Higgs boson pair production at a photon-photon collision in the two Higgs doublet model

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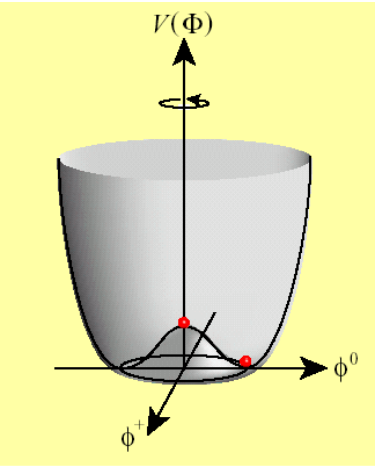
Introduction

The Higgs sector is the last unknown part of the standard model.



Higgs potential

$$V = \frac{1}{2}m_h^2 h^2 + \frac{1}{3!}\lambda_{hhh} h^3 + \frac{1}{4!}\lambda_{hhhh} h^4 + \cdots.$$

In the SM, tree level hhh coupling is given by

$$\lambda_{hhh}^{\mathrm{SM}} = \frac{3m_h^2}{v}$$

It is important to measure the Higgs mass and the Higgs self-coupling.

- Test for the Higgs potential
- Search for New Physics effect

Higgs self coupling measurement is one of main purposes at the ILC.

Measurement of hhh coupling

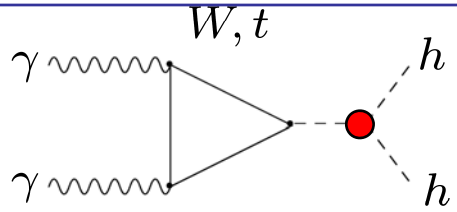
Measurement at collider experiment

LHC (SLHC) $gg \to hh$

ILC $e^+e^- \to Zhh$ $e^+e^- \to hh\bar{\nu}\nu$

PLC $\gamma\gamma \to hh$

My talk focus on this process.



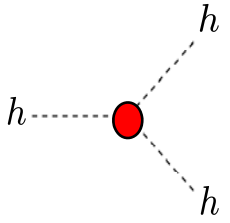
Photon Linear Collider (PLC) is optional experiment for ILC

We estimate sensitivity of hhh coupling at the PLC.

We calculate $\gamma\gamma \to hh$ in THDM

$\gamma\gamma \to hh$ process

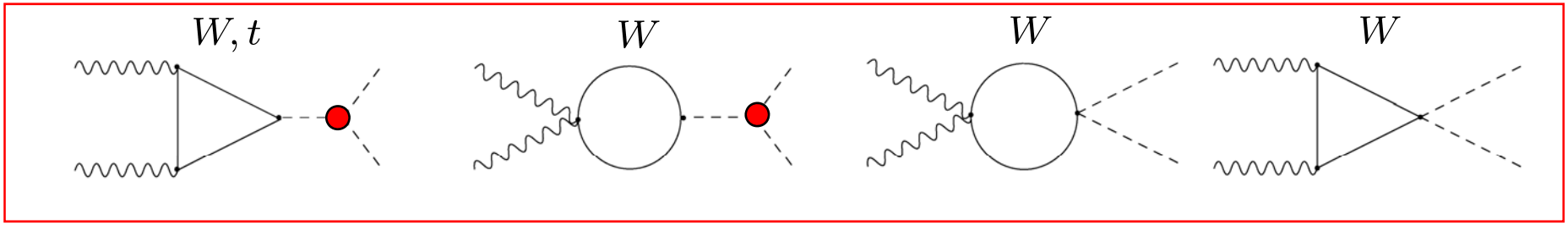
We consider anomalous hhh coupling $\lambda_{hhh}^{\mathrm{SM}} = \frac{3m_h^2}{v}$



$$\lambda_{hhh} = \lambda_{hhh}^{\mathrm{SM}} + \delta\lambda = \lambda_{hhh}^{\mathrm{SM}}(1 + \delta\kappa)$$

SM diagrams

pole



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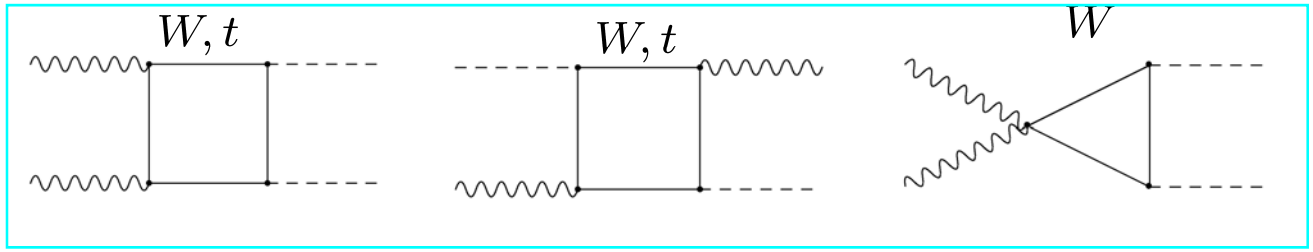
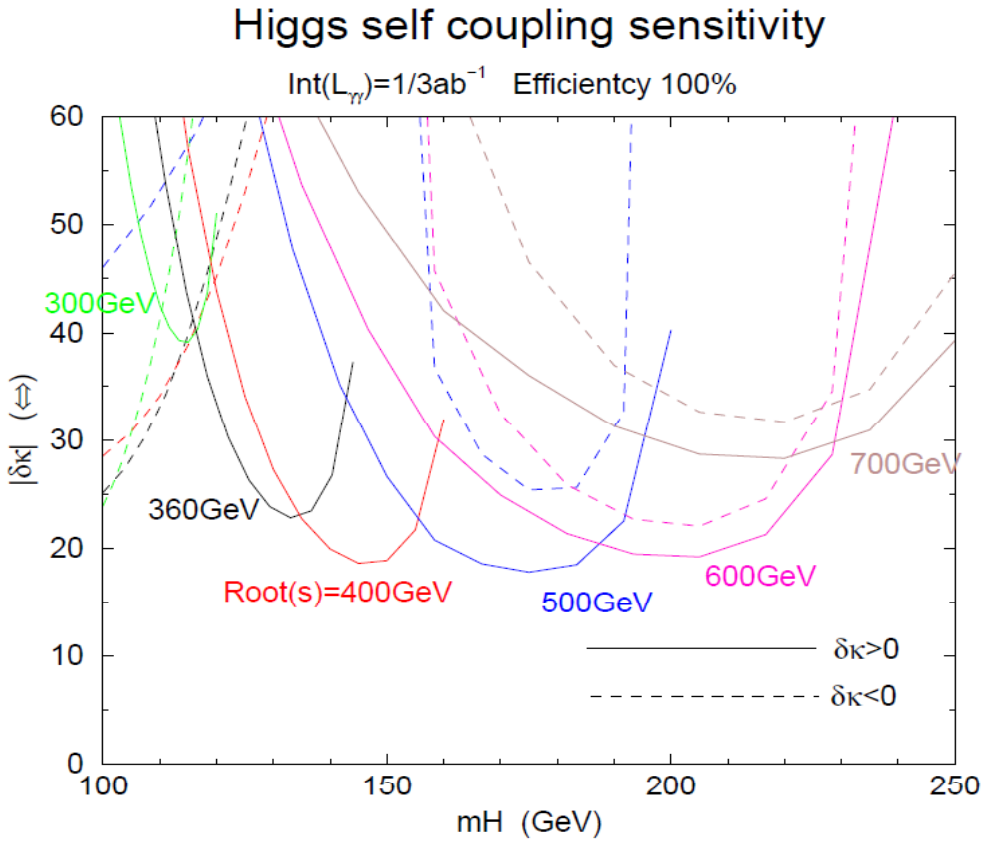
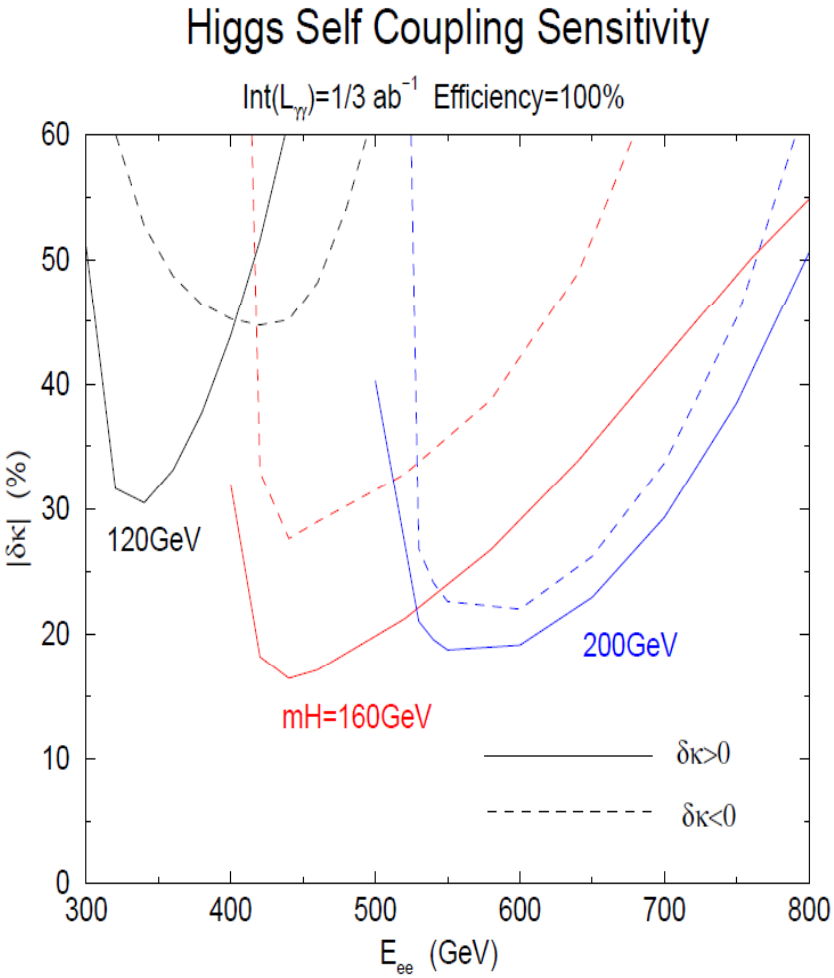


Estimation of hhh sensitivity

E.Asakawa, D. Harada, S. Kanemura, Y. Okada, K. Tsumura at TILC 08





Photon linear collider (Eee < 500GeV) is useful to measure the HHH coupling for mH = 150-200.

$\gamma\gamma \to hh$ in the THDM

We calculated $\gamma\gamma \to hh$ process in THDM with SM-like limit

- Non-decoupling effects
- Charged Higgs loop effects

Two Higgs Doublet Model

Higgs potential

$$V_{\mathrm{THDM}} = \mu_1^2|\Phi_1|^2 + \mu_2^2|\Phi_2|^2 - (\mu_3^2\Phi_1^\dagger\Phi_2 + \mathrm{h.c.})$$
$$+\lambda_1|\Phi_1|^4 + \lambda_2|\Phi_2|^4 + \lambda_3|\Phi_1|^2|\Phi_2|^2 + \lambda_4|\Phi_1^\dagger\Phi_2|^2 + \frac{\lambda_5}{2}\{(\Phi_1^\dagger\Phi_2)^2 + \mathrm{h.c.}\}$$

Higgs doublets

$$\Phi_i = \begin{pmatrix} \omega_i^+ \\ \frac{1}{\sqrt{2}}(v_i + h_i + iz_i) \end{pmatrix} \quad (i = 1, 2)$$

$$\begin{pmatrix} h_1 \\ h_2 \end{pmatrix} = R(\alpha) \begin{pmatrix} H \\ h \end{pmatrix}$$
$$\begin{pmatrix} z_1 \\ z_2 \end{pmatrix} = R(\beta) \begin{pmatrix} z \\ A \end{pmatrix}$$
$$\begin{pmatrix} \omega_1^+ \\ \omega_2^+ \end{pmatrix} = R(\beta) \begin{pmatrix} \omega^+ \\ H^+ \end{pmatrix} \qquad R(\theta) = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix}$$

$$\tan\beta = \frac{v_2}{v_1} \qquad v^2 = v_1^2 + v_2^2 \simeq (246\mathrm{GeV})^2$$

CP-even h, H CP-odd A Charged bosons $H^\pm$

$$m_h^2 = \{\lambda_1 \cos^4\beta + \lambda_2 \sin^4\beta + 2(\lambda_3 + \lambda_4 + \lambda_5)\cos^2\beta \sin^2\beta\}v^2$$
$$m_H^2 = M^2 + \frac{1}{8}\{\lambda_1 + \lambda_2 - 2(\lambda_3 + \lambda_4 + \lambda_5)\}(1 - \cos 4\beta)v^2$$
$$m_A^2 = M^2 - \lambda_5 v^2$$
$$m_{H^\pm}^2 = M^2 - \frac{\lambda_4 + \lambda_5}{2}v^2$$
$$M = \frac{|\mu_3|}{\sqrt{\sin\beta\cos\beta}}$$

We consider following parameters

- SM-like limit $\sin(\alpha - \beta) = -1$

  Lightest Higgs has the same tree-level coupling as the SM Higgs boson and the other Higgs bosons do not couple to gauge bosons.

- Non-decoupling limit $M = 0$

  In the THDM, extra Higgs boson loop correction is known as non-decoupling effect.

- rho parameter constrain $m_H \simeq m_A \simeq m_{H^\pm}$

$$m_H = m_A = m_{H^\pm}$$

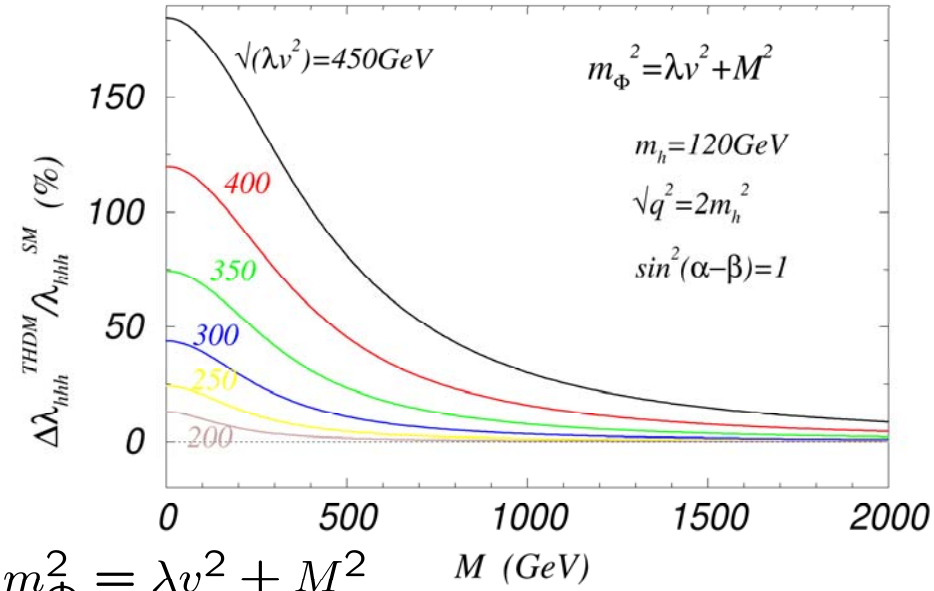
We assume that the masses of the extra Higgs bosons degenerate.

New Physics effect on hhh coupling

S. Kanemura, Y. Okada, E. Senaha, C. P. Yuan

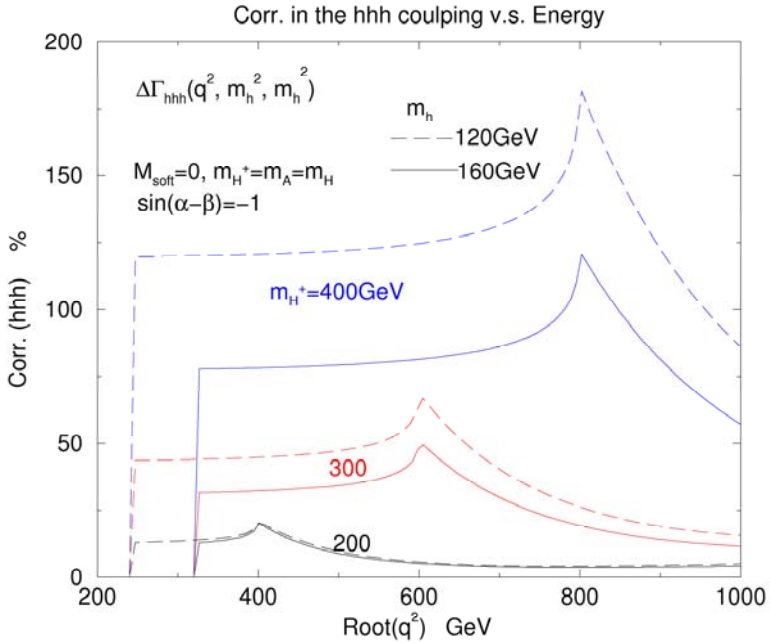
$M \sim 0$ non-decoupling

$M \gg v$ decoupling



$m_\Phi^2 = \lambda v^2 + M^2$

$h^* \to hh$



Effective hhh coupling

$$\frac{\Delta\Gamma^{\rm THDM}_{hhh}}{\Gamma^{\rm SM}_{hhh}} \equiv \frac{\Gamma^{\rm THDM}_{hhh} - \Gamma^{\rm SM}_{hhh}}{\Gamma^{\rm SM}_{hhh}}$$

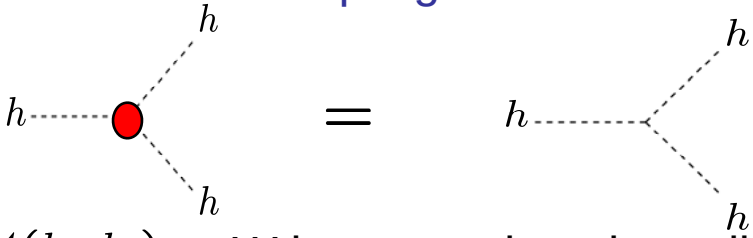
$$\Gamma^{\rm THDM}_{hhh} \simeq -\frac{3m_h^2}{v}\left[1 + \sum_\Phi \frac{m_\Phi^4}{12\pi^2 v^2 m_h^2}\left(1-\frac{M^2}{m_\Phi^2}\right)^3 - \frac{N_c m_t^4}{3\pi^2 v^2 m_h^2}\right]$$

m_Φ^4 term appear in 1-loop correction

We set M=0. $H, A, H^\pm$ receive their masses from the VEV.

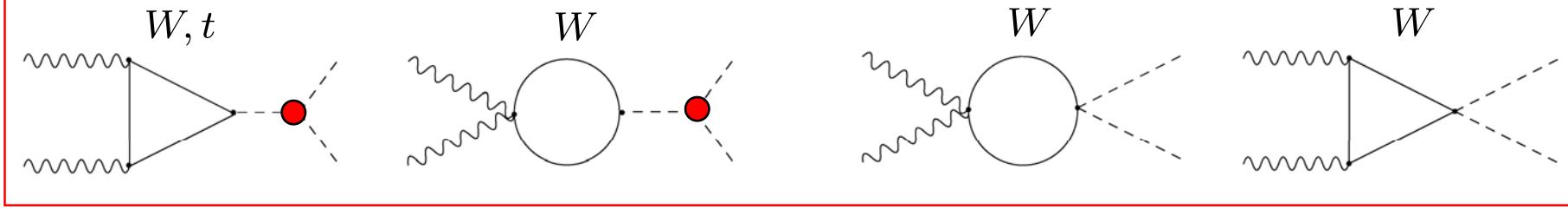
heavier Higgs boson loop effect ~ 100% non-decoupling

Effective hhh coupling



"extra Higgs boson / top" loop effect

$\mathcal{M}(l_1, l_2)$ W boson and top loop diagrams $\gamma\gamma \to hh$ pole



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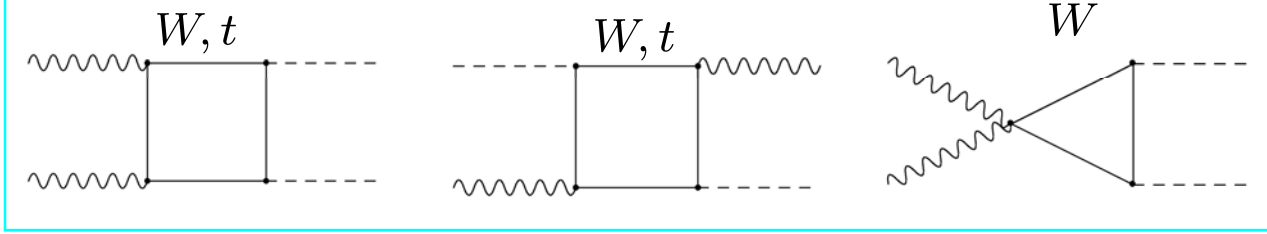
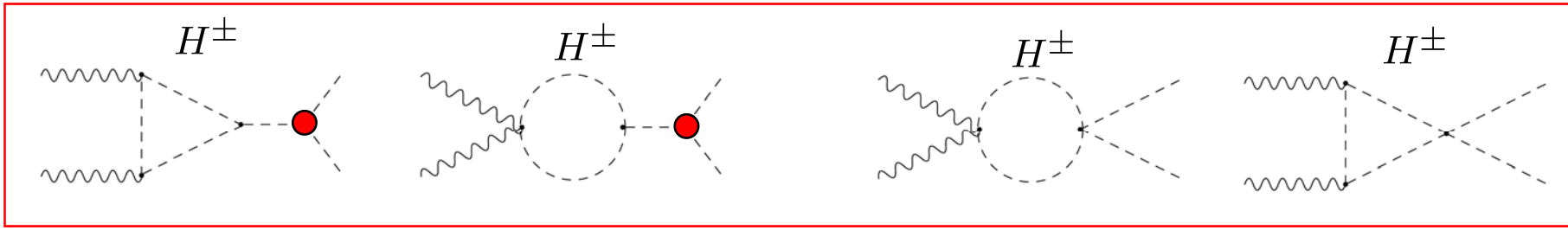


$\Delta\mathcal{M}(l_1, l_2)$ Additional one-loop diagrams (charged Higgs boson loop) pole



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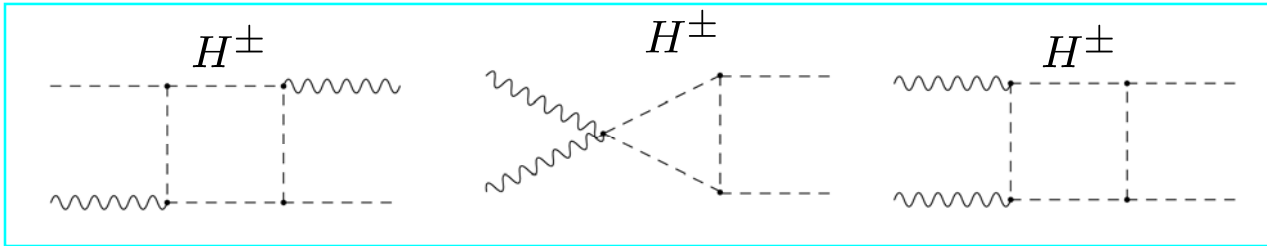
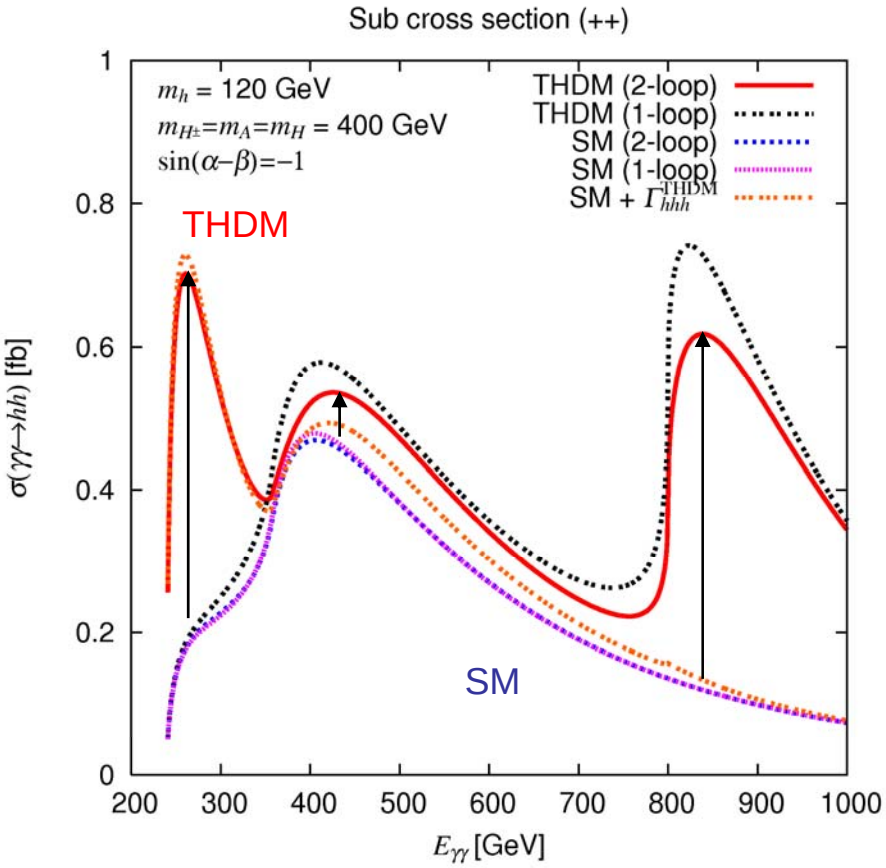
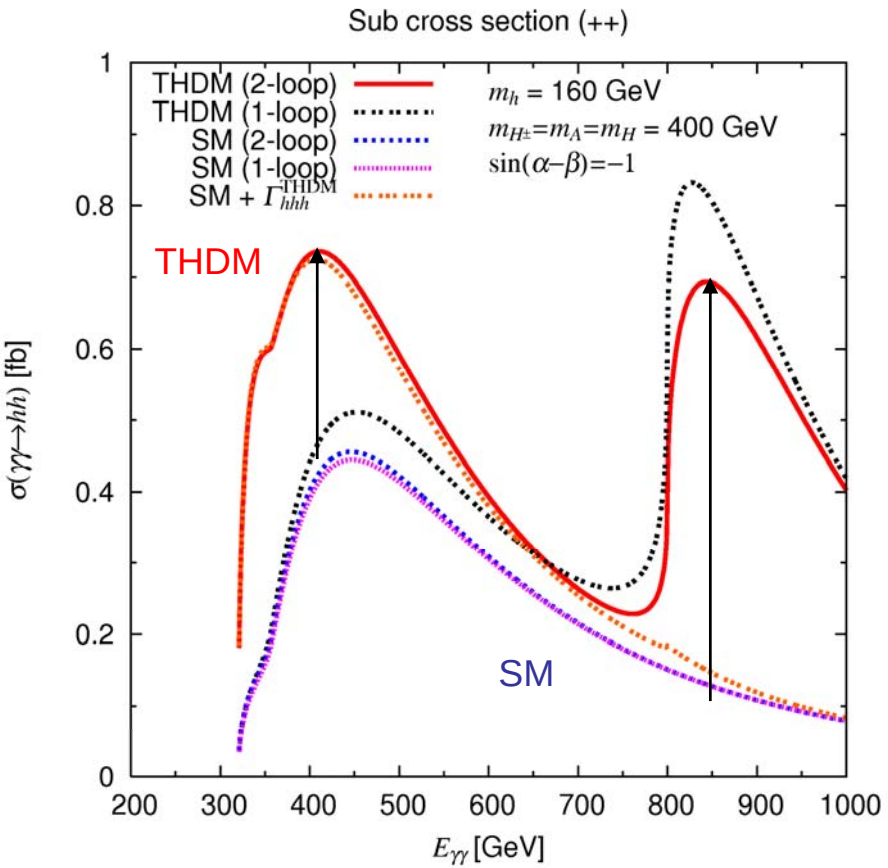


$m_H = m_A = m_{H^\pm} = 400\text{GeV}$

$m_h = 120$ GeV



$m_h = 160$ GeV



$E_{\gamma\gamma} \sim 250$ GeV Cross section is enhanced by the effect of $\frac{\Delta\Gamma^{\text{THDM}}_{hhh}}{\Gamma^{\text{SM}}_{hhh}} \sim 120\%$

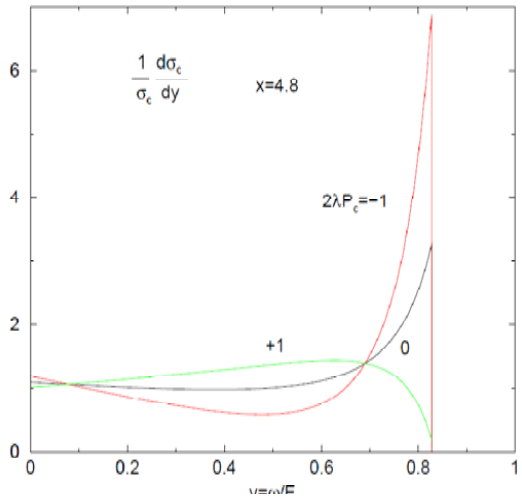
$E_{\gamma\gamma} \sim 400$ GeV Threshold enhancement of top pair production

$E_{\gamma\gamma} \sim 850$ GeV Threshold enhancement of charged Higgs pair production

Full Cross Section

Photon luminosity spectrum

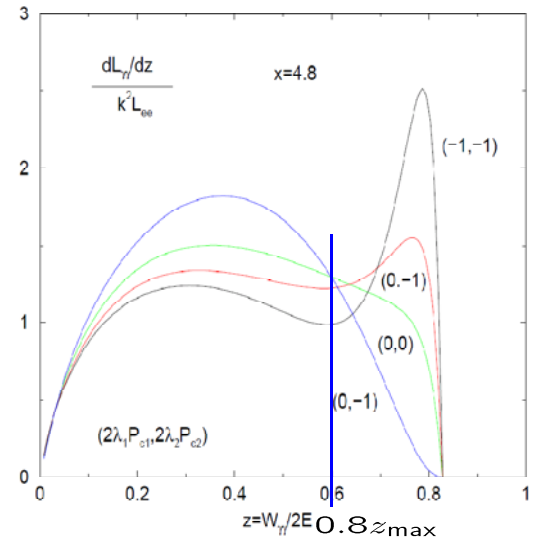
Ginzburg, et. al

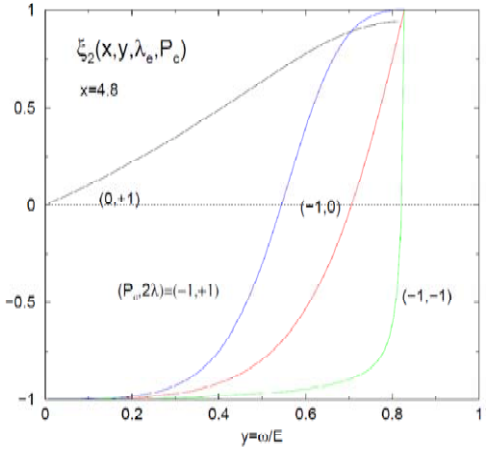


$$d\sigma = \int_{\frac{4m_H^2}{s}}^{y_m^2} d\tau \frac{dL_{\gamma\gamma}}{d\tau} \left(\frac{1 + \langle \xi_2^{(1)} \xi_2^{(2)} \rangle}{2} d\hat{\sigma}(+,+) + \frac{1 - \langle \xi_2^{(1)} \xi_2^{(2)} \rangle}{2} d\hat{\sigma}(+,-) \right)$$

$$\frac{L_{\gamma\gamma}}{d\tau} = \int_{\tau/y_m}^{y_m} \frac{dy}{y} f_\gamma(x,y) f_\gamma(x,\tau/y)$$

$$\tau = \hat{s}/s, y = E_\gamma/E_e \qquad y_m = \frac{x}{1+x}, x = \frac{4E_e\omega_0}{m_e^2}$$





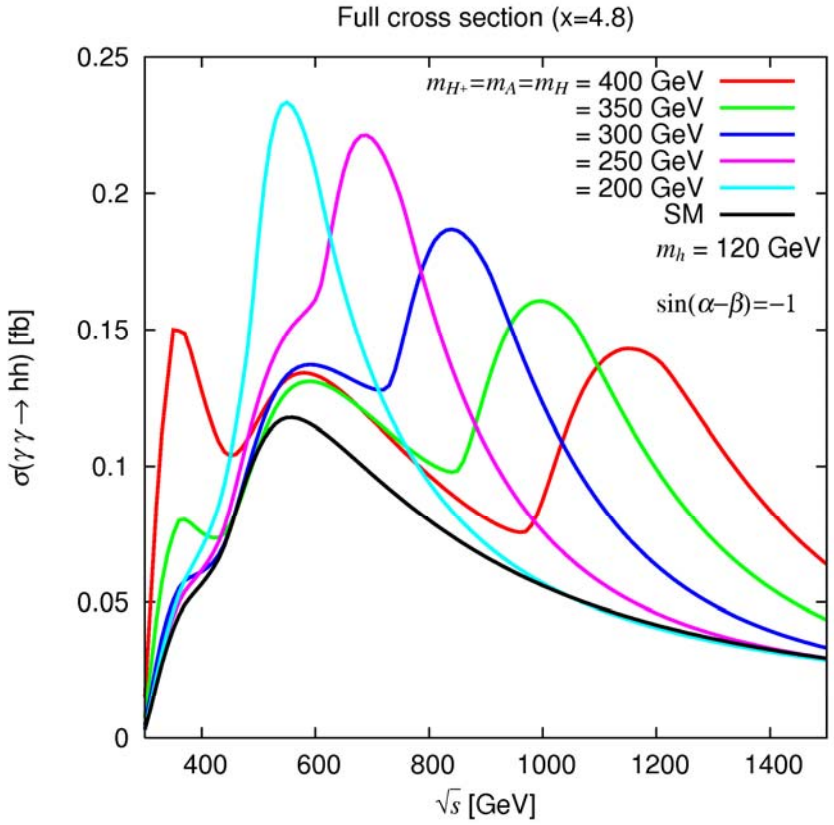
$\langle \xi_2 \rangle$: mean polarzation of the γ beam

λ_e:electron helicity

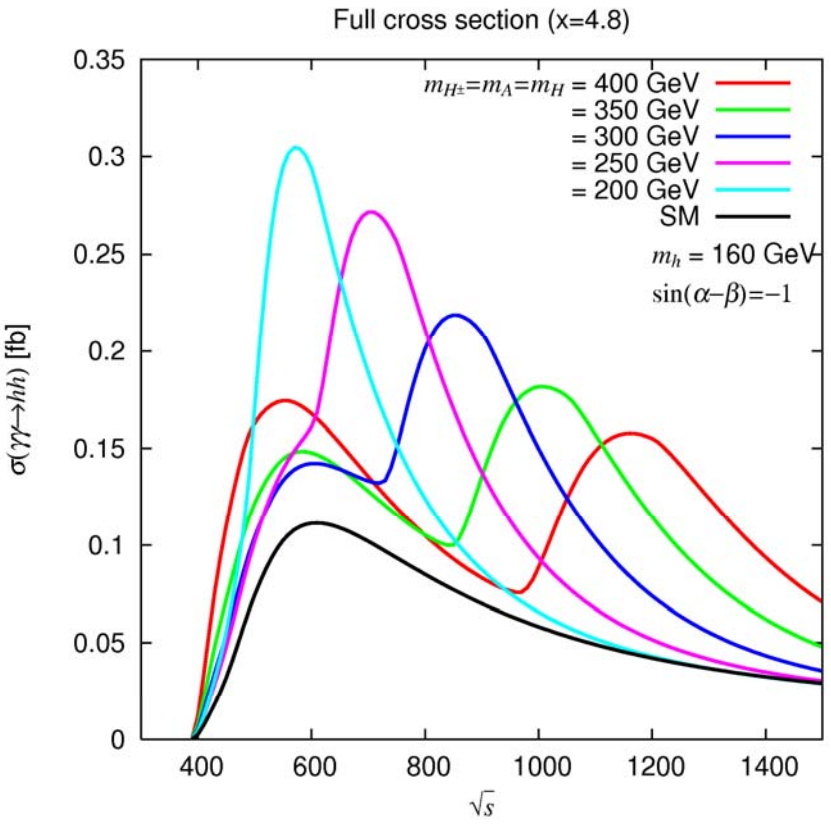
P_c:laser photon mean helicity

$e^-e^- \to \gamma\gamma \to hh$

$m_h = 120$ GeV



$m_h = 160$ GeV

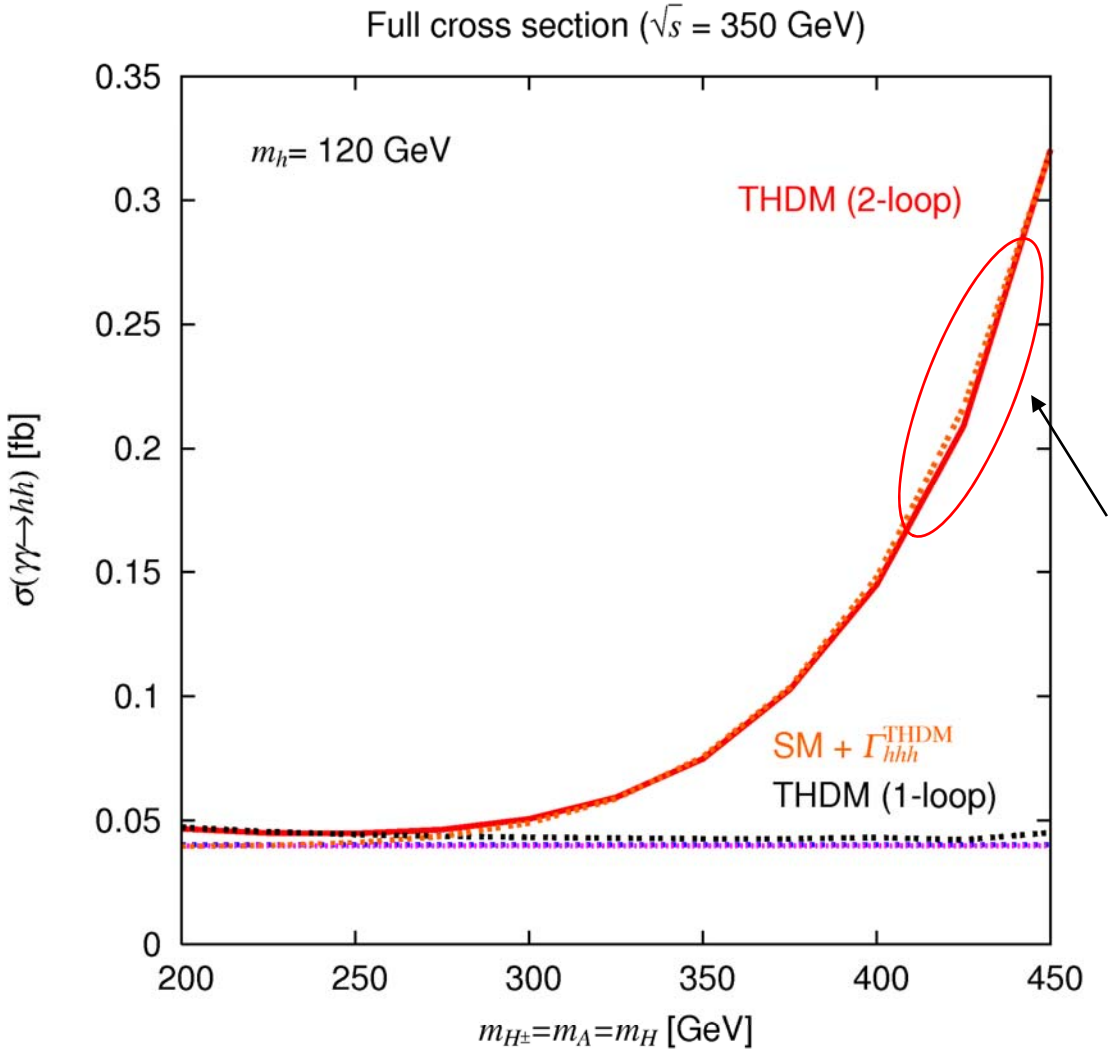


The full cross section is given from the sub cross section by convoluting the photon luminosity spectrum.

We use following values

Initial laser beam mean helicity $P_c = -1$ Initial electron helicity $\lambda_e = +0.45$

$\sqrt{s} = 350$ GeV $\quad m_h = 120$ GeV

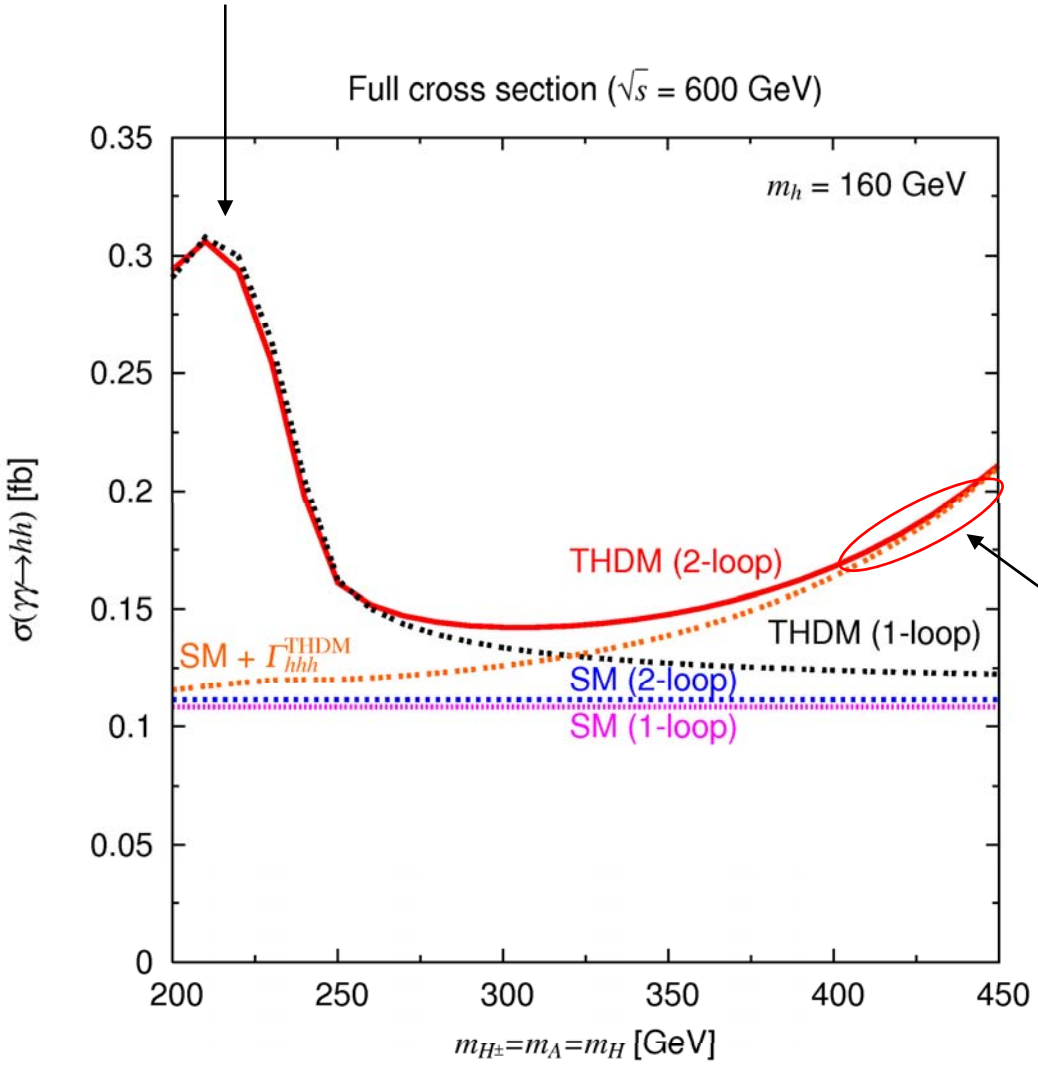


Cross section is largely enhanced by the effective hhh coupling.

Effective hhh coupling is important

$\sqrt{s} = 600$ GeV $\quad m_h = 160$ GeV

Threshold enhancement of charged Higgs pair production



Effective hhh coupling is important.

For 250-400 GeV, charged Higgs boson loop contribution and the effective hhh coupling are important.

Conclusion

We calculate $\gamma\gamma \to hh$ in THDM with SM-like limit

- The cross section can be largely changed from the SM.
  - additional contribution of charged Higgs boson loop
  - Effective 1-loop hhh vertex enhanced by the non-decoupling effect
- The cross section strongly depend on m_h m_Φ $\sqrt{s}$

	THDM $m_\Phi = 450\text{GeV}$	200GeV	SM
$\sqrt{s} = 350\text{GeV}$ $m_h = 120\text{GeV}$	$\sigma \sim 0.3\text{fb}$	$\sigma \sim 0.05\text{fb}$	$\sigma \sim 0.05\text{fb}$
$\sqrt{s} = 600\text{GeV}$ $m_h = 160\text{GeV}$	$\sigma \sim 0.2\text{fb}$	$\sigma \sim 0.3\text{fb}$	$\sigma \sim 0.1\text{fb}$

In the region between threshold of top pair production and that of charged Higgs boson pair production, both the contributions are important.

Backup Slide

(a) THDM 2-loop THDM with additional one-loop corrections to the hhh coupling

$$\mathcal{M}^{2-\text{loop}}_{\text{THDM}}(l_1,l_2) = \mathcal{M}(l_1,l_2,\Gamma^{\text{THDM}}_{hhh}) + \Delta\mathcal{M}(l_1,l_2,\Gamma^{\text{THDM}}_{hhh})$$

(b) THDM 1-loop THDM with the tree level hhh coupling

$$\mathcal{M}^{1-\text{loop}}_{\text{THDM}}(l_1,l_2) = \mathcal{M}(l_1,l_2,\lambda_{hhh}) + \Delta\mathcal{M}(l_1,l_2,\lambda_{hhh}) \qquad \lambda_{hhh} = -\frac{3m_h^2}{v}$$

(c) SM 2-loop SM with additional top loop correction to the hhh coupling

$$\mathcal{M}^{2-\text{loop}}_{\text{SM}}(l_1,l_2) = \mathcal{M}(l_1,l_2,\Gamma^{\text{SM}}_{hhh})$$

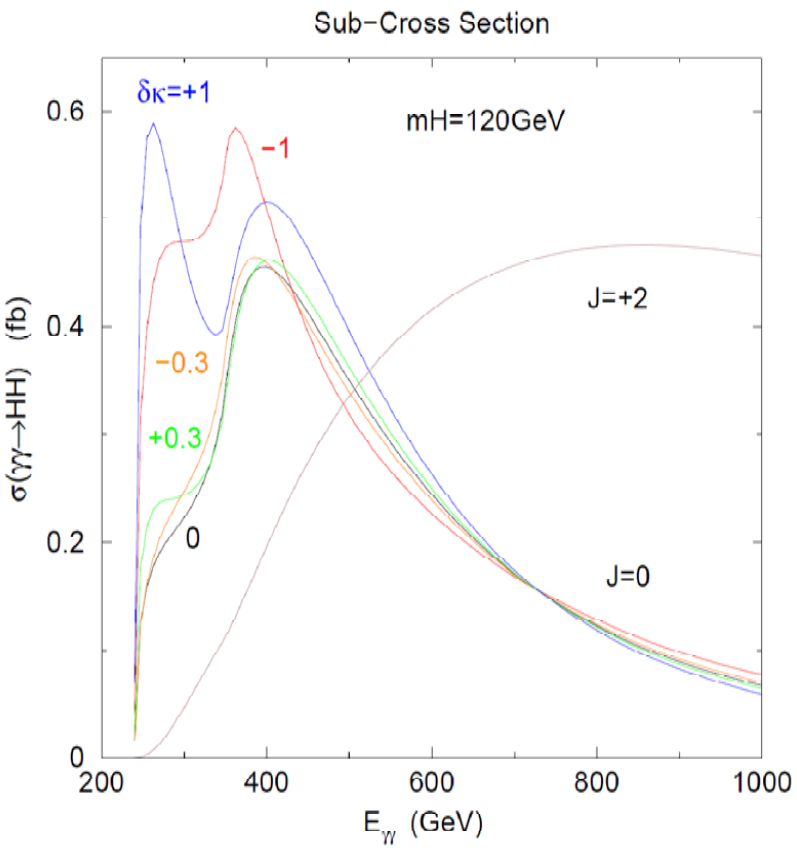
(d) SM 1-loop SM with the tree level hhh coupling

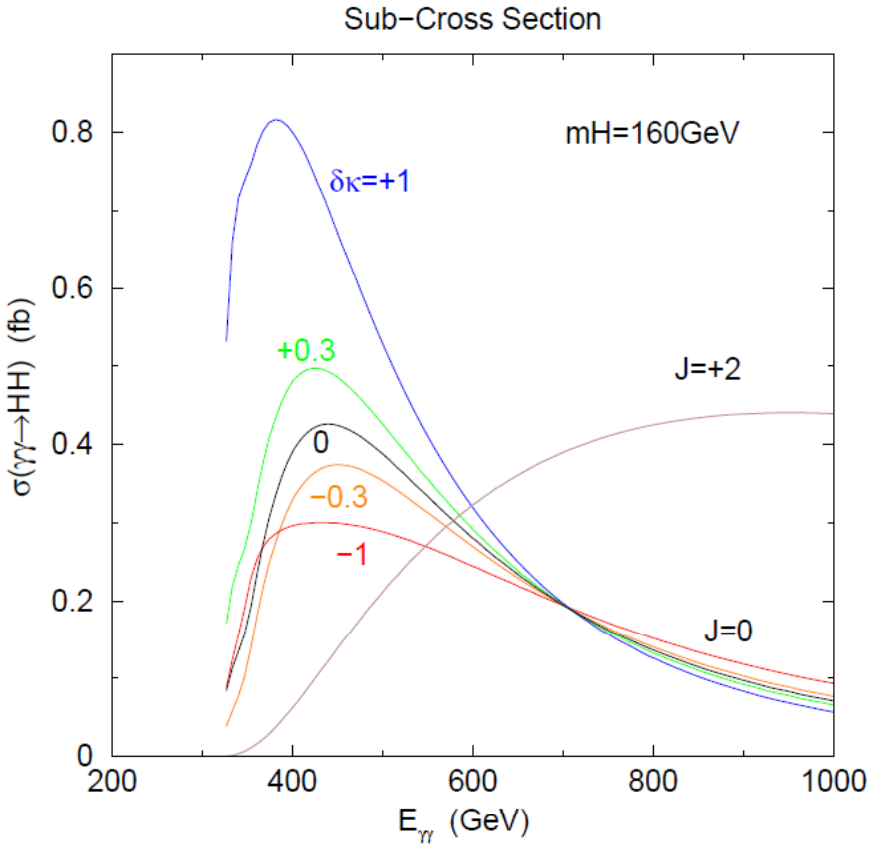
$$\mathcal{M}^{1-\text{loop}}_{\text{SM}}(l_1,l_2) = \mathcal{M}(l_1,l_2,\lambda_{hhh})$$

(e) SM $+\Gamma^{\text{THDM}}_{hhh}$ SM with additional one-loop corrections (THDM) to the hhh coupling

$$\mathcal{M}_{\text{SM}+\Gamma^{\text{THDM}}_{hhh}}(l_1,l_2) = \mathcal{M}(l_1,l_2,\Gamma^{\text{THDM}}_{hhh})$$

Anomalous hhh coupling

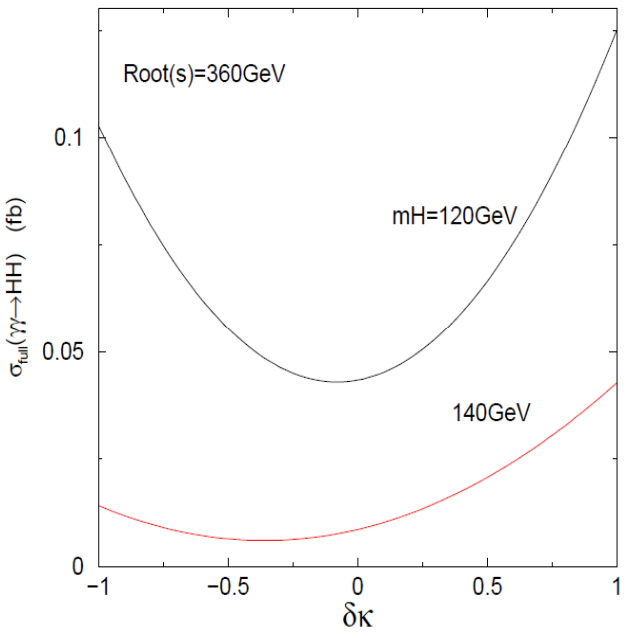




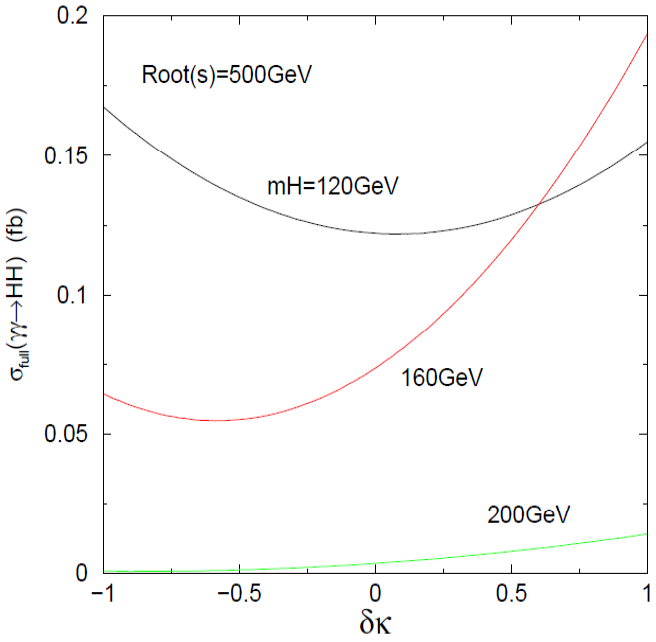
$$\lambda_{hhh} = \lambda_{hhh}^{\mathrm{SM}}(1 + \delta\kappa)$$

Full Cross Section ($\delta\kappa$ dependences)

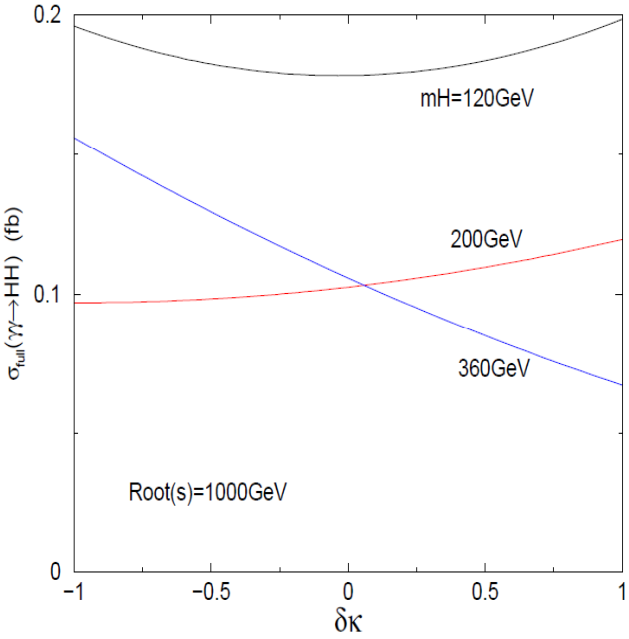
$\sqrt{s} = 360\text{GeV}$



$\sqrt{s} = 500\text{GeV}$



$\sqrt{s} = 1000\text{GeV}$



$$\lambda_{hhh} = \lambda^{\text{SM}}_{hhh}(1 + \delta\kappa)$$