Higgs interferometry in the $\gamma\gamma$ channel

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Introduction

- Using interference effects in $gg \to \gamma\gamma$, LHC may bound Higgs width much better than in direct measurement [Dixon,Li] arXiv:1305.3854
- Maybe possible to get close to SM value of 4 MeV
- Similar idea can be used for $gg \to ZZ/WW$ in off-shell region [Caola,Melnikov] arXiv:1307.4935, [Campbell,Ellis,Williams] arXiv:1311.3589 ($\nearrow$ talk by N. Kauer)
- $gg \to \gamma\gamma$ more direct, as it operates in neighborhood of resonance
- $gg \to ZZ/WW$ method could be invalidated by e.g. form factors [Englert,Spannowsky] arXiv:1405.0285

Interference between Higgs production and continuum

[Dixon,Siu] hep-ph/0302233

- Full amplitude

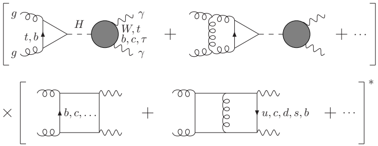
$$\mathcal{A}_{gg\to\gamma\gamma} = \frac{-\mathcal{A}_{gg\to H}\mathcal{A}_{H\to\gamma\gamma}}{\hat{s} - m_H^2 + i m_H \Gamma_H} + \mathcal{A}_{\text{cont}}$$

- Change in cross section from interference

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

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

$=$



- Real part of interference asymmetric around peak
- Imaginary part symmetric

Parametrizing new physics effects

- Effective coupling of Higgs to gluons & photons

$$\mathcal{L} = -\left[\frac{\alpha_s}{8\pi} c_g b_g G^a_{\mu\nu} G_a^{\mu\nu} + \frac{\alpha}{8\pi} c_\gamma b_\gamma F_{\mu\nu} F^{\mu\nu}\right] \frac{h}{v} \qquad b_g = \frac{2}{3},\ b_\gamma = \frac{47}{9} \quad \text{at LO}$$

$c_{g/\gamma}$ – new physics correction factors

- In Narrow width approximation

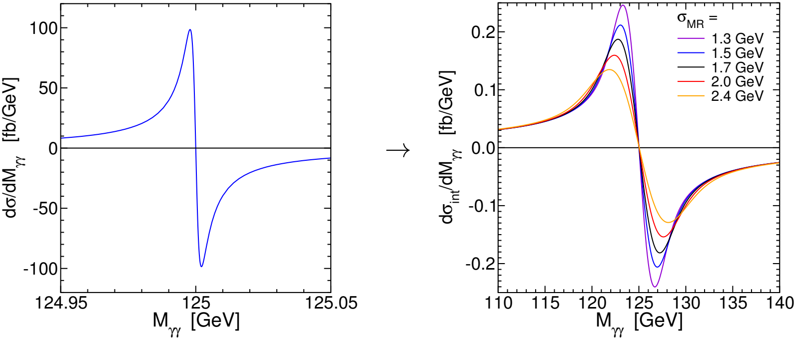
$$\mathrm{d}\sigma_{gg\to H\to\gamma\gamma} = \frac{\mathrm{d}\hat{s}\,|\mathcal{A}_{gg\to H}\mathcal{A}_{H\to\gamma\gamma}|^2}{(\hat{s}-m_H^2)^2 + m_H^2\Gamma_H^2} \propto \frac{c_g^2 c_\gamma^2}{\Gamma_H}$$

- Non-interference measurements invariant under scaling $c_{g/\gamma} \to \xi c_{g/\gamma}$ as $\Gamma_H \to \xi^4 \Gamma_H$
- Interference breaks degeneracy
- Allows to bound or even measure Higgs width

Mass shift from real part

[Martin] arXiv:1208.1533, arXiv:1303.3342
[deFlorian et al.] arXiv:1303.1397

- Smear lineshape with Gaussian of width 1.7 GeV ($\sim$ detector resolution)

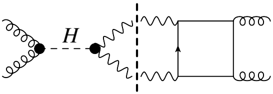


- Re-fitting to Gaussian of mass $M + \delta M$ gives $\delta M \sim 100$ MeV

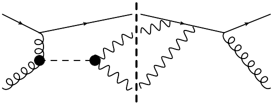
Contributions to mass shift at NLO

[Dixon,Li] arXiv:1305.3854

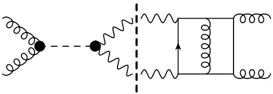
LO (gg):



LO (qg):



NLO (gg):



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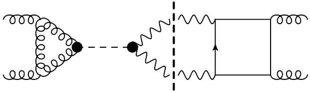

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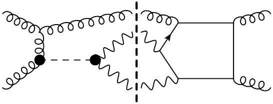

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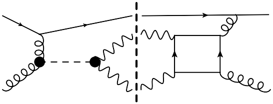
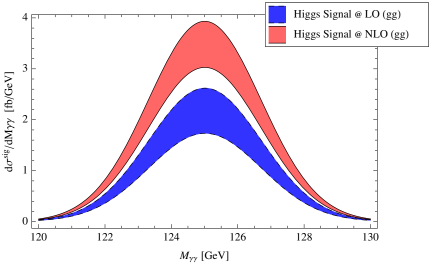
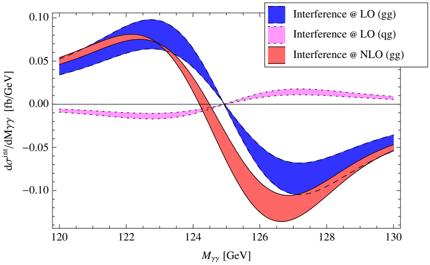


Mass shift at NLO

[Dixon,Li] arXiv:1305.3854

- Large K-factor of Higgs production, smaller K-factor in background $\rightarrow$ relative size of interference reduced compared to LO
- Additional contribution from interference with tree-level diagrams further reduces mass shift [deFlorian et al.] arXiv:1303.1397

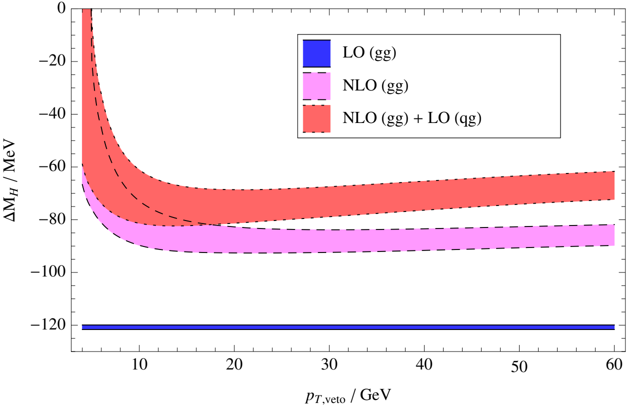




Mass shift at NLO

[Dixon,Li] arXiv:1305.3854

- Mass shift vs jet veto p_T - mostly insensitive



Control masses

Possible control masses

1. $h \to ZZ \to 4l$
2. $h \to \gamma\gamma$ itself [Dixon,Li] arXiv:1305.3854
3. VBF-enriched $h \to \gamma\gamma$ [Dixon,Li,SH] in progress

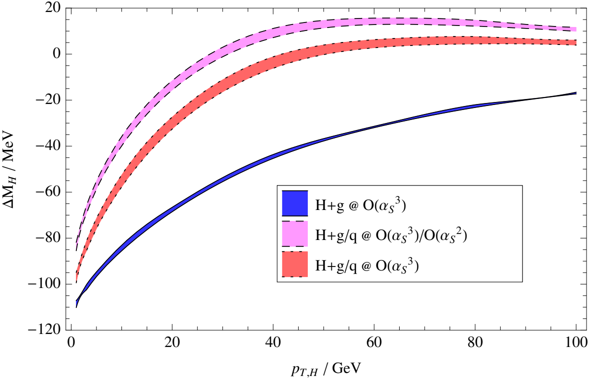
- Theoretically ideal reference mass for measuring mass shift $\to$ ZZ channel, as $\delta m_{ZZ} \ll \delta m_{\gamma\gamma}$ [Kauer,Passarino] arXiv:1206.4803
- But experiments differ significantly

$$m_{\gamma\gamma} - m_{ZZ} = \begin{cases} +1.5 \pm 0.7 \text{ GeV} & \text{ATLAS} \\ -0.9 \pm 0.6 \text{ GeV} & \text{CMS} \end{cases}$$

Control mass from $h \to \gamma\gamma$

[Dixon,Li] arXiv:1305.3854, [Martin] arXiv:1303.3342

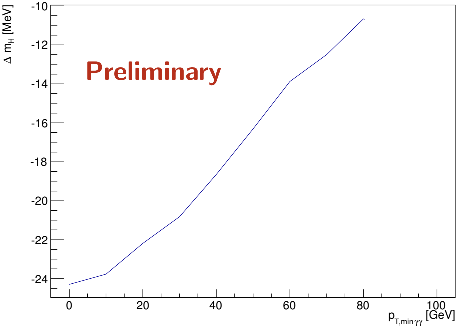
- Cancellation between qg and gg cannels leaves strong dependence on $p_{T,h}$
- Points towards a possible measurement of shift in $\gamma\gamma$ channel alone by using sample with $p_{T,h} \gtrsim 40$ GeV as “control” region
- Experimental uncertainties (γ energy scale) would largely cancel

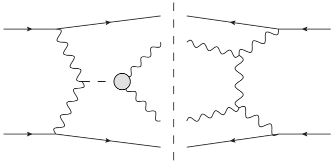


Control mass from VBF

[Dixon,Fidanza,deFlorian,Ita,Li,Mazzitelli,SH] in progress

- VBF more robust theoretically than high-$p_{T,h}$ region in $pp \to \gamma\gamma$
  $\to$ good possible control sample for mass measurement
- Mass shift from interference with $pp \to \gamma\gamma$+2 jets
- About 1/3 the effect of $pp \to \gamma\gamma$, so 2/3 of effect remains





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

$p_{T,j} > 20$ GeV
$m_{jj} > 800$ GeV, $|\Delta\eta_{jj}| > 4$

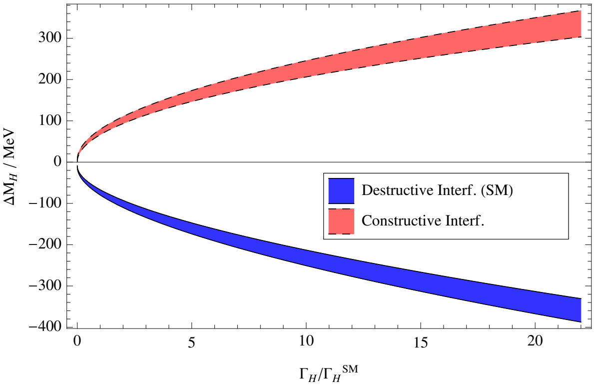
Mass shift versus width

[Dixon,Li] arXiv:1305.3854

- Assuming constant event yield, $c_{g\gamma} = c_g c_\gamma$ determined by

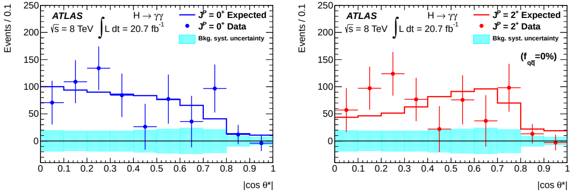
$$\frac{c_{g\gamma}^2 S}{m_H \Gamma_H} + c_{g\gamma} I \stackrel{!}{=} \left(\frac{S}{m_H \Gamma_H^{SM}} + I \right) \mu_{\gamma\gamma}$$

- Ignoring I leaves $c_{g\gamma} = \sqrt{\mu_{\gamma\gamma} \Gamma_H / \Gamma_H^{SM}}$



What if “the boson” was spin 2?

- Rejection of spin 2 hypothesis relies on $\cos\theta^*$ distribution
  [Maltoni et al.] arXiv:1306.6464, [Boer et al.] arXiv:1304.2654
- Without interference $\begin{cases} 1 & \text{for spin 0} \\ 1 + 6\cos^2\theta^* + \cos^4\theta^* & \text{for } 2^+ \end{cases}$



- Interference from different helicity amplitudes:
  $\mathcal{A}(+,+,\pm,\pm)$ (spin 0) vs $\mathcal{A}(+,-,\pm,\mp)$ (spin 2^+_m)
  Assuming graviton-like couplings in spin-2 case

Signal vs interference in spin 2 case

[Dixon,Li,SH] in progress

$$\overline{|\mathcal{A}^{gg}|^2} = \left[\frac{\hat{s}^4}{M_G^4}\frac{\kappa_g^2}{256}\,f_0^{gg}(c) + \frac{\hat{s}^2}{M_G^2}\pi\xi M_G\Gamma_G f_i^{gg}(c)\right]\frac{1}{(\hat{s}-M_G^2)^2+M_G^2\Gamma_G^2}$$

$$+\frac{\hat{s}^2}{M_G^2}\xi f_r^{gg}(c)\frac{\hat{s}-M_G^2}{(\hat{s}-M_G^2)^2+M_G^2\Gamma_G^2}$$

where $c = \cos\theta^*$ and $\xi = \frac{11}{72}\kappa_g\alpha\alpha_s$

$$f_0^{gg}(c) = 1+6c^2+c^4$$

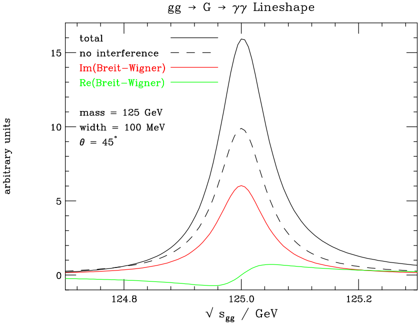
$$f_i^{gg}(c) = 2\left[\left(1+\frac{(1-c)^2}{4}\right)\ln\left(\frac{2}{1-c}\right)+\left(1+\frac{(1+c)^2}{4}\right)\ln\left(\frac{2}{1+c}\right)\right]-3+c^2$$

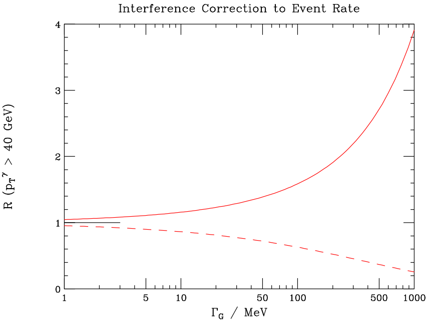
$$f_r^{gg}(c) = \left(1+\frac{(1-c)^2}{4}\right)\ln^2\left(\frac{2}{1-c}\right)-\frac{(1+c)(3-c)}{2}\ln\left(\frac{2}{1-c}\right)$$

$$+\left(1+\frac{(1+c)^2}{4}\right)\ln^2\left(\frac{2}{1+c}\right)-\frac{(1-c)(3+c)}{2}\ln\left(\frac{2}{1+c}\right)+1+c^2$$

Line shapes and signal yields

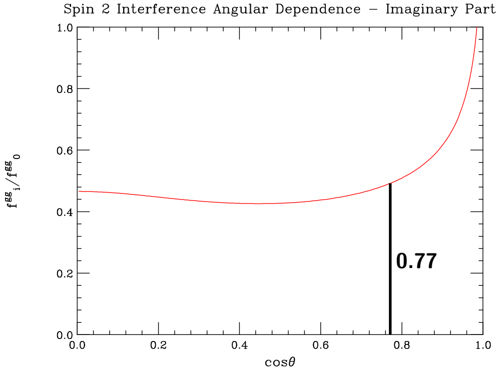
- Large constructive/destructive interference at large width
- Affects coupling measurement in spin 2 case





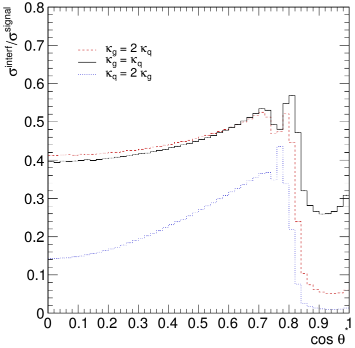
Angular dependence of imaginary part

- Standard cut $p_{T\mathrm{min}} = 40$ GeV $\leftrightarrow \cos\theta^*_{\mathrm{max}} \approx 0.77$
- Imaginary part nearly flat in observed region $\rightarrow$
  difference in spin 0 and spin 2 yields can be accomodated by κ_g & Γ_G



Angular dependence of imaginary part

- Include radiation and coupling to quark part of energy-momentum tensor
  $\rightarrow$ Less flat distribution, depending on size of κ_g vs κ_q



Summary

- Interference effects allow to bound Higgs width well below experimental resolution in a fairly model independent way
- $\gamma\gamma$ channel shows large effect while working close to resonance mass
- Several possible control masses, including ZZ, $\gamma\gamma$ at high-$p_{T,h}$, and VBF
- Interferences also important for testing hypothesis involving non-SM quantum numbers
- Numerical code available in Sherpa (versions $>$2.0.0)