Signal-background interference in $gg \to H \to VV$

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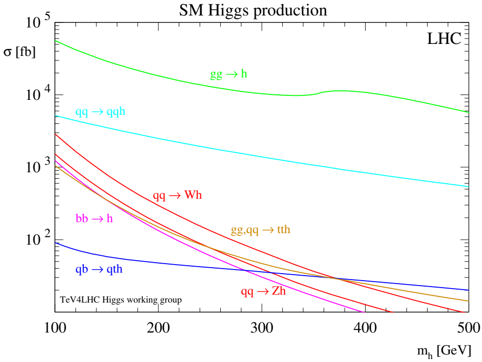
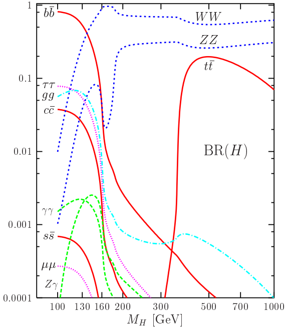
RADCOR 2011
Mamallapuram, India
September 27, 2011

Outline

- SM Higgs $\to VV$ search at the LHC ($V = W, Z$)
- Gluon-fusion Higgs $\to VV$ production
- Gluon-induced VV continuum production
- Higgs-continuum interference
- Intermediate Higgs mass range
- Heavy Higgs
- Conclusion

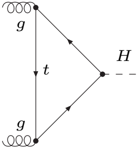
Higgs boson production and decay at the LHC





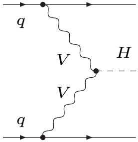
Gluon fusion:

$(gg \to H)$



Vector boson fusion:

$(qq \to Hqq,\ V = W, Z)$



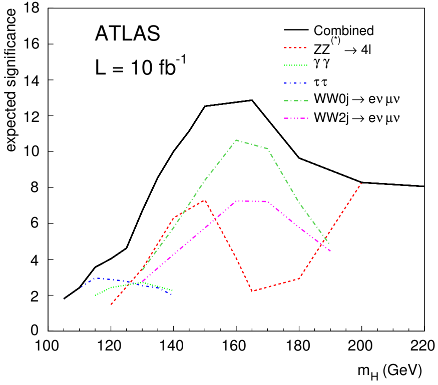
Dominant decay modes:

$H \to b\bar{b}$ for $M_H < 135$ GeV

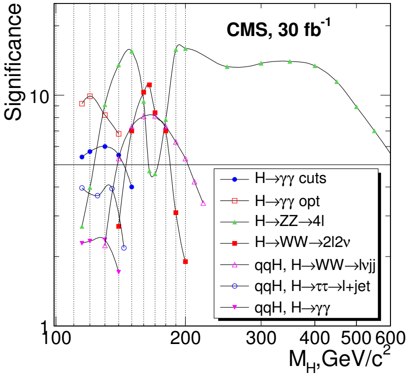
$H \to WW, ZZ$ for $M_H > 135$ GeV

source: Tevatron-for-LHC Higgs Report (2007), Djouadi (2005)

LHC discovery potential for the SM Higgs boson



ATLAS

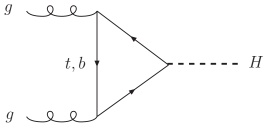


CMS

LEP: $M_H > 114.4$ GeV, $M_H = 89^{+35}_{-26}$ $(< 158, 185)$ GeV

Tevatron: $M_H \notin [158, 175]$ GeV

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)   Dawson (1991); Djouadi, Spira, Zerwas (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)

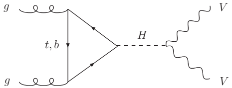
leading soft contributions @ NNNLO   Moch, Vogt (2005); Laenen, Magnea (2006); Idilbi, Ji, Ma, Yuan (2006); Ravindran (2006)

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)

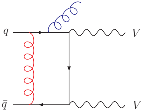
Recent updates   de Florian, Grazzini (2009); Baglio, Djouadi (2010, 2011); Baglio, Djouadi, Ferrag, Godbole (2011); Catani, Grazzini (2011); de Florian, Ferrera, Grazzini, Tommasini (2011)

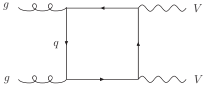
Gluon-fusion Higgs $\to VV$ and continuum VV production



$gg \to H \to VV$ 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)

$gg \to VV$ [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)

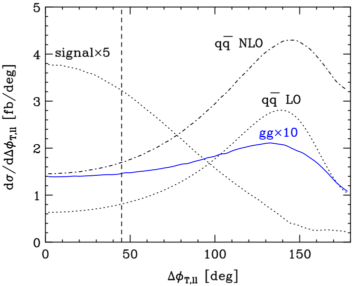
Higgs-continuum VV interference Glover, van der Bij (1989); Binoth, Ciccolini, NK, Krämer (2006); Campbell, Ellis, Williams (2011)

Importance of gluon-induced continuum contribution

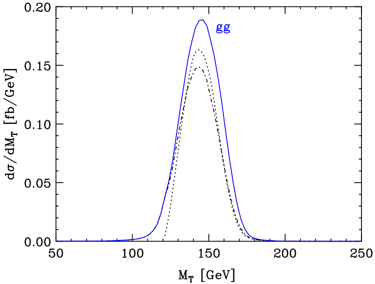
Formally contributes at NNLO, but enhanced by

- large gluon-gluon luminosity at the LHC
- Higgs search selection cuts
  (boost of VV system only in $q\bar{q}$ scattering, dilepton opening angle, ...)

Example for $pp \to W^*W^* \to \ell\bar{\nu}\bar{\ell}'\nu'$:



$p_{T\ell} > 20$ GeV, $|\eta_\ell| < 2.5$, $\not{E}_T > 25$ GeV

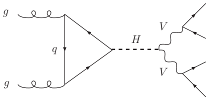


Higgs search cuts $\longrightarrow$ gg: dominant higher order correction

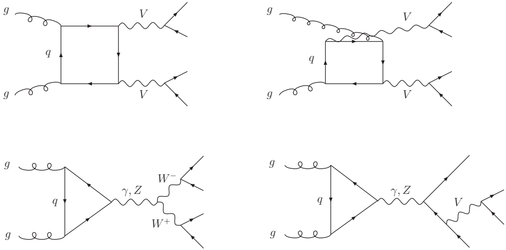
Higgs search cuts = standard cuts (left) and $\Delta\phi_{T,\ell\ell} < 45^\circ$, $m_{\ell\ell} < 35$ GeV, jet veto: $p_{Tj} > 20$ GeV and $|\eta_j| < 3$, 35 GeV $< p_{T\ell,\text{max}} < 50$ GeV, 25 GeV $< p_{T\ell,\text{min}}$ Davatz, Dissertori, Dittmar, Grazzini, Pauss (2004)

Typical $\dfrac{\sigma_{gg}}{\sigma_{q\bar{q},NLO}}$: WW: 5% [10–30%] (3% [5–8%]) at 14 (7) TeV for standard [Higgs search] cuts
ZZ: 15% (8%) at 14 (7) TeV

Calculation



Higgs amplitude (sig)



continuum amplitude (cont)

- continuum triangles vanish Landau (1948), Yang (1950) $\rightarrow$ spin 1 not allowed for state with 2 real gluons (thanks, Gudrun)
- two amplitude codes: BCKK Binoth, Ciccolini, Kauer, Krämer and FeynArts/FormCalc/LoopTools Hahn *et al.*
- massless and massive quarks in loop
  t, b $\rightarrow$ $\sigma_{tot,WW}$: $+12\%$, σ_{ZZ}: $+65\%$ ($\mathcal{M}_{\text{cont}}$, LHC, 14 TeV, $m_{t(b)} = 178(4.4)$ GeV, $|M_{ZZ} - M_Z| < 15$ GeV)
- off-shell V bosons, decay to different-flavour leptons ($\ell^\pm, \nu$) included
- simultaneous calculation of multiple scales and PDF error
- $V = W$: $V_{\text{CKM}} = 1$ for BCKK code, $V_{\text{CKM}} \neq 1$ for FormCalc code (CKM effects $< 0.01\%$)
- $V = Z$: γ^* contributions included (important if $M_H < 2M_Z$)
- custom PS mapping/integration for $M_H \sim$ 120 GeV to 1 TeV and $|\mathcal{M}_{\text{sig}}|^2$, $|\mathcal{M}_{\text{cont}}|^2$, $|\mathcal{M}_{\text{sig}} + \mathcal{M}_{\text{cont}}|^2$

Gram determinant and numerical precision

Inverse Gram determinant: $\boxed{\det G = 2s(tu - M_{V_1}^2 M_{V_2}^2) = 2s^2 p_{T,V}^2}$ (in parton CMS)

$\rightarrow$ spurious singularities for $p_{T,V} \rightarrow 0$

BCKK amplitude contains $(\det G)^{-1}$ (after symbolic simplification/cancellation)

FeynArts/FormCalc/LoopTools (FC) amplitude contains $(\det G)^{-4}$

Implications for numerical evaluation:

MC integration error $\sim 0.1\%$ $\rightarrow$ $\mathcal{O}(10^6)$ PS points $\rightarrow$ $p_{T,V} < 0.01$ GeV very likely

double precision (16 digits) insufficient for $p_{T,V} \lesssim 1$ GeV

Observed: quadruple precision (32 digits) insufficient for FC amplitude and PS configuration with $p_{T,V} = 0.007$ GeV

Estimate of quadruple precision boundary for FC amplitude:

$$\frac{(p_{T,V,\text{quad-critical}}^2)^4}{((1\text{ GeV})^2)^4} \approx \frac{10^{-32}}{10^{-16}} \rightarrow p_{T,V,\text{quad-critical}} \approx 10^{-2}\text{ GeV} \quad (\checkmark)$$

Algorithm for numerical evaluation of FC amplitude

Approach: increase numerical precision in critical PS region
Problem: cannot go beyond quadruple precision without arbitrary-precision LoopTools
Solution: use heuristic to detect problematic PS points

Algorithm:

[definition of relative deviation: $\mathrm{reldev}(x, y) := |x - y|/\min(x, y)$]

if $\mathcal{M}_{\text{cont}} \notin \mathcal{M}$ or $p_{T,V} > p_{T,\text{cut}}$ $\longrightarrow$ evaluate FC amplitude in double precision

else: assess $\mathcal{M}_{\text{cont}}$ stability using quadruple precision:

1st criterion: exploit that instabilities spoil Lorentz invariance
compare $|\mathcal{M}_{\text{cont}}|^2$ evaluated at PS point and boosted PS point, $p_{\text{boost},z} = 0.001 + 0.1\,r_1$ with random $r_1 \in [0, 1]$
if $\mathrm{reldev}(|\mathcal{M}_{\text{cont}}|^2, |\mathcal{M}_{\text{cont,boosted}}|^2) > 10^{-4}$ $\longrightarrow$ quadruple precision not sufficient

2nd criterion:
like 1st criterion, except boost in reverse direction: $p_{\text{boost},z} = -(0.001 + 0.1\,r_2)$ with random $r_2 \in [0, 1]$
if $\mathrm{reldev}(|\mathcal{M}_{\text{cont}}|^2, |\mathcal{M}_{\text{cont,boosted-rev}}|^2) > 10^{-4}$ $\longrightarrow$ quadruple precision not sufficient

3rd criterion: exploit that instabilities occur at exceptional PS configurations
compare $|\mathcal{M}_{\text{cont}}|^2$ evaluated at PS point and PS point mapped to single precision,
if $\mathrm{reldev}(|\mathcal{M}_{\text{cont}}|^2, |\mathcal{M}_{\text{cont,single}}|^2) > 1$ $\longrightarrow$ quadruple precision not sufficient

if quadruple precision sufficient $\longrightarrow$ evaluate FC amplitude in quadruple precision

else: set $|\mathcal{M}|^2$ to zero

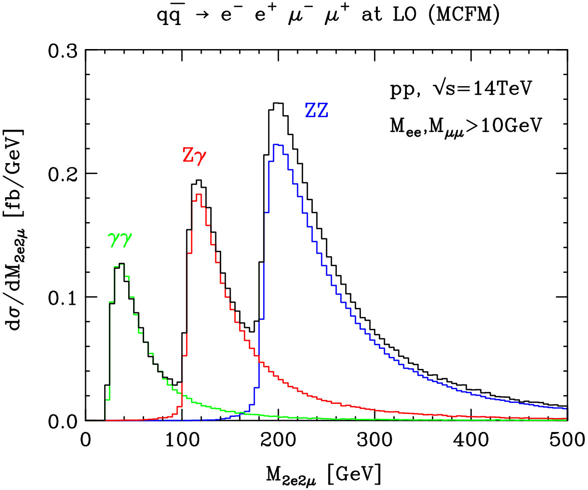
Diagnostics: $\longrightarrow$ need combination of criteria to detect all instabilities

assess quality of algorithm by comparison with $(\det G)^{-1}$ amplitude (stable in quadruple precision)

- number of undetected unstable results: none
- number of discarded good results: minimize by adjusting parameters

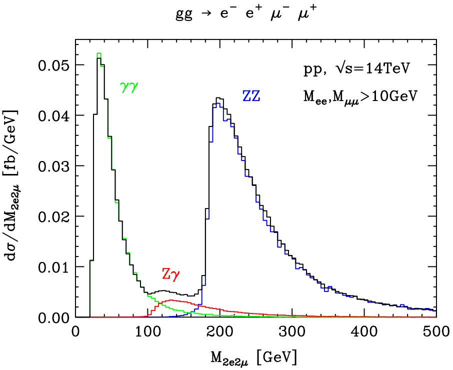
integrate $|\mathcal{M}_{\text{BCKK}}|^2 - |\mathcal{M}_{\text{FC}}|^2$ $\longrightarrow$ $1 - \sigma_{\text{FC}}/\sigma_{\text{BCKK}} < 3 \cdot 10^{-4}$ dropped points $\longrightarrow$ error of $\mathcal{O}(0.01\%)$

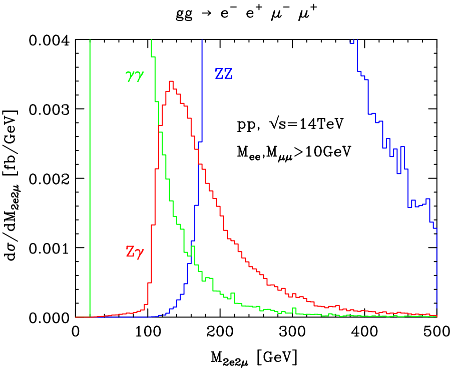
Contributions for $q\bar{q} \to (Z, \gamma^*)(Z, \gamma^*)$



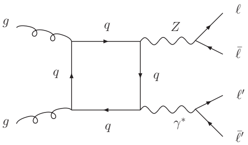
$\gamma^*\gamma^*$: 15%, $Z\gamma^*$: 29%, ZZ: 56%

Contributions for $gg \to (Z, \gamma^*)(Z, \gamma^*)$





$\gamma^*\gamma^*$: 30%, $Z\gamma^*$: 5%, ZZ: 65%



axial vector coupling of Z boson does not contribute to $gg \to Z\gamma^*$ (Furry's theorem for closed loops)

Signal-background interference for $M_H = 140, 170, 200$ GeV

	$\sigma[gg(\to H) \to WW \to \ell\bar{\nu}\bar{\ell}'\nu']$ [fb]					
Selection	**no cuts**			**Higgs search cuts**		
$\lvert\mathcal{M}_{cont(gg:1,2)}\rvert^2$	53.64(1)			1.3837(3)		
$\lvert\mathcal{M}_{cont(gg:3)}\rvert^2$	2.859(3)			0.00377(2)		
$\lvert\mathcal{M}_{cont(gg:1,2,3)}\rvert^2$	60.00(1)			1.4153(3)		
$\frac{\lvert\mathcal{M}_{cont(gg:1,2,3)}\rvert^2}{\lvert\mathcal{M}_{cont(gg:1,2)}\rvert^2+\lvert\mathcal{M}_{cont(gg:3)}\rvert^2}$	1.06			1.02		
M_H [GeV]	**140**	**170**	**200**	**140**	**170**	**200**
$\lvert\mathcal{M}_{sig}\rvert^2$	79.83(2)	116.23(3)	75.40(2)	1.8852(5)	12.974(2)	1.6663(7)
$\lvert\mathcal{M}_{sig+cont(gg:1,2,3)}\rvert^2$	132.50(5)	174.58(9)	134.46(5)	3.174(2)	15.287(6)	3.413(2)
$\frac{\lvert\mathcal{M}_{sig+cont(gg:1,2,3)}\rvert^2}{\lvert\mathcal{M}_{sig}\rvert^2+\lvert\mathcal{M}_{cont(gg:1,2,3)}\rvert^2}$	**0.948**	0.991	0.993	**0.962**	**1.062**	**1.108**

Signal-background interference for $M_H = 400$ GeV
Settings and cuts

$\mu_R = \mu_F = M_H/2 = 200$ GeV, $\Gamma_H = 29.16$ GeV
MSTW2008LO (68% C.L.), other: LHC Higgs Cross Section WG, arXiv:1101.0593 [hep-ph], App. A (with G_μ scheme)

WW standard cuts:

$p_{T\ell} > 20$ GeV , $|\eta_\ell| < 2.5$

$\not{p}_T > 30$ GeV , $M_{\ell\bar{\ell}'} > 12$ GeV

WW Higgs search cuts ($M_H = 400$ GeV):

standard cuts and

$p_{T\ell\text{min}} > 25$ GeV , $p_{T\ell\text{max}} > 90$ GeV

$M_{\ell\bar{\ell}'} < 300$ GeV , $\Delta\phi_{\ell\bar{\ell}'} < 175°$

ZZ standard cuts:

$p_{T\ell} > 20$ GeV , $|\eta_\ell| < 2.5$

76 GeV $< M_{\ell\bar{\ell}}, M_{\ell'\bar{\ell}'} < 106$ GeV

Signal-background interference for $M_H = 400$ GeV
Results

$gg \to WW \to \ell\bar{\nu}_\ell \bar{\ell}'\nu_{\ell'}$, LHC, 7 TeV, standard cuts:

$\sigma(|\mathcal{M}_{\text{sig}} + \mathcal{M}_{\text{cont}}|^2) = 10.5817$ MC: $\pm 0.0063(\pm 0.059\%)$ scale($\times$2): $-2.5573(-24\%) + 3.6967(+35\%)$ PDF: $-0.2723(-2.6\%) + 0.2382(+2.3\%)$ fb, sym. scale error: $\pm 28\%$, sym. PDF error: $\pm 2.4\%$

$\sigma(|\mathcal{M}_{\text{sig}}|^2) = 4.3611$ MC: $\pm 0.0021(\pm 0.048\%)$ scale($\times$2): $-1.1500(-26\%) + 1.7227(+40\%)$ PDF: $-0.1318(-3\%) + 0.1261(+2.9\%)$ fb, sym. scale error: $\pm 31\%$, sym. PDF error: $\pm 3\%$

$\sigma(|\mathcal{M}_{\text{cont}}|^2) = 6.3506$ MC: $\pm 0.0039(\pm 0.062\%)$ scale($\times$2): $-1.4583(-23\%) + 2.0621(+32\%)$ PDF: $-0.1526(-2.4\%) + 0.1243(+2\%)$ fb, sym. scale error: $\pm 26\%$, sym. PDF error: $\pm 2.2\%$

$$\frac{\sigma(|\mathcal{M}_{\text{sig}} + \mathcal{M}_{\text{cont}}|^2)}{\sigma(|\mathcal{M}_{\text{sig}}|^2) + \sigma(|\mathcal{M}_{\text{cont}}|^2)} = 0.9879(8) \quad \text{(at 14 TeV: } 0.9680(8))$$

Signal-background interference for $M_H = 400$ GeV

$gg \to WW \to \ell\bar{\nu}_\ell \bar{\ell}' \nu_{\ell'}$, **LHC, 7 TeV, Higgs search cuts**:

$\sigma(|\mathcal{M}_{\text{sig}} + \mathcal{M}_{\text{cont}}|^2) = 3.007$ MC: $\pm 0.003(\pm 0.1\%)$ scale($\times$2): $-0.782(-26\%) + 1.164(+39\%)$ PDF: $-0.088(-2.9\%) + 0.084(+2.8\%)$ fb, sym. scale error: $\pm 30\%$, sym. PDF error: $\pm 2.9\%$

$\sigma(|\mathcal{M}_{\text{sig}}|^2) = 2.502$ MC: $\pm 0.002(\pm 0.081\%)$ scale($\times$2): $-0.660(-26\%) + 0.989(+40\%)$ PDF: $-0.076(-3\%) + 0.073(+2.9\%)$ fb, sym. scale error: $\pm 31\%$, sym. PDF error: $\pm 3\%$

$\sigma(|\mathcal{M}_{\text{cont}}|^2) = 0.633$ MC: $\pm 0.001(\pm 0.15\%)$ scale($\times$2): $-0.161(-25\%) + 0.237(+38\%)$ PDF: $-0.018(-2.8\%) + 0.017(+2.6\%)$ fb, sym. scale error: $\pm 30\%$, sym. PDF error: $\pm 2.7\%$

$$\frac{\sigma(|\mathcal{M}_{\text{sig}} + \mathcal{M}_{\text{cont}}|^2)}{\sigma(|\mathcal{M}_{\text{sig}}|^2) + \sigma(|\mathcal{M}_{\text{cont}}|^2)} = 0.959(2) \quad \text{(at 14 TeV: } 0.940(2))$$

Signal-background interference for $M_H = 400$ GeV

$gg \to Z(\gamma^*)Z(\gamma^*) \to \ell\bar{\ell}\ell'\bar{\ell}'$, LHC, 7 TeV, standard cuts:

$\sigma(|\mathcal{M}_{\text{sig}} + \mathcal{M}_{\text{cont}}|^2) = 0.6875$ MC: $\pm 0.0009(\pm 0.12\%)$ scale($\times$2): $-0.1696(-25\%) + 0.2470(+36\%)$ PDF: $-0.0185(-2.7\%) + 0.0163(+2.4\%)$ fb, sym. scale error: $\pm 29\%$, sym. PDF error: $\pm 2.5\%$

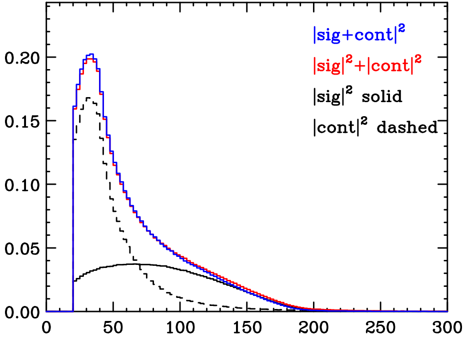
$\sigma(|\mathcal{M}_{\text{sig}}|^2) = 0.3658$ MC: $\pm 0.0004(\pm 0.11\%)$ scale($\times$2):$-0.0961(-26\%) + 0.1437(+39\%)$ PDF: $-0.0110(-3\%) + 0.0104(+2.8\%)$ fb, sym. scale error: $\pm 31\%$, sym. PDF error: $\pm 2.9\%$

$\sigma(|\mathcal{M}_{\text{cont}}|^2) = 0.3332$ MC: $\pm 0.0004(\pm 0.1\%)$ scale($\times$2):$-0.0774(-23\%) + 0.1099(+33\%)$ PDF: $-0.0083(-2.5\%) + 0.0068(+2\%)$ fb, sym. scale error: $\pm 27\%$, sym. PDF error: $\pm 2.3\%$

$$\frac{\sigma(|\mathcal{M}_{\text{sig}} + \mathcal{M}_{\text{cont}}|^2)}{\sigma(|\mathcal{M}_{\text{sig}}|^2) + \sigma(|\mathcal{M}_{\text{cont}}|^2)} = 0.984(2)$$

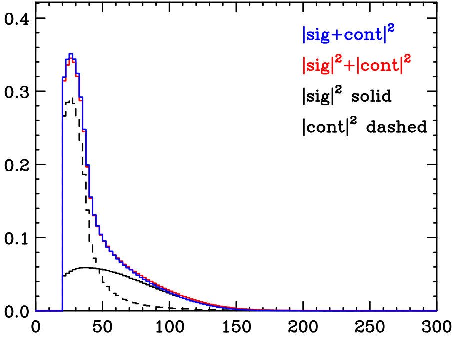
$gg \to WW \to \ell\bar{\nu}_\ell \bar{\ell}' \nu_{\ell'}$ distributions (LHC, 7 TeV, standard cuts)

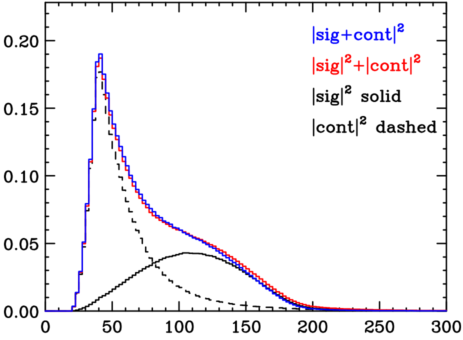
$p_{T\ell}$ and η_ℓ distributions ([GeV,] fb)



$gg \to WW \to \ell\bar{\nu}_\ell \bar{\ell}' \nu_{\ell'}$ distributions (LHC, 7 TeV, standard cuts)

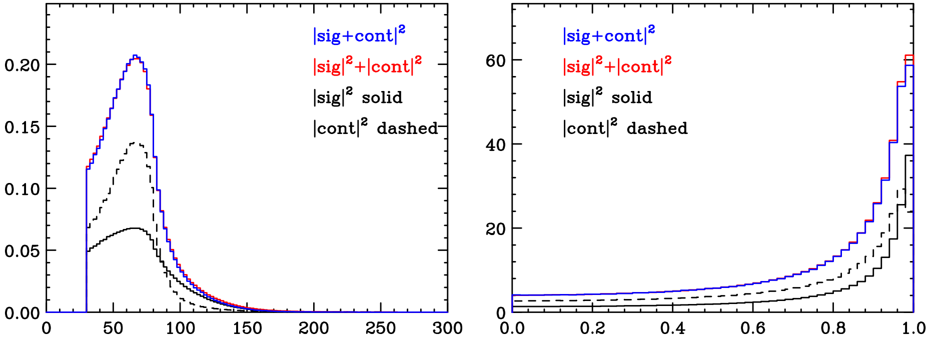
$p_{T\ell\text{min}}$ and $p_{T\ell\text{max}}$ distributions ([GeV,] fb)





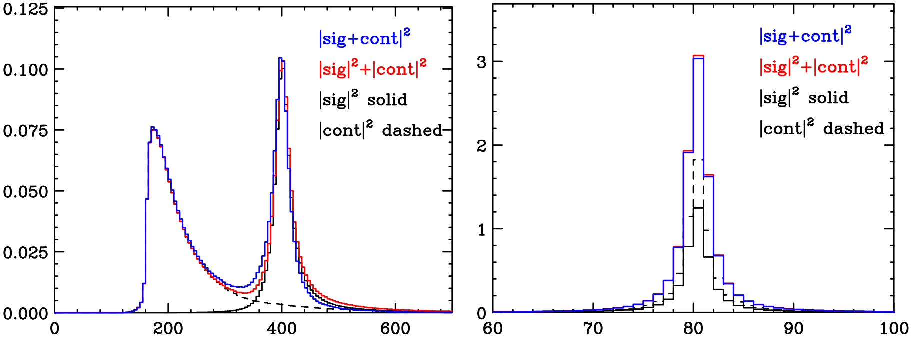
$gg \to WW \to \ell\bar{\nu}_\ell \bar{\ell}'\nu_{\ell'}$ distributions (LHC, 7 TeV, standard cuts)

$\not{p}_T$ and $|\cos\theta_{\ell\bar{\ell}',\mathrm{beam}}|$ distributions ([GeV,] fb)



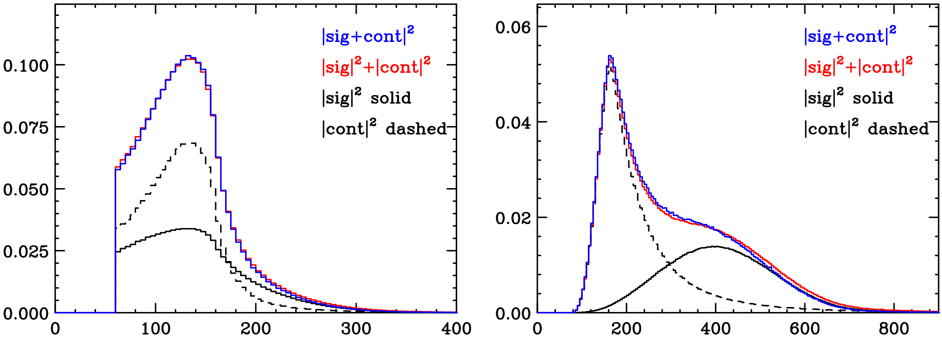
$gg \to WW \to \ell\bar{\nu}_\ell \bar{\ell}'\nu_{\ell'}$ distributions (LHC, 7 TeV, standard cuts)

M_{WW} and $M_{\ell\bar{\nu}_\ell}$ distributions ([GeV,] fb)



$gg \to WW \to \ell\bar{\nu}_\ell \bar{\ell}' \nu_{\ell'}$ distributions (LHC, 7 TeV, standard cuts)

$M_T(WW)$ distributions ([GeV,] fb)

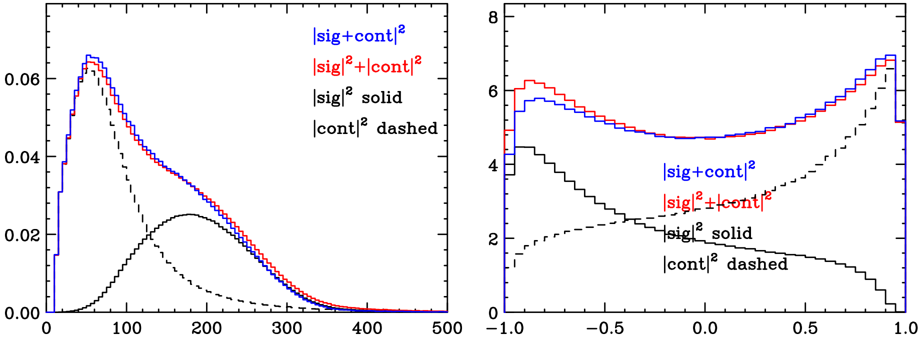


left: $M_T = \sqrt{2\, p_{T\ell\bar{\ell}'}\, \not{p}_T (1 - \cos\Delta\phi_{\ell\bar{\ell}',\text{miss}})}$

right: $M_T = \sqrt{(E_{T,\ell\bar{\ell}'} + \not{E}_T)^2 - (\vec{p}_{T,\ell\bar{\ell}'} + \vec{\not{p}}_T)^2}\,,\ E_{T,\ell\bar{\ell}'} = \sqrt{p^2_{T,\ell\bar{\ell}'} + m^2_{\ell\bar{\ell}'}}\,,\ \not{E}_T = \sqrt{\not{p}^2_T + m^2_{\ell\bar{\ell}'}}$

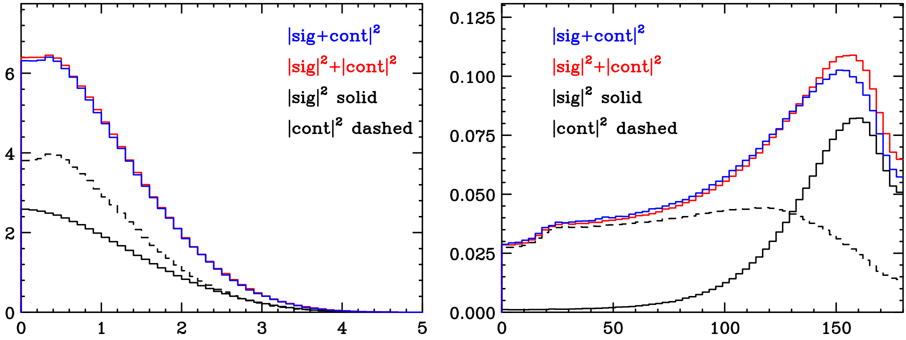
$gg \to WW \to \ell\bar{\nu}_\ell \bar{\ell}' \nu_{\ell'}$ distributions (LHC, 7 TeV, standard cuts)

$M_{\ell\bar{\ell}'}$ and $\cos\theta_{\ell\bar{\ell}'}$ distributions ([GeV,] fb)



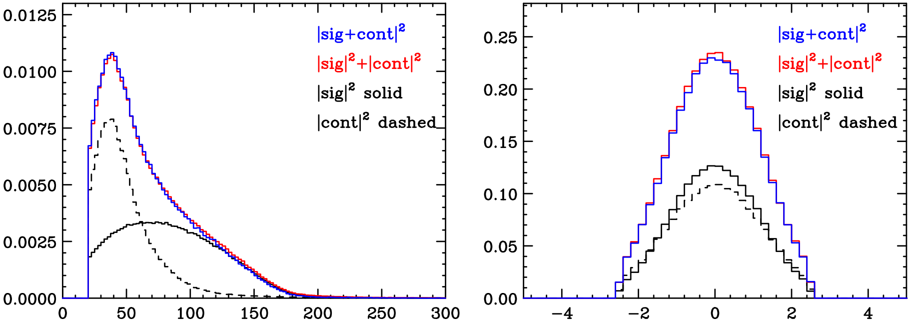
$gg \to WW \to \ell\bar{\nu}_\ell\bar{\ell}'\nu_{\ell'}$ distributions (LHC, 7 TeV, standard cuts)

$|\eta_\ell - \eta_{\bar{\ell}}|$ and $\Delta\phi_{\ell\bar{\ell}'}$ distributions (0-180 degrees, fb)



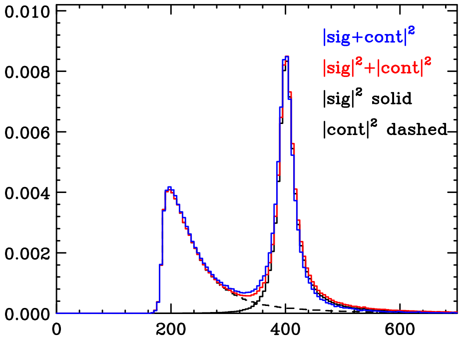
$gg \to Z(\gamma^*)Z(\gamma^*) \to \ell\bar{\ell}\ell'\bar{\ell}'$ distributions (LHC, 7 TeV, standard cuts)

$p_{T\ell}$ and η_ℓ distributions ([GeV,] fb)



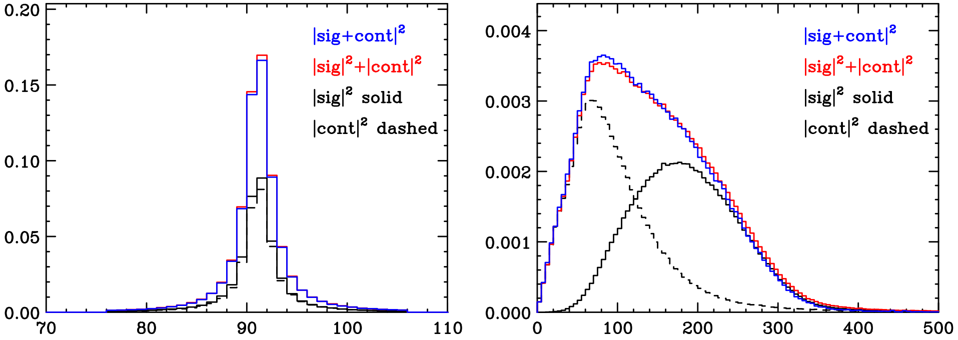
$gg \to Z(\gamma^*)Z(\gamma^*) \to \ell\bar{\ell}\ell'\bar{\ell}'$ distributions (LHC, 7 TeV, standard cuts)

$M_{\ell\bar{\ell}\ell'\bar{\ell}'}$ distribution ([GeV,] fb)



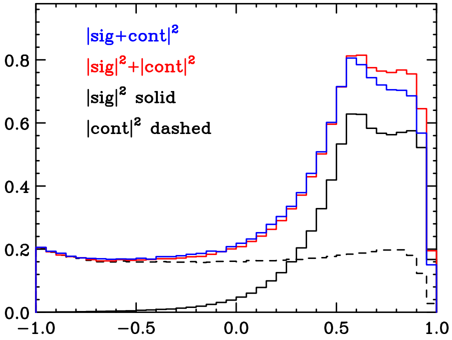
$gg \to Z(\gamma^*)Z(\gamma^*) \to \ell\bar{\ell}\ell'\bar{\ell}'$ distributions (LHC, 7 TeV, standard cuts)

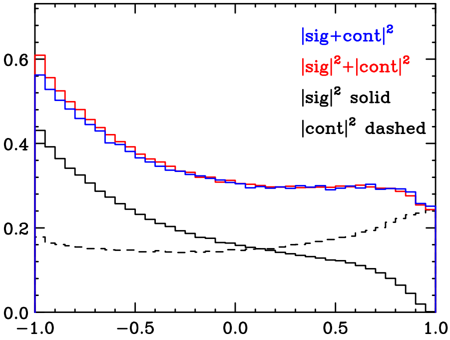
$M_{\ell\bar{\ell}}$ and $M_{\ell\ell'}$ distributions ([GeV,] fb)



$gg \to Z(\gamma^*)Z(\gamma^*) \to \ell\bar{\ell}\ell'\bar{\ell}'$ distributions (LHC, 7 TeV, standard cuts)

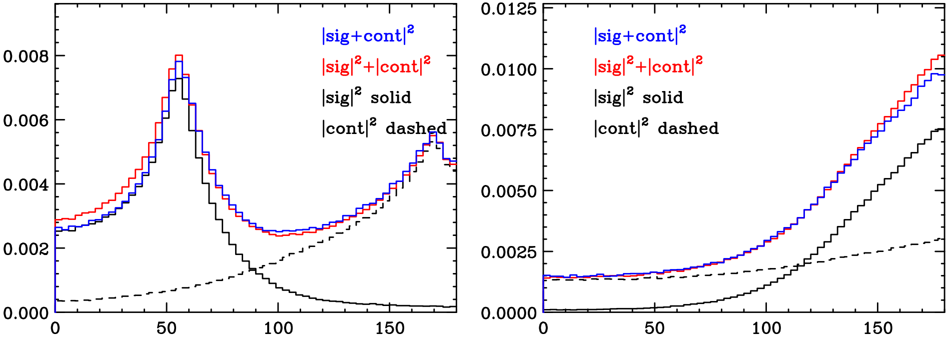
$\cos\theta_{\ell\bar{\ell}}$ and $\cos\theta_{\ell\ell'}$ distributions ([GeV,] fb)





$gg \to Z(\gamma^*)Z(\gamma^*) \to \ell\bar{\ell}\ell'\bar{\ell}'$ distributions (LHC, 7 TeV, standard cuts)

$\Delta\phi_{\ell\bar{\ell}}$ and $\Delta\phi_{\ell\ell'}$ distributions ([GeV,] fb)



Interfacing with experimental tool chains

use gg2VV to generate weighted or unweighted events

for $|\mathcal{M}_{\text{sig}}|^2$, $|\mathcal{M}_{\text{cont}}|^2$ and $|\mathcal{M}_{\text{sig}} + \mathcal{M}_{\text{cont}}|^2$

in Les Houches standard format Boos *et al.* (2001), Alwall *et al.* (2006)

$\rightarrow$ experimenters can investigate interference effects in their studies

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0.0238075 4.9e-05 1 661
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21 -1 0 0 502 501 -0 -0 -16.80868571 16.80868571 0. 0. 9.
-13 1 1 2 0 0 12.468732324 -17.951966792 199.52446548 200.71809765 0. 0. 9.
13 1 1 2 0 0 -10.259332044 -2.8475365938 -7.5613254442 13.058943338 0. 0. 9.
-15 1 1 2 0 0 5.6111092327 56.393834702 195.47236211 203.52197299 0. 0. 9.
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Conclusions

$gg\ (\to\ H)\ \to\ VV$ interference effects are not suppressed and can be as large as 5-10% when Higgs search selection cuts are applied or for $M_H \ll 2M_V$.

$\to$ should be taken into account in LHC data analysis

- updated gg2WW and gg2ZZ including Higgs-continuum interference and all different-flavour leptonic decays will become publically available in October
- extension to same-flavour leptonic decays planned for early next year