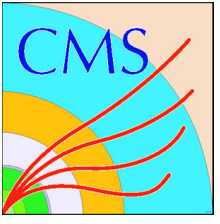
Measurements of Higgs couplings and properties at the LHC

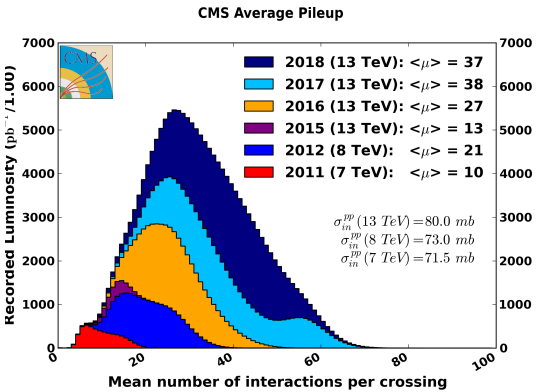
Antonio De Maria
on the behalf of the ATLAS and CMS collaborations

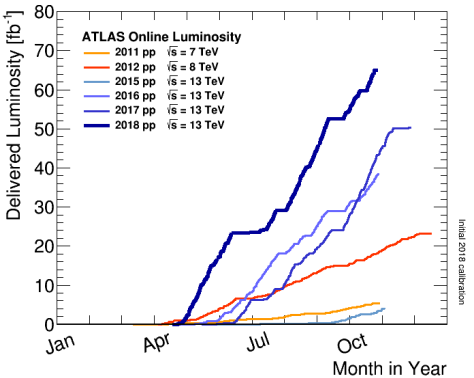
La Thuile 2019



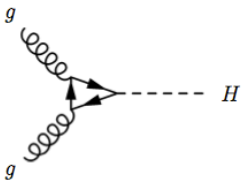
LHC performance

- LHC Run 2 is just finished in 2018
- Luminosity reached record value of 2.1×10^{34} cm^{-1}s^{-1}
- Pileup increased by factor 2-3 with respect to Run 1 conditions
- Available datasets to fulfil LHC physics programme:
  - 25 fb^{-1} collected in 2011/2012 at $\sqrt{s} = 7, 8$ TeV (Run 1)
  - 140 fb^{-1} collected both from 2015 to 2018 at $\sqrt{s} = 13$ TeV (Run 2)

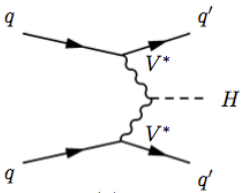




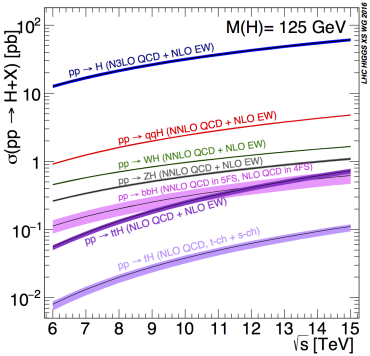
Higgs boson production modes



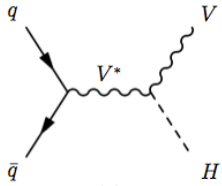
gluon fusion (ggF)



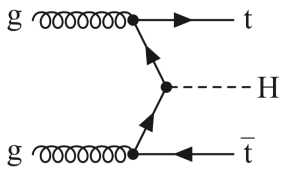
vector boson fusion (VBF)



Higgs boson production cross section



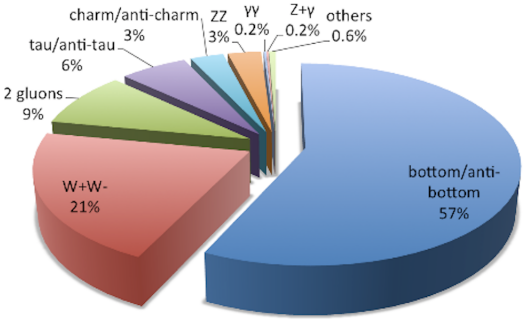
associated production with a gauge boson (VH)



associated production with a $t\bar{t}$ pair (ttH)

- Largest cross section for gluon fusion and vector boson fusion production modes

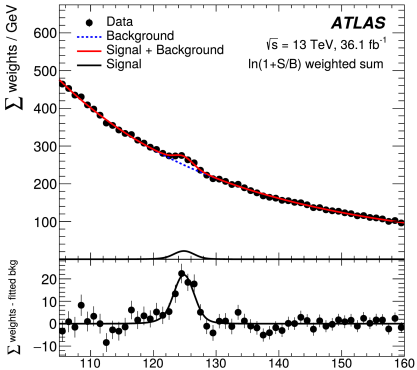
Higgs boson decay branching ratios



Higgs decay branching ratios

- Larger branching ratio (BR) for $H \to b\bar{b}$, $H \to WW^*$ and $H \to \tau\tau$, however poor mass resolution and large background contamination
- $H \to \gamma\gamma$ and $H \to ZZ^*(\to 4l)$ have lower BR, but high mass resolution; can be used for precision measurements

Mass measurements



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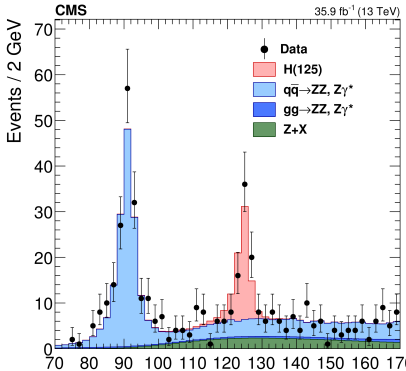


JHEP11(2017)047

	Mass value (GeV)
ATLAS + CMS (Run 1)	125.09 ± 0.21 (stat) ± 0.12 (syst)
CMS (Run 2 4l)	125.26 ± 0.20 (stat) ± 0.08 (syst)
ATLAS (Run 1 + Run 2 4l)	124.71 ± 0.30 (stat) ± 0.01 (syst)
ATLAS (Run 1 + Run 2 $\gamma\gamma$)	125.32 ± 0.19 (stat) ± 0.29 (syst)
ATLAS (Run 1 + Run 2)	124.97 ± 0.16 (stat) ± 0.18 (syst)

- High precision from the *golden* channels : $H \to \gamma\gamma$ and $H \to ZZ^*$
- Precision at per-mille level

Width measurements

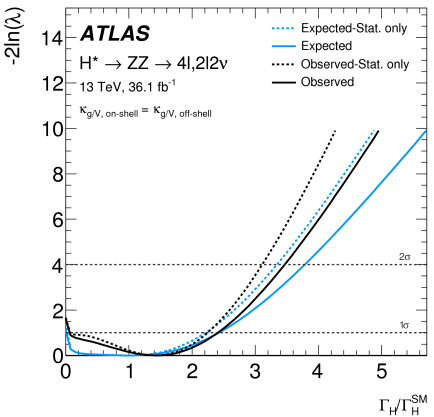
- Standard Model (SM) prediction, $\Gamma_H \simeq 4$ MeV, too small to be measured directly
  - Best limit from CMS in $H \to ZZ^*$: $\Gamma_H < 1.10$ GeV at 95% C.L.
- Limits from ratio of *on-* and *-off* shell cross section measured in $H \to ZZ^*/WW^*$:

$$\sigma_{\text{off-shell}} \propto k^2_{\text{g,off-shell}} \times k^2_{\text{V,off-shell}}$$

$$\sigma_{\text{on-shell}} \propto \frac{k^2_{\text{g,on-shell}} \times k^2_{\text{V,on-shell}}}{\Gamma_H/\Gamma^H_{SM}}$$

Assumption:

$$k_{\text{on-shell}} = k_{\text{off-shell}}$$



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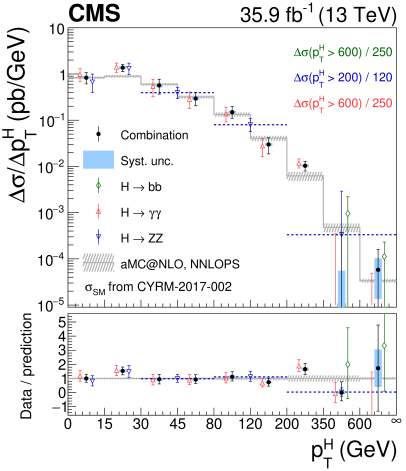
	Γ_H (MeV) at 95 % C.L.
ATLAS	< 14.4
CMS	< 9.16

- Improves on Run-1 ATLAS and CMS expected limits by almost factor 2
- Expected results from ATLAS at HL-LHC (`ATL-PHYS-PUB-2015-024`):

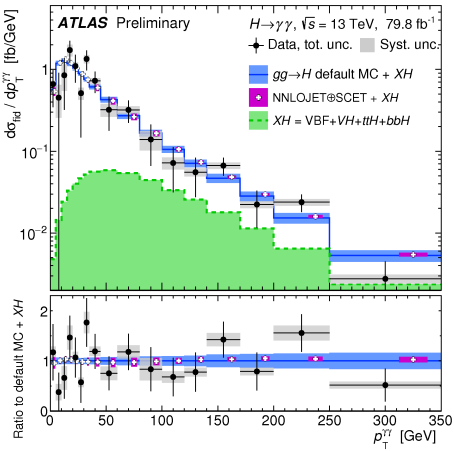
$$\Gamma_H = 4.2^{+1.5}_{-2.1} \quad \text{MeV}$$

Differential cross section : $d\sigma/dp_T^H$

- High p_T^H region is sensitive to perturbative QCD calculation and to new physics



arXiv:1812.06504

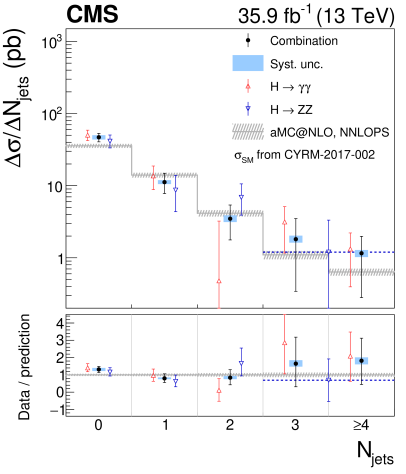


ATLAS-CONF-2018-028

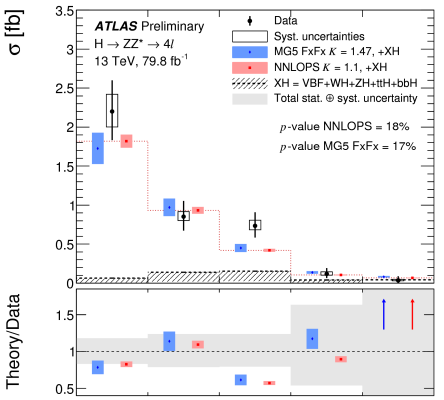
- Good agreement with the SM predictions

Differential cross section : $d\sigma/dN_{\text{jets}}$

- Sensitive to QCD corrections and composition of the production modes



arXiv:1812.06504

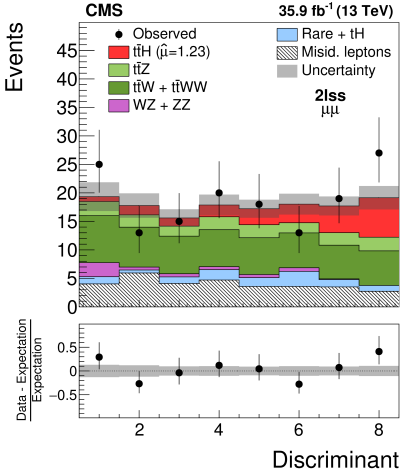


ATLAS-CONF-2018-018

- Good agreement with the SM predictions

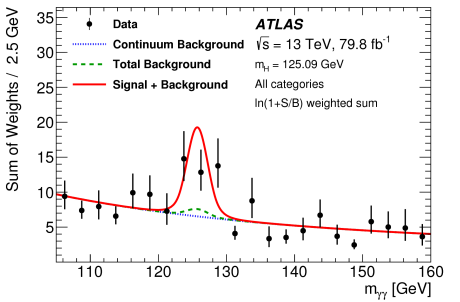
Coupling to 3rd quark family : ttH

- Largest Yukawa coupling → sensitive to new physics
- Combination from different decay channels : $\gamma\gamma$, $\tau\tau$, WW*, ZZ*, $b\bar{b}$



H→ WW^*

JHEP 08 (2018) 066



H→ $\gamma\gamma$

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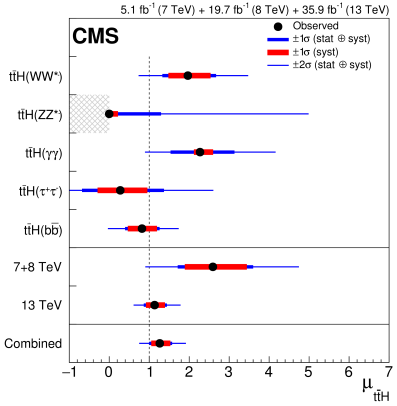
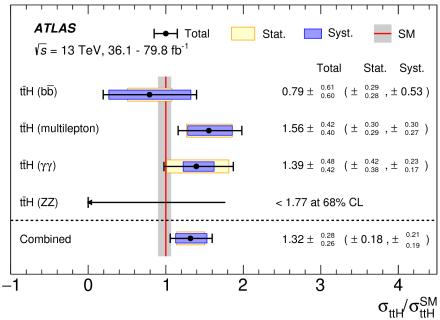
Coupling to 3rd quark family : ttH

- Observation by each experiment alone
- Results in agreement with SM expectations



Phys. Rev. Lett. 120, 231801 (2018)



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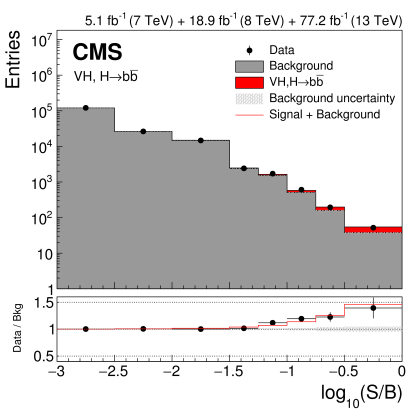
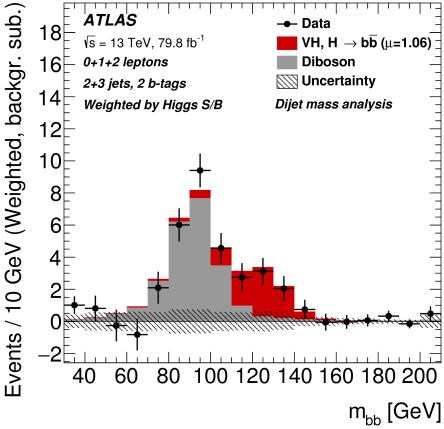
	Signal Strength	Obs/Exp significance
ATLAS (Run 2)	$1.32\ ^{+0.28}_{-0.26}$	5.8 σ / 4.9 σ
CMS (Run1 + Run 2)	$1.26\ ^{+0.31}_{-0.26}$	5.2 σ / 4.2 σ

Coupling to 3^{rd} quark family : $H \to b\bar{b}$

- Measurement driven by VH production, most sensitive mode at LHC
- 3 channels, depending on the number of leptons from W/Z decay



Phys. Rev. Lett. 121 (2018) 121801



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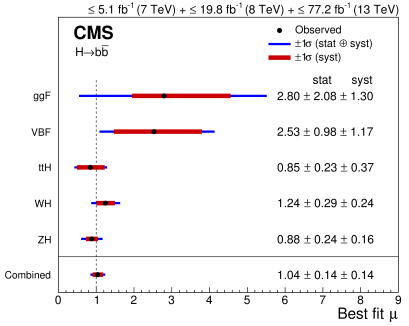
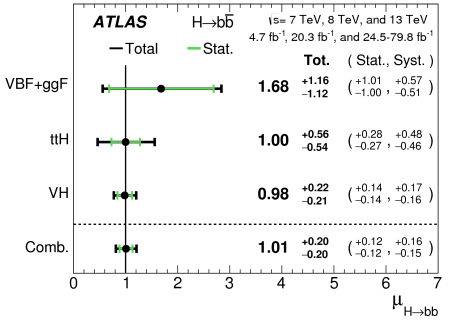
Coupling to 3^{rd} quark family : $H \to b\bar{b}$

- Combination of all production modes leads to direct observation
- Observation by each experiment alone
- Results in agreement with SM expectations



Phys. Rev. Lett. 121 (2018) 121801



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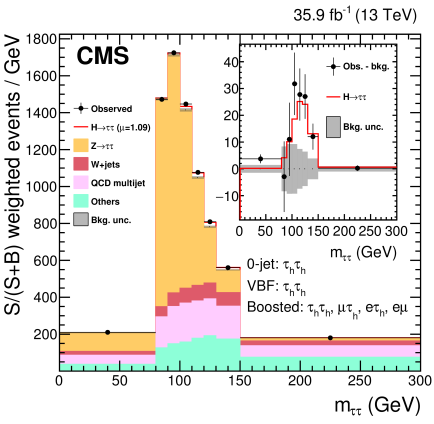
	Signal Strength	Obs/Exp significance
ATLAS (Run1 + Run 2)	1.01 ± 0.20	$5.4\ \sigma$ / $5.5\ \sigma$
CMS (Run1 + Run 2)	1.04 ± 0.20	$5.6\ \sigma$ / $5.5\ \sigma$

Coupling to 3rd lepton family : $H \to \tau\tau$

- Considering mainly ggF and VBF production modes
- Results extracted from fit of di-tau mass, $M_{\tau\tau}$
- Observation by each experiment alone
- Agreement with SM expectations



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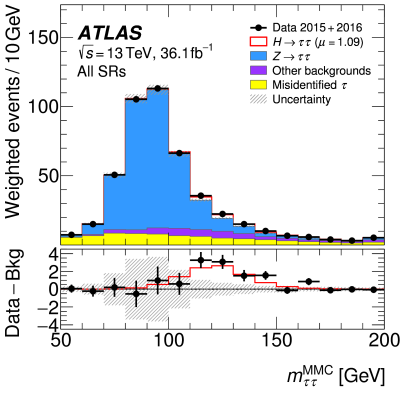


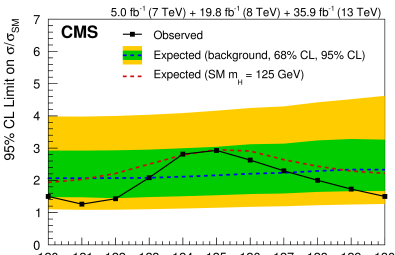
arXiv:1811.08856

	Signal Strenght
ATLAS (Run 2)	$1.09\ ^{+0.35}_{-0.30}$
CMS (Run 2)	$1.09\ ^{+0.27}_{-0.26}$

	Obs/Exp significance
ATLAS (Run1 + Run 2)	6.4 σ / 5.4 σ
CMS (Run1 + Run 2)	5.9 σ / 5.9 σ

Coupling to 2nd lepton family : $H \to \mu\mu$

- Low branching ratio due to coupling proportional to lepton mass
- Results from fit to di-muon mass in each category
- Results close to the SM sensitivity



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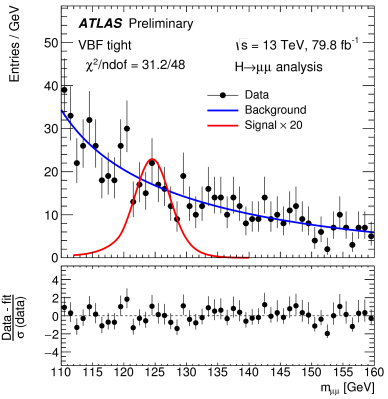
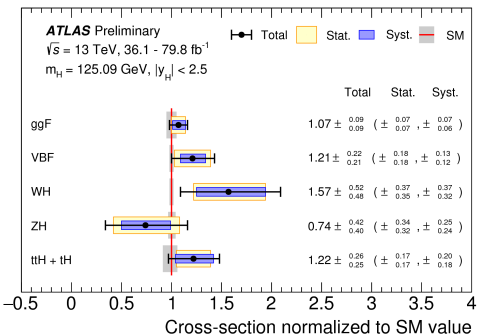


ATLAS-CONF-2018-026

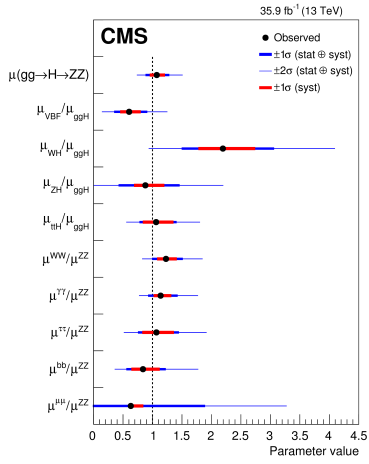
- Limits on the signal strength:

	Obs./Exp. μ at 95 % C.L.
ATLAS (Run 2 at 80 fb^{-1})	< 2.1 / < 2.0
CMS (Run1 + Run 2)	< 2.9 / < 2.2

Production modes measurement



ATLAS-CONF-2018-031



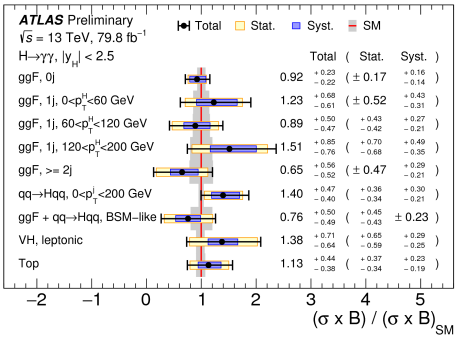
arXiv:1809.10733

	Global signal strength
ATLAS	$1.13\ ^{+0.09}_{-0.08}$
CMS	1.17 ± 0.10

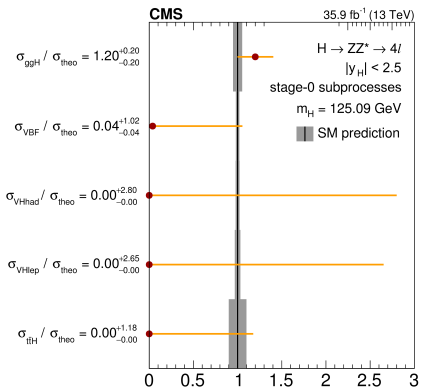
- Combination from most sensitive decay modes assuming SM value for the BR
- All main production modes have been observed

Results in the STXS framework

- Measure the cross-section times BR in exclusive phase space regions (Bins)
- Bins chosen to maximise measurement precision and sensitivity to BSM
- Allow combination of different decay modes
- Results in agreement with SM expectations



ATLAS-CONF-2018-028



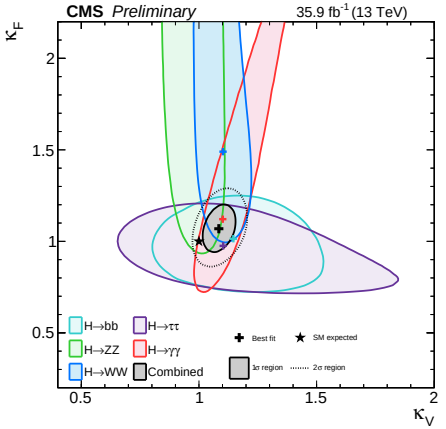
JHEP 11 (2017) 047

Results in the k-framework

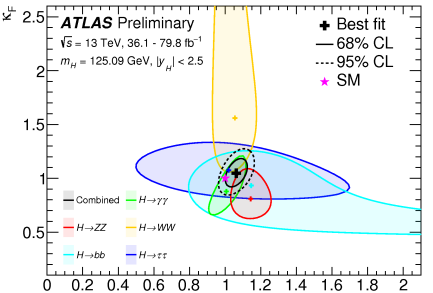
- k-framework expresses Higgs boson interactions through multiplicative modifiers so SM cross-section and width:

$$(\sigma \times B)_{if} = k_i^2 \sigma_i^{SM} \frac{k_f^2 \Gamma_f^{SM}}{k_H^2 \Gamma_H^{SM}}$$

- Assuming common coupling modifiers for bosons and fermions
- Not considering BSM contribution to Higgs total width
- Results in agreement with prediction in the 95 % C.L.



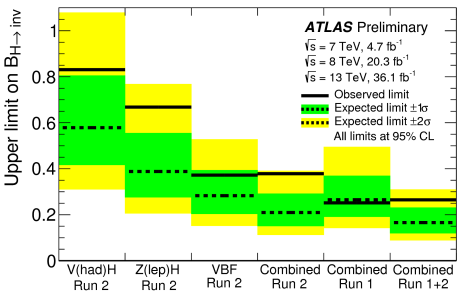
arXiv:1809.10733



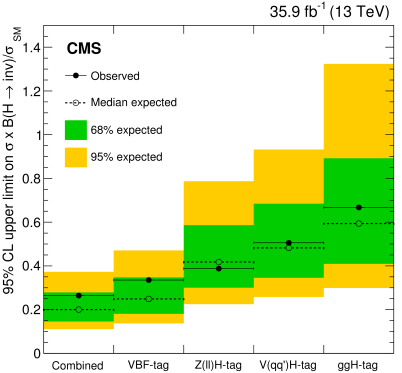
ATLAS-CONF-2018-031 SM

H → invisible decays

- Considering system recoiling against H → invisible
- Most sensitivity from VBF production mode
- Results from combination with other production modes



ATLAS-CONF-2018-054



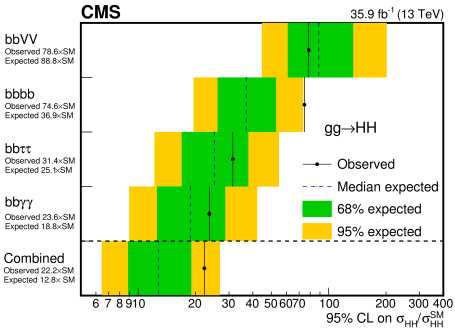
arXiv:1809.05937

- Limits on the branching ratio:

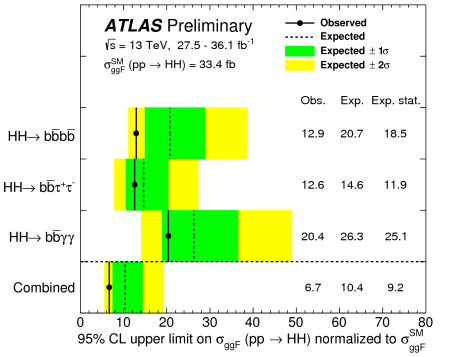
	Obs./Exp. $BR(H \to \text{inv})$ at 95 % C.L.
ATLAS (Run 1 + Run 2)	< 0.26 / < 0.17
CMS (Run 2 at 36 fb^{-1})	< 0.26 / < 0.20

Di-Higgs production

- Expected results near to 10 $\times$ SM prediction
- Goal is to reach SM sensitivity at the end of HL-LHC ($\simeq$ 3000 fb^{-1})



arXiv:1811.09689



ATLAS-CONF-2018-043

- Limits on the signal strength:

	Obs./Exp. μ at 95 % C.L.
ATLAS	< 6.7 / < 10.4
CMS	< 22 / < 13.0

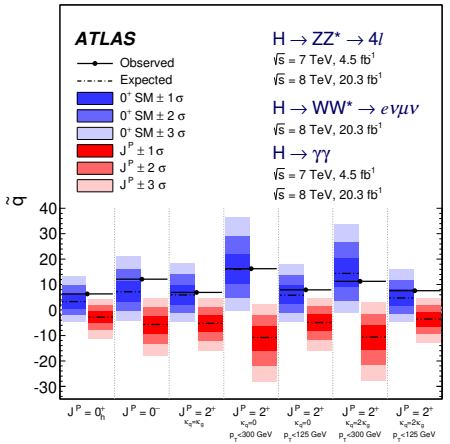
Conclusion

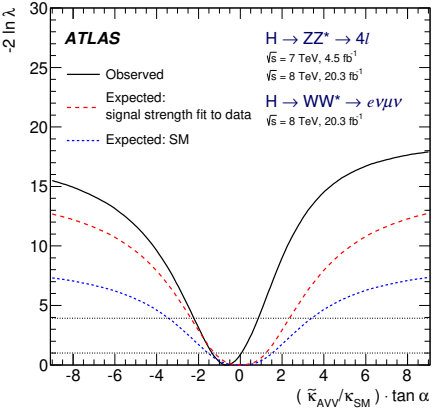
- Lots of analyses are ongoing using Run 2 dataset
- So far, results led to:
  - Precision measurement in the bosonic decay channels
  - Observation of all main production and decay modes
  - Observation of direct coupling to the third-generation fermions
- All measurements are in good agreement with SM prediction
  - still no sign of new physics unfortunately ...
- However, still long list of measurements to do/improve waiting for HL-LHC

Thanks For Your Attention

Backup

Charge-Parity conjugation measurement





Phys. Rev. D 98, 030001 (2018)

- In all investigated scenarios, data are compatible with $J^{CP} = 0^+$ hypothesis
- Need to improve precision to exclude CP-odd mixing