Highlights of $H \to ff$ at the LHC

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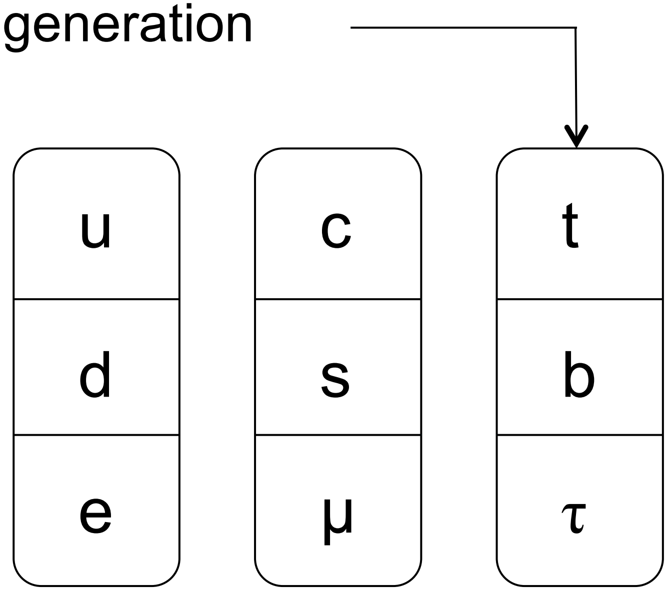
Introduction

Fermion masses emerge in the SM through Yukawa couplings between the Higgs and fermion fields:

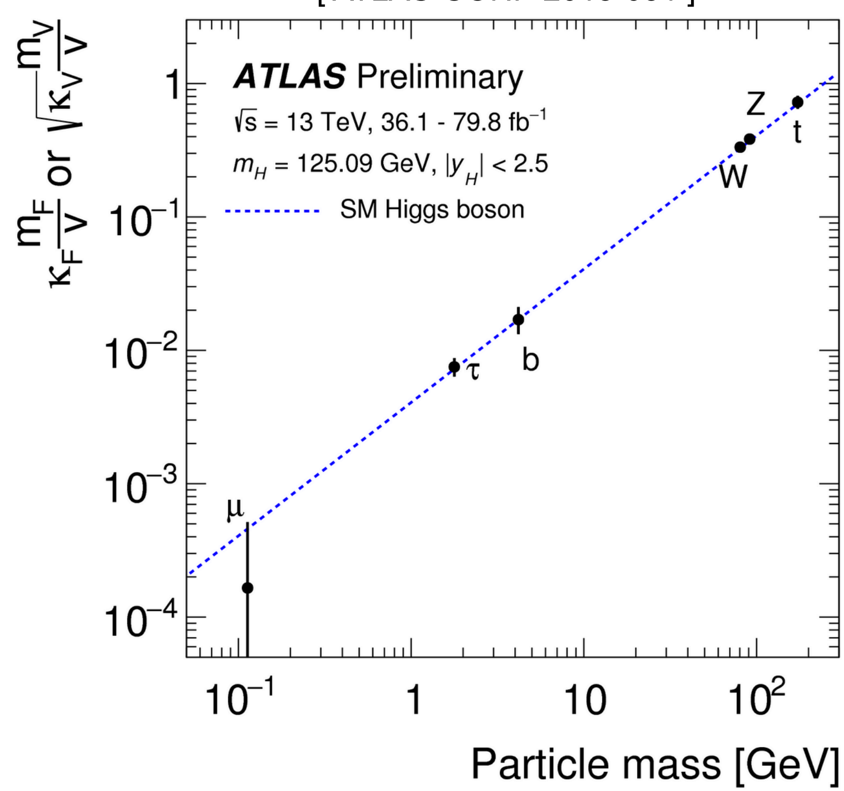
$$L_Y \supset \left(1+\frac{h}{v}\right) m_f \bar{f}_L f_R + \text{h.c.}$$

Higgs coupling to fermions is proportional to fermion mass – behaviour distinct from gauge couplings

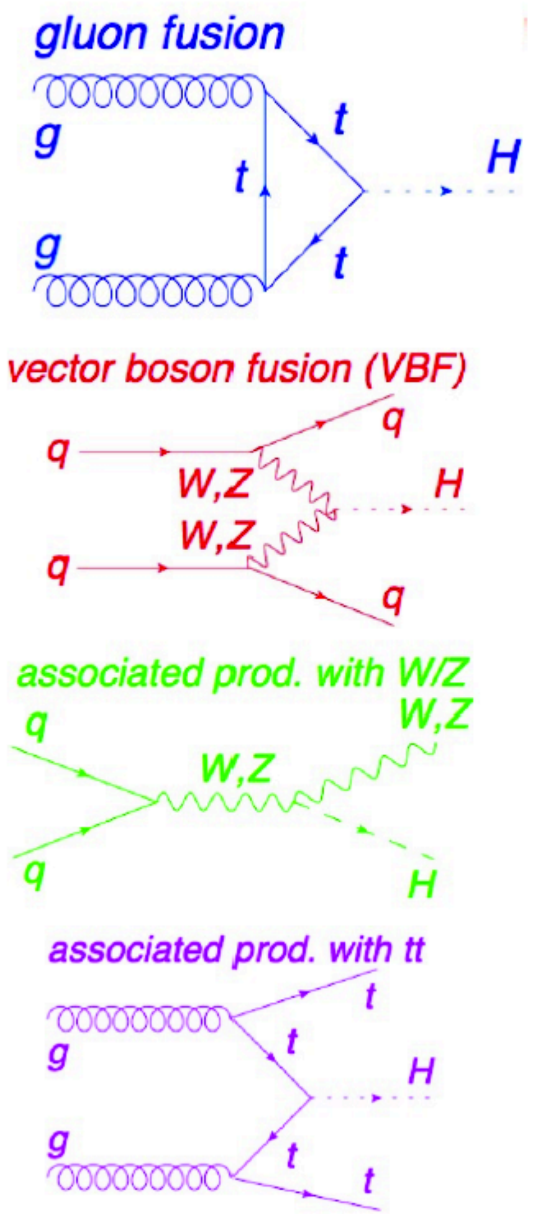
Higgs couplings to fermions are strongest for the 3rd generation

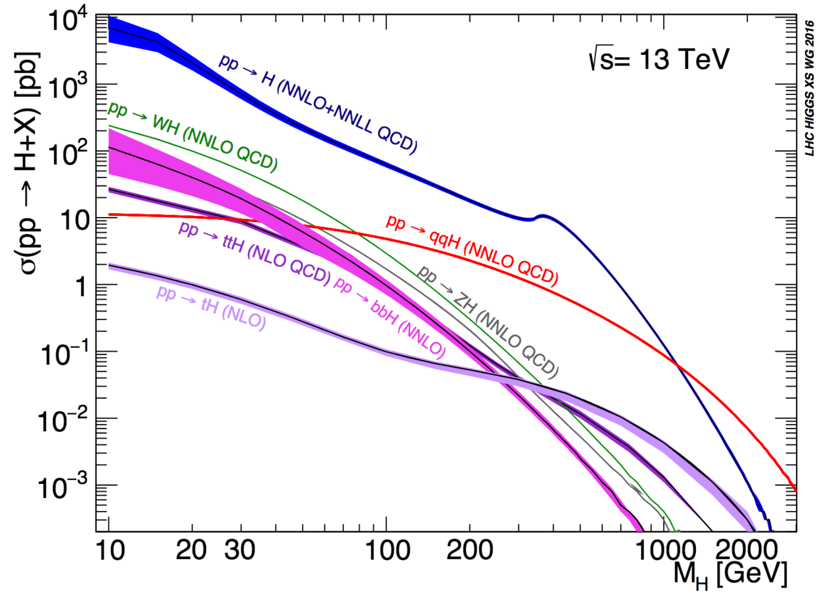


[ATLAS-CONF-2018-031]

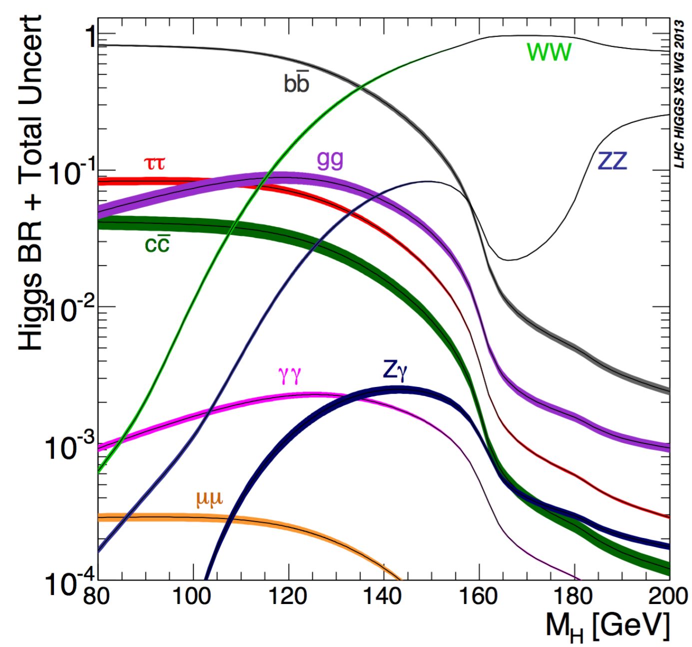


Higgs production and decays

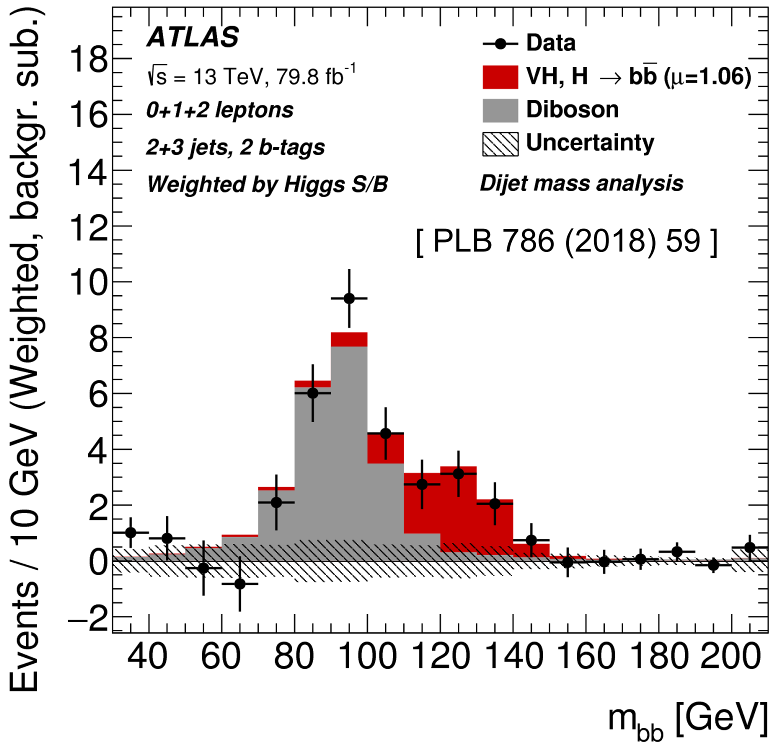


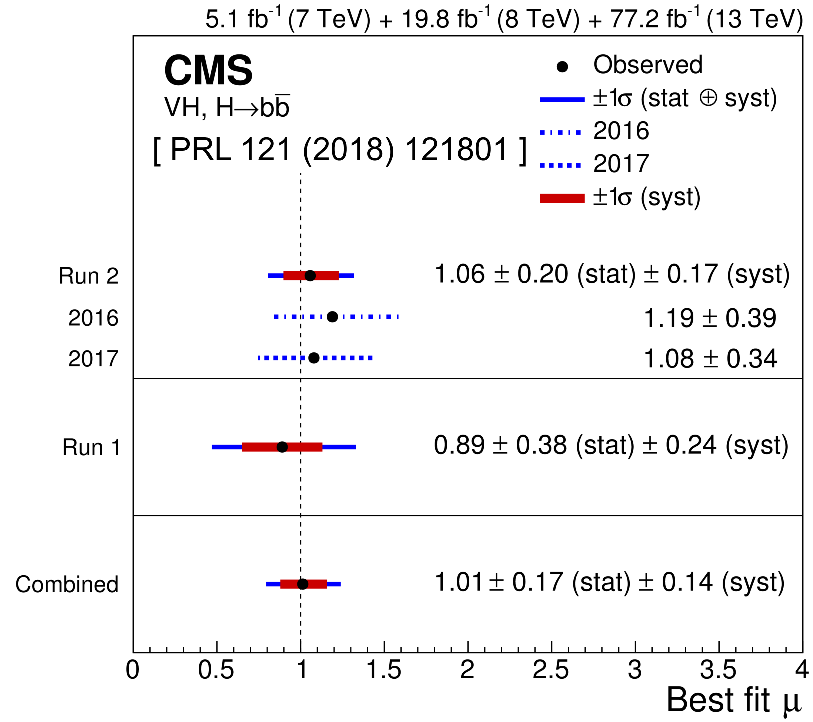


- Four main production modes: ggF, VBF, VH and ttH
- Main fermions decay modes: bb and ττ



VH, H→bb





Most sensitive channel: VH, H→bb

Require two b-tagged jets and 0/1/2 leptons, for Z→νν, W→lν and Z→ll

Cross check with W/Z + Z→bb background

Run 1+2	obs. (exp.) significance
ATLAS	4.9 (5.1) σ
CMS	4.8 (4.9) σ

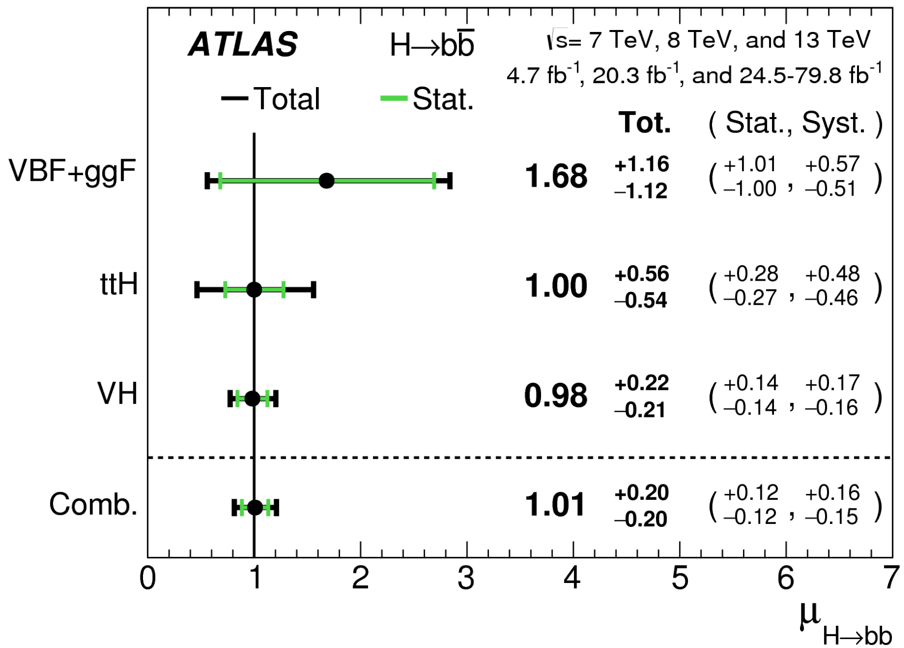
ATLAS: observed VH prod. when combined with H→4l,γγ

Run 1+2	obs (exp) significance
VH prod.	5.3 (4.8) σ

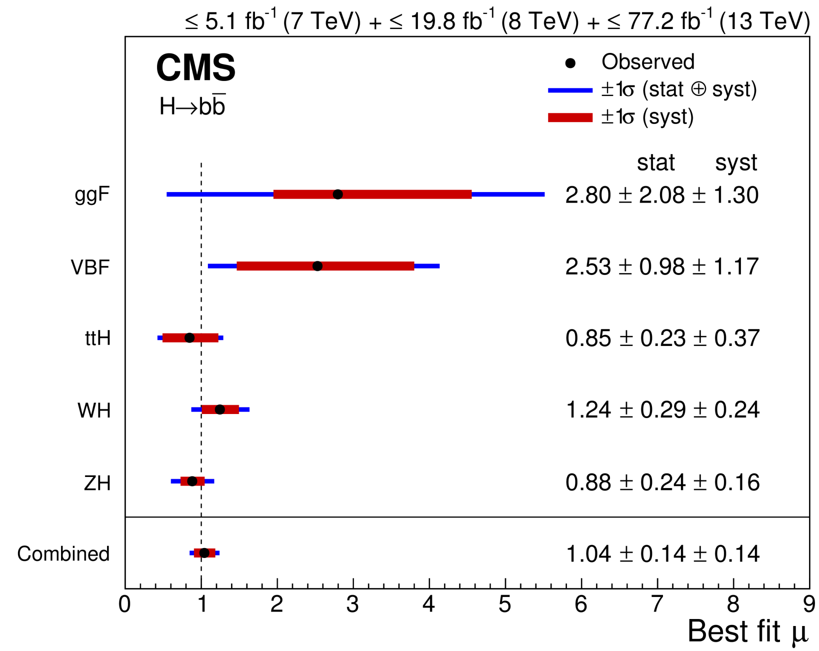
H→bb

Search for H→bb is also done in ggF, VBF and ttH production modes

[PLB 786 (2018) 59]



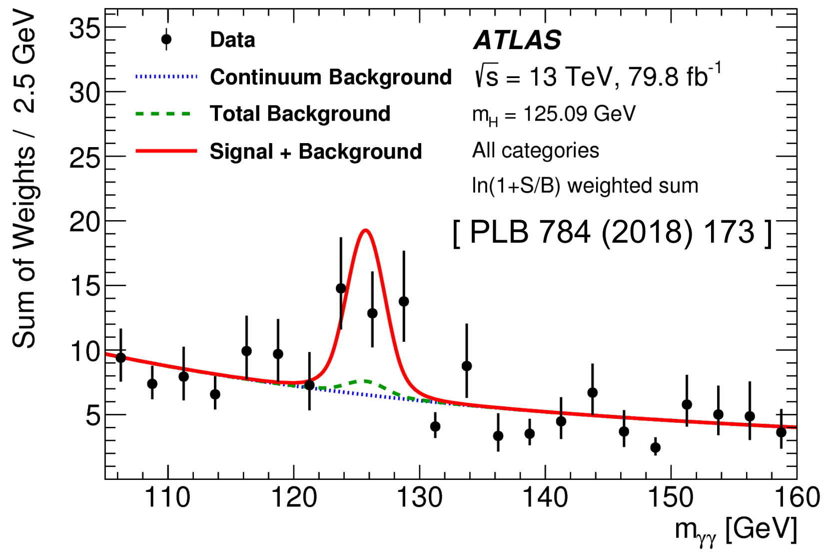
[PRL 121 (2018) 121801]

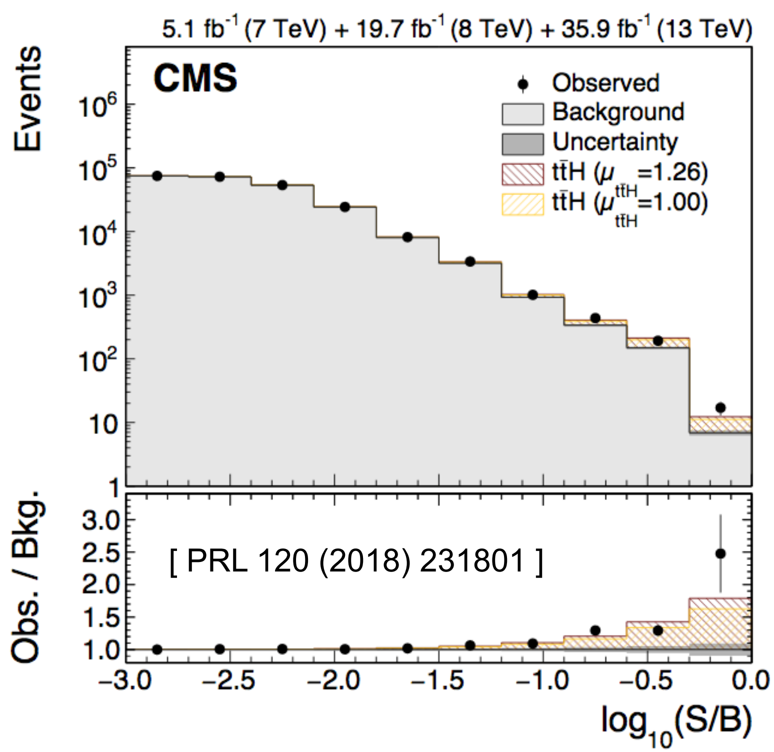


All production modes for for H→bb combined for the observation

Run 1+2	obs. (exp.) significance	signal strength μ
ATLAS	5.4 (5.5) σ	$1.01 \pm 0.12(\text{stat})^{+0.16}_{-0.15}(\text{syst})$
CMS	5.6 (5.5) σ	$1.04 \pm 0.14(\text{stat}) \pm 0.14(\text{syst})$

ttH





ttH production offers direct measurement of Higgs-top coupling

SM ttbar and ttV process are main backgrounds to the search

$H \to \gamma\gamma$:

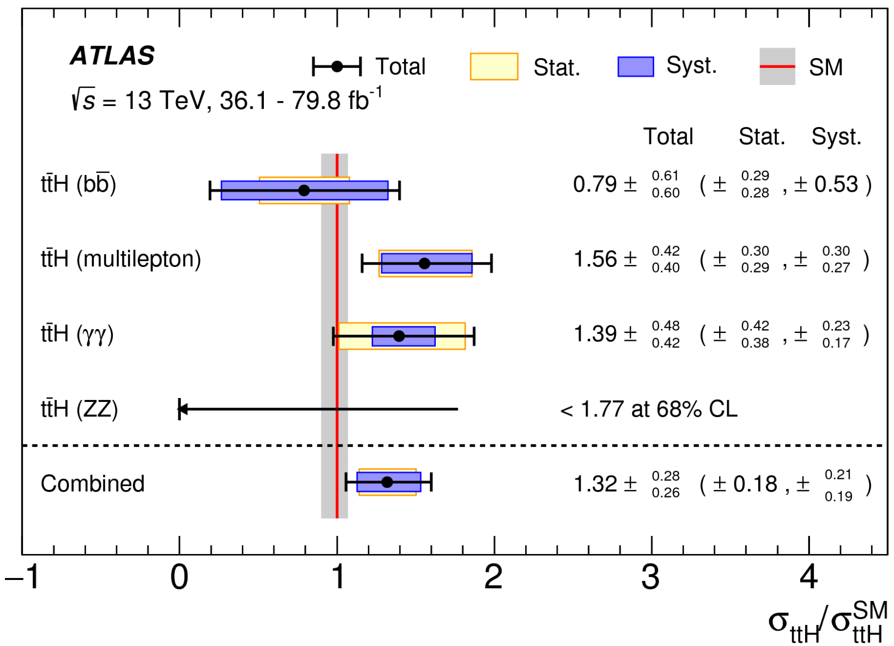
- Small cross section, $\sigma \times$ BR = 507 fb $\times$ 0.227%
- Low background and good diphoton mass resolution

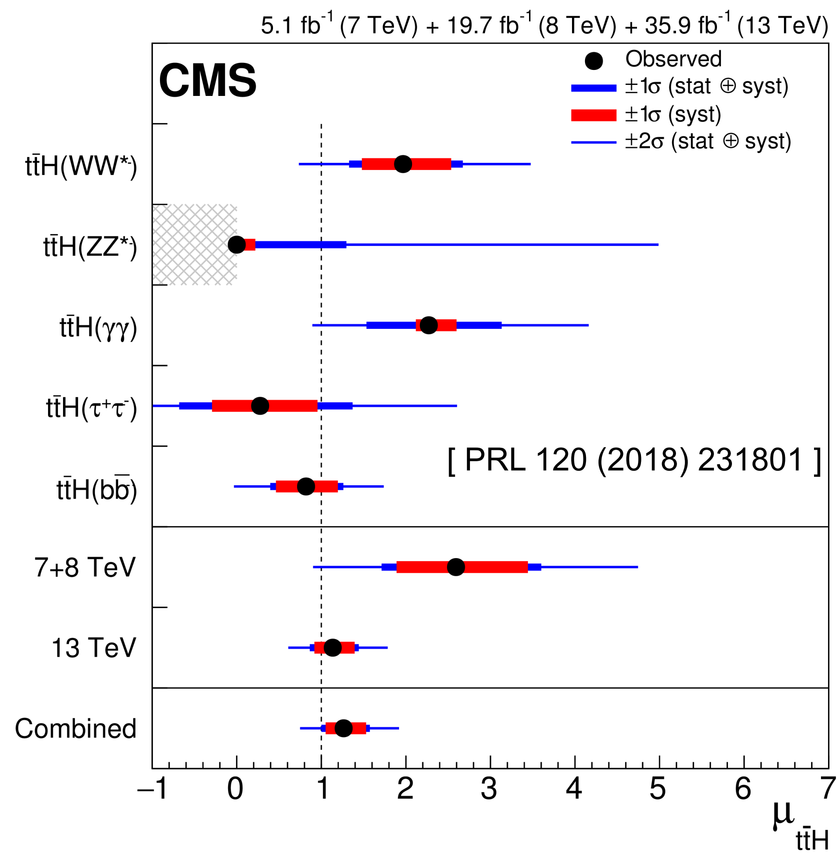
$H \to VV/\tau\tau \to$ multilepton+X:

- Select events with ttbar plus multiple leptons (including taus)
- Use SS leptons and hadronic tau objects to suppress background
- Use BDT to purify the signal

ttH combination

[PLB 784 (2018) 173]





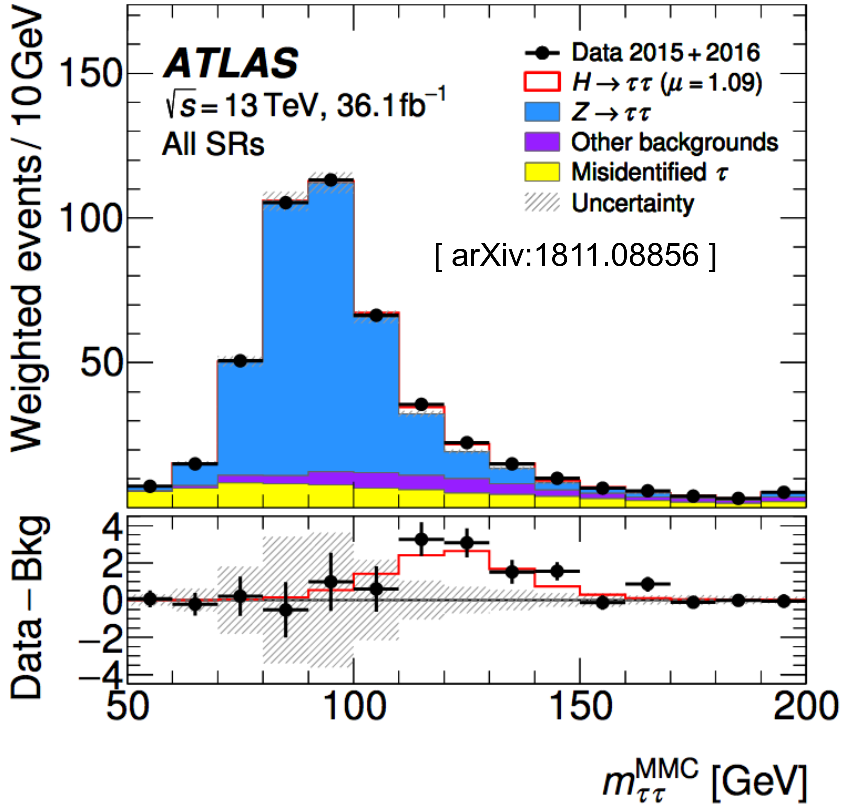
80 fb^{-1} data was used for ATLAS

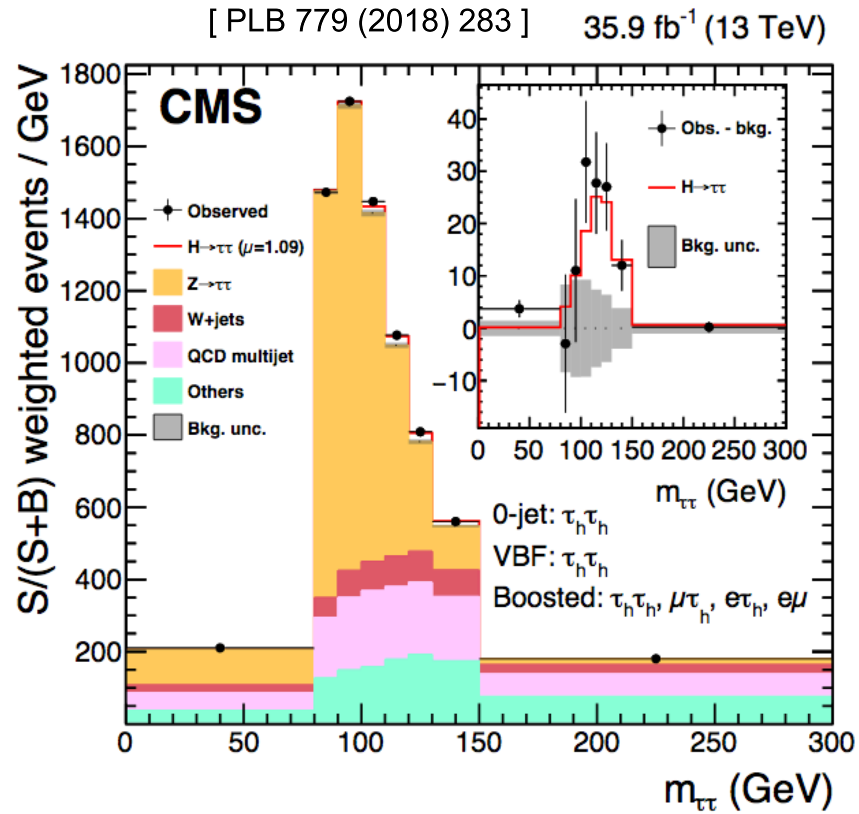
$H \to 4l, \gamma\gamma$

ATLAS	obs. (exp.) significance
Run 2	5.8 (4.9) σ
Run1+2	6.3 (5.1) σ

CMS	obs (exp) significance
Run 1+2	5.2 (4.2) σ

H→ττ



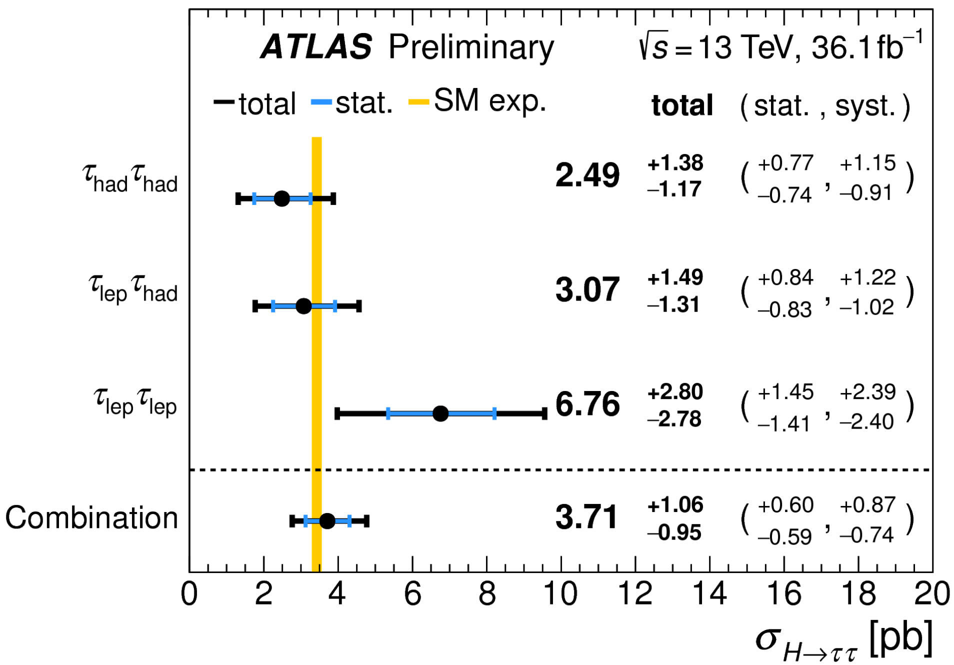


Dominant backgrounds are Z→ττ and jets faking taus (QCD, W+jets). It is MC based but validated with dedicated Z→ll CRs

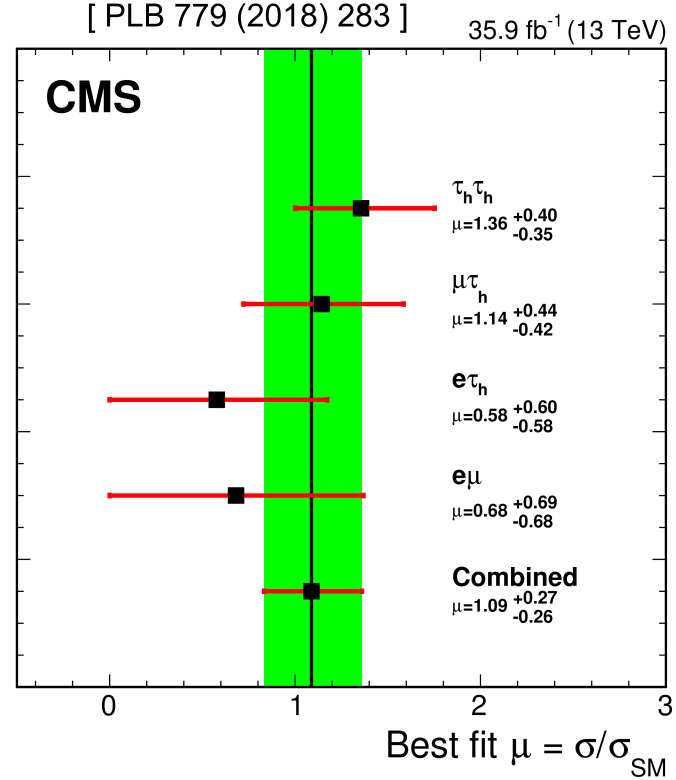
Main signal regions considered: VBF and Boosted. CMS also has 0-jet for $\tau_{had}\tau_{had}$

H→ττ

[arXiv:1811.08856]



[PLB 779 (2018) 283]



ATLAS: 1D fit to ττ (MMC) mass, with multiple SRs

ATLAS	obs. (exp.) significance
Run 2	4.4 (4.1) σ
Run1+2	6.4 (5.4) σ

CMS: 2D fit to ττ mass vs m_{jj} (VBF) and $p_T^{\tau\tau}$ (Boosted)

CMS	obs. (exp.) significance
Run 2	4.9 (4.7) σ
Run1+2	5.9 (5.9) σ

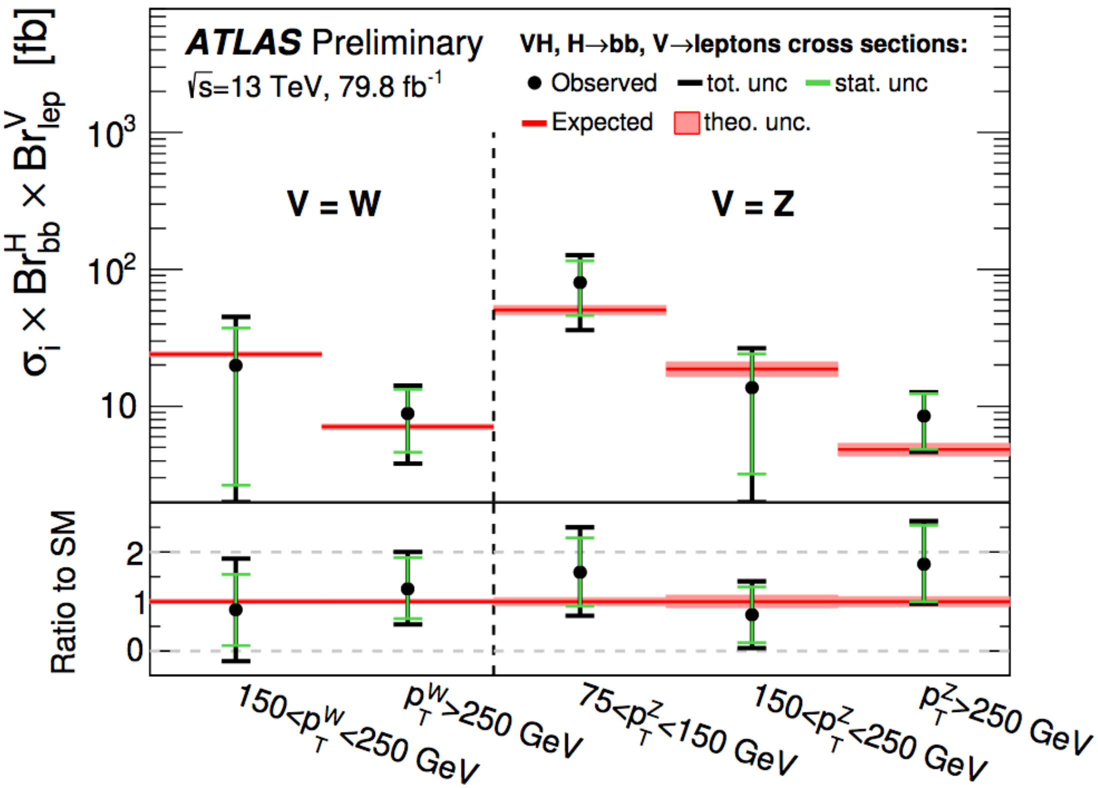
STXS of H→ττ & H→bb

From Run 2, moving from signal strength ($\mu = \sigma/\sigma_{SM}$) to Simplified Template Cross Sections (STXS) in fiducial regions per production mode, split into e.g. jet bins, p_T(H) or p_T(jet)

Starting to exploit the differential information for EFT search, beyond the Kappa-frame

Depending on data statistics, separate in stages (0,1,2…)

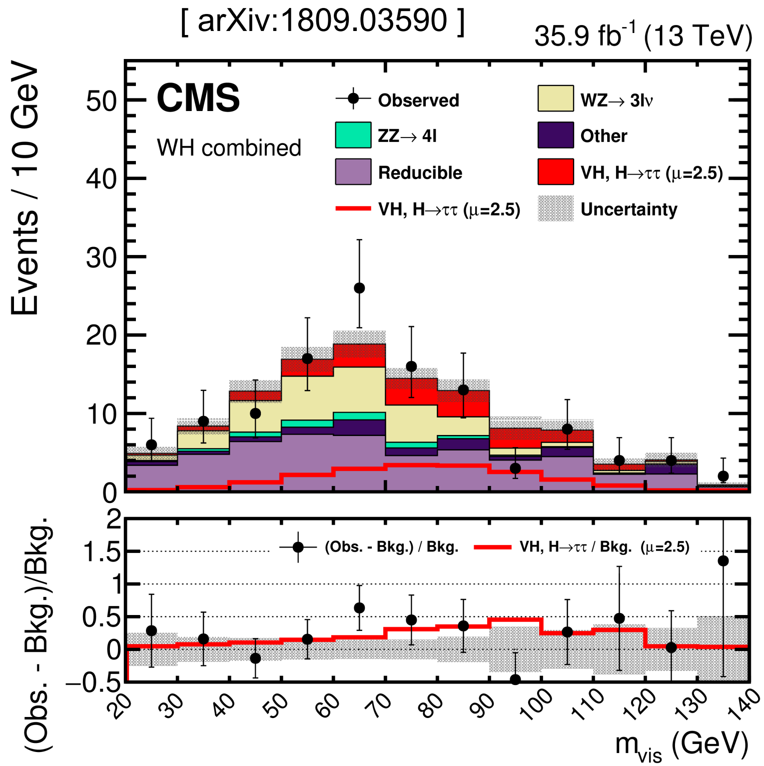
H→bb: stage-1 [ATLAS-CONF-2018-053]

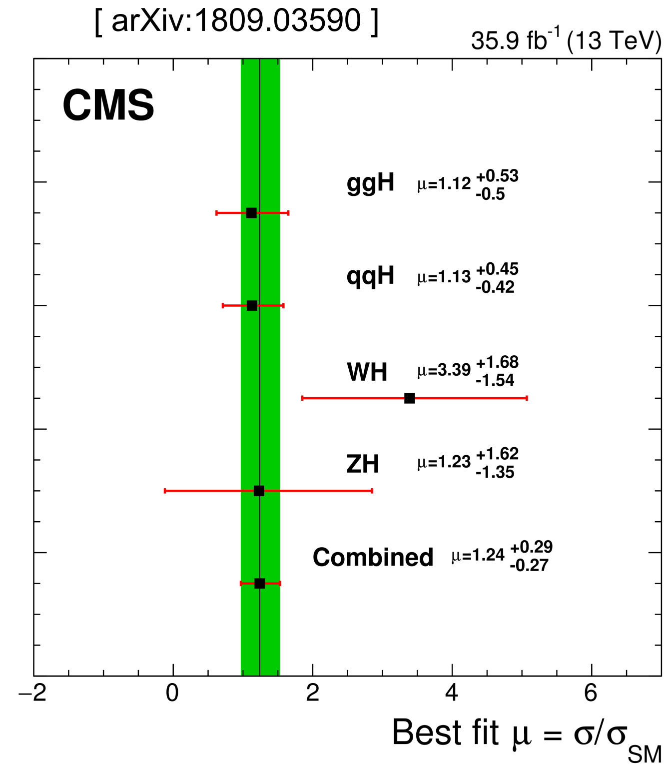


H→ττ: "reduced" stage-1 [arXiv:1811.08856]

Process	Particle-level selection	σ [pb]	σ^{SM} [pb]
ggF	$N_{jets} \geq 1, 60 < p_T^H < 120\,\text{GeV}, \lvert y_H \rvert < 2.5$	1.79 ± 0.53 (stat.)$\pm$ 0.74 (syst.)	0.40 ± 0.05
ggF	$N_{jets} \geq 1, p_T^H > 120\,\text{GeV}, \lvert y_H \rvert < 2.5$	0.12 ± 0.05 (stat.)$\pm$ 0.05 (syst.)	0.14 ± 0.03
VBF	$\lvert y_H \rvert < 2.5$	0.25 ± 0.08 (stat.)$\pm$ 0.08 (syst.)	0.22 ± 0.01

VH, H→ττ





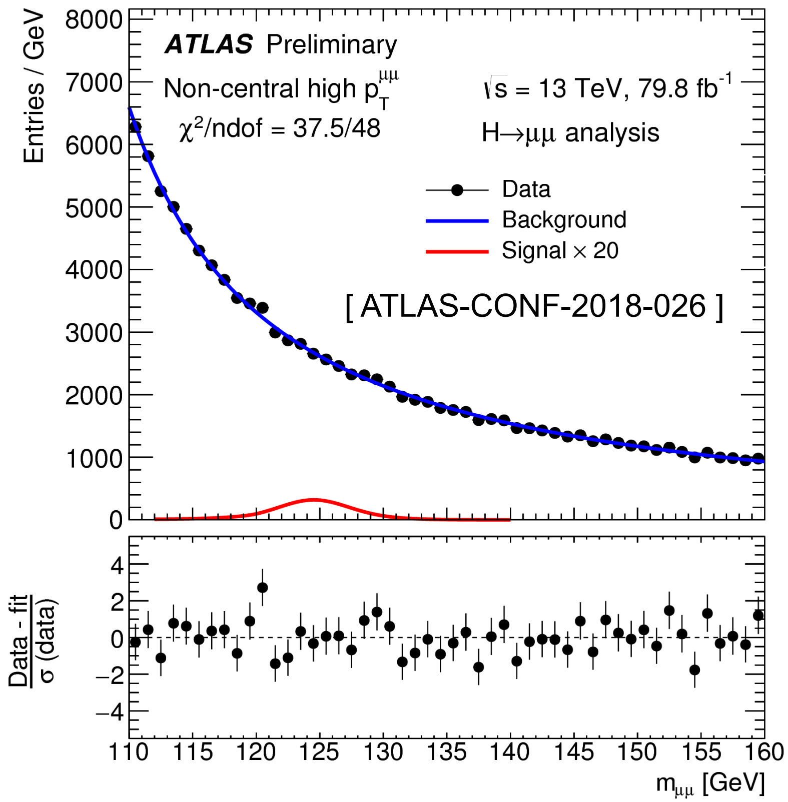
Require OS leptons + ττ (any decays) for ZH, and SS leptons + τ_{had} for WH

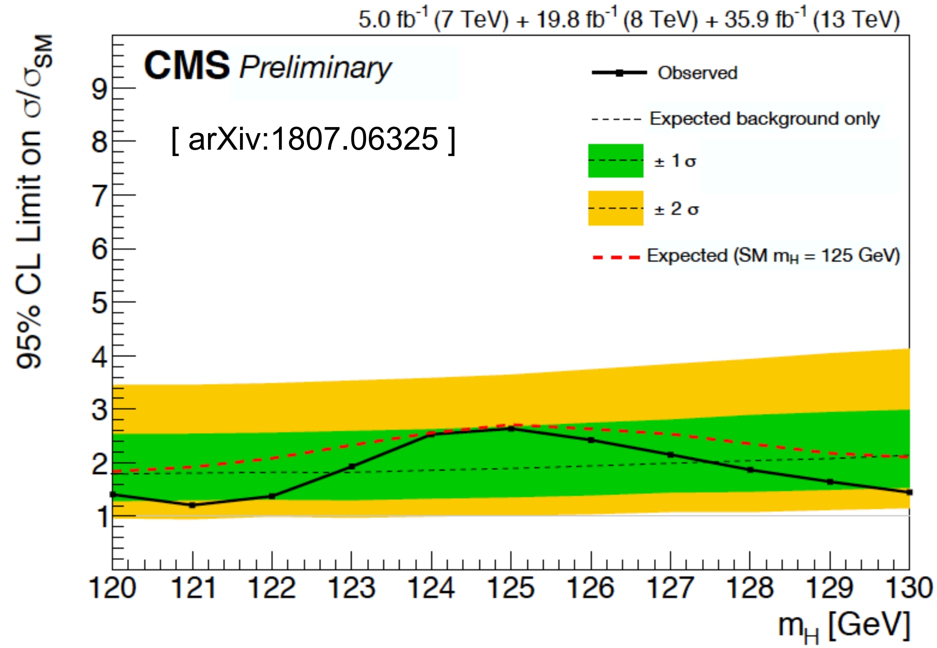
Largest backgrounds from di-boson and fake

Likelihood fit to reconstructed $m_{\tau\tau}$ in ZH and m_{vis} in WH

CMS	obs. (exp.) significance
VH	2.3 (1.0) σ
VH+ggH+VBF	5.5 (4.8) σ

H→μμ





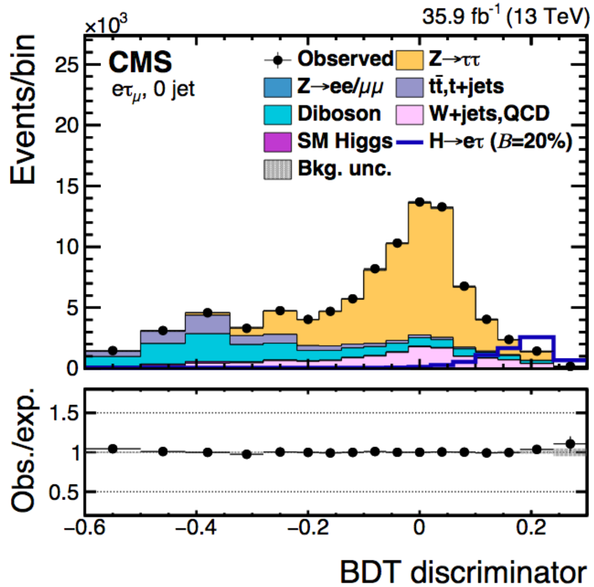
Good dimuon mass resolution, but large Drell-Yan background

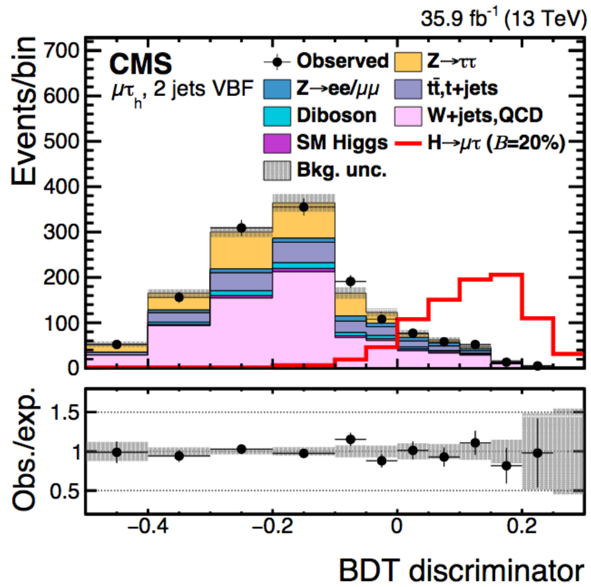
Background shape extrapolated from data sidebands. Categorize events by muon p_T resolution, and targets VBF production using a BDT based on di-jet variables, for optimal results

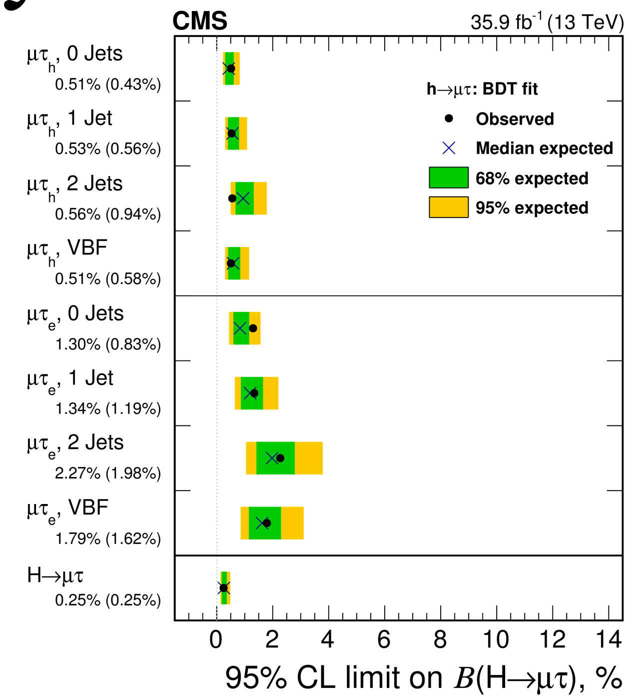
	Data luminosity	obs. (exp.) upper limits
ATLAS	Run 2 (79.8 fb^{-1})	< 2.1 (2.0) x SM
CMS	Run 1+2 (24.8+35.9 fb^{-1})	< 2.92 (2.16) x SM

Higgs LFV decays

[JHEP 06 (2018) 001]

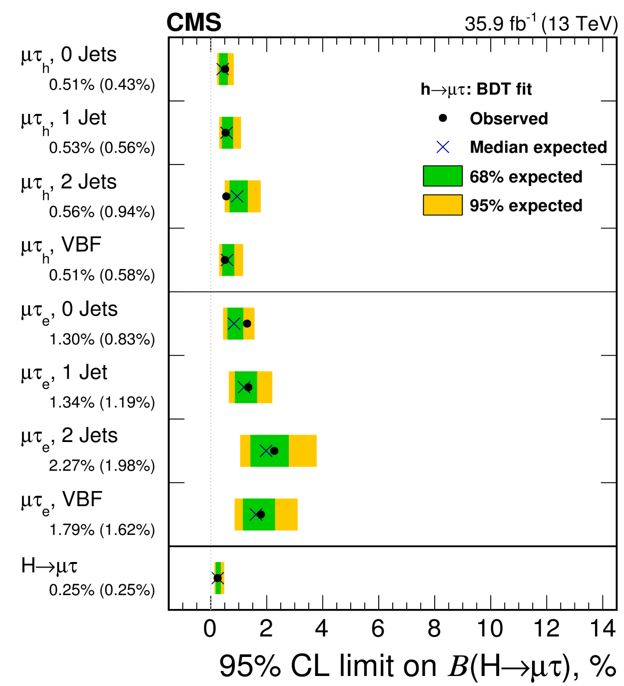






- Search for H→eτ and H→μτ using lep. and had. tau decays
- Main backgrounds are Z+jets and jets faking taus
- Use BDTs to classify signal and background in 8 SRs per final state, depending on N_{jets}

	obs. (exp.) upper limits on BRs
H→eτ	0.61% (0.37%)
H→μτ	0.25% (0.25%)

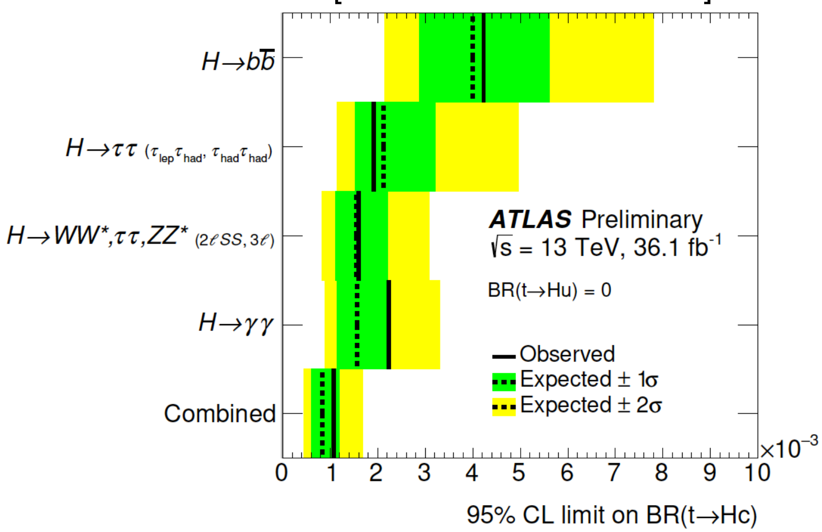


Higgs-top FCNC and tH prod.

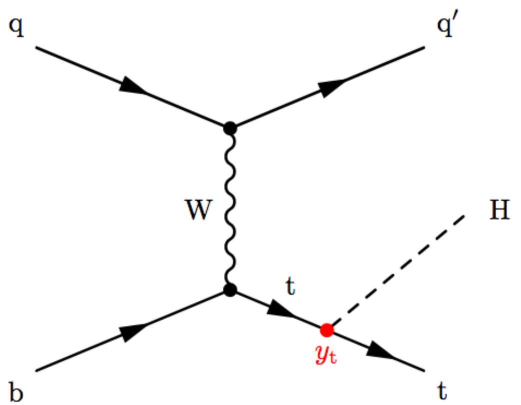
Recent ATLAS search limits for t→Hq with H→γγ or H→WW/ZZ/ττ (2lepSS or 3lep), H→bb and ττ

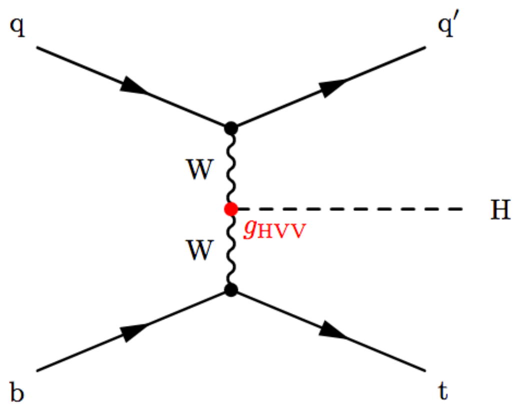
	Obs. (exp.) BR(t→uH) (%)	Obs. (exp.) BR(t→cH) (%)
H→bb	0.52 (0.49)	0.42 (0.40)
H→ττ	0.17 (0.20)	0.19 (0.21)
Comb. with ML and γγ	0.11 (0.083)	0.12 (0.083)

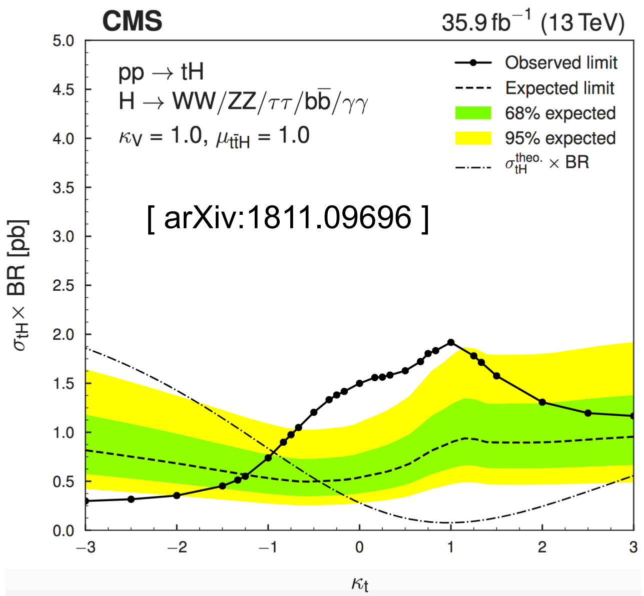
[ATLAS-CONF-2018-049]



Single top+Higgs sensitive to Yukawa y_t and g_{HVV} couplings. With SM g_{HVV}, CMS exclude $y_t < -0.9\, y_t^{SM}$

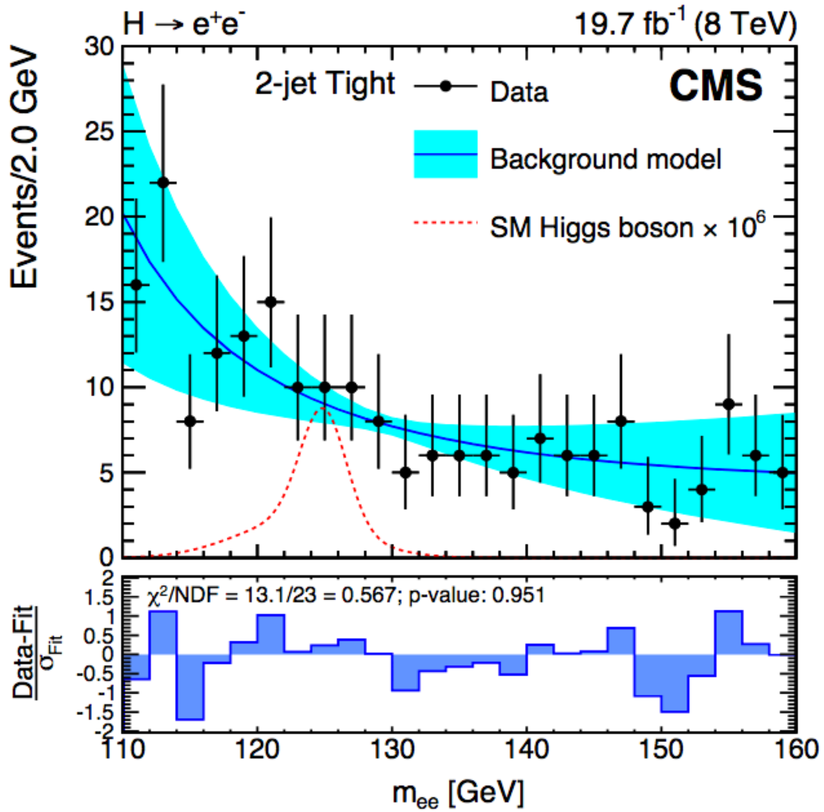


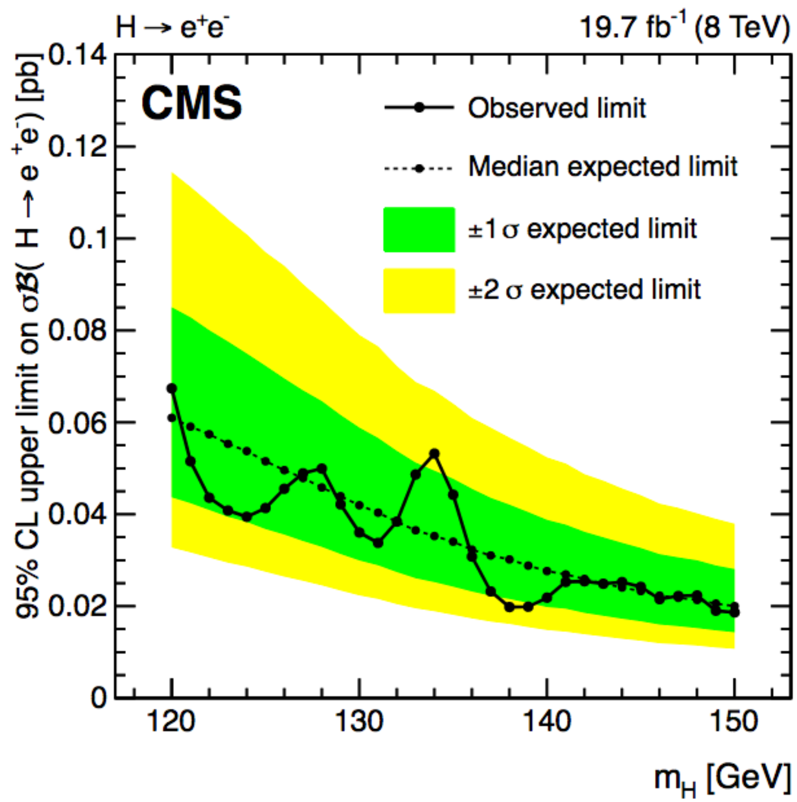




H→ee

[PLB 744 (2015) 184]

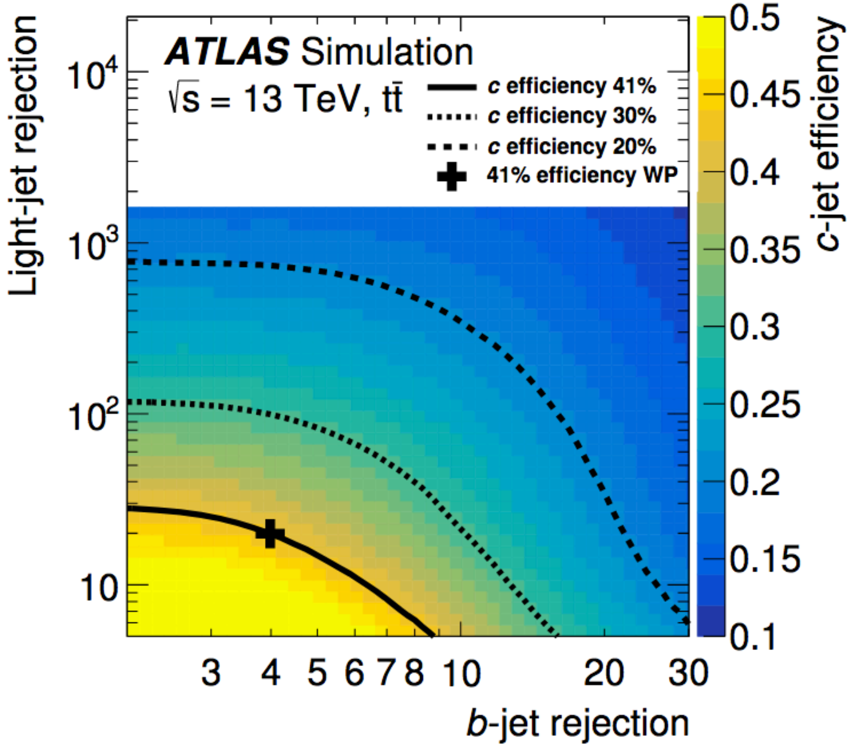


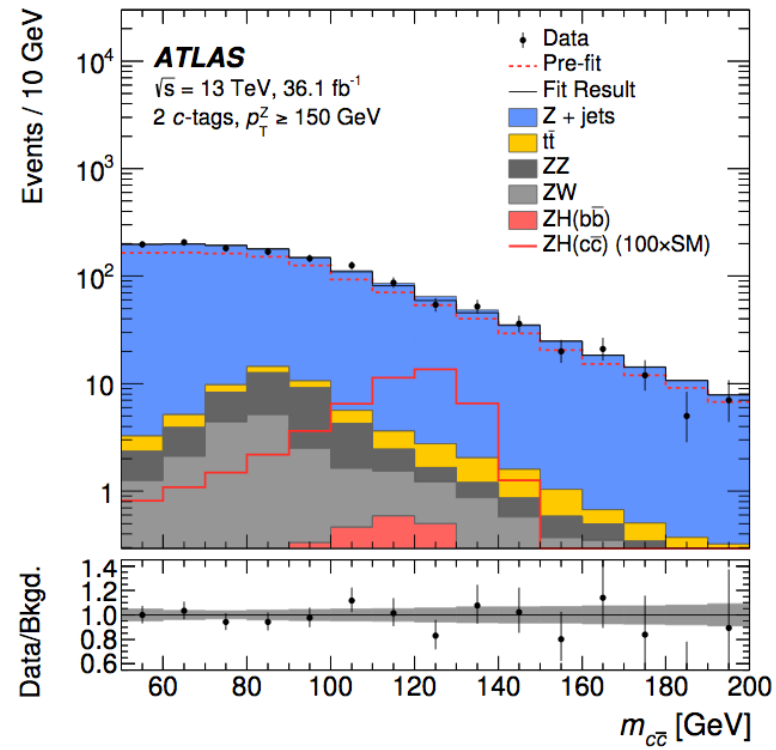


- Divide events into 0/1/2-jet categories. The 2-jet is for VBF prod.
- The 0/1-jet are further divided into Barrel and non-Barrel categories
- Upper limit for B(H→ee): 0.0019, which is 3.7×10^5 times the SM pred.
- Unless the branching fraction is enhanced by New Physics, impossible to reach SM sensitivity at the (HL)LHC

$H \rightarrow cc$

[PRL 120 (2018) 211802]





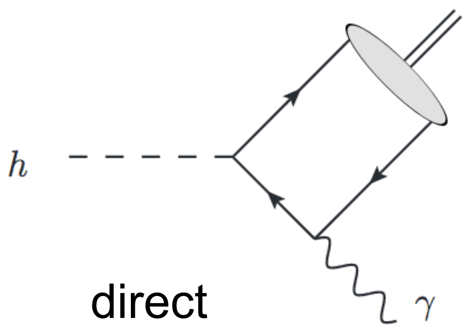
- Search for $ZH \rightarrow ll+cc$
- c-tagging working point: efficiency 41% with b-jet rejection ~4 and light-jet rejection ~20
- The upper limit (2.7 pb) is ~110 times of the SM pred. (25.5 fb)

ATLAS	obs. (exp.) upper limits on σ×BR
Run 2	2.7 pb ($3.9^{+2.1}_{-1.1}$ pb)

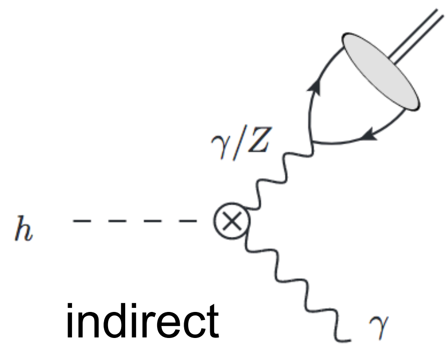
Hcc vertex

The Hcc vertex can be probed with the Higgs radiative decays: H→J/ψ+γ, ψ(nS)+γ

Direct and indirect contributions to Hcc vertex:



direct



indirect

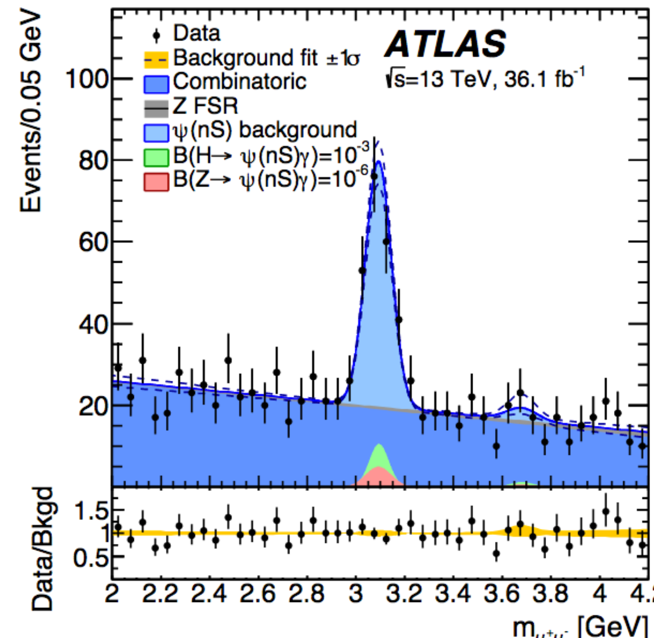
[PLB 786 (2018) 134]

ATLAS	obs. (exp.) upper limits on BRs
H→J/ψ+γ	3.5 ($3.0^{+1.4}_{-0.8}$)×10^{-4}
H→ψ(2S)+γ	19.8 ($15.6^{+7.7}_{-4.4}$)×10^{-4}

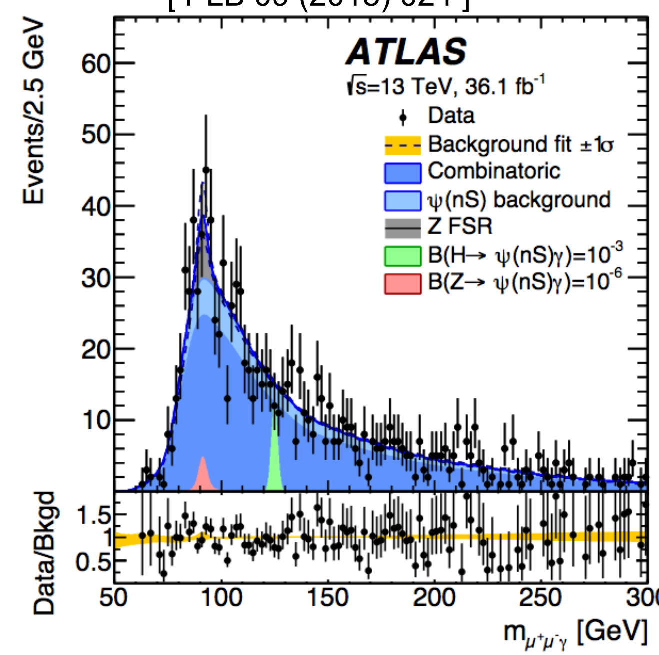
SM predictions of the BRs are ~10^{-6}, which is ~100 times smaller than these limits

[arXiv:1810.10056]

CMS	obs. (exp.) upper limits on BRs
H→J/ψ+γ	7.6 ($5.2^{+2.4}_{-1.6}$)×10^{-4}

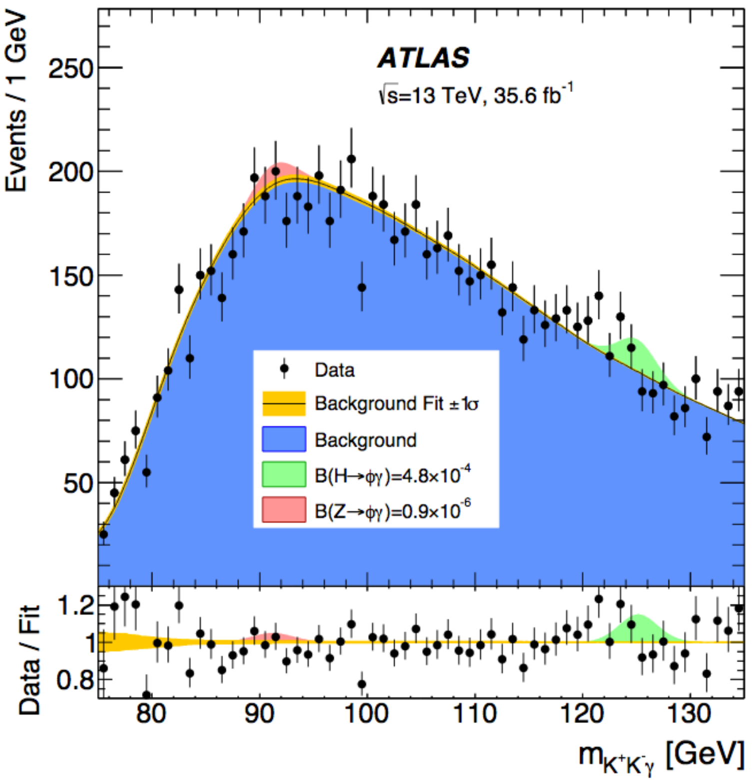


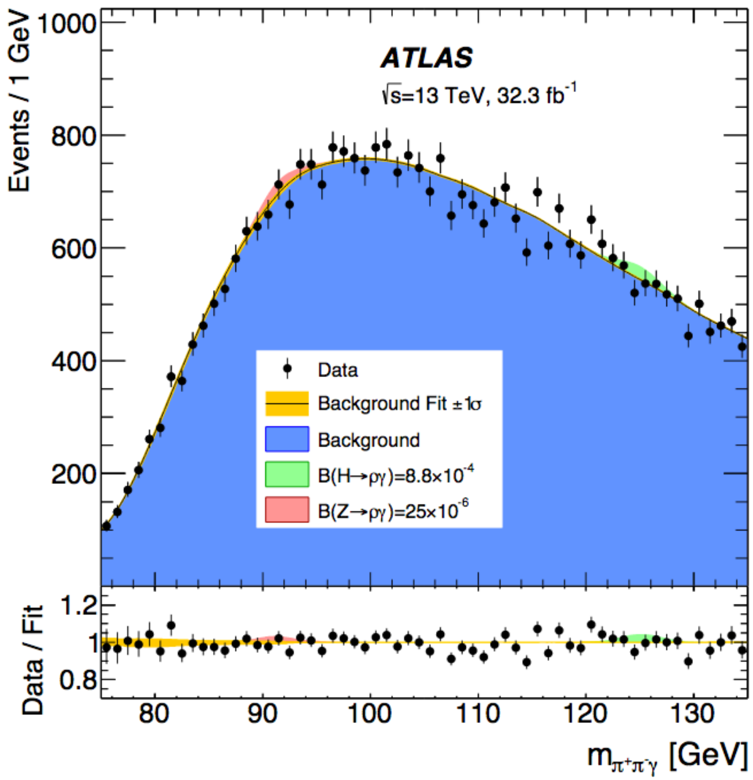
[PLB 09 (2018) 024]



Hss/Huu/Hdd vertices

[JHEP 07 (2018) 127]





H→φγ→KKγ with BR(φ→KK)~50% H→ργ→ππγ with BR(ρ→ππ)~100%

φγ and (ργ) trigger was introduced in 09/2015 (05/2016)

	obs. (exp.) upper limits on BRs	SM pred.
H→φγ	4.8 ($4.2^{+1.8}_{-1.2}$)×10^{-4}	(2.31±0.11)×10^{-6}
H→ργ	8.8 ($8.4^{+4.1}_{-2.4}$)×10^{-4}	(1.68±0.08)×10^{-5}

Summary

Disclaimer: results selected have personal preferences (Run-2 and latest ones). Not all results are shown in the talk

Measurements of Higgs couplings to fermions are very important for precision determination of Higgs property

- Observations of Higgs couplings to the 3rd generation fermions (t, b, τ) established – differential measurements is becoming possible
- Measurement of Higgs couplings to muons is improving with more data
- Higgs couplings to other fermions in the 1st and 2nd generations are challenging, and upper limits comply with SM predictions

Results will be updated with full Run 2 data. Stay tuned