	29	21


ATLAS Preliminary
√s = 13 TeV, 24.5 - 79.8 fb-1
mH = 125.09 GeV, |yH| < 2.5
68% CL
κgZ
λtg
λZg
λWZ
λγZ
λτZ
λbZ
pSM = 85%
0.8
0.9
1
1.1
1.2
1.3

POIs	Granularity	$\kappa_F{}^{+1\sigma}_{-1\sigma}$	$\kappa_V{}^{+1\sigma}_{-1\sigma}$	$\kappa_\lambda{}^{+1\sigma}_{-1\sigma}$	κ_λ [95% C.L.]
κ_λ	STXS	1	1	$4.0^{+4.3}_{-4.1}$	$[-3.2, 11.9]$
				$1.0^{+8.8}_{-4.4}$	$[-6.2, 14.4]$
κ_λ	inclusive	1	1	$4.6^{+4.3}_{-4.2}$	$[-2.9, 12.5]$
				$1.0^{+9.5}_{-4.3}$	$[-6.1, 15.0]$
κ_λ, κ_V	STXS	1	$1.04^{+0.05}_{-0.04}$	$4.8^{+7.4}_{-6.7}$	$[-6.7, 18.4]$
			$1.00^{+0.05}_{-0.04}$	$1.0^{+9.9}_{-6.1}$	$[-9.4, 18.9]$
κ_λ, κ_F	STXS	$0.99^{+0.08}_{-0.08}$	1	$4.1^{+4.3}_{-4.1}$	$[-3.2, 11.9]$
		$1.00^{+0.08}_{-0.08}$		$1.0^{+8.8}_{-4.4}$	$[-6.3, 14.4]$


CMS Preliminary
137.1 fb-1 (13 TeV)
σfid (fb)
Combined Data (stat. ⊕ sys. unc.)
2016 Data (35.9 fb-1)
2017 Data (41.5 fb-1)
2018 Data (59.7 fb-1)
Systematic uncertainty
gg→H (NNLOPS) + XH
gg→H (POWHEG) + XH
XH = VBF + VH + ttH (POWHEG)
(LHC HXSWG YR4, mH=125.09 GeV)
4l
2e2μ
4μ
4e


CMS Preliminary
137.1 fb-1 (13 TeV)
H→ZZ→4l
mH profiled
SM
best fit
68% CL
95% CL
μVBF,VH
μggH,bb̄H,tt̄H,tH



Event category	Signal ggH	VBF	WH	ZH	ttH	bbH	tqH	Total signal	Background $q\bar{q} \to ZZ$	$gg \to ZZ$	$Z + X$	Total expected	Observed
ggH-0j/pT[0,10]	25.31	0.08	0.02	0.02	0.00	0.14	0.00	25.57	26.46	0.97	1.19	54.18	61
ggH-0j/pT[10-200]	86.80	1.69	0.54	0.86	0.00	0.90	0.00	90.80	35.42	3.79	15.48	145.49	153
ggH-1j/pT[0-60]	26.24	1.43	0.50	0.45	0.01	0.43	0.01	29.06	10.26	1.19	5.54	46.05	40
ggH-1j/pT[60-120]	12.35	1.24	0.45	0.47	0.01	0.10	0.01	14.63	2.76	0.16	3.21	20.76	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	14.17	2.94	0.20	0.18	0.00	0.12	0.01	17.61	2.37	0.43	1.05	21.46	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