Higgs Boson Measurements at LHC

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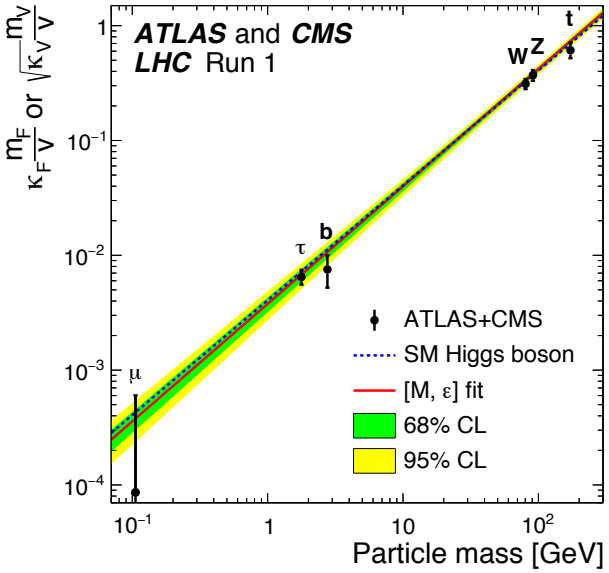
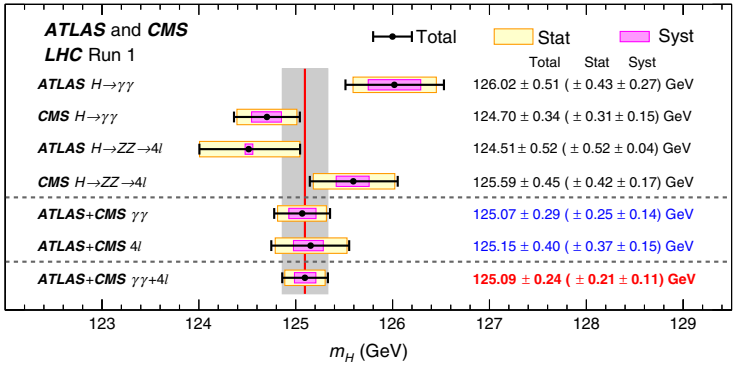
Introduction

- The discovery of the Higgs boson is a triumph of the SM.

JHEP 08 (2016) 045

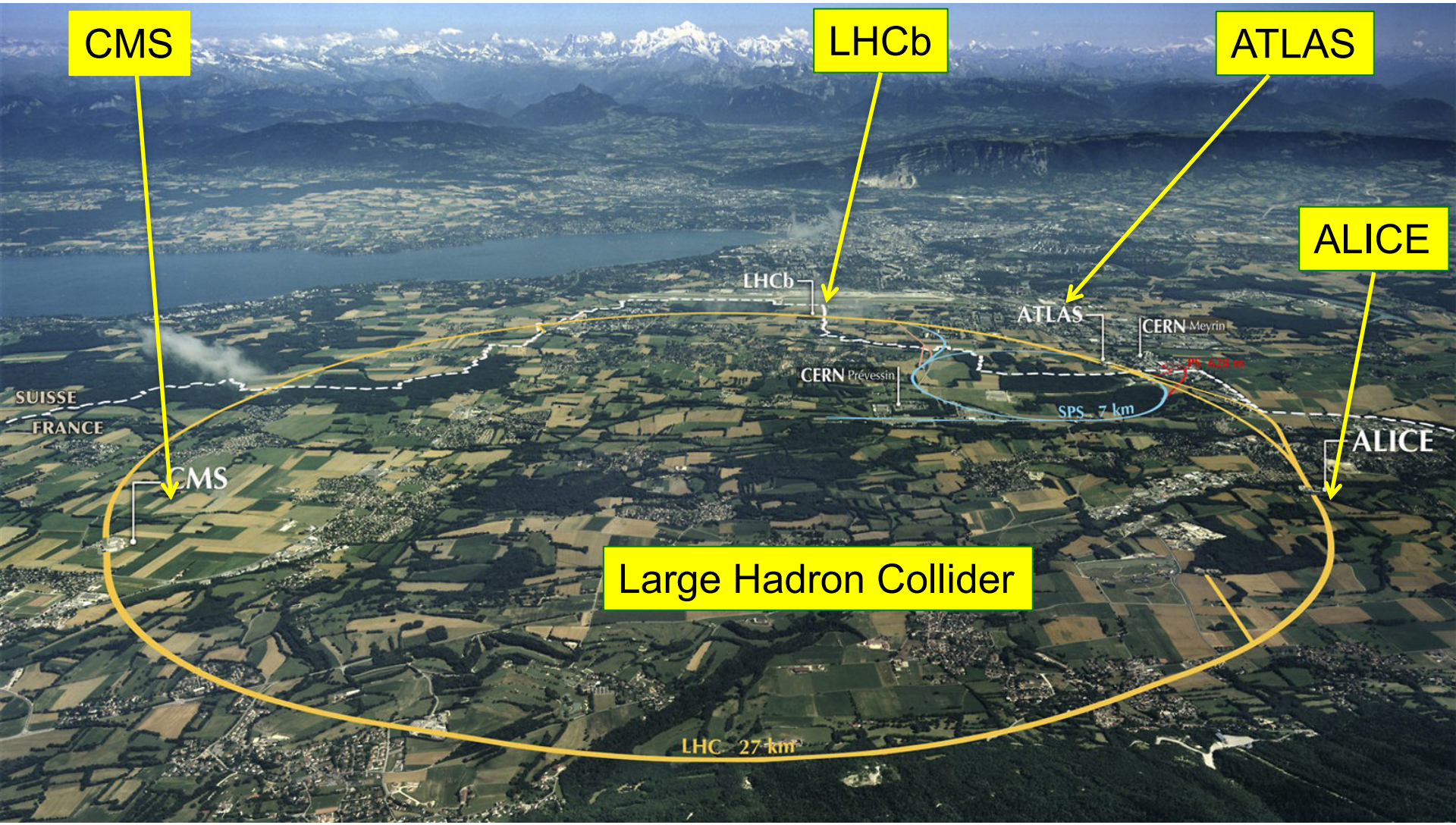


PRL 114, 191803 (2015)



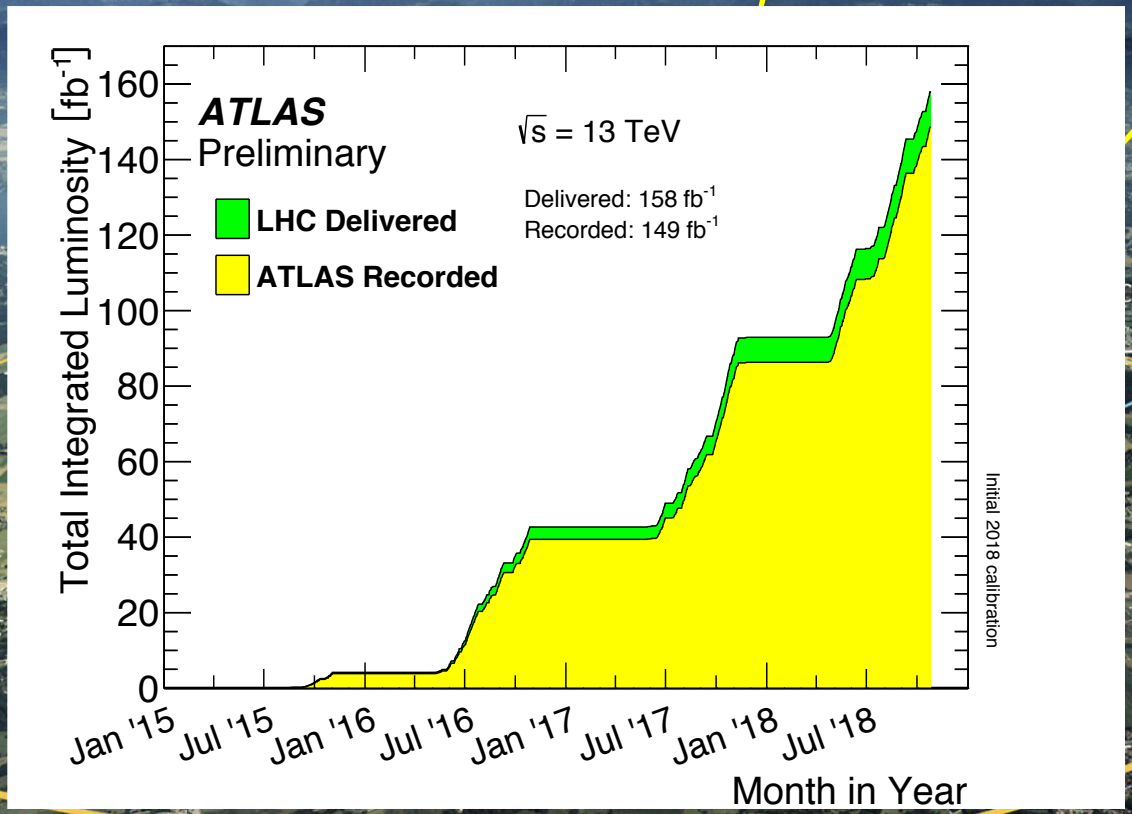
- Need to measure the property of Higgs boson with precision
- Probe other decay modes
- Any deviation from SM prediction is a sign of new physics

Status of LHC Data Taking



Status of LHC Data Taking

149 fb^{-1} recorded by ATLAS for Run-2



Peak lumi: 2.1 x 10^{34} cm^{-2}s^{-1}

Status of LHC Data Taking

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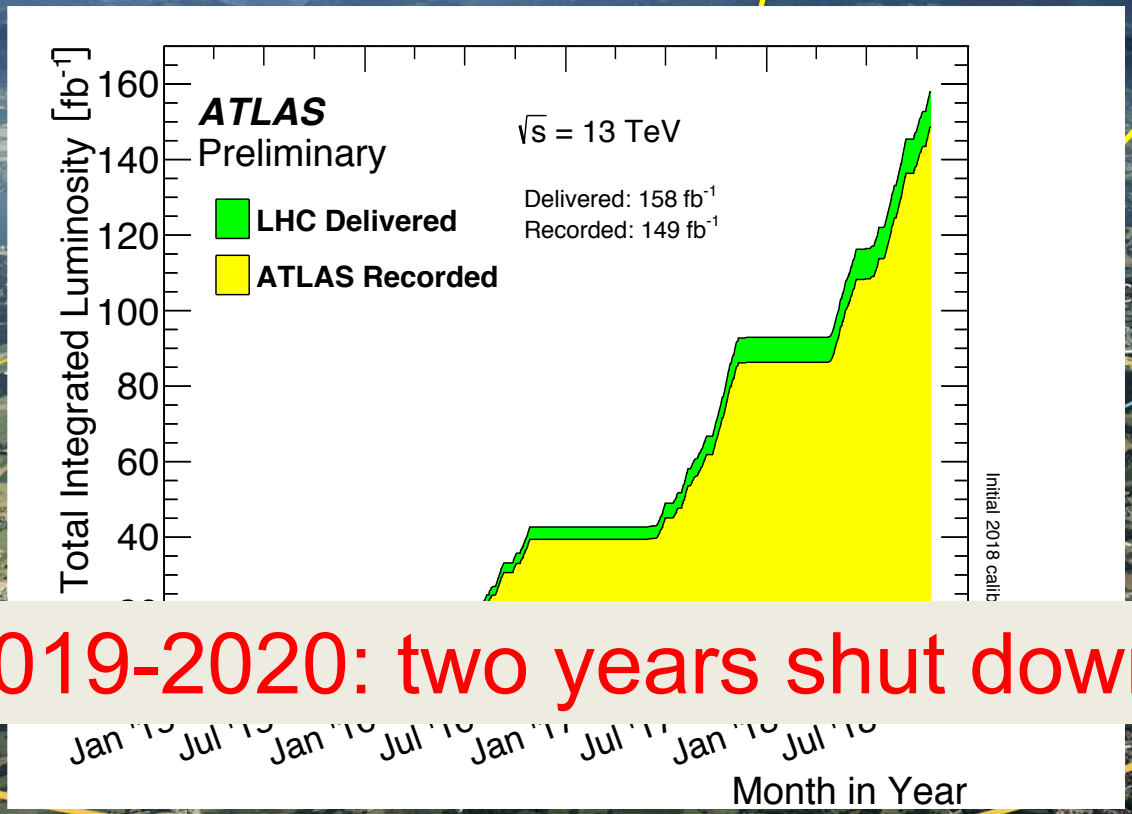


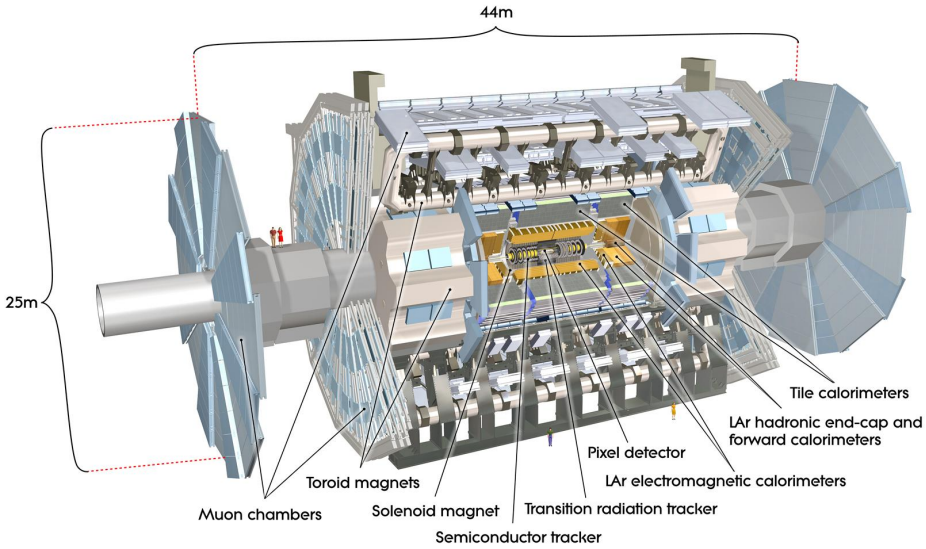
- 2019-2020: two years shut down

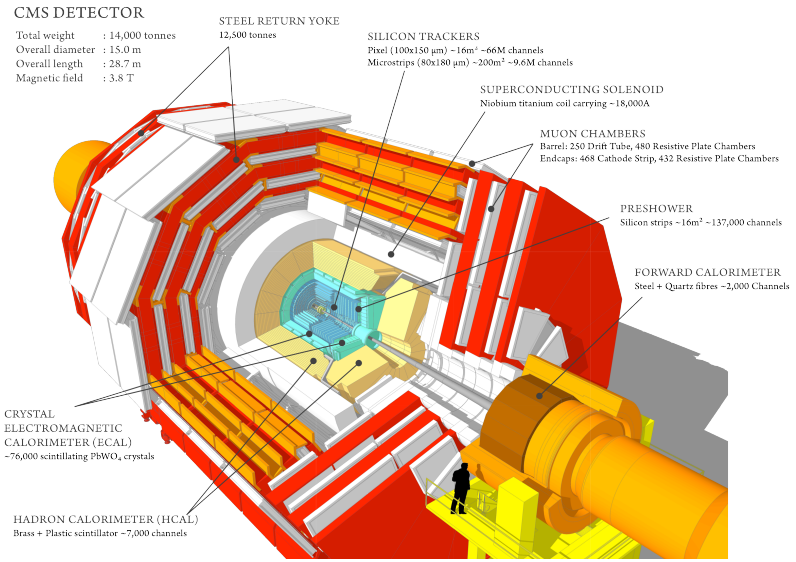
Peak lumi: 2.1 x 10^{34} cm^{-2}s^{-1}

Detectors

ATLAS EXPERIMENT

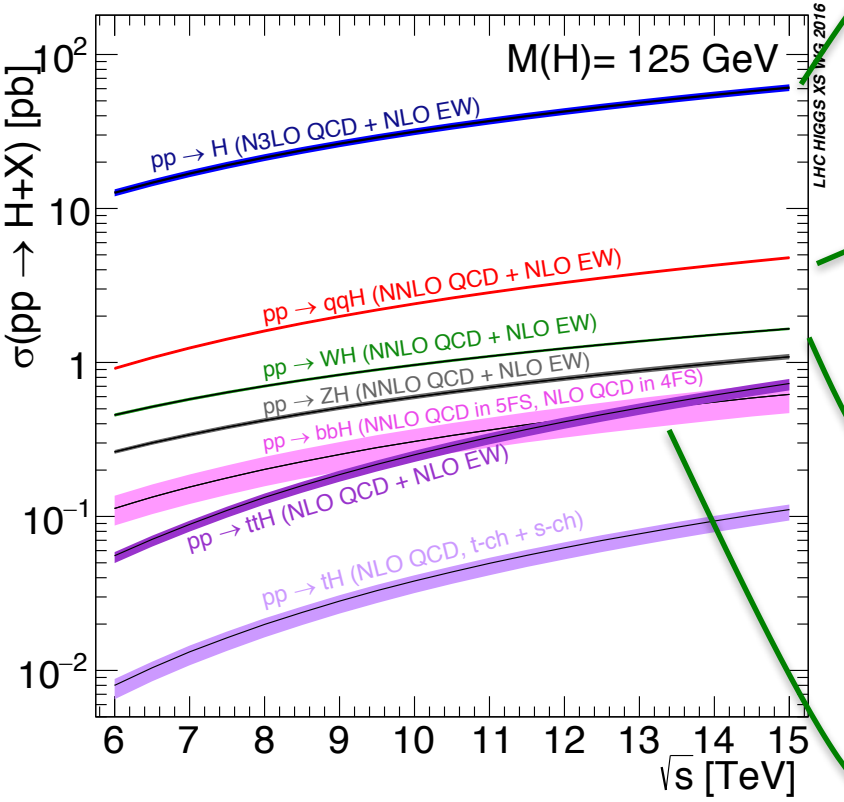
CMS

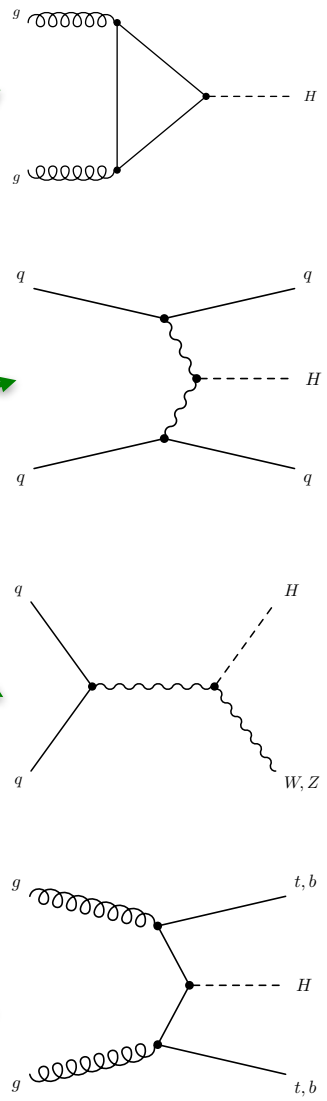




Higgs Boson Production at LHC

LHC Higgs Cross Section Working Group





ggF: dominant, larger initial state radiation from gluons

VBF: two forward jets with high mass and large rapidity gap

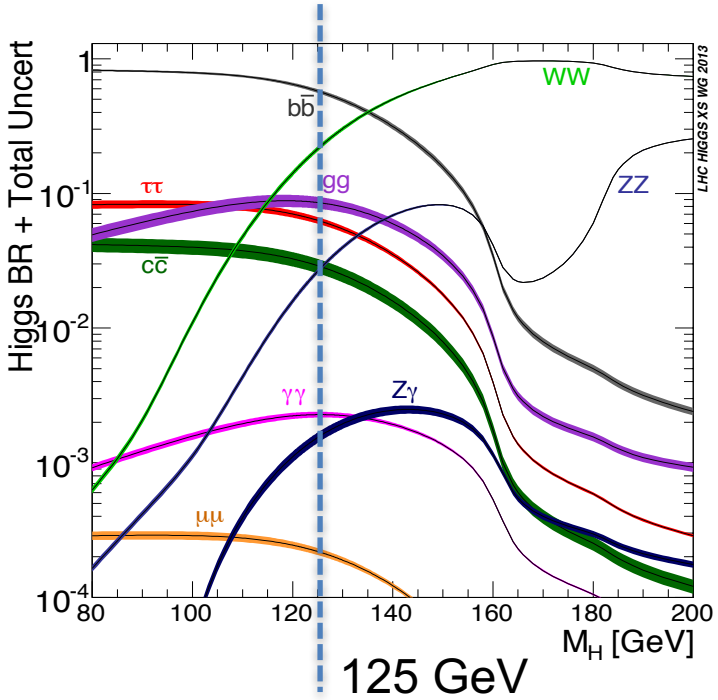
VH: vector boson (lν, ll', qq')

ttH: many b-jets, leptons, E_T^{miss}

With 80 fb-1, about 4M ggF events, 300K VBF, 200K VH and 40K ttH events

Higgs Boson Decays

LHC Higgs Cross Section Working Group



Decay mode	Branching fraction [%]
$H \to bb$	57.5 ± 1.9
$H \to WW$	21.6 ± 0.9
$H \to gg$	8.56 ± 0.86
$H \to \tau\tau$	6.30 ± 0.36
$H \to cc$	2.90 ± 0.35
$H \to ZZ$	2.67 ± 0.11
$H \to \gamma\gamma$	0.228 ± 0.011
$H \to Z\gamma$	0.155 ± 0.014
$H \to \mu\mu$	0.022 ± 0.001

- Low BR channels (ZZ→4l, γγ, Zγ and μμ) have better mass resolutions but small rate. Channels with higher BRs (the rest) are challenging experimentally

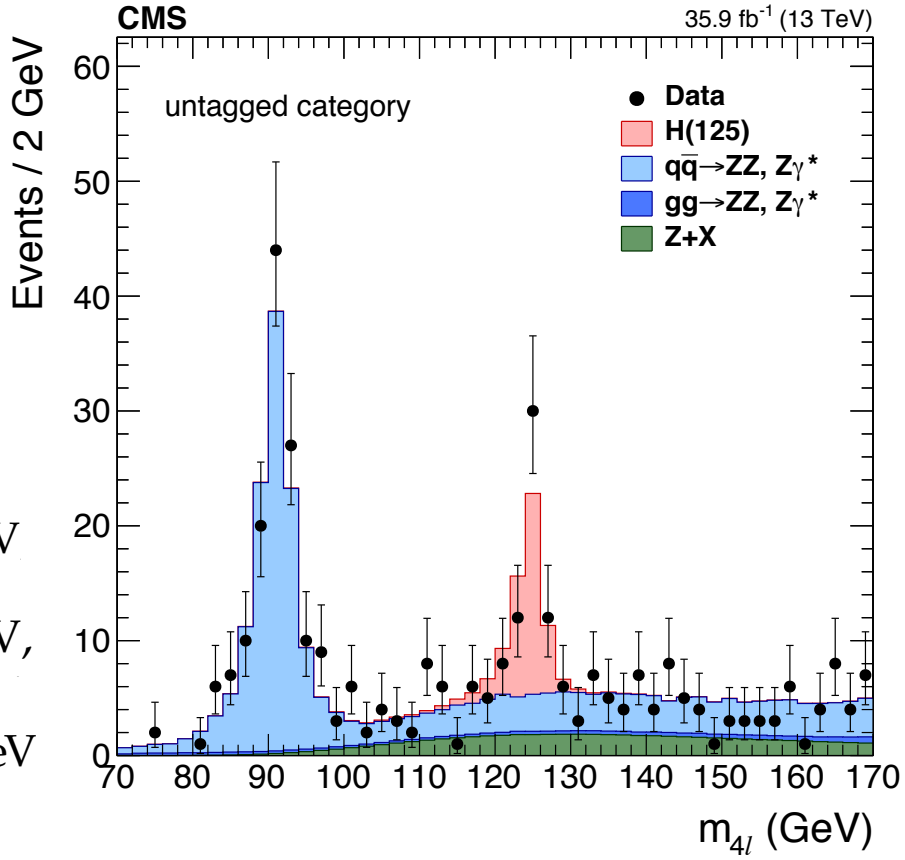
Higgs Mass

Higgs Boson Mass

arXiv: 1706.09936

Higgs mass is the only free parameter in BEH mechanism

- H→ZZ→4l
- 36 fb-1 Run 2 data



$$m_{\mathrm{H}}^{4\mu} = 124.94 \pm 0.25\,(\mathrm{stat}) \pm 0.08\,(\mathrm{syst})\,\mathrm{GeV}$$

$$m_{\mathrm{H}}^{4\mathrm{e}} = 124.37 \pm 0.62\,(\mathrm{stat}) \pm 0.38\,(\mathrm{syst})\,\mathrm{GeV},$$

$$m_{\mathrm{H}}^{2\mathrm{e}2\mu} = 125.95 \pm 0.32\,(\mathrm{stat}) \pm 0.14\,(\mathrm{syst})\,\mathrm{GeV}$$

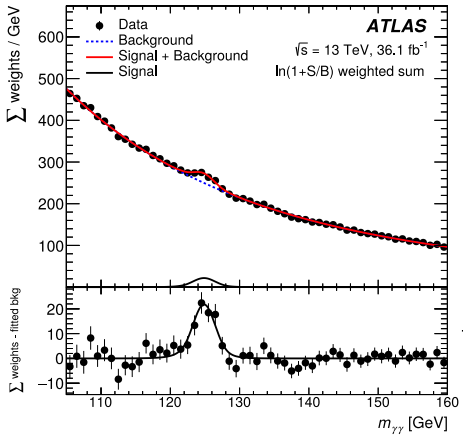
$$m_{\mathrm{H}} = 125.26 \pm 0.21\,\mathrm{GeV}$$

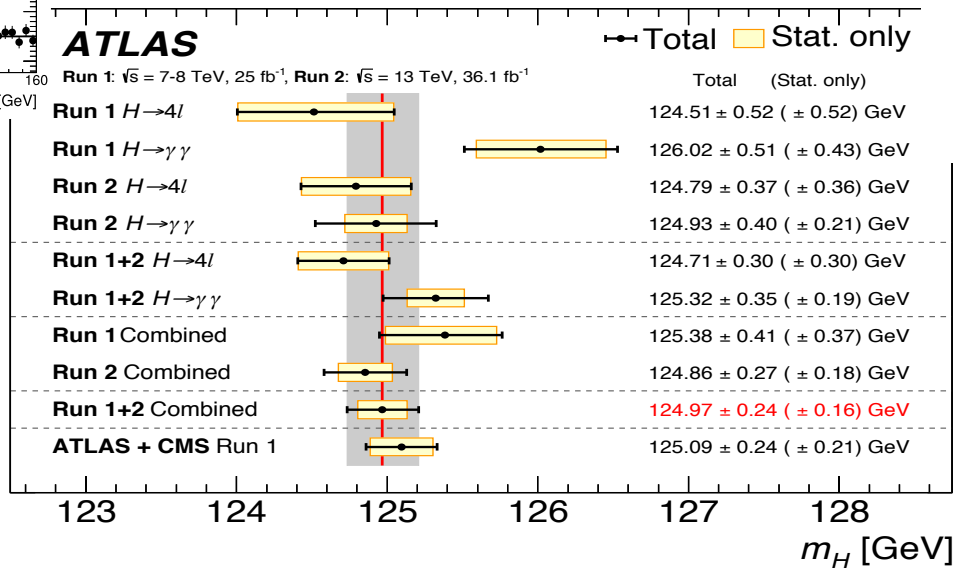
Higgs Boson Mass

arXiv: 1806.00242

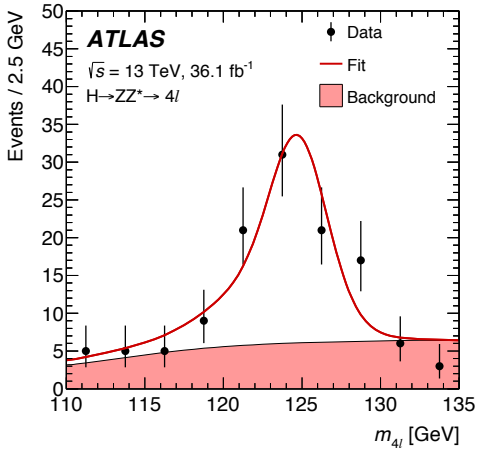
Use 36 fb^{-1} LHC Run 2 data

$H\to\gamma\gamma$





$H\to ZZ\to 4l$

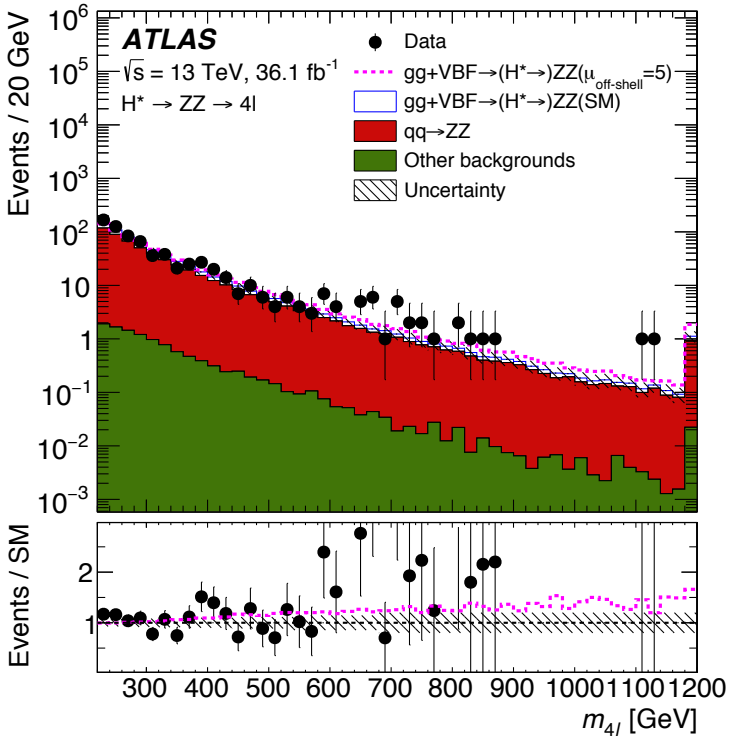


ATLAS Run1+2 combined: $m_H = 124.97 \pm 0.24$ GeV

- Precise object reconstruction is important for this measurement
- H→ZZ is still statistics limited; H→$\gamma\gamma$ is systematics limited (photon energy scale)

Higgs Width

- Measure the ZZ production in high mass region to constrain the Higgs width (using the interface between Higgs signal and continuum ZZ)



ATLAS EXPERIMENT

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36 fb-1

- Uses ZZ->4l and ZZ->2l2v
- Γ_H < 14.4 MeV at 95% CL

CMS

CMS-PAS-HIG-18-002

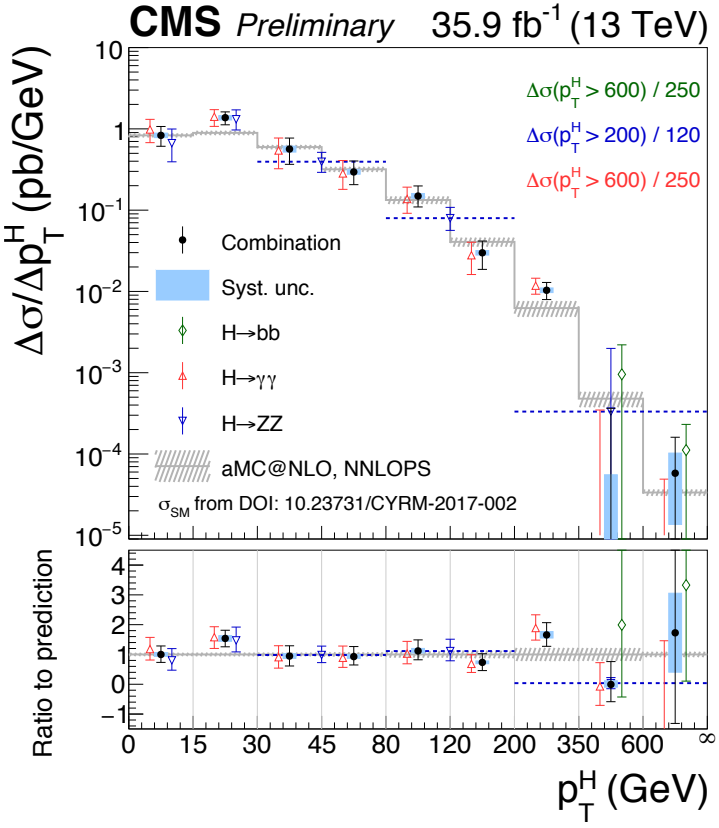
80.2 fb-1

- Uses 4l finals states
- Γ_H < 9.16 MeV at 95% CL

Differential Cross Sections

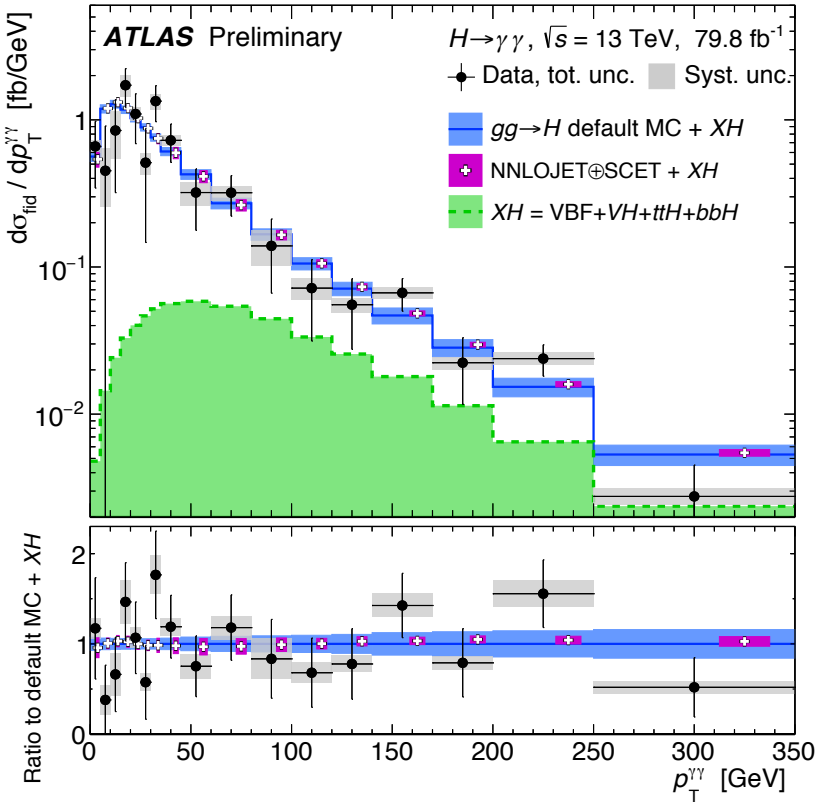
CMS-HIG-17-028

36 fb-1



CONF-ATLAS-2018-028

80 fb-1



Consistent with SM predictions

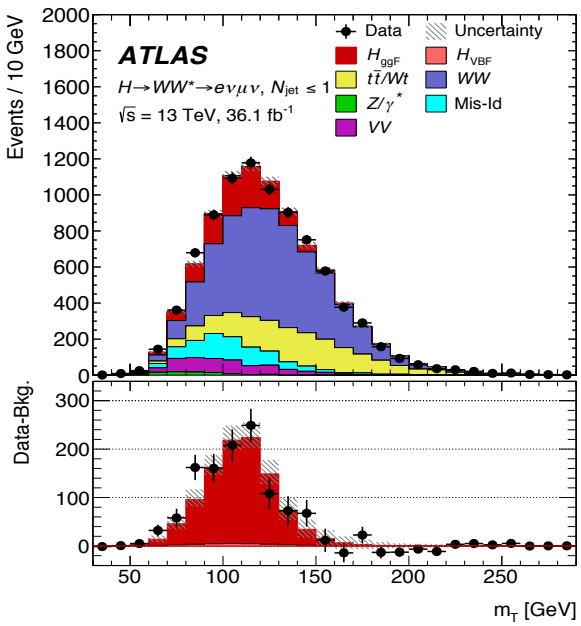
Many other distributions in the doc.

Higgs Coupling to Bosons

H→WW

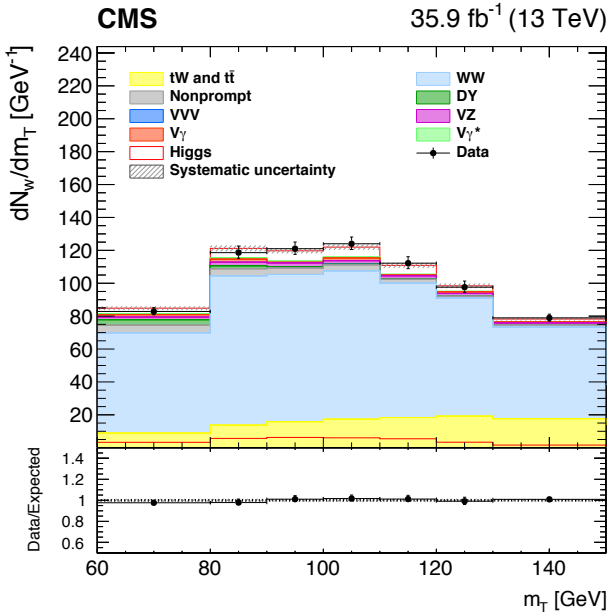
Transverse mass

arXiv: 1808.09054



- 36 fb-1
- Only include ggF and VBF categories
- Only e mu final states

arXiv: 1806.05246

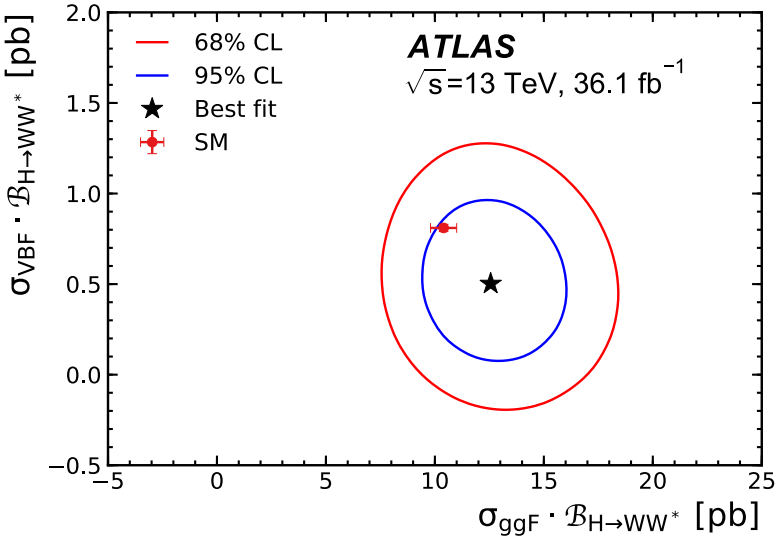


0 jet

- 36 fb-1
- Include ggF, VBF and VH categories
- Also include same flavor channels

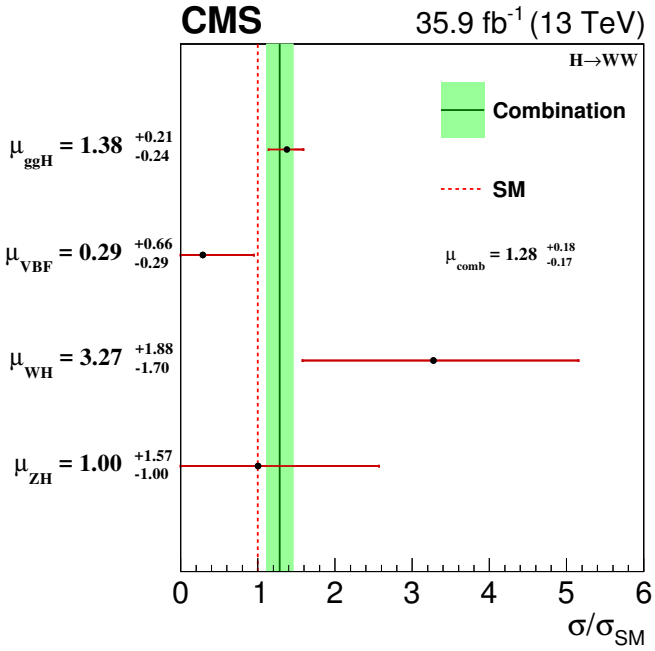
H→WW

arXiv: 1808.09054



- **μ** (ggF) = 1.21 $^{+0.22}_{-0.21}$
- **μ** (VBF) = 0.62 $^{+0.37}_{-0.36}$

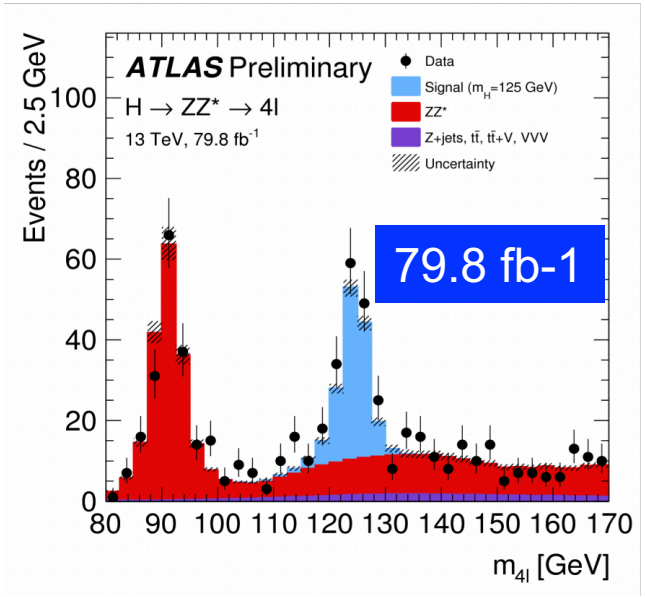
arXiv: 1806.05246



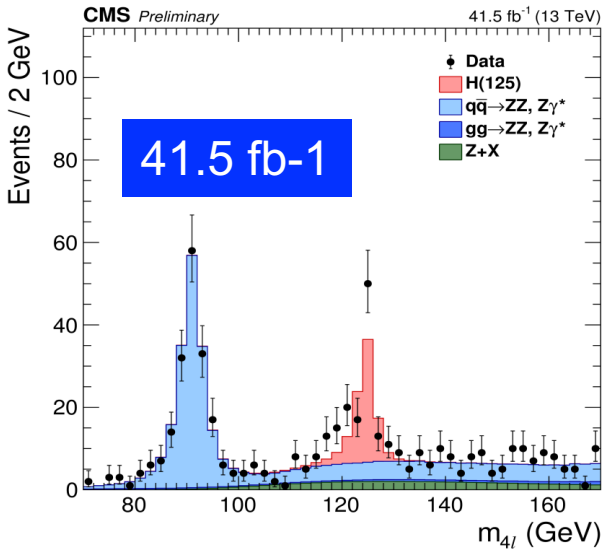
- **μ** (ggF) = 1.38 $^{+0.21}_{-0.24}$
- **μ** (VBF) = 0.29 $^{+0.66}_{-0.29}$

H→ZZ

ATLAS-CONF-2018-018

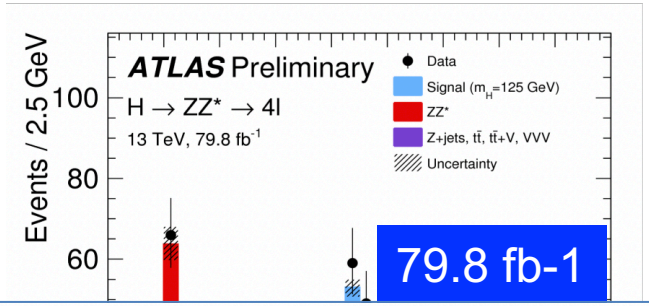


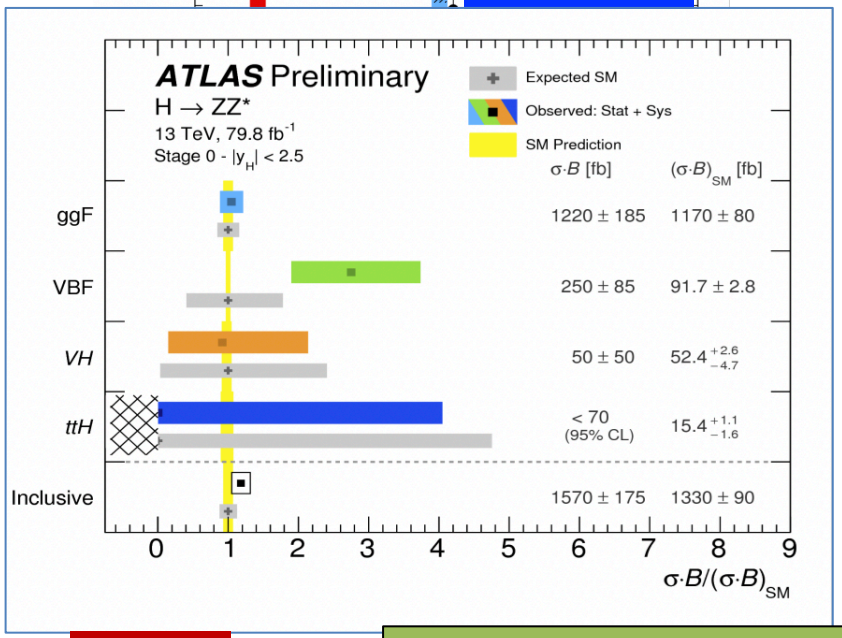
CMS-PAS-HIG-2018-001



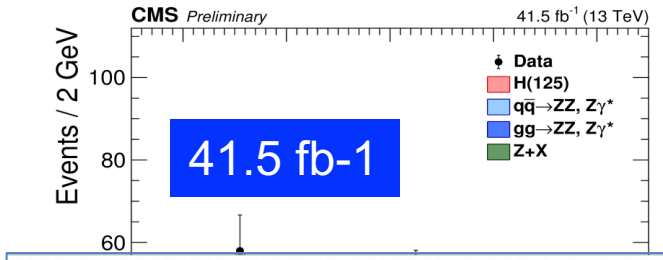
H→ZZ

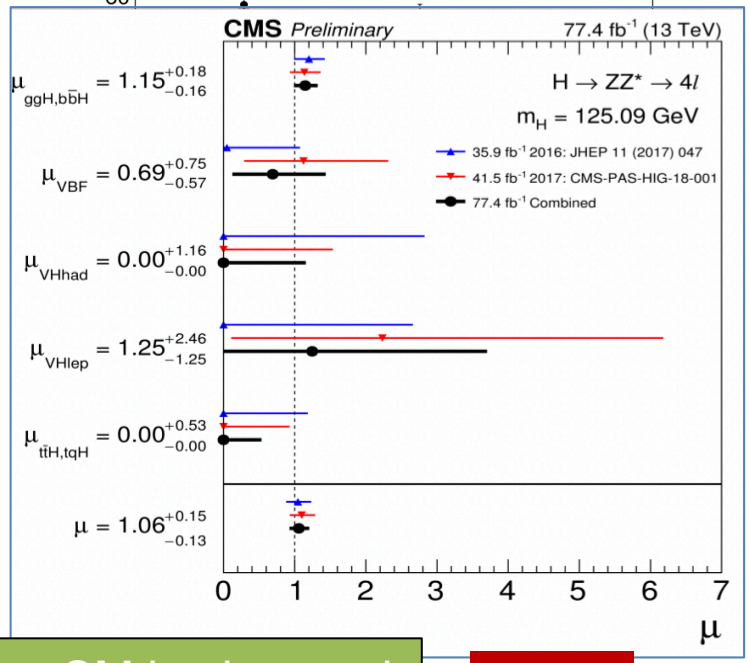
ATLAS-CONF-2018-018





CMS-PAS-HIG-2018-001





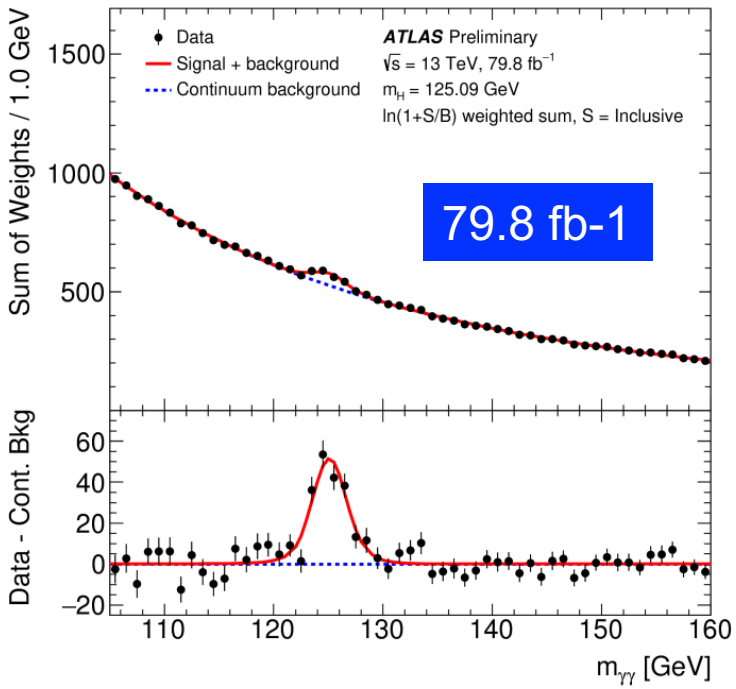
~11%

No significant deviation from SM is observed

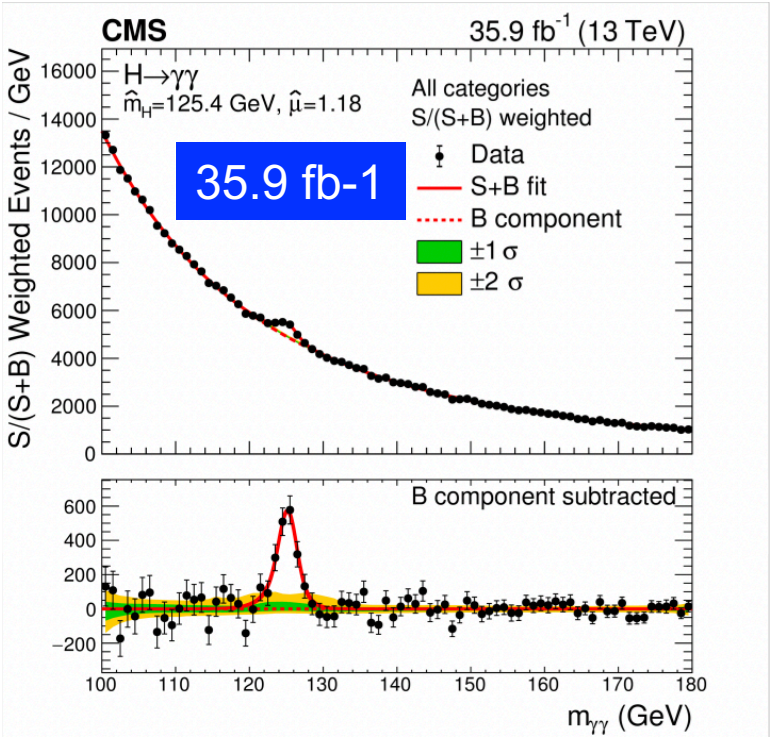
~14%

H→γγ

ATLAS-CONF-2018-028

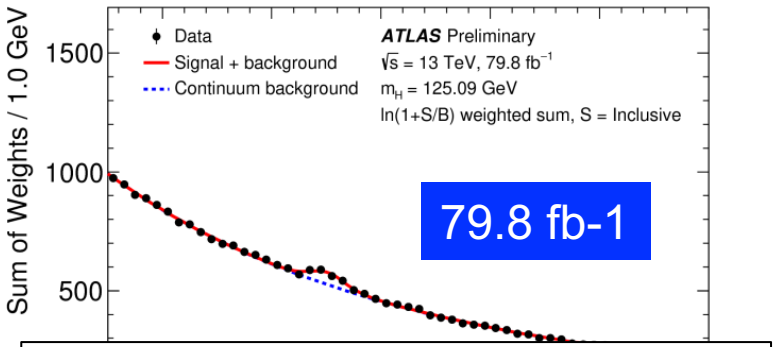


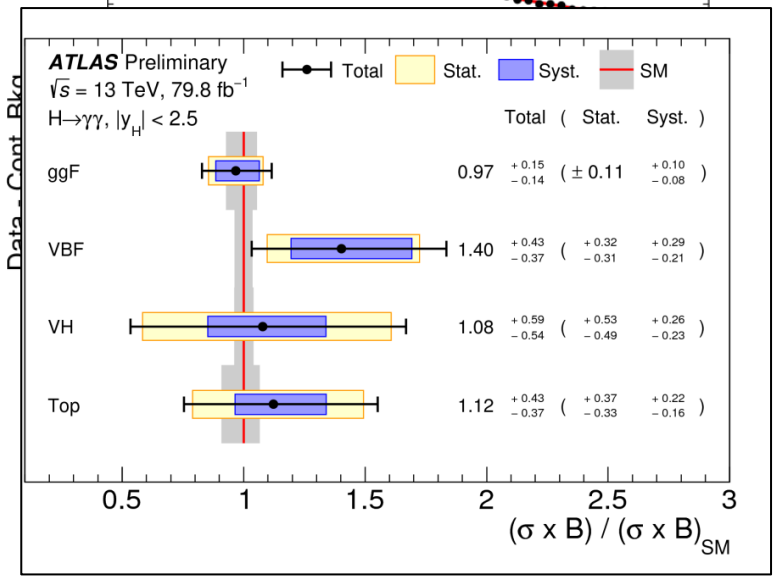
arXiv: 1804.02716



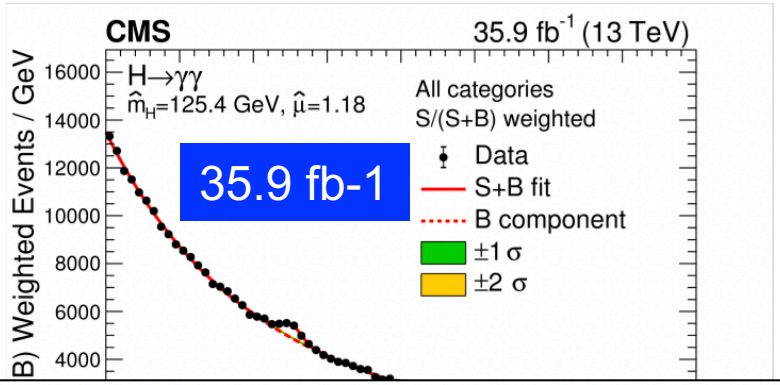
H→γγ

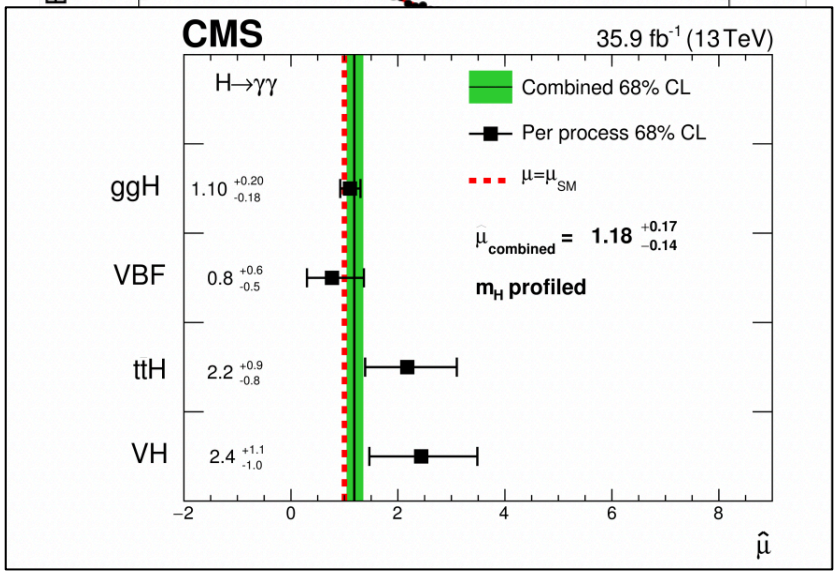
ATLAS-CONF-2018-028





arXiv: 1804.02716





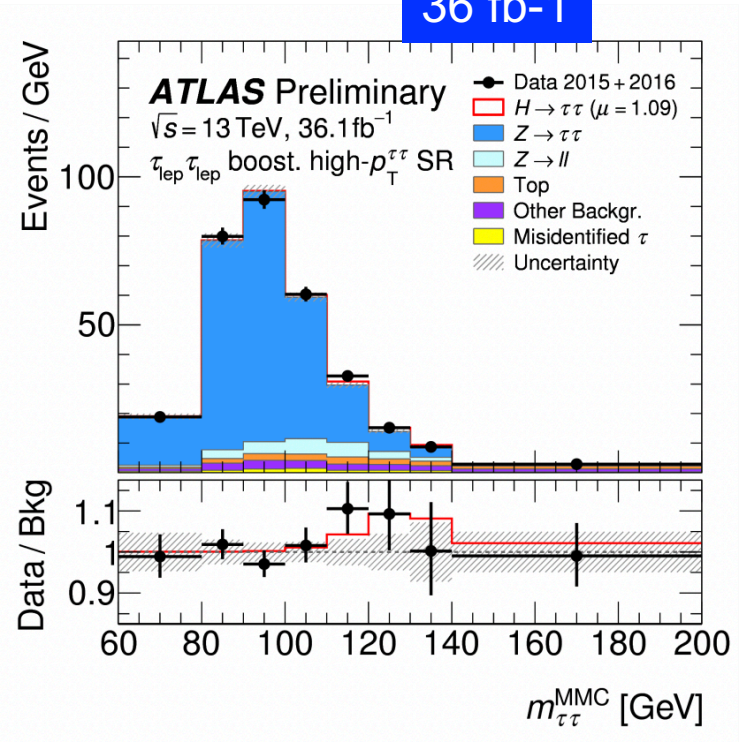
Higgs Coupling to Fermions

H→ττ

- Dominant background is Z→ττ
- Most sensitive categories: VBF and boosted

ATLAS-CONF-2018-021

36 fb-1



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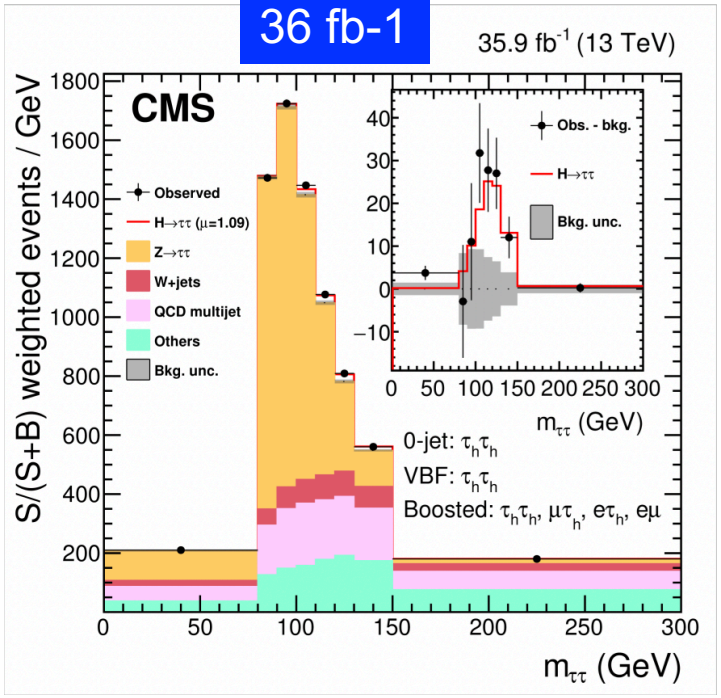
36 fb-1

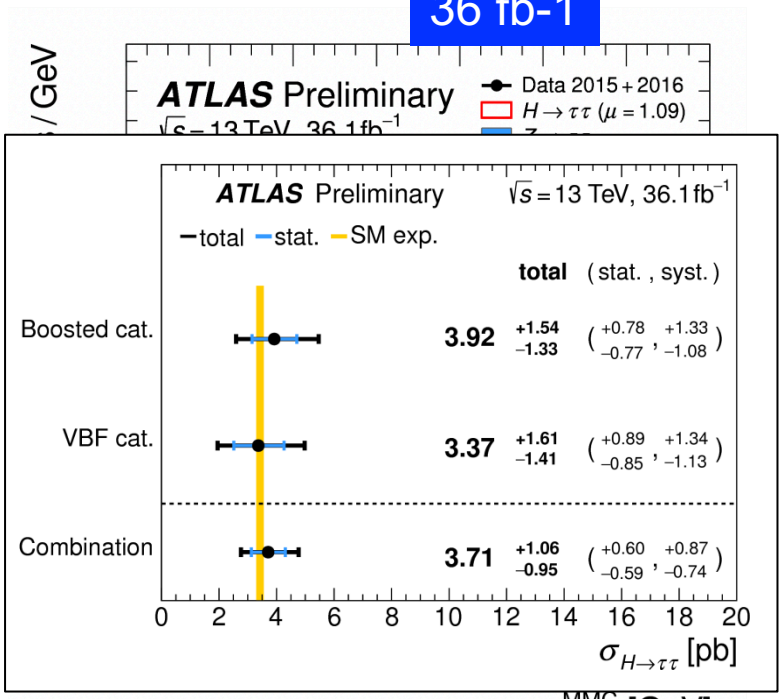


H→ττ

- Dominant background is Z→ττ
- Most sensitive categories: VBF and boosted

ATLAS-CONF-2018-021

36 fb-1



Combined with Run 1: 6.4 σ

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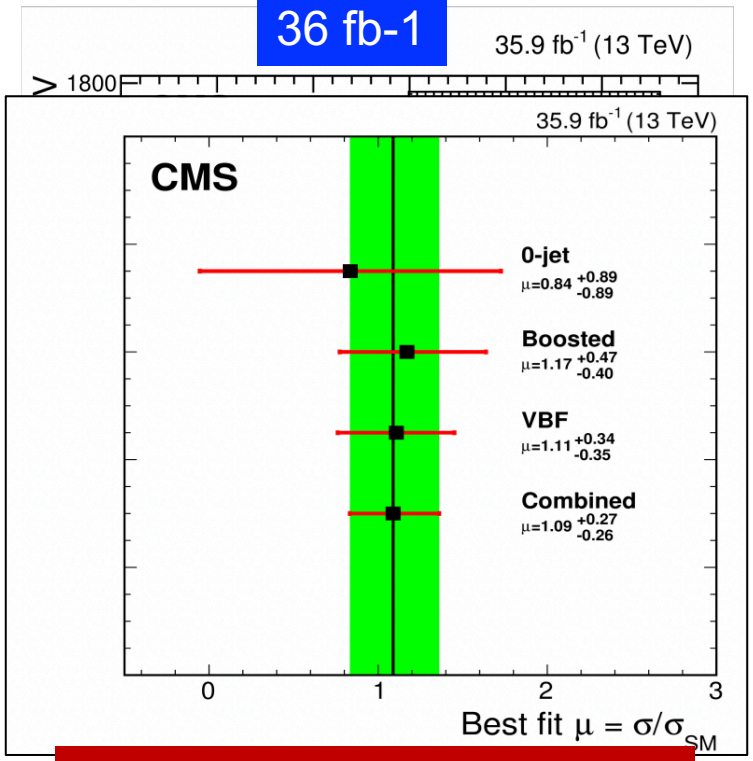
36 fb-1

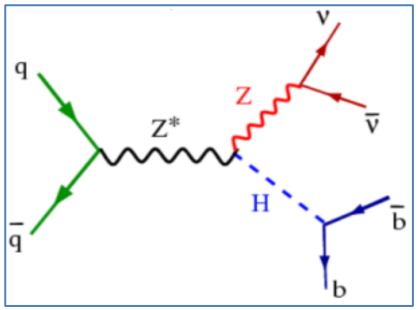


Combined with Run 1: 5.9 σ

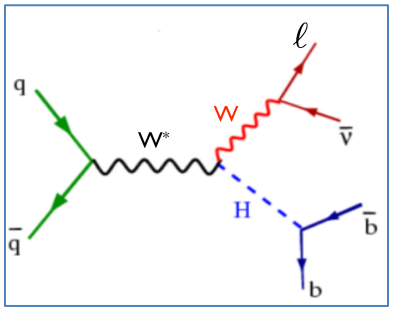
H→bb

- About 58% of Higgs decay to bb
- Probe this decay mode using VH

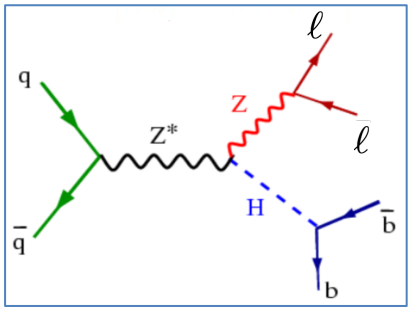
0-lepton

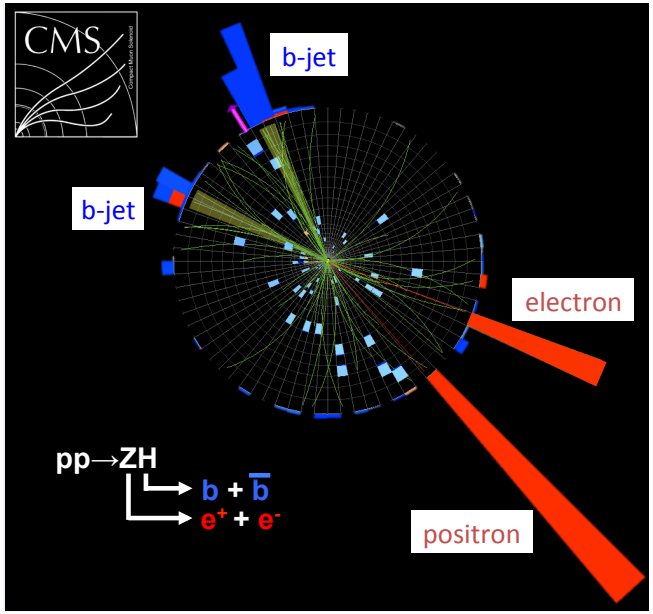


1-lepton



2-lepton





H→bb

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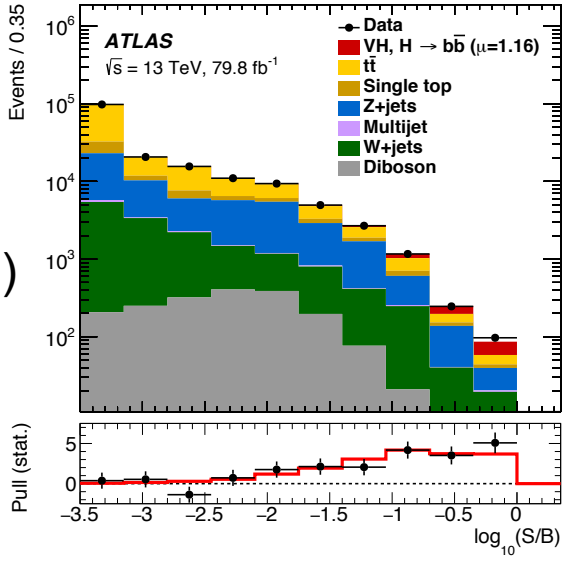
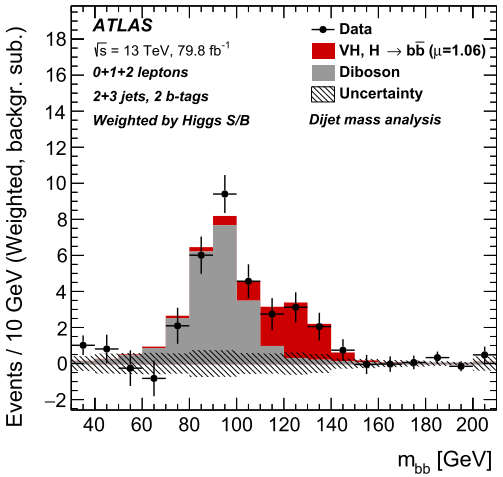
VH, H→bb

- ATLAS uses 80 fb-1 data
- Run 2: obs. 4.9 σ (exp. 4.3 σ)
- Run 1 + Run 2: obs. 4.9 σ (exp. 5.1 σ)

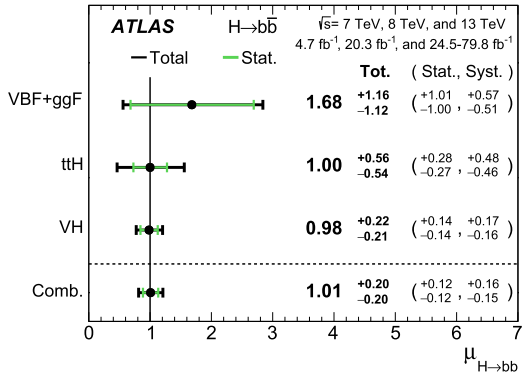




Combined with VBF, H→bb and ttH, H→bb

obs. 5.4 σ (exp. 5.5 σ)

Channel	Significance	
	Exp.	Obs.
VBF+ggF	0.9	1.5
$t\bar{t}H$	1.9	1.9
VH	5.1	4.9
$H \to b\bar{b}$ combination	5.5	5.4



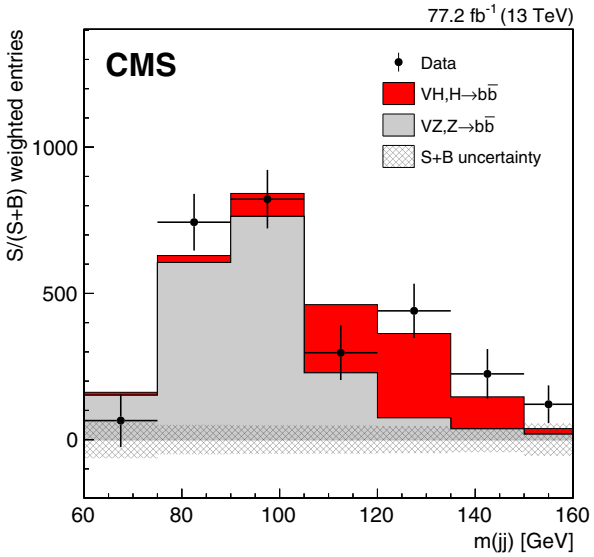
Observation of H→bb from ATLAS

H→bb

PRL 121, 121801 (2018)

VH, H→bb

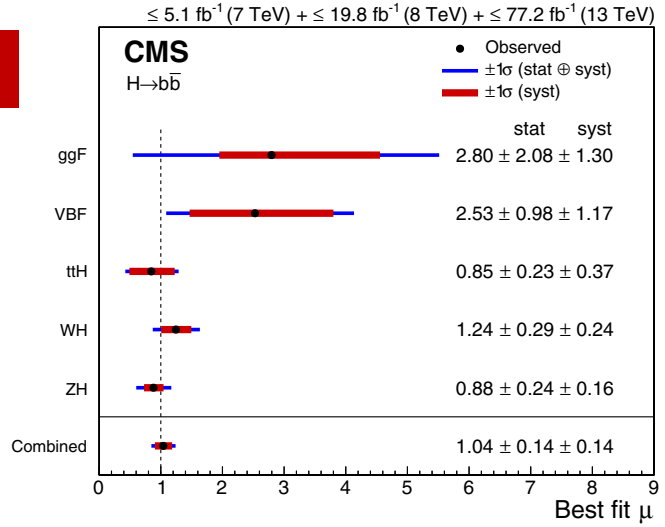
- CMS uses 77.2 fb-1 data
- Run 2: obs. 4.2 σ (exp. 4.4 σ)
- Run 1 + Run 2: obs. 4.8 σ (exp. 4.9 σ)



Combined with VBF, H→bb and ttH, H→bb

obs. 5.6 σ (exp. 5.5 σ)

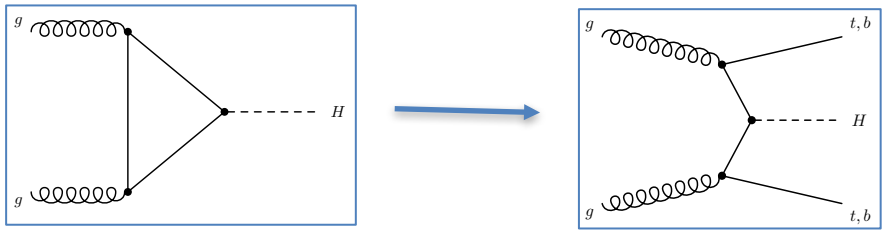
Observation of H→bb from CMS



ttH

arXiv:1806.00425

ttH allows direct probe of top Higgs Yukawa coupling



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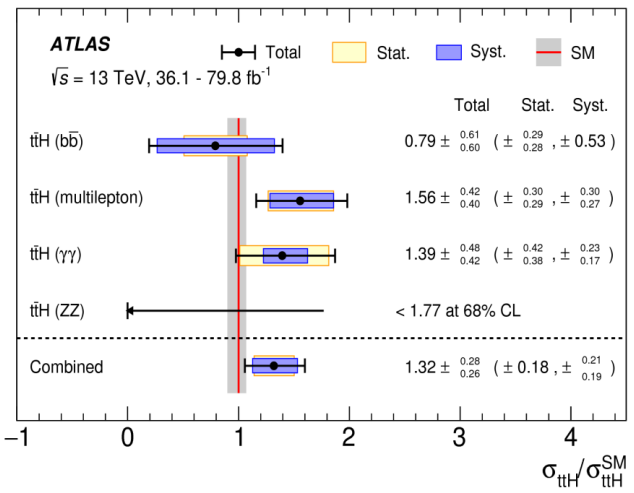
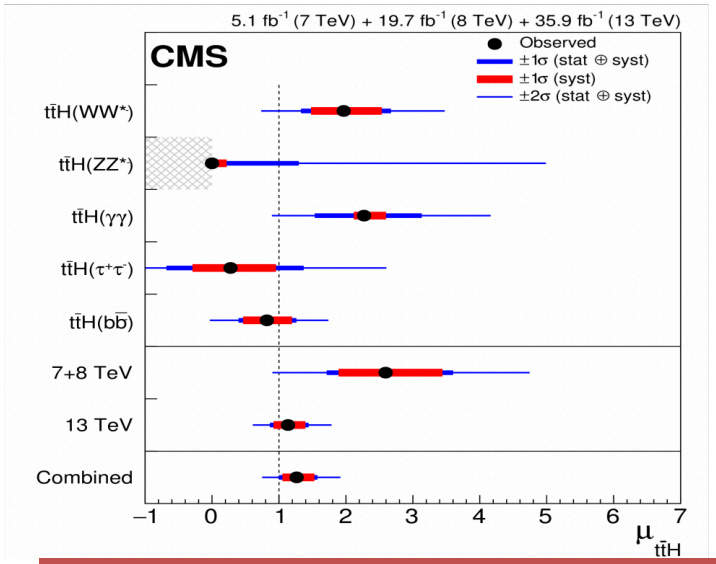


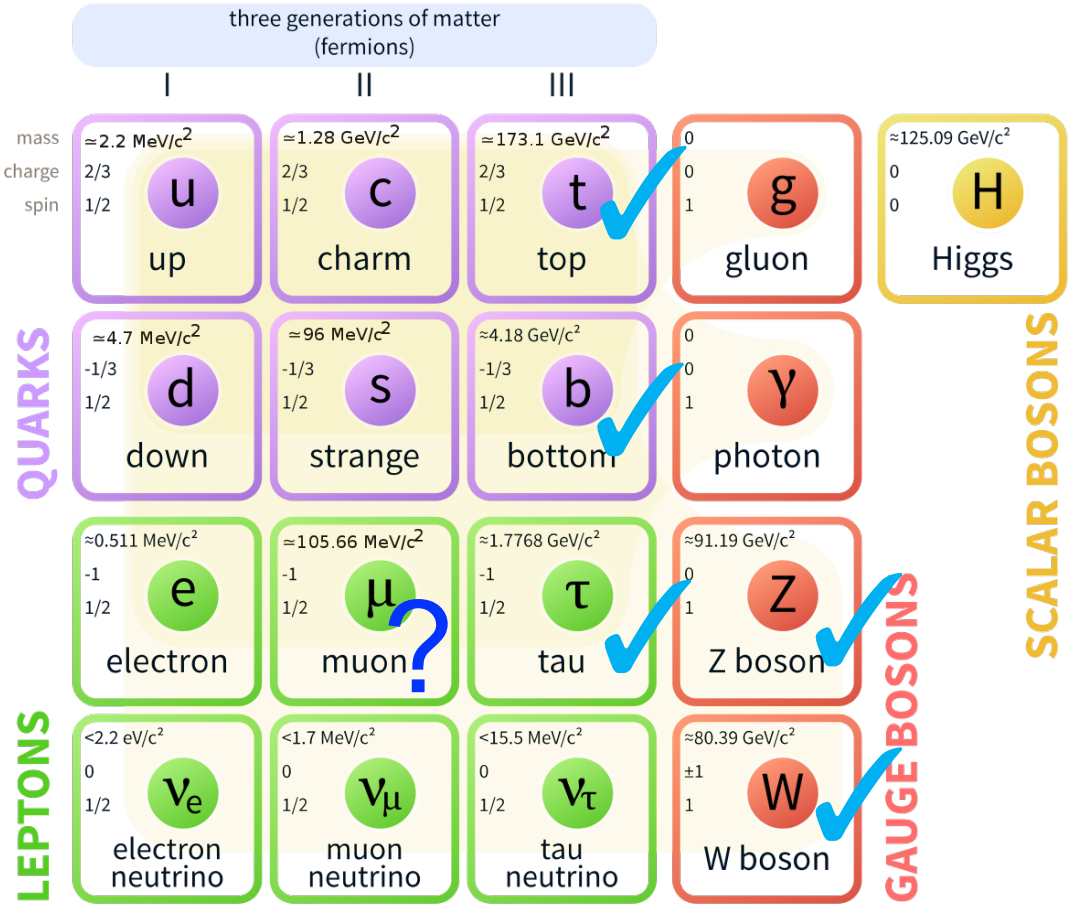
Significance: 6.3σ (5.1 σ exp.)

PRL 120, 231801 (2018)



Significance: 5.2σ (4.2 σ exp.)

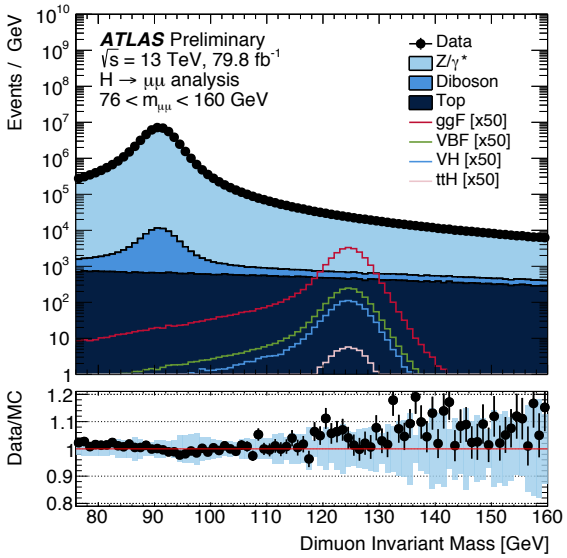
Higgs Couplings to Massive Elementary Particles



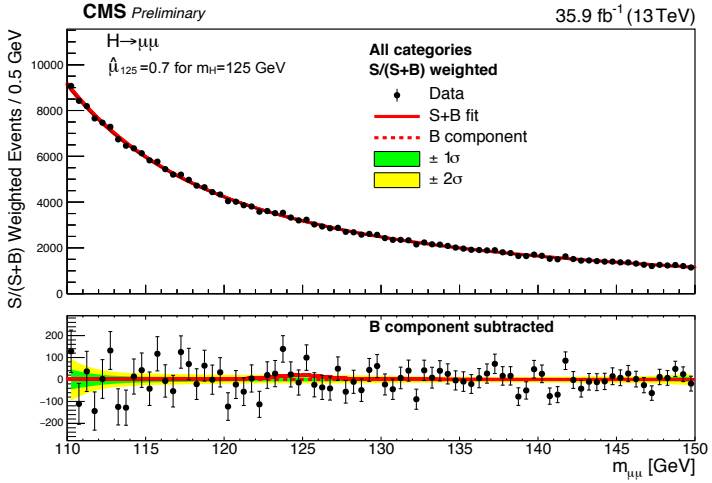
$H \rightarrow \mu\mu$

- Dominant background is $Z \rightarrow \mu\mu$
- Most sensitive categories: VBF and boosted
- Both experiments use analytical functions to model background and signal
- Reply on d-muon mass resolution to have better sensitivity

ATLAS-CONF-2018-026



CMS-PAS-HIG-17-019

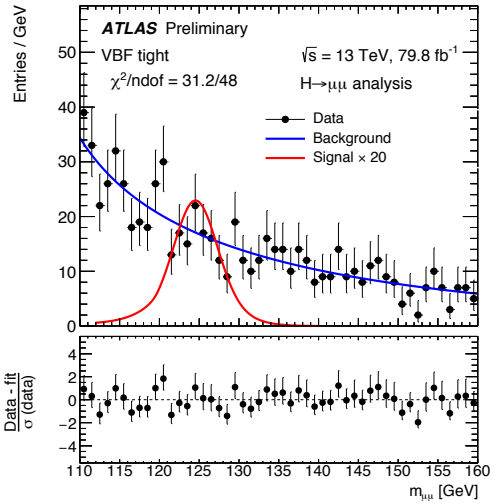


H→$\mu\mu$

- Dominant background is Z→$\mu\mu$
- Most sensitive categories: VBF and boosted
- Both experiments use analytical functions to model background and signal
- Rely on d-muon mass resolution to have better sensitivity

ATLAS-CONF-2018-026

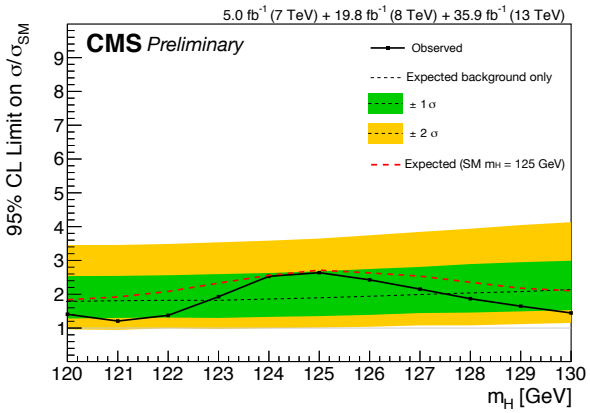
79.8 fb-1



Upper limit on signal strength: 2.1 (2.0) for obs (exp)

CMS-PAS-HIG-17-019

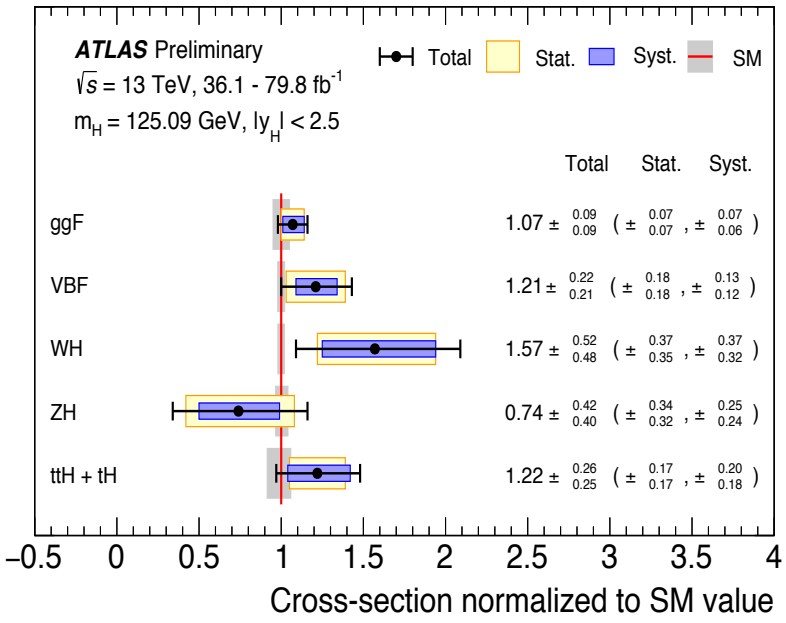
36 fb-1



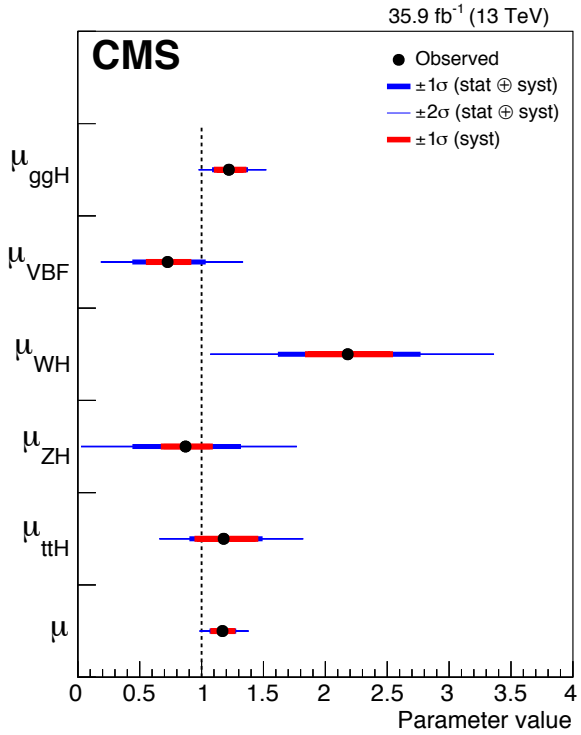
Upper limit on signal strength: 2.6 (1.9) for obs (exp)

Combined measurement of Higgs couplings

ATLAS-CONF-2018-031



arXiv: 1809.10733

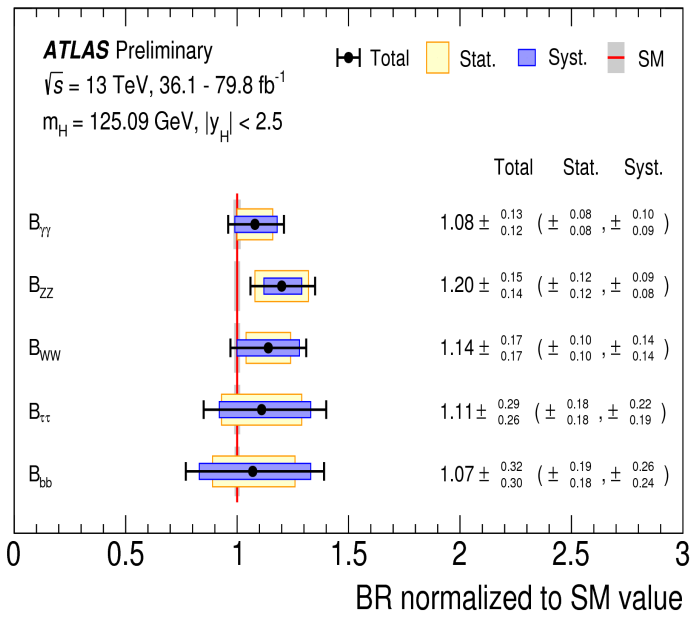


Four productions modes have been observed at LHC

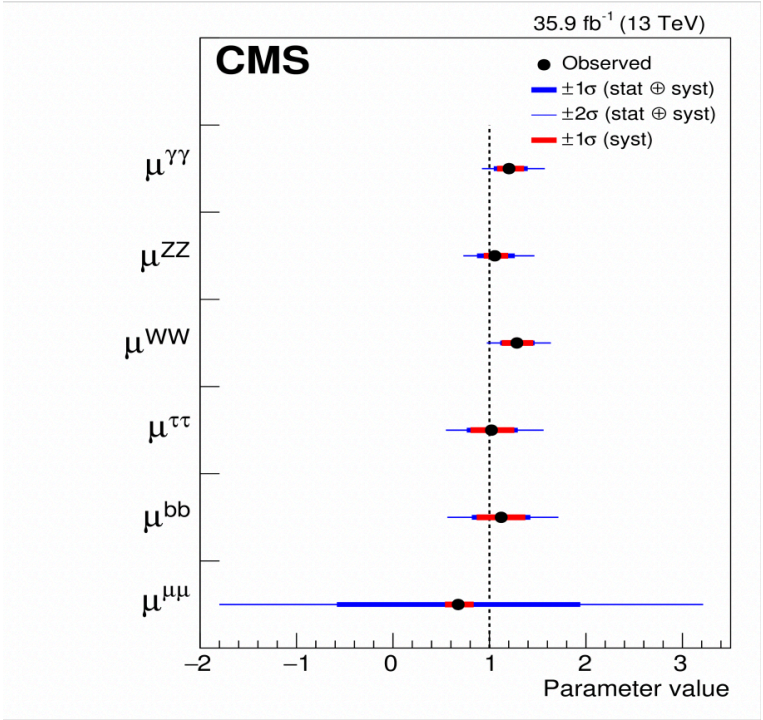
Productions

Combined measurement of Higgs couplings

ATLAS-CONF-2018-031



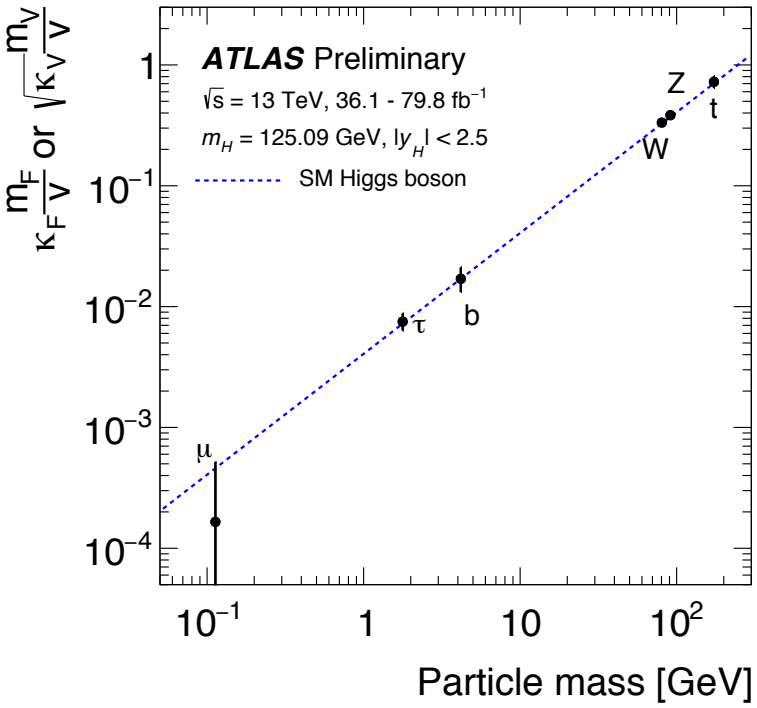
arXiv: 1809.10733



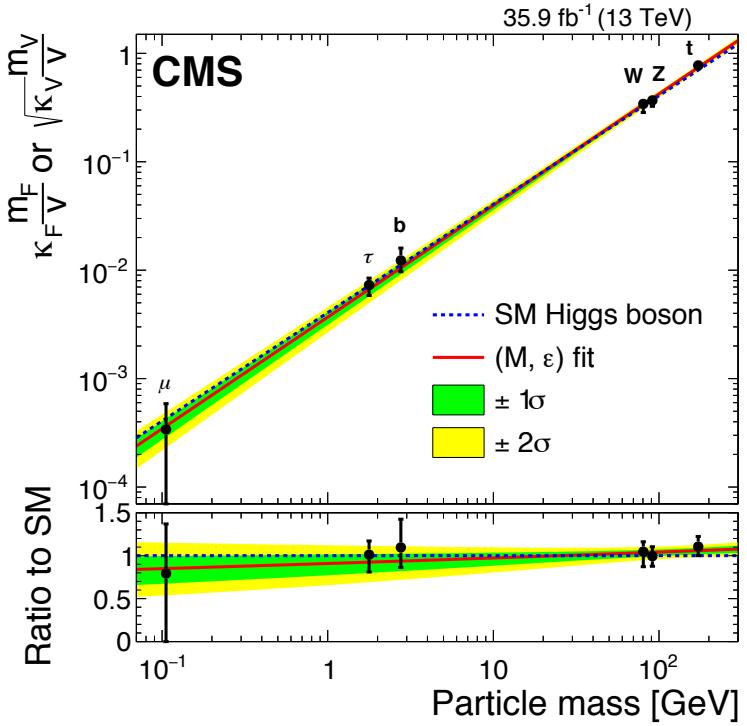
Decays

Combined measurement of Higgs couplings

ATLAS-CONF-2018-031



arXiv: 1809.10733



Summary

- CMS and ATLAS have performed Higgs measurements using 36-80 fb^{-1} LHC Run 2 data
- Observed ttH and VH production modes
- Observed H→bb decay mode
- H→$\mu\mu$ will be the next one to be observed at the LHC

No obvious deviation from the SM has been found at Higgs sector at the LHC

Backup

	ATLAS	CMS
Magnetic field	2 T solenoid + toroid: 0.5 T (barrel), 1 T (endcap)	4 T solenoid + return yoke
Tracker	Silicon pixels and strips + transition radiation tracker $\sigma/p_T \approx 5 \cdot 10^{-4}\, p_T + 0.01$	Silicon pixels and strips (full silicon tracker) $\sigma/p_T \approx 1.5 \cdot 10^{-4}\, p_T + 0.005$
EM calorimeter	Liquid argon + Pb absorbers $\sigma/E \approx 10\%/\sqrt{E} + 0.007$	$PbWO_4$ crystals $\sigma/E \approx 3\%/\sqrt{E} + 0.003$
Hadronic calorimeter	Fe + scintillator / Cu+LAr (10λ) $\sigma/E \approx 50\%/\sqrt{E} + 0.03$ GeV	Brass + scintillator (7 λ + catcher) $\sigma/E \approx 100\%/\sqrt{E} + 0.05$ GeV
Muon	$\sigma/p_T \approx 2\%$ @ 50GeV to 10% @ 1TeV (Inner Tracker + muon system)	$\sigma/p_T \approx 1\%$ @ 50GeV to 10% @ 1TeV (Inner Tracker + muon system)
Trigger	L1 + HLT (L2+EF)	L1 + HLT (L2 + L3)