Resonance-Continuum Interference in $\gamma\gamma \to H \to b\bar{b}$

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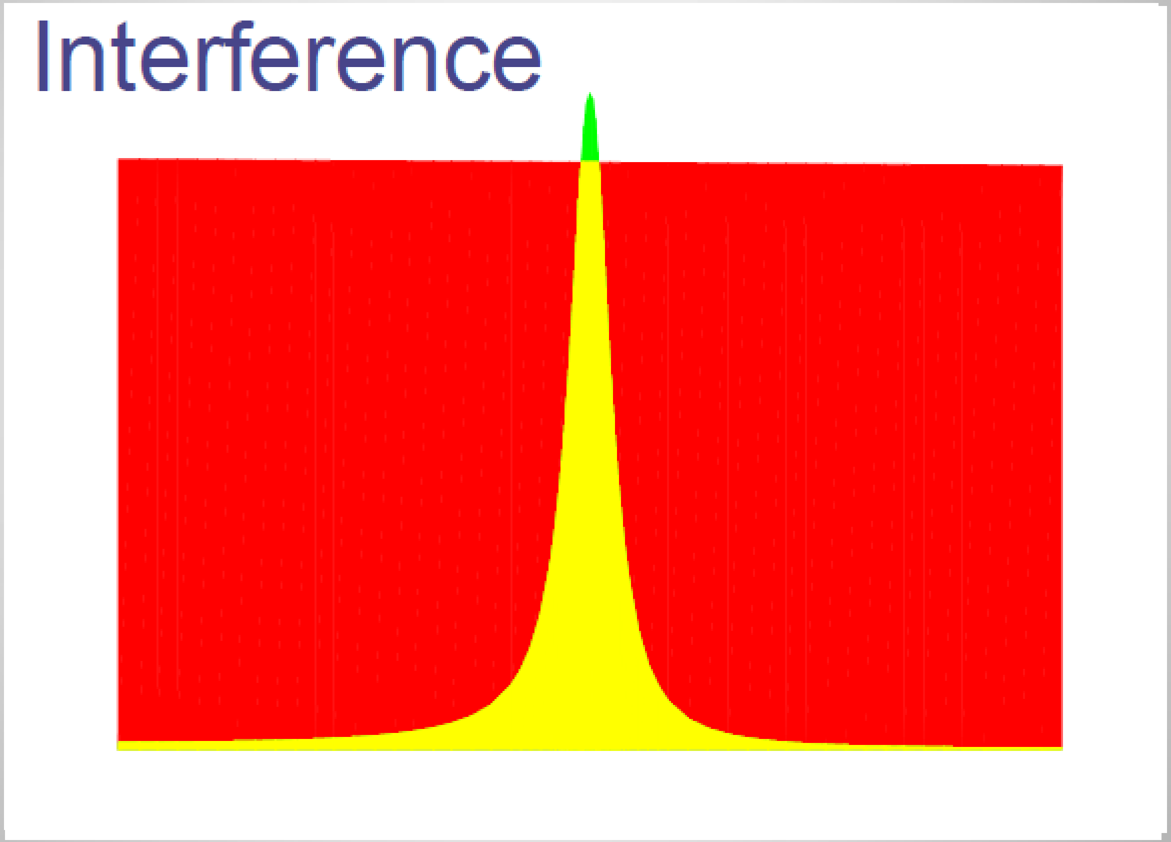
Motivation

- One of the principal motivations for building a $\gamma\gamma$ collider is to produce a light Higgs boson via $\gamma\gamma \rightarrow$ H, and then detect its dominant decay to b quark pairs.
- In order to extract Higgs couplings, would like to interpret the size of the bump as

$$\Gamma(H \to \gamma\gamma) \times \mathrm{Br}(H \to b\bar{b}) = \frac{\Gamma_\gamma \Gamma_b}{\Gamma_{\mathrm{tot}}}$$

- But this is not necessarily true if the signal interferes appreciably with the continuum background, in this case $\gamma\gamma \to b\bar{b}$

Motivation in pictures



Motivation (cont.)

- For $$\gamma\gamma \to H \to b\bar{b}$$

the anticipated experimental uncertainty in

$$\Gamma(H \to \gamma\gamma) \times \mathrm{Br}(H \to b\bar{b})$$

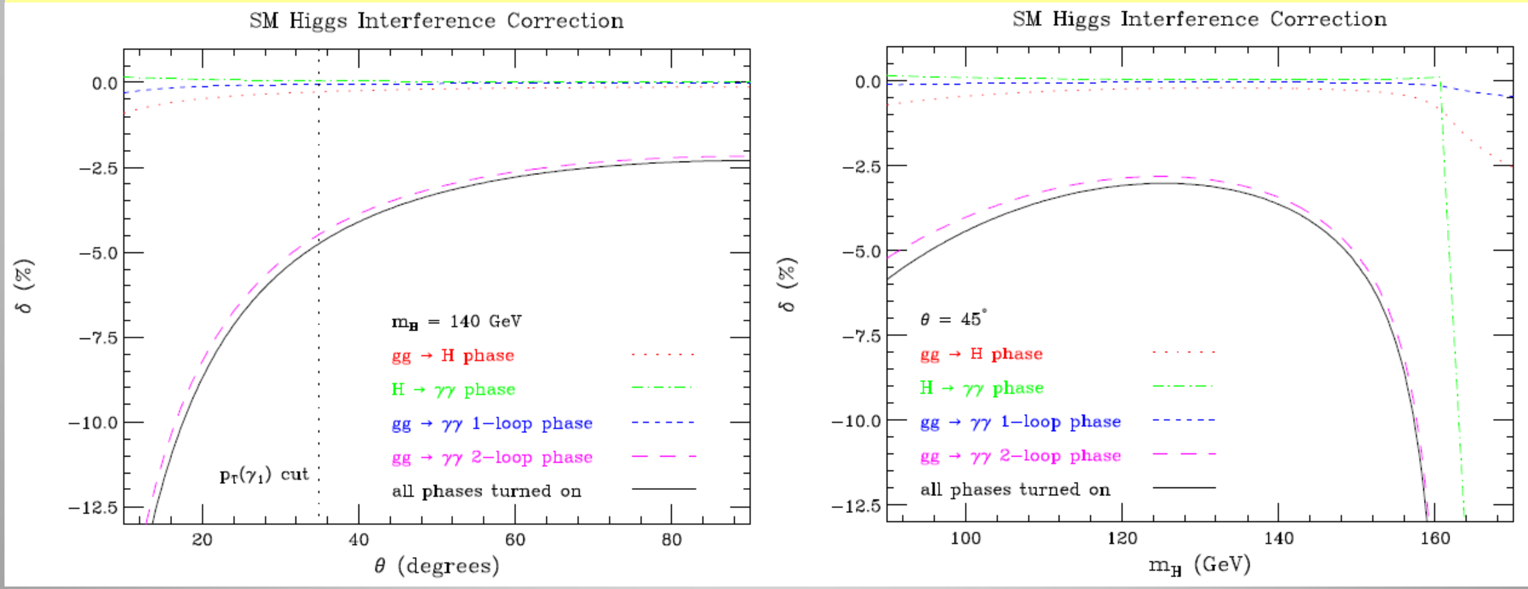
assuming 80 fb^{-1} in the high-energy peak and $m_H < 140$ GeV is 2%

Melles, Stirling, Khoze, hep-ph/9970238;
Ginsburg, Krawczyk, Osland, hep-ph/0101208, hep-ph/0101229;
Soldner-Rembold, Jikia, hep-ex/0101056;
Niezurawski, Zarnecki and Krawczyk, hep-ph/0208034, hep-ph/0307183;
Nieurawski, hep-ph/0503295, hep-ph/0507004;
Bechtel et al., physics/0601204; K. Monig and A. Rosca, 0705.1259.

- So we should check whether the peak height is equal to this quantity to better than 2%.

Motivation (cont.)

- Another place resonance-continuum interference could be significant is in the SM Higgs $\gamma\gamma$ decay mode at the LHC (gluon fusion production). LD, Siu, hep-ph/0302233
- Here effect is 3-5%, smaller than currently envisaged experimental uncertainties, and smaller than some of the estimated theoretical uncertainties (but not all).
- But not a lot smaller.



Amplitude interference

- Total $\gamma\gamma \longrightarrow b\bar{b}$ amplitude:

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

- Interference term has 2 pieces:

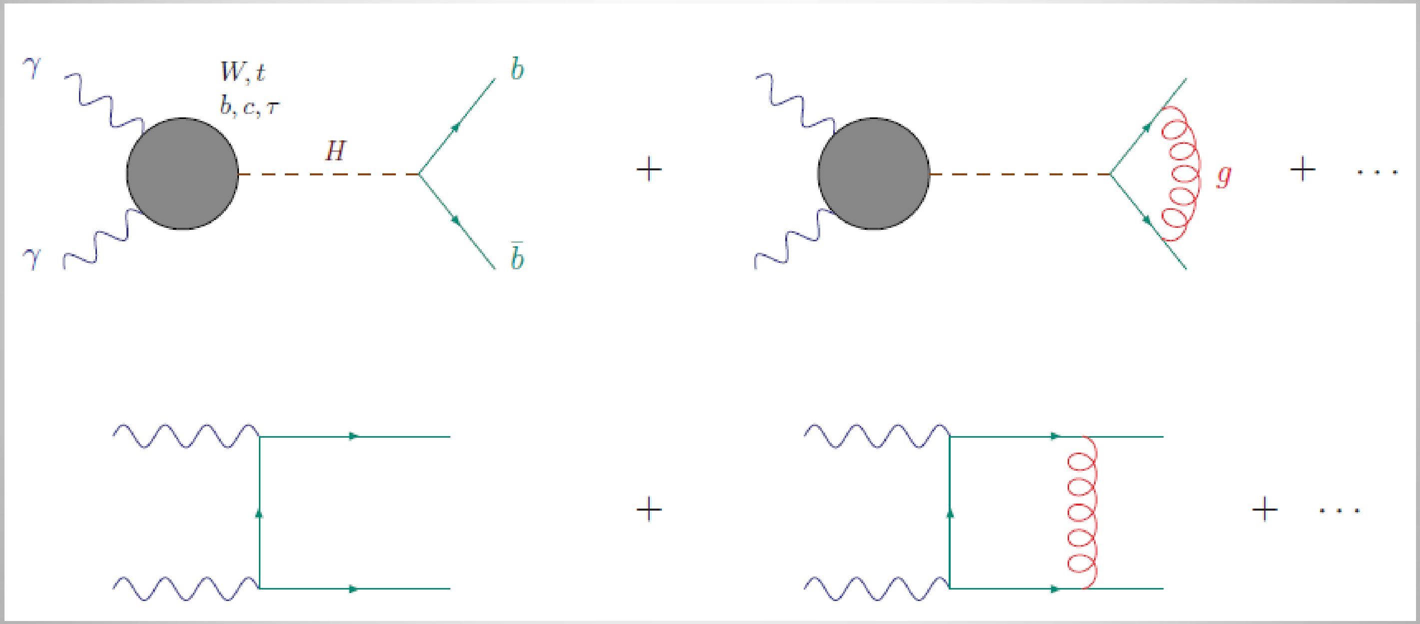
$$\delta\hat{\sigma}_{\gamma\gamma\to H\to b\bar{b}} = -2(\hat{s} - m_H^2)\frac{\mathrm{Re}(\mathcal{A}_{\gamma\gamma\to H}\mathcal{A}_{H\to b\bar{b}}\mathcal{A}^*_{\mathrm{cont}})}{(\hat{s} - m_H^2)^2 + m_H^2\Gamma_H^2} - 2m_H\Gamma_H\frac{\mathrm{Im}(\mathcal{A}_{\gamma\gamma\to H}\mathcal{A}_{H\to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

- First term vanishes upon integration over $\hat{s}$ as long as $\mathcal{A}_{\gamma\gamma\to H}$, $\mathcal{A}_{H\to b\bar{b}}$, $\mathcal{A}_{\mathrm{cont}}$ don’t vary too quickly

Dicus, Stange, Willenbrock, hep-ph/9404359

In search of a phase

- Need $\mathrm{Im}(\mathcal{A}_{\gamma\gamma\to H}\mathcal{A}_{H\to b\bar{b}}\mathcal{A}^{*}_{\mathrm{cont}}) \neq 0$
- All mostly real in SM.



Computing the phase

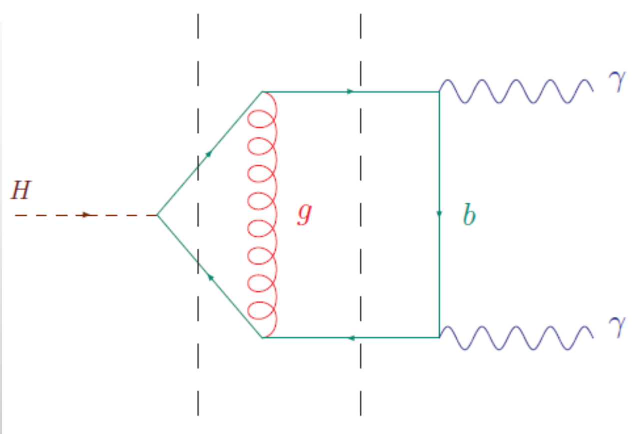
- A little algebra →

$$\delta \equiv \frac{\delta\sigma_{\gamma\gamma\to H\to b\bar{b}}}{\sigma_{\gamma\gamma\to H\to b\bar{b}}} = 2m_H\Gamma_H \,\mathrm{Im}\left\{ \frac{\mathcal{A}^{\rm tree}_{\gamma\gamma\to b\bar{b}}}{\mathcal{A}^{(1)}_{\gamma\gamma\to H}\mathcal{A}^{\rm tree}_{H\to b\bar{b}}} \left[1 + \frac{\mathcal{A}^{(1)}_{\gamma\gamma\to b\bar{b}}}{\mathcal{A}^{\rm tree}_{\gamma\gamma\to b\bar{b}}} - \frac{\mathcal{A}^{(2)}_{\gamma\gamma\to H}}{\mathcal{A}^{(1)}_{\gamma\gamma\to H}} - \frac{\mathcal{A}^{(1)}_{H\to b\bar{b}}}{\mathcal{A}^{\rm tree}_{H\to b\bar{b}}} \right] \right\}$$

$$= \frac{2m_H\Gamma_H}{\left|\mathcal{A}^{\rm tree}_{H\to b\bar{b}}\right|^2} \left[-\frac{\mathcal{A}^{\rm tree}_{\gamma\gamma\to b\bar{b}}\mathcal{A}^{*\,\rm tree}_{H\to b\bar{b}}}{\left|\mathcal{A}^{(1)}_{\gamma\gamma\to H}\right|^2} \,\mathrm{Im}\left\{\mathcal{A}^{(1)}_{\gamma\gamma\to H}\right\} \right.$$

$$\left. + \frac{1}{\mathrm{Re}\left\{\mathcal{A}^{(1)}_{\gamma\gamma\to H}\right\}} \,\mathrm{Im}\left\{ \mathcal{A}^{*\,\rm tree}_{H\to b\bar{b}}\mathcal{A}^{(1)}_{\gamma\gamma\to b\bar{b}} - \mathcal{A}^{\rm tree}_{\gamma\gamma\to b\bar{b}}\mathcal{A}^{*\,(1)}_{H\to b\bar{b}} \right\} \right]$$

- 2^{nd} term dominates
- Comes just from this cut graph



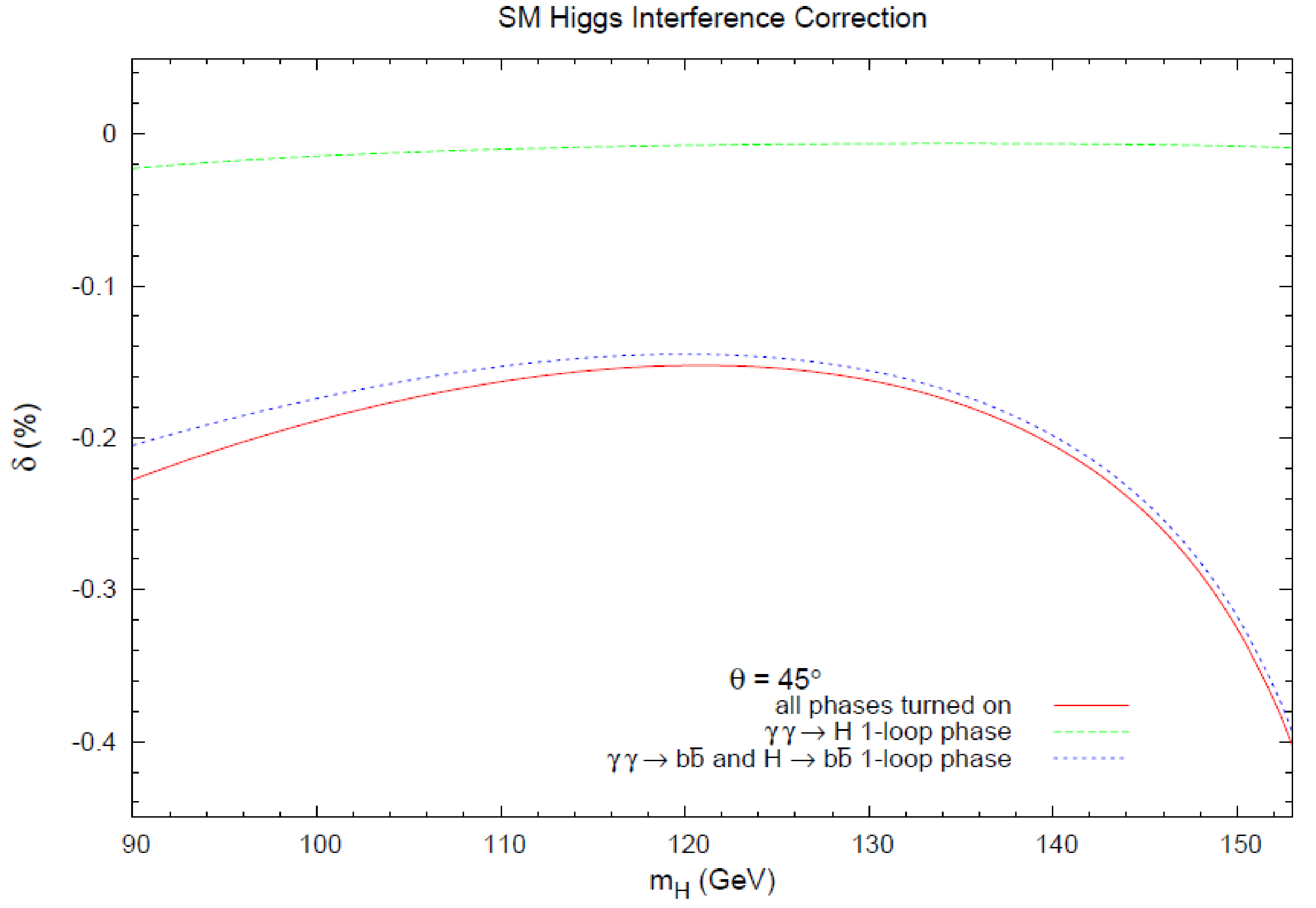
Analytical result

$$\mathrm{Im}\left\{\mathcal{A}^{*\mathrm{tree}}_{H\to b\bar{b}}\mathcal{A}^{(1)}_{\gamma\gamma\to b\bar{b}} - \mathcal{A}^{\mathrm{tree}}_{\gamma\gamma\to b\bar{b}}\mathcal{A}^{*(1)}_{H\to b\bar{b}}\right\} = 32\pi Q_b^2\alpha\alpha_s\frac{m_b^2}{v}\Bigg\{ (m_H^2 - 2m_b^2)\left[1 + \frac{m_H^2 t}{(m_b^2-t)^2}\right]\left[\frac{(1+\beta)\ln\left[\frac{m_H^2(1+\beta)}{2(m_b^2-t)}\right]}{m_H^2(1+\beta)+2(t-m_b^2)} - \frac{(1-\beta)\ln\left[\frac{m_H^2(1-\beta)}{2(m_b^2-t)}\right]}{m_H^2(1-\beta)+2(t-m_b^2)}\right] - \left[\frac{(m_H^2-2m_b^2)(t+m_b^2)}{2(m_b^2-t)^2} + \frac{2m_b^2}{m_H^2}\right]\ln\left(\frac{1+\beta}{1-\beta}\right) + \frac{2\beta m_b^2}{m_b^2-t}\Bigg\} + \left(\cos\theta \to -\cos\theta\right).$$

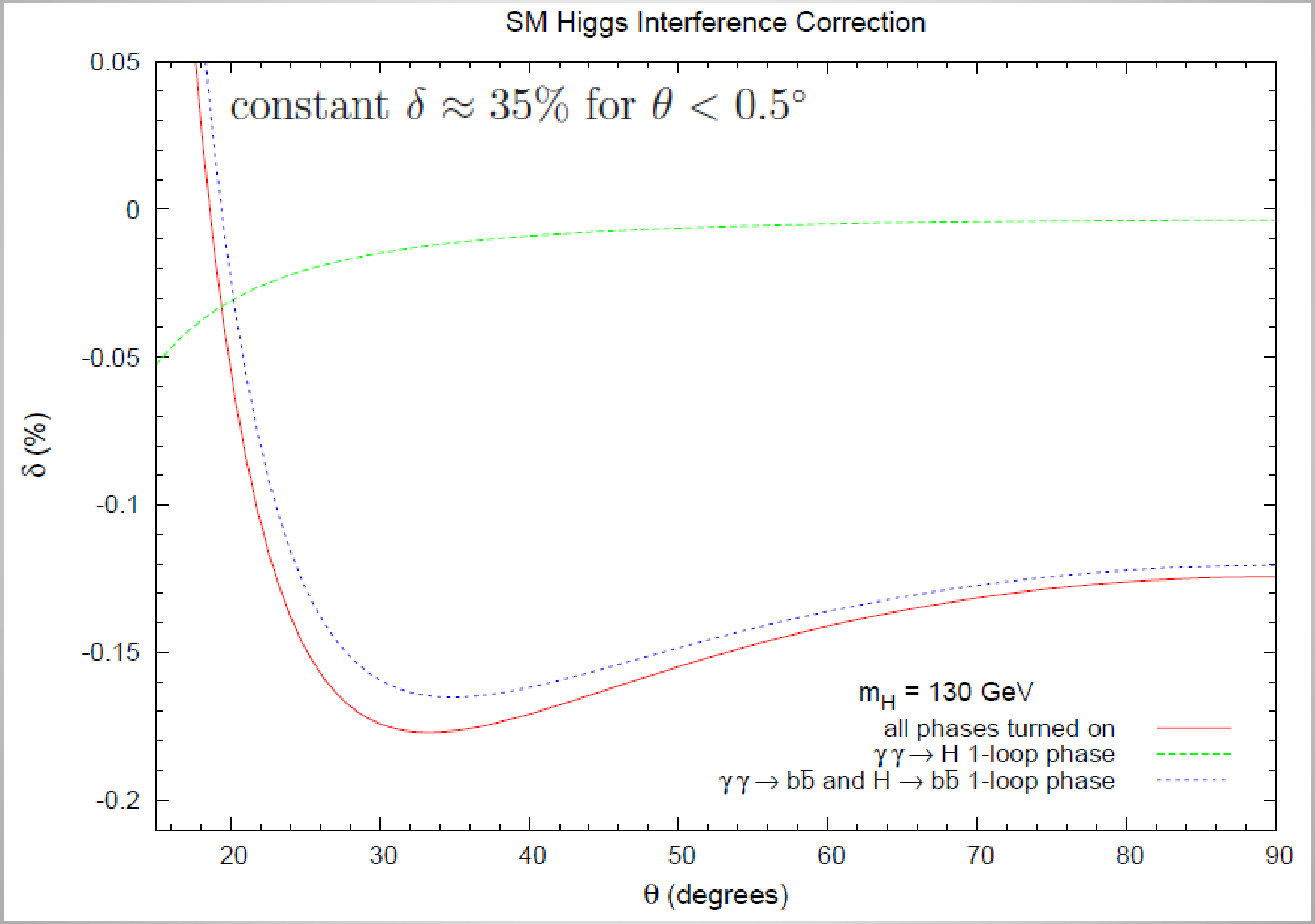
For all but very forward scattering angles, we can let $m_b \to 0$ in the brackets, obtaining:

$$\delta \approx \frac{128\pi Q_b^2\alpha\alpha_s m_H\Gamma_H}{v}\, m_b^2\, \frac{2\ln\left(\frac{m_H}{2m_b}\right) + 2\ln\left(\sin\theta\right) + \ln\left(\frac{1-\cos\theta}{1+\cos\theta}\right)\cos\theta}{\sin^2\theta\ \left|\mathcal{A}^{\mathrm{tree}}_{H\to b\bar{b}}\right|^2 \mathrm{Re}\{\mathcal{A}^{(1)}_{\gamma\gamma\to H}\}} + \mathcal{O}\left(m_b^4\right)$$

Numerical result at 45°



Dependence on scattering angle



Beyond SM?

- We did not study this very thoroughly; however, δ scales withYukawa coupling λ_b (for a while):

$$\delta = \frac{2m_H\Gamma_H}{\left|\mathcal{A}^{\rm tree}_{H\to b\bar b}\right|^2}\left[-\frac{\mathcal{A}^{\rm tree}_{\gamma\gamma\to b\bar b}\mathcal{A}^{*\,\rm tree}_{H\to b\bar b}}{\left|\mathcal{A}^{(1)}_{\gamma\gamma\to H}\right|^2}\,{\rm Im}\left\{\mathcal{A}^{(1)}_{\gamma\gamma\to H}\right\} + \frac{1}{{\rm Re}\left\{\mathcal{A}^{(1)}_{\gamma\gamma\to H}\right\}}\,{\rm Im}\left\{\mathcal{A}^{*\,\rm tree}_{H\to b\bar b}\mathcal{A}^{(1)}_{\gamma\gamma\to b\bar b} - \mathcal{A}^{\rm tree}_{\gamma\gamma\to b\bar b}\mathcal{A}^{*(1)}_{H\to b\bar b}\right\}\right]$$

$\frac{\lambda_b^2}{\lambda_b^2} = 1$

λ_b

- E.g., MSSM "intense coupling regime" can have large λ_b

Boos, Djouadi, Muhlleitner, Vologdin, hep-ph/0205160;
Boos Djouadi, Nikitenko, hep-ph/0307079

- As an example, we took λ_b = 20 x λ_b(SM)

→ δ = - 4% for $m_H = 130$ GeV, θ = 45° .

(Now ${\rm Im}(\mathcal{A}_{\gamma\gamma\to H})$ is significant too.)

Conclusions

- In the SM, resonance-continuum interference in the process $\gamma\gamma \to H \to b\bar{b}$

  is safely below the anticipated experimental uncertainties for

  $$\Gamma(H \to \gamma\gamma) \times \mathrm{Br}(H \to b\bar{b})$$

- However, if there is evidence that the b quark Yukawa coupling is greatly enhanced over that in the SM, then the interference effect could be significant and should be investigated further, as a function of model parameters.