H(125) width and lifetime measurements in the $4l$ final state

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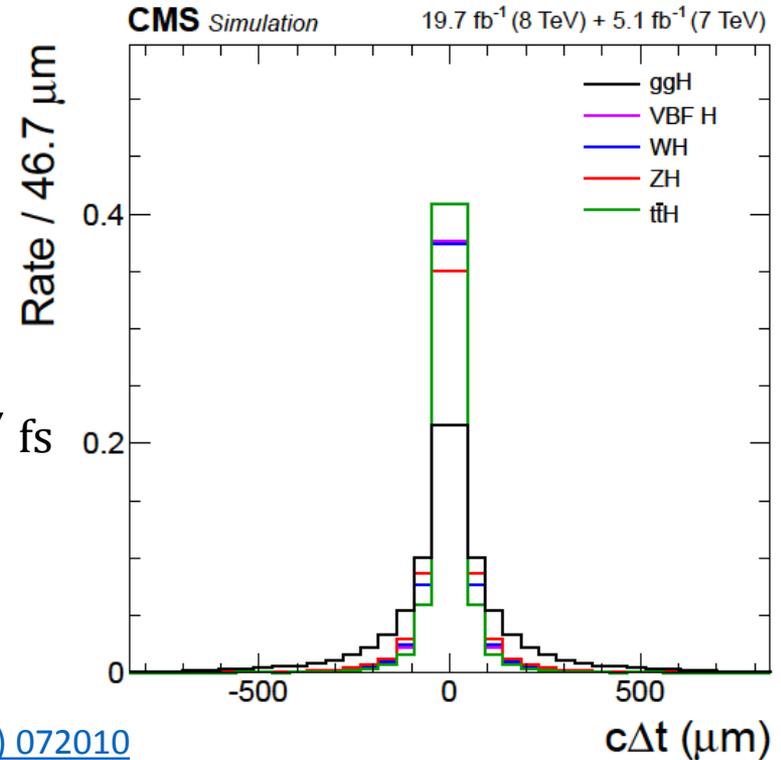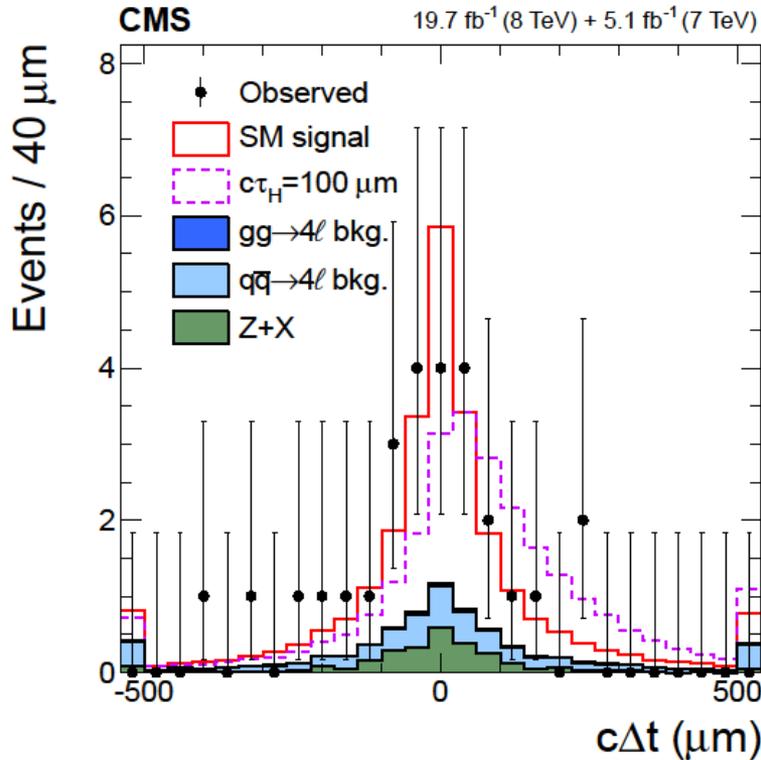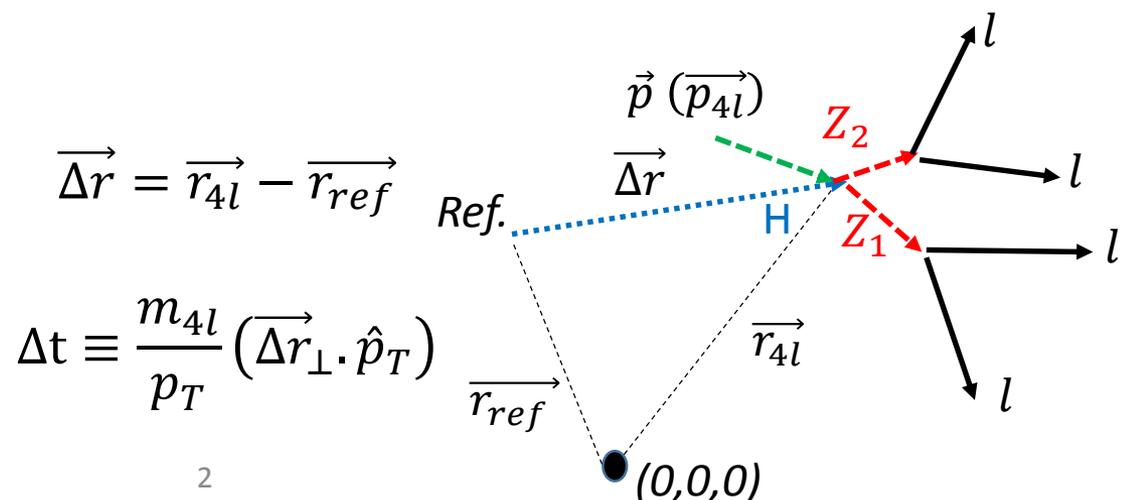on behalf of the CMS Collaboration

Outline

➔ Presenting results from CMS with focus on the $4l$ final state:
  ➔ Run I introduction and Run II progress in width measurements
    ➔ Lifetime measurement
    ➔ Width vs. mass
        ➔ Onshell-only or onshell+offshell combination
    ➔ Width vs. anomalous couplings (tensor structure)

➔ Related talks:
  ➔ Diboson results by A. Calderon
  ➔ BSM searches by D. N. Taylor
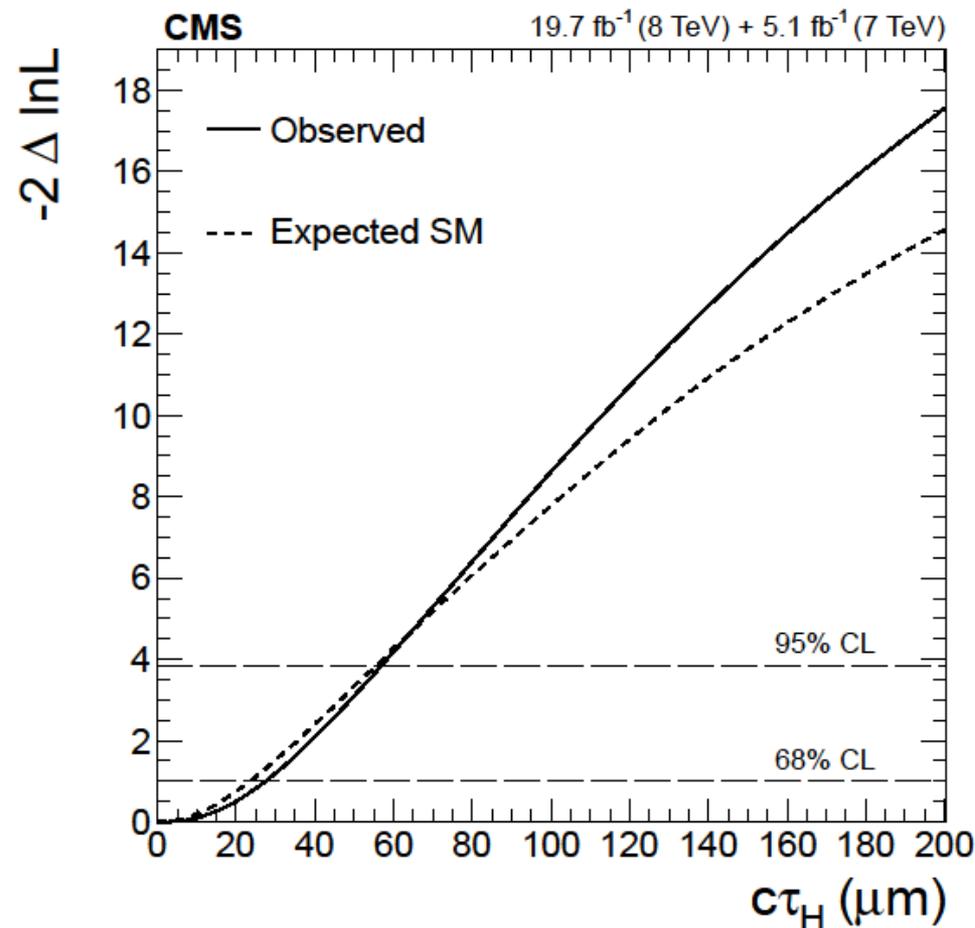 ➔ Run II prospects by D. Sperka

Run I: Lifetime from $H \rightarrow 4l$

CMS 19.7 fb^{-1} (8 TeV) + 5.1 fb^{-1} (7 TeV)

- Observed
- SM signal
- $c\tau_H = 100$ μm
- $gg \rightarrow 4\ell$ bkg.
- $q\bar{q} \rightarrow 4\ell$ bkg.
- Z+X

Events / 40 μm

$c\Delta t$ (μm) [Phys. Rev. D 92 (2015) 072010](#)

SM:
$\tau_H \approx 1.6 \times 10^{-7}$ fs
($\Gamma_H \approx 4$ MeV)

CMS *Simulation* 19.7 fb^{-1} (8 TeV) + 5.1 fb^{-1} (7 TeV)

- ggH
- VBF H
- WH
- ZH
- t$\bar{t}$H

Rate / 46.7 μm

$c\Delta t$ (μm)

→ Use transverse vectors
  → Reduce dependence on z resolution
→ Beamspot as reference
  → No dependence on associated particles
  → $4l$ p_T only other difference

$$\overrightarrow{\Delta r} = \overrightarrow{r_{4l}} - \overrightarrow{r_{ref}}$$

$$\Delta t \equiv \frac{m_{4l}}{p_T}\left(\overrightarrow{\Delta r_\perp} \cdot \hat{p}_T\right)$$

$\vec{p}\ (\overrightarrow{p_{4l}})$
Z_2
$\overrightarrow{\Delta r}$
Ref.
Z_1
H
$\overrightarrow{r_{4l}}$
$\overrightarrow{r_{ref}}$
$(0,0,0)$
l

2

Run I: Width lower bound from lifetime

CMS — 19.7 fb^{-1} (8 TeV) + 5.1 fb^{-1} (7 TeV)

Observed / Expected SM

95% CL / 68% CL

Expected $c\tau_H < 56\ \mu m$
Observed $c\tau_H < 57\ \mu m$

Translates to
Expected $\Gamma_H > 3.6 \times 10^{-9}$ MeV
Observed $\Gamma_H > 3.5 \times 10^{-9}$ MeV

CMS Simulation — 19.7 fb^{-1} (8 TeV) + 5.1 fb^{-1} (7 TeV)

SM VBF
$f_{a2}=1$ VBF
$f_{a3}=1$ VBF
SM t$\bar{t}$H

$c\tau_H = 0\ \mu m$

Phys. Rev. D 92 (2015) 072010

Conservative constraints when anomalous couplings in production present

3
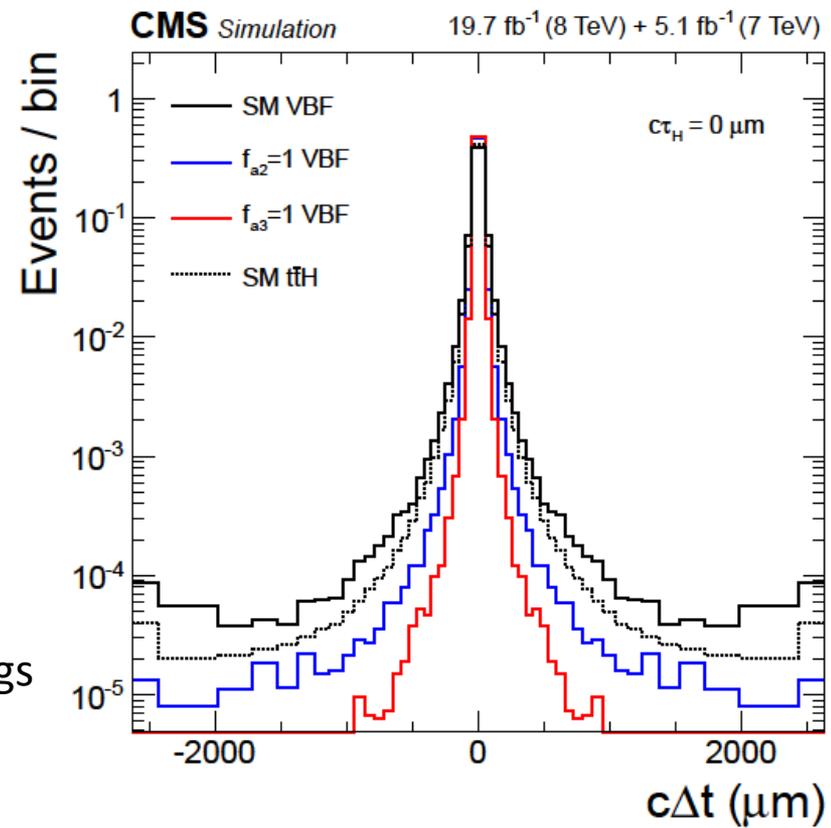
Run I: Width onshell upper bound
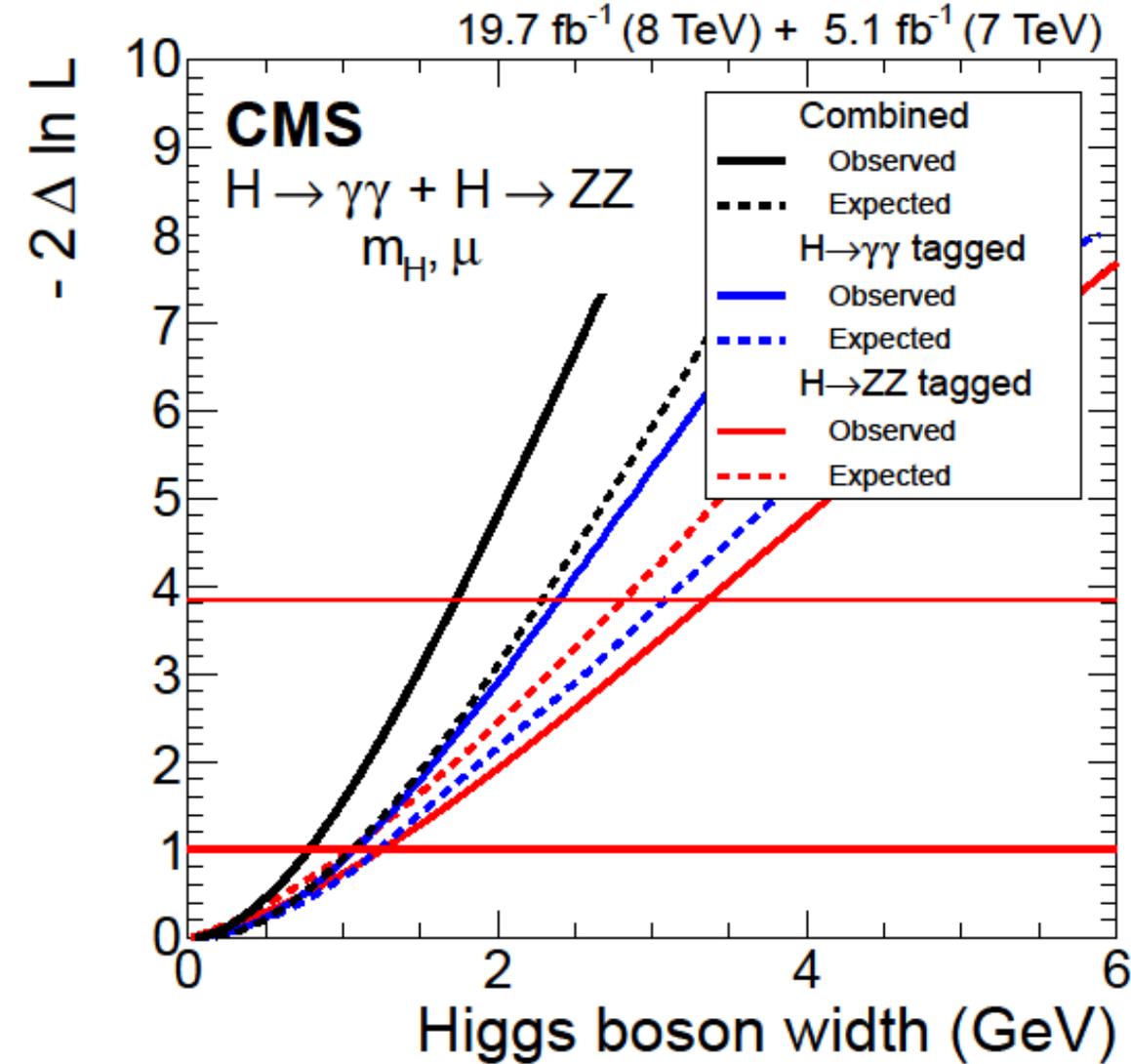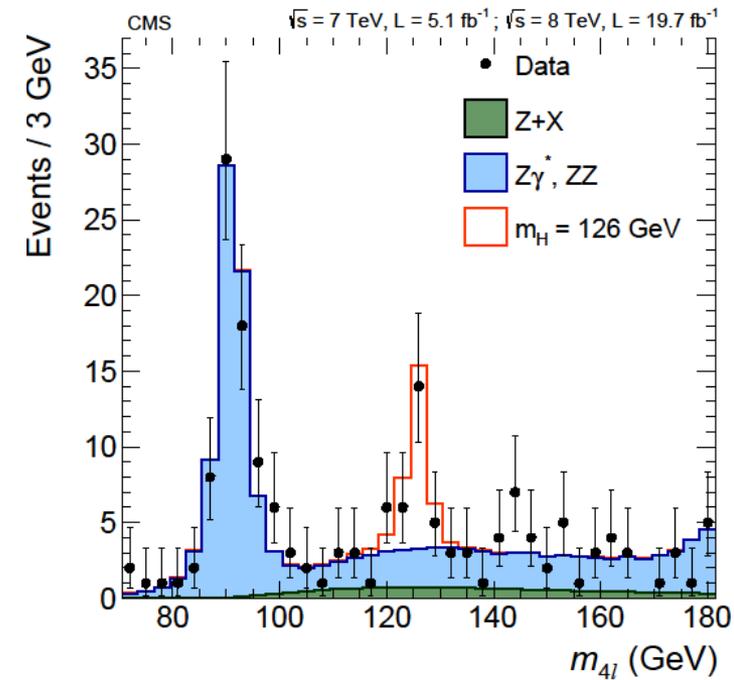
Direct upper bound from onshell $4l + \gamma\gamma$:
Expected $\Gamma_H < 2.3$ GeV
Observed $\Gamma_H < 1.7$ GeV

→ Limited by detector resolution

Run I: Width upper bound: Offshell method

Phys. Rev. D 92 (2015) 072010
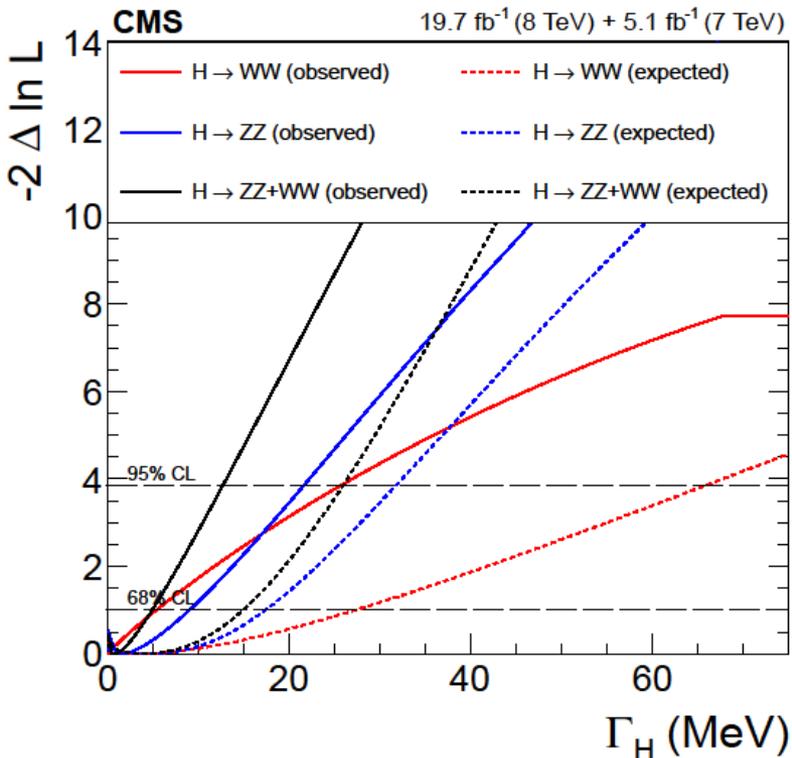
Proposed by F. Caola and K. Melnikov using the large offshell tail pointed out by N. Kauer and G. Passarino

$$\sigma^{on-shell}_{vv\to H\to ZZ} \sim \mu_{vvH}$$
$$\Rightarrow \sigma^{off-shell}_{vv\to H\to ZZ} \sim \mu_{vvH} \times \Gamma_H$$

- Tight constraints on Γ_H with SM-like tensor structure
- Possible BSM physics

Phys. Rev. D 92 (2015) 012004

Expected $\Gamma_H < 26$ MeV
Observed $\Gamma_H < 13$ MeV

NEW

Latest width combination using $4l$, and WW and ZZ $\to 2l2\nu$ using onshell + offshell combination of events (arxiv:1605.02329, submitted to JHEP)
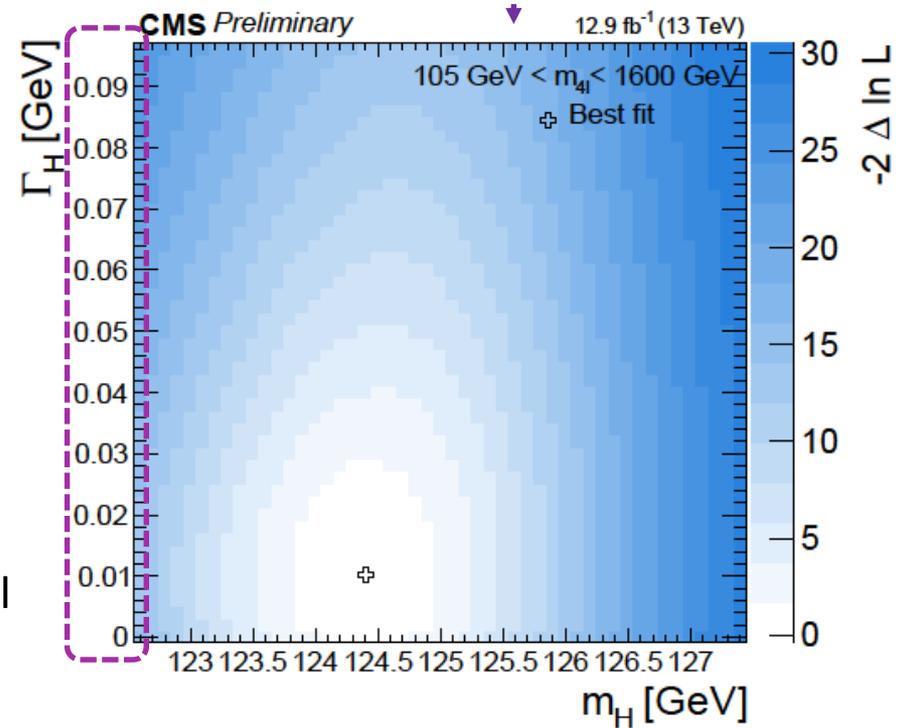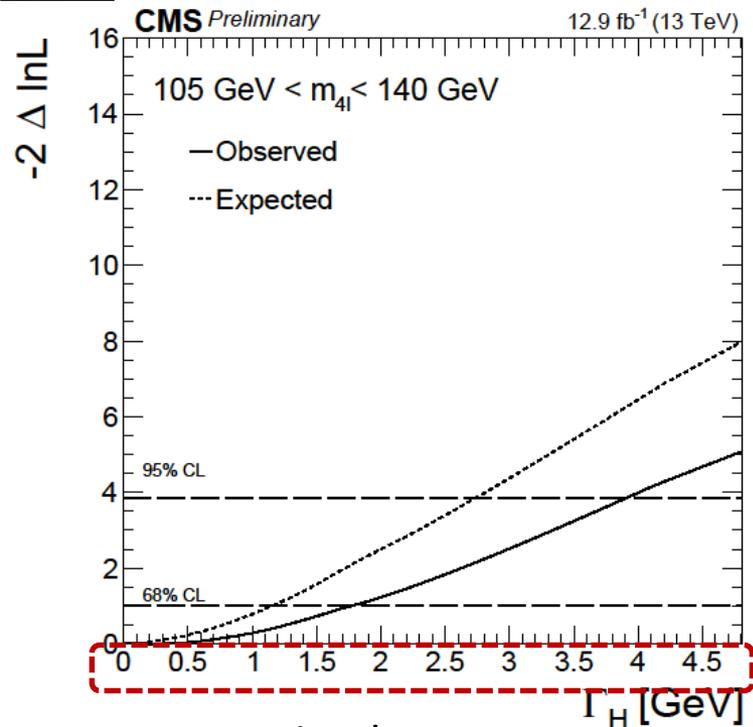
5
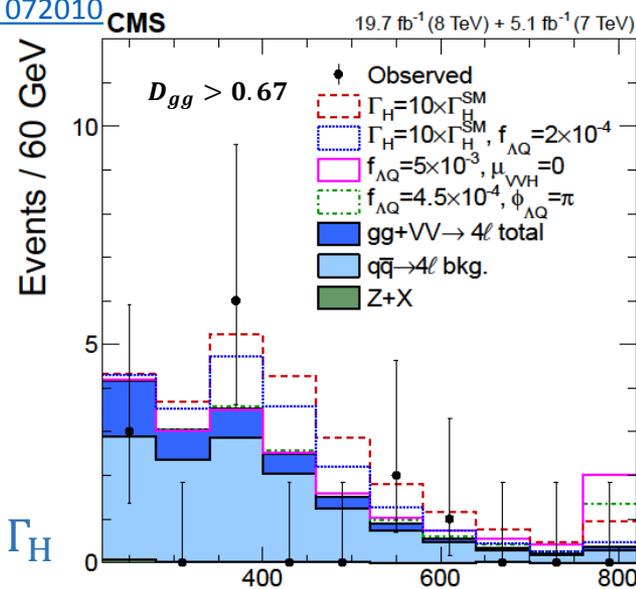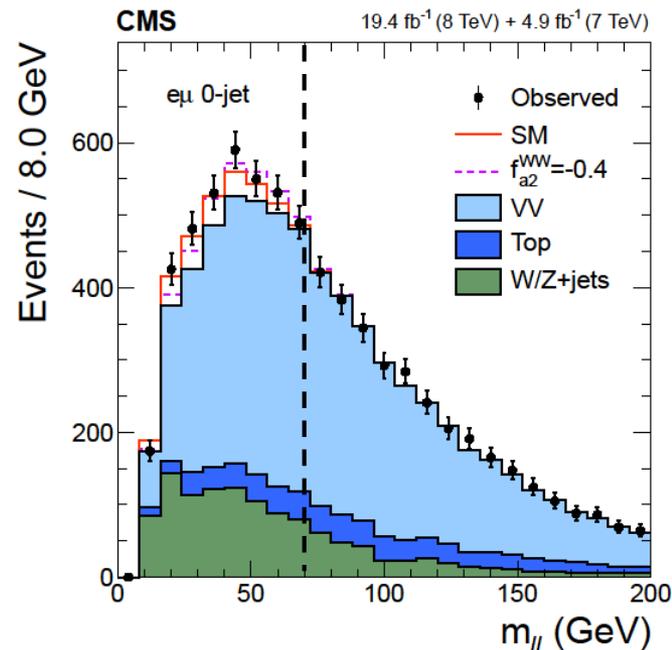
Run II: Width-mass measurement ($4l$)
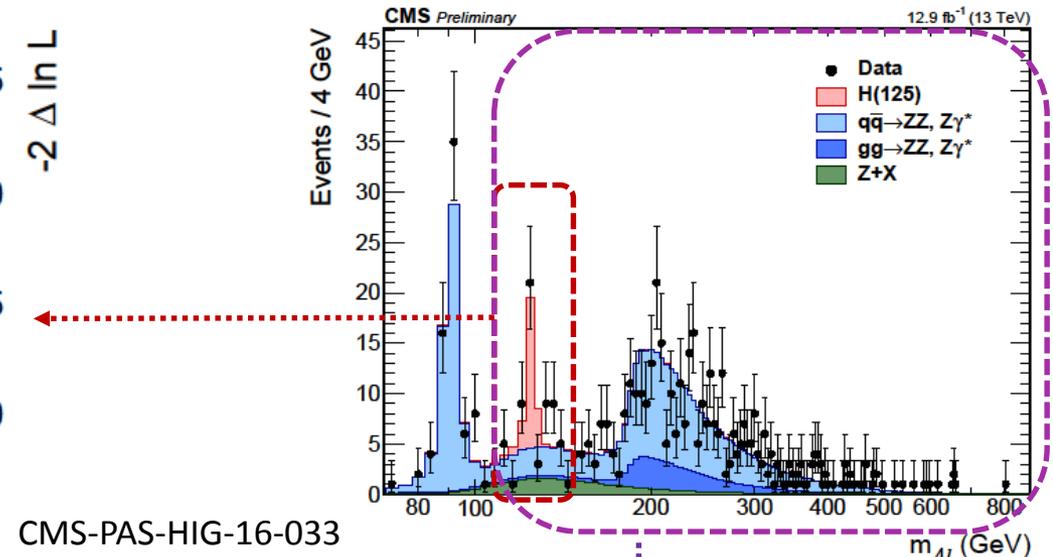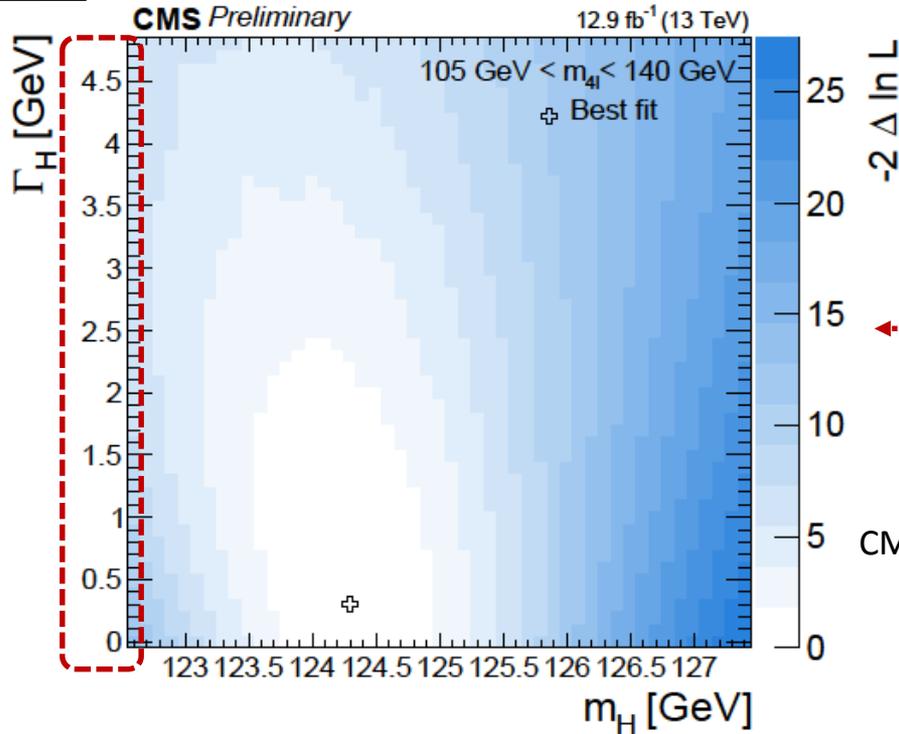
CMS-PAS-HIG-16-033

Using continuous m_{4l} onshell only

→ Sig., bkg. and int. models based on
MCFM/JHUGen+HNNLO in ggH,
MCFM/JHUGen+Phantom in VBF+VH
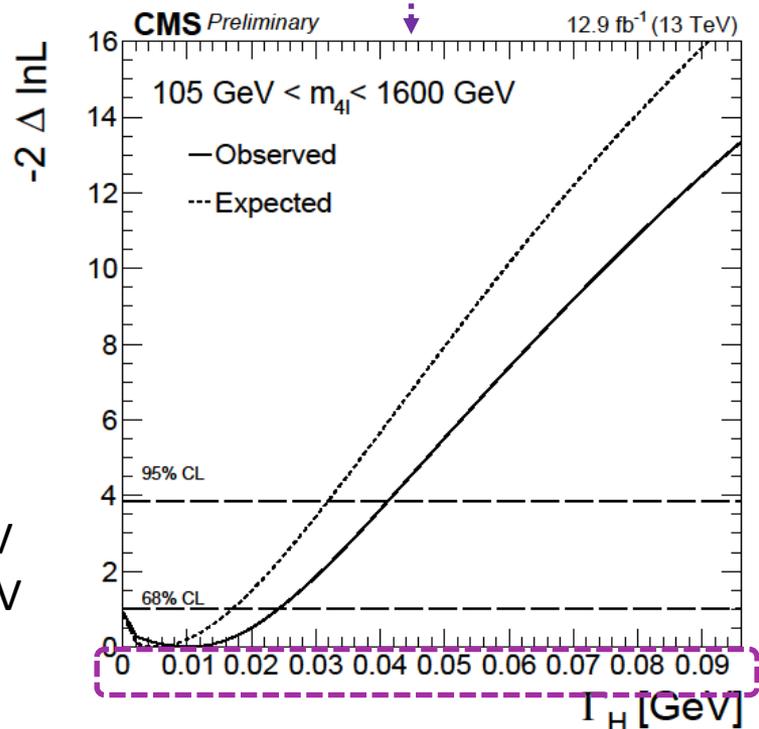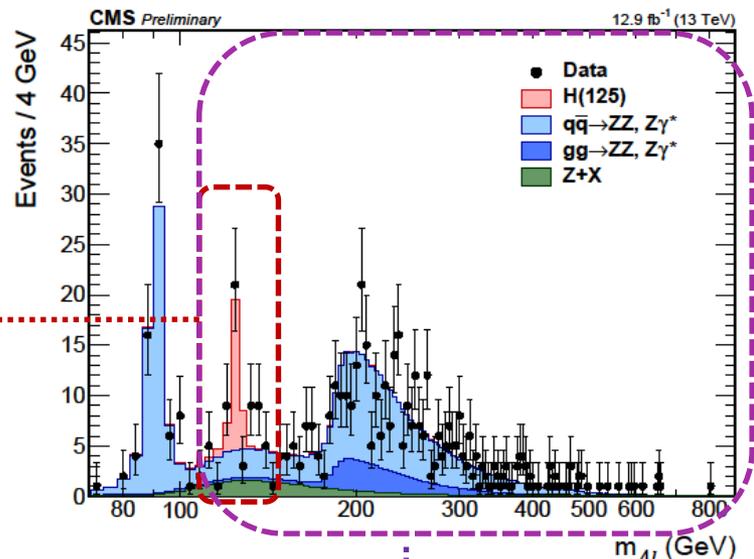
Using continuous m_{4l}
parameterization onshell+offshell

CMS-PAS-HIG-16-033

m_H unconstrained
Onshell only

Expected $\Gamma_H < 2.7$ GeV
Observed $\Gamma_H < 3.9$ GeV

m_H unconstrained
Onshell+offshell

Expected $\Gamma_H < 32$ MeV
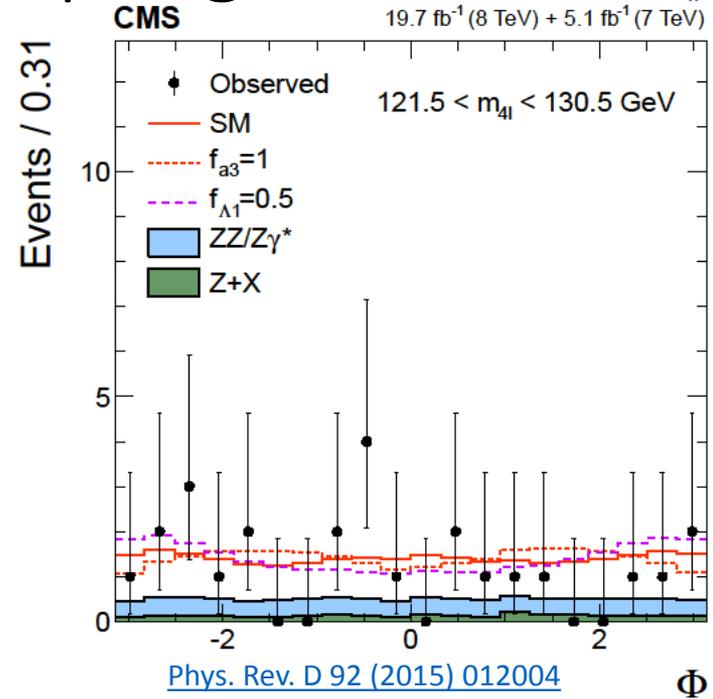Observed $\Gamma_H < 41$ MeV

HVV anomalous couplings

$$A(HVV) \sim \left[\boldsymbol{a_1} - e^{i\phi_{\Lambda Q}} \frac{(q_{V1} + q_{V2})^2}{\Lambda_Q^2} - e^{i\phi_{\Lambda 1}} \frac{(q_{V1}^2 + q_{V2}^2)}{\Lambda_1^2} \right] m_V^2 \epsilon_{V1}^* \epsilon_{V2}^*$$

$$+ \, a_2 f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + a_3 f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu}$$

→ Any anomalous coupling can be described with an effective onshell cross sectional fraction and a phase

$$f_{ai} = \frac{|a_i|^2 \sigma_i}{\sum_j |a_j|^2 \sigma_j} \qquad \phi_{ai} = \tan^{-1}(a_i/a_1)$$

→ $f_{\Lambda Q}$ observable only from offshell, others measurable from either onshell or offshell

Phys. Rev. D 92 (2015) 012004

In $4l$, use discriminants based on MELA from MCFM/JHUGen:

$$D_{A \, vs \, B} = \frac{P_A}{P_A + P_B}$$

$$D_{A-B \, int.} = \frac{P_{A+B} - P_A - P_B}{P_A + P_B}$$
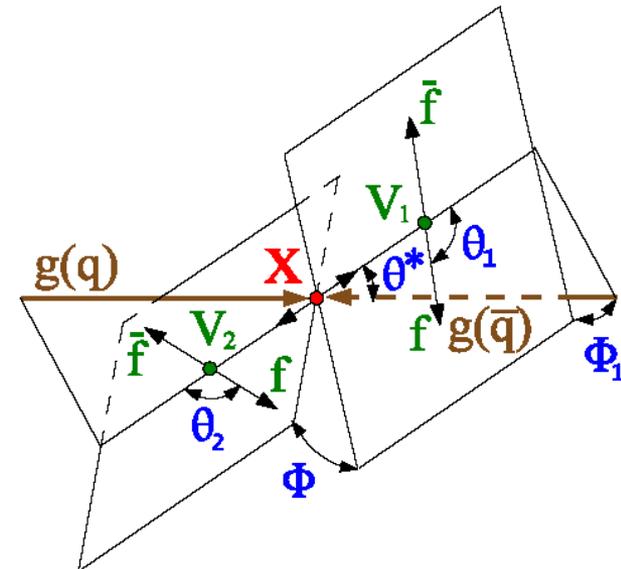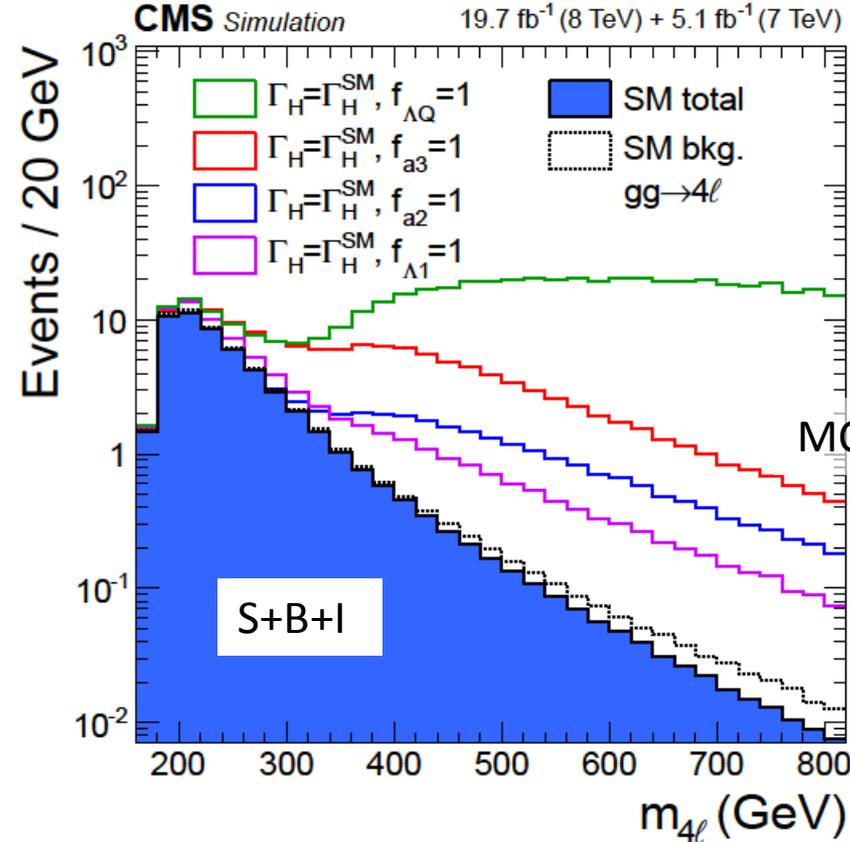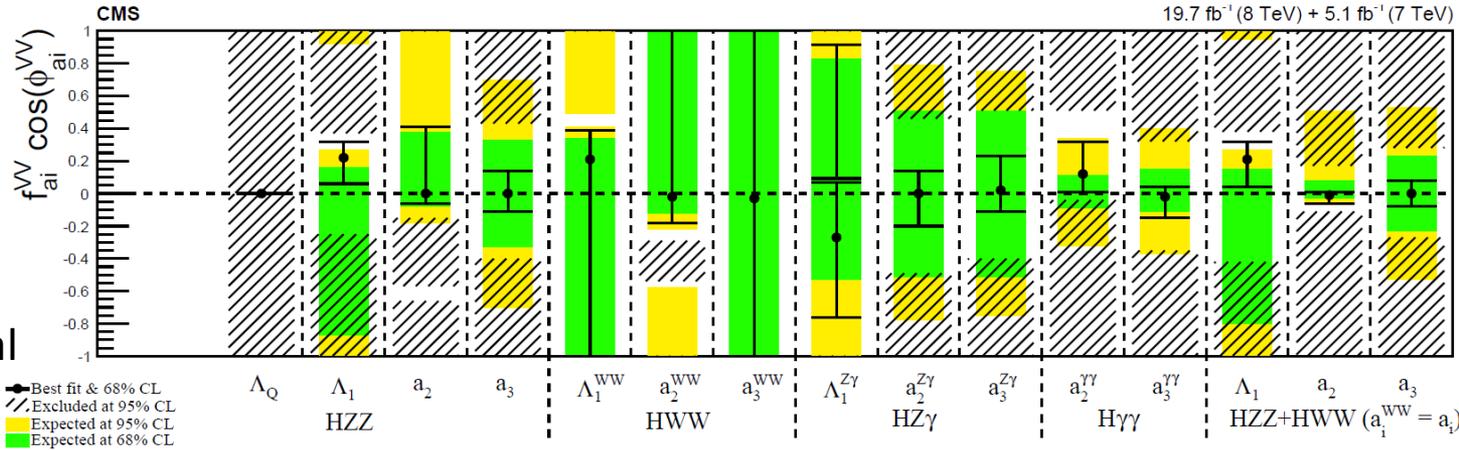

8

Run I: Anomalous couplings combination
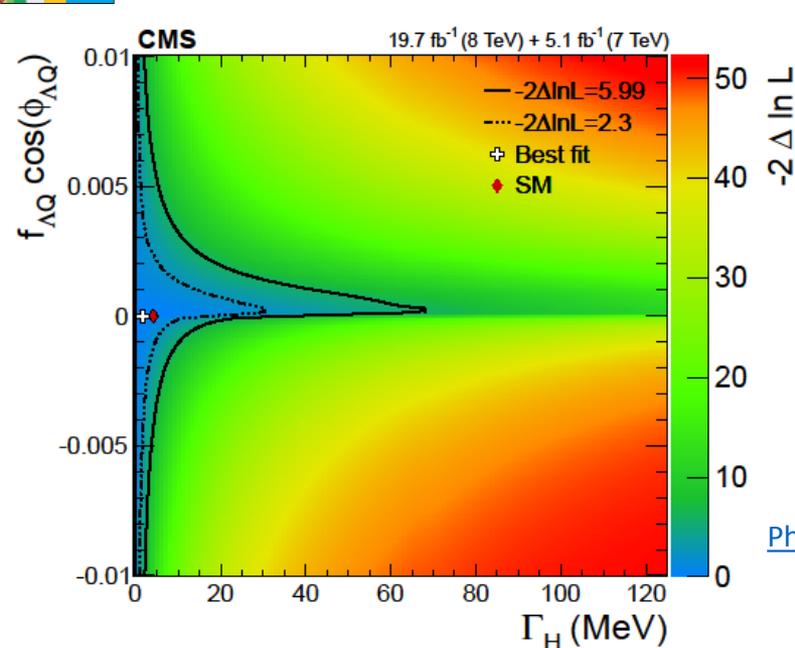
$4l+WW \rightarrow 2l2\nu \rightarrow$

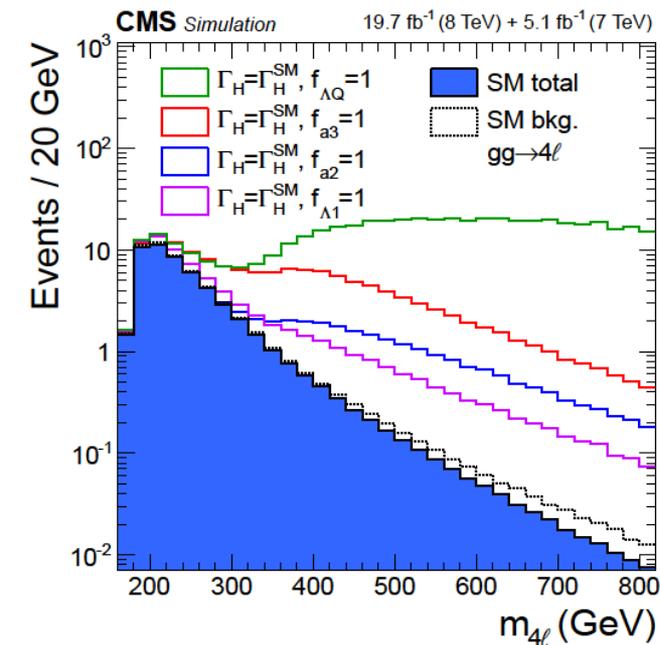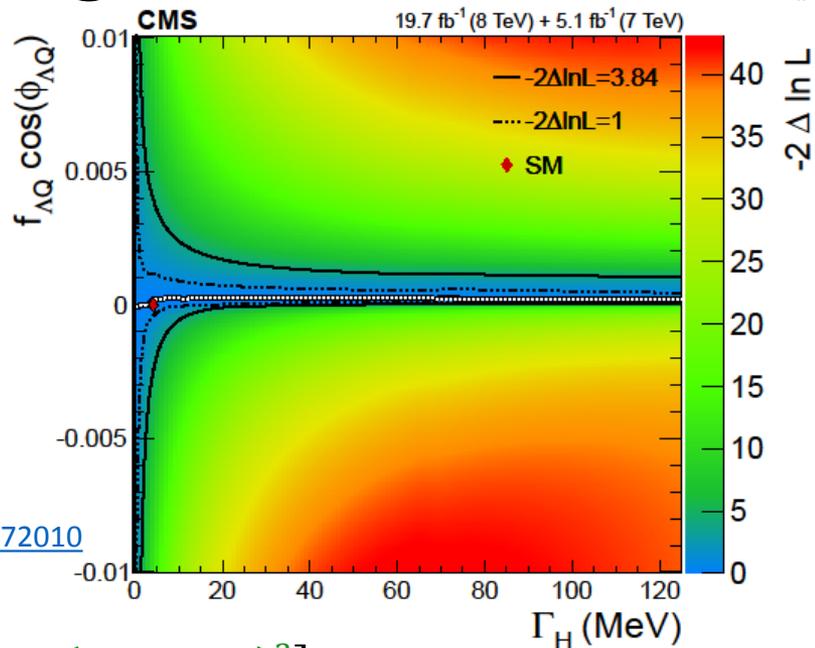Offshell enhanced for the same onshell signal strength ↓

Using MCFM/JHUGen
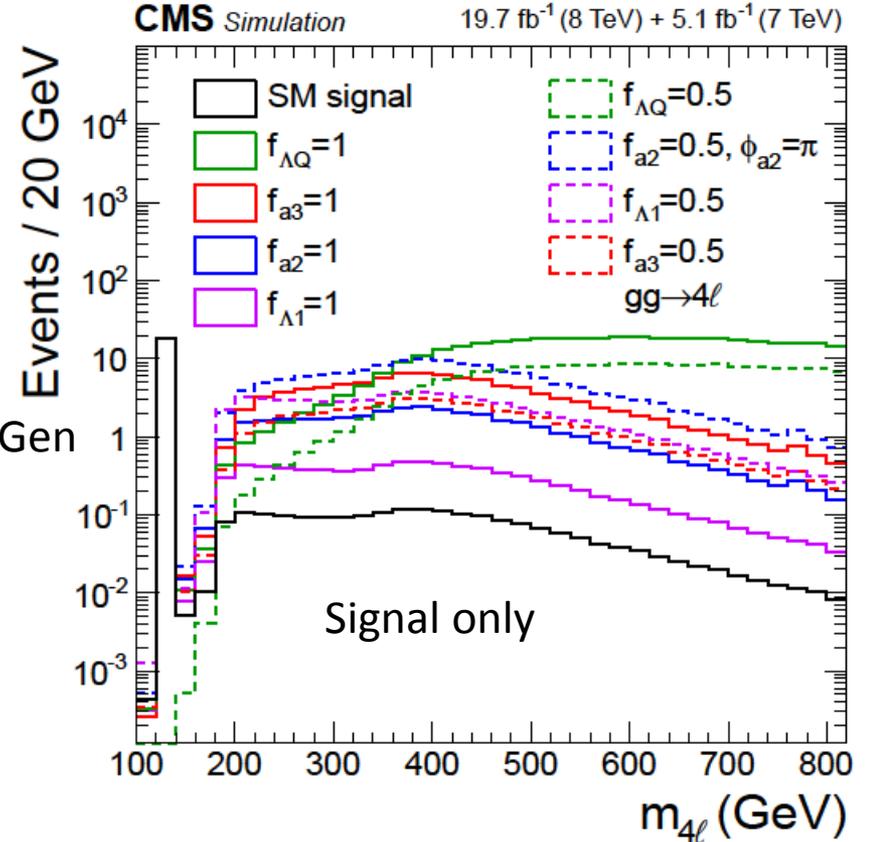
Run I: Anomalous couplings from off-shell

Phys. Rev. D 92 (2015) 072010

$$A(HVV) \sim \left[\boldsymbol{a_1} - e^{i\phi_{\Lambda Q}} \frac{(q_{V1} + q_{V2})^2}{\Lambda_Q^2} \right] m_V^2 \epsilon_{V1}^* \epsilon_{V2}^*$$

$f_{\Lambda Q}$ vs. Γ_H joint constraints
using $4l$
onshell+offshell

$f_{\Lambda Q} \cos(\phi_{\Lambda Q})$ (68%) [95% CL]
when $\Gamma_H = \Gamma_H^{SM}$
Expected: (-0.4, 1.1) [-3.6,4.4]$\times 10^{-3}$
Observed: (-0.4, 1.0) [-1.4, 3.8] $\times 10^{-3}$

Summary

→ Presented results from CMS with focus on $H \rightarrow 4l$:

→ Model-independent constraint on lifetime from $4l$

→ Lower bound on width

→ Width vs. mass

→ Joint width constraints with mass

→ Resolution-limited width constraint from onshell

→ Tighter width constraint from offshell+onshell combination

→ Combination of final states possible as in Run I

→ Width vs. anomalous couplings (tensor structure)

→ Could apply joint constraints on f_{ai} vs. Γ_H for any a_i in the future, as exemplified in the Run I $f_{\Lambda Q}$ vs. Γ_H result
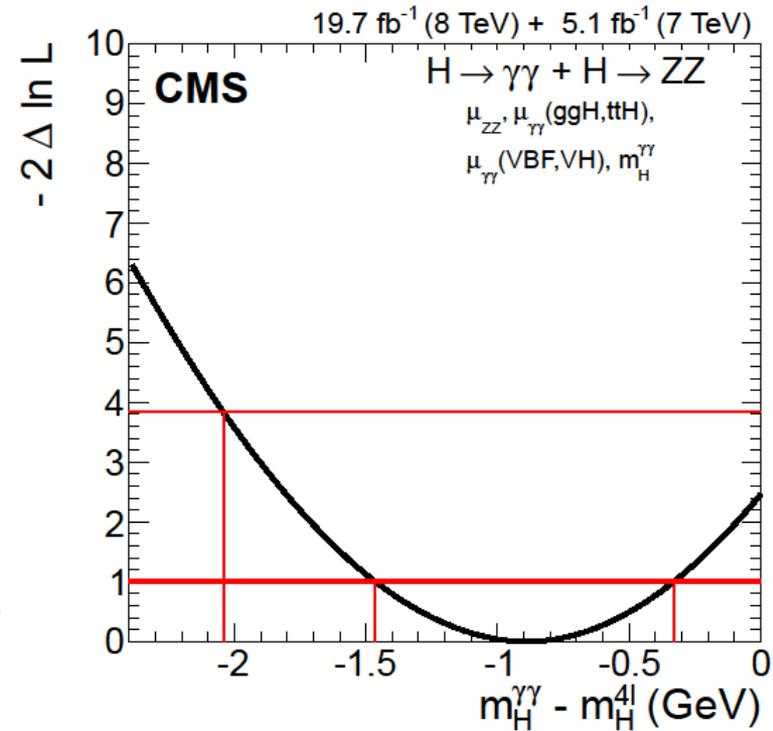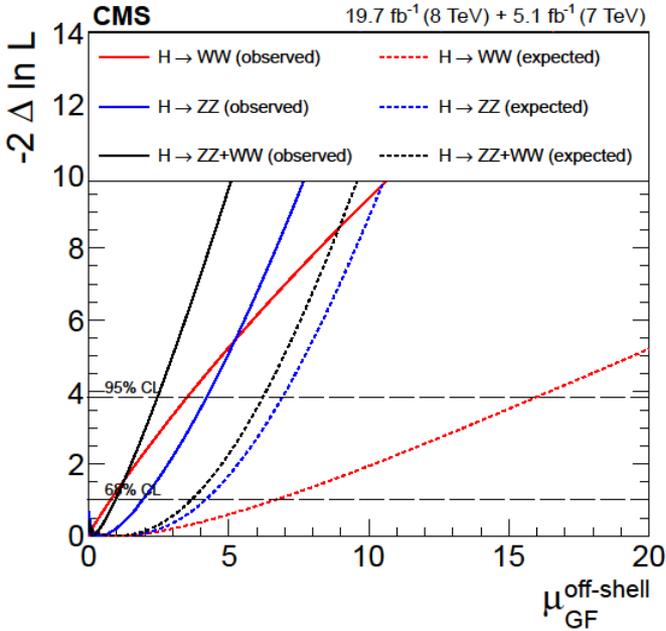
Backup

Run I: Mass measurement from CMS
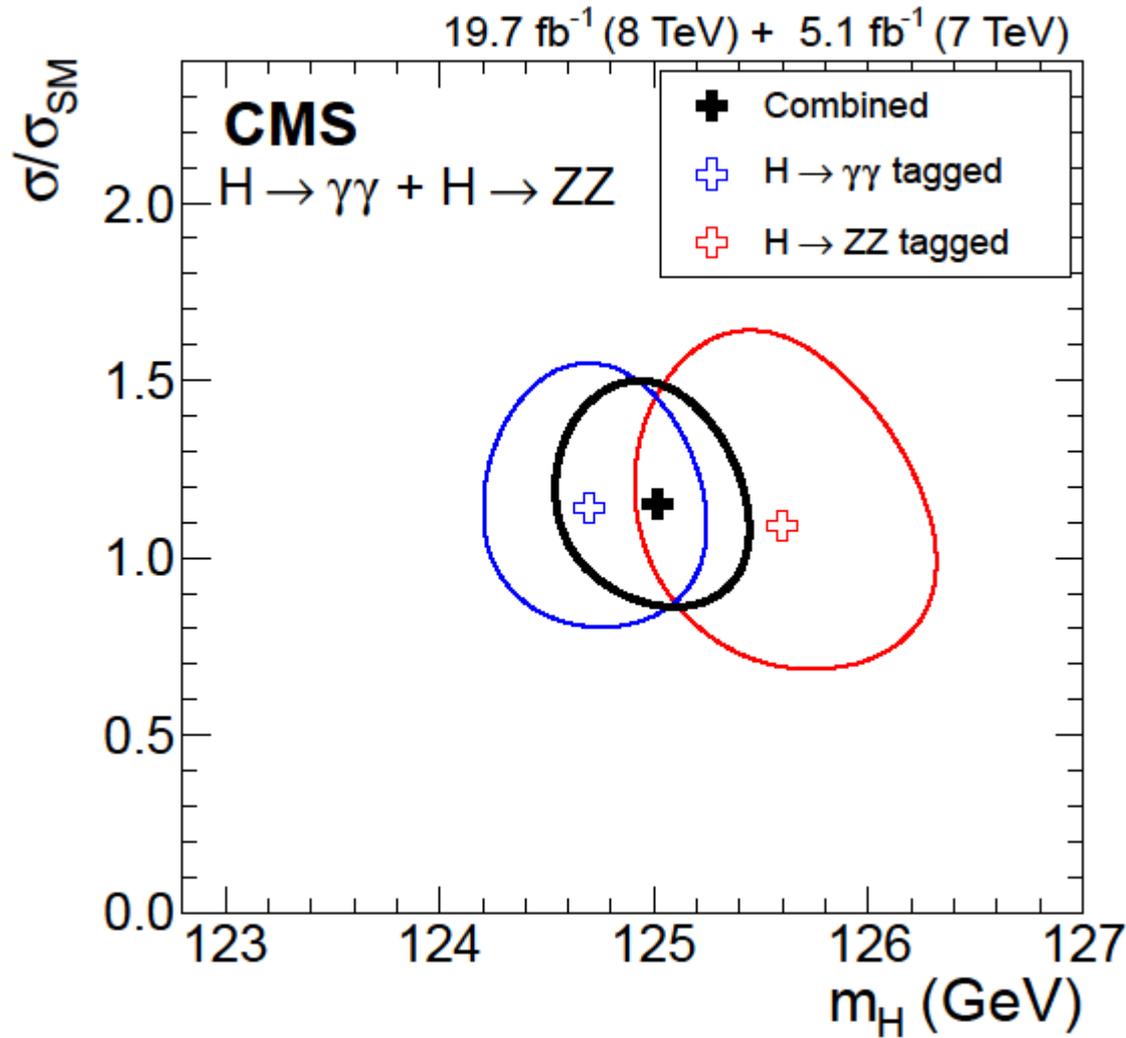
Observed $m_H = 125.02^{+0.29}_{-0.31}$ GeV

$4l$ and $\gamma\gamma$ channels compatible within $1.6\ \sigma$
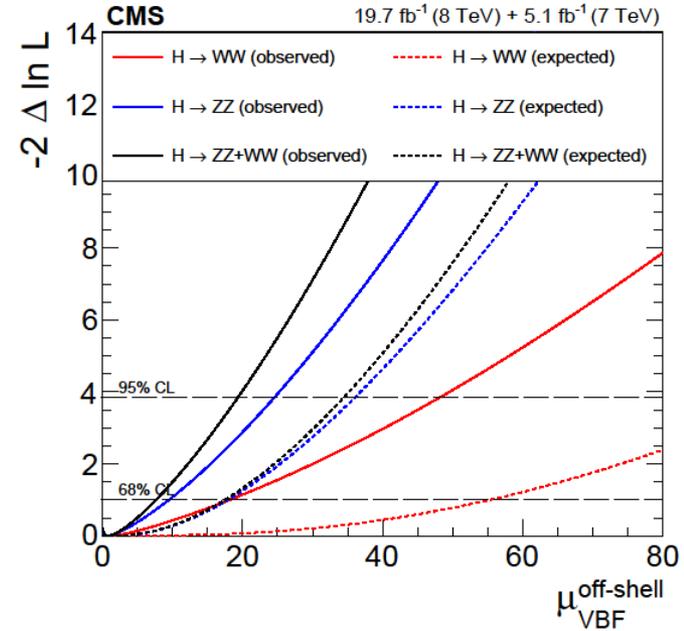
Latest Run I CMS+ATLAS 7 and 8 TeV mass measurement:
arXiv:1503.07589, Phys. Rev. Lett. 114 (2015) 191803

13

Run I: Width upper bound from CMS

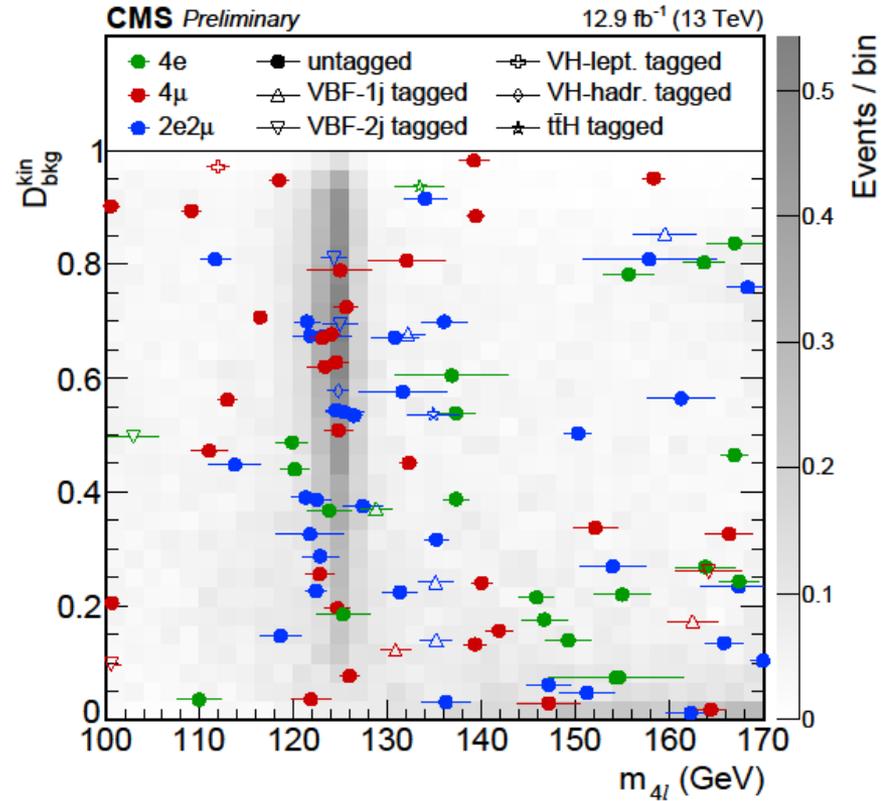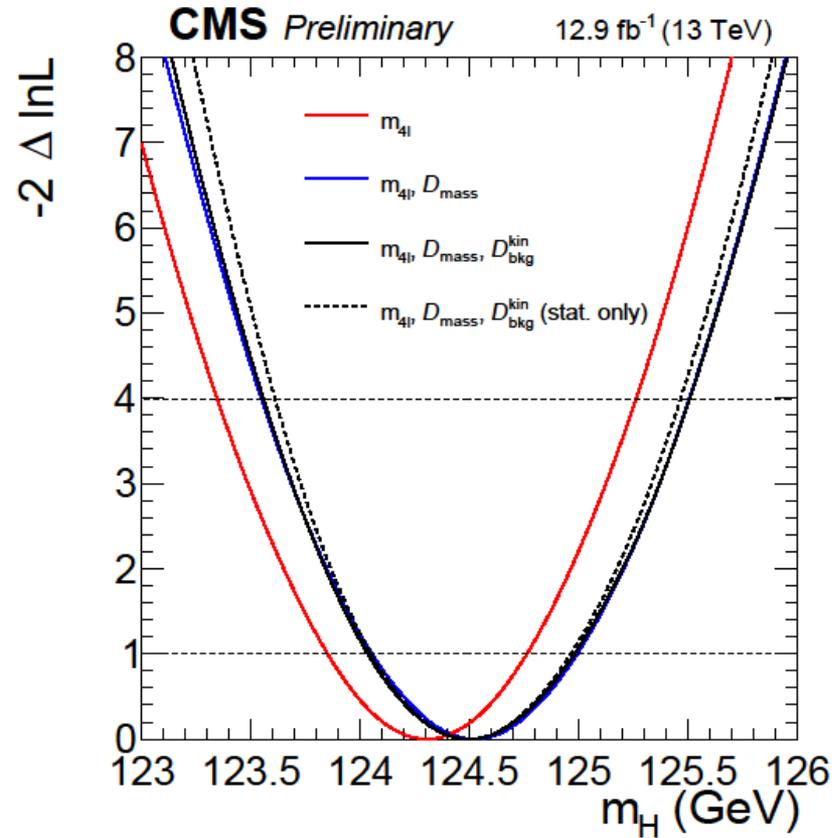Observed:
$$\mu_{GF}^{off-shell} < 2.4$$
$$\mu_{VBF}^{off-shell} < 19.3$$

Expected:
$$\mu_{GF}^{off-shell} < 6.2$$
$$\mu_{VBF}^{off-shell} < 34.4$$

Latest width combination using $4l$, and WW and ZZ $\rightarrow 2l2\nu$ using on-shell + off-shell combination of events (arxiv:1605.02329, submitted to JHEP)

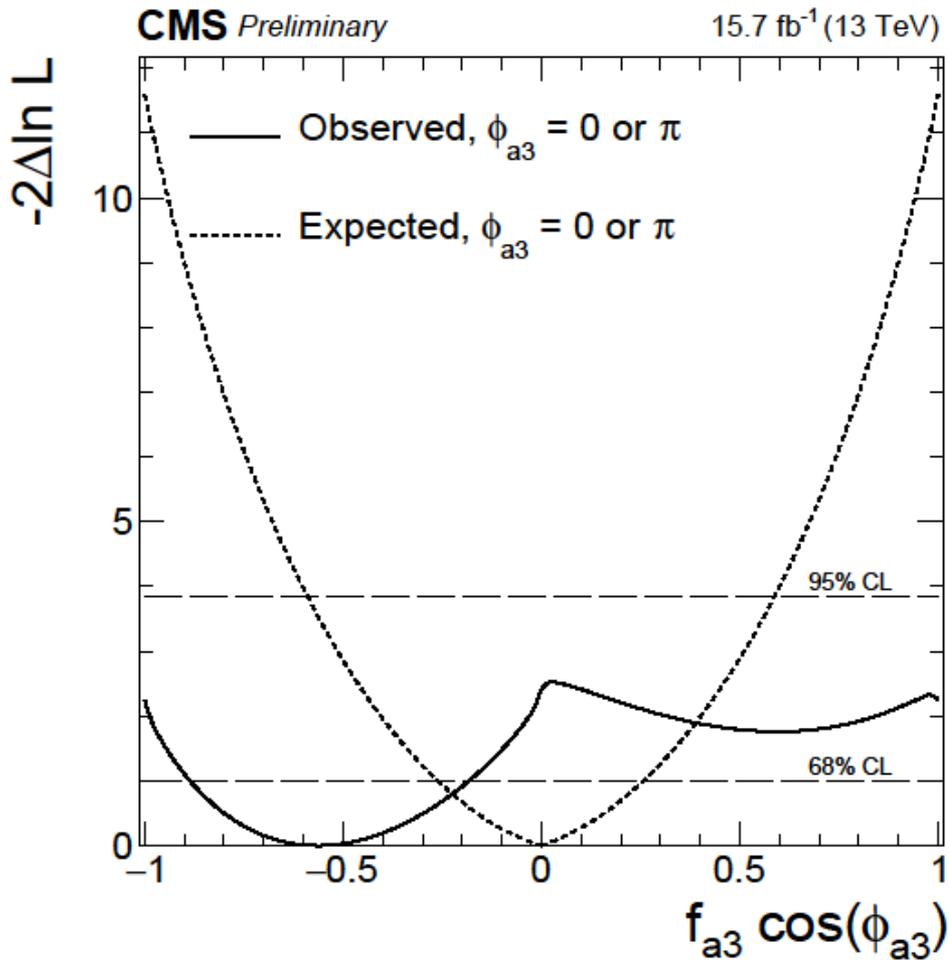# Run II: Mass measurement (4l)

CMS-PAS-HIG-16-033

Using 4l 3D measurement,
observed $m_H = 124.50^{+0.48}_{-0.46}$
$\left(stat\ ^{+0.47}_{-0.45}, syst\ ^{+0.13}_{-0.11}\right)$ GeV

D_{mass} from lepton
momentum errors
→ Corrected in data and
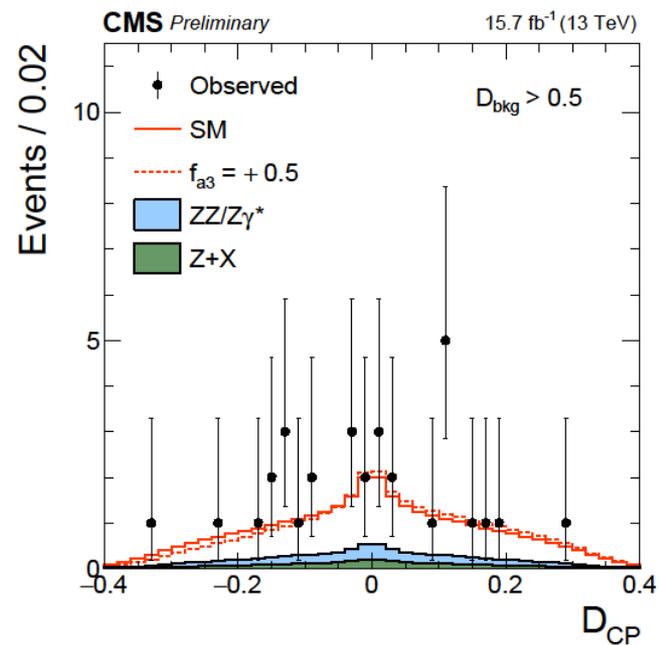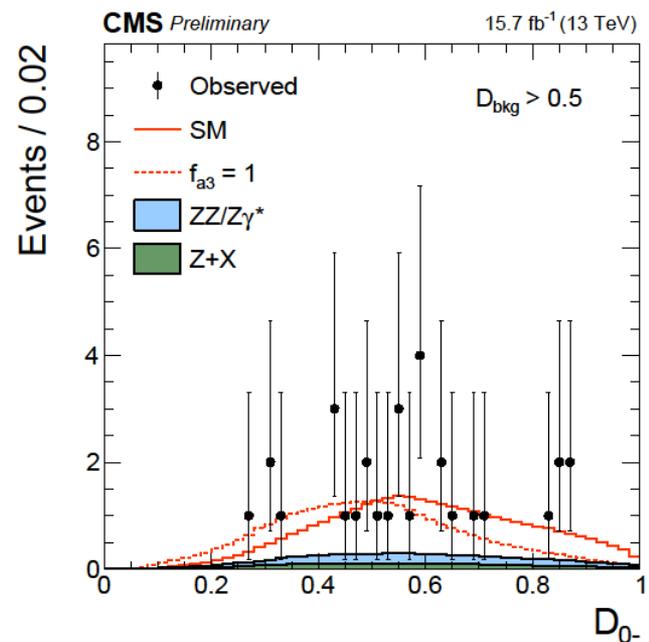MC using Z decay events
→ Improves resolution
by 8%

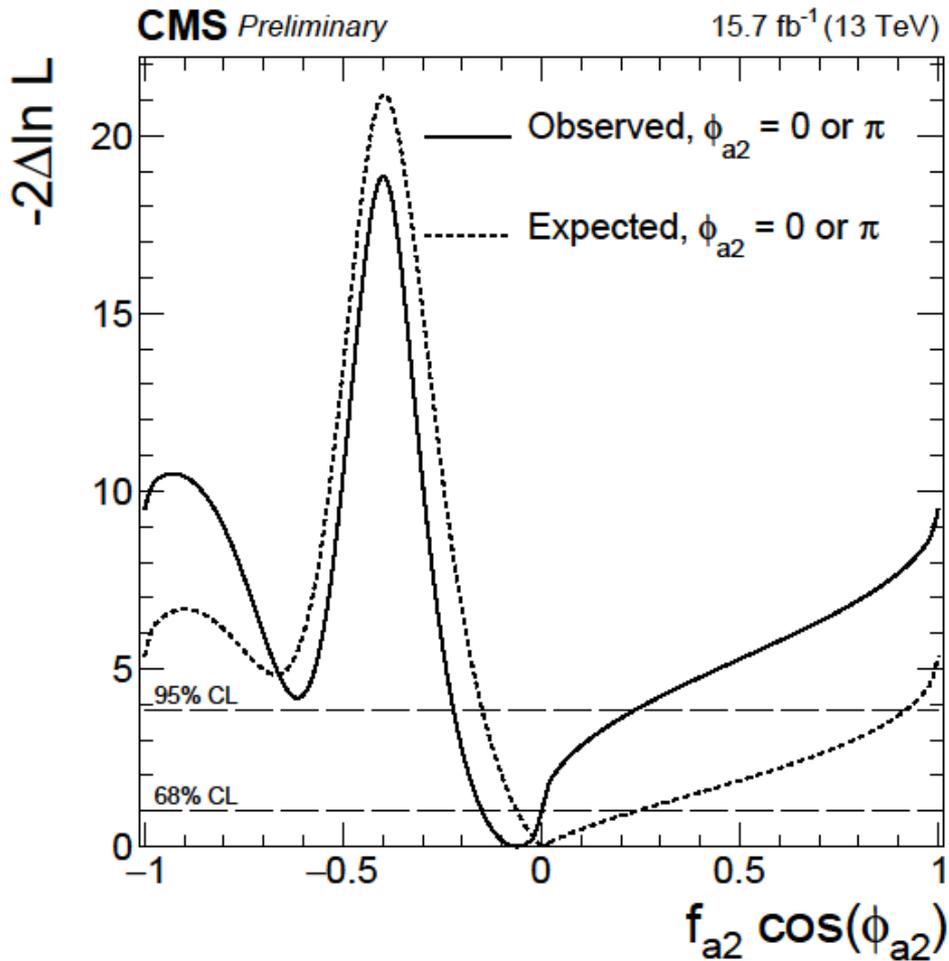# Run II: Anomalous couplings (f_{a3} result)

From 4l

Expected: $0.00^{+0.26}_{-0.26}$ (95% CL: [-0.59, 0.59])
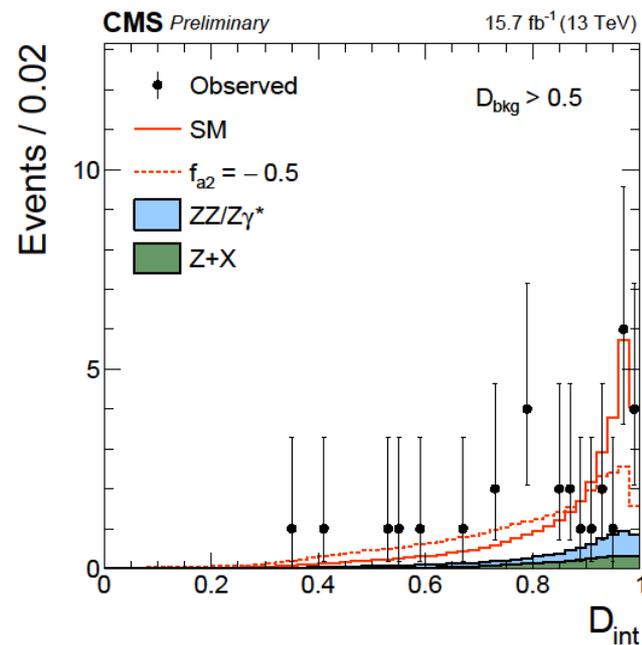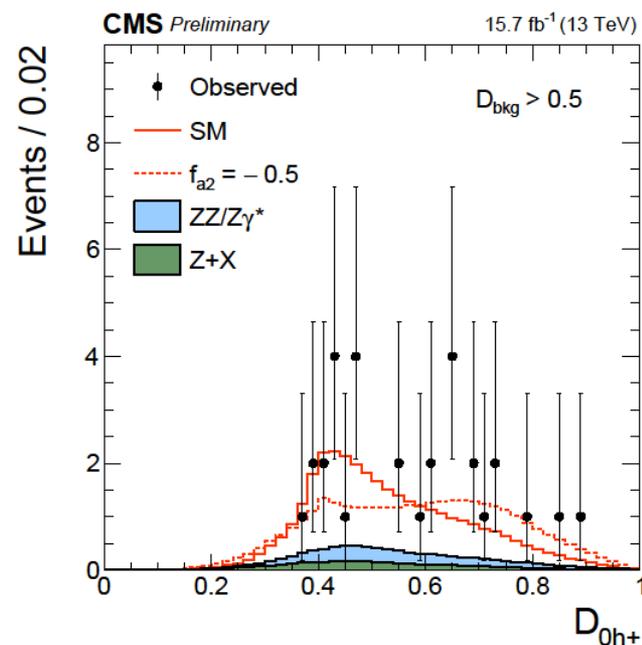Observed: $-0.56^{+0.38}_{-0.32}$ (95% CL: [-1.00, 1.00])

CMS-PAS-HIG-16-033

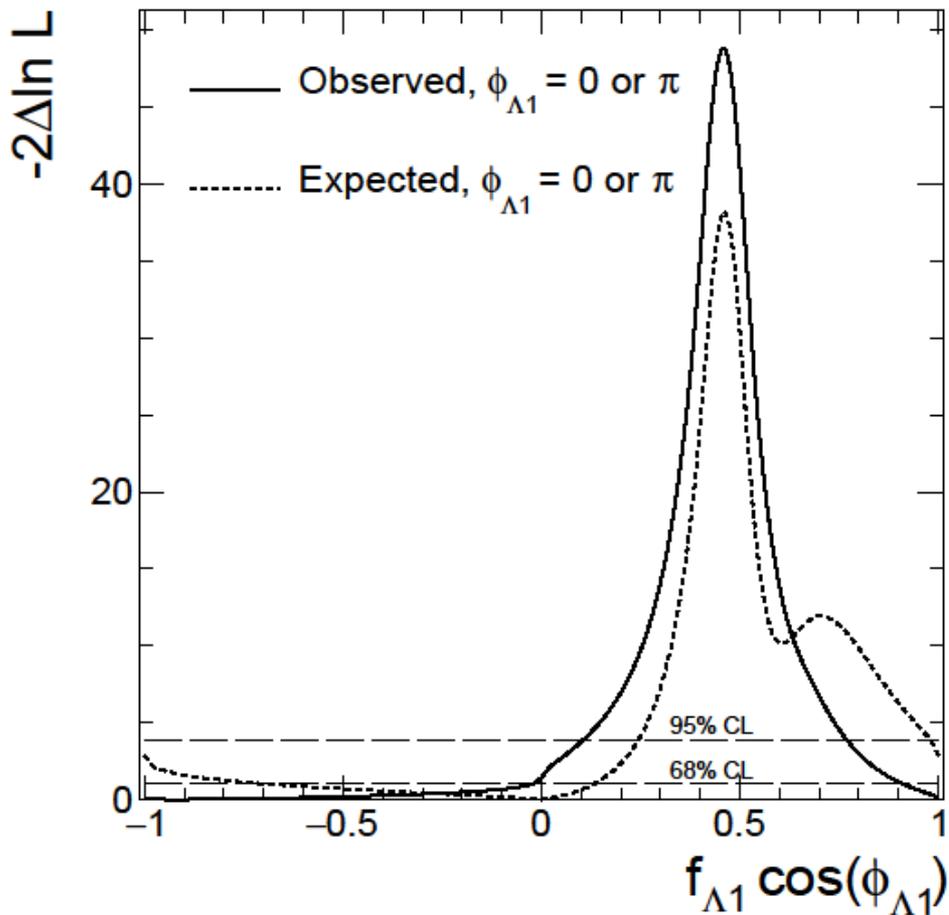# Run II: Anomalous couplings (f_{a2} result)

From 4l

Expected: $0.00^{+0.24}_{-0.06}$ (95% CL: [-0.15, 0.92])
Observed: $-0.06^{+0.06}_{-0.09}$ (95% CL: [-0.22, 0.24])

CMS-PAS-HIG-16-033

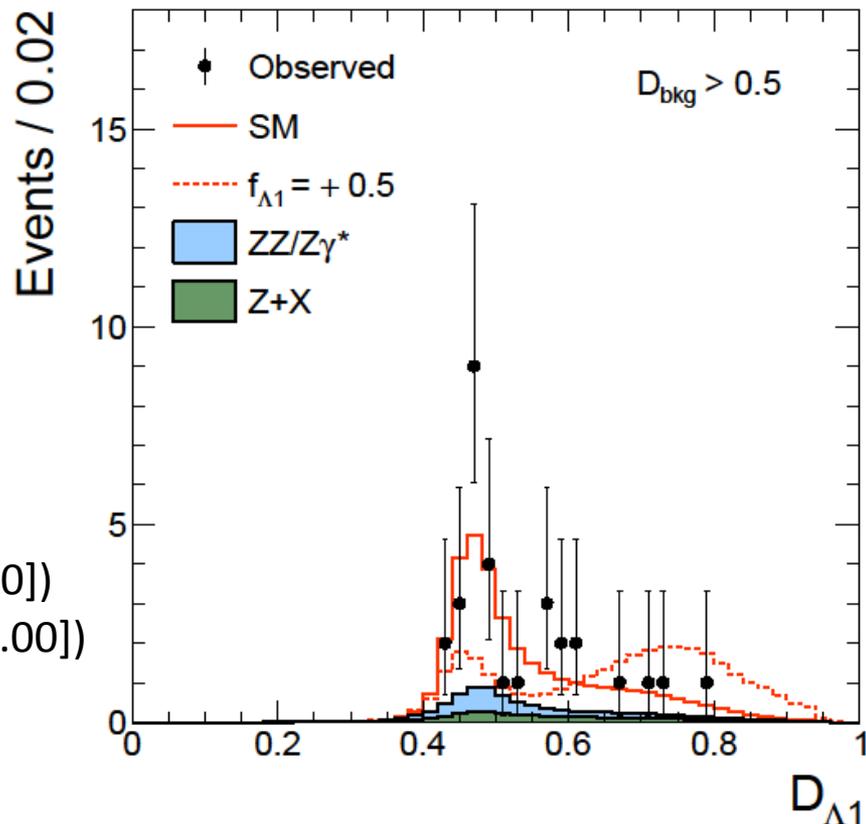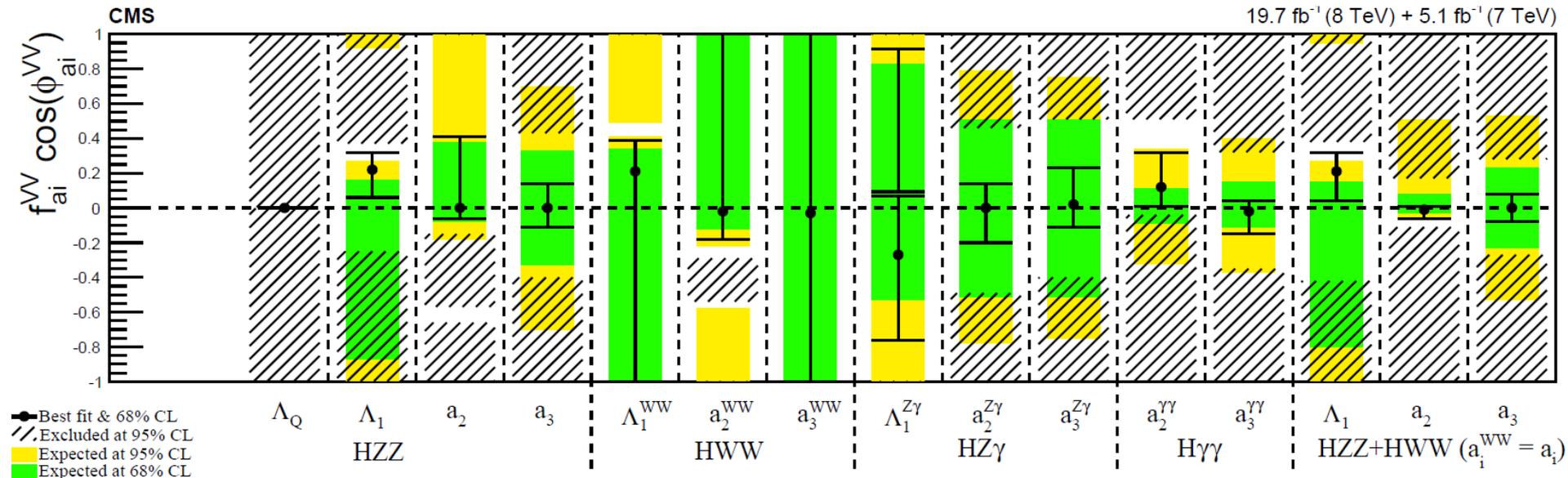# Run II: Anomalous couplings ($f_{\Lambda 1}$ result)

From 4l

Expected: $0.00^{+0.13}_{-0.69}$ (95% CL: [-1.00, 0.24]U[0.98, 1.00])
Observed: $-0.93^{+0.90}_{-0.16}$ (95% CL: [-1.00, 0.10]U[0.77,1.00])
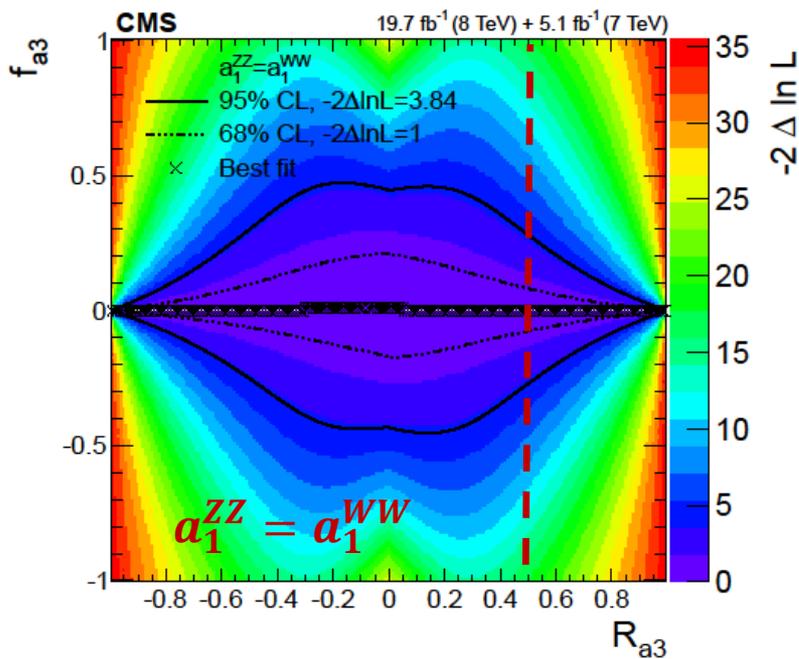
CMS-PAS-HIG-16-033

Run I: Anomalous couplings combination

Phys. Rev. D 92 (2015) 012004
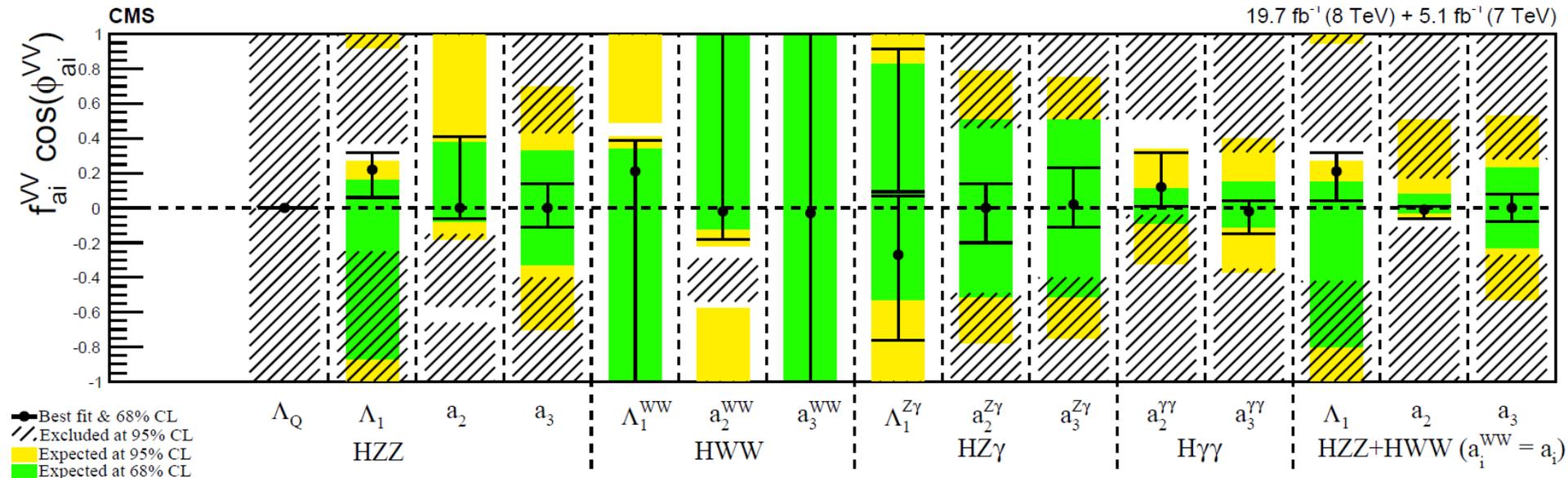
$4l + WW \to 2l2\nu$ combination ($+\gamma\gamma$ for spin-2 couplings)

$$R_{ai} = \frac{\left| \dfrac{a_i^{WW}/a_1^{WW}}{a_i^{ZZ}/a_1^{ZZ}} \right| \cdot \dfrac{a_i^{WW}/a_1^{WW}}{a_i^{ZZ}/a_1^{ZZ}}}{1 + \left(\dfrac{a_i^{WW}/a_1^{WW}}{a_i^{ZZ}/a_1^{ZZ}} \right)^2}$$
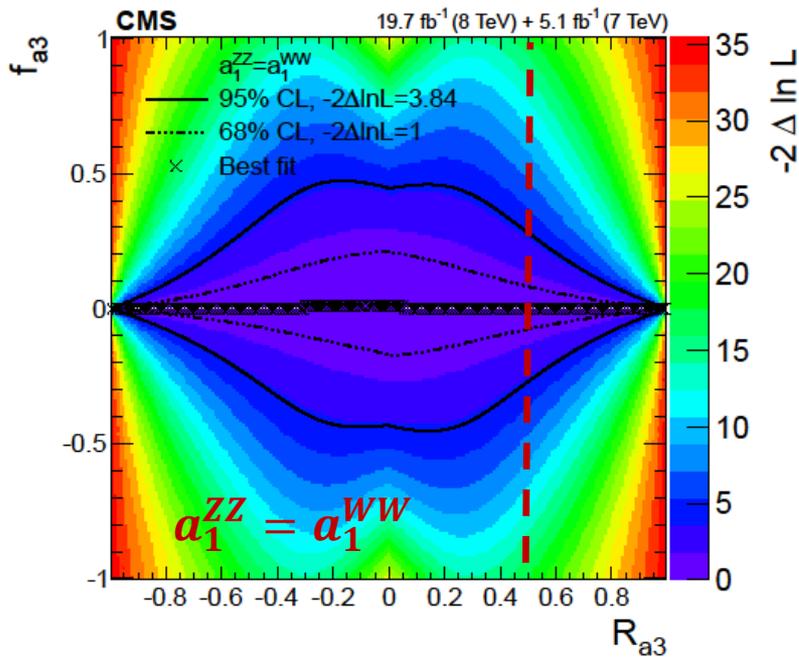
19

Run I: Anomalous couplings combination
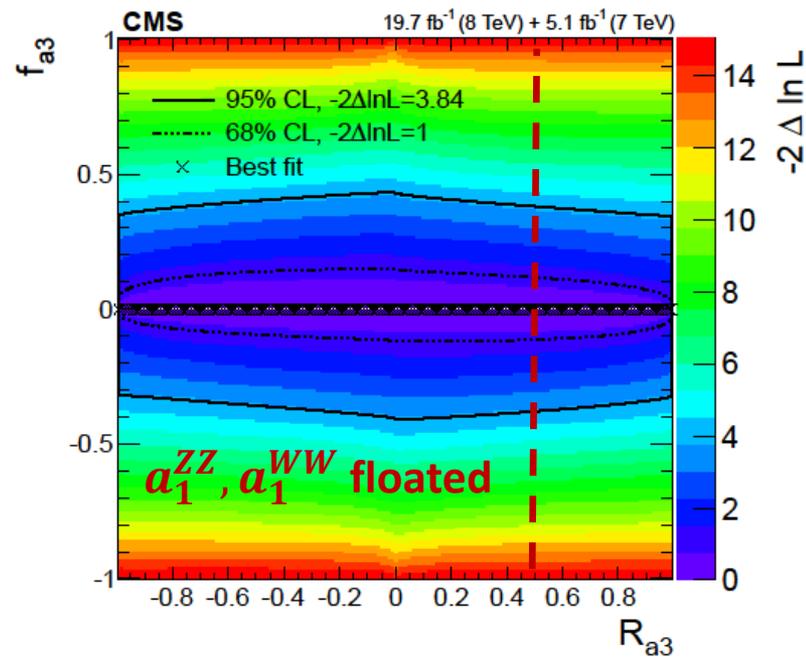

CMS   19.7 fb⁻¹ (8 TeV) + 5.1 fb⁻¹ (7 TeV)

Phys. Rev. D 92 (2015) 012004

$4l+WW \rightarrow 2l2\nu$ combination (+$\gamma\gamma$ for spin-2 couplings)

$VH \rightarrow b\bar{b}$
combination with
$H \rightarrow VV$

18.9 fb^{-1} (8 TeV)

CMS

correlated μ

- VH+VV observed
- VH+VV expected
- ZH+ZZ observed
- ZH+ZZ expected
- WH+WW observed
- WH+WW expected
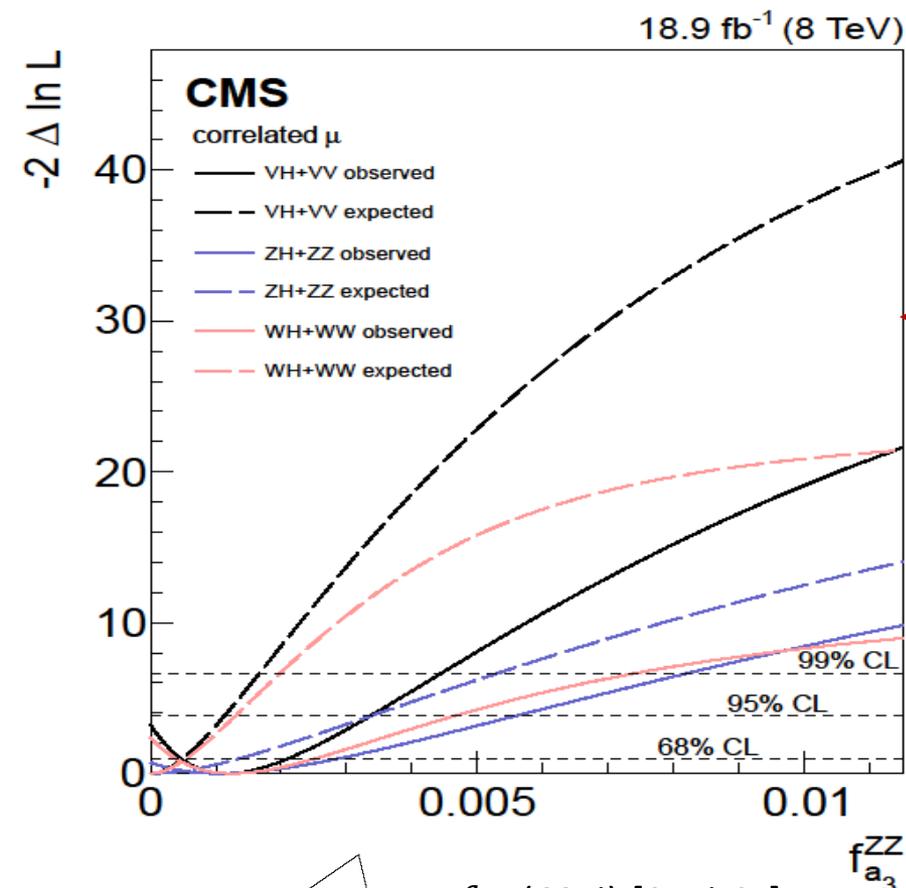
f_{a3} (68%) [95% CL]
$a_3^{ZZ}/a_1^{ZZ} = a_3^{WW}/a_1^{WW}$
$t\bar{t}H$ and $b\bar{b}H$ couplings ratio as in SM:
Expected: (0, 0.00050) [0,0.0011]
Observed: (0.00047, 0.0021) [0,0.0034]

99% CL
95% CL
68% CL

$f_{a_3}^{ZZ}$
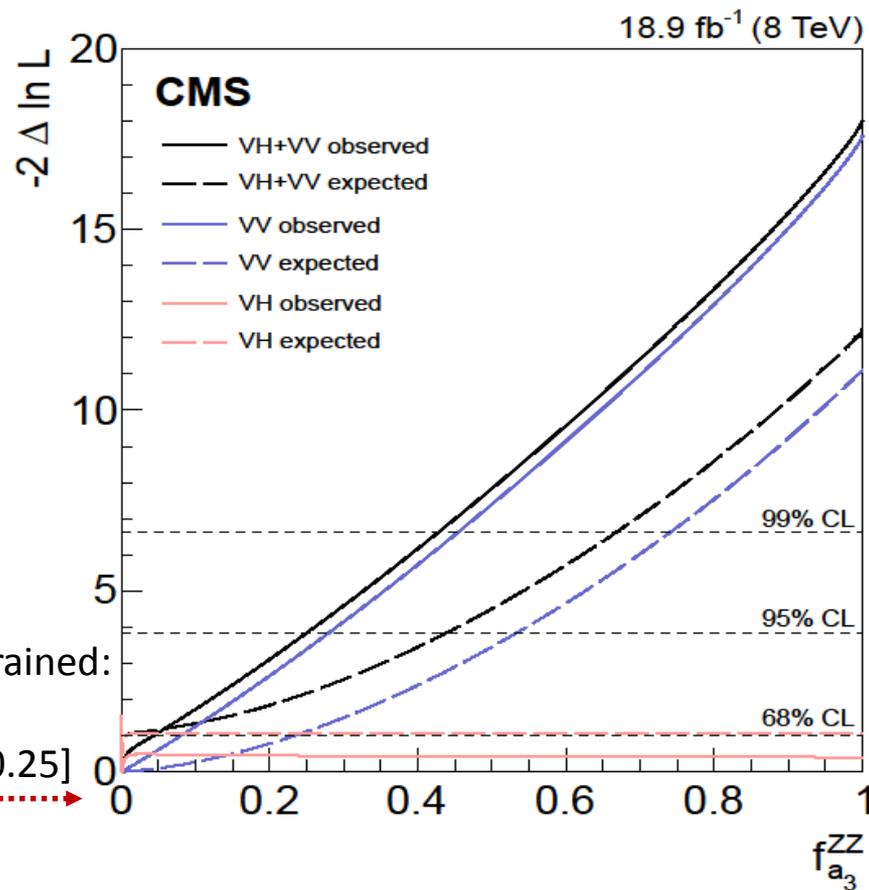
f_{a3} (68%) [95% CL]
$a_3^{ZZ}/a_1^{ZZ} = a_3^{WW}/a_1^{WW}$
$t\bar{t}H$ and $b\bar{b}H$ couplings unconstrained:
Expected: (0, 0.0062) [0,0.44]
Observed: (0.00011, 0.0021) [0,0.25]

18.9 fb^{-1} (8 TeV)

CMS

- VH+VV observed
- VH+VV expected
- VV observed
- VV expected
- VH observed
- VH expected

99% CL
95% CL
68% CL

$f_{a_3}^{ZZ}$

21