News and prospects about Higgs self-coupling and top-Yukawa coupling at the LHC and HL-LHC

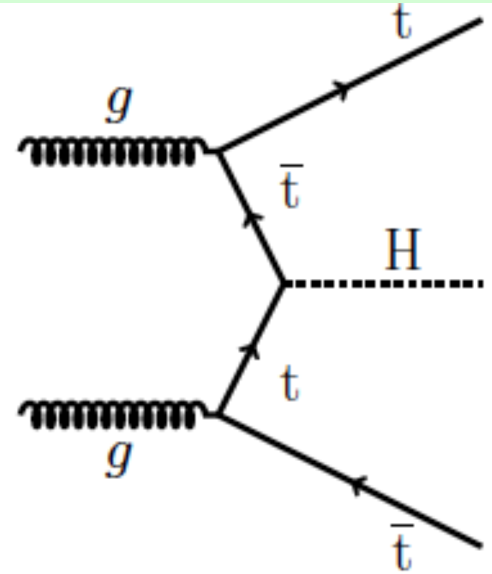
S. Paganis (NTU) on behalf of ATLAS and CMS collaborations

ALCW, Fukuoka, 日本, May 2018

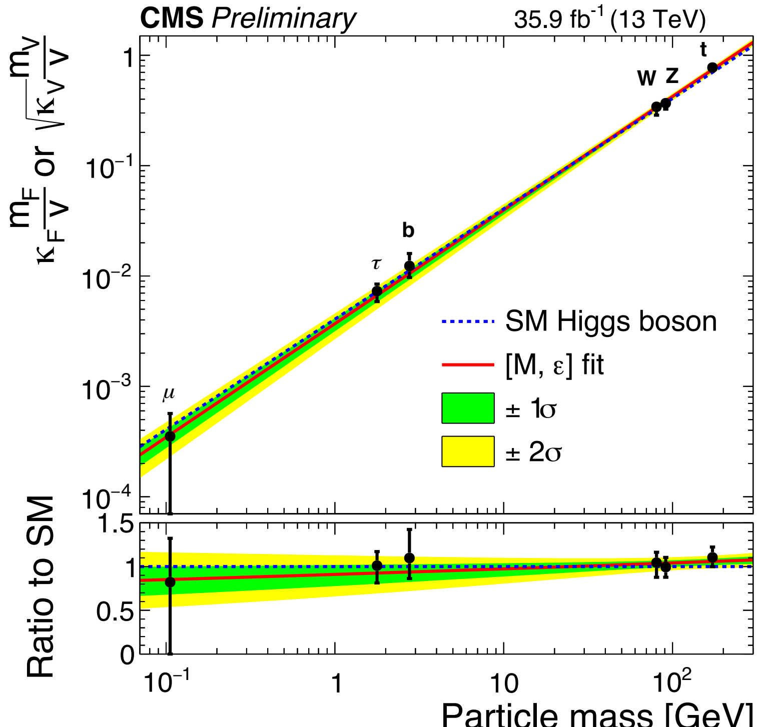
Outline

- Top Yukawa and ttH production mode measurements.
- HH searches in Run 1 and Run 2
- Prospects for top Yukawa in High Luminosity LHC
- Prospects for Higgs self-coupling at HL-LHC

ttH production mode, and y_t



- Top coupling measured indirectly through gg→H, and H→γγ loops.
- ttH mode has small xsection ~0.5 pb at 13TeV.
- Observation of ttH production mode → ttH production cross-section is a direct measurement of y_t, and a consistency test of SM.
- This would be the first observation of Higgs coupling with "up"-type quark.

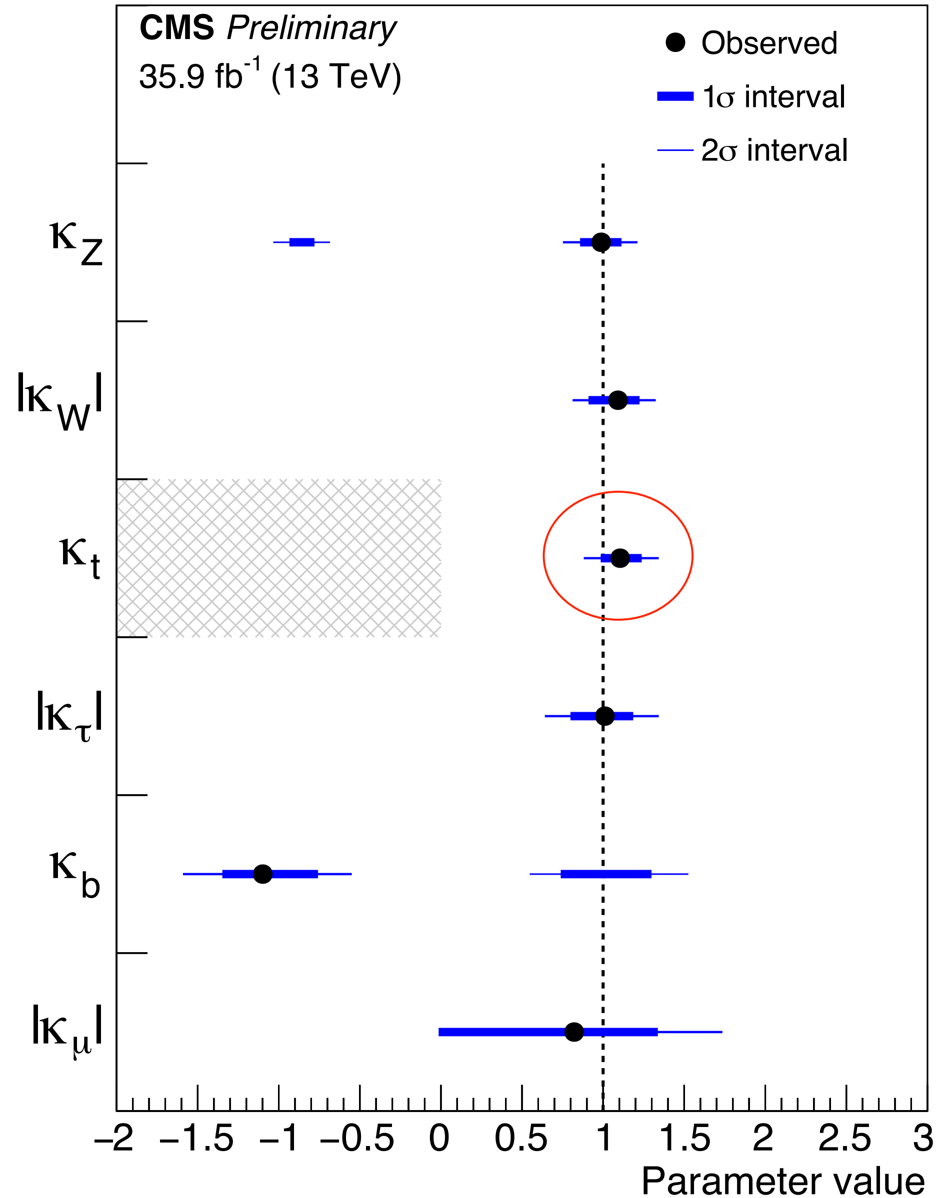


top-Yukawa $y_t/y_{t,SM}$ 13TeV, 35.9 fb^{-1}

CMS-PAS-HIG-17-031

- Measurements interpreted within the k-framework
- Assume no BSM contributions in ggH and H→γγ loops
  - loops expressed in terms of SM coupling modifiers
- Sensitive to relative sign of couplings

κ_t			
Best fit value		Uncertainty	
		Stat.	Syst.
1.11	$^{+0.12}_{-0.11}$	$^{+0.08}_{-0.07}$	$^{+0.09}_{-0.08}$



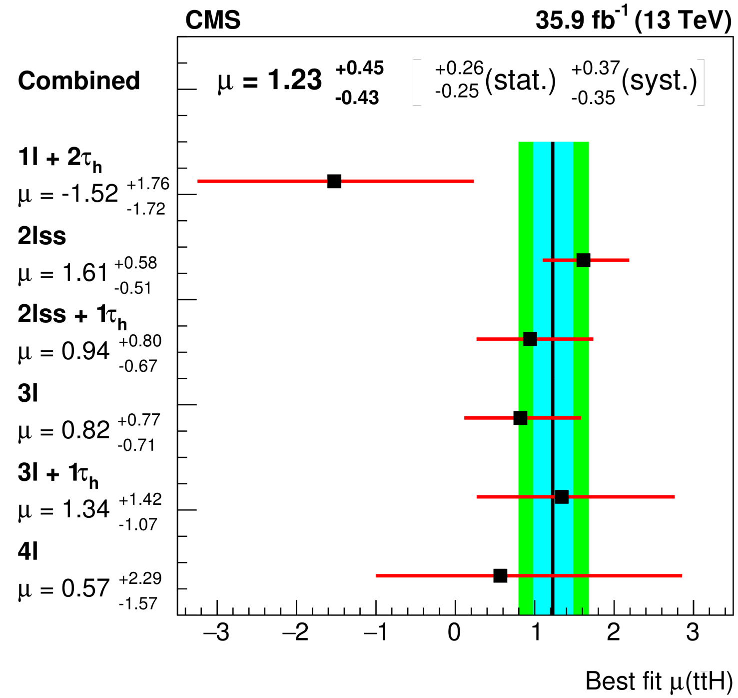
ttH production measurements

arXiv:1803.05485

ttH Multilepton: H→ττ, WW, ZZ*

$$\mu_{ttH} = 1.23^{+0.45}_{-0.43}$$

Significance obs(exp): 3.2(2.8) σ

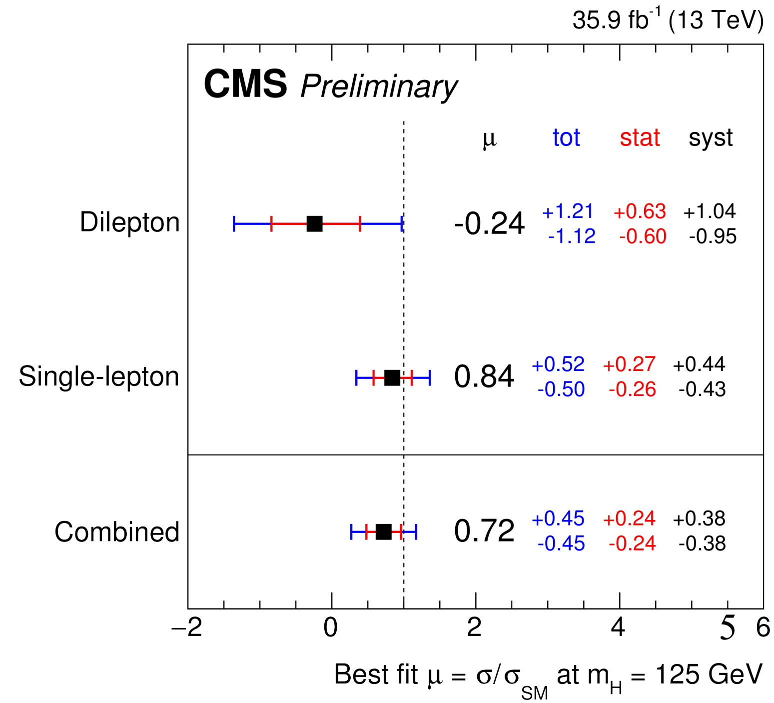


CMS-HIG-17-026

ttH: H→bb + leptons

$$\mu_{ttH} = 0.72^{+0.45}_{-0.45}$$

Significance obs(exp): 1.6(2.2) σ



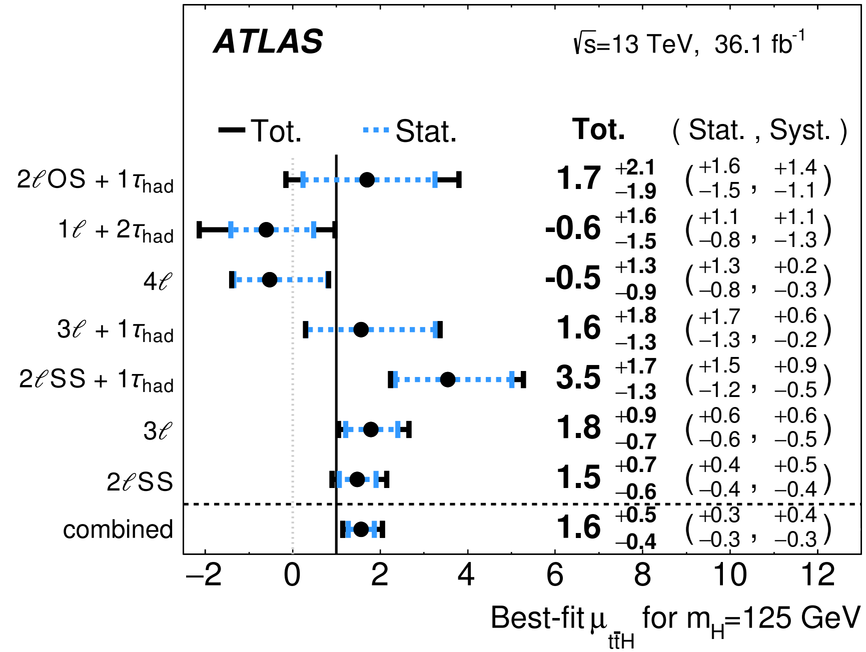
ttH production measurements

arXiv:1712.08891

ttH Multilepton: H→ττ, WW, ZZ*

$$\mu_{\mathrm{ttH}} = 1.6^{+0.5}_{-0.4}$$

Significance obs(exp): 4.1(2.8) σ

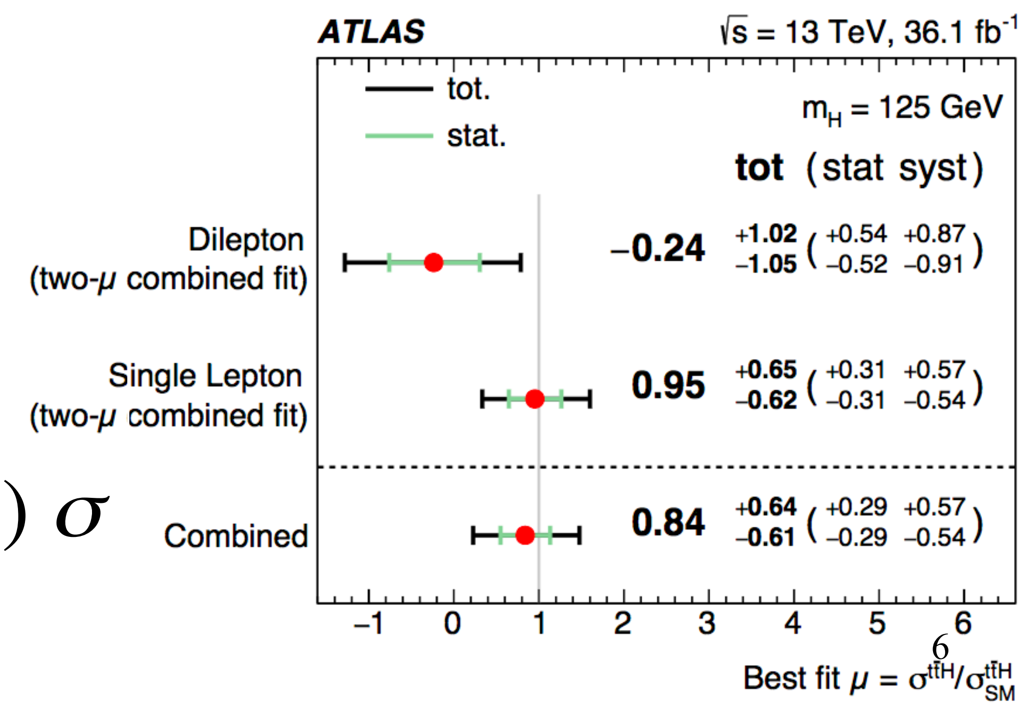


arXiv:1712.08895

ttH: H→bb + leptons

$$\mu_{\mathrm{ttH}} = 0.84^{+0.64}_{-0.61}$$

Significance obs(exp): 1.4(1.6) σ



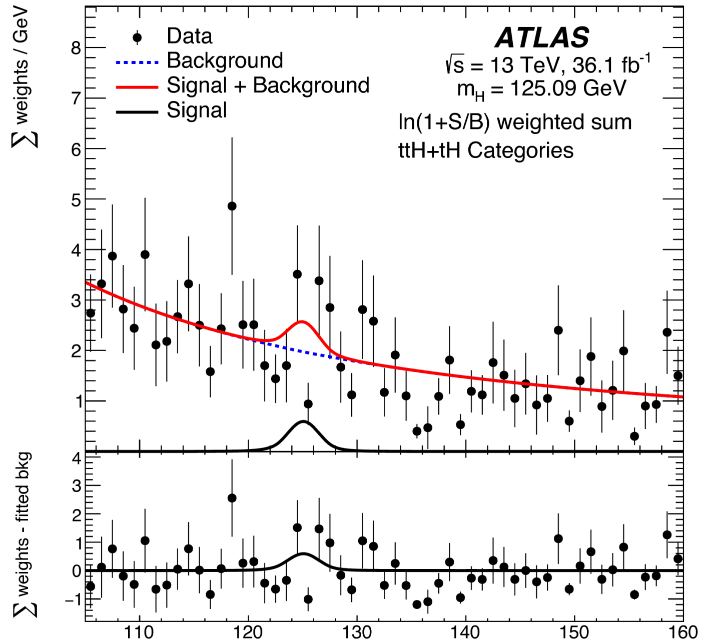
ttH production measurements

arXiv:1802.04146 (submitted to PRD)

ttH+tH: H→γγ with tt→all

$$\mu_{ttH} = 0.5^{+0.6}_{-0.6}$$

Significance obs(exp): 1.0(1.8) σ

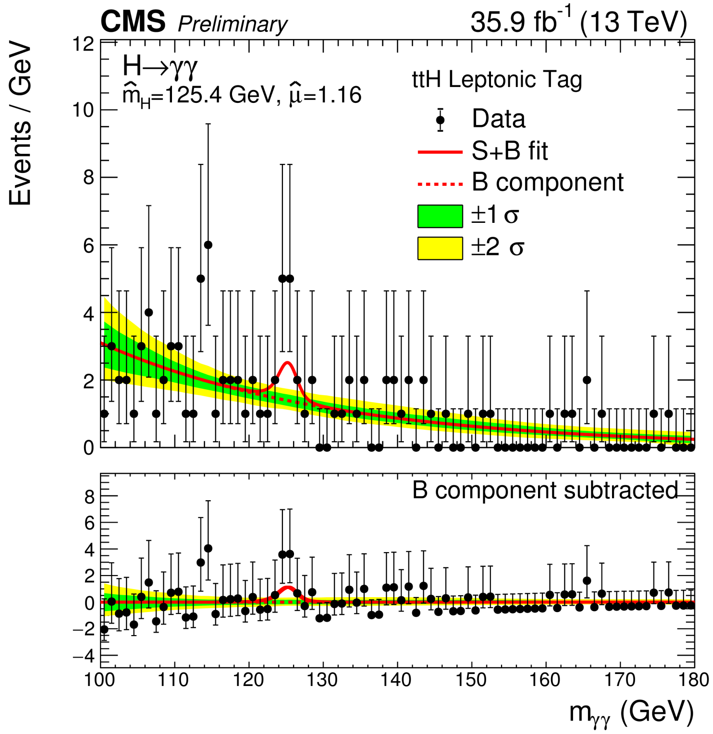


CMS-PAS-HIG-16-040

ttH: H→γγ with tt→all

$$\mu_{ttH} = 2.2^{+0.9}_{-0.8}$$

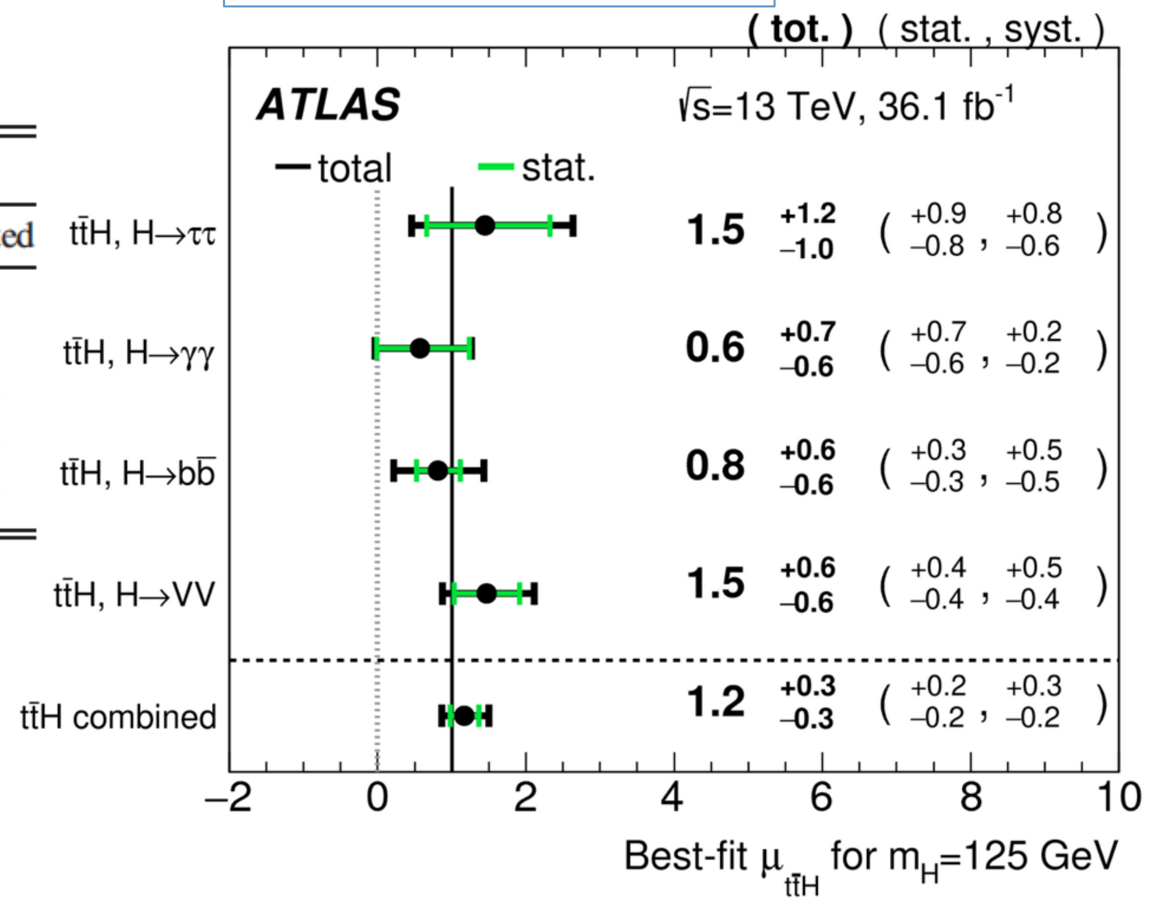
Significance obs(exp): 3.2(1.5) σ



ttH mode: combination

PRD 97, 072003 (2018)
arXiv:1712.08891

Channel	Best-fit μ Observed	Best-fit μ Expected	Significance Observed	Significance Expected
Multilepton	$1.6^{+0.5}_{-0.4}$	$1.0^{+0.4}_{-0.4}$	4.1σ	2.8σ
$H \to b\bar{b}$	$0.8^{+0.6}_{-0.6}$	$1.0^{+0.6}_{-0.6}$	1.4σ	1.6σ
$H \to \gamma\gamma$	$0.6^{+0.7}_{-0.6}$	$1.0^{+0.8}_{-0.6}$	0.9σ	1.7σ
$H \to 4\ell$	< 1.9	$1.0^{+3.2}_{-1.0}$	$\cdots$	0.6σ
Combined	$1.2^{+0.3}_{-0.3}$	$1.0^{+0.3}_{-0.3}$	4.2σ	3.8σ



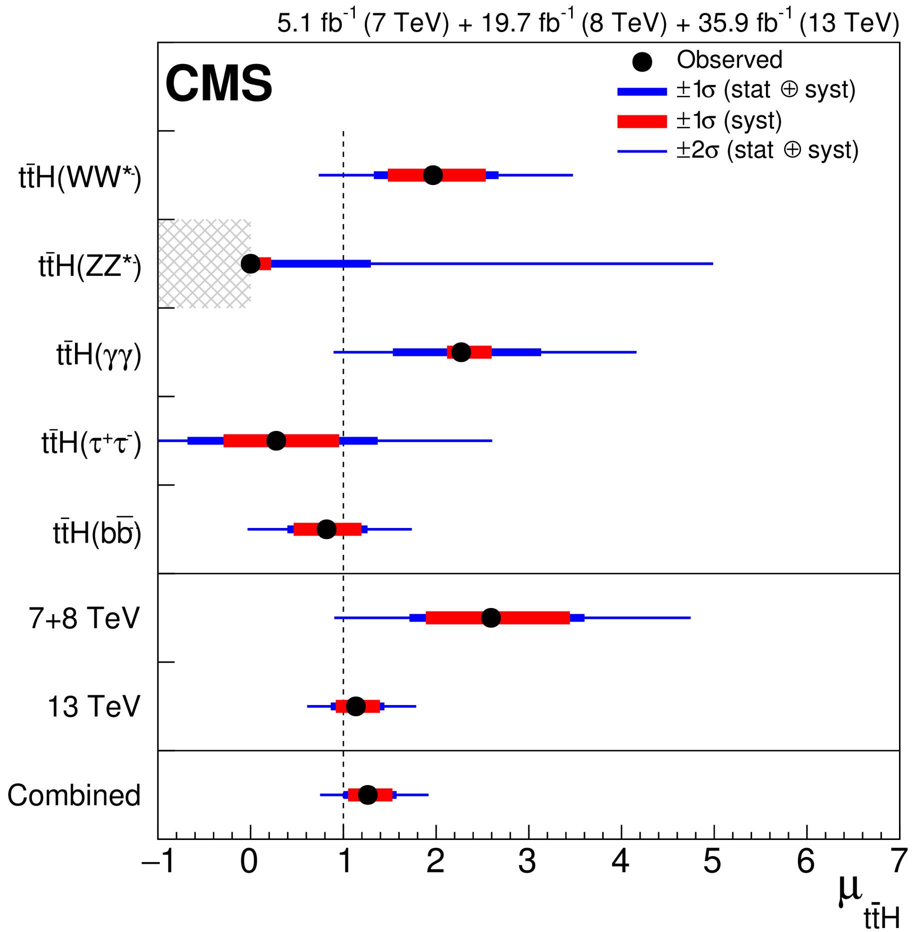
Best fitted $\mu_{\mathrm{ttH}} = 1.2^{+0.3}_{-0.3}$

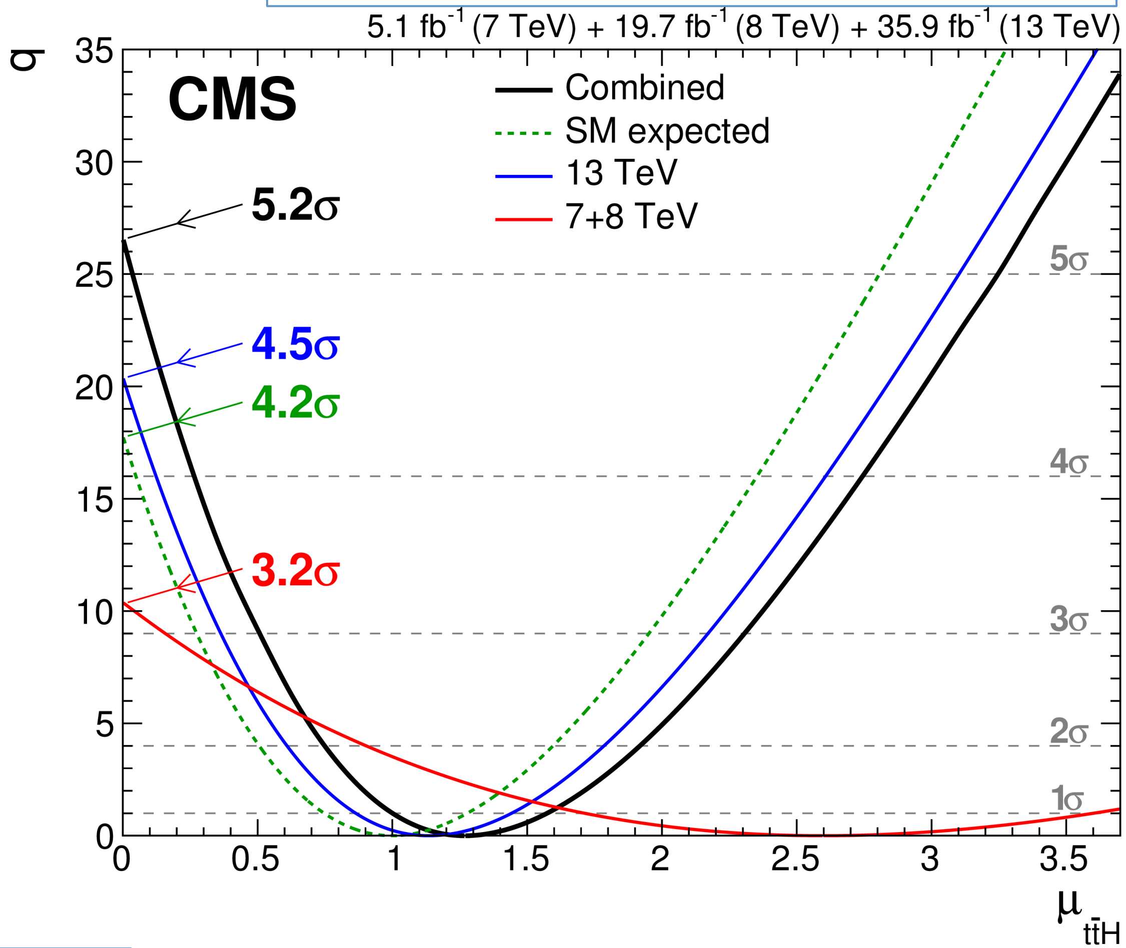
Significance obs(exp): 4.2 (3.8)σ

- **Consistent with SM**
- **7-8 TeV data not included**

ttH production mode: combination

CMS-HIG-17-035 (Accepted by PRL)





Best fitted $\mu_{ttH} = 1.26^{+0.31}_{-0.26}$

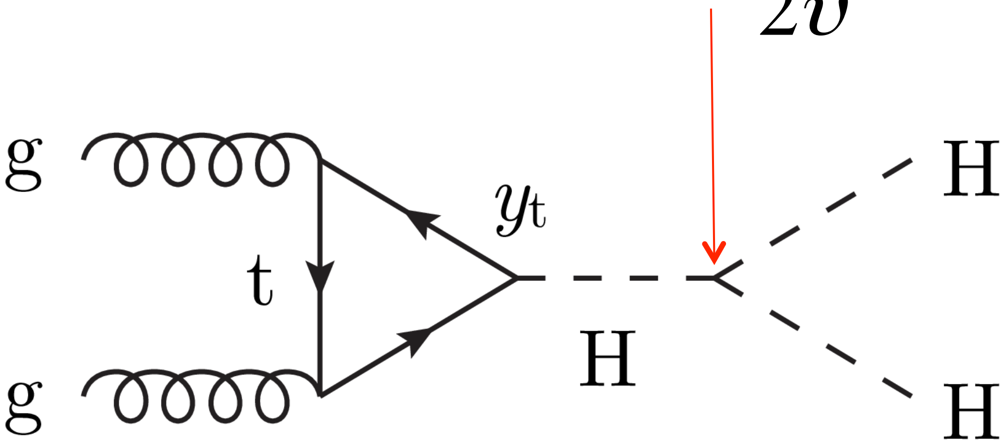
Significance obs(exp): 5.2 (4.2)σ

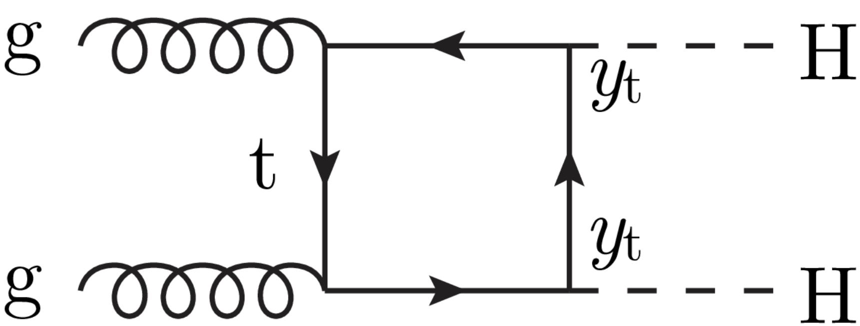
- **Consistent with SM**
- **7-8 TeV data included**

HH final state: involves y_t and λ_{hhh}

- Measurement of the Higgs self coupling: fundamental test of the SM.
- SM predicts a extremely small cross section for HH production: 33.5 fb at 13 TeV.
- Main production mode: gluon-gluon fusion.

$$\lambda_{hhh}^{SM} = \frac{m^2}{2v^2} = 0.13$$





CMS HH result summary

Run 1

- $bb\tau\tau$ + $bb\gamma\gamma$ combination 43 (47) x SM observed (expected) PRD 96, 072004 (2017)

Run 2

- $bb\gamma\gamma$ CMS-HIG-17-008
- $bb\tau\tau$ Phys. Lett. B 778 (2018) 101
- bbVV*(→lνlν) JHEP 01 (2018) 054
- bbbb CMS-HIG-16-026 (based on L= 2.3 fb^{-1} only)

Channel	Obs (exp) 95% CL limit on σ/σ_{SM}
$b\bar{b}WW^*(\rightarrow l\nu l\nu)$	79(89)
$bb\tau\tau$	31(25)
$bb\gamma\gamma$	19(16)

ATLAS HH result summary

Run-2 results.

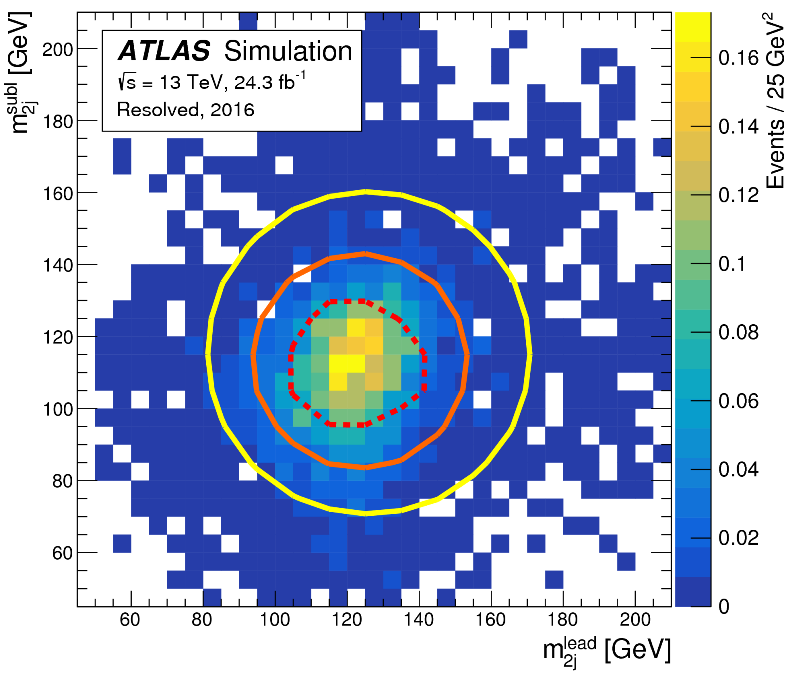
Channel	Limit
bbbb	13(21)
bbγγ	117(161)
WWγγ	747(386)

bbbb luminosity used: 36.1 fb^{-1}
bbγγ luminosity used: 3.2 fb^{-1}
WWγγ luminosity used: 13.0 fb^{-1}

ATLAS **bbbb**:
arXiv:1804.06174

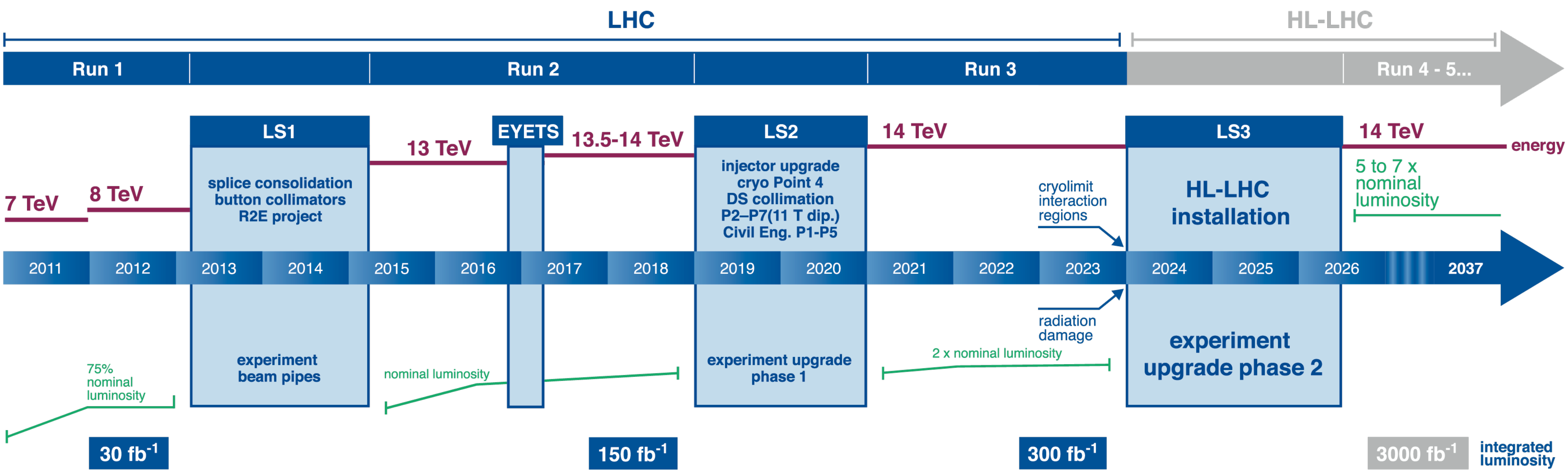
ATLAS **bbγγ**
ATLAS-CONF-2016-004

ATLAS **WWγγ**
ATLAS-CONF-2016-071



High Luminosity LHC

LHC / HL-LHC Plan

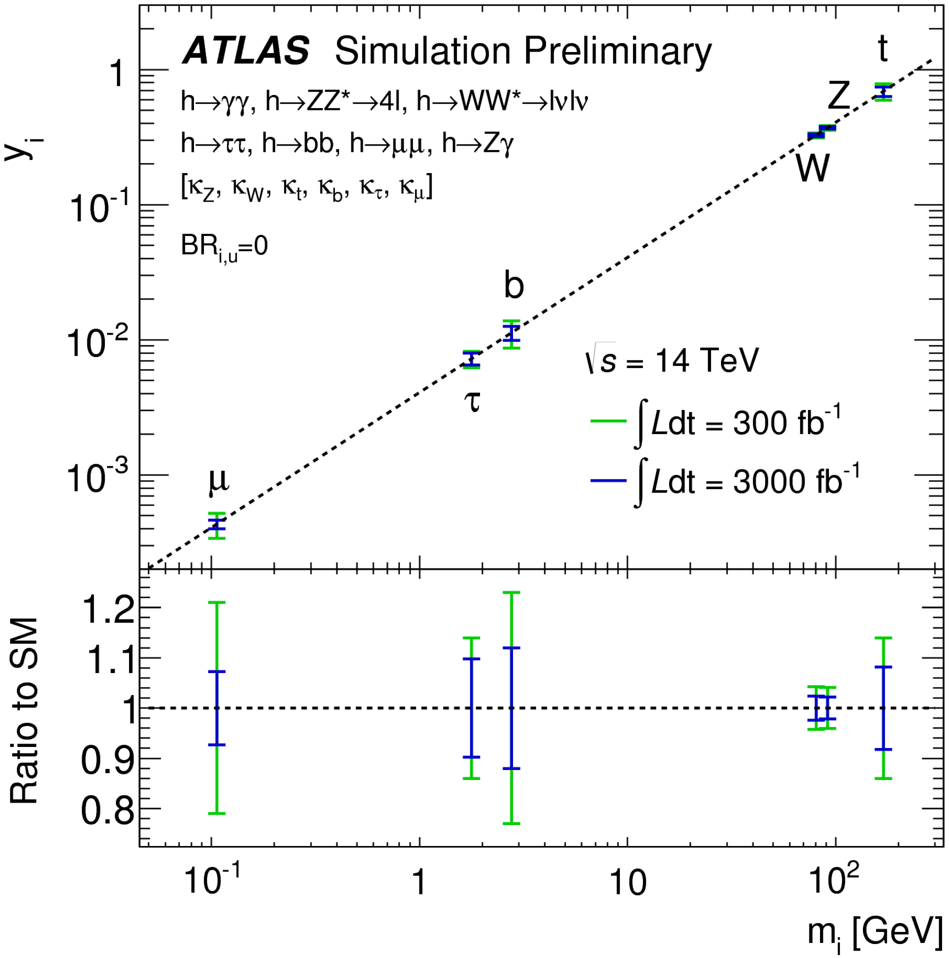


HL-LHC will enable precision measurements of H properties (couplings, self-couplings,…) and to probe the existence of very rare new physics processes.

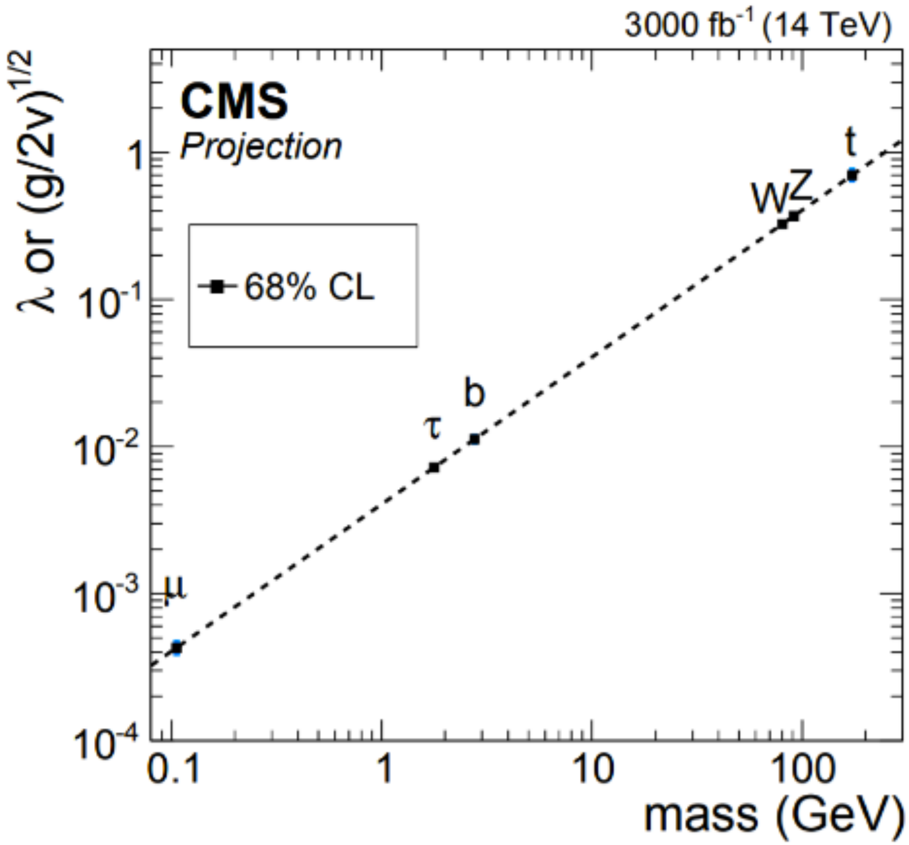
Major detector upgrades foreseen to maximise the physics outcome from high integrated luminosity and limit the degradation from radiation and high pileup rate.

top Yukawa projections

ATL-PHYS-PUB-2014-016



CMS Phase-2 TDR

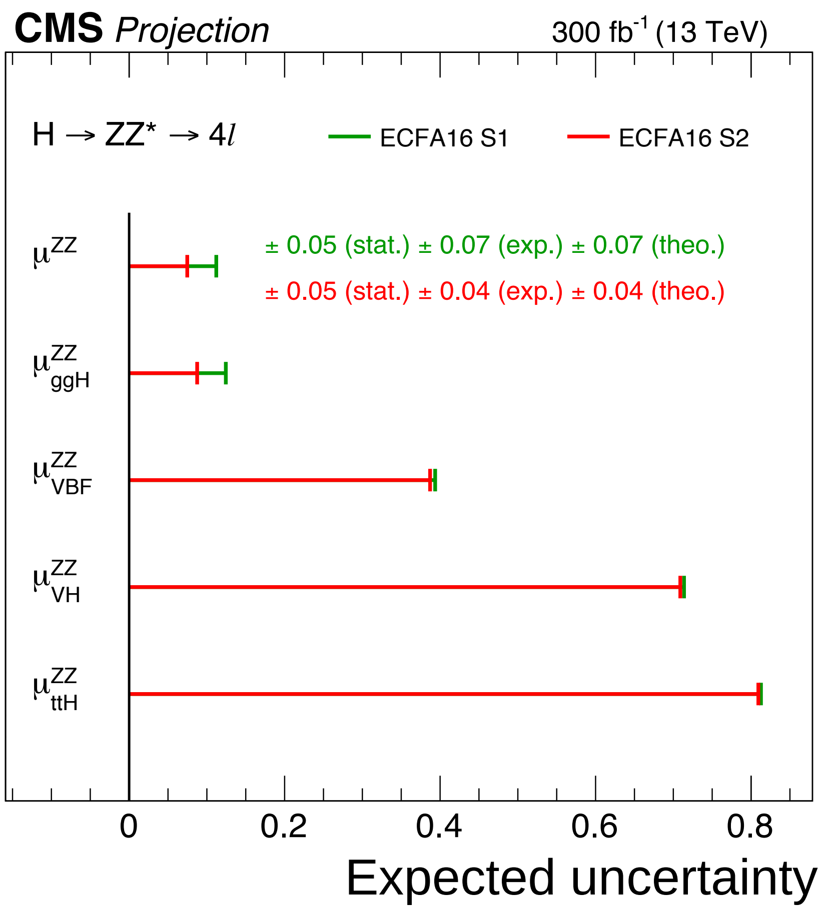


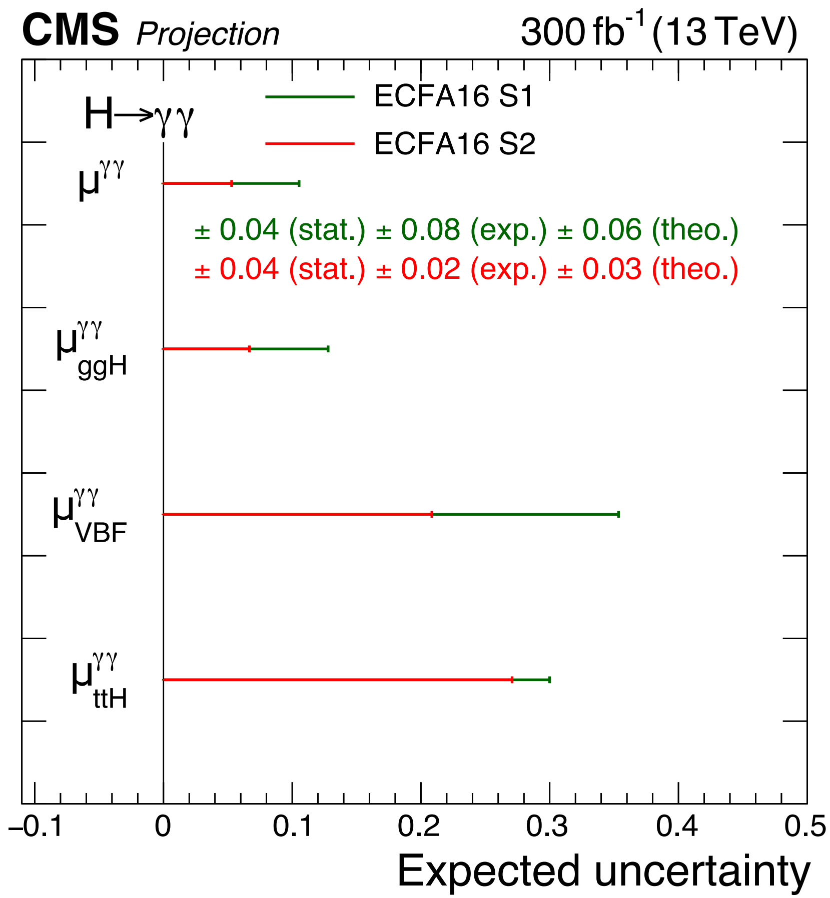
A ~sqrt(10) improvement due to statistics is mitigated by systematics.

k_t accuracy 95% CL estimate:
Scenario1: 10% (systematics unchanged)
Scenario2: 7% (1/2 theory)

HL-LHC projections ttH : 300 fb^{-1}

CMS-PAS-FTR-16-002



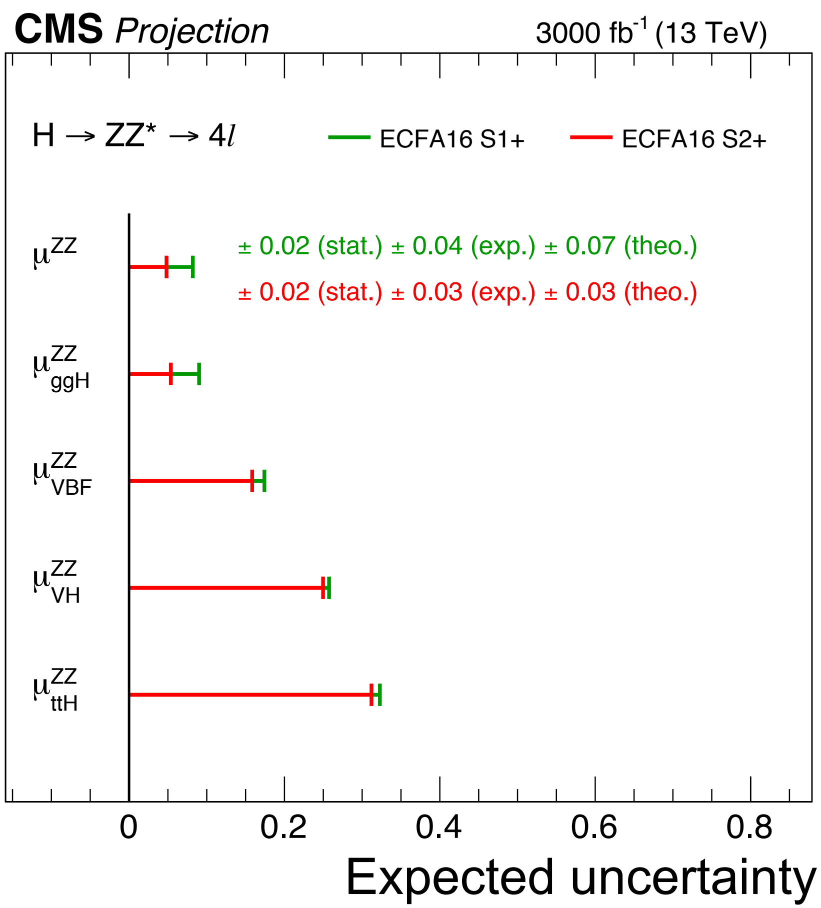


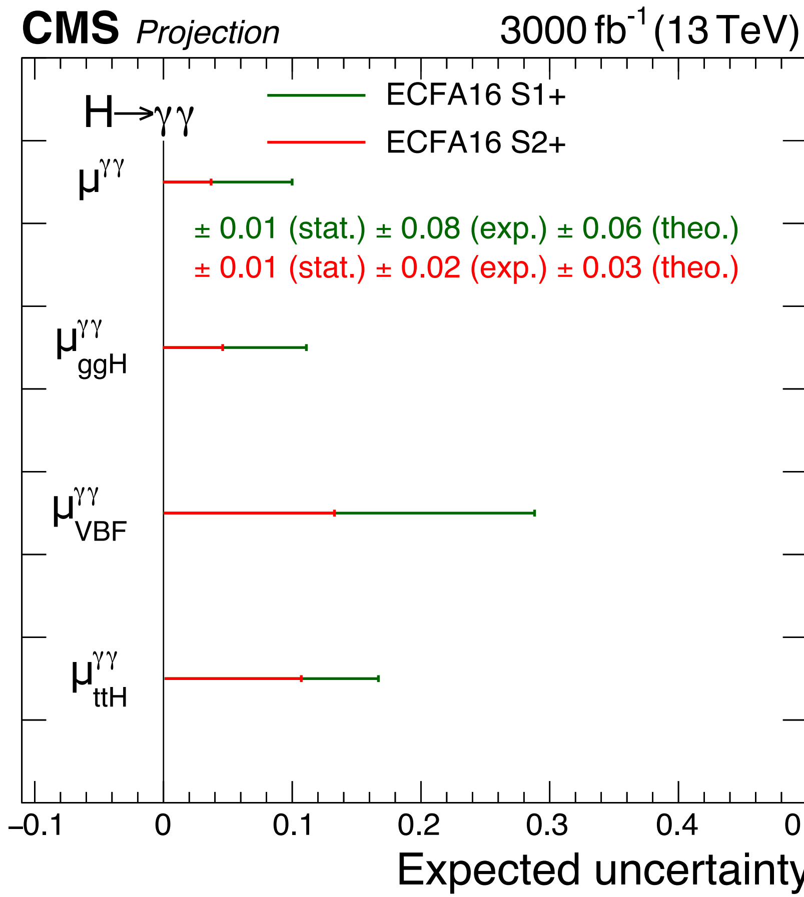
S1+: systematics uncertainties kept constant with presence of high pile-up and detector improvements

S2+: Theory scaled by 1/2, exp. syst. scaled down by sqrt(L) until they reach a lower limit based on estimates of the achievable accuracy with the upgraded detector. Higher pileup conditions on future performance of CMS are taken into account.

HL-LHC projections ttH : 3000 fb^{-1}

CMS-PAS-FTR-16-002



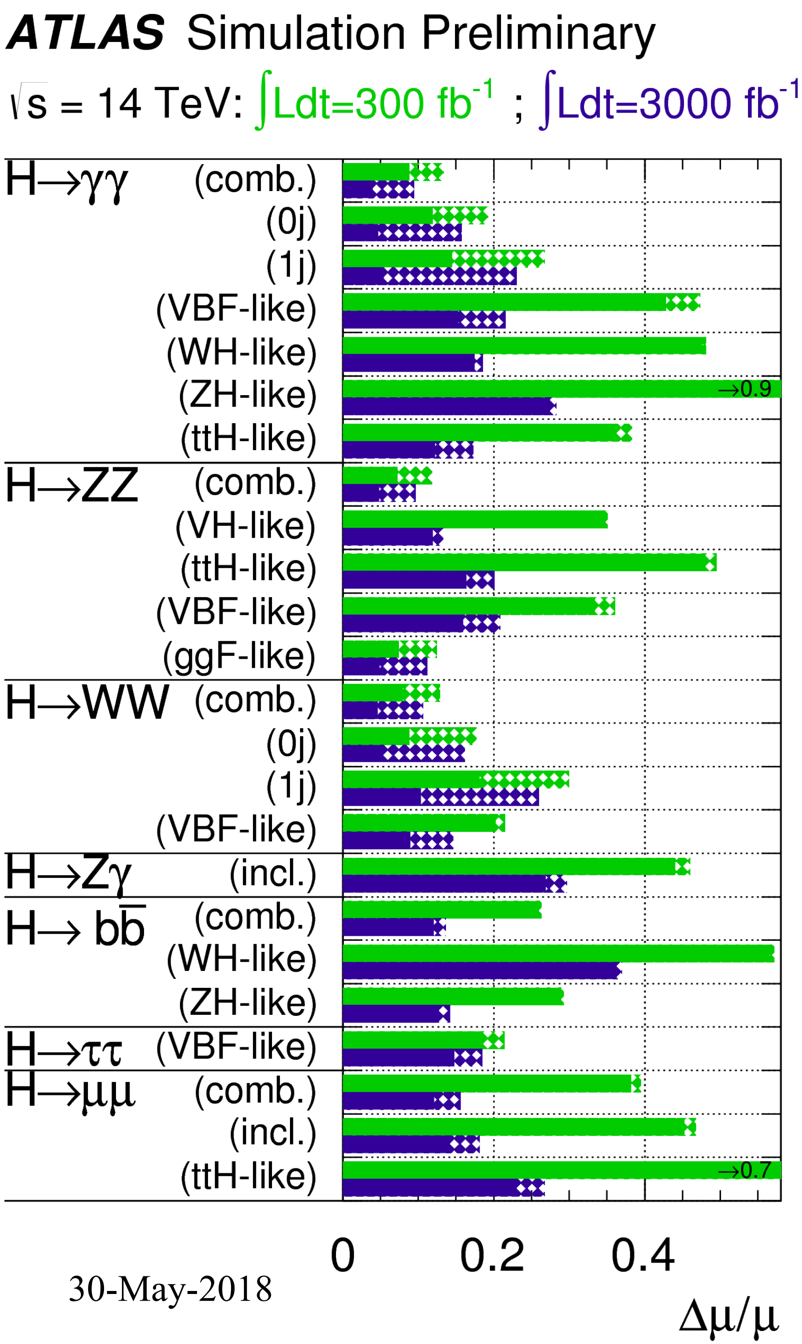


S1+: systematics uncertainties kept constant with presence of high pile-up and detector improvements

S2+: Theory scaled by 1/2, exp. syst. scaled down by sqrt(L) until they reach a lower limit based on estimates of the achievable accuracy with the upgraded detector. Higher pileup conditions on future performance of CMS are taken into account.

ATLAS ttH projections: 300/3000 fb^{-1}

ATL-PHYS-PUB-2014-016



3000 fb^{-1}:
$\Delta\mu_{tth}/\mu_{tth} \sim 10\%$

Comparison with published ATLAS Run2 results (already similar precision):

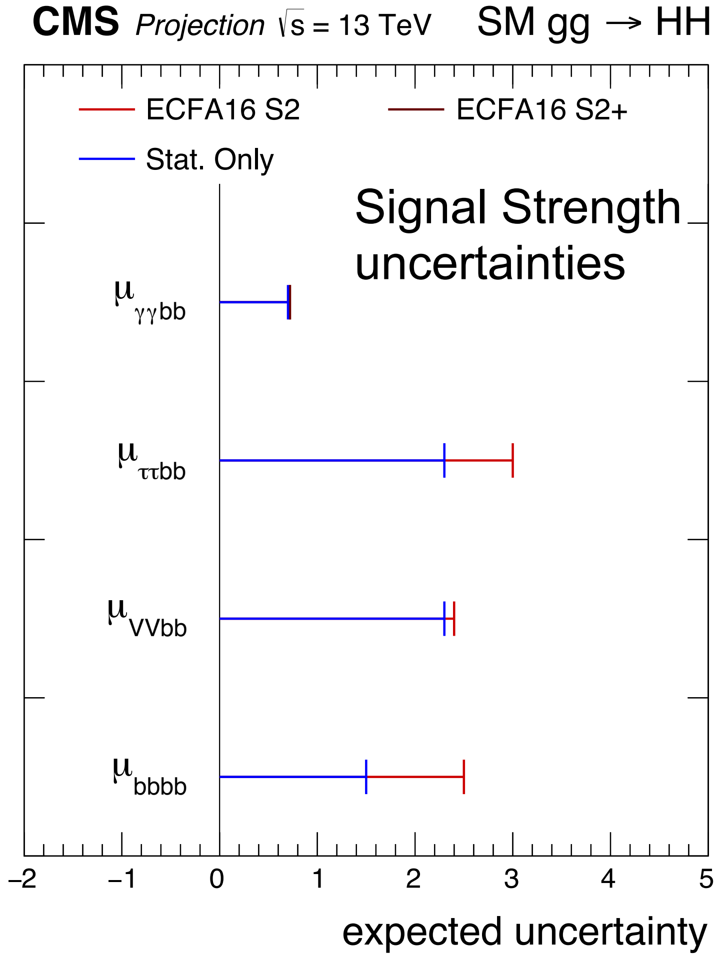
- ttH->VV: 0.4 stat error with 36 fb^{-1} to be compared to ttH->ZZ stat error of ~0.5 with 300 fb^{-1}
- ttH->γγ: 0.6 stat error with 36 fb^{-1} to be compared to ttH->γγ stat error of 0.35 with 300 fb^{-1}

HH projections 3000 fb^{-1}

HL-LHC/HE-LHC Workshop (Apr/2018): towards a Yellow Report in 2018

Channel	Significance (ATLAS)
$bb\gamma\gamma$	1.5σ $0.2<\lambda_{hhh}/\lambda_{SM}<6.9$ (95%CL)
$bb\tau\tau$	0.6σ $-4.0<\lambda_{hhh}/\lambda_{SM}<12$ (95%CL)
bbbb	$-4.1<\lambda_{hhh}/\lambda_{SM}<8.7$ (ggF, 95%CL) (0.35σ for ttHH, HH→4b)

CMS-FTR-16-002



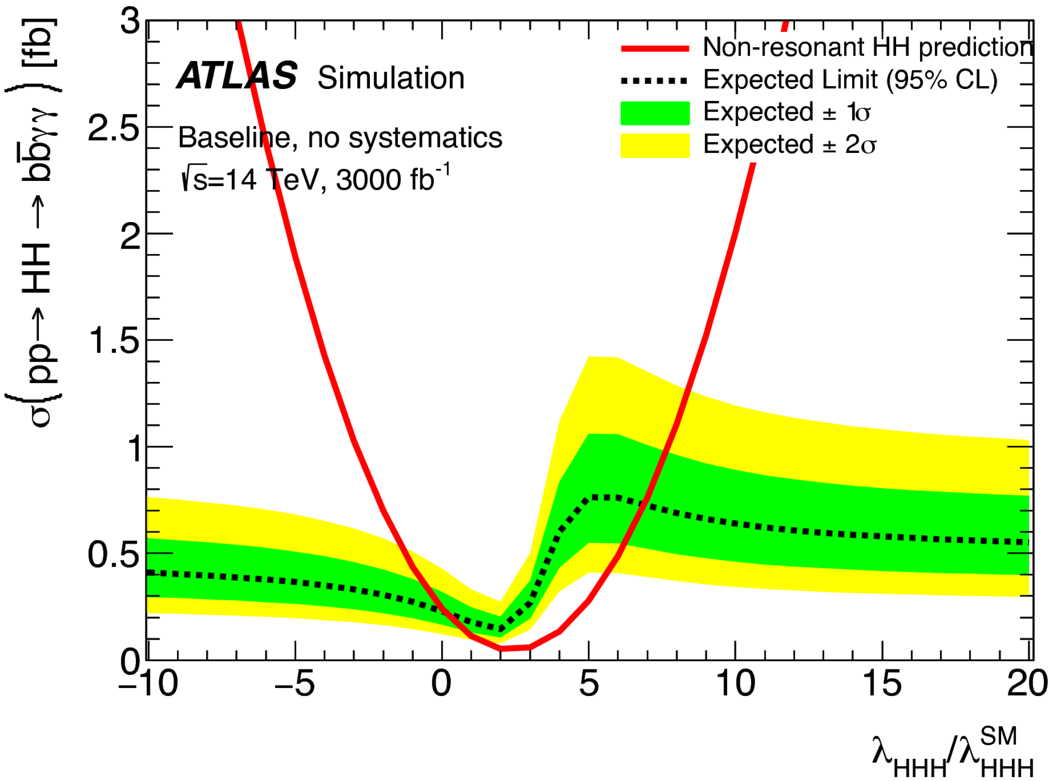
Extrapolation from Run II to HL-LHC (3000 fb^{-1}) based on 2015 data, about 2.3-2.7 fb^{-1}

Scenarios:

- No systematics
- S2 reduced theory uncertainties, reduced systematics
- S2+ including future detector performance

HH→bbγγ λ_{hhh} projection

ATLAS Pixel TDR, ITK-2018-001 April 2018



$$0.2 < \frac{\lambda_{hhh}}{\lambda_{hhh}^{SM}} < 6.9 \quad \text{at } 95\% \text{ CL}$$

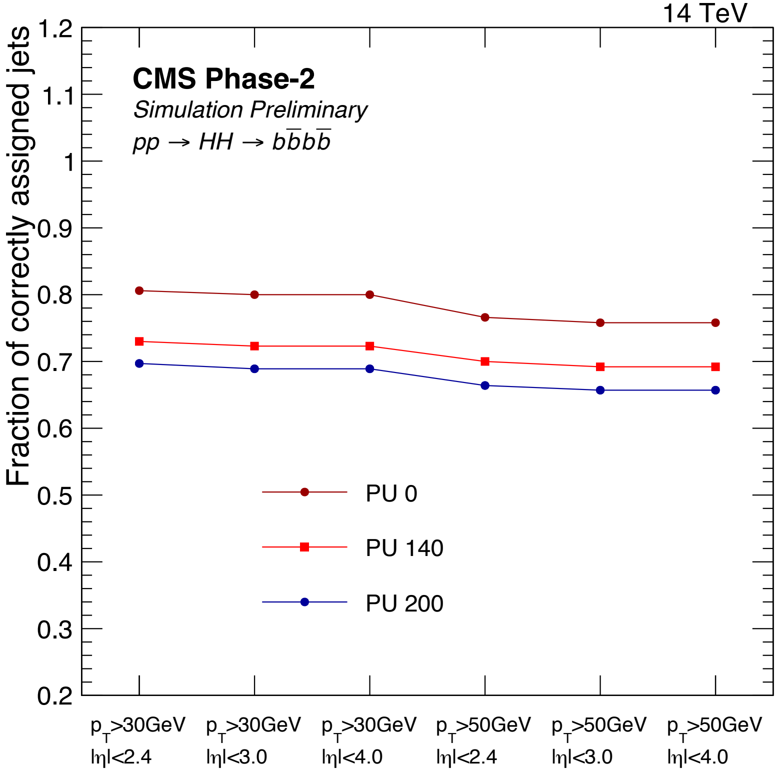
Without systematics

Expected 95% CL upper limit on σ(HH→ bbγγ) with 3000 fb^{-1} and neglecting systematic uncertainties, as a function of the Higgs self-coupling constant λ in units of λ_{SM}.

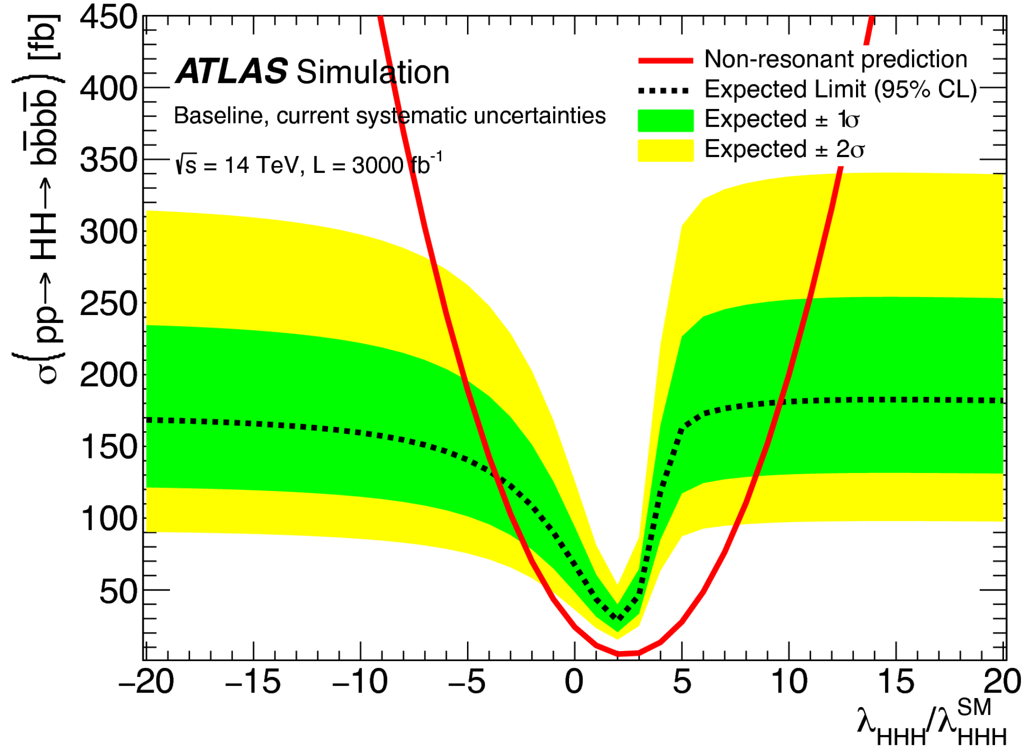
The result is obtained from smeared truth particle simulation.

HH→bbbb λ_{hhh} projections

CMS-TDR-17-001



ATL-ITK-2018-001 April 2018



Systematics dominated by the uncertainty from QCD multijet modeling extrapolated from the Control Region.

$$-4.1 < \frac{\lambda_{hhh}}{\lambda_{hhh}^{SM}} < 8.7 \quad \text{with systematics}$$

A challenge (also for CMS) is the 4-jet trigger threshold.

Result obtained from extrapolation from Run 2.

HH→bbγγ, bbττ projections (new)

CMS-TDR-17-015 (ECAL Barrel TDR)

Table 9.5: Projection of the sensitivity to the SM HH $\rightarrow \gamma\gamma bb$ production at 3000 fb^{-1}. The projections are based on a 13 TeV analysis performed with data collected in 2015. The median expected limit, expected significance, and uncertainty in the signal modifier, $\mu_r = \sigma_{HH}/\sigma_{SMHH}$, are provided with and without systematic uncertainties.

	Median expected limits in μ_r		Significance		Uncertainty as fraction of $\mu_r = 1$	
Process	Stat. + Sys.	Stat. Only	Stat. + Sys.	Stat. Only	Stat. + Sys.	Stat. Only
HH $\rightarrow \gamma\gamma bb$	1.1	1.00	1.9	2.0	0.55	0.52

CMS-TDR-17-019 (EndCap TDR)

Table 11.6: Final expected limit, presented as ratio over the SM double Higgs production.

Category	95%CL on σ_{HH}/σ_{SM}	95%CL on $\sigma_{ggHH}/\sigma_{SM}$	95%CL on σ_{VBF}/σ_{SM}
2b0j	1.8	1.9	71.7
VBF	3.9	4.2	85.5
Combined	1.6	1.7	51.1

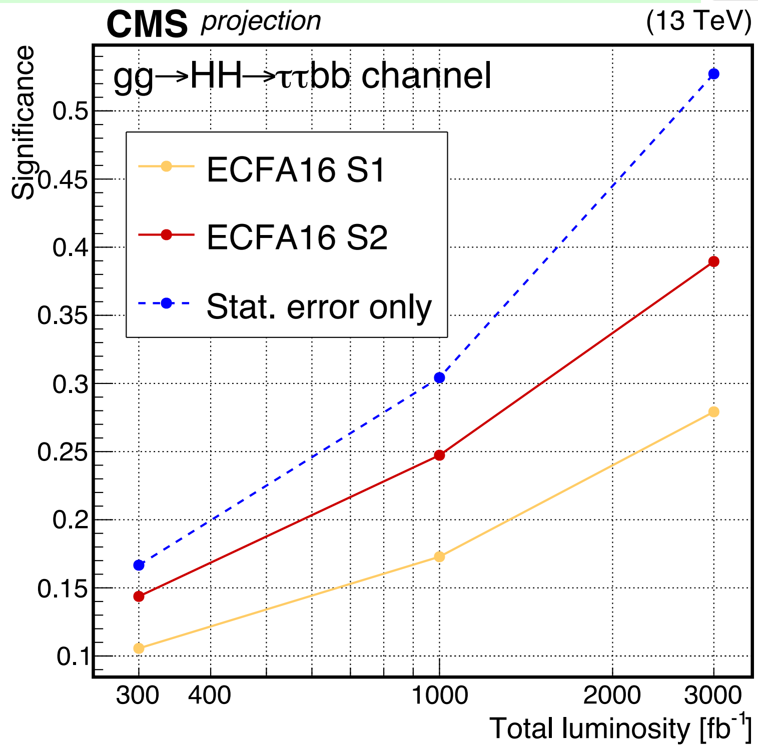
Dedicated VBF HH category

HH projections

Dedicated analysis for Phase II shows that SM HH production can be measured by CMS with about 50% precision using 3000 fb^{-1}

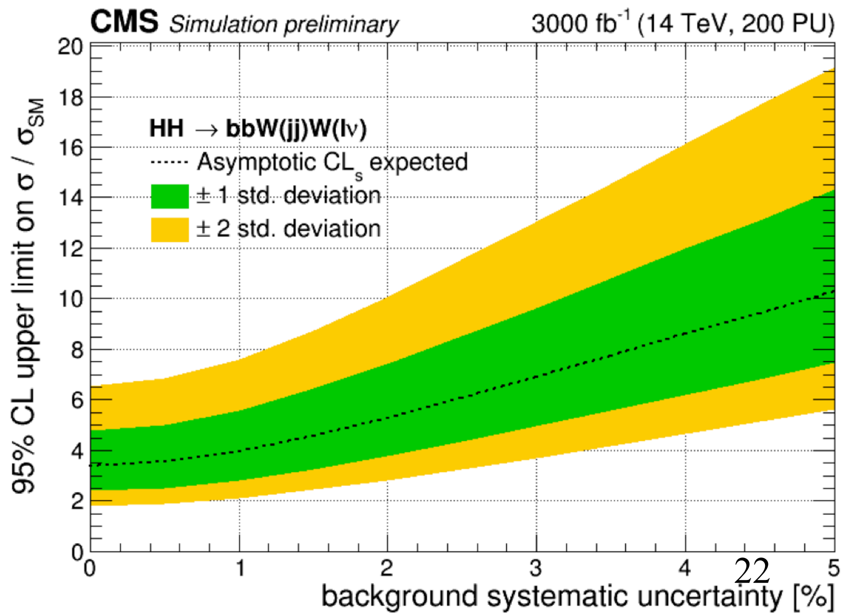
Older studies also show that for 3000 fb^{-1} the Higgs self-coupling can be measured to about 50% (arXiv:1310.8361).

H(bb)H(bb) not included but a promising channel



The increased acceptance of the tracker above $|\eta| > 2.4$ provides an improvement of about 10% in signal acceptance for H(bb)H(bb).

- b-tagging performance will benefit from a more granular detector
- Better background discrimination from selection optimization



Summary

- ttH production mode was measured by ATLAS & CMS:

$$\mu_{\mathrm{ttH}} = 1.2^{+0.3}_{-0.3} \text{ (ATLAS)} \qquad \mu_{\mathrm{ttH}} = 1.26^{+0.31}_{-0.26} \text{ (CMS)}$$

- Top Yukawa k_t was measured (ggH, $H\gamma\gamma$ loops) at 13TeV.

- HH searches in a number of final states were performed.
  - Best present limits between 10-20×SM
  - For some key channels (bbbb, $bb\gamma\gamma$), analyses with the full dataset are in the pipeline.

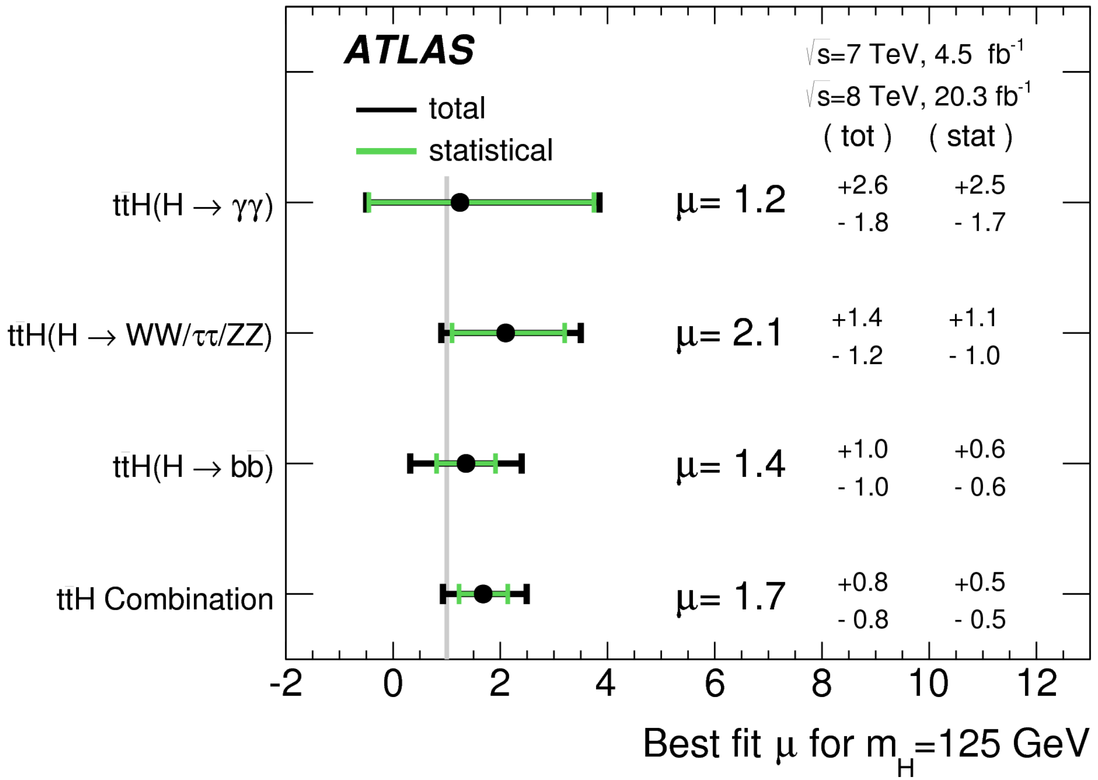
- At 3000/fb[1]
  - ttH mode can be measured with a ~10% precision.
  - A number of HH and λ_{hhh} projections presented.

- **An update of expected HL-LHC extrapolation results will be documented in CERN Yellow report by the end of 2018.**

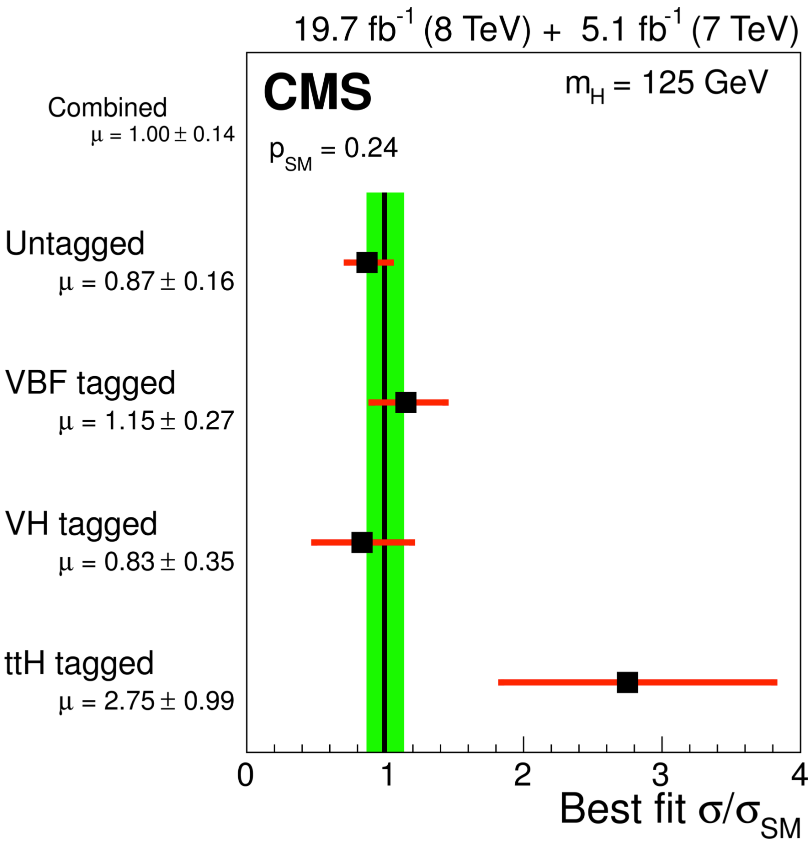
Extra Slides

ttH mode: 7-8 TeV

JHEP 05 (2016) 160

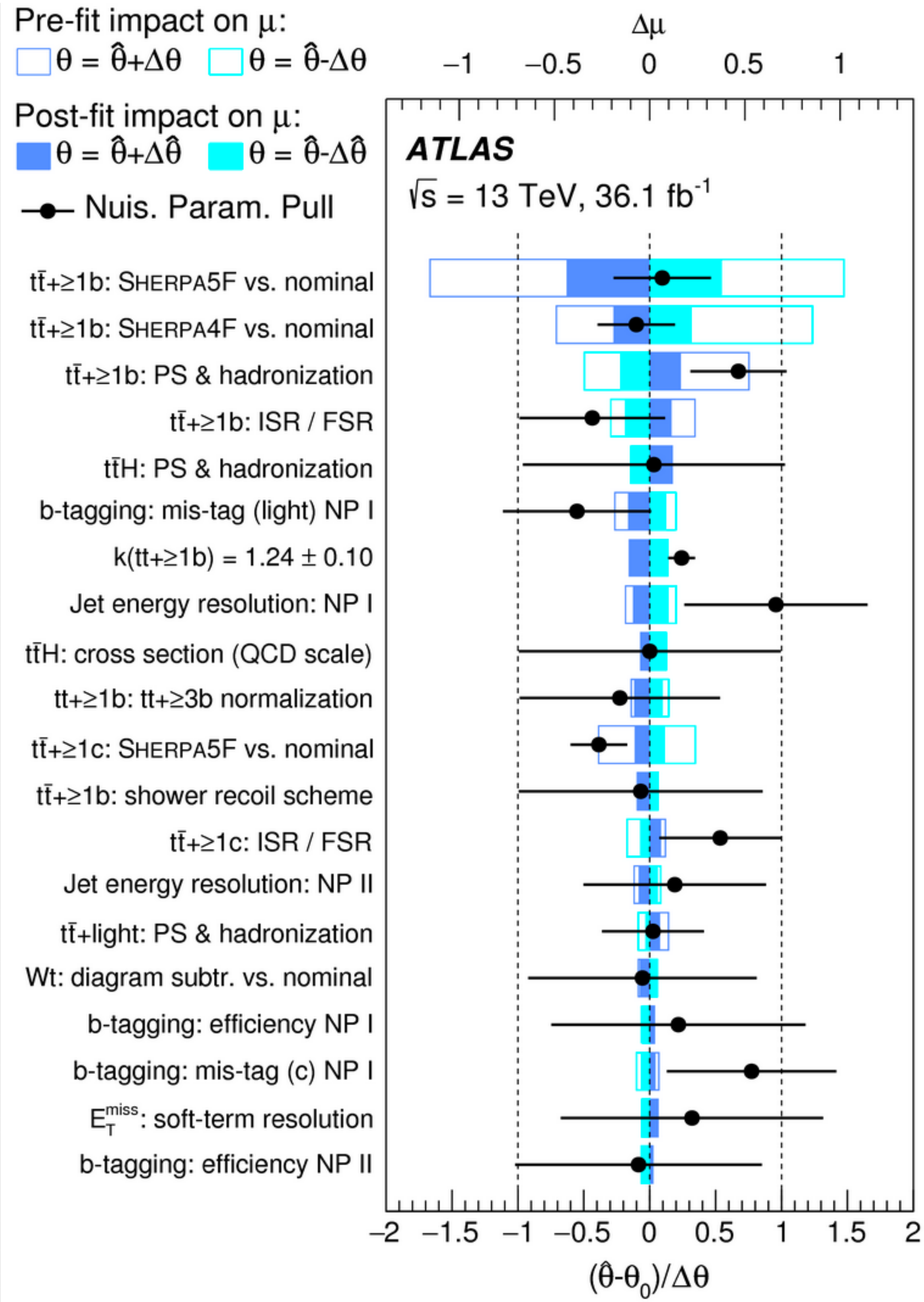


Eur. Phys. J. C 75 (2015) 212

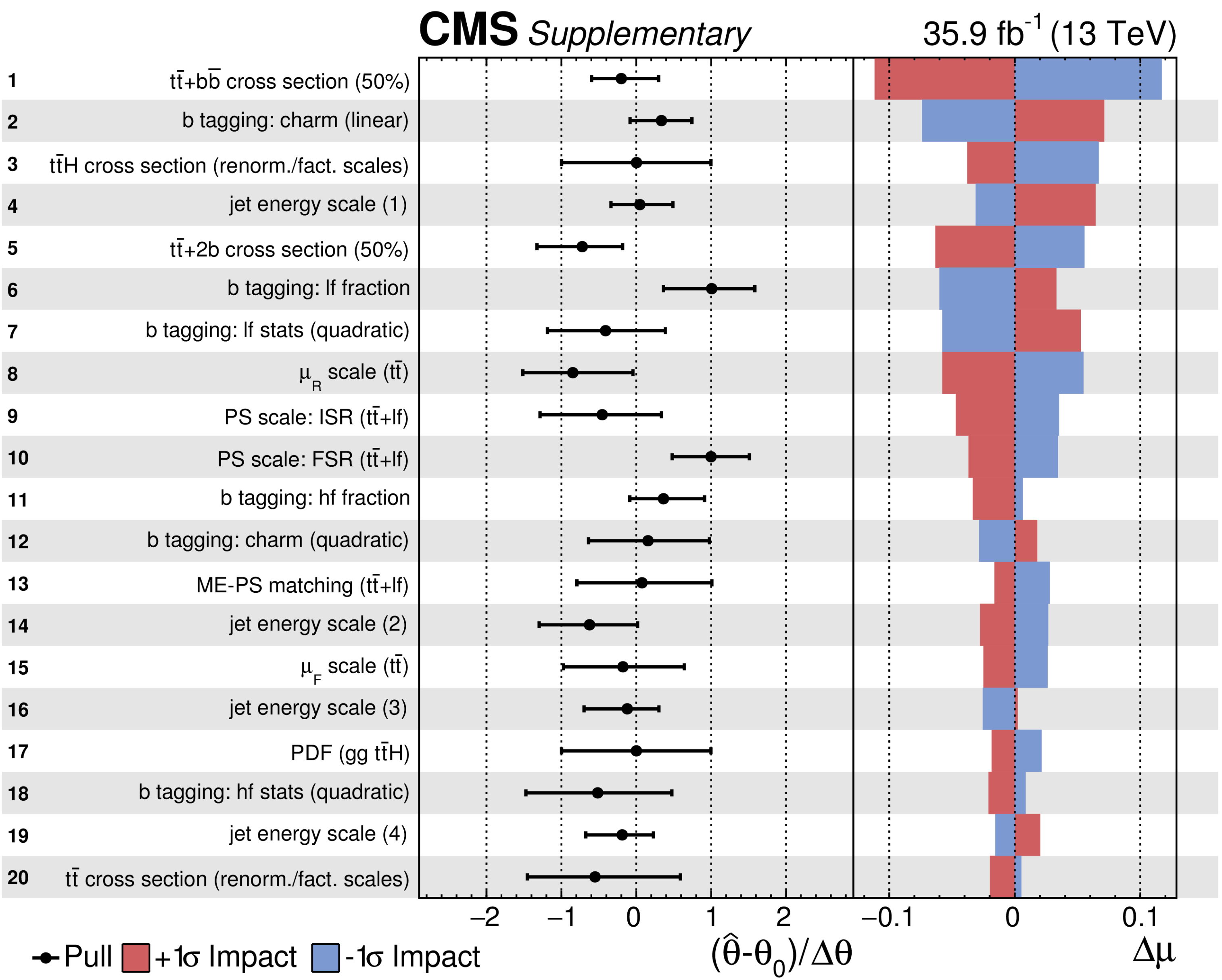


HL-LHC projections ttH : 3000fb^{-1}

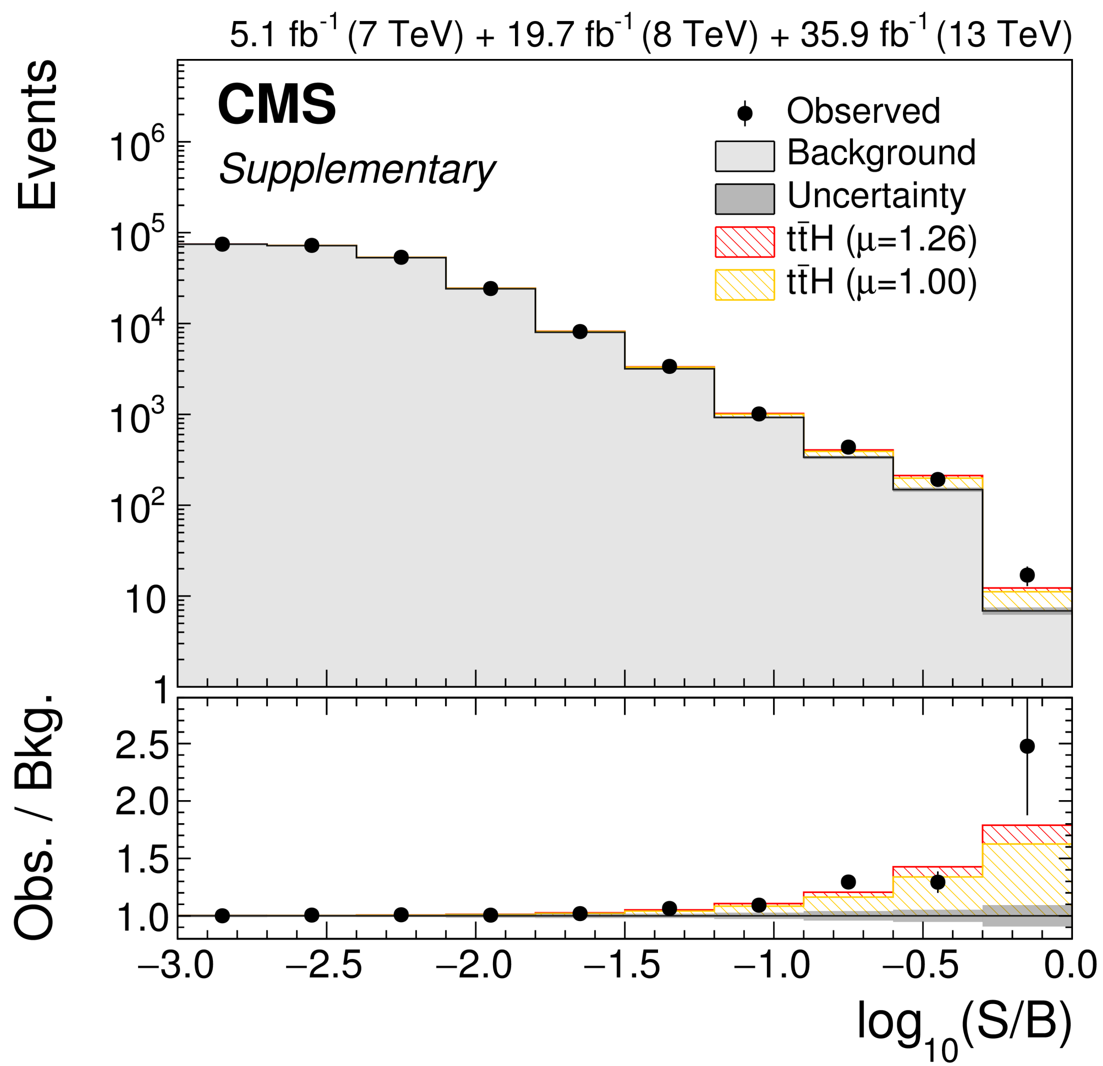
- ATLAS and CMS are working on Run 2 extrapolation for HL-LHC (3000 fb-1 @ 14 TeV)
  - current analysis is limited by very large tt+HF (mostly tt+≥1b) modeling systematic
  - two-point systematics → comparison of various MC predictions with different matrix element and PS (PowhegPythia vs Sherpa 4-flavour and 5-flavour)
  - large constraint of nuisance parameters for extrapolation at 3000 fb^{-1}→we need a recipe
- Plan to define conservative and optimistic scenarios to carry out extrapolation
  - keep same systematics as Run 2 (already available)
  - reduce theory and/or modeling systematics
  - results on impact on Asimov signal strength will be split in uncertainty components



HL-LHC projections ttH : 3000fb^{-1}



ttH production mode observation



Distribution of all events as a function of $\log_{10}$(S/B), evaluated for each bin in the combined analysis. The yields are determined using the values of the nuisance parameters after the fit to data.

Loops

Production	Loops	Interference	Effective scaling factor	Resolved scaling factor
$\sigma(\mathrm{ggH})$	✓	b − t	κ_g^2	$1.04 \cdot \kappa_t^2 + 0.002 \cdot \kappa_b^2 - 0.038 \cdot \kappa_t \kappa_b$
$\sigma(\mathrm{VBF})$	–	–		$0.73 \cdot \kappa_W^2 + 0.27 \cdot \kappa_Z^2$
$\sigma(\mathrm{WH})$	–	–		κ_W^2
$\sigma(\mathrm{qq/qg} \to \mathrm{ZH})$	–	–		κ_Z^2
$\sigma(\mathrm{gg} \to \mathrm{ZH})$	✓	Z − t		$2.46 \cdot \kappa_Z^2 + 0.47 \cdot \kappa_t^2 - 1.94 \cdot \kappa_Z \kappa_t$
$\sigma(\mathrm{ttH})$	–	–		κ_t^2
$\sigma(\mathrm{gb} \to \mathrm{WtH})$	–	W − t		$2.91 \cdot \kappa_t^2 + 2.40 \cdot \kappa_W^2 - 4.22 \cdot \kappa_t \kappa_W$
$\sigma(\mathrm{qb} \to \mathrm{tHq})$	–	W − t		$2.63 \cdot \kappa_t^2 + 3.58 \cdot \kappa_W^2 - 5.21 \cdot \kappa_t \kappa_W$
$\sigma(\mathrm{bbH})$	–	–		κ_b^2
Partial decay width				
Γ^{ZZ}	–	–		κ_Z^2
Γ^{WW}	–	–		κ_W^2
$\Gamma^{\gamma\gamma}$	✓	W − t	κ_γ^2	$1.59 \cdot \kappa_W^2 + 0.07 \cdot \kappa_t^2 - 0.67 \cdot \kappa_W \kappa_t$
$\Gamma^{\tau\tau}$	–	–		κ_τ^2
Γ^{bb}	–	–		κ_b^2
$\Gamma^{\mu\mu}$	–	–		κ_μ^2
Total width for $\mathrm{BR_{BSM}} = 0$				
Γ_H	✓	–	κ_H^2	$0.58 \cdot \kappa_b^2 + 0.22 \cdot \kappa_W^2 + 0.08 \cdot \kappa_g^2 +$ $+ 0.06 \cdot \kappa_\tau^2 + 0.026 \cdot \kappa_Z^2 + 0.029 \cdot \kappa_c^2 +$ $+ 0.0023 \cdot \kappa_\gamma^2 + 0.0015 \cdot \kappa_{Z\gamma}^2 +$ $+ 0.00025 \cdot \kappa_s^2 + 0.00022 \cdot \kappa_\mu^2$

ttH production measurements

arXiv:1803.06986

ttH: H→bb with tt→jets

$$\mu_{ttH} = 0.9^{+0.15}_{-0.15}$$

$$\text{Limits: } 3.8(3.1)\times\text{SM}$$