Measurement of cross sections and properties of the Higgs boson in decays to bosons

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on behalf of the ATLAS and CMS Collaboration

26th International Conference on Supersymmetry and Unification of Fundamental Interactions
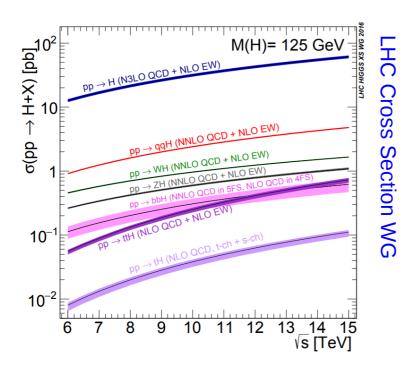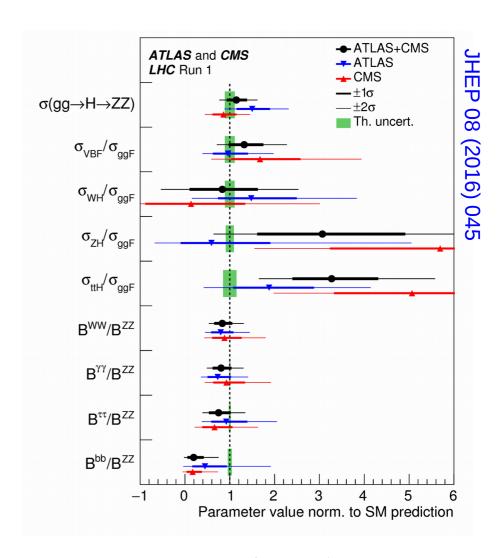Barcelona, July 23-27, 2018

First results obtained from the combination of ATLAS & CMS measurements (5 fb^{-1} @ 7 TeV + 20 fb^{-1} @ 8 TeV) provided:

- fiducial cross section measurements,

- differential cross section measurements,

- production mode cross section ratios in most sensitive channels.

LHC Cross Section WG

JHEP 08 (2016) 045

No significant deviation from SM predictions

Introduction: LHC - Run2

Both detectors have been successfully recording the delivered luminosity at sqrt(s) = 13 TeV → 80 fb⁻¹ dataset in 2015 – 2017.

Updated Results

- Fiducial cross section measurements,
- Differential cross section measurements,
- Production mode cross section also in the Simplified Template XS Framework.

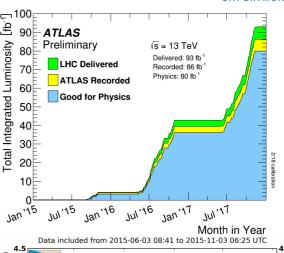**Latest results at 13 TeV**

H→ZZ→4l , H→γγ , H→WW→ lνlν
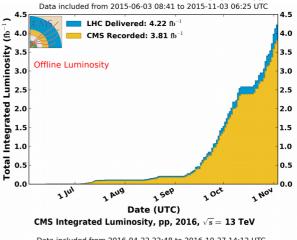
CMS: finalized 2015-2016 (36 fb⁻¹) data analyses & combination of analysis channels.
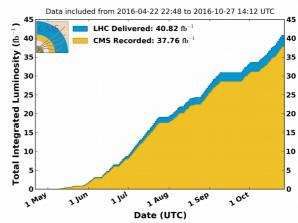
ATLAS: updated results including 2017 data for a total of 80 fb⁻¹. (combination of H→4l, H→γγ also available @ 36 fb⁻¹)

H → ZZ → 4l:
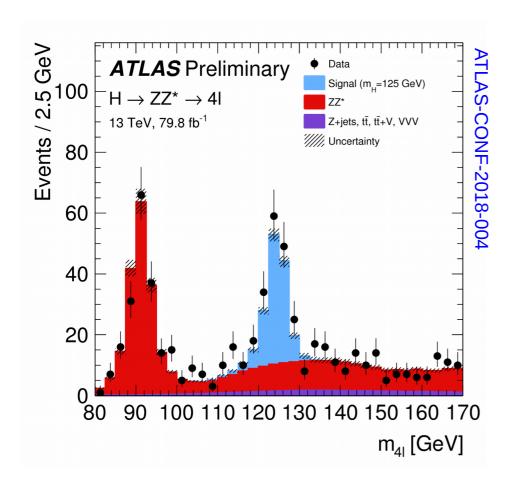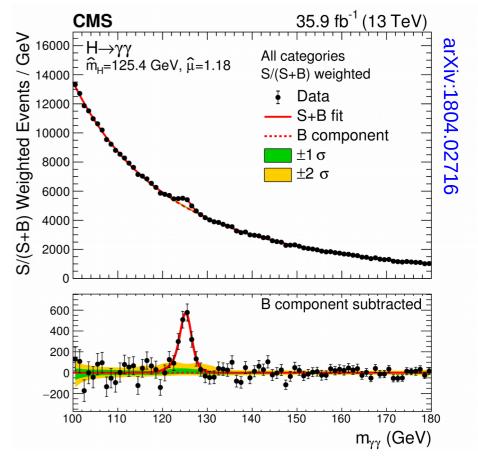
- 2 same-flavor / opposite charge-sign leptons from the same vertex.
- Uses m_{4l} (fiducial XS) or BDT (STXS) as discriminant.
- Splitting according to lepton flavor.

H → $\gamma\gamma$:
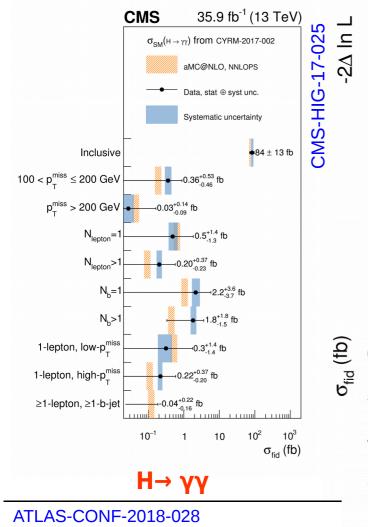
- Selects the 2 leading in p_T photons.
- Uses $m_{\gamma\gamma}$ as discriminant.
- Tight kinematic criteria.

H→ γγ
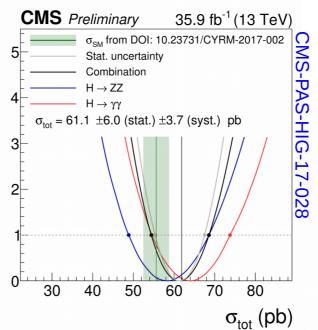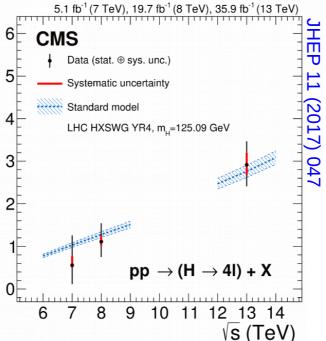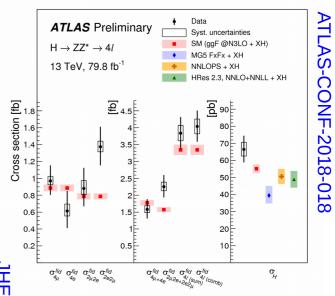
ATLAS-CONF-2018-028
60.4 ± 6.1 (stat.) ± 6.0 (exp.) ± 0.3 (th.) fb
64 ± 3 fb

CMS-PAS-HIG-17-015
84 ± 11 (stat.) ± 7.0 (syst.) fb
75 ± 4 fb

H → ZZ → 4l

ATLAS-CONF-2018-018
4.04 ± 0.41(stat.) ± 0.22(sys.) fb
3.35 ± 0.15 fb

JHEP 11 (2017) 047
2.92$^{+0.48}_{-0.44}$ (stat) $^{+0.28}_{-0.24}$ (syst) fb
2.76 ± 0.14 fb
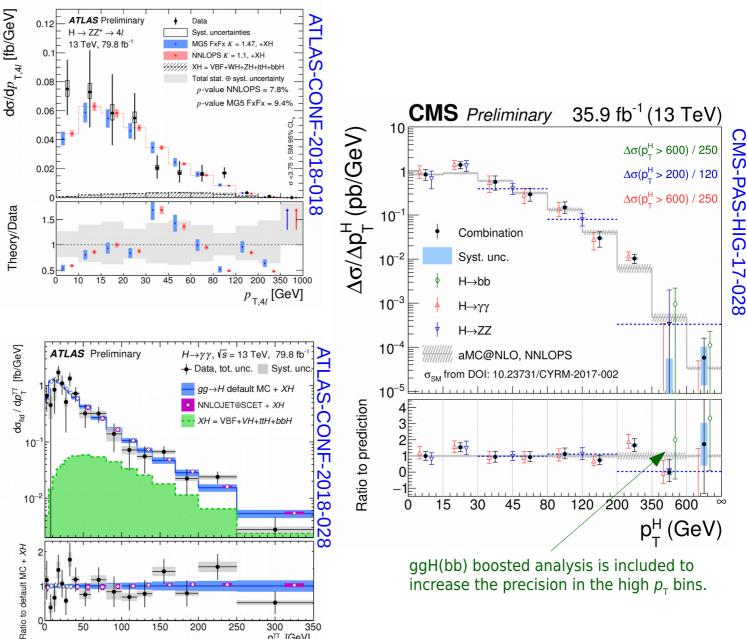
Sensitive to:

- relative rates of Higgs boson production modes
- spin/CP
- perturbative QCD

No significant deviation from SM predictions

ATLAS-CONF-2018-018

ATLAS-CONF-2018-028

CMS-PAS-HIG-17-028

ggH(bb) boosted analysis is included to increase the precision in the high p_T bins.

Differential cross-sections (jet multiplicity)
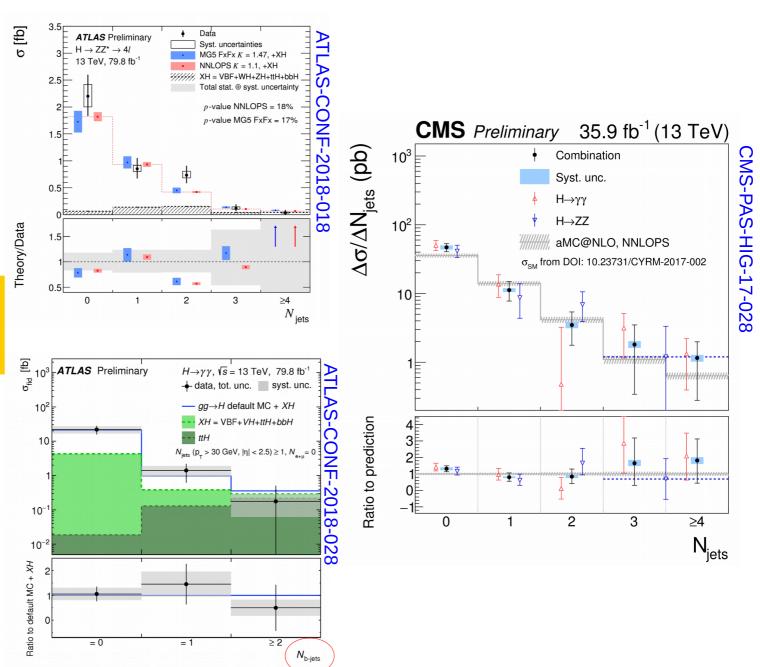
Sensitive to:

- QCD radiation

- relative rates of Higgs boson production modes

No significant deviation from SM predictions
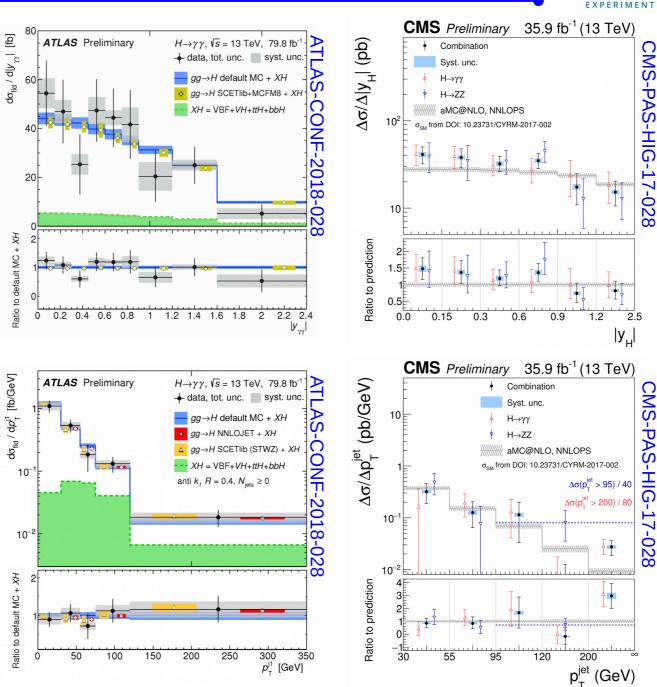
Rapidity
(probing PDFs)

No significant deviation from SM predictions

Leading jet p_T
(quark/gluon radiation hypotheses)

Simplified Template XS

Categorization scheme for cross section measurements to:

arXiv:1610.07922
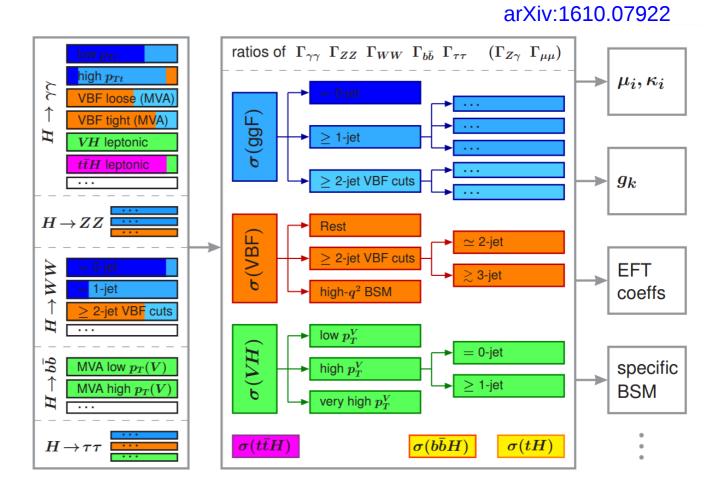
- simplify the combination of analysis results;
- decouple the measurements from specific models;
- cross sections with minimal theoretical uncertainties.

> **Followed by both ATLAS & CMS**

First results are available for:

Stage0: minimal categorization, with disentangled Higgs boson production modes in $y_H < 2.5$)

+Reduced Stage1 (ATLAS).

CMS — 35.9 fb⁻¹ (13 TeV) — arXiv:1804.02716

$H \to \gamma\gamma$

Process	$\sigma_{proc}/\sigma_{theo}$
ggH	$1.02^{+0.19}_{-0.18}$
VBF	$0.8^{+0.6}_{-0.5}$
ttH	$2.0^{+0.8}_{-0.7}$
WH leptonic	$3.0^{+1.5}_{-1.3}$
ZH leptonic	$0.0^{+0.9}_{-0.0}$
VH hadronic	$5.1^{+2.5}_{-2.3}$

Per process 68% CL
SM Prediction
m_H profiled

CMS *Preliminary* — 41.5 fb⁻¹ (13 TeV) — JHEP 11 (2017) 047

$H \to ZZ^* \to 4l$
Stage 0 sub-process
$m_H = 125.09$ GeV
SM prediction

$\sigma_{ggH+b\bar{b}H}/\sigma_{theo} = 1.13^{+0.21}_{-0.20}$

$\sigma_{VBF}/\sigma_{theo} = 1.12^{+1.19}_{-0.83}$

$\sigma_{VHhad}/\sigma_{theo} = 0.00^{+1.53}_{-0.00}$
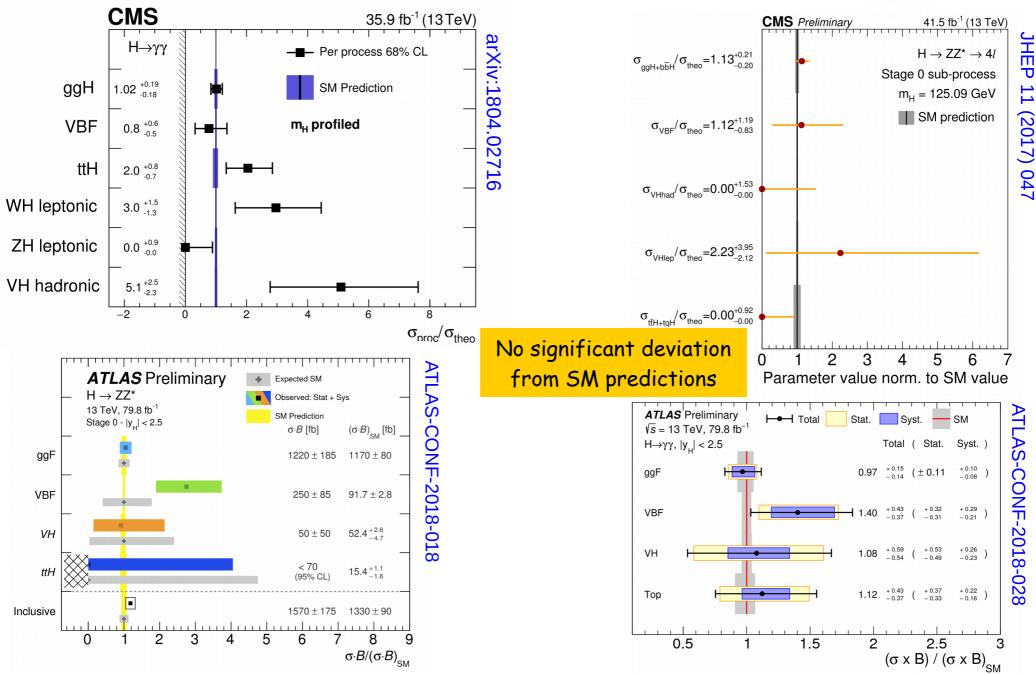
$\sigma_{VHlep}/\sigma_{theo} = 2.23^{+3.95}_{-2.12}$

$\sigma_{t\bar{t}H+tqH}/\sigma_{theo} = 0.00^{+0.92}_{-0.00}$

Parameter value norm. to SM value

No significant deviation from SM predictions

ATLAS Preliminary — ATLAS-CONF-2018-018

$H \to ZZ^*$
13 TeV, 79.8 fb⁻¹
Stage 0 - $|y_H| < 2.5$

Expected SM
Observed: Stat + Sys
SM Prediction

	$\sigma \cdot B$ [fb]	$(\sigma \cdot B)_{SM}$ [fb]
ggF	1220 ± 185	1170 ± 80
VBF	250 ± 85	91.7 ± 2.8
VH	50 ± 50	$52.4^{+2.6}_{-4.7}$
ttH	< 70 (95% CL)	$15.4^{+1.1}_{-1.6}$
Inclusive	1570 ± 175	1330 ± 90

$\sigma \cdot B / (\sigma \cdot B)_{SM}$

ATLAS Preliminary — ATLAS-CONF-2018-028

$\sqrt{s} = 13$ TeV, 79.8 fb⁻¹
$H \to \gamma\gamma$, $|y_H| < 2.5$

Total — Stat. — Syst. — SM

	Total (Stat. Syst.)
ggF	$0.97^{+0.15}_{-0.14}$ (± 0.11 $^{+0.10}_{-0.08}$)
VBF	$1.40^{+0.43}_{-0.37}$ ($^{+0.32}_{-0.31}$ $^{+0.29}_{-0.21}$)
VH	$1.08^{+0.59}_{-0.54}$ ($^{+0.53}_{-0.49}$ $^{+0.26}_{-0.23}$)
Top	$1.12^{+0.43}_{-0.37}$ ($^{+0.37}_{-0.33}$ $^{+0.22}_{-0.16}$)

$(\sigma \times B) / (\sigma \times B)_{SM}$

No statistically significant deviation from SM predictions

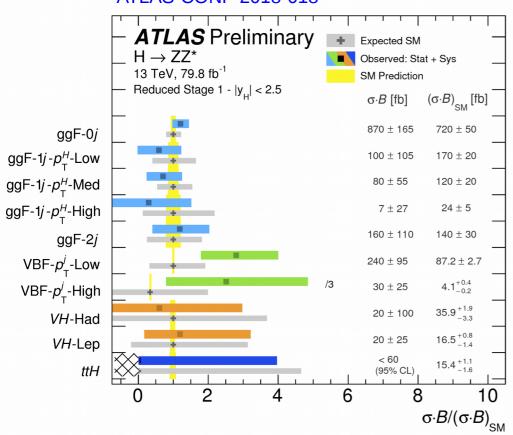**Significant improvement of the measurement precision, w.r.t Run-1 combined results.**
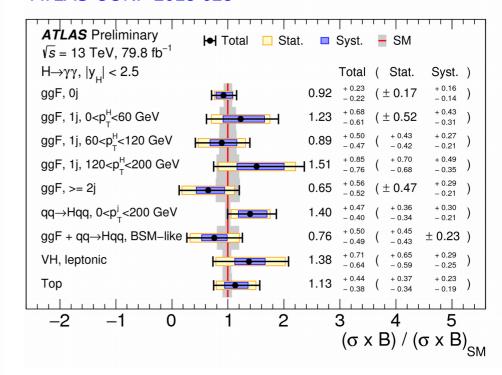
Simplified Template XS (reduced Stage-1)

Further STXS categorisation according to the available sensitivity.
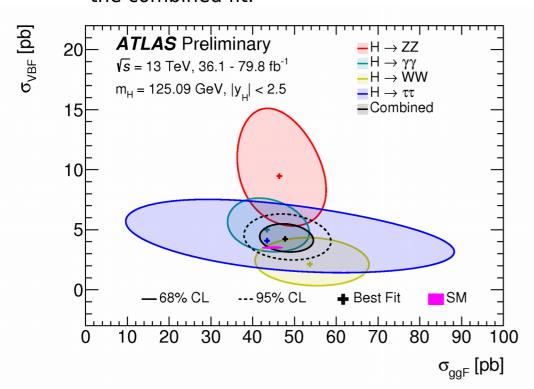
ATLAS-CONF-2018-018

ATLAS-CONF-2018-028

Coupling modifiers
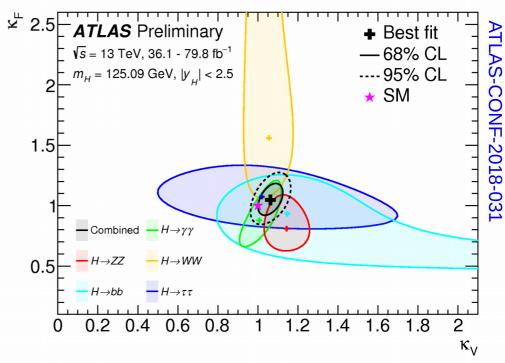
Observed likelihood contours in the plane of σ_{VBF} versus σ_{ggF} from individual channels and the combined fit.

The κ framework expresses Higgs boson interactions using multiplicative modifiers to SM cross-sections and partial widths.

$$\kappa_V = 1.06^{+0.04}_{-0.04}$$

$$\kappa_F = 1.05^{+0.09}_{-0.09}$$

Interpretations of differential Higgs production XS

according to theoretical models.
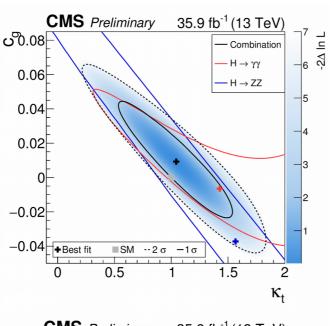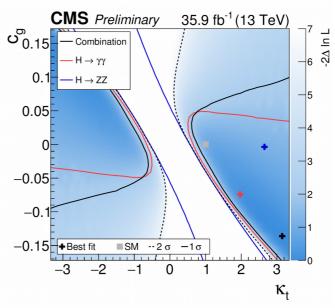
Branching Fractions depending on couplings
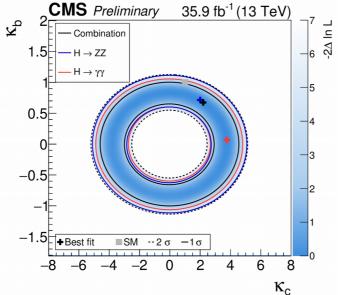
Floating Branching Fractions

CMS-PAS-HIG-17-028

Outline

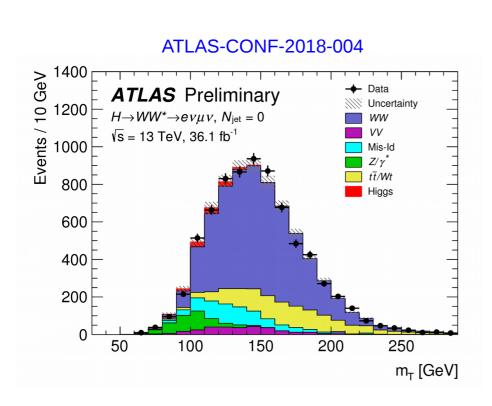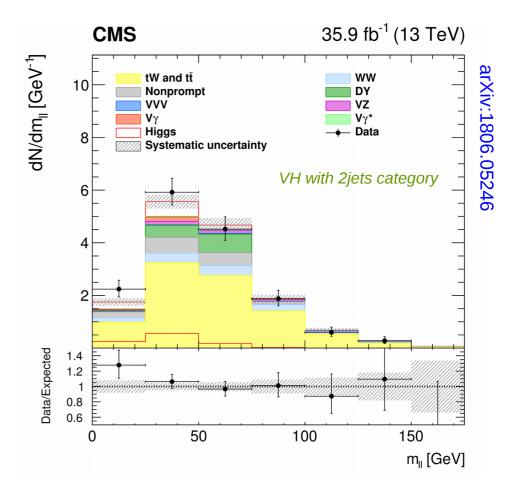- ggH and VBF production with 0, 1 and 2 jets.
- WH/ZH production also studied by CMS (3l+4l events).
- Major backgrounds (WW, ttbar, …) determined from data control regions.
- Discriminant: m_T (also m_{ll} for the VH categories)
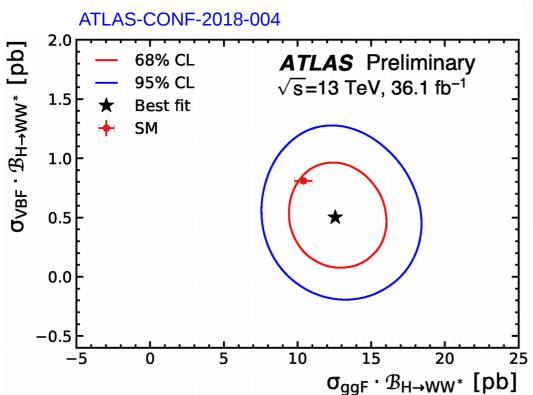
ATLAS-CONF-2018-004

arXiv:1806.05246

H→ WW→ 2l2ν

No statistically significant deviation from SM predictions

ATLAS-CONF-2018-004

$\sigma_{ggF} \cdot \mathcal{B}_{H \to WW^*} = 12.6^{+1.3}_{-1.2}(\text{stat.})^{+1.9}_{-1.8}(\text{sys.}) \text{ pb} = 12.6^{+2.3}_{-2.1} \text{ pb}$

$\sigma_{VBF} \cdot \mathcal{B}_{H \to WW^*} = 0.50^{+0.24}_{-0.23}(\text{stat.}) \pm 0.18(\text{sys.}) \text{ pb} = 0.50^{+0.30}_{-0.29} \text{ pb}$

CMS   35.9 fb⁻¹ (13 TeV)

$\sigma_{ggH}/\sigma_{SM} = 1.24 \, ^{+0.20}_{-0.26}$

$\sigma_{VBF}/\sigma_{SM} = 0.24 \, ^{+0.74}_{-0.24}$

$\sigma_{WH \text{ lep.}}/\sigma_{SM} = 1.80 \, ^{+1.96}_{-1.64}$

$\sigma_{ZH \text{ lep.}}/\sigma_{SM} = 0.71 \, ^{+1.68}_{-0.71}$

$\sigma_{VH \text{ had.}}/\sigma_{SM} = 12.88 \, ^{+4.92}_{-4.89}$

arXiv:1806.05246

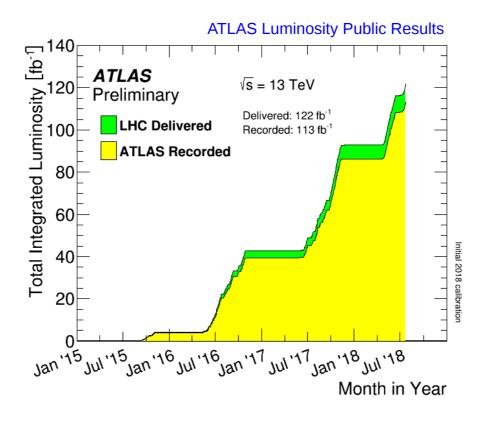arXiv:1806.05246

Conclusion
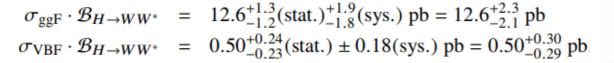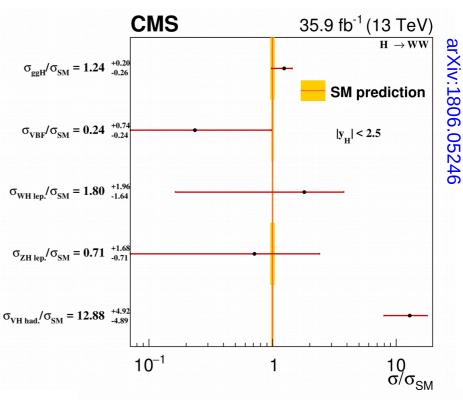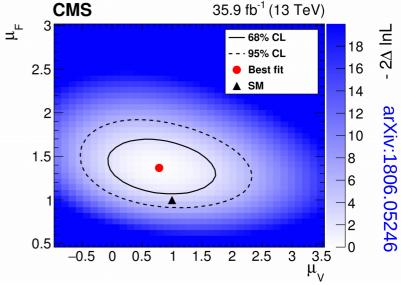
- The analysis of 2015+2016 data has been finalized by both ATLAS and CMS.

- First results with 2017 dataset have been produced.

- Significantly better precision with respect to Run 1 cross section measurements.

- So far, the Higgs cross section measurements show good agreement with the SM.

ATLAS Luminosity Public Results

Backup

ATLAS-CONF-2018-018

Leptons and jets	
Leptons:	$p_T > 5$ GeV, $|\eta| < 2.7$
Jets:	$p_T > 30$ GeV, $|y| < 4.4$
remove jets with:	$\Delta R(\text{jet}, \ell) < 0.1$
Lepton selection and pairing	
Lepton kinematics:	$p_T > 20, 15, 10$ GeV
Leading pair (m_{12}):	SFOS lepton pair with smallest $|m_Z - m_{\ell\ell}|$
Subleading pair (m_{34}):	remaining SFOS lepton pair with smallest $|m_Z - m_{\ell\ell}|$
Event selection (at most one quadruplet per event)	
Mass requirements:	50 GeV$< m_{12} < 106$ GeV and 12 GeV$< m_{34} < 115$ GeV
Lepton separation:	$\Delta R(\ell_i, \ell_j) > 0.1$
J/ψ veto:	$m(\ell_i, \ell_j) > 5$ GeV for all SFOS lepton pairs
Mass window:	115 GeV$< m_{4\ell} < 130$ GeV
If extra leptons with $p_T > 12$ GeV:	Quadruplet with the largest ME

Measurement [-0.5ex]	Experimental uncertainties [%]				Theory uncertainties [%]				
	Lum.	e, μ, pile-up	Jets, flavour tagging	Reducible backgr.	ZZ^* backgr.	PDF	QCD scale	Signal Parton Shower	Composition
Fiducial cross section									
	2.8	4.3	< 0.1	0.3	1.6	0.6	0.5	0.4	0.1
Per decay channel fiducial cross sections									
4μ	2.8	3.9	< 0.1	0.3	1.6	0.6	0.4	0.6	0.2
$4e$	2.8	9.0	< 0.1	1.0	1.6	0.6	0.8	0.5	0.1
$2\mu2e$	2.7	8.6	< 0.1	0.9	1.5	0.6	0.7	0.5	0.1
$2e2\mu$	2.8	3.6	< 0.1	0.4	1.8	0.6	0.7	0.5	0.2
Stage-0 production bin cross sections									
ggF	2.9	3.9	1.3	0.7	2.3	0.4	2.1	0.7	-
VBF	1.7	1.5	10.5	0.5	2.3	2.3	9.5	5.1	-
VH	2.0	1.7	7.8	1.8	5.6	2.1	14.9	3.1	-
ttH	2.5	1.9	3.9	1.5	1.9	0.3	8.8	9.6	-
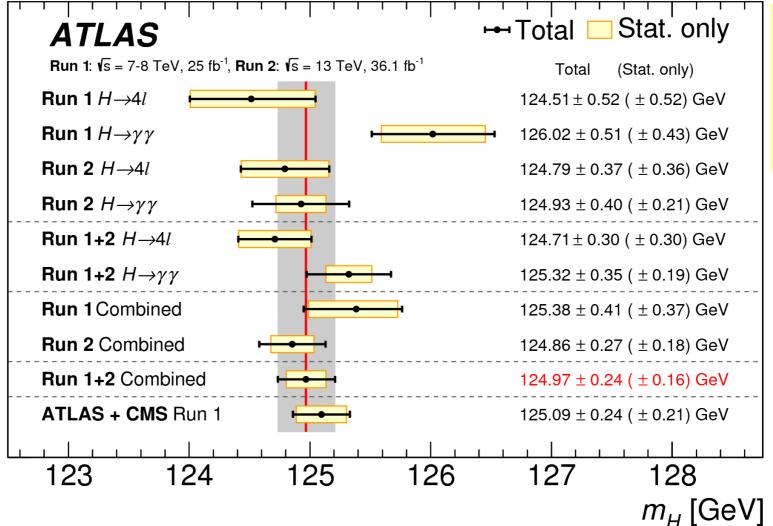
| Lepton kinematics and isolation	
Leading lepton p_T	$p_T > 20\,\text{GeV}$
Subleading lepton p_T	$p_T > 10\,\text{GeV}$
Additional electrons (muons) p_T	$p_T > 7\,(5)\,\text{GeV}$
Pseudorapidity of electrons (muons)	$|\eta| < 2.5\,(2.4)$
Sum p_T of all stable particles within $\Delta R < 0.3$ from lepton	$< 0.35 p_T$
Event topology	
Existence of at least two same-flavor OS lepton pairs, where leptons satisfy criteria above	
Invariant mass of the Z_1 candidate	$40 < m_{Z_1} < 120\,\text{GeV}$
Invariant mass of the Z_2 candidate	$12 < m_{Z_2} < 120\,\text{GeV}$
Distance between selected four leptons	$\Delta R(\ell_i, \ell_j) > 0.02$ for any $i \neq j$
Invariant mass of any opposite-sign lepton pair	$m_{\ell^+\ell'^-} > 4\,\text{GeV}$
Invariant mass of the selected four leptons	$105 < m_{4\ell} < 140\,\text{GeV}$
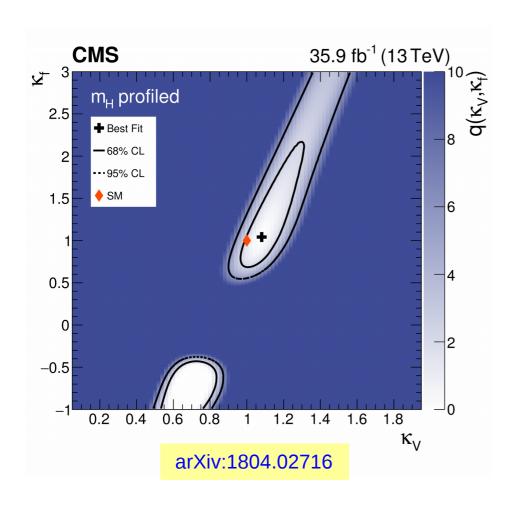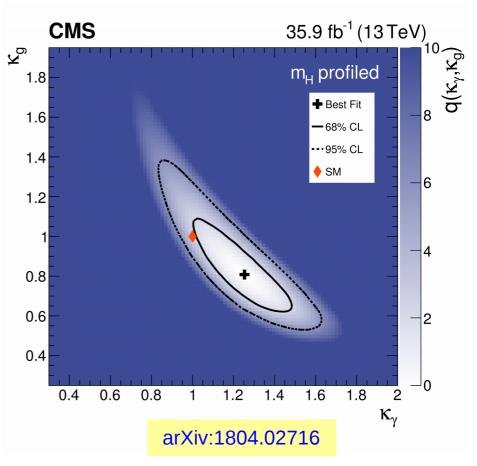
Source	Uncertainty (%)
Fit (stat.)	10
Fit (syst.)	8.3
Photon energy scale & resolution	4.0
Background modeling (spurious signal)	7.3
Correction factor	5.2
Photon isolation efficiency	4.6
Pileup	1.9
Photon ID efficiency	1.3
Trigger efficiency	0.7
Dalitz Decays	0.4
Theoretical modeling	$+0.3$ -0.4
Diphoton vertex selection	0.1
Photon energy scale & resolution	0.1
Luminosity	2.0
Total	14

arXiv:1804.02716

arXiv:1804.02716

Expected composition of signal events per XTGS category(%)

ATLAS Simulation Preliminary   H→γγ, √s = 13 TeV, m_H=125.09 GeV