Higgs-continuum and Higgs-Higgs interference effects in $gg \to VV$

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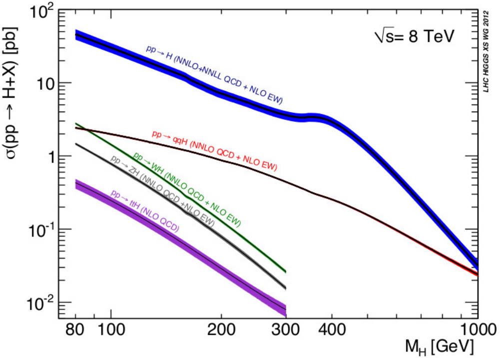
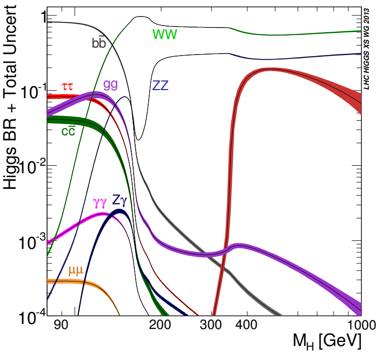
Outline

- Overview
- $gg \to H \to ZZ, WW$: sizeable off-shell Higgs signal contribution with large signal-background interference
- Interference effects for semileptonic decay modes
- Heavy Higgs - light Higgs - background interference effects
- Summary

SM Higgs boson production and decay at the LHC





Discovery publications:

ATLAS, *Observation of a new particle in the search for the SM Higgs boson ...*, Phys. Lett. B **716** (2012) 1.

CMS, *Observation of a new boson at a mass of 125 GeV ...*, Phys. Lett. B **716** (2012) 30.

And many papers with updates and more detailed characterisation (couplings, spin/CP), e.g.:

ATLAS, *Measurements of Higgs boson production and couplings in diboson final states ...*, Phys. Lett. B **726** (2013) 88; ATLAS, *Updated coupling measurements of the Higgs boson ...*, ATLAS-CONF-2014-009; ATLAS, *Evidence for the spin-0 nature of the Higgs boson ...*, Phys. Lett. B **726** (2013) 120.

CMS, *Observation of a new boson with mass near 125 GeV ...*, JHEP **1306** (2013) 081; CMS, *Study of the mass and spin-parity of the Higgs boson candidate via its decays to Z boson pairs*, Phys. Rev. Lett. **110** (2013) 081803; CMS, *Measurement of the properties of a Higgs boson in the four-lepton final state*, Phys. Rev. D **89** (2014) 092007.

SM Higgs boson production and decay at the LHC

Experimental studies have been informed by numerous theoretical papers (too many to list), summarised in Higgs physics reviews, e.g.:

A. Djouadi, *The Anatomy of electro-weak symmetry breaking. I: The Higgs boson in the standard model*, Phys. Rept. **457** (2008) 1.

A. Djouadi, *The Anatomy of electro-weak symmetry breaking. II. The Higgs bosons in the minimal supersymmetric model*, Phys. Rept. **459** (2008) 1.

A. Djouadi, *Higgs Physics: Theory*, Pramana **79** (2012) 513.

D. Carmi, A. Falkowski, E. Kuflik, T. Volansky and J. Zupan, *Higgs After the Discovery: A Status Report*, JHEP **1210** (2012) 196.

L. Reina, *TASI 2011: lectures on Higgs-Boson Physics*, arXiv:1208.5504 [hep-ph].

S. Dittmaier and M. Schumacher, *The Higgs Boson in the Standard Model - From LEP to LHC: Expectations, Searches, and Discovery of a Candidate*, Prog. Part. Nucl. Phys. **70** (2013) 1.

Higgs Working Group Report of the Snowmass 2013 Community Planning Study, arXiv:1310.8361 [hep-ex].

J. Ellis, *Higgs Physics*, arXiv:1312.5672 [hep-ph].

H. E. Logan, *TASI 2013 lectures on Higgs physics within and beyond the Standard Model*, arXiv:1406.1786 [hep-ph].

and the LHC Higgs Cross Section Working Group reports (also other WGs, see above):

LHC Higgs Cross Section WG, *Handbook of LHC Higgs Cross Sections: 1. Inclusive Observables*, CERN-2011-002.

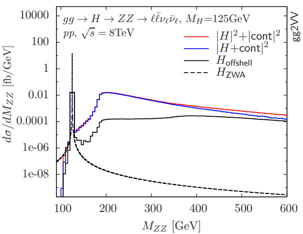
LHC Higgs Cross Section WG, *Handbook of LHC Higgs Cross Sections: 2. Differential Distributions*, CERN-2012-002.

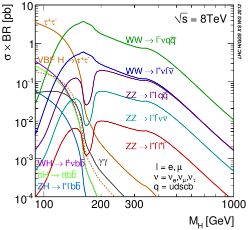
LHC Higgs Cross Section WG, *Handbook of LHC Higgs Cross Sections: 3. Higgs Properties*, CERN-2013-004.

LHC Higgs Cross Section WG, Interim recommendations to explore the coupling structure of a Higgs-like particle, arXiv:1209.0040 [hep-ph].

bottom line: no compelling Standard Model deviations found so far, search continues in Run 2

$gg \to H \to ZZ, WW$: sizeable off-shell Higgs signal with large signal-background interference





- $gg \to H \to VV \to 4\ell$ and $2\ell 2\nu$ signal-background interference very well studied at LO:

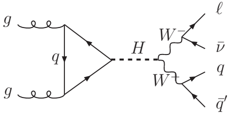
Glover, van der Bij (1989); Kao, Dicus (1991); Binoth, Ciccolini, NK, Krämer (2006) (gg2WW); Campbell, Ellis, Williams (2011) (MCFM); NK (2012) (gg2VV); NK, Passarino (2012); Campanario, Li, Rauch, Spira (2012); Bonvini, Caola, Forte, Melnikov, Ridolfi (2013); Caola, Melnikov (2013); NK (2013) (gg2VV); Campbell, Ellis, Williams (2013) (MCFM); Campbell, Ellis, Williams (2014) (MCFM); related interference effects: Bredenstein, Denner, Dittmaier, Weber (2006) (PROPHECY4f); YR3: Denner, Dittmaier, Mück (2013) and Anderson, Bolognesi, Caola, Gao, Gritsan, Martin, Melnikov, Schulze, Tran, Whitbeck, Zhou (2013); Chen, Cheng, Gainer, Korytov, Matchev, Milenovic, Mitselmakher, Park, Rinkevicius, Snowball (2013); Chen, Vega-Morales (2013)

- tools: MCFM-6.8, gg2VV-3.1.7 (parton-calculators and event generators)
- loop technology closing in on NLO calculation (bottleneck: heavy quark loop) Zurich and Karlsruhe groups
- gluon-fusion Higgs production and semileptonic decay: Dobrescu, Lykken (2010); Lykken, Martin, Winter (2012); Kao, Sayre (2012); ATLAS arXiv:1206.2443; ATLAS arXiv: 1206.6074; CMS PAS HIG-13-008

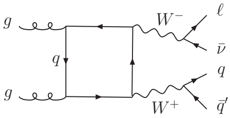
Interference effects for semileptonic decay modes

Charged currents (representative Feynman graphs)

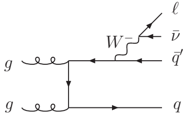
$$gg \to H \to W^-W^+ \to \ell\bar{\nu}q\bar{q}' \quad \text{(and c.c.)}$$



signal



loop background



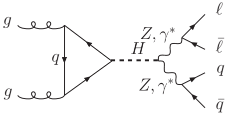
tree background

new feature of signal-background interference: large tree-level graphs contribute

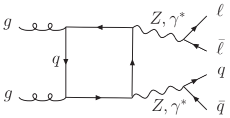
part of $pp \to (W \to \ell\bar{\nu})$+2 jet @ LO and $pp \to W \to \ell\bar{\nu}$ @ NNLO

Similarly: Neutral currents (representative Feynman graphs)

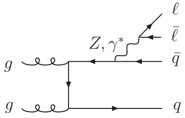
$$gg \to H \to ZZ \to \ell\bar{\ell}q\bar{q}$$



signal



loop background



tree background

tree background part of $pp \to (Z \to \ell\bar{\ell})$+2 jet @ LO and $pp \to Z \to \ell\bar{\ell}$ @ NNLO

Interference effects for semileptonic decay modes

Processes

$$gg \to H \to W^-W^+ \to \ell\bar{\nu}_\ell q_u\bar{q}_d$$
$$gg \to H \to W^+W^- \to \bar{\ell}\nu_\ell \bar{q}_u q_d$$
$$gg \to H \to ZZ \to \ell\bar{\ell}q_u\bar{q}_u$$
$$gg \to H \to ZZ \to \ell\bar{\ell}q_d\bar{q}_d$$

Input parameters and settings

pp, $\sqrt{s} = 8$ TeV, $M_H = 126$ GeV, other: default settings of gg2VV-3.1.6

Selection cuts

"minimal cuts": $p_{Tj} > 4$ GeV, $p_{T\ell} > 4$ GeV, for ZZ also: $\Delta R_{q\bar{q}} > 0.4$, $M_{q\bar{q}} > 4$ GeV, $M_{\ell\bar{\ell}} > 4$ GeV

LHC cuts: minimal cuts & $p_{T\ell} > 20$ GeV, $p_{Tj} > 20$ GeV, $\not{p}_T > 20$ GeV, $|\eta_\ell| < 2.5$, $|\eta_j| < 4.5$

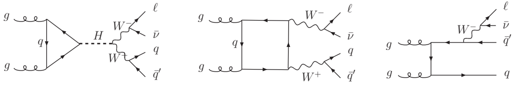
background suppression cuts: LHC cuts & $M_V - 5\Gamma_V < M_{jj} < M_V + 5\Gamma_V$

no jet clustering, technical cut: $p_{TV} > 1$ GeV to exclude numerical instabilities $\to \approx 0.3\%$ uncertainty on σ

Interference effects for semileptonic decay modes

Integrated results

using standard multi-channel phase space sampling and FeynArts/FormCalc/LoopTools adapted amplitude code, various tests



$$\mathcal{M} = \mathcal{M}_{signal} + \mathcal{M}_{background} = \mathcal{M}_{signal} + \mathcal{M}_{loop} + \mathcal{M}_{tree}$$

Notation for amplitude contributions to cross sections:

$$S \sim |\mathcal{M}_{signal}|^2$$
$$B_{full} \sim |\mathcal{M}_{background}|^2 = |\mathcal{M}_{loop} + \mathcal{M}_{tree}|^2$$
$$B_{loop} \sim |\mathcal{M}_{loop}|^2$$
$$B_{tree} \sim |\mathcal{M}_{tree}|^2$$
$$I_{full} \equiv I \sim 2\,\mathrm{Re}(\mathcal{M}^*_{signal}\mathcal{M}_{background})$$
$$I_{tree} \sim 2\,\mathrm{Re}(\mathcal{M}^*_{signal}\mathcal{M}_{tree})$$

Interference effects for semileptonic decay modes

Integrated results for $gg \to H \to W^-W^+ \to \ell\bar{\nu}_\ell q_u \bar{q}_d$ (minimal cuts):

$\lvert\mathcal{M}\rvert^2$	σ [fb]
S	$49.1(2)$
I_{tree}	-1.91
I_{full}	-8.02
$S + I_{tree}$	$47.21(6)$
$S + I_{full}$	$41.1(1)$
$\lvert S + I_{full}\rvert/S$	0.84
$\lvert S + I_{tree}\rvert/S$	0.96

$\lvert\mathcal{M}\rvert^2$	σ [fb]
B_{full}	$6.73(4) \cdot 10^4$
B_{tree}	$6.84(6) \cdot 10^4$
B_{loop}	$59.1(3)$
$B_{full}/(B_{tree} + B_{loop})$	0.98

Integrated results for $gg \to H \to W^-W^+ \to \ell\bar{\nu}_\ell q_u \bar{q}_d$ (LHC cuts):

$\lvert\mathcal{M}\rvert^2$	σ [fb]
S	$3.467(5)$
I_{tree}	0.0
I_{full}	-4.01
$S + I_{tree}$	$3.46(2)$
$S + I_{full}$	$-0.550(5)$
$\lvert S + I_{full}\rvert/S$	0.15
$\lvert S + I_{tree}\rvert/S$	1

$\lvert\mathcal{M}\rvert^2$	σ [fb]
B_{full}	$5.29(1) \cdot 10^3$
B_{tree}	$5.315(8) \cdot 10^3$
B_{loop}	$28.6(1)$
$B_{full}/(B_{tree} + B_{loop})$	0.98

Interference effects for semileptonic decay modes

Integrated results for $gg \to H \to W^-W^+ \to \ell\bar{\nu}_\ell q_u\bar{q}_d$ (bkg. suppression cuts):

$\lvert\mathcal{M}\rvert^2$	σ [fb]
S	$2.184(1)$
I_{tree}	-0.024
I_{full}	-3.8
$S + I_{tree}$	$2.16(2)$
$S + I_{full}$	$-1.650(6)$
$\lvert S + I_{full}\rvert/S$	0.75
$\lvert S + I_{tree}\rvert/S$	0.99

$\lvert\mathcal{M}\rvert^2$	σ [fb]
B_{full}	$802(2)$
B_{tree}	$796(1)$
B_{loop}	$27.2(1)$
$B_{full}/(B_{tree} + B_{loop})$	0.97

Integrated results for $gg \to H \to W^+W^- \to \bar{\ell}\nu_\ell \bar{q}_u q_d$ (minimal cuts):

$\lvert\mathcal{M}\rvert^2$	σ [fb]
S	$48.94(8)$
I_{tree}	-1.47
I_{full}	-7.84
$S + I_{tree}$	$47.16(9)$
$S + I_{full}$	$41.1(1)$
$\lvert S + I_{full}\rvert/S$	0.84
$\lvert S + I_{tree}\rvert/S$	0.96

$\lvert\mathcal{M}\rvert^2$	σ [fb]
B_{full}	$7.04(1) \cdot 10^4$
B_{tree}	$6.82(3) \cdot 10^4$
B_{loop}	$59.6(4)$
$B_{full}/(B_{tree} + B_{loop})$	1.03

Interference effects for semileptonic decay modes

Integrated results for $gg \to H \to W^+W^- \to \bar{\ell}\nu_\ell\bar{q}_u q_d$ (LHC cuts):

$\lvert\mathcal{M}\rvert^2$	σ [fb]
S	$3.464(1)$
I_{tree}	-0.01
I_{full}	-4.016
$S + I_{tree}$	$3.45(2)$
$S + I_{full}$	$-0.552(4)$
$\lvert S + I_{full}\rvert/S$	0.159
$\lvert S + I_{tree}\rvert/S$	0.99

$\lvert\mathcal{M}\rvert^2$	σ [fb]
B_{full}	$5.330(6) \cdot 10^4$
B_{tree}	$5.32(1) \cdot 10^4$
B_{loop}	$28.8(1)$
$B_{full}/(B_{tree} + B_{loop})$	0.99

Integrated results for $gg \to H \to W^+W^- \to \bar{\ell}\nu_\ell\bar{q}_u q_d$ (bkg. suppression cuts):

$\lvert\mathcal{M}\rvert^2$	σ [fb]
S	$2.1831(7)$
I_{tree}	-0.03
I_{full}	-3.82
$S + I_{tree}$	$2.15(1)$
$S + I_{full}$	$-1.64(1)$
$\lvert S + I_{full}\rvert/S$	0.75
$\lvert S + I_{tree}\rvert/S$	0.98

$\lvert\mathcal{M}\rvert^2$	σ [fb]
B_{full}	$786.2(8)$
B_{tree}	$797(1)$
B_{loop}	$27.5(1)$
$B_{full}/(B_{tree} + B_{loop})$	0.95

Interference effects for semileptonic decay modes

Integrated results for $gg \to H \to ZZ \to \ell\bar{\ell}q_u\bar{q}_u$ (minimal cuts):

$\|\mathcal{M}\|^2$	σ [fb]
S	$1.237(4)$
I_{tree}	0.458
I_{full}	-0.165
$S + I_{tree}$	$1.695(7)$
$S + I_{full}$	$1.072(2)$
$\|S + I_{full}\|/S$	0.86
$\|S + I_{tree}\|/S$	1.37

$\|\mathcal{M}\|^2$	σ [fb]
B_{full}	$3.33(2) \cdot 10^4$
B_{tree}	$3.40(3) \cdot 10^4$
B_{loop}	$1.90(1)$
$B_{full}/(B_{tree} + B_{loop})$	0.98

Integrated results for $gg \to H \to ZZ \to \ell\bar{\ell}q_u\bar{q}_u$ (LHC cuts):

$\|\mathcal{M}\|^2$	σ [fb]
S	$0.168(1)$
I_{tree}	0.008
I_{full}	-0.17
$S + I_{tree}$	$0.176(1)$
$S + I_{full}$	$-0.0023(1)$
$\|S + I_{full}\|/S$	0.01
$\|S + I_{tree}\|/S$	1.04

$\|\mathcal{M}\|^2$	σ [fb]
B_{full}	$381(7)$
B_{tree}	$479(9)$
B_{loop}	$0.456(1)$
$B_{full}/(B_{tree} + B_{loop})$	0.795

Interference effects for semileptonic decay modes

Integrated results for $gg \to H \to ZZ \to \ell\bar{\ell}q_u\bar{q}_u$ (bkg. suppression cuts):

$\|\mathcal{M}\|^2$	σ [fb]
S	$0.1420(4)$
I_{tree}	-0.001
I_{full}	-0.1679
$S + I_{tree}$	$0.141(3)$
$S + I_{full}$	$-0.0259(1)$
$\|S + I_{full}\|/S$	0.18
$\|S + I_{tree}\|/S$	0.99

$\|\mathcal{M}\|^2$	σ [fb]
B_{full}	$37.1(3)$
B_{tree}	$79.3(2)$
B_{loop}	$0.4249(9)$
$B_{full}/(B_{tree} + B_{loop})$	0.46

Integrated results for $gg \to H \to ZZ \to \ell\bar{\ell}q_d\bar{q}_d$ (minimal cuts):

$\|\mathcal{M}\|^2$	σ [fb]
S	$1.858(6)$
I_{tree}	-0.168
I_{full}	-0.358
$S + I_{tree}$	$1.69(1)$
$S + I_{full}$	$1.50(2)$
$\|S + I_{full}\|/S$	0.81
$\|S + I_{tree}\|/S$	0.91

$\|\mathcal{M}\|^2$	σ [fb]
B_{full}	$3.11(4) \cdot 10^4$
B_{tree}	$3.38(7) \cdot 10^4$
B_{loop}	$1.71(4)$
$B_{full}/(B_{tree} + B_{loop})$	0.92

Interference effects for semileptonic decay modes

Integrated results for $gg \to H \to ZZ \to \ell\bar{\ell}q_d\bar{q}_d$ (LHC cuts):

$\|\mathcal{M}\|^2$	σ [fb]
S	$0.2200(8)$
I_{tree}	0.005
I_{full}	-0.146
$S + I_{tree}$	$0.225(3)$
$S + I_{full}$	$0.074(1)$
$\|S + I_{full}\|/S$	0.33
$\|S + I_{tree}\|/S$	1.02

$\|\mathcal{M}\|^2$	σ [fb]
B_{full}	$378(3)$
B_{tree}	$458(4)$
B_{loop}	$0.457(3)$
$B_{full}/(B_{tree} + B_{loop})$	0.82

Integrated results for $gg \to H \to ZZ \to \ell\bar{\ell}q_d\bar{q}_d$ (bkg. suppression cuts):

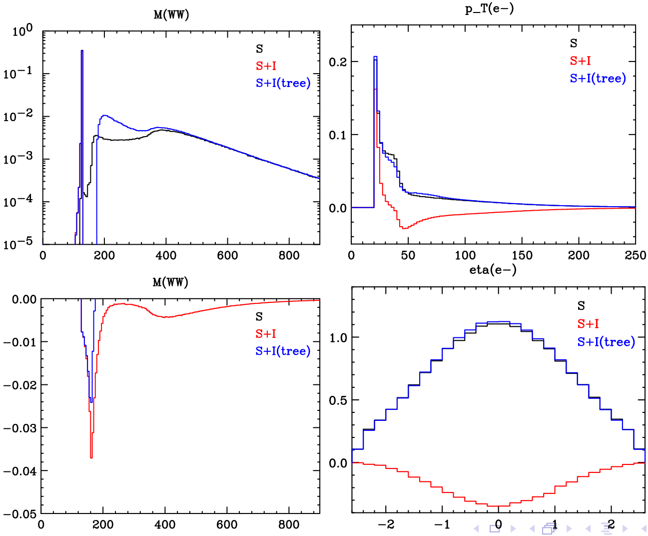
$\|\mathcal{M}\|^2$	σ [fb]
S	$0.1815(3)$
I_{tree}	-0.001
I_{full}	-0.15
$S + I_{tree}$	$0.180(2)$
$S + I_{full}$	$0.0354(5)$
$\|S + I_{full}\|/S$	0.195
$\|S + I_{tree}\|/S$	0.99

$\|\mathcal{M}\|^2$	σ [fb]
B_{full}	$37.1(1)$
B_{tree}	$80.3(1)$
B_{loop}	$0.458(3)$
$B_{full}/(B_{tree} + B_{loop})$	0.46

Interference effects for semileptonic decay modes

Differential results

$gg \to H \to W^- W^+ \to e^- \bar{\nu}_e u \bar{d}$, LHC cuts, fb/GeV

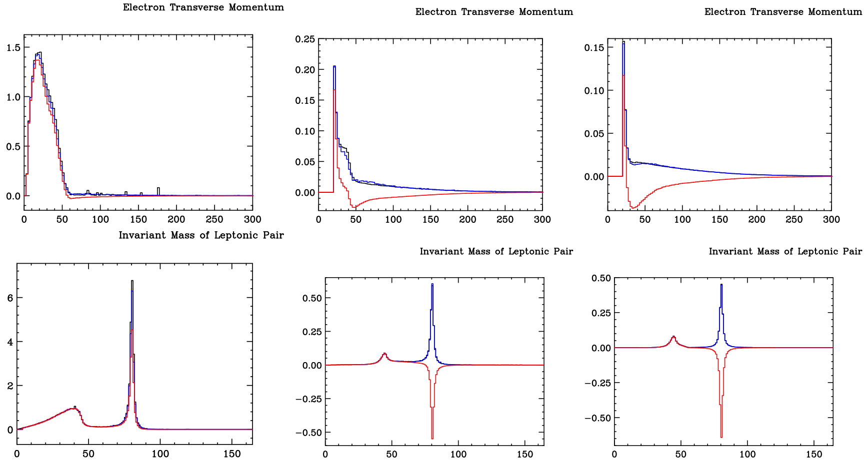


Interference effects for semileptonic decay modes

Differential results

$$gg \to H \to W^-W^+ \to e^-\bar{\nu}_e u\bar{d}$$

left: minimal cuts, centre: LHC cuts, right: bkg. suppression cuts

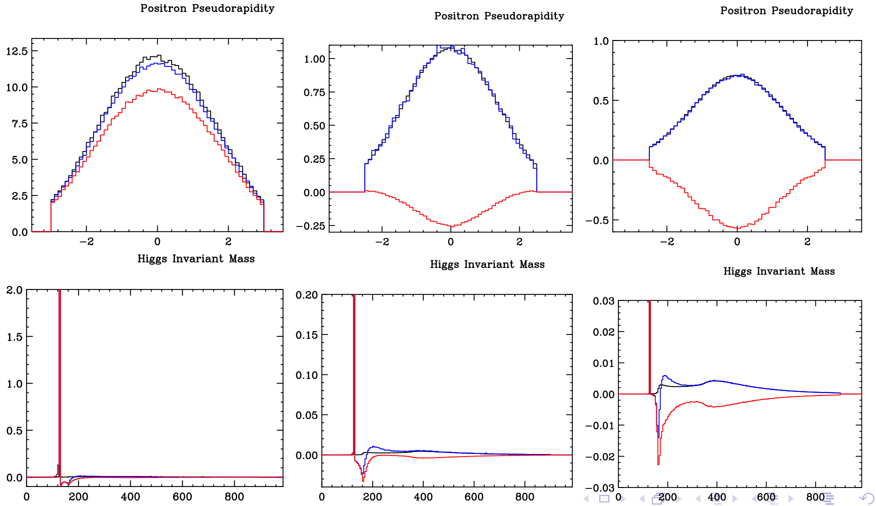


Interference effects for semileptonic decay modes

Differential results

$$gg \to H \to W^+W^- \to e^+\nu_e\bar{u}d$$

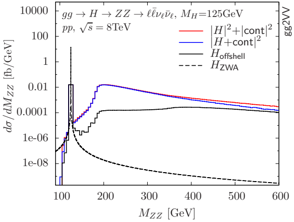
left: minimal cuts, centre: LHC cuts, right: bkg. suppression cuts

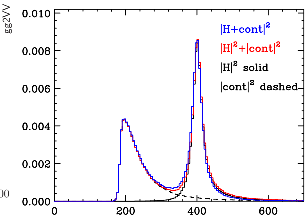


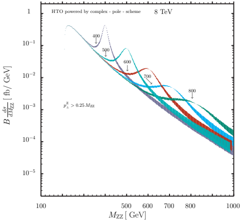
Heavy Higgs - light Higgs - continuum interference

explore effects by assuming a heavy SM Higgs in addition to a SM Higgs at $M_H = 126$ GeV

$$\mu_R = \mu_F = M_{VV}/2$$







right fig.: G. Passarino (arXiv:1206.3824)

What is the impact of interference with the far-offshell tail of the 126 GeV Higgs for a heavy Higgs of 300, 600 or 900 GeV?

Notation for amplitude contributions to cross sections $(X, Y \in \{heavy, light, cont\})$:

$$\sigma_{full} \sim \left|\mathcal{M}_{heavy} + \mathcal{M}_{light} + \mathcal{M}_{cont}\right|^2$$

$$\sigma_X \sim |\mathcal{M}_X|^2$$

$$\sigma_{X+Y} \sim |\mathcal{M}_X + \mathcal{M}_Y|^2$$

$$I_{X,Y} \sim 2\,\text{Re}(\mathcal{M}_X^* \mathcal{M}_Y)$$

Heavy Higgs - light Higgs - continuum interference

$$gg \to H \to W^-W^+ \to \ell\bar{\nu}_\ell\bar{\ell}'\nu_{\ell'}$$ (single flavour)

cuts: $p_{T\ell} > 4$ GeV

$M_{H,heavy}$ [GeV]	300	600	900
σ_{heavy} [fb]	$11.867(6)$	$1.4249(7)$	$0.14863(8)$
σ_{light} [fb]	$16.75(5)$		
σ_{cont} [fb]	$16.00(5)$		
σ_{full} [fb]	$44.30(4)$	$33.49(4)$	$32.04(4)$
$I_{heavy,cont}/\sigma_{heavy}$	$-0.026(7)$	$-0.48(6)$	$-5.7(6)$
$I_{heavy,light}/\sigma_{heavy}$	$0.077(5)$	$-0.14(4)$	$-0.7(4)$
$I_{heavy,light}/\sigma_{heavy+light}$	$0.031(2)$	$-0.011(3)$	$-0.006(3)$

Heavy Higgs - light Higgs - continuum interference

$$gg \to H \to W^-W^+ \to \ell\bar{\nu}_\ell\bar{\ell}'\nu_{\ell'}$$ (single flavour)

cuts: $p_{T\ell} > 4$ GeV and $|M_{WW} - M_{H,heavy}| < \Gamma_{H,heavy}$ (theoretical)

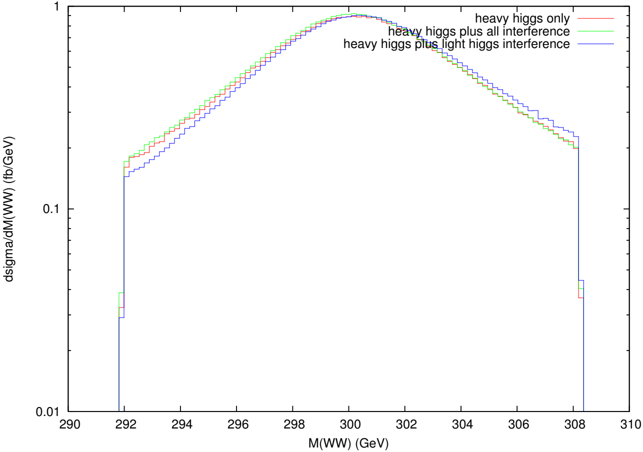
(no “window-type” cut applied by ATLAS)

$M_{H,heavy}$ [GeV]	300	600	900
σ_{heavy} [fb]	$8.086(4)$	$1.1588(6)$	$0.12570(7)$
σ_{light} [fb]	$0.008513(6)$	$0.07591(5)$	$0.05599(5)$
σ_{cont} [fb]	$0.4229(3)$	$0.2444(2)$	$0.1493(1)$
σ_{full} [fb]	$8.692(3)$	$0.2528(1)$	$0.2428(2)$
$I_{heavy,cont}/\sigma_{heavy}$	$0.0216(6)$	$-1.0583(8)$	$-0.701(2)$
$I_{heavy,light}/\sigma_{heavy}$	$0.0018(6)$	$-0.0569(6)$	$-0.4187(8)$
$I_{heavy,light}/\sigma_{heavy+light}$	$0.0018(6)$	$-0.0564(6)$	$-0.4077(8)$

Heavy Higgs - light Higgs - continuum interference

$$gg \to H \to W^-W^+ \to \ell\bar{\nu}_\ell\bar{\ell}'\nu_{\ell'}$$ (single flavour)

cuts: $p_{T\ell} > 4$ GeV and $|M_{WW} - M_{H,heavy}| < \Gamma_{H,heavy}$ (theoretical)



Higgs-Higgs interference is destructive (constructive) below (above) $M_{H,heavy}$

opposite behaviour than Higgs-cont interference!

Heavy Higgs - light Higgs - continuum interference

$$gg \to H \to ZZ \to \ell\bar{\ell}\ell'\bar{\ell}'$$ (single flavour)

cuts: $M_{\ell\bar{\ell}}, M_{\ell'\bar{\ell}'} > 4$ GeV, $p_{T\ell} > 4$ GeV

$M_{H,heavy}$ [GeV]	300	600	900
σ_{heavy} [fb]	1.0040(4)	0.13094(5)	0.013847(6)
σ_{light} [fb]	0.343(6)		
σ_{cont} [fb]	0.53(4)		
σ_{full} [fb]	2.71(3)	1.57(2)	1.48(3)
$I_{heavy,cont}/\sigma_{heavy}$	0.83(5)	4.3(3)	4.3(3)$e+01$
$I_{heavy,light}/\sigma_{heavy}$	0.136(6)	0.23(5)	2.8(4)
$I_{heavy,light}/\sigma_{heavy+light}$	0.092(4)	0.06(2)	0.10(2)

Heavy Higgs - light Higgs - continuum interference

$$gg \to H \to ZZ \to \ell\bar{\ell}\ell'\bar{\ell}'$$ (single flavour)

cuts: $M_{\ell\bar{\ell}}, M_{\ell'\bar{\ell}'} > 4$ GeV, $p_{T\ell} > 4$ GeV and $|M_{ZZ} - M_{H,heavy}| < \Gamma_{H,heavy}$

(no “window-type” cut applied by ATLAS(?))

$M_{H,heavy}$ [GeV]	300	600	900
σ_{heavy} [fb]	$0.6811(3)$	$0.10668(5)$	$0.011761(6)$
σ_{light} [fb]	$0.001257(2)$	$0.006813(6)$	$0.005244(3)$
σ_{cont} [fb]	$0.0030(9)$	$0.0023(3)$	$0.0022(2)$
σ_{full} [fb]	$0.7483(5)$	$0.1114(3)$	$0.0142(2)$
$I_{heavy,cont}/\sigma_{heavy}$	$0.092(2)$	$-0.042(4)$	$-0.42(2)$
$I_{heavy,light}/\sigma_{heavy}$	$0.0011(6)$	$-0.0531(6)$	$-0.4157(6)$
$I_{heavy,light}/\sigma_{heavy+light}$	$0.0011(6)$	$-0.0526(6)$	$-0.4035(6)$

Heavy Higgs - light Higgs interference effects can be mitigated with “window-type” cuts, but are still significant for very large Higgs masses ($M_H \gtrsim 600$ GeV), especially in the $gg \to H \to ZZ$ channel

Summary

- $gg \to H \to ZZ, WW$: sizeable off-shell Higgs signal contribution with large signal-background interference (should be taken into account, complementary physics information)
- $gg \to H \to ZZ, WW \to 4$ leptons: interference studied in great detail & tools/events available (caveat: LO); NLO calculation hard, but on agena/ in progress, also: soft approximation/resummation improvements
- Semileptonic channels $gg \to H \to WW \to \ell\nu qq'$ and $gg \to H \to ZZ \to \ell\bar{\ell}q\bar{q}$ contribute to ongoing Higgs analysis
- First analysis of interference effects in semileptonic channels (new feature: interfering tree-level background): contribution of tree amplitude to (large) full interference is subleading and $< 2\%$ when on-shell hadronic decay cuts are applied to suppress tree-level background (compensation at differential level!, p. 17)
- First analysis of heavy Higgs - light Higgs interference effects in $gg \to H \to VV$: can be significant compared to Higgs-continuum interference (can be eliminated with "window" cut, but only for fairly small $\frac{\Gamma_H}{M_H}$, i.e. $M_H \lesssim 400$ GeV)
- outlook: improved amplitude implementation in gg2VV, more detailed phenomenological studies