Offshell studies experimental summary

18th workshop LHC Higgs WG

Dec 1st 2021

Savvas Kyriacou (CMS /JHU) for the Offshell LHC Higgs WG

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Experimental offshell Higgs results and studies

Utilize offshell events to constrain Higgs width – most precise method currently exploited at the LHC

$$\frac{\sigma^{\text{off-shell}}_{vv\to H\to 4\ell}}{\sigma^{\text{on-shell}}_{vv\to H\to 4\ell}} \propto \Gamma_H$$

Measure tensor structure of the Higgs couplings using offshell events

Γ_H^{SM} = 4.1 MeV

ATLAS:

- Offshell **width measurement** (4l +2l2v partial Run2)

CMS:

- **NEW** public offshell **width and AC measurement** (4l partial + **Full 2l2v** Run2)

Γ_H: Offshell (ATLAS)

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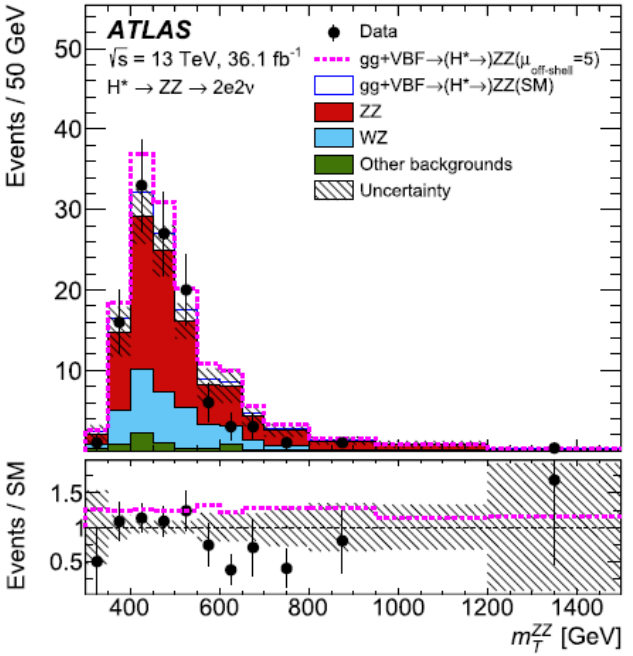
Most recent

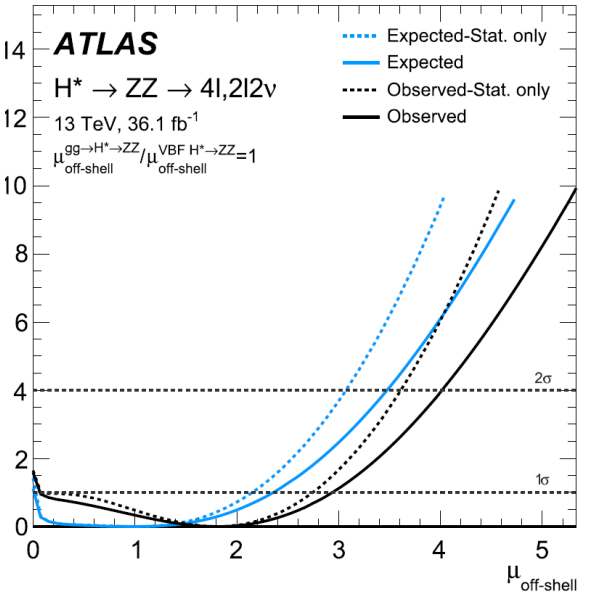
- H→4l + H→2l2ν combination
- 220GeV < m_{4l} < 2 TeV
- Fit: D_{ME} (4l) and M_T^{ZZ} (2l2ν)

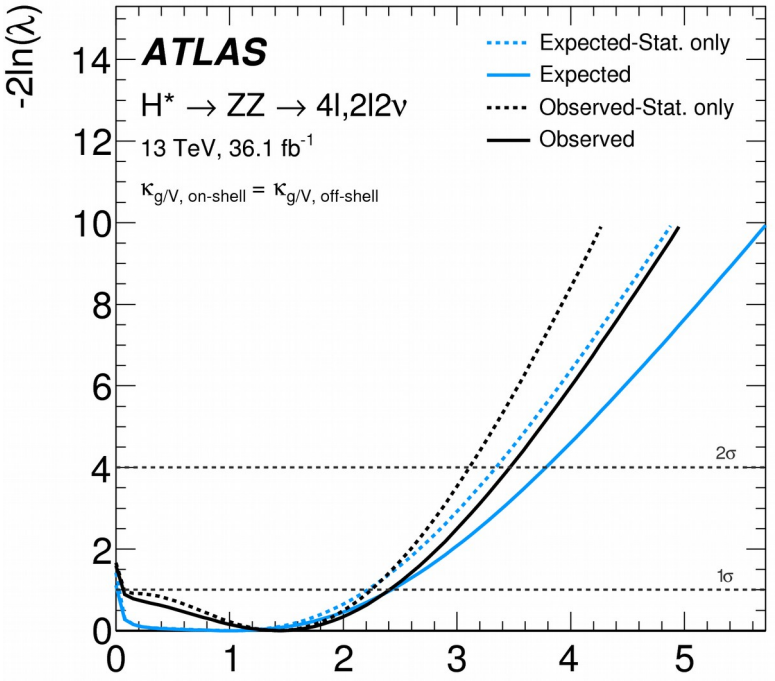
$$D_{\mathrm{ME}} = \log_{10}\left(\frac{P_H}{P_{gg} + c \cdot P_{q\bar{q}}}\right)$$

- '15+'16 data
- Upper bound set

Γ_H < 14.4 MeV





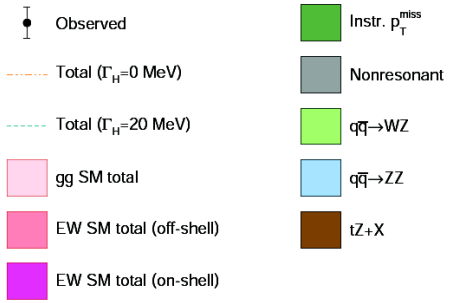


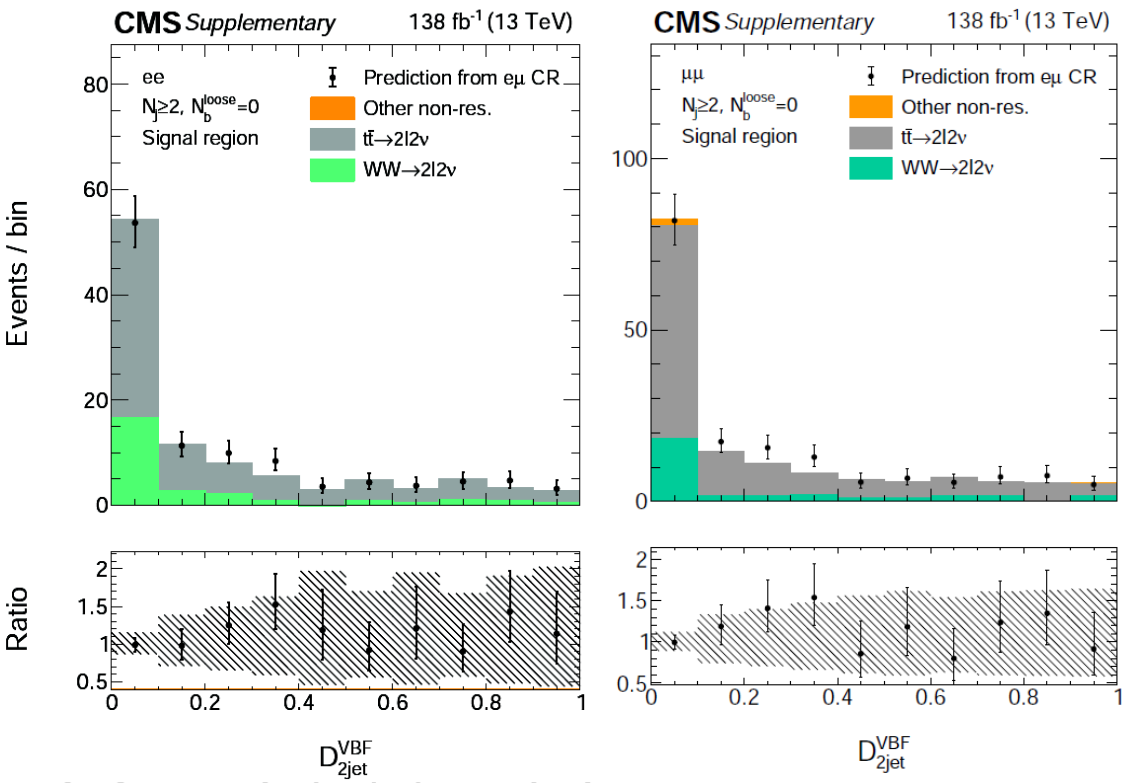
Γ_H: Offshell (CMS)

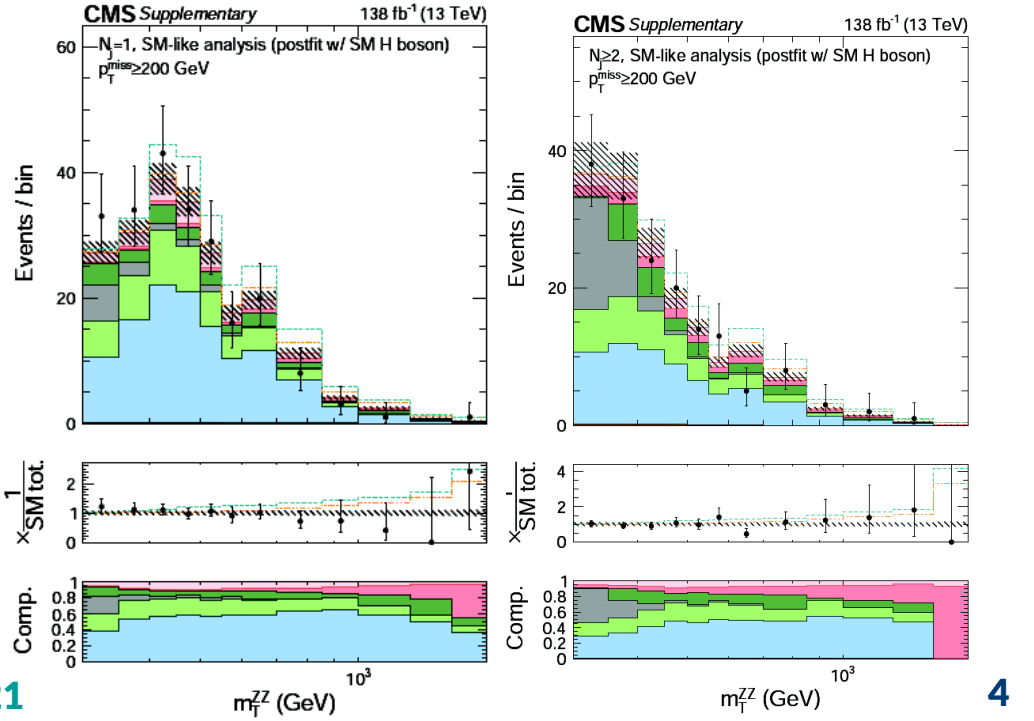
CMS-PAS-HIG-21-013

NEW!!!!

- **Analysis of offshell H→ 2l2ν Full Run2**
- Multiple control regions (CR) for background estimations
  - Reducible Z+jets background estimated from γ+jets CR
  - e/μ CR for WW/tt backgrounds
  - Trilepton CR for qq→ ZZ/WZ
- Other backgrounds estimated from simulation
- Events split in Nj categ. (0J ,1J ,>=2J) + 2e or 2μ







Γ_H: Offshell (CMS) NEW!!!!

$$m_{\mathrm{T}}^{\mathrm{ZZ}\,2} = \left[\sqrt{p_{\mathrm{T}}^{\ell\ell\,2} + m_{\ell\ell}^{\,2}} + \sqrt{p_{\mathrm{T}}^{\mathrm{miss}\,2} + m_{\mathrm{Z}}^{\,2}}\right]^2 - \left|\vec{p}_{\mathrm{T}}^{\,\ell\ell} + \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}\right|^2$$

Fit :

$$m_{\mathrm{T}}^{\mathrm{ZZ}},\ p_{\mathrm{T}}^{\mathrm{miss}},\ \mathcal{D}_{\mathrm{2jet}}^{\mathrm{VBF}} \text{ and } \mathcal{D}_{\mathrm{2jet}}^{\mathrm{VBF},ai}$$

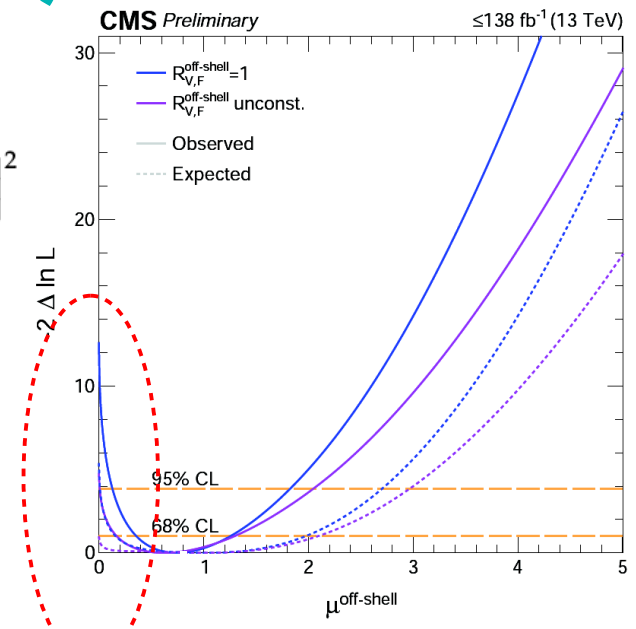
Fit Γ_H , μV , μF offshell
+anomalous couplings

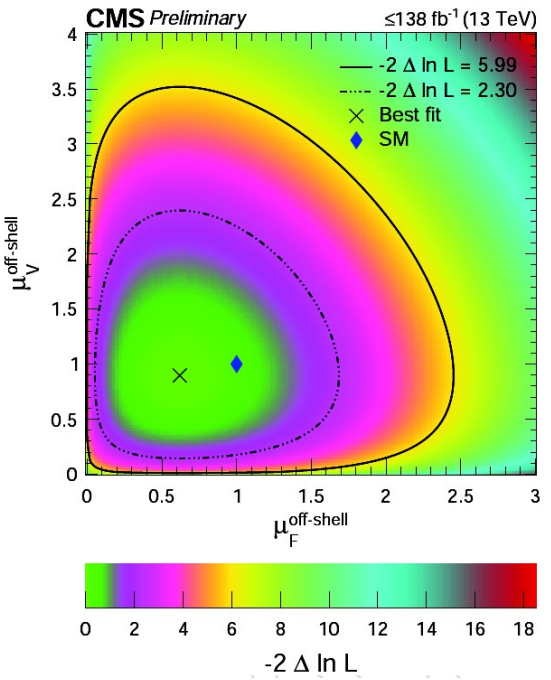
Combination of H→2l2v (offshell Full Run2) + H→4l (onshell Full Run2 + offshell '15-'16-'17)

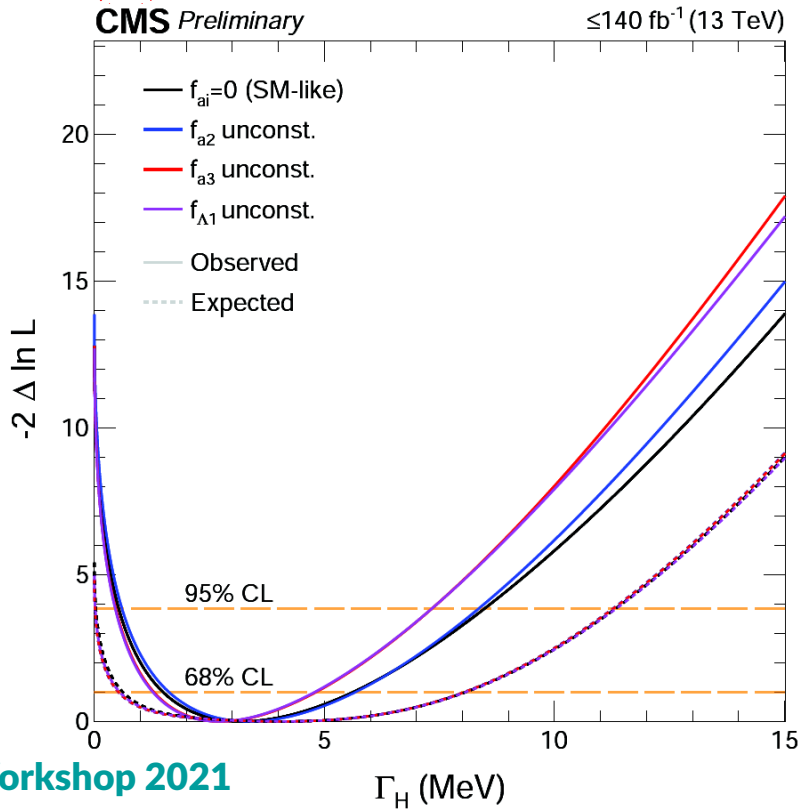
Evidence for offshell production at 3.6σ

Most precise Γ_H measurement to-date

$$\Gamma_H = 3.2^{+2.4}_{-1.7}\ \mathrm{MeV}$$

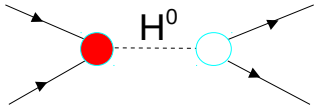






AC: HVV in H→4l + H→2l2v Offshell (CMS)

CMS-PAS-HIG-21-013



NEW!!!!

Full Run2

$\mathcal{D}_{2\text{jet}}^{\text{VBF},ai}$

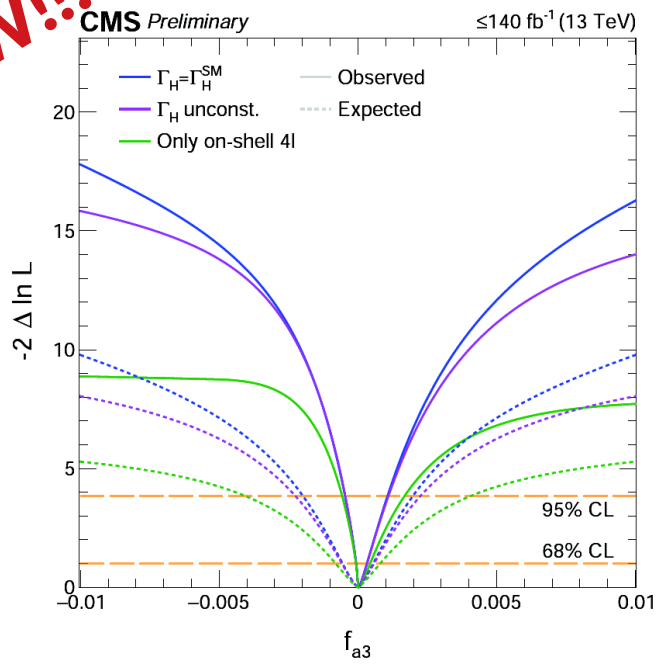
Combine **onshell** and **offshell**

H→4l + **H→2l2v**

A.C. parametrized using mass eigenstate basis

single A.C. scans

width constrained and unconstrained



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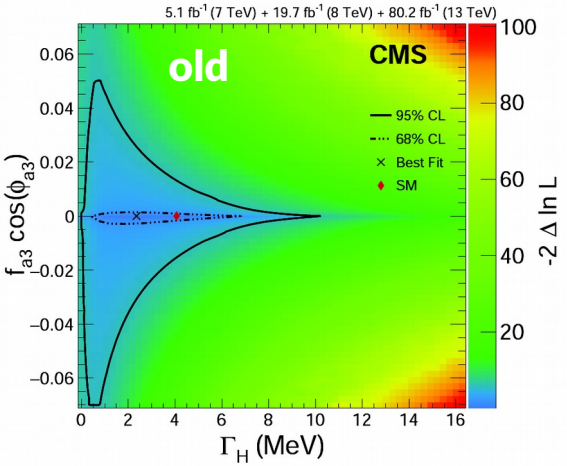
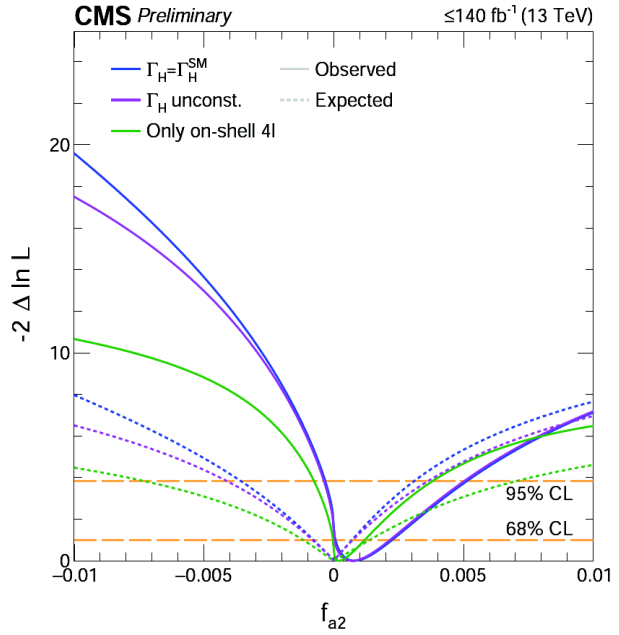
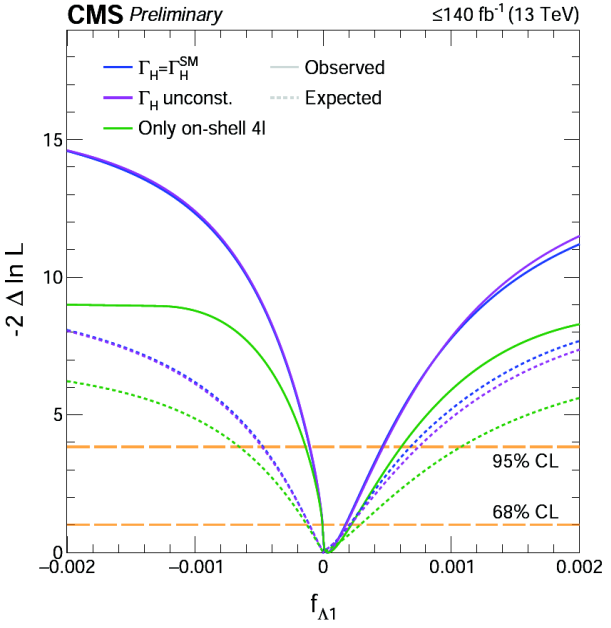






Summary and current efforts

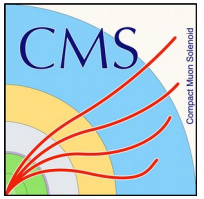
ATLAS

- **Public results on width using partial Run2 (4l+2l2v)**
- HZZ offshell analysis has been ongoing and quite mature. Two final states, 4l and 2l2v, are used and will be combined
- HWW (lvlv) offshell analysis has been started and still in the very early stage
- Interferometry in the on-shell diphoton channel has also been under development

CMS

- **Fresh Full Run2 2l2v + partial 4l**
- **Most sensitive Higgs width measurement to-date!**
- Offshell production evidence at 3.6σ

$$\Gamma_H = 3.2^{+2.4}_{-1.7}\ \text{MeV}$$



- Constraints on AC using offshell data

Additional Material

AC parametrization CMS offshell

Parametrize H couplings in the mass eingestate base:

$$A(\mathrm{HVV}) = \frac{1}{v}\left[a_1^{\mathrm{VV}} + \frac{\kappa_1^{\mathrm{VV}} q_{\mathrm{V1}}^2 + \kappa_2^{\mathrm{VV}} q_{\mathrm{V2}}^2}{\left(\Lambda_1^{\mathrm{VV}}\right)^2} + \frac{\kappa_3^{\mathrm{VV}}(q_{\mathrm{V1}} + q_{\mathrm{V2}})^2}{\left(\Lambda_{\mathrm{Q}}^{\mathrm{VV}}\right)^2}\right] m_{\mathrm{V1}}^2 \epsilon_{\mathrm{V1}}^* \epsilon_{\mathrm{V2}}^*$$
$$+ \frac{1}{v} a_2^{\mathrm{VV}} f^{*(1)}_{\mu\nu} f^{*(2),\mu\nu} + \frac{1}{v} a_3^{\mathrm{VV}} f^{*(1)}_{\mu\nu} \tilde{f}^{*(2),\mu\nu}$$

a1 SM
a2 CP even AC
a3 CP odd AC

CP: HVV in H→4l offshell (CMS)

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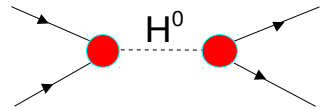

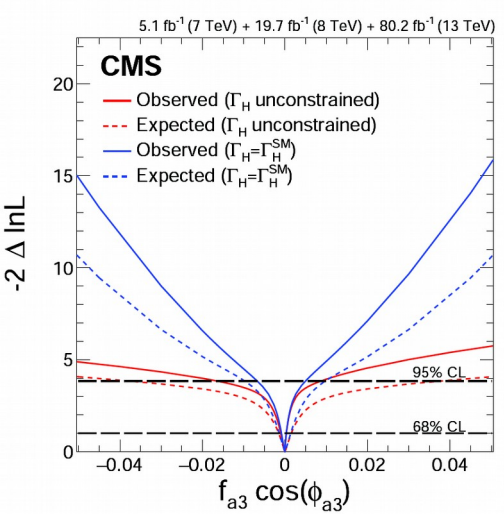

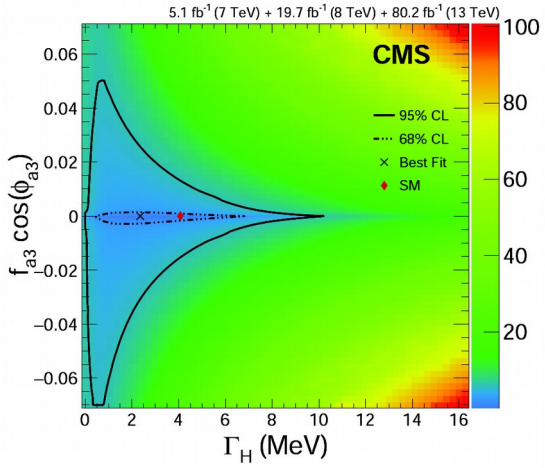

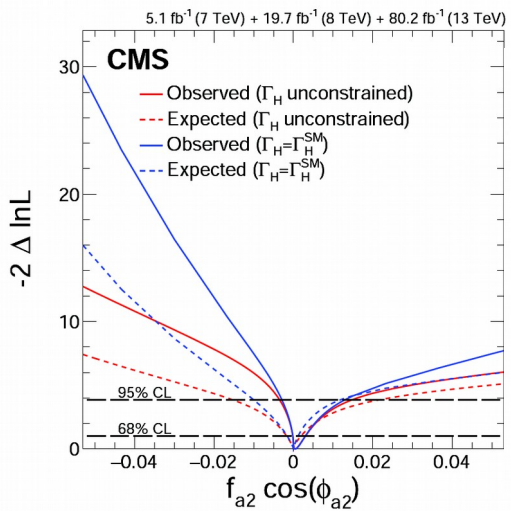

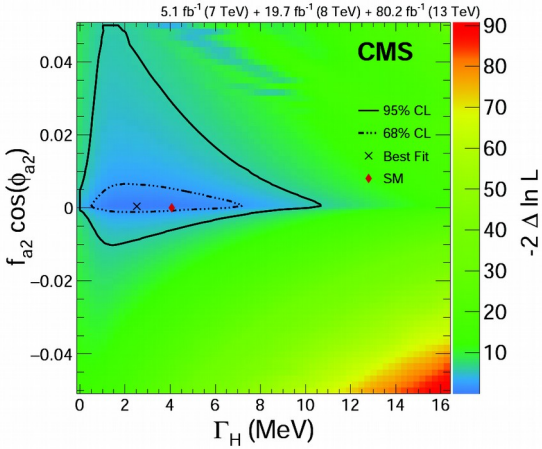

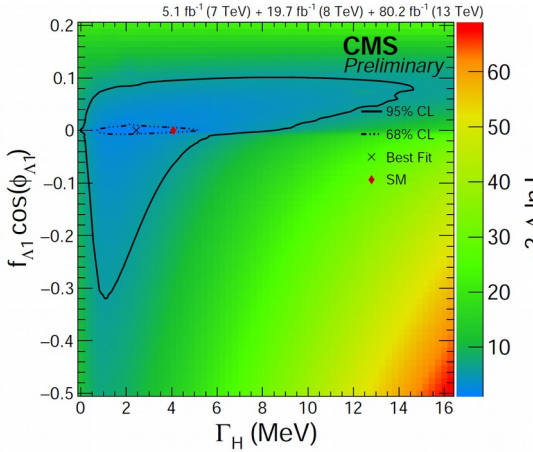

- AC parametrization and analysis strategy as in HVV, H→4l onshell
- AC greatly affect offshell H production
- Background interferes with signal → more challenging analysis
- AC, Γ_H simultaneous measurement
- Individual AC scanned
- First Offshell AC measurement

H→4l off-shell

anomalous couplings :

→ increase the number of off-shell events