$gg \to ZZ$ Higgs-continuum interference and zero-width approximation failure

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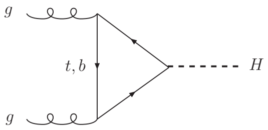
HP^2 High Precision for Hard Processes at the LHC Workshop
MPI Munich
September 6, 2012

Outline

- Introduction
- Zero-width approximation
- Light Higgs: Inclusive analysis
- Light Higgs: Analysis with selection cuts
- Heavy Higgs: Interference
- Summary

Gluon-fusion Higgs production



Leading order (LO), loop-induced   Georgi, Glashow, Machacek, Nanopoulos (1978)

Next-to-leading order (NLO), $m_t \to \infty$ approx. (few percent accuracy)   Djouadi, Spira, Zerwas (1991); Dawson (1991)

NLO, full m_t, m_b dependence, LHC: $K - 1 \sim$ 80–100%   Graudenz, Spira, Zerwas (1993); Spira, Djouadi, Graudenz, Zerwas (1995)

Next-to-next-to-leading order (NNLO), $m_t \to \infty$ approx., NNLO/NLO – 1 $\sim$ 25%   Harlander (2000); Catani, de Florian, Grazzini (2001); Harlander, Kilgore (2001, 2002); Anastasiou, Melnikov (2002); Ravindran, Smith, van Neerven (2003); Blümlein, Ravindran (2005); Catani, Grazzini (2007)

soft-gluon resummation, $\leq$NNLL, + 7–9%(6–7%) at 7(14) TeV   Catani, de Florian, Grazzini, Nason (2003)

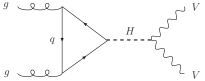
leading soft contributions @ NNNLO   Moch, Vogt (2005); Laenen, Magnea (2006); Idilbi, Ji, Ma, Yuan (2006); Ravindran (2006)

accuracy of $m_t \to \infty$ approx. @ NNLO (<1% if $M_H \lesssim$ 300 GeV)   Marzani, Ball, Del Duca, Forte, Vicini (2008); Harlander, Ozeren (2009); Harlander, Mantler, Marzani, Ozeren (2010); Pak, Rogal, Steinhauser (2009, 2010); Anastasiou, Boughezal, Petriello (2009)

Electroweak corrections: +5% (M_H = 120 GeV) to –2% (M_H = 300 GeV)   Djouadi, Gambino (1994); Aglietti, Bonciani, Degrassi, Vicini (2004); Degrassi, Maltoni (2004); Actis, Passarino, Sturm, Uccirati (2009); Actis, Passarino, Sturm, Uccirati (2008); Anastasiou, Boughezal, Petriello (2008); Keung, Petriello (2009); Brein (2010)

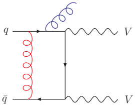
Recent updates   de Florian, Grazzini (2009); Baglio, Djouadi (2010, 2011); Baglio, Djouadi, Ferrag, Godbole (2011); Catani, Grazzini (2011); Spira (HIGLU update); de Florian, Ferrera, Grazzini, Tommasini (2011, 2012) (HRes); LHCHXS2 (2012); Anastasiou, Buehler, Herzog, Lazopoulos (2012) (ihixs); de Florian, Grazzini (2012)

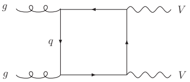
Gluon-fusion Higgs $\to VV$ and continuum VV production



$gg \to H \to VV$ searches Dittmar, Dreiner (1996); Davatz, Giolo-Nicollerat, Zanetti (2006); Mellado, Quayle, Sau Lan Wu (2007); Davatz, Dittmar, Giolo-Nicollerat (2007); Davatz (2007); Quayle (2008); Mellado, Ruan, Zhang (2011)

QCD corrections/shower MCs for $gg \to H \to VV$ searches Cranmer, Mellado, Quayle, Sau Lan Wu (2003); Davatz, Dissertori, Dittmar, Grazzini, Pauss (2004); Davatz, Stöckli, Anastasiou, Dissertori, Dittmar, Melnikov, Petriello (2006); Davatz, Dittmar, Pauss (2006); Grazzini (2006, 2008); Anastasiou, Dissertori, Stöckli (2007); Anastasiou, Dissertori, Stöckli, Webber (2008); Frederix, Grazzini (2008); Anastasiou, Dissertori, Grazzini, Stöckli, Webber (2009)





$q\bar{q} \to VV$ (LO, NLO, decays) Brown, Mikaelian (1979); Stirling, Kleiss, Ellis (1985); Gunion, Kunszt (1986); Muta, Najima, Wakaizumi (1986); Berends, Kleiss, Pittau (1994); Ohnemus (1991); Mele, Nason, Ridolfi (1991); Ohnemus, Owens (1991); Frixione (1993); Ohnemus (1994); Dixon, Kunszt, Signer (1998, 1999); Campbell, Ellis (1999) (MCFM); Campbell, Ellis, Williams (2011) (MCFM); Melia, Nason, Röntsch, Zanderighi (2011) (POWHEG BOX)

$gg \to VV$ and $gg \to VVg$ [loop induced] (LO, decays) Dicus, Kao, Repko (1987); Glover, van der Bij (1989); Kao, Dicus (1991); Matsuura, v.d. Bij (1991); Zecher, Matsuura, v.d. Bij (1994); Dührssen, Jakobs, v.d. Bij, Marquard (2005); Binoth, Ciccolini, NK, Krämer (2005, 2006) (gg2WW); Binoth, NK, Mertsch (2008) (gg2ZZ); Campbell, Ellis, Williams (2011) (MCFM); Frederix, Frixione, Hirschi, Maltoni, Pittau, Torrielli (2011) (aMC@NLO); Melia, Melnikov, Rontsch, Schulze, Zanderighi (2012) (MCFM); NK (2012) (gg2VV); Agrawal, Shivaji (2012); VBFNLO-2.6

Higgs-continuum VV interference Glover, van der Bij (1989); Binoth, Ciccolini, NK, Krämer (2006) (gg2WW); Campbell, Ellis, Williams (2011) (MCFM); NK (2012) (gg2VV); Passarino (2012); NK, Passarino (2012); VBFNLO-2.6; S.P. Martin (2012, $\gamma\gamma$)

Zero-width approximation (ZWA)
a.k.a. narrow-width approximation (NWA)

for scalar particle:

$$D(q^2) = \frac{1}{(q^2 - M^2)^2 + \Gamma^2 M^2} = \frac{\pi}{M\,\Gamma}\,\delta\left(q^2 - M^2\right)$$

$$+ PV\left[\frac{1}{(q^2 - M^2)^2}\right] + \sum_{n=0}^{N} c_n(\alpha)\,\delta_n\left(q^2 - M^2\right)$$

with $\delta_n(x) := (-1)^n/n!\,\delta^{(n)}(x)$

in limit $\Gamma \to 0$: $\boxed{D(q^2) \sim K\,\delta(q^2 - M^2)}$ with $K = \frac{\pi}{M\Gamma} = \int_{-\infty}^{+\infty} dq^2\, D(q^2)$

common error estimate $\mathcal{O}(\Gamma/M)$ not reliable:

$$\sigma = \frac{1}{2s}\left[\int_{q^2_{\text{min}}}^{q^2_{\text{max}}} \frac{dq^2}{2\pi}\left(\int d\phi_p |\mathcal{M}_p(q^2)|^2 D(q^2) \int d\phi_d |\mathcal{M}_d(q^2)|^2\right)\right]$$

$$\sigma_{\text{ZWA}} = \frac{1}{2s}\left(\int d\phi_p |\mathcal{M}_p(M^2)|^2\right)\left(\int_{-\infty}^{\infty} \frac{dq^2}{2\pi} D(q^2)\right)\left(\int d\phi_d |\mathcal{M}_d(M^2)|^2\right)$$

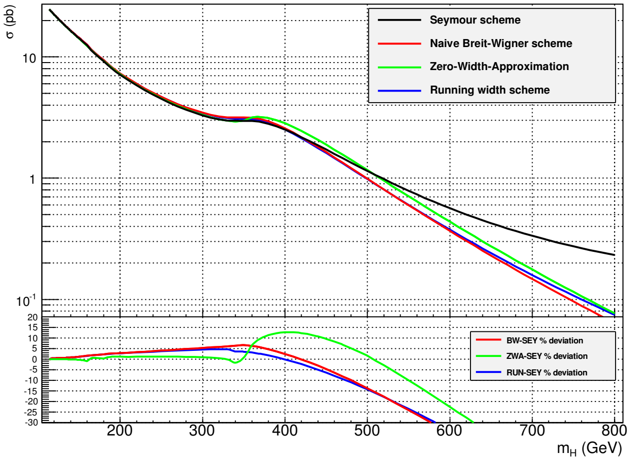
$$\sigma_{\text{ZWA}} = \frac{1}{2s}\left(\int d\phi_p |\mathcal{M}_p|^2\right)\frac{1}{2M\Gamma}\left(\int d\phi_d |\mathcal{M}_d|^2\right)\Bigg|_{q^2=M^2}$$

tails of Breit-Wigner ($\frac{\sigma_{\text{tail}}}{\sigma} \approx \frac{1}{n\pi}$ with $|\sqrt{q^2} - M| > n\Gamma$) are not nearly as suppressed as tails of Gaussian

for $H \to f\bar{f}$: $|\mathcal{M}_d(q^2)|^2 \sim m_f^2 q^2$, for $H \to VV$: $|\mathcal{M}_d(q^2)|^2 \sim (q^2)^2$ for $\sqrt{q^2} \gtrsim 2\,M_V$

ZWA: the big picture

$gg \to H \to$ all:



Anastasiou, Buehler, Herzog, Lazopoulos (2012)

Light Higgs: Inclusive analysis

Signal cross section calculated with HTO (Passarino, unpublished):

complex pole, OFFP schemes Goria, Passarino, Rosco (2011); Passarino, Sturm, Uccirati (2010); Actis, Passarino (2006)

$$\sigma_{gg\to H\to ZZ}(M_{ZZ}) = \frac{1}{\pi}\,\sigma_{gg\to H}\,(M_{ZZ})\;\frac{M_{ZZ}^4}{\left|M_{ZZ}^2 - s_H\right|^2}\;\frac{\Gamma_{H\to ZZ}\,(M_{ZZ})}{M_{ZZ}}$$

Higgs complex pole: $s_H = \mu_H^2 - i\,\mu_H\,\gamma_H$

Note: γ_H is not the on-shell width, but numerical difference tiny for light Higgs GPR (2011)

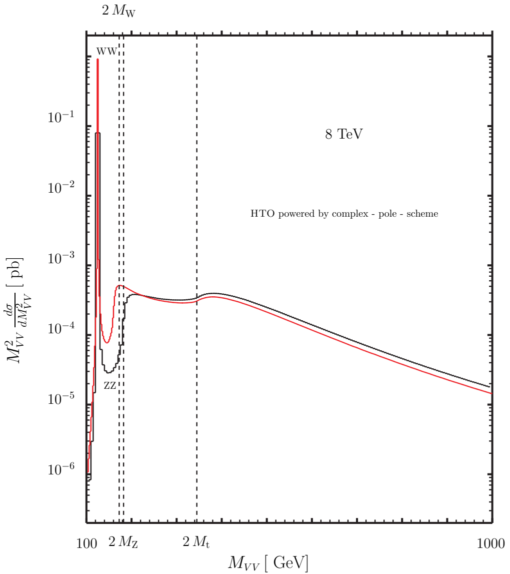
$\sigma_{gg\to H}(M_{ZZ})$: NNLO QCD LHCHXS2 (2012), NLO EW Actis, Passarino, Sturm, Uccirati (2008)

$\Gamma_{H\to ZZ}(M_{ZZ})$: NLO + leading NNLO Bredenstein, Denner, Dittmaier, Weber (2007)

using MSTW2008 PDF sets Martin, Stirling, Thorne, Watt (2009)

$\mu_H = 125$ GeV, $\gamma_H = 4.03$ MeV, $\mu_R = \mu_F = M_{ZZ}$

NNLO $gg \to H \to ZZ$: ZZ invariant mass distribution (black, $M_H = 125$ GeV)



Light Higgs: Inclusive analysis

Total cross-sections:

	Tot [pb]	$M_{ZZ} > 2\,M_Z$ [pb]	R
$gg \to H \to$ all	19.146	0.1525	0.8%
$gg \to H \to ZZ$	0.5462	0.0416	7.6%

$gg \to H \to \gamma\gamma$: the effect is drastically reduced and confined to the region $M_{\gamma\gamma}$ between 157 GeV and 168 GeV, where the distribution is already five orders of magnitude below the peak

Light Higgs: Analysis with selection cuts

Calculate $gg \to H \to VV \to$ leptons ($V = W, Z$) cross sections and distributions at LO using gg2VV with Higgs in ZWA as well as off-shell including interference with continuum VV production (γ^* contributions included, important for $M_H < 2M_Z$) including experimental selection cuts.

- pp collisions at $\sqrt{s} = 8$ TeV
- all results for single lepton flavour combination ($\ell^\pm$ and ν)
- input parameters: LHC Higgs Cross Section WG, arXiv:1101.0593 [hep-ph], App. A (with NLO Γ_V and G_μ scheme)
- MSTW2008NNLO PDF
- finite top and bottom quark mass effects included
- $M_H = 125\ (200)$ GeV with $\Gamma_H = 0.004434\ (1.428)$ GeV (HDECAY)
- $\mu_R = \mu_F = M_H/2$
- fixed-width Breit-Wigner for Higgs and V propagators
- $V_{\text{CKM}} = 1$: negligible error ($< 10^{-5}$)

For on/off-shell comparison, define the ZWA M_{VV} distribution as:

$$\left(\frac{d\sigma}{dM_{VV}}\right)_{\text{ZWA}} = \sigma_{H,\text{ZWA}}\,\frac{M_H\Gamma_H}{\pi}\,\frac{2M_{VV}}{\left(M_{VV}^2 - M_H^2\right)^2 + (M_H\Gamma_H)^2}$$

ZWA/off-shell and signal-background interference measures

Relative measure for accuracy of ZWA/off-shell effect

$$R_0 := \frac{\sigma_{H,\text{ZWA}}}{\sigma_{H,\text{offshell}}}$$

Relative measures for interference effect

$S + B$-inspired measure:

$$R_1 := \frac{\sigma(|\mathcal{M}_\text{H} + \mathcal{M}_\text{cont}|^2)}{\sigma(|\mathcal{M}_\text{H}|^2) + \sigma(|\mathcal{M}_\text{cont}|^2)}$$

$S/\sqrt{B}$-inspired measure:

$$R_2 := \frac{\sigma(|\mathcal{M}_\text{H}|^2 + 2\,\text{Re}(\mathcal{M}_\text{H}\mathcal{M}^*_\text{cont}))}{\sigma(|\mathcal{M}_\text{H}|^2)}$$

$gg \to H \to ZZ \to \ell\bar{\ell}\ell\bar{\ell}$ and $\ell\bar{\ell}\ell'\bar{\ell}'$ at $M_H = 125$ GeV

Same- and different-flavour 4-charged-lepton channels

In these search channels, the invariant mass of the intermediate Higgs ($M_{H^*} \equiv M_{ZZ}$) can be reconstructed. The M_{ZZ} spectrum is hence used as the discriminant variable in the final stage of the analysis, and the test statistic is evaluated with a binned maximum-likelihood fit of signal and background models to the observed M_{ZZ} distribution. For light Higgs masses, the observed M_{ZZ} distribution is dominated by experimental resolution effects and for example fitted as Gaussian with a standard deviation of 2–2.5 GeV (or similar bin sizes are used). The constraints on M_{ZZ} (binning) introduce an error of order 0.1%. Invariant masses above $2\,M_Z$, where large deviations from the Breit-Wigner shape occur, are excluded by the experimental procedure. Higgs-continuum interference effects are negligible.

Light Higgs: Analysis with selection cuts

$gg \to H \to ZZ \to \ell\bar{\ell}\ell\bar{\ell}$ and $\ell\bar{\ell}\ell'\bar{\ell}'$ at $M_H = 125$ GeV

	$gg\ (\to H) \to ZZ \to 4\ell$ and $2\ell\,2\ell'$						
	σ [fb], pp, $\sqrt{s} = 8$ TeV, $M_H = 125$ GeV				ZWA	interference	
mode	H_{ZWA}	H_{offshell}	cont	$\lvert H_{\text{ofs}}\text{+cont}\rvert^2$	R_0	R_1	R_2
$\ell\bar{\ell}\,\ell\bar{\ell}$	0.0748(2)	0.0747(2)	0.000437(3)	0.0747(6)	1.002(3)	0.994(8)	0.994(8)
$\ell\bar{\ell}\,\ell'\bar{\ell}'$	0.1395(2)	0.1393(2)	0.000583(2)	0.1400(3)	1.002(2)	1.001(2)	1.001(2)

Cross sections for $gg\ (\to H) \to ZZ \to \ell\bar{\ell}\ell\bar{\ell}$ and $\ell\bar{\ell}\ell'\bar{\ell}'$ in pp collisions at $\sqrt{s} = 8$ TeV for $M_H = 125$ GeV and $\Gamma_H = 0.004434$ GeV calculated at LO with gg2VV. The zero-width approximation (ZWA) and off-shell Higgs cross sections, the continuum cross section and the sum of off-shell Higgs and continuum cross sections including interference are given. The accuracy of the ZWA and the impact of off-shell effects are assessed with $R_0 = \sigma_{H,\text{ZWA}}/\sigma_{H,\text{offshell}}$. Interference effects are illustrated through $R_1 = \sigma(|\mathcal{M}_H + \mathcal{M}_{\text{cont}}|^2)/\sigma(|\mathcal{M}_H|^2 + |\mathcal{M}_{\text{cont}}|^2)$ and $R_2 = \sigma(|\mathcal{M}_H|^2 + 2\,\text{Re}(\mathcal{M}_H\mathcal{M}^*_{\text{cont}}))/\sigma(|\mathcal{M}_H|^2)$. γ^* contributions are included in $\mathcal{M}_{\text{cont}}$. Applied cuts: $|M_{ZZ} - M_H| < 1$ **GeV**, $p_{T\ell} > 5$ GeV, $|\eta_\ell| < 2.5$, $\Delta R_{\ell\ell} > 0.1$, 76 GeV $< M_{\ell\bar{\ell},12} < 106$ GeV and 15 GeV $< M_{\ell\bar{\ell},34} < 115$ GeV, $M_{\ell\bar{\ell}} > 4$ GeV. The invariant mass of the same-flavour, opposite-sign lepton pair closest to M_Z is denoted by $M_{\ell\bar{\ell},12}$. $M_{\ell\bar{\ell},34}$ denotes the invariant mass of the remaining lepton pair. Cross sections are given for a single lepton flavour combination. No flavour summation is carried out for charged leptons or neutrinos. The integration error is given in brackets.

Light Higgs: Analysis with selection cuts

$gg \to H \to ZZ \to \ell\bar{\ell}\nu_\ell\bar{\nu}_\ell$ at $M_H = 200$ GeV

- $M_H > 2\,M_Z$ (Higgs resonance in region with large continuum background)
- $\Gamma_H/M_H = 0.7\%$
- M_{T3} (unlike M_{T1}, see below) does not have a kinematic edge at M_{H^*}
- significant constructive signal-background interference occurs

$gg\ (\to H) \to ZZ \to \ell\bar{\ell}\nu_\ell\bar{\nu}_\ell$						
σ [fb], pp, $\sqrt{s} = 8$ TeV, $M_H = 200$ GeV				ZWA	interference	
H_{ZWA}	H_{offshell}	cont	$\lvert H_{\text{ofs}}\text{+cont}\rvert^2$	R_0	R_1	R_2
2.0357(8)	2.0608(9)	1.1888(6)	3.380(2)	0.9878(6)	1.0400(7)	1.063(1)

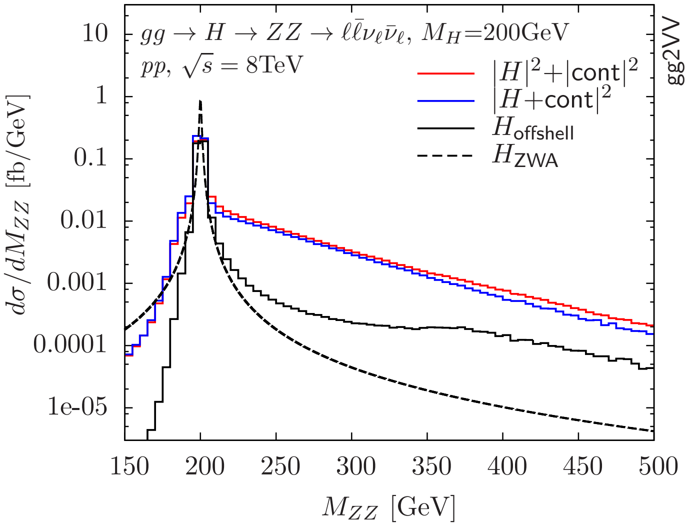
Cross sections for $gg\ (\to H) \to ZZ \to \ell\bar{\ell}\nu_\ell\bar{\nu}_\ell$ for $M_H = 200$ GeV and $\Gamma_H = 1.428$ GeV. Applied cuts: $p_{T\ell} > 20$ GeV, $|\eta_\ell| < 2.5$, 76 GeV $< M_{\ell\ell} < 106$ GeV, $\not{p}_T > 10$ GeV, $\Delta\phi_{\ell\ell} > 1$.

$$\text{CMS:}\quad M_{T3} = \sqrt{\left(M_{T,\ell\ell} + \not{M}_T\right)^2 - (\mathbf{p}_{T,\ell\ell} + \not{\mathbf{p}}_T)^2}$$

$$\text{with}\quad M_{T,\ell\ell} = \sqrt{p^2_{T,\ell\ell} + M^2_{\ell\ell}} \quad\text{and}\quad \not{M}_T = \sqrt{\not{p}^2_T + M^2_{\ell\ell}}$$

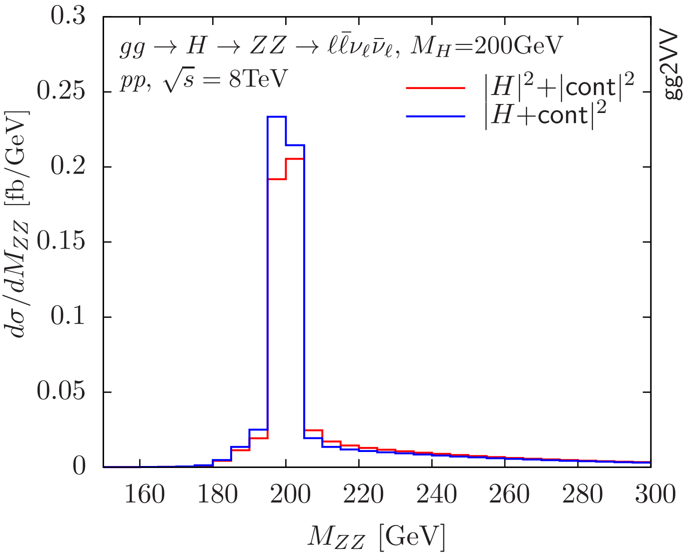
ATLAS uses M_{T3} with $M_{\ell\ell} \to M_Z$

Light Higgs: Analysis with selection cuts



Applied cuts: $p_{T\ell} > 20$ GeV, $|\eta_\ell| < 2.5$, 76 GeV $< M_{\ell\ell} < 106$ GeV, $\not{p}_T > 10$ GeV, $\Delta\phi_{\ell\ell} > 1$

Light Higgs: Analysis with selection cuts



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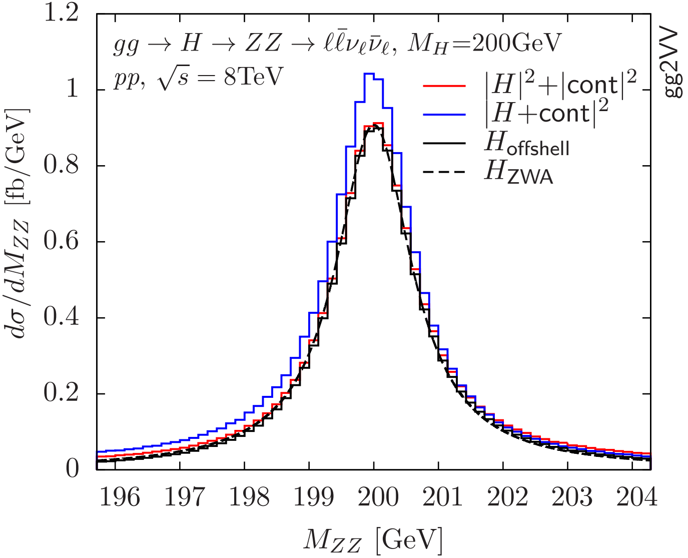
Light Higgs: Analysis with selection cuts



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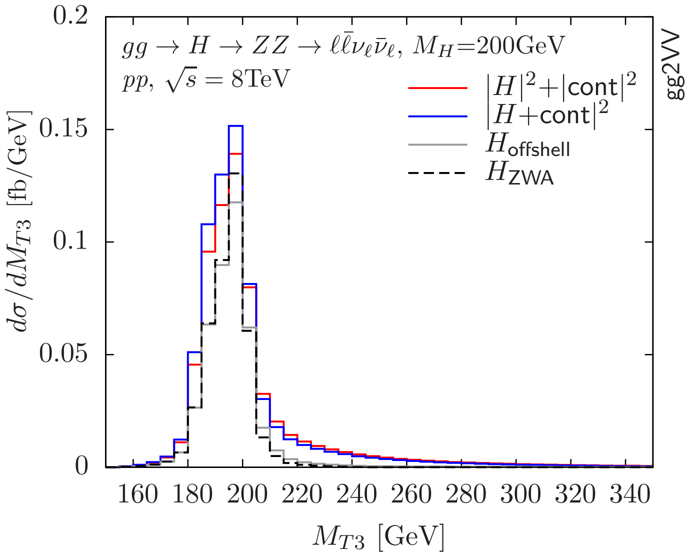
Light Higgs: Analysis with selection cuts



Applied cuts: $p_{T\ell} > 20$ GeV, $|\eta_\ell| < 2.5$, 76 GeV $< M_{\ell\ell} < 106$ GeV, $\not{p}_T > 10$ GeV, $\Delta\phi_{\ell\ell} > 1$

Light Higgs: Analysis with selection cuts

$gg \to H \to ZZ \to \ell\bar{\ell}\nu_\ell\bar{\nu}_\ell$ at $M_H = 125$ GeV

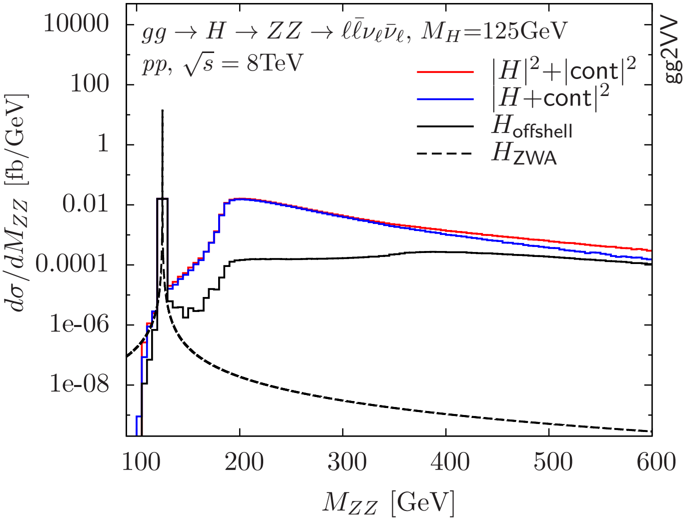
- no experimental studies of this channel at $M_H = 125$ GeV yet
- off-shell enhancement of tail is stronger for ZZ than WW
- $M_{ZZ} > 180$ GeV $= M_H + 12000\Gamma_H$: 37% of off-shell signal ($\not{p}_T$ cut dependent)
- ZWA inappropriate, large interference
- significant mitigation if $M_{T1} < M_H$ cut is applied

	$gg\ (\to H) \to ZZ \to \ell\bar{\ell}\nu_\ell\bar{\nu}_\ell$						
	σ [fb], pp, $\sqrt{s} = 8$ TeV, $M_H = 125$ GeV				ZWA	interference	
M_T cut	H_{ZWA}	H_{offshell}	cont	$\lvert H_{\text{ofs}}\text{+cont}\rvert^2$	R_0	R_1	R_2
none	0.1593(2)	0.2571(2)	1.5631(7)	1.6376(9)	0.6196(7)	0.8997(6)	0.290(5)
$M_{T1} < M_H$	0.1593(2)	0.1625(2)	0.4197(5)	0.5663(6)	0.980(2)	0.973(2)	0.902(5)

Cross sections for $gg\ (\to\ H)\ \to\ ZZ\ \to\ \ell\bar{\ell}\nu_\ell\bar{\nu}_\ell$ for $M_H\ =\ 125$ GeV without and with transverse mass cut. Applied cuts: $p_{T\ell} > 20$ GeV, $|\eta_\ell| < 2.5$, 76 GeV $< M_{\ell\ell} < 106$ GeV, $\not{p}_T > 10$ GeV.

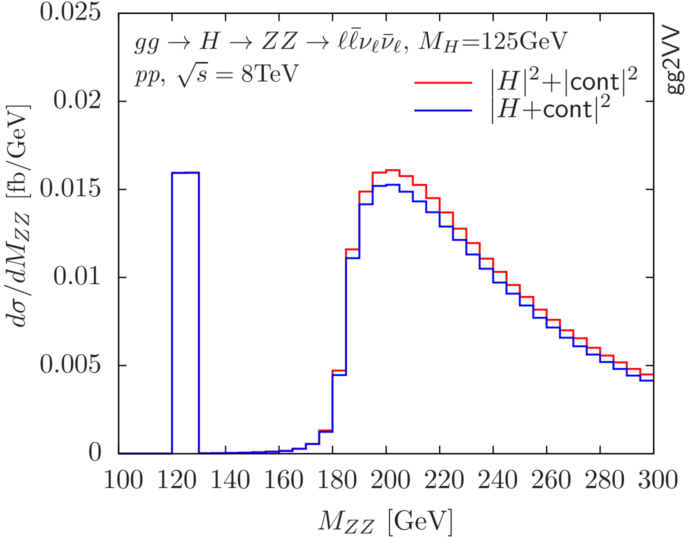
$$M_{T1} = \sqrt{(M_{T,\ell\ell} + \not{p}_T)^2 - (\mathbf{p}_{T,\ell\ell} + \not{\mathbf{p}}_T)^2}$$

Light Higgs: Analysis with selection cuts



Applied cuts: $p_{T\ell} > 20$ GeV, $|\eta_\ell| < 2.5$, 76 GeV $< M_{\ell\ell} < 106$ GeV, $\not{p}_T > 10$ GeV

Light Higgs: Analysis with selection cuts



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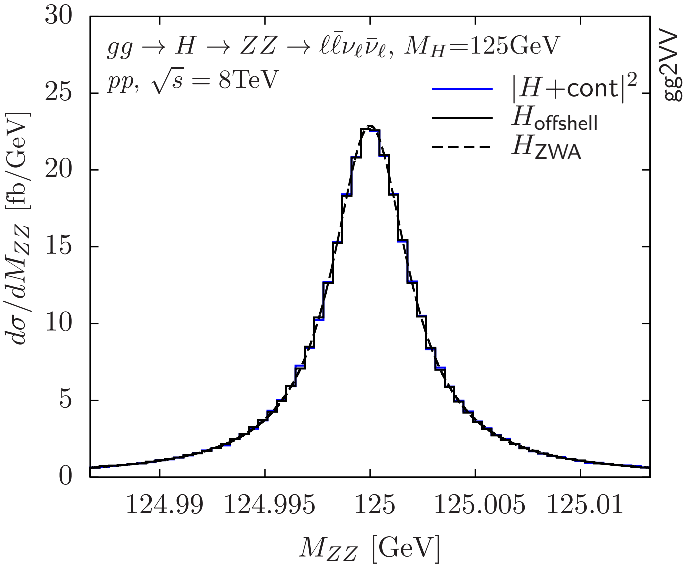
Light Higgs: Analysis with selection cuts



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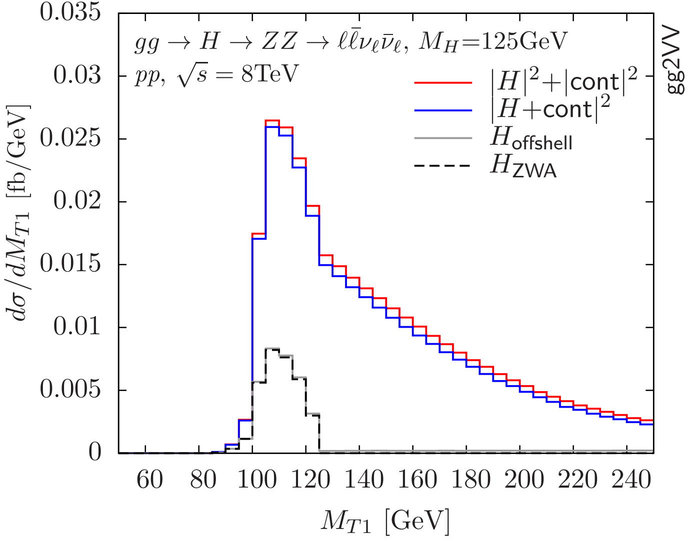
Light Higgs: Analysis with selection cuts



Applied cuts: $p_{T\ell} > 20$ GeV, $|\eta_\ell| < 2.5$, 76 GeV $< M_{\ell\ell} < 106$ GeV, $\not{p}_T > 10$ GeV

Signal-background interference for $M_H = 400$ GeV

$gg\ (\to H) \to ZZ \to l\bar{l}l'\bar{l}'$

Settings and cuts:

$\mu_R = \mu_F = M_H/2 = 200$ GeV, $\Gamma_H = 29.16$ GeV (HDECAY)
MSTW2008LO, other: LHC Higgs Cross Section WG, arXiv:1101.0593 [hep-ph], App. A (with NLO Γ_V and G_μ scheme)

ZZ standard cuts:

$p_{T\ell} > 20$ GeV, $|\eta_\ell| < 2.5$, 76 GeV $< M_{\ell\bar{\ell}}, M_{\ell'\bar{\ell}'} < 106$ GeV

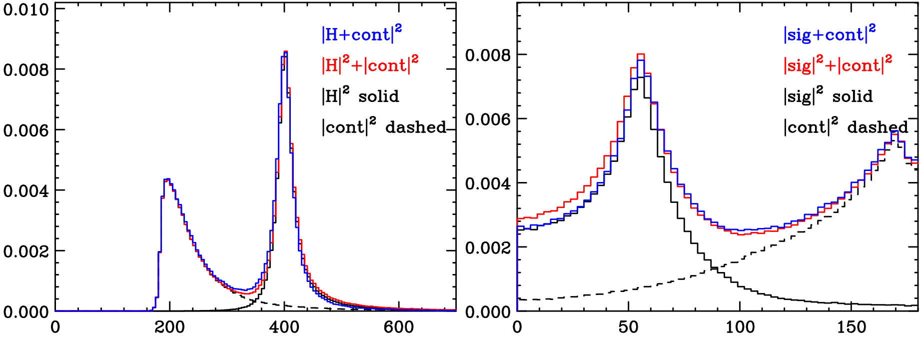
ZZ Higgs search cuts: standard cuts and $|M_{l\bar{l}l'\bar{l}'} - M_H| < \Gamma_H$

		σ [fb], pp, $\sqrt{s} = 7$ TeV, $M_H = 400$ GeV			interference	
process	cuts	$\lvert\mathcal{M}_H\rvert^2$	$\lvert\mathcal{M}_{\text{cont}}\rvert^2$	$\lvert\mathcal{M}_H + \mathcal{M}_{\text{cont}}\rvert^2$	R_1	R_2
$gg\ (\to H) \to ZZ$	stand.	0.3654(4)	0.3450(4)	0.7012(8)	0.987(2)	0.975(3)
$gg\ (\to H) \to ZZ$	Higgs	0.2729(3)	0.01085(2)	0.2867(3)	1.010(2)	1.011(2)
		σ [fb], pp, $\sqrt{s} = 14$ TeV, $M_H = 400$ GeV			interference	
process	cuts	$\lvert\mathcal{M}_H\rvert^2$	$\lvert\mathcal{M}_{\text{cont}}\rvert^2$	$\lvert\mathcal{M}_H + \mathcal{M}_{\text{cont}}\rvert^2$	R_1	R_2
$gg\ (\to H) \to ZZ$	stand.	1.893(3)	1.417(2)	3.205(5)	0.969(2)	0.945(3)
$gg\ (\to H) \to ZZ$	Higgs	1.377(2)	0.0531(1)	1.445(2)	1.011(2)	1.011(3)

similar interference effects in 4l and 2l2v channels and for $M_H = 500$ GeV, $\sqrt{s} = 8$ TeV

Signal-background interference for $M_H = 400$ GeV
Differential results

$gg\ (\to H) \to ZZ \to l\bar{l}l'\bar{l}'$, LHC, 7 TeV, standard cuts



$M_{l\bar{l}l'\bar{l}'}$ [GeV] (left) and $\Delta\phi_{l\bar{l}}$ [°] (right) distributions [fb/[o]]

Summary

- $M_H \approx 125$ GeV: ZWA expected to be excellent ($\Gamma_H/M_H \approx 3 \cdot 10^{-5}$)
- But: M_H dependence of Higgs decay rates $\rightarrow$
  off-shell cross sections essential to reach 1% precision level
- ZWA: $\mathcal{O}(10\%)$ corrections for inclusive $gg \rightarrow H \rightarrow VV$
  (due to sizeable Higgs signal from region with invariant mass above $2M_V$)
- $\mathcal{O}(5\text{–}10\%)$ signal-background interference effects for $gg \rightarrow H \rightarrow VV$
- Experimental selection cuts (e.g. on M_T) allow to eliminate/mitigate effects
- Experiments: check where ZWA is used explicitly/implicitly
- Higgs couplings extraction: take into account effects as extra uncertainty
- Weak boson fusion Higgs production channels similarly affected
- Tools: gg2VV allows to simulate interference and off-shell effects