Measurements of the Higgs boson width and anomalous HVV couplings at CMS

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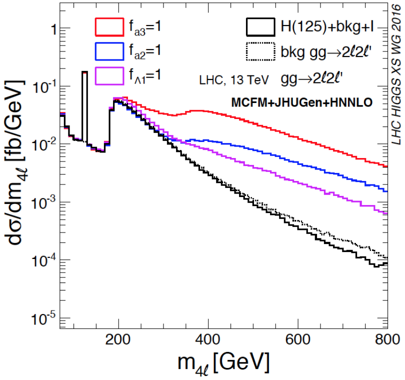
Introduction

The CMS and ATLAS experiments have set constraints on Higgs boson:

- $J^{PC} = 0^{++}$
- Allow small anomalous couplings to EW gauge boson.
- $\Gamma_H < 13$ MeV at 95% C.L.

Motivation

- Test the effects of possible anomalous HVV couplings.
- Measure the H boson decay width associated with HVV couplings.
- If measured width deviate from the SM: non-SM rates or BSM.



on-shell and off-shell

- Consider process $vv \to H \to 4l$ (vv=gg,WW,ZZ,Zγ,$\gamma\gamma$)
- The H boson production relationship between on-shell and off-shell regions has been considered.
- $\sigma^{on-shell}_{vv\to H\to 4l} \propto \mu_{vvH}$ and $\sigma^{off-shell}_{vv\to H\to 4l} \propto \mu_{vvH}\Gamma_H$
- on-shell: $105 < m_{4l} < 140 GeV$; off-shell:$m_{4l} > 220 GeV$.
- The constraints on Γ_H and anomalous couplings are set using off-shell production method.

Anomalous couplings

The scattering amplitude describing the interaction between a spin-zero the H boson and two spin-one gauge bosons VV is written:

$$A \sim \left[a_1^{VV} - \frac{\kappa_1^{VV} q_1^2 + \kappa_2^{VV} q_2^2}{\left(\Lambda_1^{VV}\right)^2} - \frac{\kappa_3^{VV} (q_1 + q_2)^2}{\left(\Lambda_Q^{VV}\right)^2} \right] \times m_{V1}^2 \epsilon_{V1}^* \epsilon_{V2}^* + a_2^{VV} f_{\mu\nu}^{*(1)} f^{*(2)\,\mu\nu} + a_3^{VV} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2)\,\mu\nu}.$$

The only leading tree-level contribution are $a_1^{ZZ} \neq 0$ and $a_1^{WW} \neq 0$.
We assume $a_1^{ZZ} = a_1^{WW}$.
non-zero a_3: CP-odd term.

Effective Fractional Cross Section

Most systematic uncertainties cancel when taking ratios to the total cross section, so use f_{ai} as measure parameters rather than a_i.

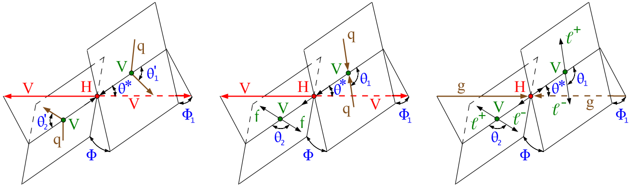
- Use a_i to denote a_2, a_3, $1/\Lambda_1$, $1/\Lambda_1^{Z\gamma}$.
- $f_{ai} = \frac{|a_i|^2\sigma_i}{\Sigma_j |a_j|^2\sigma_j}$,
- $\phi_{ai} = \arg\left(\frac{a_i}{a_1}\right)$.
- $f_{ai} = 0$: pure SM-like H boson.
- $f_{ai} = 1$: pure BSM particle.

Signal and Background, Data

- Consider three channels: $H \to 4e, 4\mu, 2e2\mu$.
- Background: $gg/qq \to zz/z\gamma^*/\gamma^*\gamma^*/Z \to 4l$.

- Data: 35.9 fb^{-1}(2016) and 41.5 fb^{-1}(2017) at 13 TeV
- Combine with earlier data: 7 TeV(2011), 8 TeV(2012) and 13 TeV(2015).

Kinematic Variables



13 kinematic observables are defined for the $2 \to 6$ associated production process with subsequent H boson decay to a four-fermion final state.

- $H \to 4f$: $\boldsymbol{\Omega}^{\text{decay}} = \{\theta_1, \theta_2, \Phi, m_1, m_2, m_{4f}\}$,
- Producition: $\boldsymbol{\Omega}^{\text{prod}} = \{\theta^*, \Phi_1\}$.
- VBF: $\boldsymbol{\Omega}^{\text{assoc, }VBF} = \{\theta_1^{VBF}, \theta_2^{VBF}, \Phi^{VBF}, q_1^{2,VBF}, q_2^{2,VBF}\}$
- VH: $\boldsymbol{\Omega}^{\text{assoc, }VH} = \{\theta_1^{VH}, \theta_2^{VH}, \Phi^{VH}, q_1^{2,VH}, q_2^{2,VH}\}$

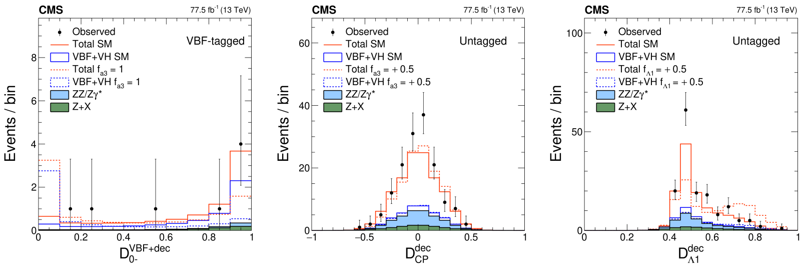
Discriminants

- It is a challenging task to perform an optimal analysis in a multidimensional space of observables.
- The MELA approach is designed to reduce the number of observables to the minimum while retaining all essential information.
- Two types of discriminants were defined for either the production or decay process.

$$\mathcal{D}_{\rm alt}\left(\boldsymbol{\Omega}\right) = \frac{\mathcal{P}_{\sf sig}\left(\boldsymbol{\Omega}\right)}{\mathcal{P}_{\sf sig}\left(\boldsymbol{\Omega}\right) + \mathcal{P}_{\rm alt}\left(\boldsymbol{\Omega}\right)},$$

$$\mathcal{D}_{\rm int}\left(\boldsymbol{\Omega}\right) = \frac{\mathcal{P}_{\rm int}\left(\boldsymbol{\Omega}\right)}{2\,\sqrt{\mathcal{P}_{\sf sig}\left(\boldsymbol{\Omega}\right)\ \mathcal{P}_{\rm alt}\left(\boldsymbol{\Omega}\right)}}.$$

Distributions

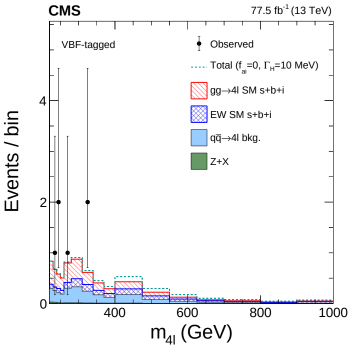


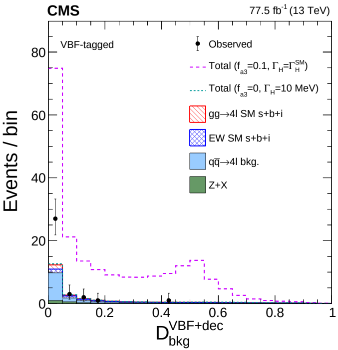
The distributions of events in on-shell region .

Categories and Discriminants

- The selected events are split into three categories: VBF-tagged, VH-tagged and untagged.
- D_{bkg} improves separation of the targeted signal production both against background and against the H boson gluon fusion production.
- D_{ai} separates the SM hypothesis $f_{ai} = 0$ from the alternative hypothesis $f_{ai} = 1$.

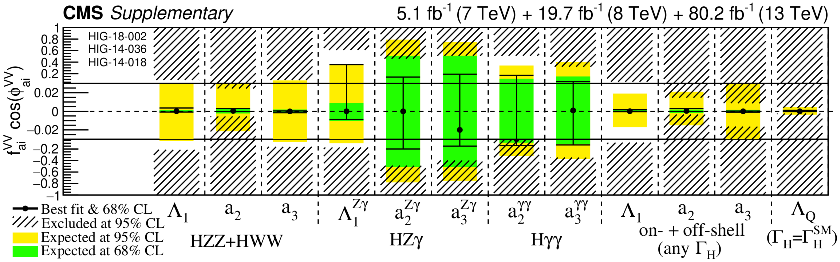
Distributions





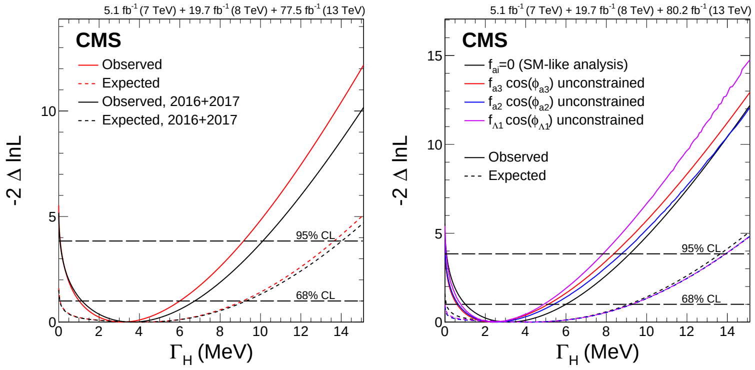
The distributions of events in off-shell region in VBF catogory.

Scan parameters



Allowd 68% C.L. and 95% C.L. interval for the anomalous coupling parameters $f_{ai}\cos(\phi_{ai})$

Constraint Width



In left plot, black: results of the SM-like couplings analysis using the data only from 2016 and 2017; red: results from the combination of Run 1 and Run 2, which do not include 2015 data. In right plot, the results is from combining Run 1 and Run 2 with 2015 data included.

Width Summary

Parameter	Observed	Expected
Γ_{H} (MeV)	$3.2^{+2.8}_{-2.2}$ $[0.08, 9.16]$	$4.1^{+5.0}_{-4.0}$ $[0.0, 13.7]$

Previous measurement: $\Gamma_H < 13$ Mev.
At 95% C.L. Γ_H is constricted to [0.08, 9.16] MeV.
Note: $\Gamma_H = 0.0$ is excluded at 95% C.L.

Summary

- Studies of on-shell and off-shell H boson production in the four-lepton final state are presented, using data from the CMS experiment.
- Joint constraints are set on the H boson total width and its anomalous couplings to electroweak vector bosons.

The End