Recent off-shell experimental results

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Run1 experimental off-shell measurements

$$\sigma^{\text{on-shell}}_{gg\to H\to ZZ^*} \sim \frac{g^2_{ggH} g^2_{HZZ}}{m_H \Gamma_H}$$

$$\sigma^{\text{off-shell}}_{gg\to H^*\to ZZ} \sim \frac{g^2_{ggH} g^2_{HZZ}}{(2m_Z)^2}$$

Assuming coupling doesn't run on mass, $\sigma_{\text{off-shell}} / \sigma_{\text{on-shell}} \sim \Gamma_H$

Analyses have been published at Run1 from both ATLAS and CMS

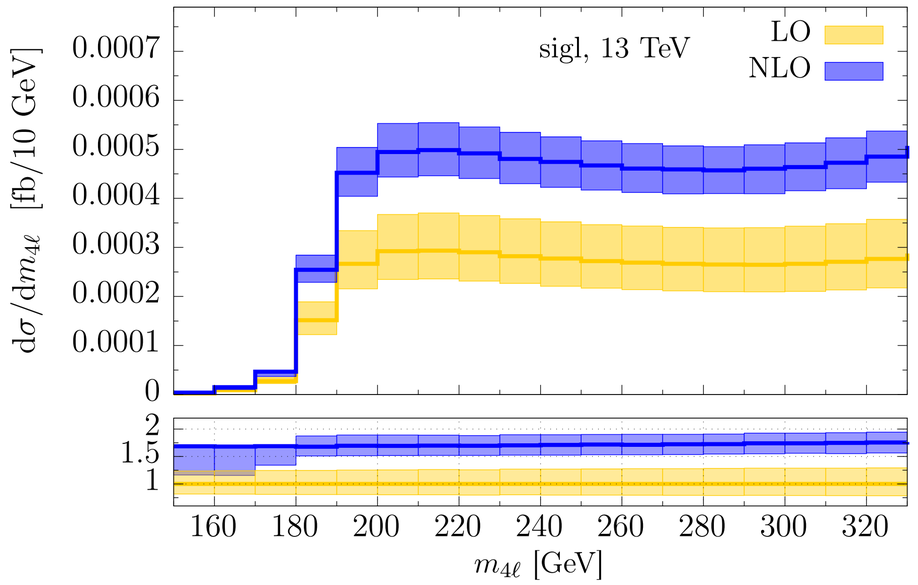
ATLAS: < 22.7 MeV (ZZ+WW)

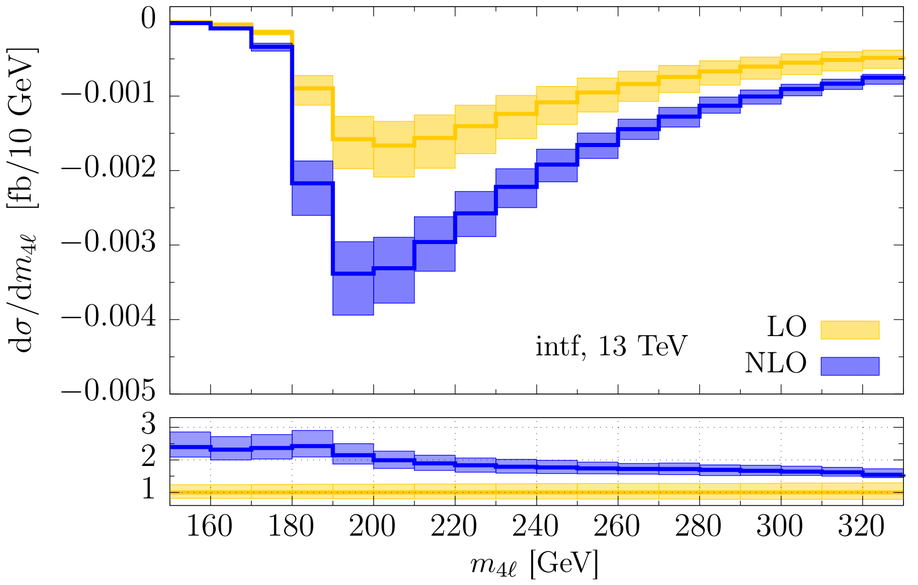
CMS: < 13 MeV (ZZ+WW)

gg→ (H)→ ZZ k-factor

- In Run1, only calculation on S, B are available
- NLO k-factor on S, B , I in paper arXiv:1605.04610
  - mzz < 2*mt: NLO calculation for massless quarks +1/mt expansion for top contribution
  - mzz > 2*mt: massless quarks; assume the identical results between massive and massless
  - agrees at 10% between B,S,I above 200 GeV
- NNLO k-factor for S known, ~1.2 NNLO/NLO
- A dedicated meeting between ATLAS, CMS and theorists were organized on how to treat the K-factors in Feb 2018, indico

arXiv:1605.04610





ATLAS off-shell measurement

- 2016 data (36.1 fb^{-1}) publication on the width measurement
  - 4l + 2l2v final states
- Apply dedicated NLO correction on S, B and I
  - QCD uncertainty (mzz)10-20%
  - < 2mt NLO calculation derived on max jet pT < 150 GeV for 1/mt expansion => uncertainty doubled for max jet pT >150 (8% events)
  - at 2mt threshold, uncertainty increased by 50%, smoothly decreased to nominal uncertainty
- An additional 1.2 to all to cover NNLO/NLO

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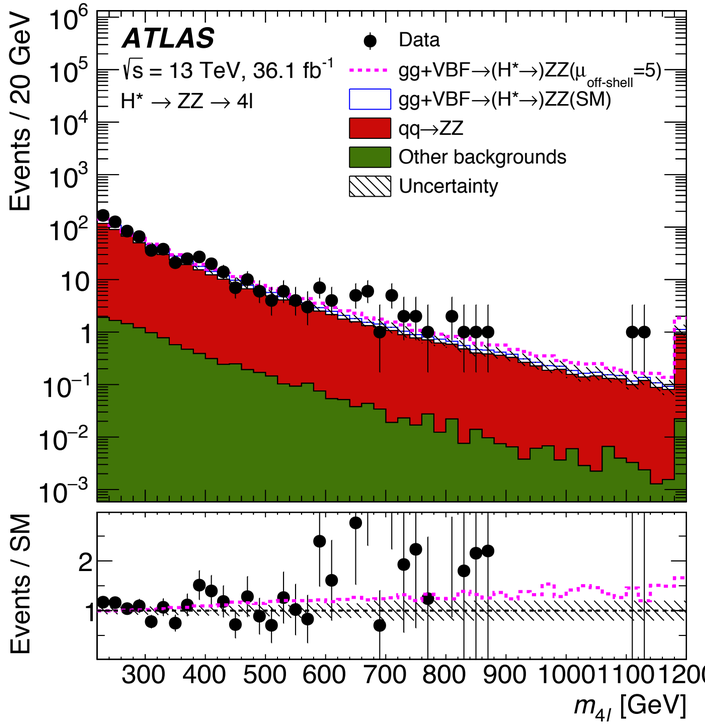

ATLAS off-shell measurement

- measurement of μ off-shell, Γ_H and $\kappa^2_{g,\text{off-shell}}/\kappa^2_{g,\text{on-shell}}$
- Γ_H <14.4 (15.2) MeV at 95% CL

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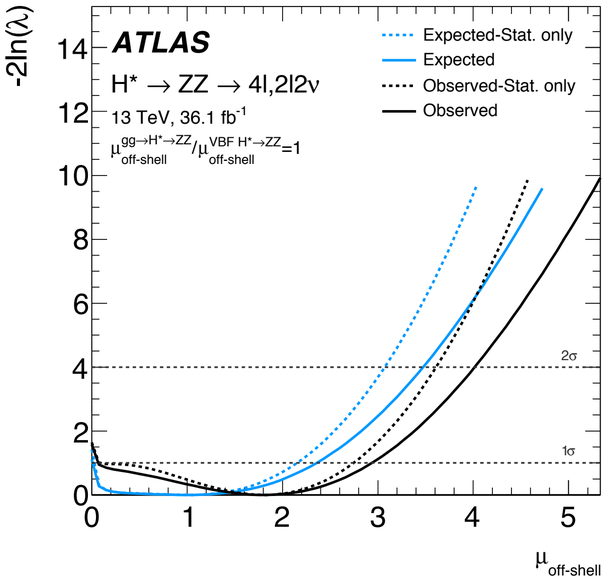
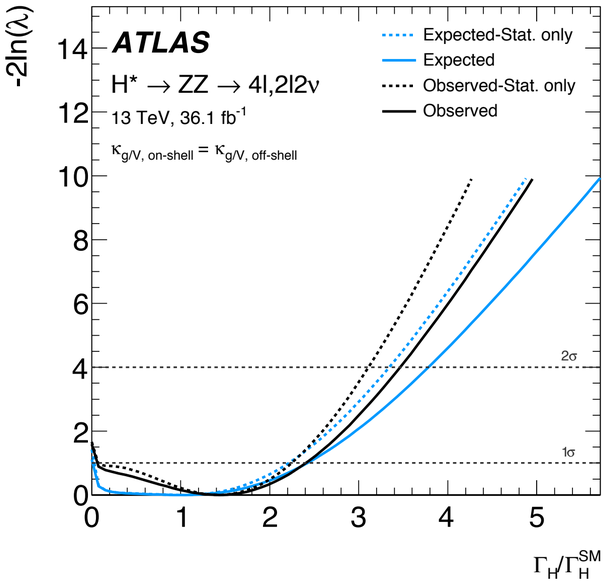
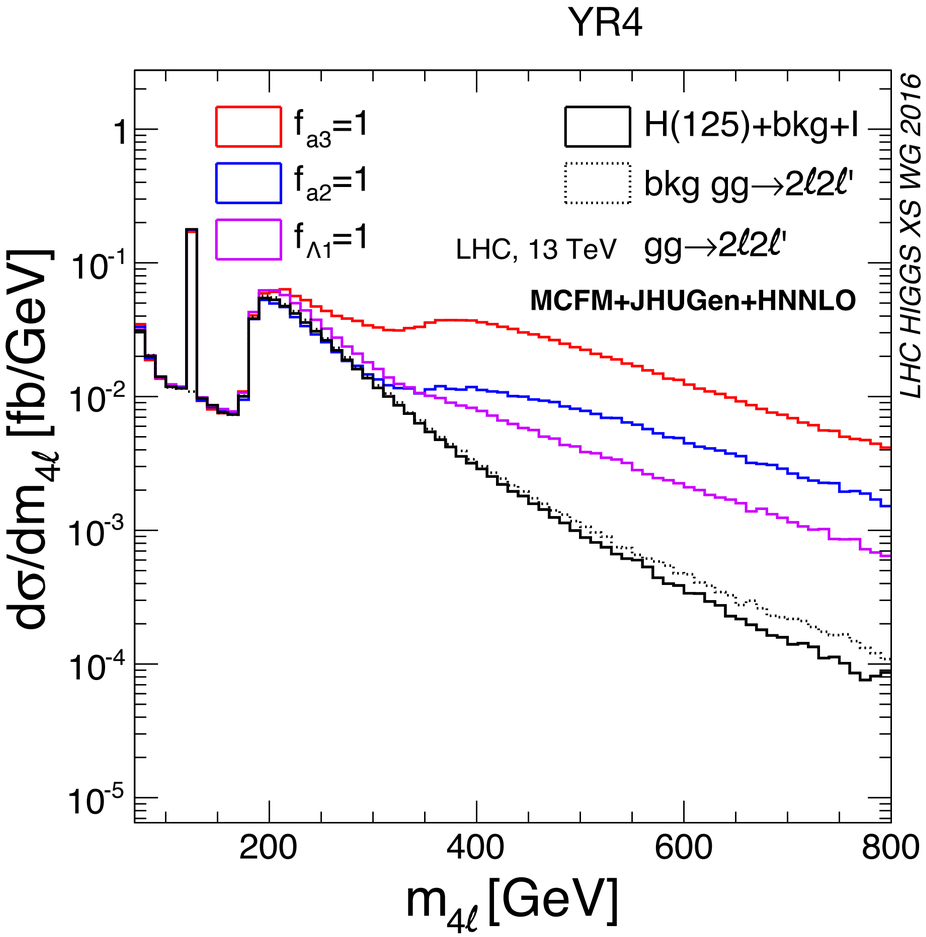
		Observed	Expected		
			Median	$\pm 1\ \sigma$	$\pm 2\ \sigma$
$\mu_{\text{off-shell}}$	$ZZ \to 4\ell$ analysis	4.5	4.3	$[3.3, 5.4]$	$[2.7, 7.1]$
	$ZZ \to 2\ell 2\nu$ analysis	5.3	4.4	$[3.4, 5.5]$	$[2.8, 7.0]$
	Combined	3.8	3.4	$[2.7, 4.2]$	$[2.3, 5.3]$
$\Gamma_H/\Gamma_H^{\text{SM}}$	Combined	3.5	3.7	$[2.9, 4.8]$	$[2.4, 6.5]$
R_{gg}	Combined	4.3	4.1	$[3.3, 5.6]$	$[2.7, 8.2]$





CMS off-shell measurement

- Anomalous coupling could give rise to off-shell enhancement
- Measure Γ_H and anomalous coupling at the same time
- Taking K-factor from NNLO signal, applied to bkg and interference
  - QCD uncertainty (mZZ) 1-10%
  - analysis uses m4l > 220 GeV, additional 10% uncertainty on B and I covering the different k-factors



CMS off-shell measurement

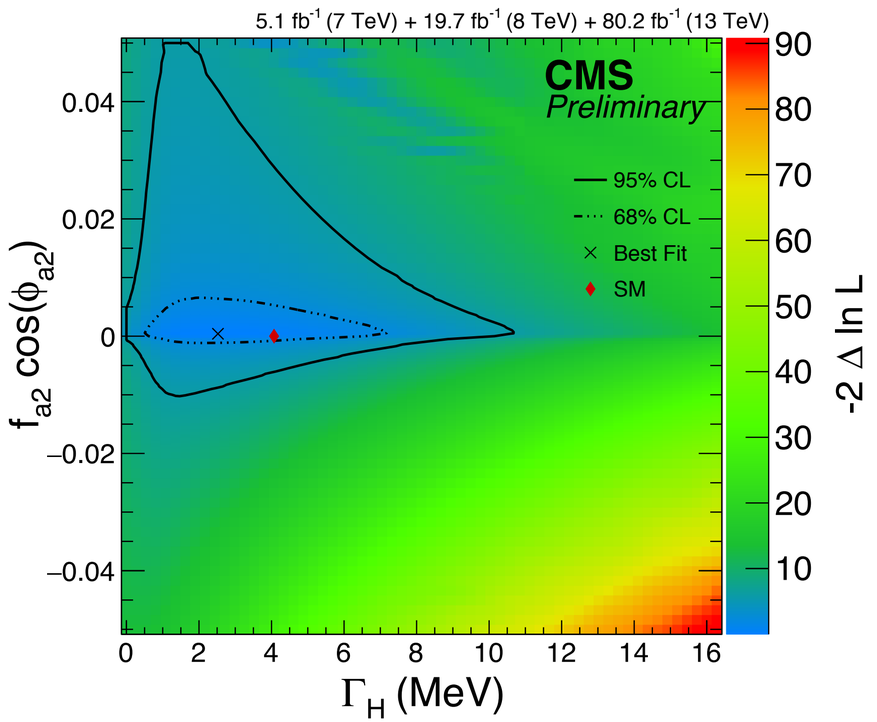
Width vs one anomalous coupling

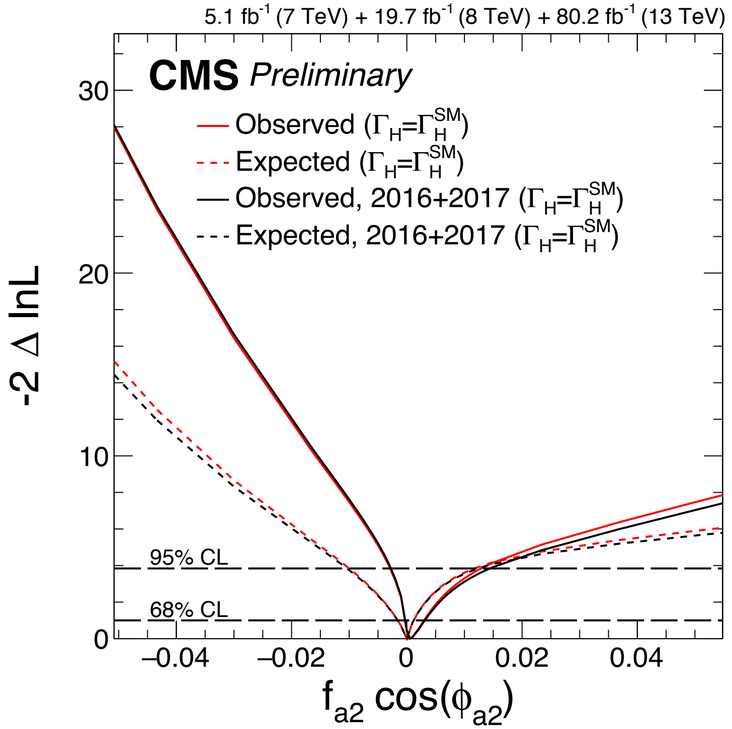
4l, Run1+16+17 (5+19.7+80.2 fb^{-1}) data

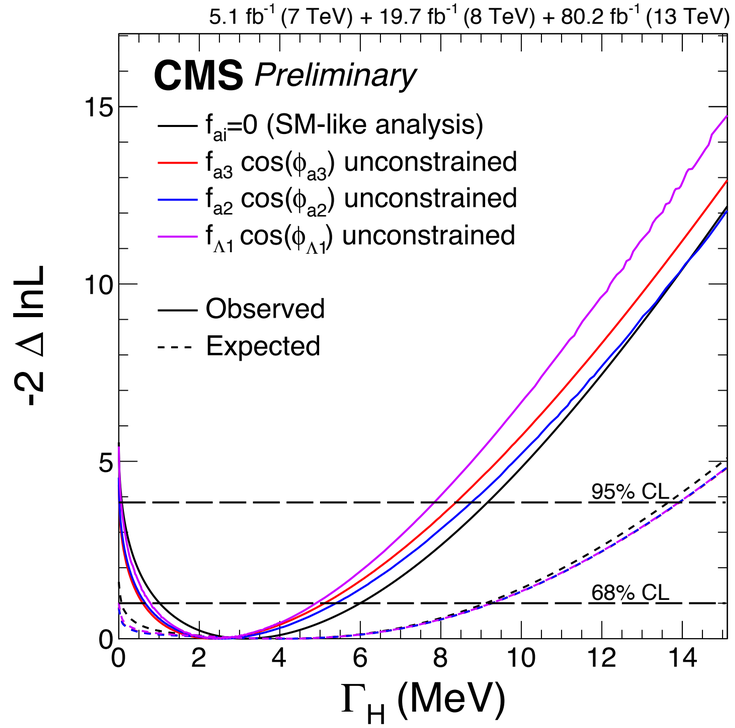
Γ_H < 9.16 (13.7) MeV

CMS-PAS-HIG-18-002

Parameter	Observed	Expected
$f_{a3}\cos(\phi_{a3})$	$-0.0001^{+0.0005}_{-0.0015}$ $[-0.16, 0.09]$	$0.0000^{+0.0019}_{-0.0019}$ $[-0.082, 0.082]$
$f_{a2}\cos(\phi_{a2})$	$0.0004^{+0.0026}_{-0.0007}$ $[-0.006, 0.025]$	$0.0000^{+0.0030}_{-0.0023}$ $[-0.021, 0.035]$
$f_{\Lambda1}\cos(\phi_{\Lambda1})$	$0.0000^{+0.0035}_{-0.0008}$ $[-0.21, 0.09]$	$0.0000^{+0.0012}_{-0.0006}$ $[-0.059, 0.032]$
$f_{\Lambda1}^{Z\gamma}\cos\left(\phi_{\Lambda1}^{Z\gamma}\right)$	$0.000^{+0.355}_{-0.009}$ $[-0.17, 0.61]$	$0.000^{+0.009}_{-0.010}$ $[-0.10, 0.34]$







Γ_H HL projection, CMS

CMS projection, 4l alone, based on the CMS analysis CMS-18-002

-Scenario 2

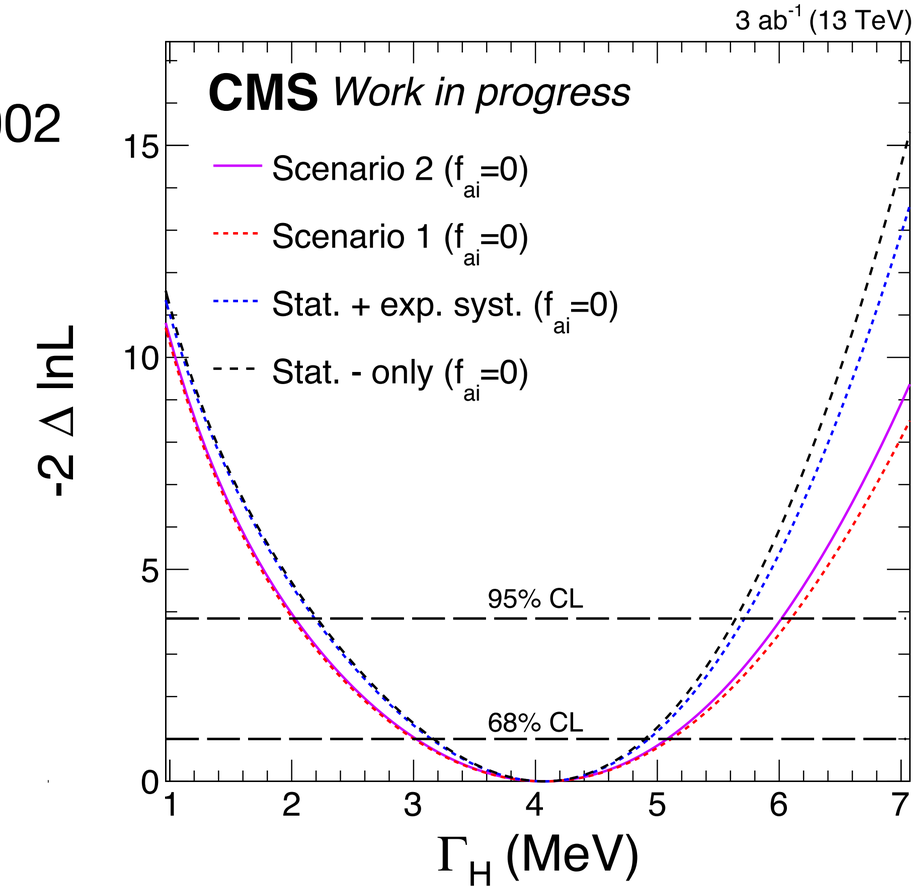
theoretical unc: 1/2 expect ggZZ k-factor

At 3 ab^{-1}

$\Gamma_H = 4.2\ ^{+1.}_{-1.1}$ MeV

$\Gamma_H < 6$ MeV

CMS-FTR-18-011



Summary

- Both ATLAS and CMS have Run2 off-shell measurements out
  - ATLAS : Γ_H <14.4 MeV (2l2v +4l on 2016 data)
  - CMS: Γ_H <9.16 MeV (4l on Run1+2016+2017 data)
    - anomalous couplings were measured at the same time
  - benefit from theorist's recents on higher order corrections
- Projections on HL-LHC was made, $\Gamma_H = 4.2\ ^{+1.}_{-1.1}$ MeV