Higgs mass, width, line shape and interferences

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I would like to invite you to present a REVIEW TALK about

"Higgs mass and width, line-shape"
(covering also signal/background/interference)

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Basic Considerations

- Higgs Boson is an unstable particle and can not be observed

Lifetime at 125 GeV $1.56 \times 10^{-22} s$

- Issue for a proper QFT treatment

- Still one talks about Higgs production cross section and Higgs partial decay widths

- YR provides numbers for both (big TH effort)

- Convention to relate pseudo-Observables (TH) $\sigma_H(m_H)$ $Br(H \to X)$

to realistic observables (EXP) $\sigma(pp \to X)$

Example: Based on Zero Width Approximation (ZWA)

signal contribution $\sigma_{signal}(pp \to X) = \sigma_H(m_H) \times Br(H \to X)$

+ neglecting interference

$$\sigma(pp \to X) \sim \sigma_{signal}(pp \to X) + \sigma_{background}(pp \to X)$$

Relate EXP and TH results

$$\frac{\sigma(pp \to X) - \sigma_{background}(pp \to X)}{Br(H \to X)} \sim \frac{\sigma_{signal}(pp \to X)}{Br(H \to X)} \sim \sigma_H(m_H)$$

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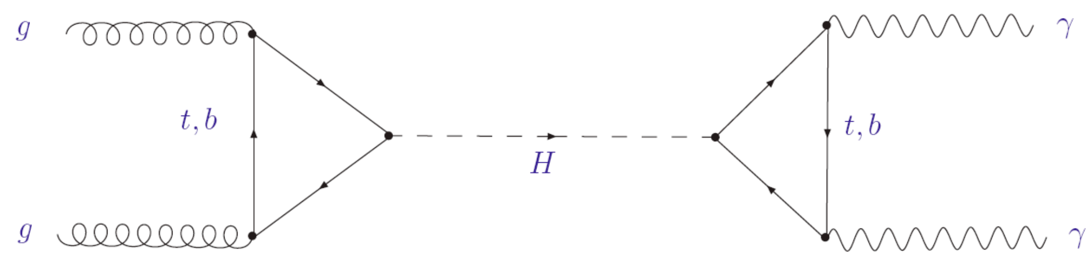
Proper treatment requires

- QFT treatment of line-shape
- Consideration of resonant and non-resonant contributions → Interferences

signal background

$$\mathcal{A}_{ij\to X} = \mathcal{A}_{ij\to H}\;\Delta_{\rm H}\;\mathcal{A}_{H\to X} + \mathcal{A}_{continuum}$$

Propagator



Goria, Passarino, Rosco

Dyson resummed propagator $\Delta_{\rm H}(s) = \left[s - M_{\rm H}^2 + S_{\rm HH}\left(s, M_{\rm t}^2, M_{\rm H}^2, M_{\rm W}^2, M_{\rm Z}^2\right)\right]^{-1}$

(renormalized) H mass H self energy

Can be written as (LO) $\Delta_{\rm H}^{-1} = s - s_{\rm H}$ Complex mass scheme

Complex solution of $s_{\rm H} - M_{\rm H}^2 + S_{\rm HH}\left(s_{\rm H}, M_{\rm t}^2, M_{\rm H}^2, M_{\rm W}^2, M_{\rm Z}^2\right) = 0$

The complex pole can be parametrized as

$$s_i = \mu_i^2 - i\,\mu_i\,\gamma_i$$

can be computed in SM as on-shell width

input parameter similar to on-shell mass

Complex mass scheme can be translated into more familiar language (Bar-scheme)

$$\frac{1}{s - s_{\rm H}} = \left(1 + i\,\frac{\overline{\Gamma}_{\rm H}}{\overline{M}_{\rm H}}\right)\left(s - \overline{M}^2_{\rm H} + i\,\frac{\overline{\Gamma}_{\rm H}}{\overline{M}_{\rm H}}\,s\right)^{-1}$$

$$\overline{M}^2_{\rm H} = \mu^2_{\rm H} + \gamma^2_{\rm H} \qquad \mu_{\rm H}\,\overline{\Gamma}_{\rm H} = \overline{M}_{\rm H}\,\gamma_{\rm H}$$

equivalent to BW with running width (not on-shell parameters)

$\mu_{\rm H}$[GeV]	$\Gamma^{\rm OS}_{\rm H}$[GeV] (Ref. [1])	$\gamma_{\rm H}$ [GeV]	$\overline{M}_{\rm H}$[GeV]	$\overline{\Gamma}_{\rm H}$[GeV]
200	1.43	1.35	200	1.35
400	29.2	25.60	400.9	26.66
600	123	103.93	608.9	105.48
700	199	162.97	718.7	167.33
800	304	235.57	834.0	245.57
900	449	320.55	955.4	340.28
1000	647	416.12	1083.1	450.71

Goria, Passarino, Rosco

Numerator provides right asymptotic behavior $s \to \infty$

Bar scheme provides good approx. for on-shell mass for light Higgs

$\gamma_{\rm H} \ll \mu_{\rm H}$

Different schemes in the literature (prop., on-shell/off-shell)

ONBW $\mathcal{A}^{prod}_{ij\to H}(\mu_H)\ \Delta^{BW}_H(Q)\ \mathcal{A}^{decay}_{H\to X}(\mu_H)$

$$\mathrm{BW}(\zeta) = \frac{1}{\pi}\,\frac{\mu_\mathrm{H}\,\Gamma^\mathrm{OS}_\mathrm{H}}{\left(\zeta-\mu^2_\mathrm{H}\right)^2+\left(\mu_\mathrm{H}\,\Gamma^\mathrm{OS}_\mathrm{H}\right)^2}$$

ad-hoc BW, neglect off-shell effects, violates gauge invariance

OFFBW $\mathcal{A}^{prod}_{ij\to H}(Q)\ \Delta^{BW}_H(Q)\ \mathcal{A}^{decay}_{H\to X}(Q)$

ad-hoc BW, violates gauge invariance

ONP $\mathcal{A}^{prod}_{ij\to H}(\mu_H)\ \Delta^{prop}_H(Q)\ \mathcal{A}^{decay}_{H\to X}(\mu_H)$

neglect off-shell effects, violates gauge invariance

OFFP $\mathcal{A}^{prod}_{ij\to H}(Q)\ \Delta^{prop}_H(Q)\ \mathcal{A}^{decay}_{H\to X}(Q)$

violates gauge invariance

CPP $\mathcal{A}^{prod}_{ij\to H}(s_H)\ \Delta^{BW}_H(Q)\ \mathcal{A}^{decay}_{H\to X}(s_H)$

respects all requirements (calculation on second Riemann sheet)

For light Higgs different implementations provide similar results (within QCD uncertainties)

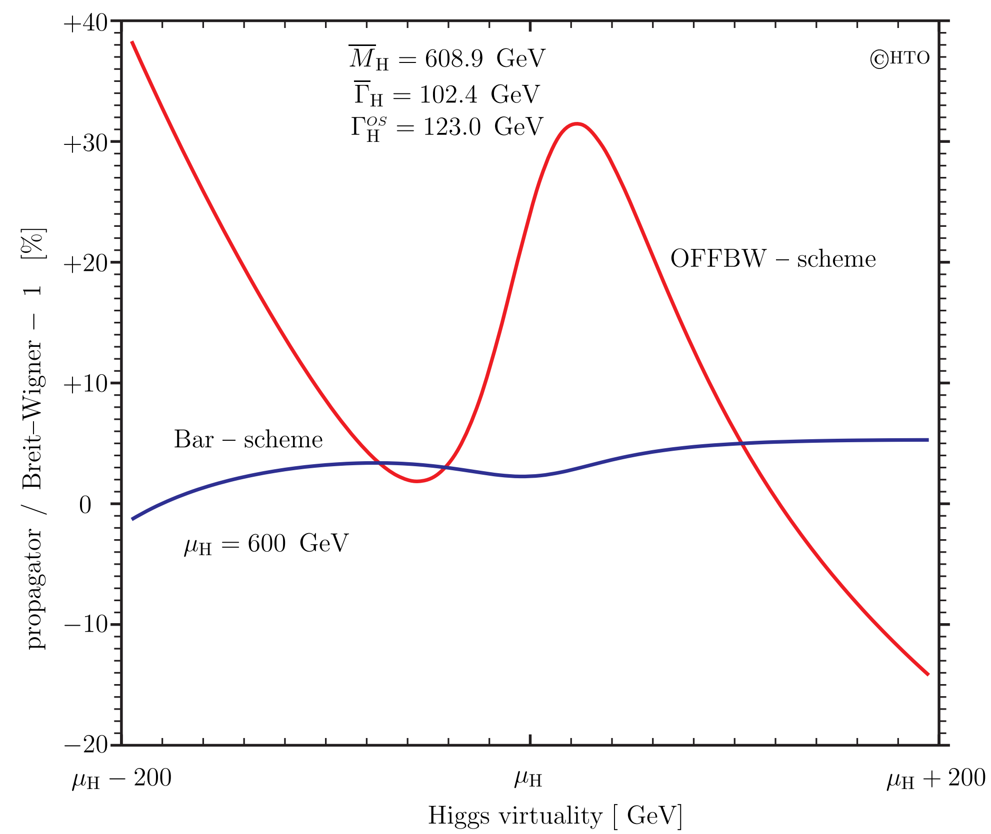
Goria, Passarino, Rosco

OFFBW

μ_H [GeV]	σ_{iHixs} [pb]	Δ_{iHixs} [%]	σ_{HTO} [pb]	Δ_{HTO} [%]	δ [%]
200	5.57	+7.19 −9.06	5.63	+9.12 −9.30	1.08
220	4.54	+6.92 −8.99	4.63	+8.93 −8.85	1.98
240	3.80	+6.68 −8.91	3.91	+8.76 −8.51	2.89
260	3.25	+6.44 −8.84	3.37	+8.61 −8.22	3.69
280	2.85	+6.18 −8.74	2.97	+8.49 −7.98	4.21
300	2.57	+5.89 −8.58	2.69	+8.36 −7.75	4.67

For heavy Higgs sizable differences in cross section and shape

μ_H [GeV]	Γ_H^{OS} [GeV]	γ_H [GeV]	σ^{OS} [pb]	σ^{BW} [pb]	σ^{prop} [pb]
500	68.0	60.2	0.8497	0.8239	0.9367
550	93.1	82.8	0.5259	0.5161	0.5912
600	123	109	0.3275	0.3287	0.3784
650	158	139	0.2064	0.2154	0.2482
700	199	174	0.1320	0.1456	0.1677
750	248	205	0.0859	0.1013	0.1171
800	304	245	0.0567	0.0733	0.0850
850	371	277	0.0379	0.0545	0.0643
900	449	331	0.0256	0.0417	0.0509



Zero width approximation?

Zero width approximation based on

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

production decay

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

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

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

$\frac{\Gamma}{M} \ll 1$ contribution from tail $\int_{(M-n\Gamma)^2}^{(M+n\Gamma)^2}\frac{dq^2}{2\pi}\frac{1}{(q^2-M^2)^2+(M\Gamma)^2} \approx \frac{1}{2M\Gamma}\left(1-\frac{1}{n\pi}\right)$

for Higgs n=1000 means only 4 GeV ~ 0.03% effect

but precise calculation shows ~0.5% difference with ZWA $\sim 100\frac{\Gamma}{M}$

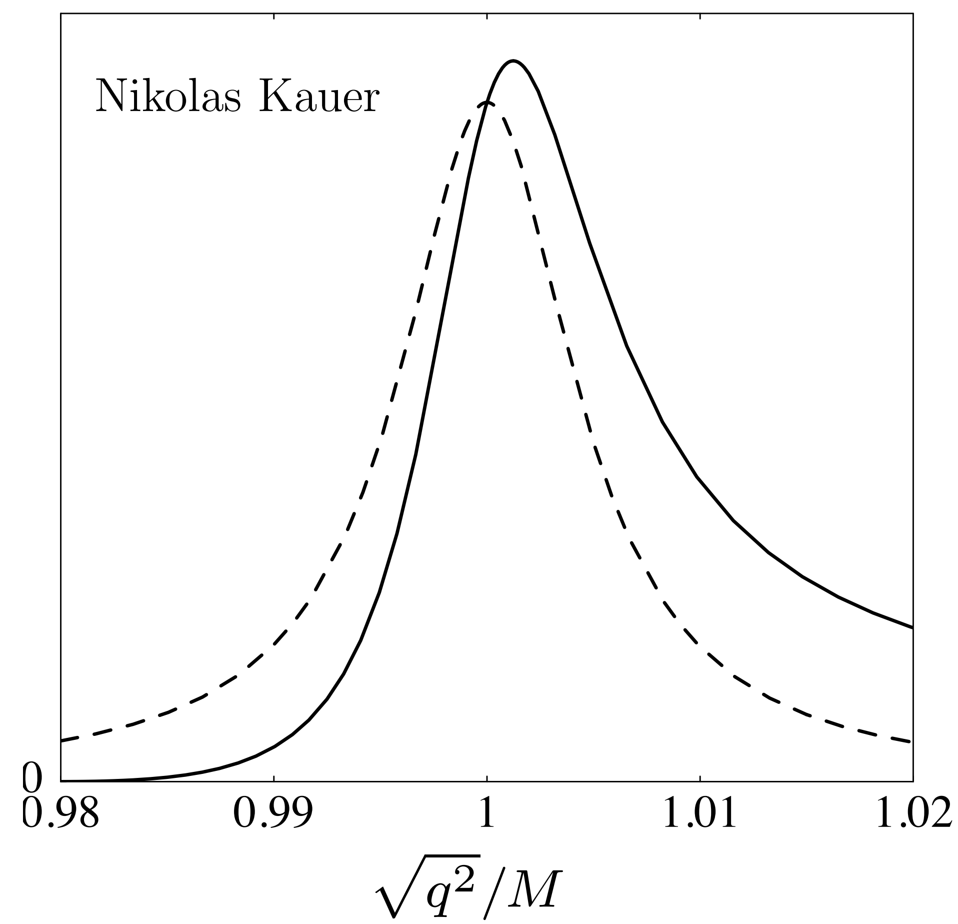
Decay amplitude can produce a significant deformation of the Higgs lineshape

Threshold effects

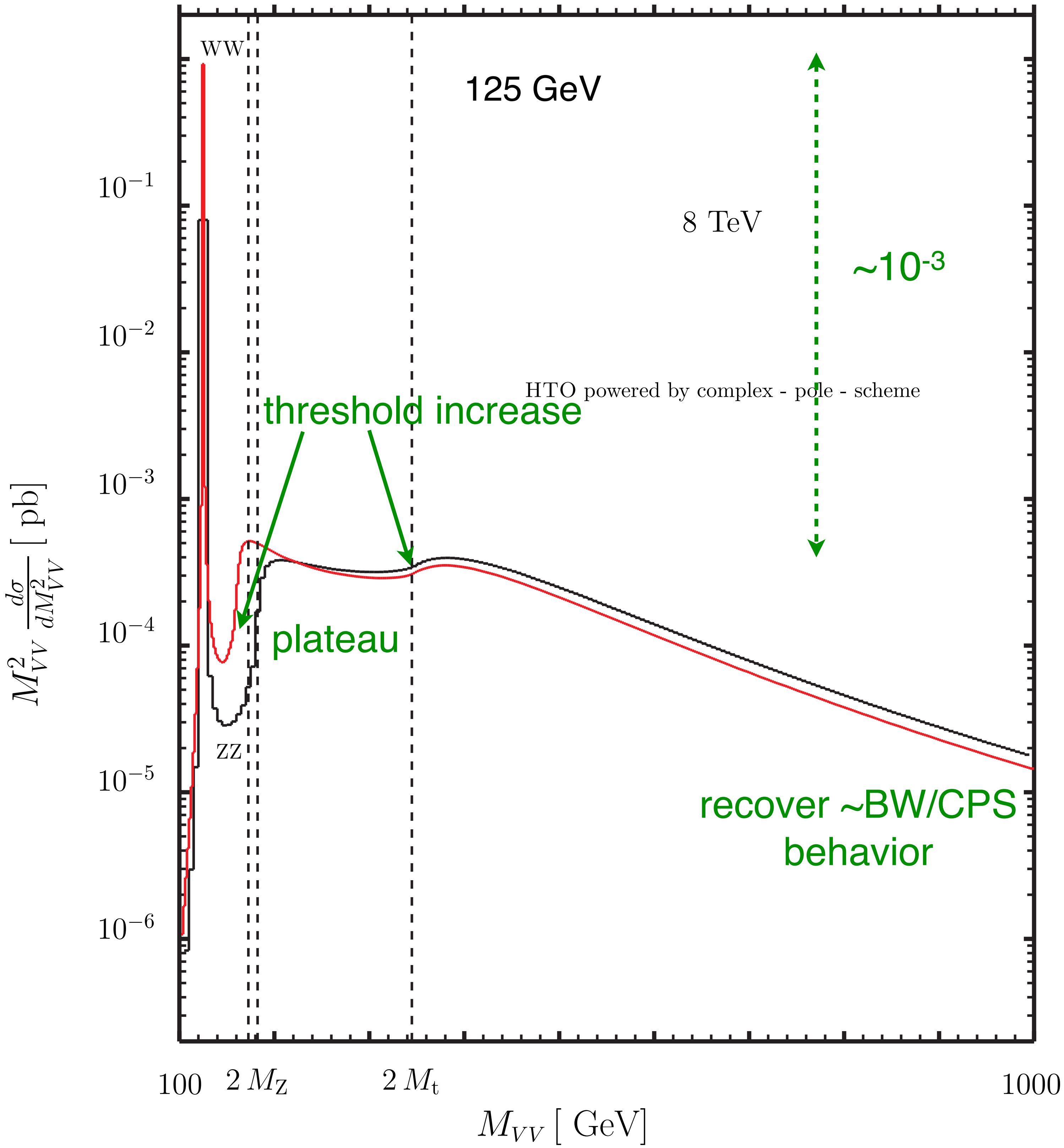
$$|\mathcal{M}_d(H \to f\bar{f})|^2 \sim M_f^2 q^2 \quad \text{for } \sqrt{q^2} \gtrsim 2\, M_f$$
$$|\mathcal{M}_d(H \to VV)|^2 \sim (q^2)^2 \quad \text{for } \sqrt{q^2} \gtrsim 2\, M_V$$

can compensate the $\dfrac{1}{q^4}$ in

$$D_H(q^2) = \frac{1}{\left(q^2 - M_H^2\right)^2 + \Gamma_H^2\, M_H^2}$$



resulting in a lineshape strongly enhanced at large virtualities



Kauer, Passarino

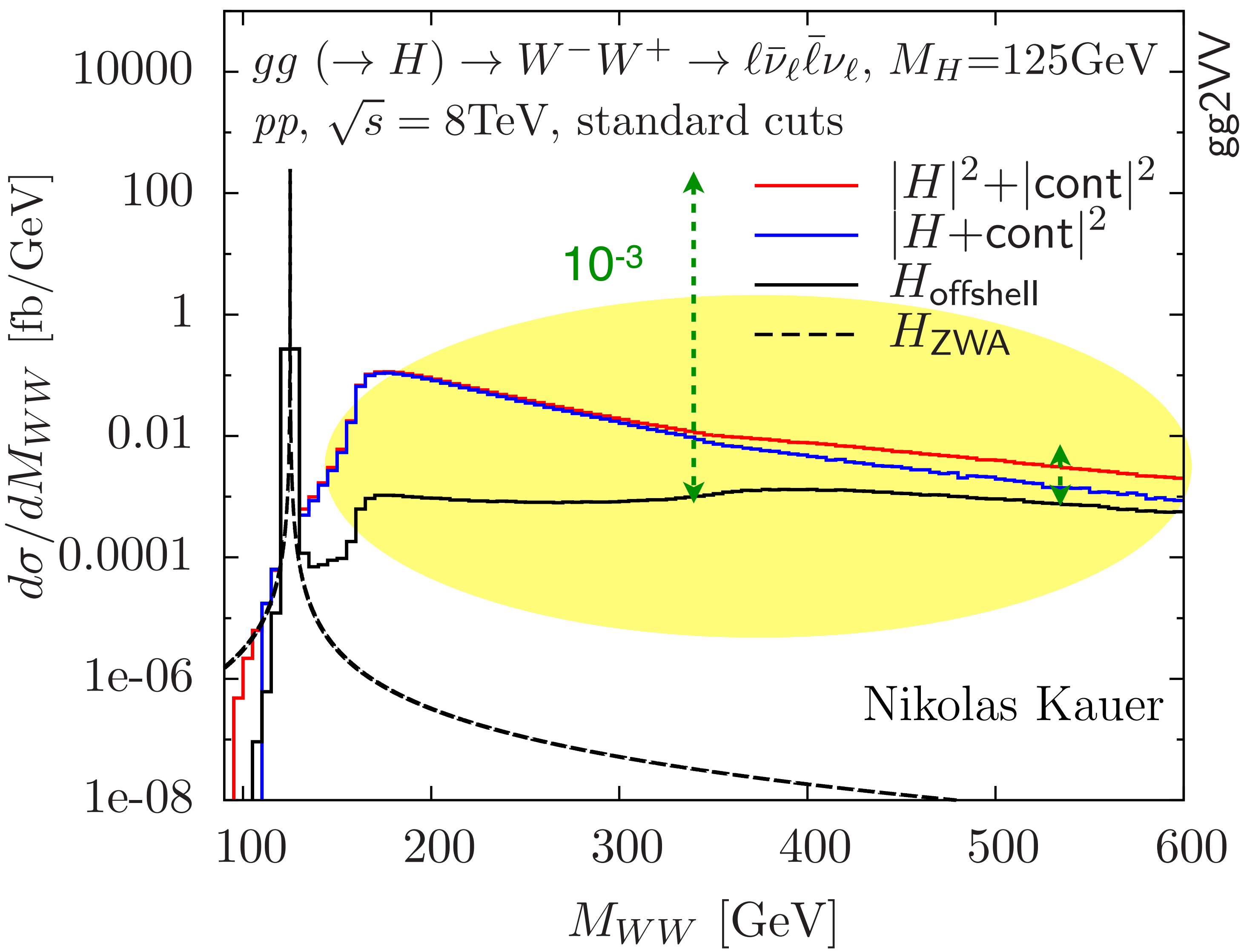
	Tot[pb]	$M_{ZZ} > 2\,M_Z$[pb]	R[%]
$gg \to H \to$ all	19.146	0.1525	0.8
$gg \to H \to ZZ$	0.5462	0.0416	7.6

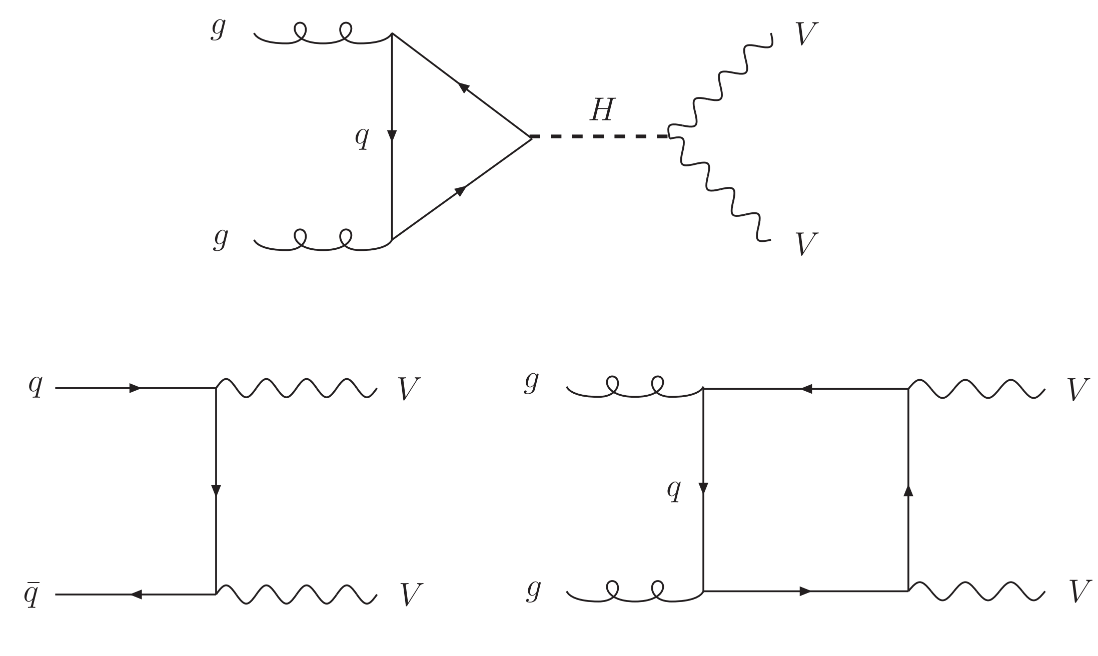
Integration over large kinematical range enhances off-shell effects

100–125	125–150	150–175	175–200	200–225	225–250	250–275
0.252	0.252	$0.195 \cdot 10^{-3}$	$0.177 \cdot 10^{-2}$	$0.278 \cdot 10^{-2}$	$0.258 \cdot 10^{-2}$	$0.240 \cdot 10^{-2}$

Offshell + Interferences in VV production

Offshell + Interference effects (WW)





Standard $M_{\ell\ell} > 12\,\text{GeV}$

$p_{T\ell} > 20\,\text{GeV},\ |\eta_\ell| < 2.5,\ \not{p}_T > 30\,\text{GeV}$

$R = \sigma_{H,\text{ZWA}}/\sigma_{H,\text{offshell}}$

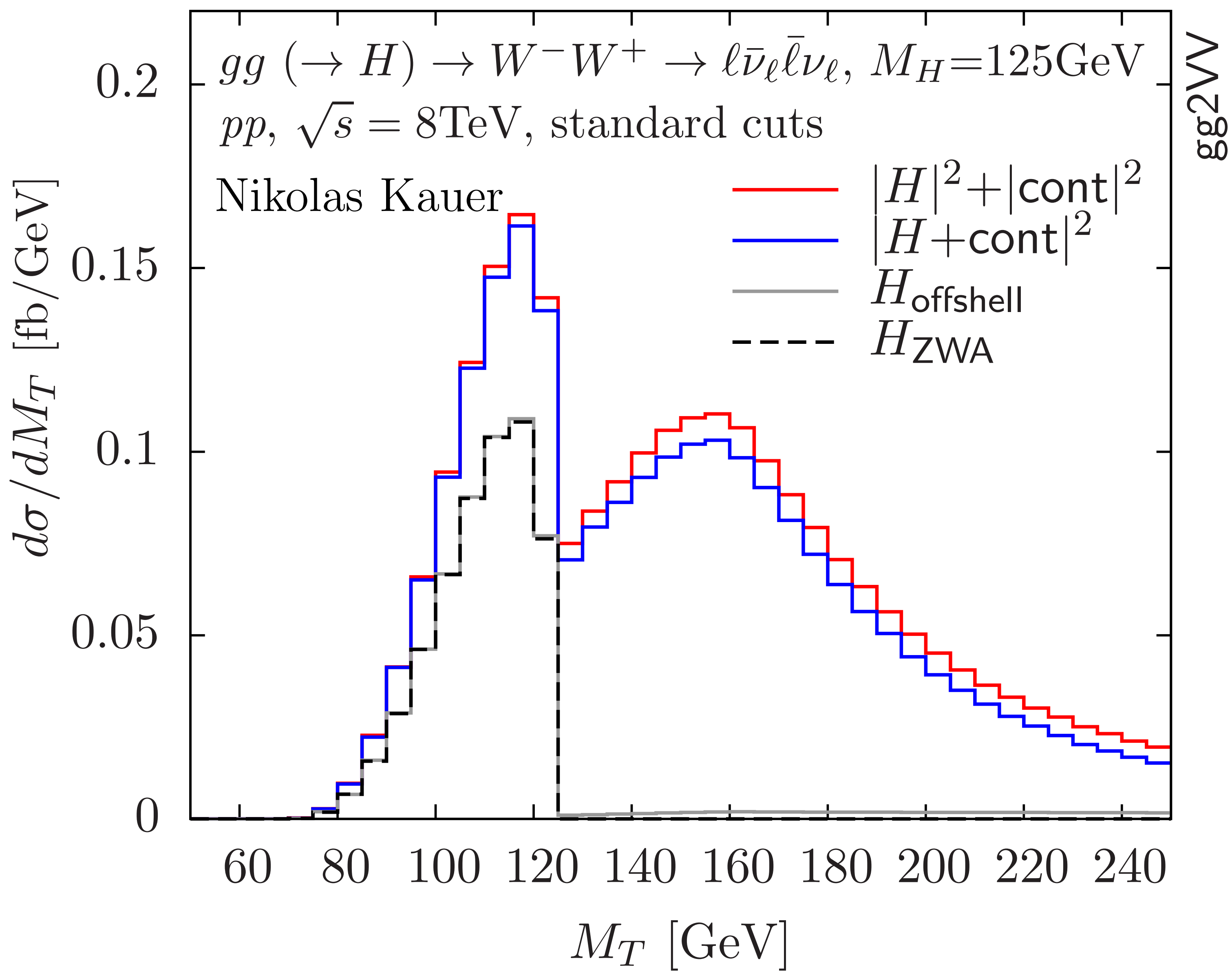
$|H_{ofs}+\text{cont}|^2/(H_{ofs}^2+\text{cont}^2)$

$gg\ (\to H) \to W^-W^+ \to \ell\bar{\nu}_\ell\bar{\ell}\nu_\ell,\ \sigma$ [fb], $pp,\ \sqrt{s} = 8$ TeV, $M_H = 125$ GeV						Interf. (dest.)
selection cuts	H_{ZWA}	H_{offshell}	cont	$\lvert H_{\text{ofs}}+\text{cont}\rvert^2$	R	
standard cuts	2.707(3)	3.225(3)	10.493(5)	12.241(8)	0.839(2)	0.89
Higgs search cuts	1.950(1)	1.980(1)	2.705(2)	4.497(3)	0.9850(7)	0.95
$0.75M_H < M_T < M_H$	1.7726(9)	1.779(1)	0.644(1)	2.383(2)	0.9966(8)	0.98

Higgs: standard+ $M_{\ell\ell} < 50\,\text{GeV},\ \Delta\phi_{\ell\ell} < 1.8$

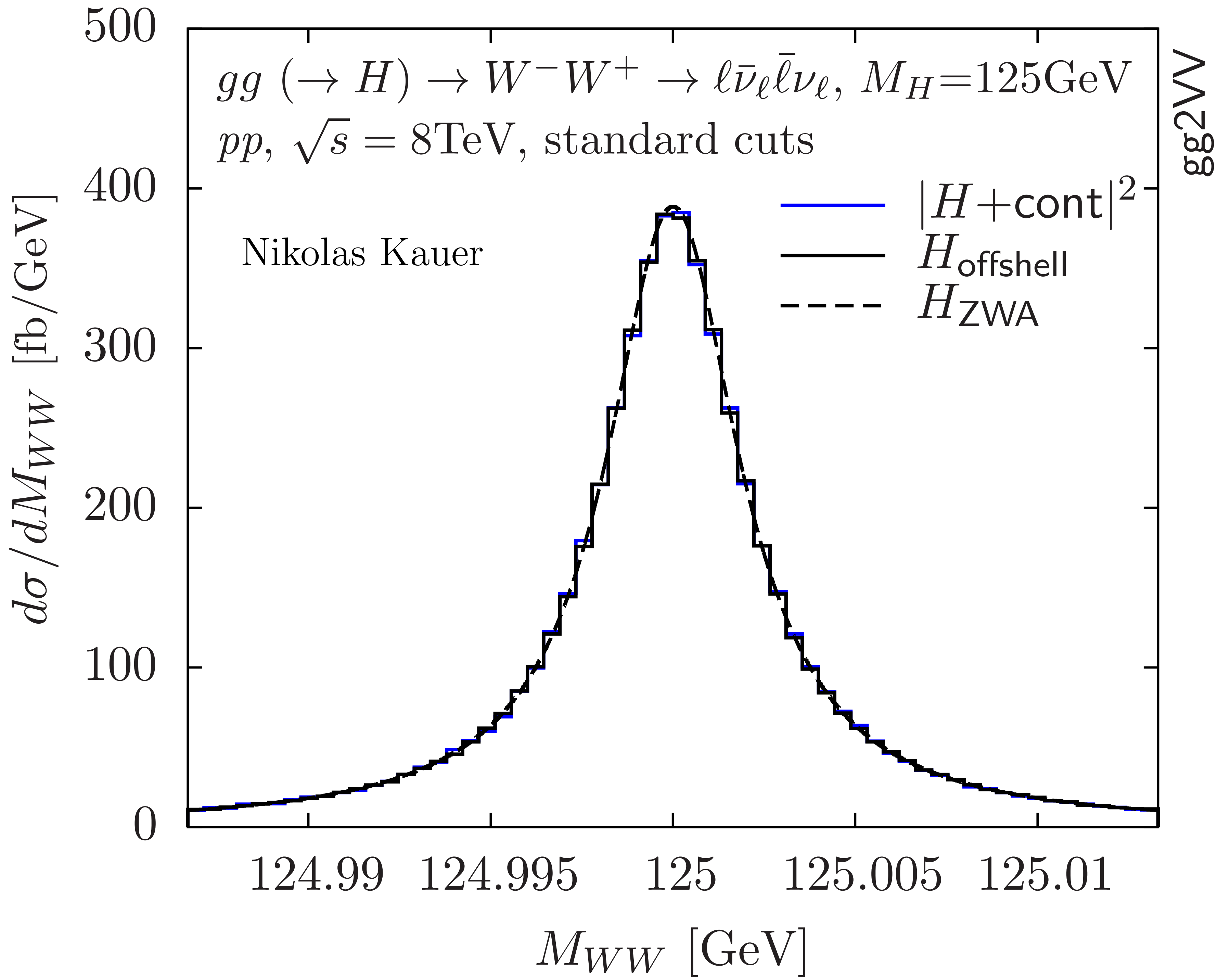
Additional cut on transverse mass to reduce contribution from $M_{WW} \gg 2M_W$

$$M_T = \sqrt{(M_{T,\ell\ell} + \not{p}_T)^2 - (\mathbf{p}_{T,\ell\ell} + \not{\mathbf{p}}_T)^2} \text{ with } M_{T,\ell\ell} = \sqrt{p_{T,\ell\ell}^2 + M_{\ell\ell}^2}\,.$$

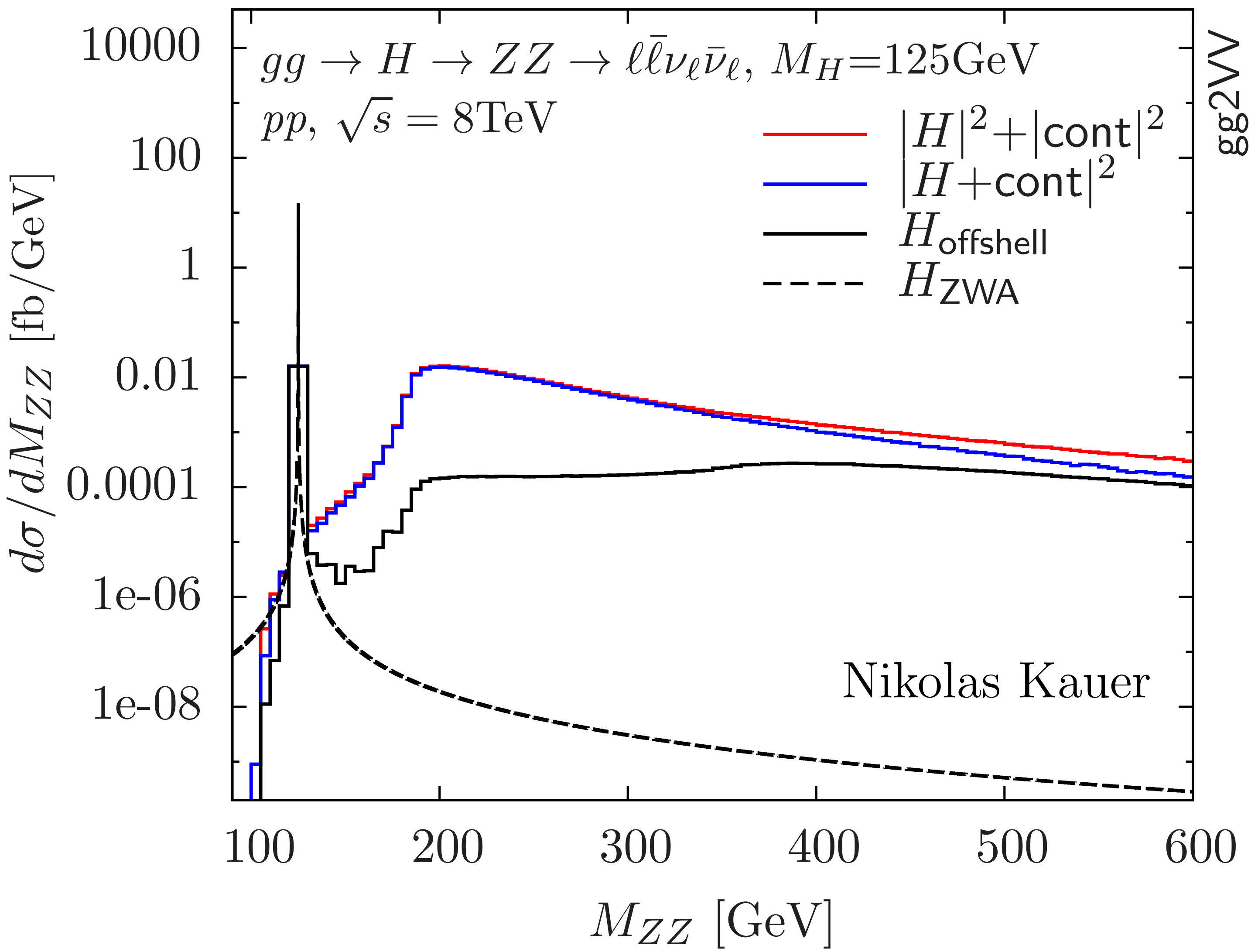


Strong suppression with $M_T < M_H$

In the vicinity of the Higgs resonance, finite width and Higgs-continuum interference effects are negligible for $gg\ (\to H) \to VV$ if $M_H \ll 2M_V$



Offshell + Interference effects (ZZ)



$$gg\ (\to H) \to ZZ \to \ell\bar{\ell}\nu_\ell\bar{\nu}_\ell$$

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

$$76\ \mathrm{GeV} < M_{\ell\ell} < 106\ \mathrm{GeV}$$

$$\not{p}_T > 10\ \mathrm{GeV}$$

$$R = \sigma_{H,\mathrm{ZWA}}/\sigma_{H,\mathrm{offshell}}$$

$|H_{ofs} + \mathrm{cont}|^2/(H_{ofs}^2 + \mathrm{cont}^2)$

$gg\ (\to H) \to ZZ \to \ell\bar{\ell}\nu_\ell\bar{\nu}_\ell$, σ [fb], pp, $\sqrt{s} = 8$ TeV, $M_H = 125$ GeV

M_T cut	H_{ZWA}	H_{offshell}	cont	$\lvert H_{\mathrm{ofs}}+\mathrm{cont}\rvert^2$	R	Interf. (dest.)
none	0.1593(2)	0.2571(2)	1.5631(7)	1.6376(9)	0.6196(7)	0.89
$M_T < M_H$	0.1593(2)	0.1625(2)	0.4197(5)	0.5663(6)	0.980(2)	0.97

$gg \to H \to ZZ \to \ell\bar{\ell}\ell\bar{\ell}$ and $\ell\bar{\ell}\ell'\bar{\ell}'$

Kauer, Passarino

	$gg\ (\to H) \to ZZ \to 4\ell$ and $2\ell\, 2\ell'$						
	σ [fb], pp, $\sqrt{s} = 8\,\text{TeV}$, $M_H = 125\,\text{GeV}$				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)

$|M_{ZZ} - M_H| < 1\,\text{GeV}$ ZWA very accurate

$gg \to H \to ZZ \to \ell\bar{\ell}\ell\bar{\ell}$ and $\ell\bar{\ell}\ell'\bar{\ell}'$ Kauer, Passarino

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

$|M_{ZZ} - M_H| < 1\,\text{GeV}$ ZWA very accurate

Off-shell region sensitive to width Caola, Melnikov

in ZWA $\sigma_{i\to H\to f} \sim \dfrac{g_i^2 g_f^2}{\Gamma_H}$ invariant under

$$g = \xi g_{\text{SM}}$$
$$\Gamma_H = \xi^4 \Gamma_{\text{H,SM}},$$

but off-shell and interference scale

$\dfrac{\Gamma_H}{\Gamma_H^{\text{SM}}}$ $\sqrt{\dfrac{\Gamma_H}{\Gamma_H^{\text{SM}}}}$

onshell

$$N_{\text{exp}} = 432 + 3.72 \times \frac{\Gamma_H}{\Gamma_H^{\text{SM}}} - 9.91 \times \sqrt{\frac{\Gamma_H}{\Gamma_H^{\text{SM}}}} \pm 31$$

$M_{4l} > 130\ \text{GeV}$

$\Gamma_H \leq 38.8\ \Gamma_H^{\text{SM}} \approx 163\ \text{MeV}$ @ 95% cl

Interference in diphoton channel

Interference in diphoton

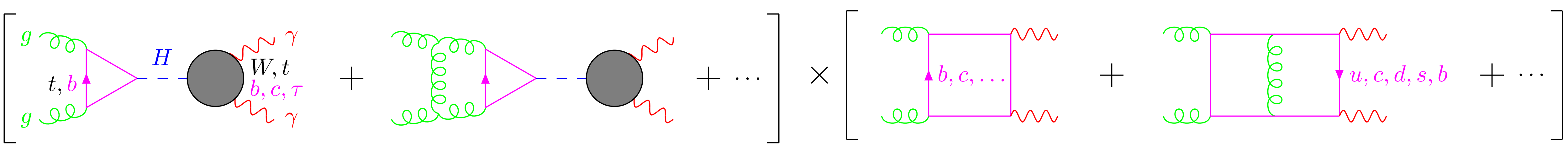
Dixon and Siu (2003)

$$\mathcal{A}_{gg\to\gamma\gamma} = \frac{-\mathcal{A}_{gg\to H}\mathcal{A}_{H\to\gamma\gamma}}{\hat{s} - m_H^2 + i m_H \Gamma_H} + \mathcal{A}_{\rm cont}$$

$$\delta\hat{\sigma}_{gg\to H\to\gamma\gamma} = -2(\hat{s} - m_H^2)\frac{\mathrm{Re}\,(\mathcal{A}_{gg\to H}\mathcal{A}_{H\to\gamma\gamma}\mathcal{A}^*_{\rm cont})}{(\hat{s} - m_H^2)^2 + m_H^2\Gamma_H^2} - 2m_H\Gamma_H\frac{\mathrm{Im}\,(\mathcal{A}_{gg\to H}\mathcal{A}_{H\to\gamma\gamma}\mathcal{A}^*_{\rm cont})}{(\hat{s} - m_H^2)^2 + m_H^2\Gamma_H^2}$$

~ vanishes upon integration over s

very different for WW where this term dominates



need relative phase to get Im part

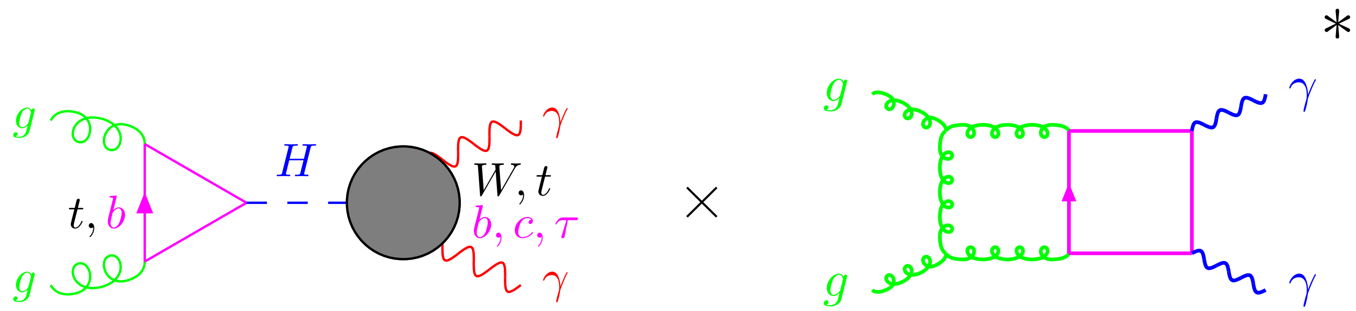
$\mathcal{A}_{gg\to H}$ and $\mathcal{A}_{H\to\gamma\gamma}$ are mainly real due to t,W dominance in the loop

$m_H < 2m_W$

At 1 loop $\mathcal{A}^*_{\rm cont}$ mainly real because

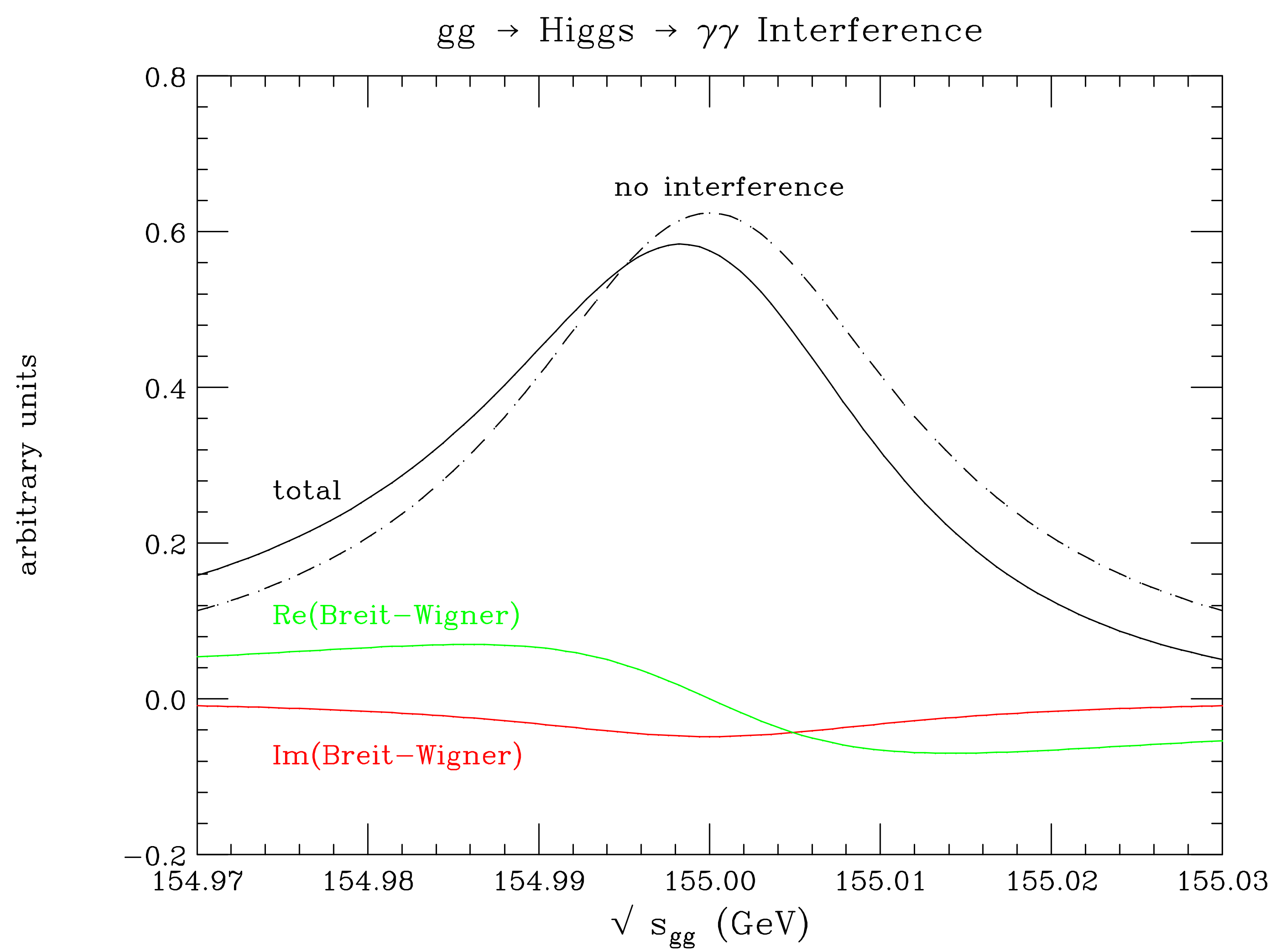
$$\mathcal{A}^{\rm tree}(g^\pm g^\pm \to q\bar{q}) = \mathcal{A}^{\rm tree}(q\bar{q} \to \gamma^\pm\gamma^\pm) = 0 \text{ for } m_q = 0$$

Needs 2 loop to interfere with signal $\mathcal{A}^{\rm 2-loop}_{gg\to\gamma\gamma}$



$\mathcal{O}(\alpha_s^3)$ formally → NLO to signal → NNNLO to background

Dominant contribution

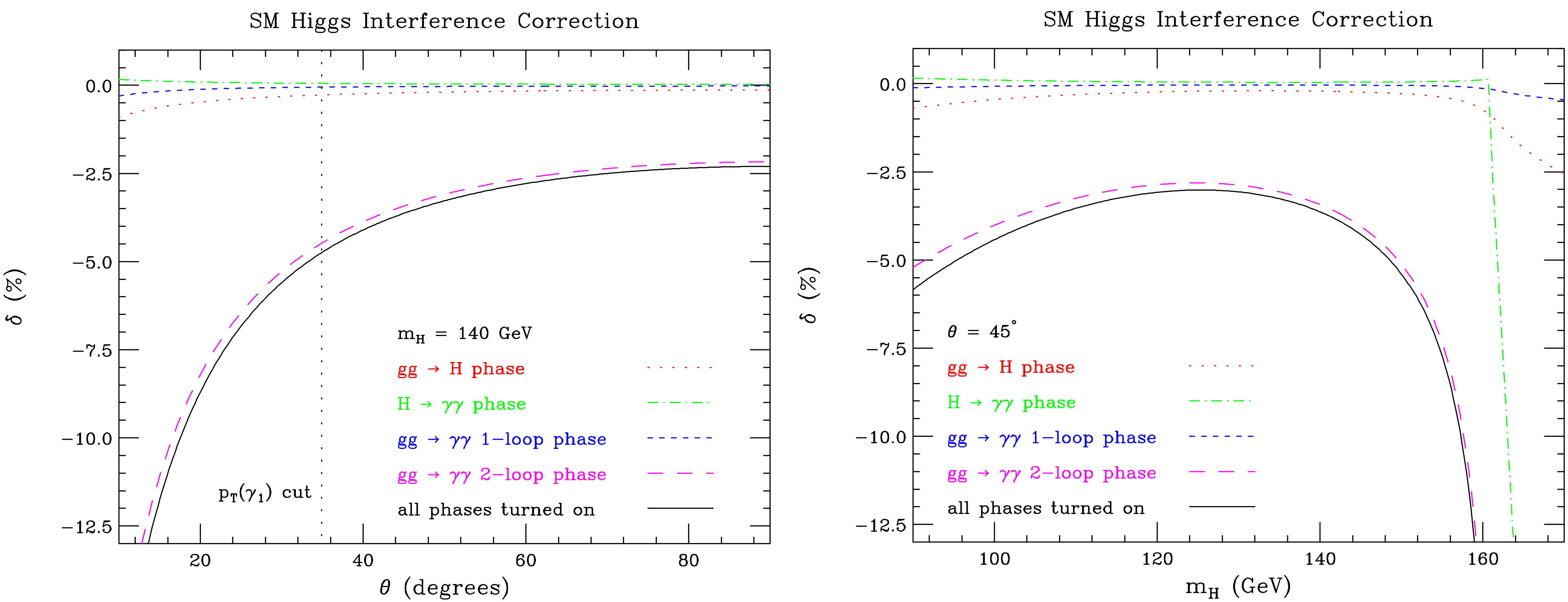


Dixon and Siu (2003)

Re integrates to ~0 (but..)

Im negative contribution

Dixon and Siu (2003)

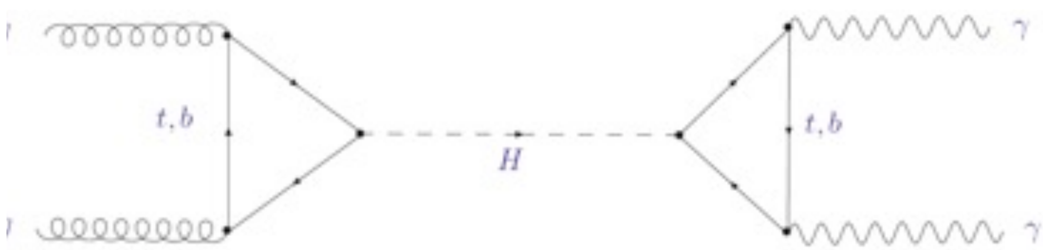


about -4% at 125 GeV, non trivial angular dependence

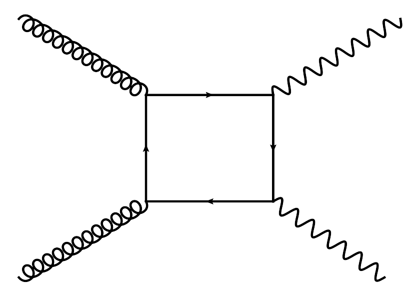
Interference in diphoton production

- S. Martin : go back to Real contribution

$$-2(\hat{s}-m_H^2)\frac{\mathrm{Re}\left(\mathcal{A}_{gg\to H}\mathcal{A}_{H\to\gamma\gamma}\mathcal{A}^*_{\mathrm{cont}}\right)}{(\hat{s}-m_H^2)^2+m_H^2\Gamma_H^2}$$



x



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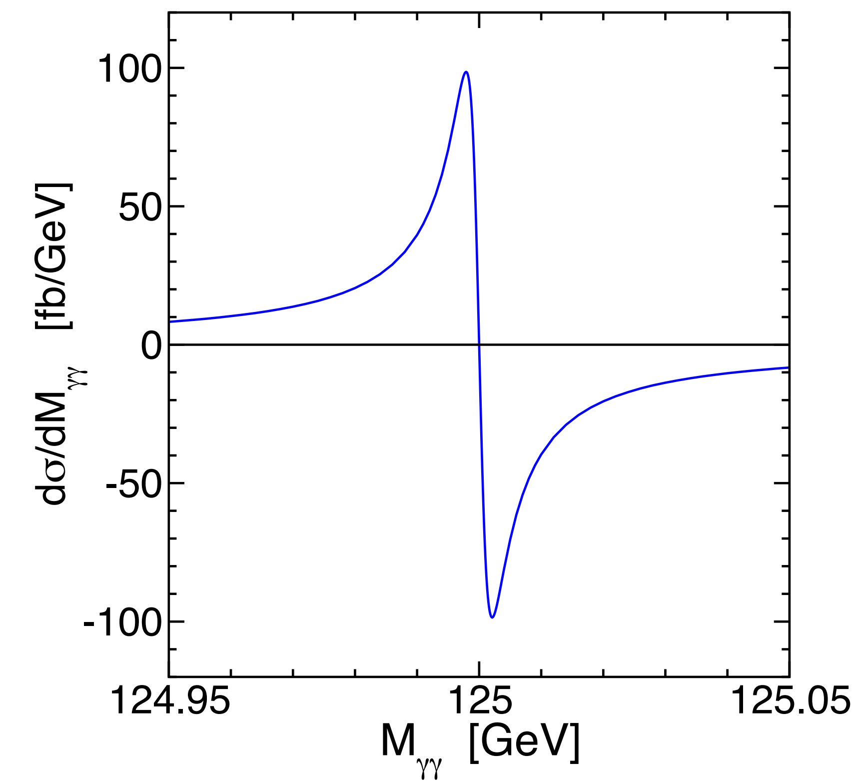
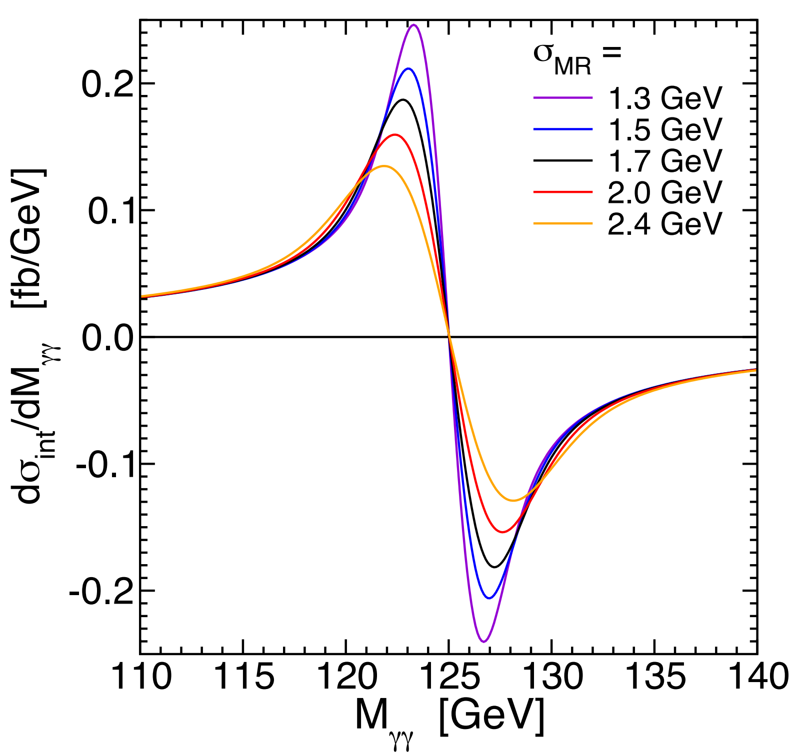
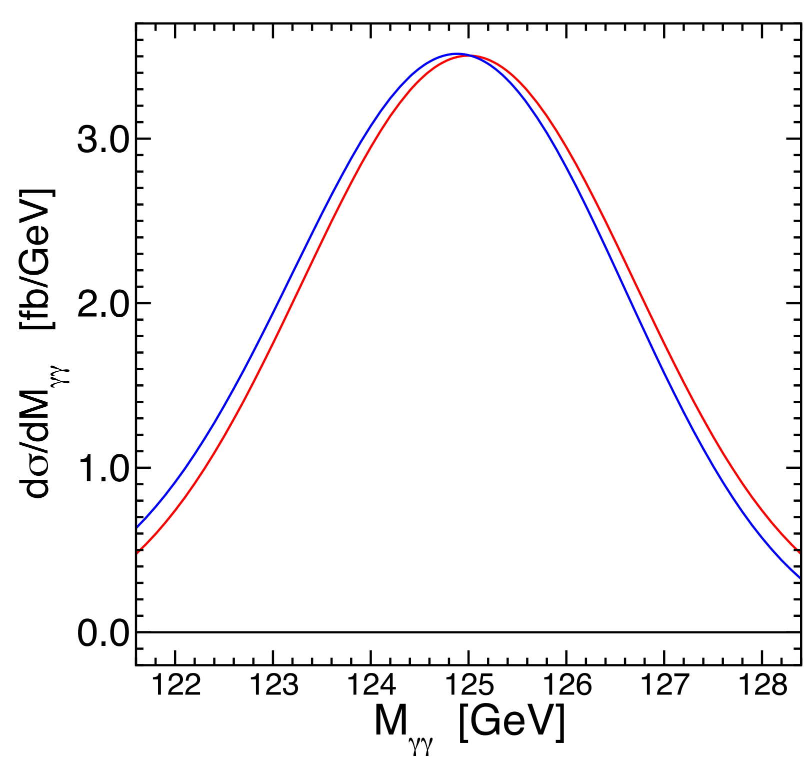
$\mathcal{O}(\alpha_s^2)$

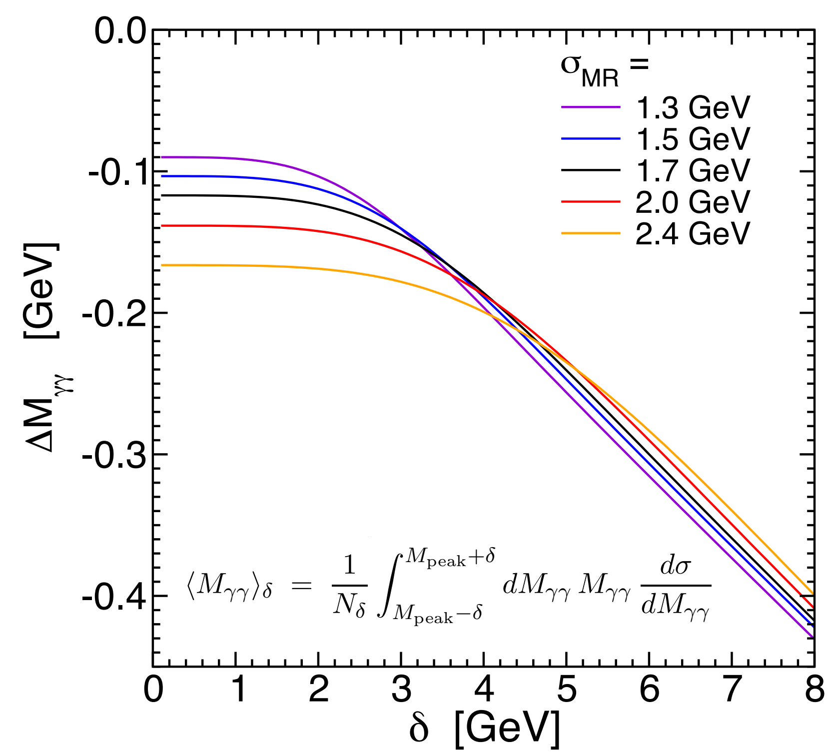


- small asymmetry in the interference
- at this level shift is O(MeV) as expected

Asymmetry enhanced by detector resolution can reach 100 MeV effect (Gaussian mass resolution)

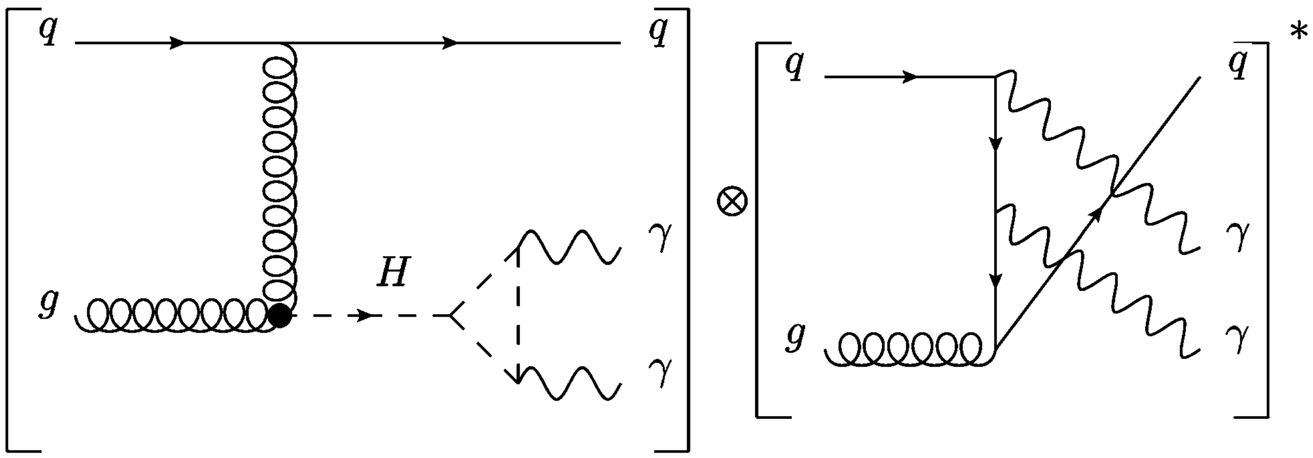


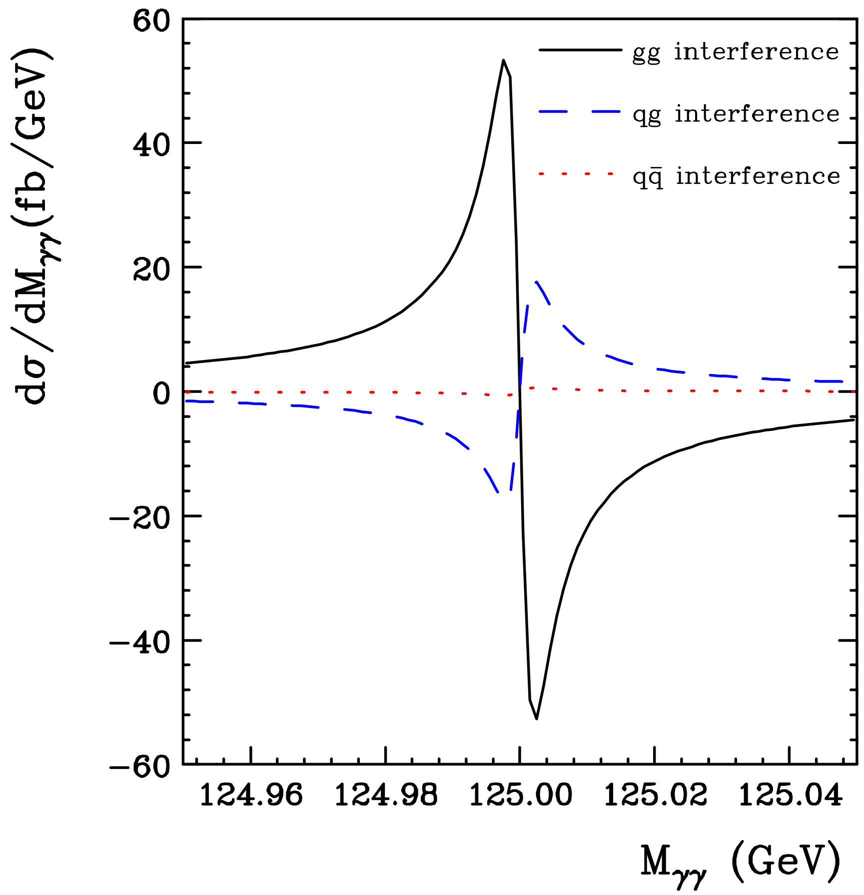




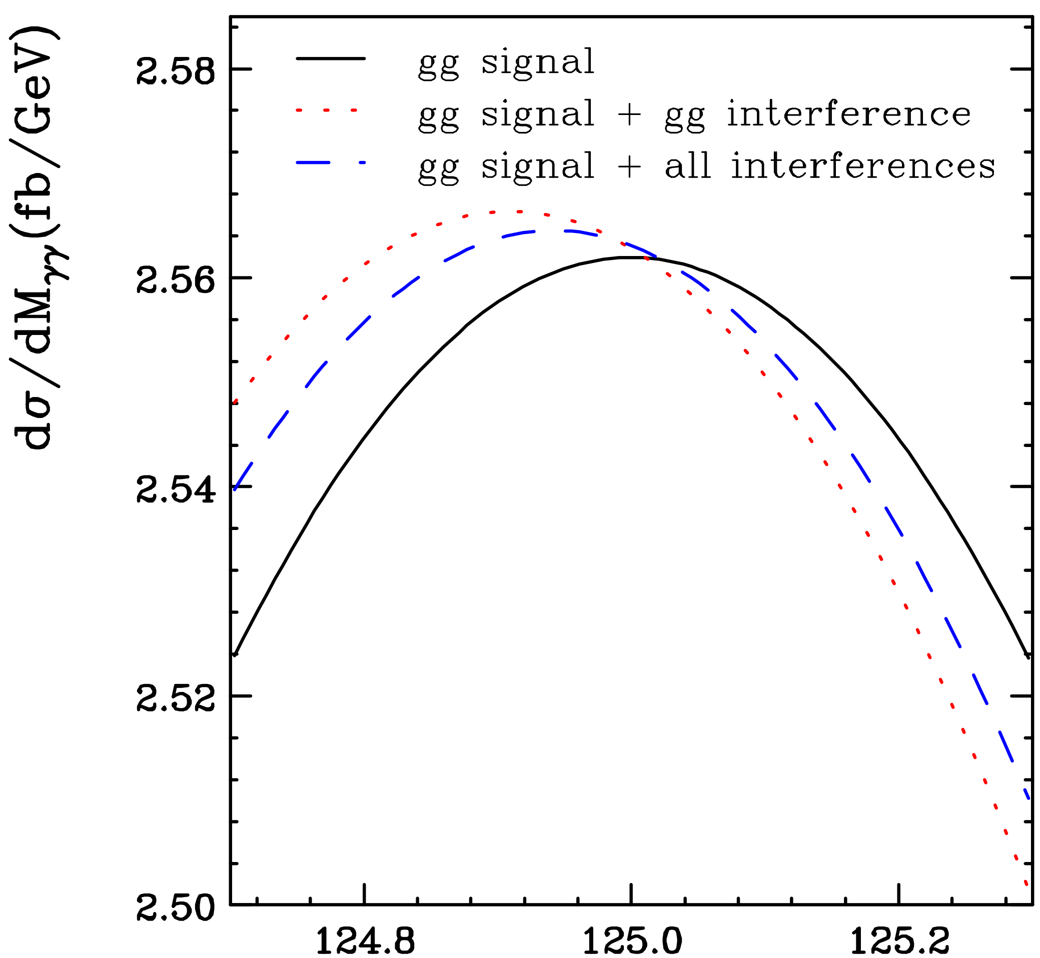
Effects from other channels go in opposite direction

• D.deF., N.Fidanza, R.Hernandez-Pinto, J.Mazzitelli, Y.Rotstein, G.Sborlini





LO for interference $\mathcal{O}(\alpha_s^2)$

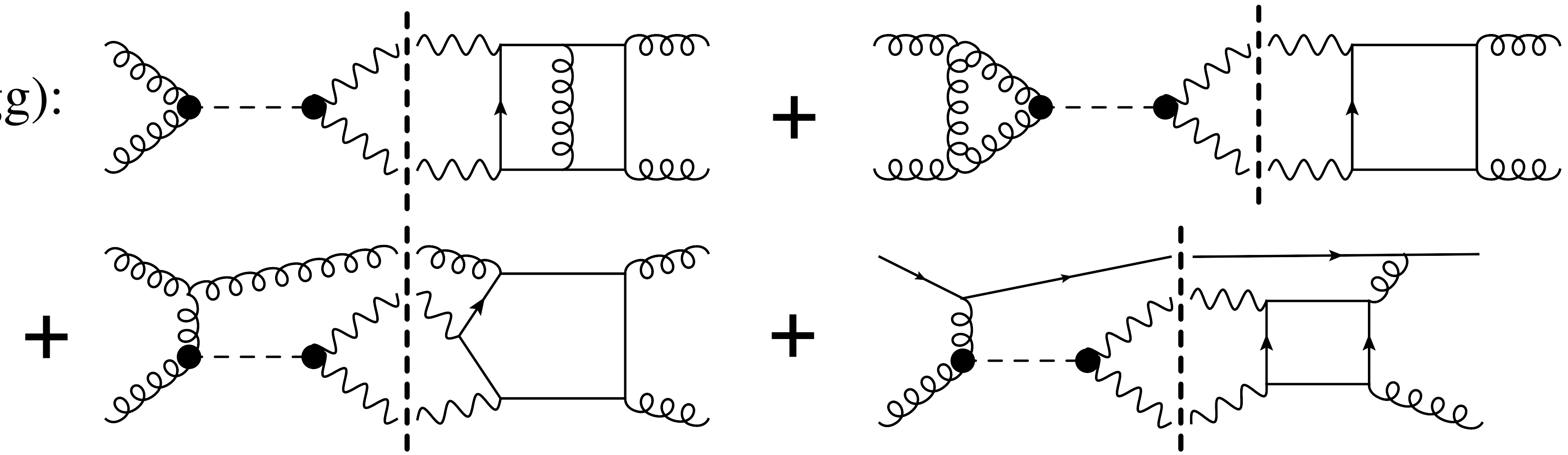


90 MeV ⟶ 60 MeV

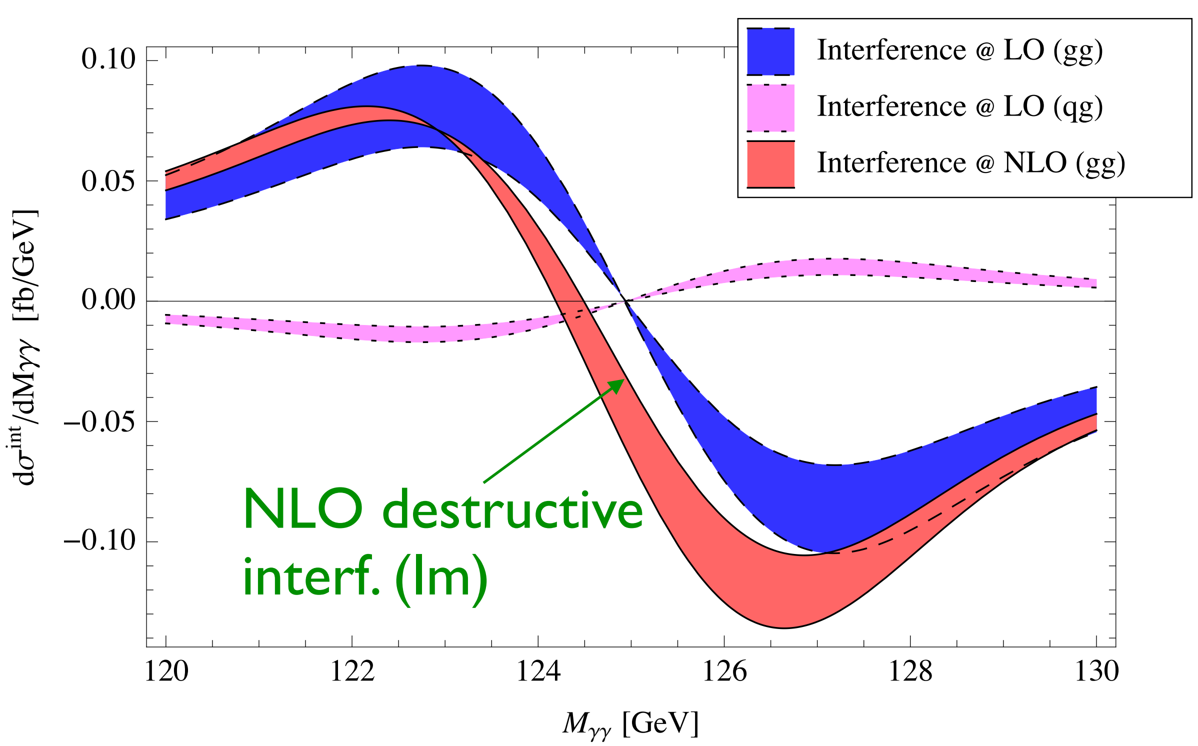
Interference at NLO

L.Dixon, Y.Li (2013) $\mathcal{O}(\alpha_s^3)$

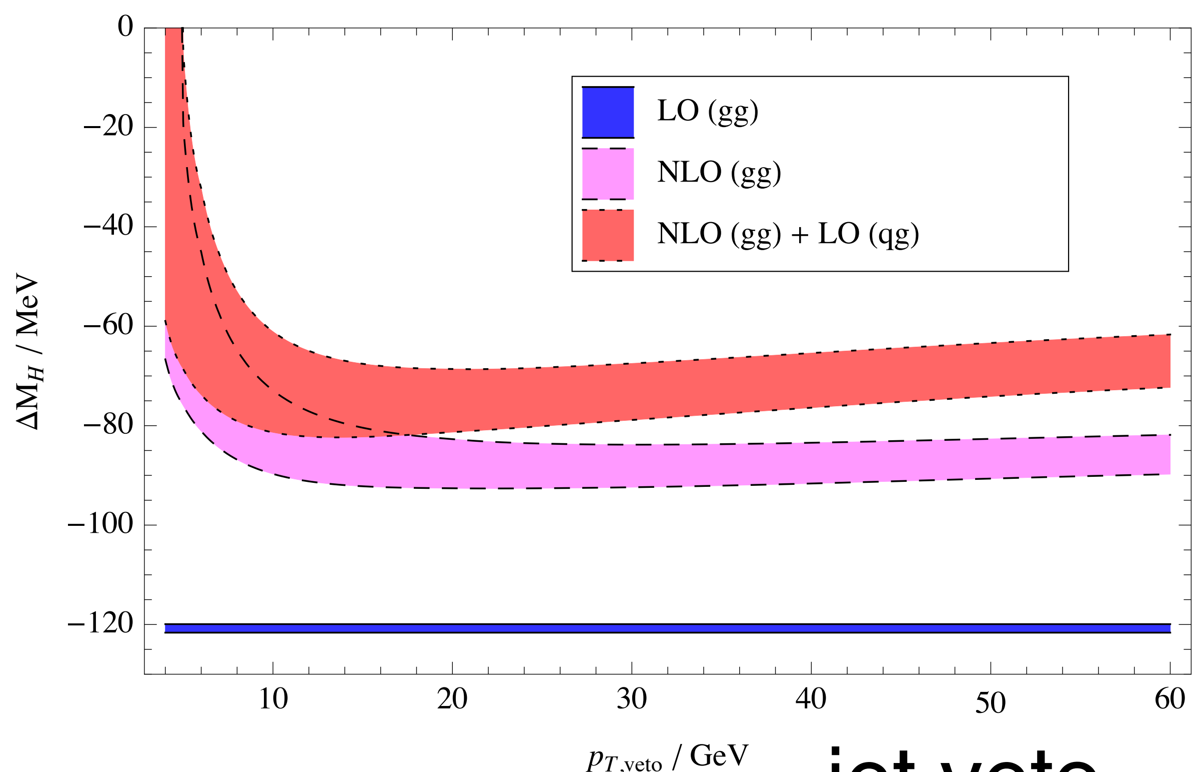
NLO (gg):



Interferences



Mass shift

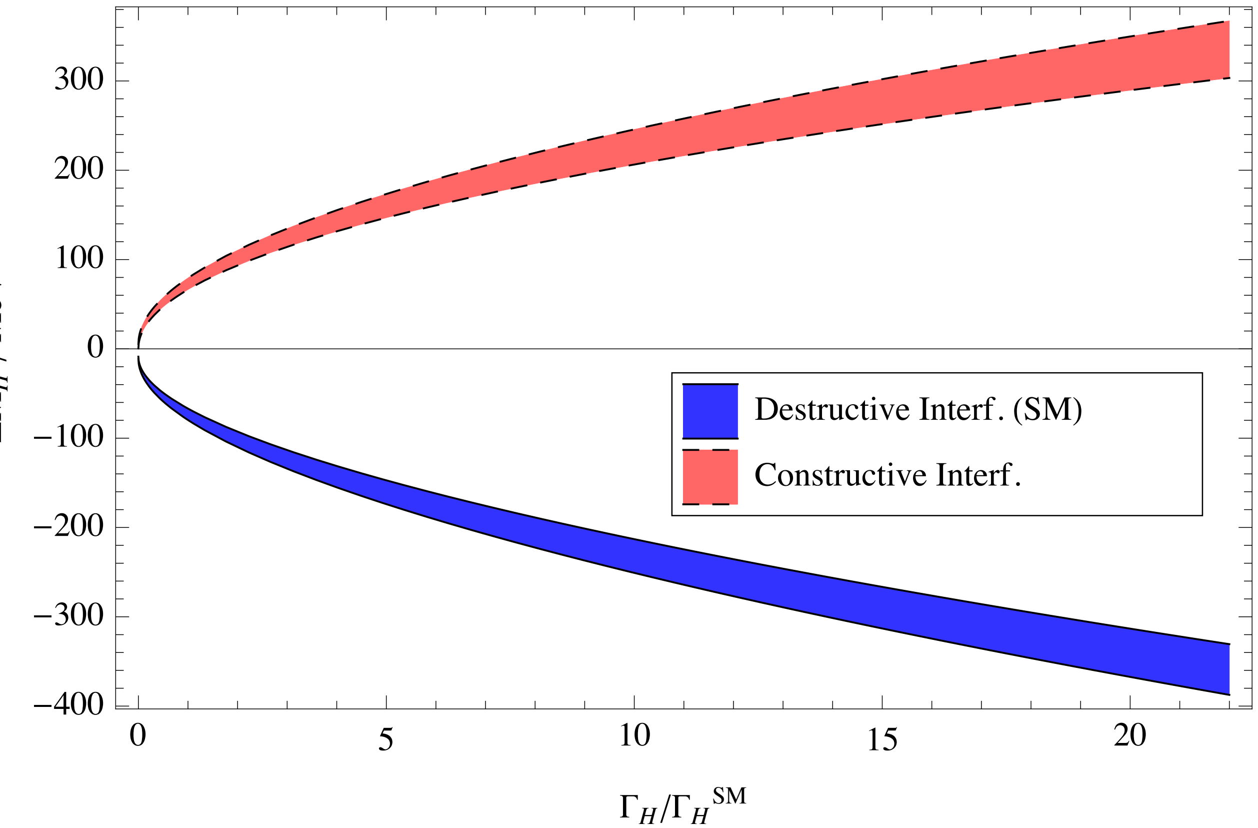


jet veto

Reduction in mass shift but sensitive to width

L.Dixon, Y.Li (2013)

Mass shift as a function of width



compare two channels

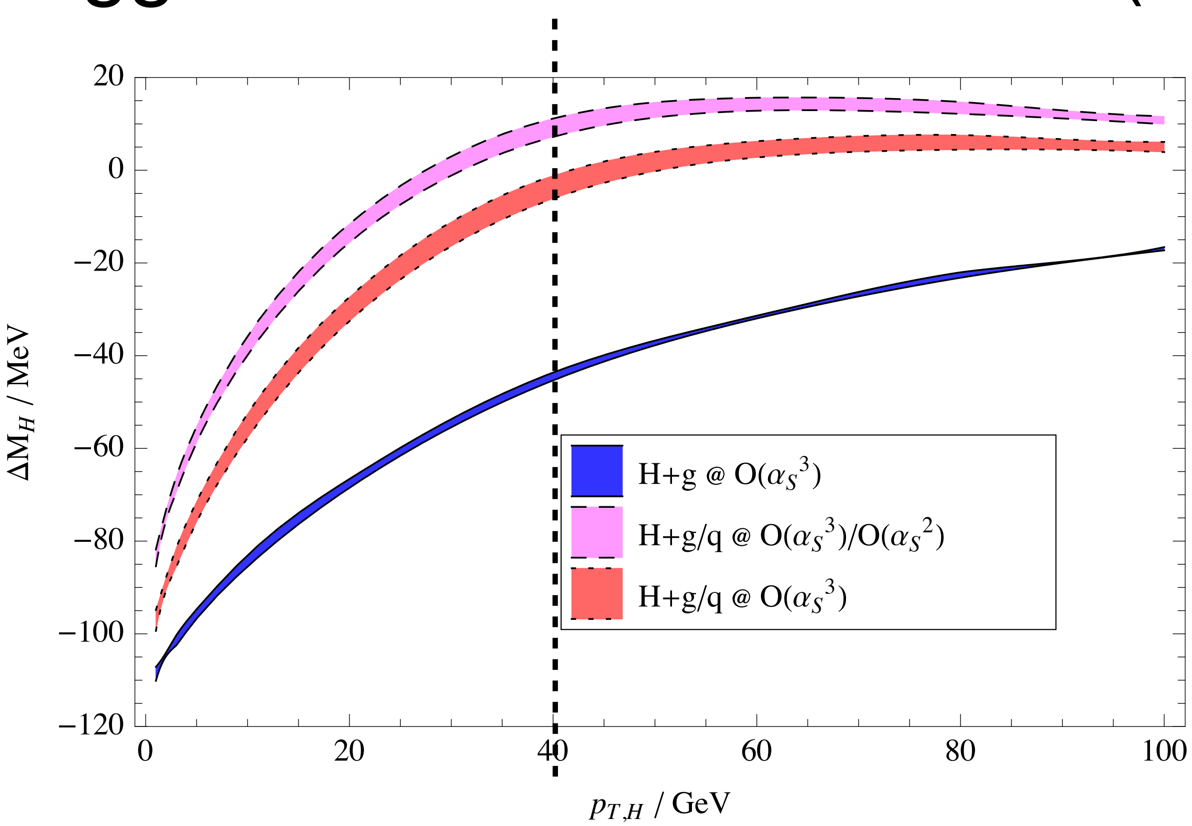
$$m_H^{\gamma\gamma} - m_H^{ZZ} = +2.3^{+0.6}_{-0.7} \pm 0.6 \text{ GeV (ATLAS)}$$
$$= -0.4 \pm 0.7 \pm 0.6 \text{ GeV (CMS)},$$

still difficult to use those numbers for limit on width

$$\Gamma_H < 200\,\Gamma_H^{SM} = 800\,\text{MeV}$$

~ 1 GeV mass shift

Higgs transverse momentum (same channel)



$$p_T > p_{T,H}$$

use two bins with 3 ab^{-1}

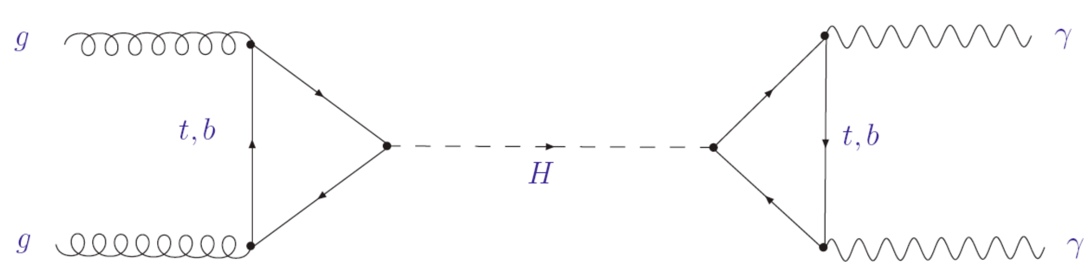
<15 x SM width at 95% c.l.

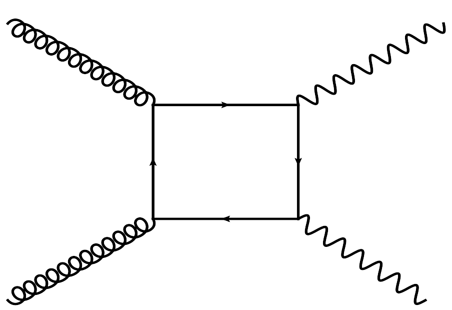
How to include interference?

Problem: signal/background computed to higher order than interference

signal to NNLO
background NLO
Interference LO

even "order counting" not trivial





$\mathcal{O}(\alpha_s^2)$

Caution, Born for interference means α_s^2 which is formally NNLO for background and LO for signal

- How to include interference

MCFM
Campbell, Ellis, Williams

Add to signal $\sigma_{Hi} = \sigma_H + \sigma_{interference}$

↖ K - factor?

- Some effects (like soft gluon emission) partially cancel in ratios

$$\sigma_{Hi}^{NNLO} = \sigma_H^{NNLO} \left(\frac{\sigma_{Hi}^{Born}}{\sigma_H^{Born}} \right)$$

full factorization of Interference effects

Some ambiguity for exclusive distributions

- Equivalent to apply signal K-factor to interference

$$\sigma_{Hi}^{NNLO} = \sigma_H^{NNLO} \left(\frac{\sigma_{Hi}^{Born}}{\sigma_H^{Born}} \right) = \left(\frac{\sigma_H^{NNLO}}{\sigma_H^{Born}} \right) \sigma_{Hi}^{Born}$$

K_{signal}

Problems :

- Privileges the signal (distorts line-shape)
- QCD correction to signal and background (box) can be different

QCD recommendations

G.Passarino

Additive

$$\frac{d\sigma^{\rm NNLO}_{eff}}{dx} = \frac{d\sigma^{\rm NNLO}}{dx}(S) + \frac{d\sigma^{\rm LO}}{dx}(I) + \frac{d\sigma^{\rm LO}}{dx}(B)$$

Multiplicative

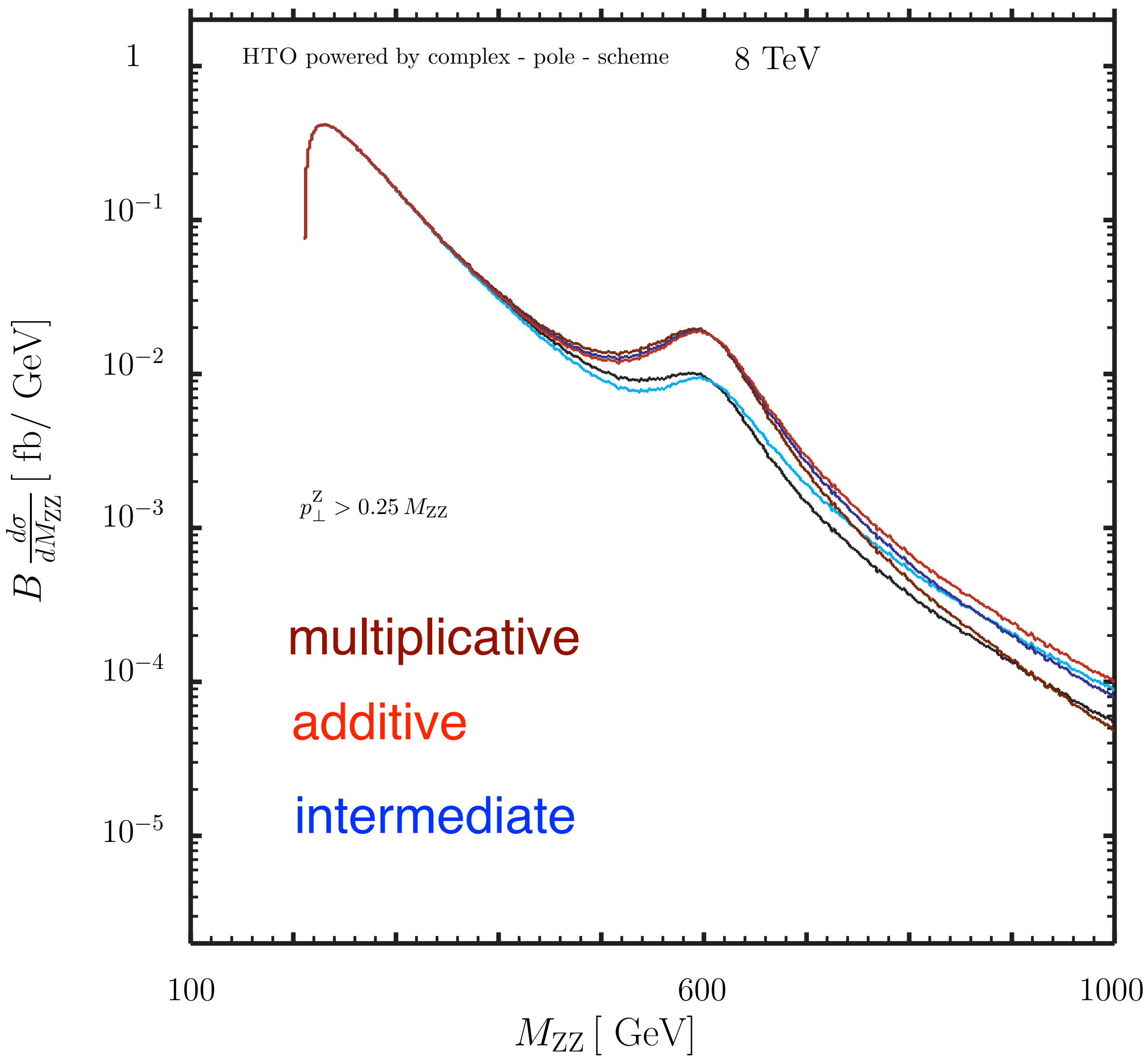
$$\frac{d\sigma^{\rm NNLO}_{eff}}{dx} = K_{\rm D}\left[\frac{d\sigma^{\rm LO}}{dx}(S) + \frac{d\sigma^{\rm LO}}{dx}(I)\right] + \frac{d\sigma^{\rm LO}}{dx}(B), \qquad K_{\rm D} = \frac{\frac{d\sigma^{\rm NNLO}}{dx}(S)}{\frac{d\sigma^{\rm LO}}{dx}(S)},$$

Intermediate

$$\frac{d\sigma^{\rm NNLO}_{eff}}{dx} = K_{\rm D}\frac{d\sigma^{\rm LO}}{dx}(S) + \left(K^{\rm gg}_{\rm D}\right)^{1/2}\frac{d\sigma^{\rm LO}}{dx}(I) + \frac{d\sigma^{\rm LO}}{dx}(B)$$

"Central value"

One possible way to account for uncertainty in the procedure



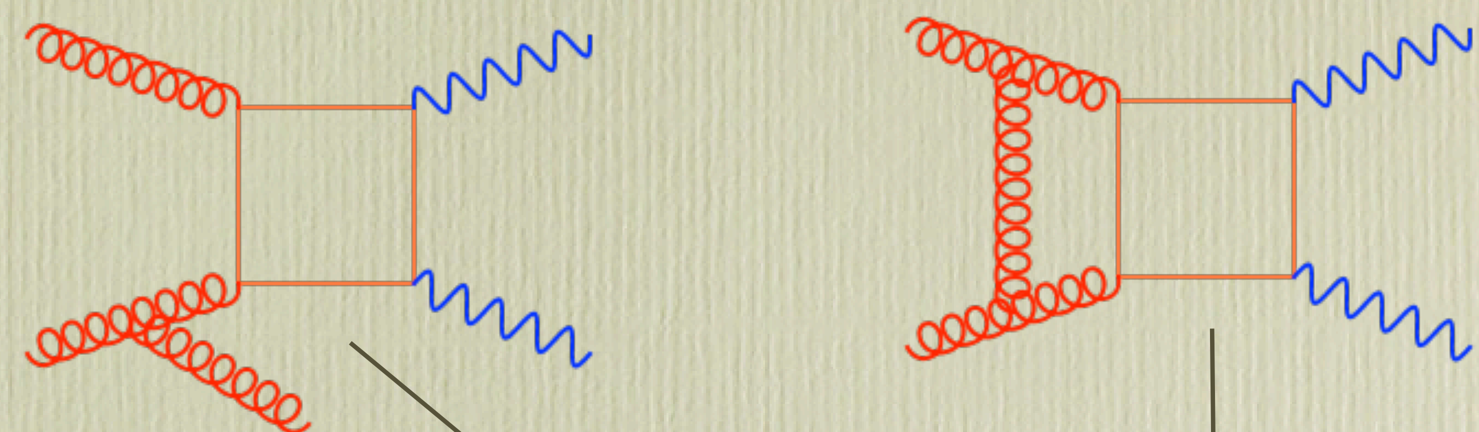
- spoil unitarity cancellation between S and B problem for high masses
- multiplicative better for regions with destructive interference
- additive better for regions with positive interference :miss higher orders from B but do not spoil cancellations

M.Bonvini, F.Caola, S.Forte, K.Melnikov, G.Ridolfi

- Use soft-virtual approximation at NNLO (assuming two-loop Higgs coefficient for background)

in the soft limit: up to NLO

F.Caola



$$\hat{\sigma} = \sigma_0 + \sigma_0 \frac{\alpha_s}{2\pi}\left(8C_A\left[\frac{\ln 1-z}{1-z}\right]_+ + c_1\delta(1-z) + \text{reg}\right) + \text{h.o.}$$

Bulk of the result, universal

Process-dependent

c_1 depends on the 1 loop corrections (+ soft)

Known up to 2 loops for the signal but not for the background

$gg \to W^+W^-$ in the kinematical limit $4m_W^2 \ll Q^2 \ll 4m_t^2,\ m_b \sim m_t$

- dominated by longitudinally polarized W's ~ $gg \to HH$
- in the large mass limit *HH* very similar to *H* production
- almost identical effective Lagrangian $\mathcal{L}_{\rm eff} = -\frac{1}{4} G_{\mu\nu}G^{\mu\nu}\left(C_H \frac{H}{v} - C_{HH}\frac{H^2}{v^2}\right)$
- use for background same "virtual coefficient" from signal

allow for uncertainty $-5\bar{c}_{1,2} < c_{1,2} < 5\bar{c}_{1,2}$ $\mathcal{O}(10\%)$

- QCD corrections enhance interference, similar to enhancement for signal (multiplicative approach)

$K_{signal} \sim K_{interf}$

$m_h = 600$ GeV	$\sqrt{s} = 8$ TeV			$\sqrt{s} = 13$ TeV		
	LO	NLO	NNLO	LO	NLO	NNLO
σ_H	0.379	0.83(2)	1.07(5)	1.55	3.29(8)	4.2(2)
σ_{Hi}	0.427	0.93(3)	1.20(7)	1.66	3.5(1)	4.5(2)
$\sigma_H/\sigma_H^{\rm LO}$	—	2.19(5)	2.8(1)	—	2.13(5)	2.7(1)
$\sigma_{Hi}/\sigma_{Hi}^{\rm LO}$	—	2.19(7)	2.8(2)	—	2.12(6)	2.7(1)

Conclusions

•Do not make naive assumptions about off-shell/interference

•Off-shell effects can be considerably enhanced in VV channels

sizable corrections wrt ZWA

•Interference effects can also be enhanced

•Interference in diphoton can produce shift due to detector resolution

requires better EXP understanding

Conclusions

•Do not make naive assumptions about off-shell/interference

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requires better EXP understanding

With some care : cuts that suppress contribution
from large virtualities (light Higgs only)

can sweep (part of) the dust under the carpet..