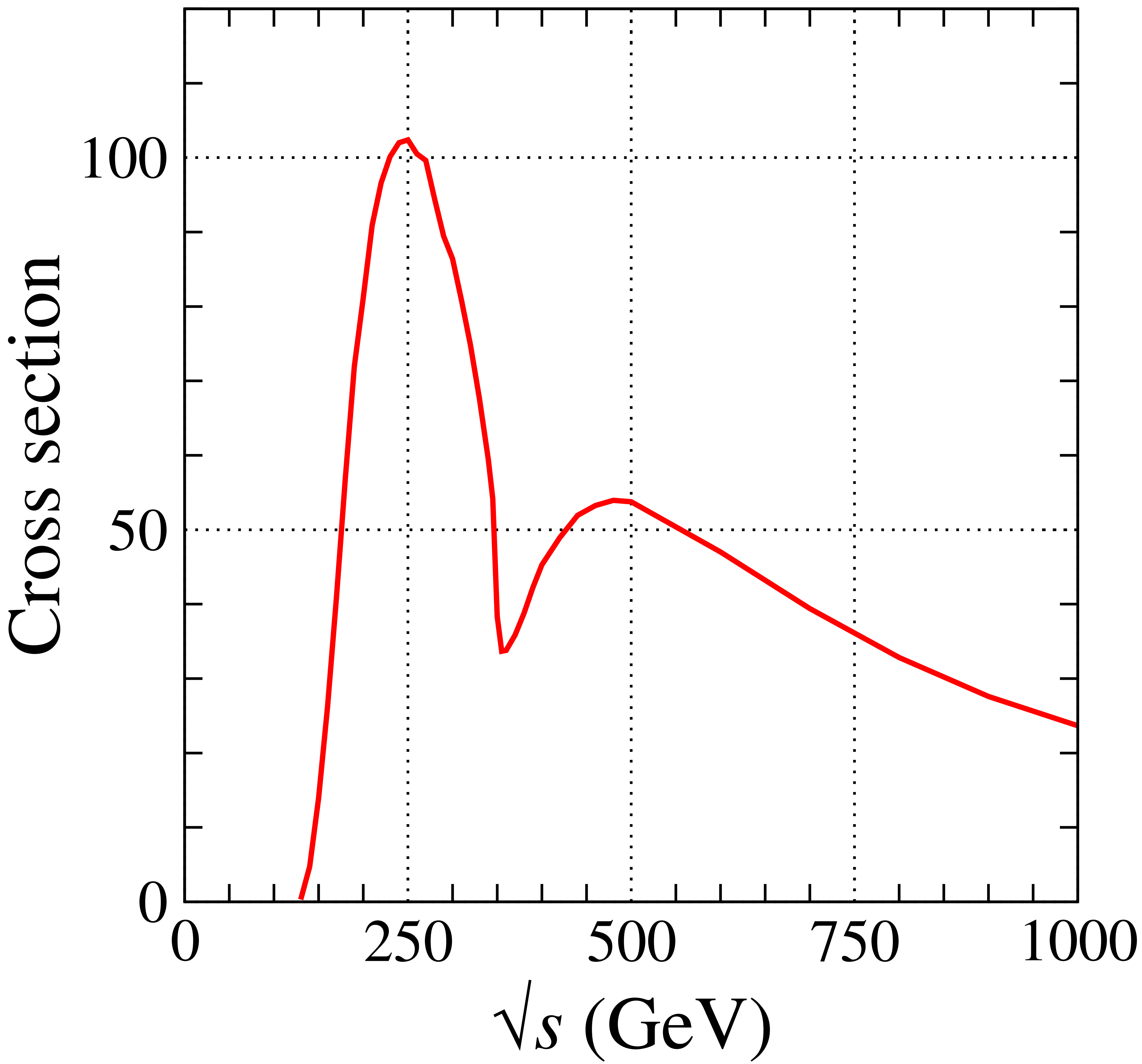


Cross section
100
50
0
0
250
500
750
1000
√s (GeV)

Higgs production in association with a photon in extended Higgs models at ILC250

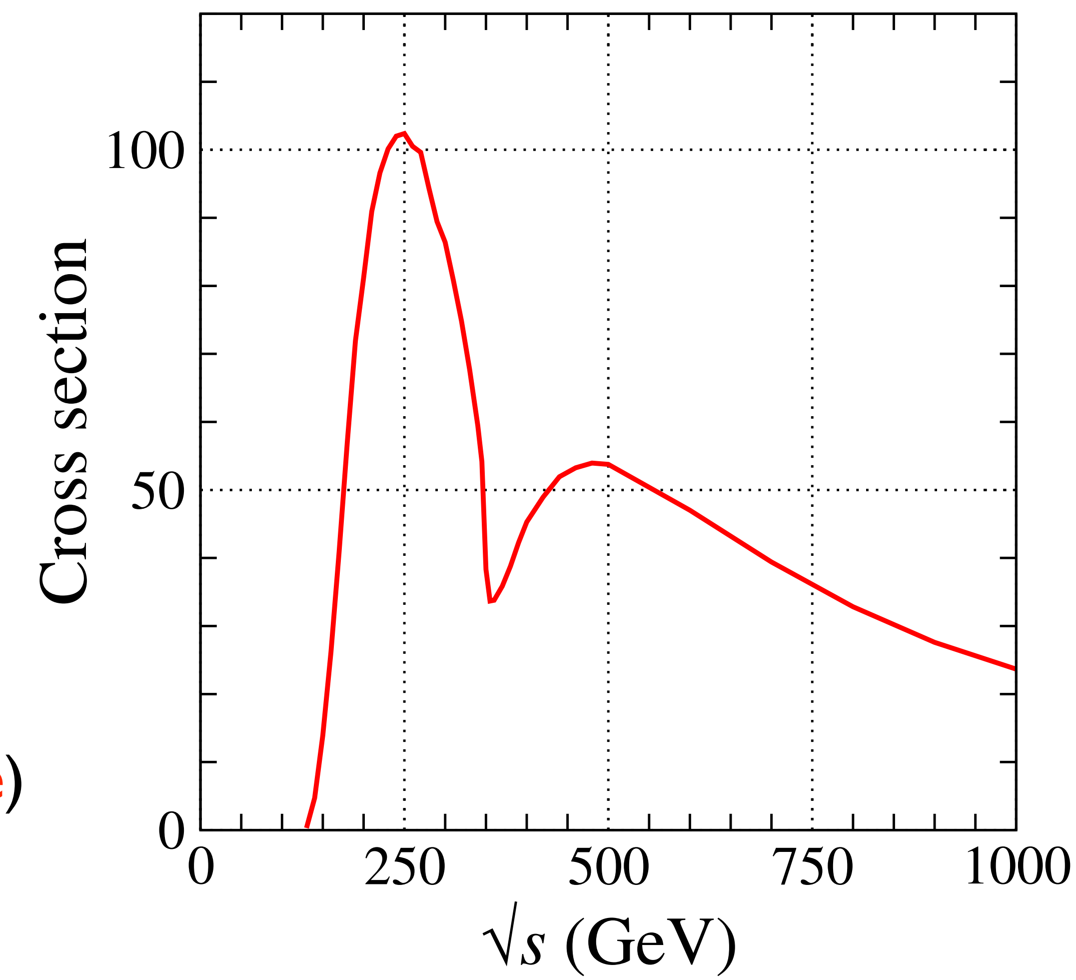
大阪大学
「ワニ博士」

大阪大学
OSAKA UNIVERSITY

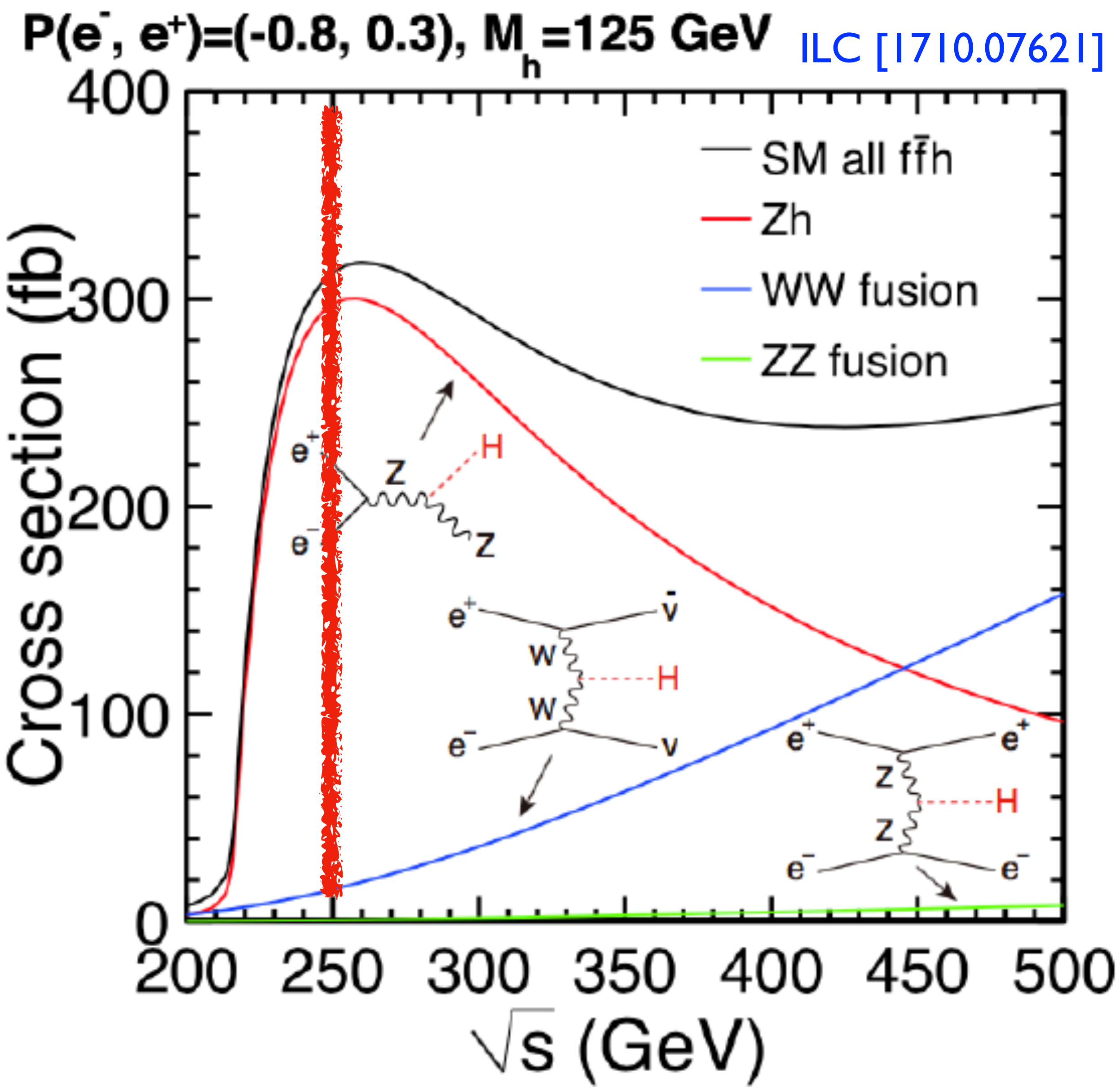
Kentarou Mawatari

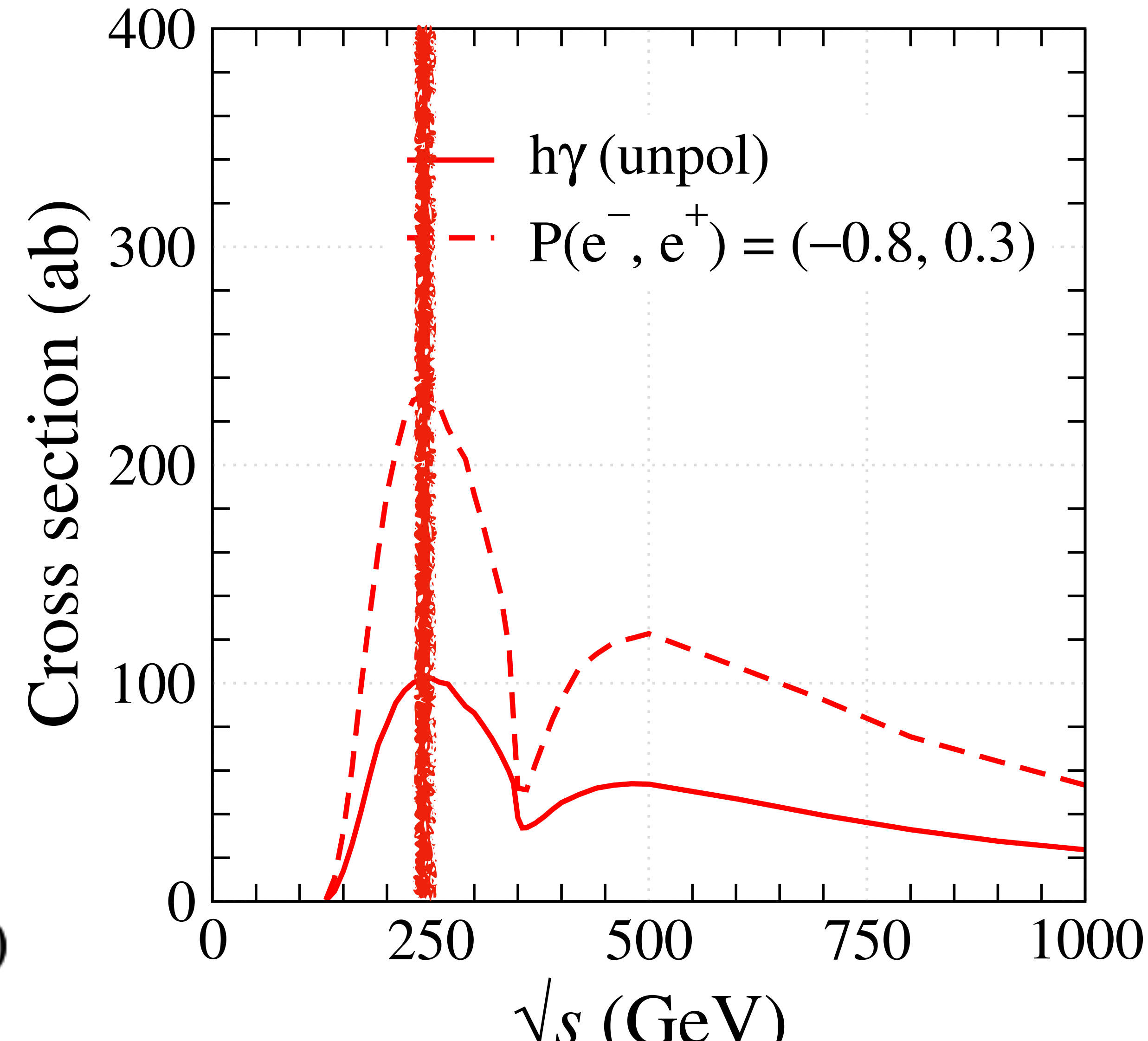
arXiv:1808.10268, PRD

with Prof. Shinya Kanemura (Osaka)
and Dr. Kodai Sakurai (Toyama/Osaka→Karlsruhe)



Higgs productions at ILC250



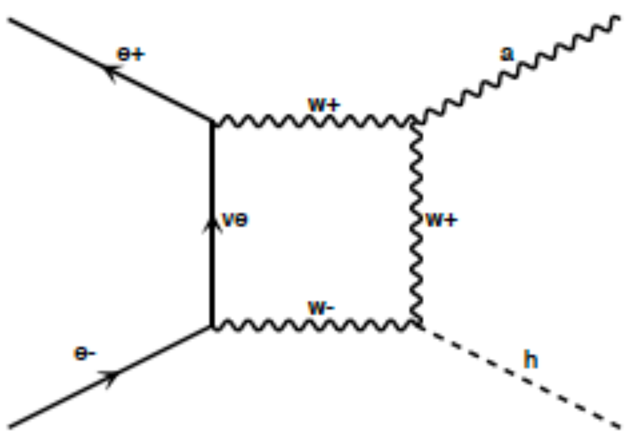


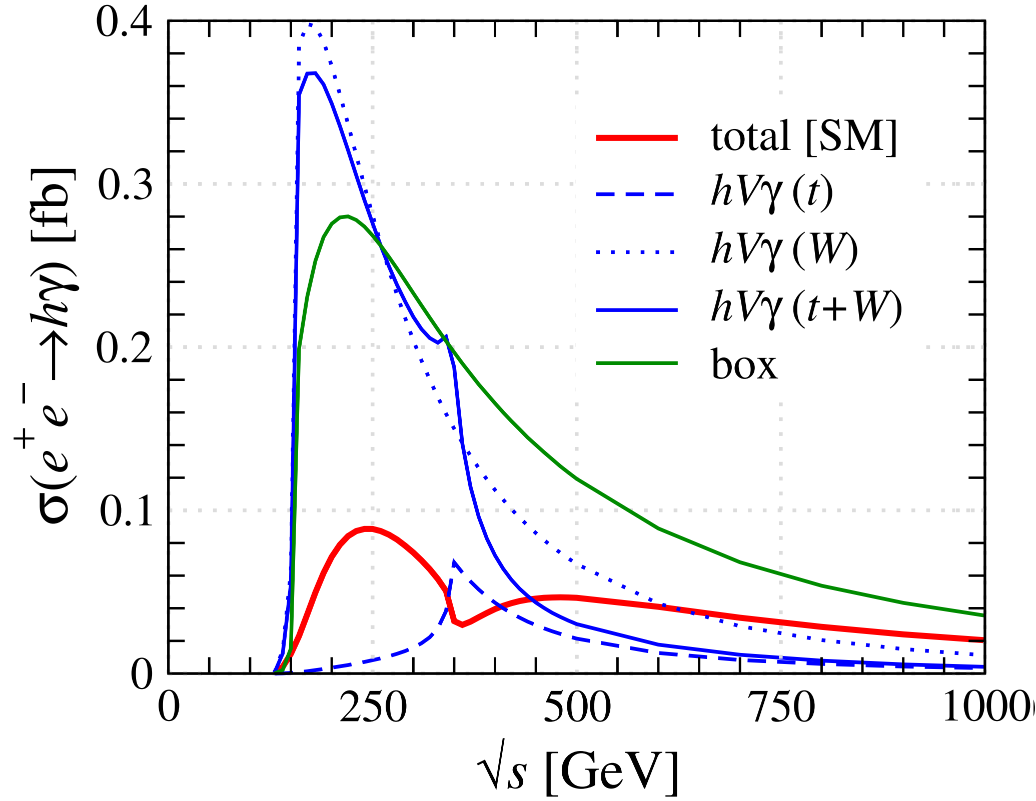
This is not the only Higgs production which has a peak at 250GeV at e^+e^- colliders.

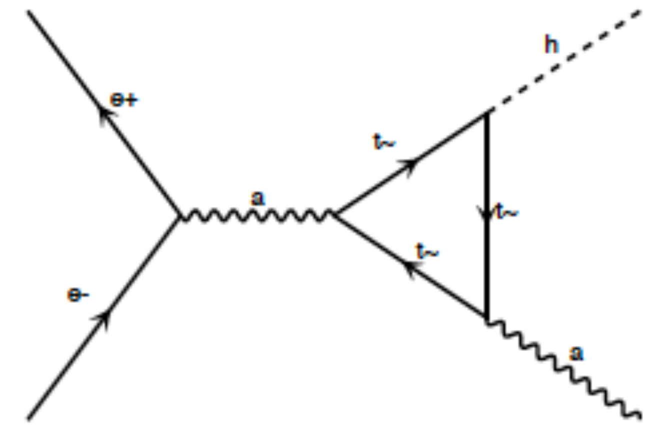
- σ(hγ) ∼ σ(hZ)x10^{-3} because of loop-induced.
- Beam polarization enhances.
- A monochromatic photon. $E_\gamma = \frac{\sqrt{s}}{2}\left(1 - \frac{m_h^2}{s}\right)$ $\sim 93.8\text{GeV}\ @\sqrt{s} = 250\text{GeV}$
- Sensitive to New Physics!

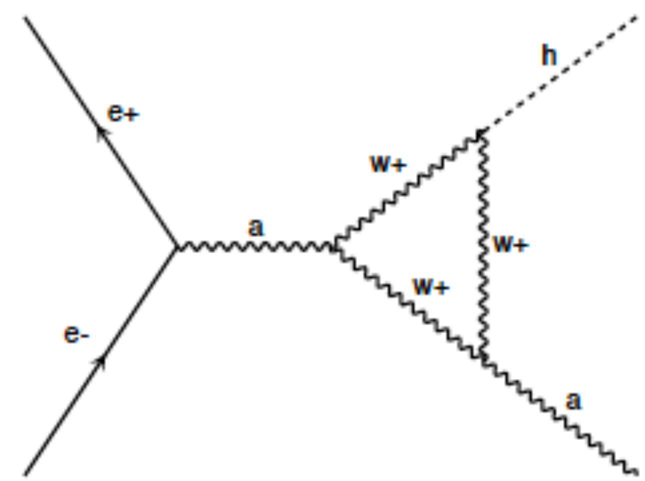
Barroso et al (1986), Abbasabadi et al (1995), Djouadi et al (1996)

$e^+e^- \to h\gamma$ in the SM





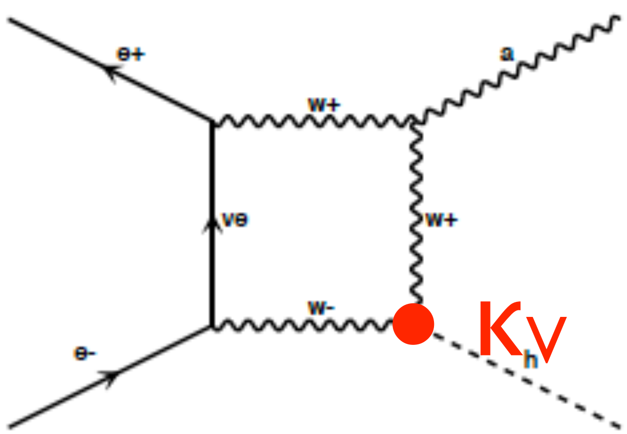


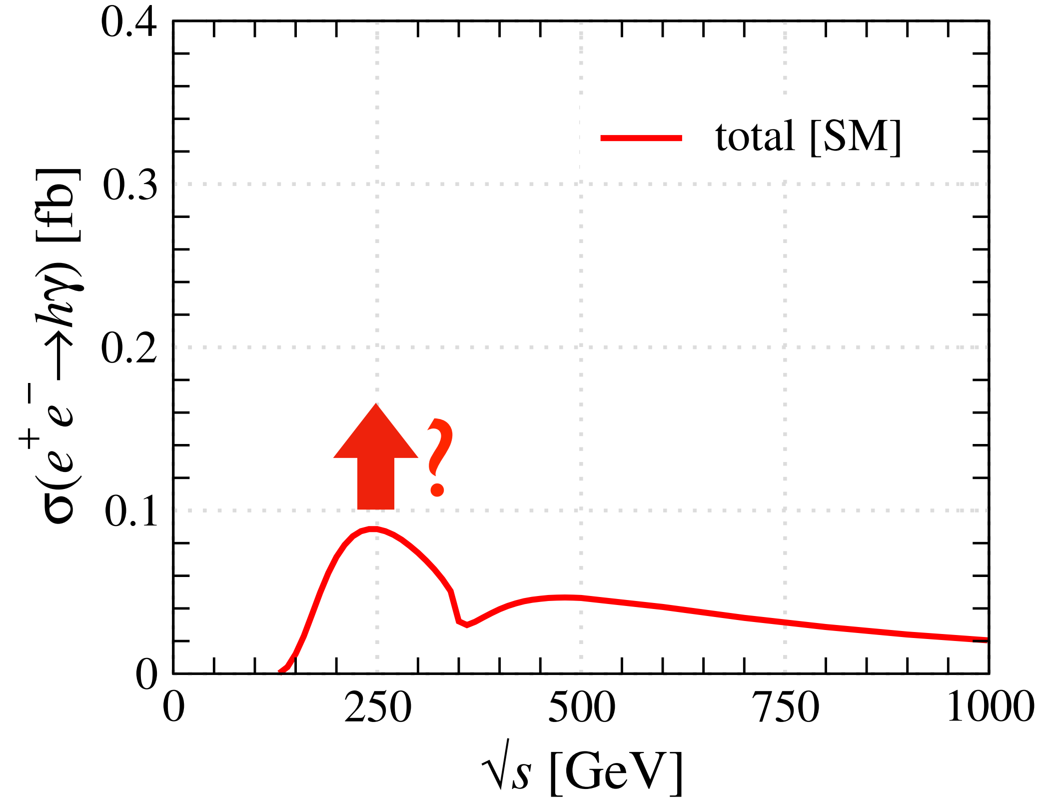


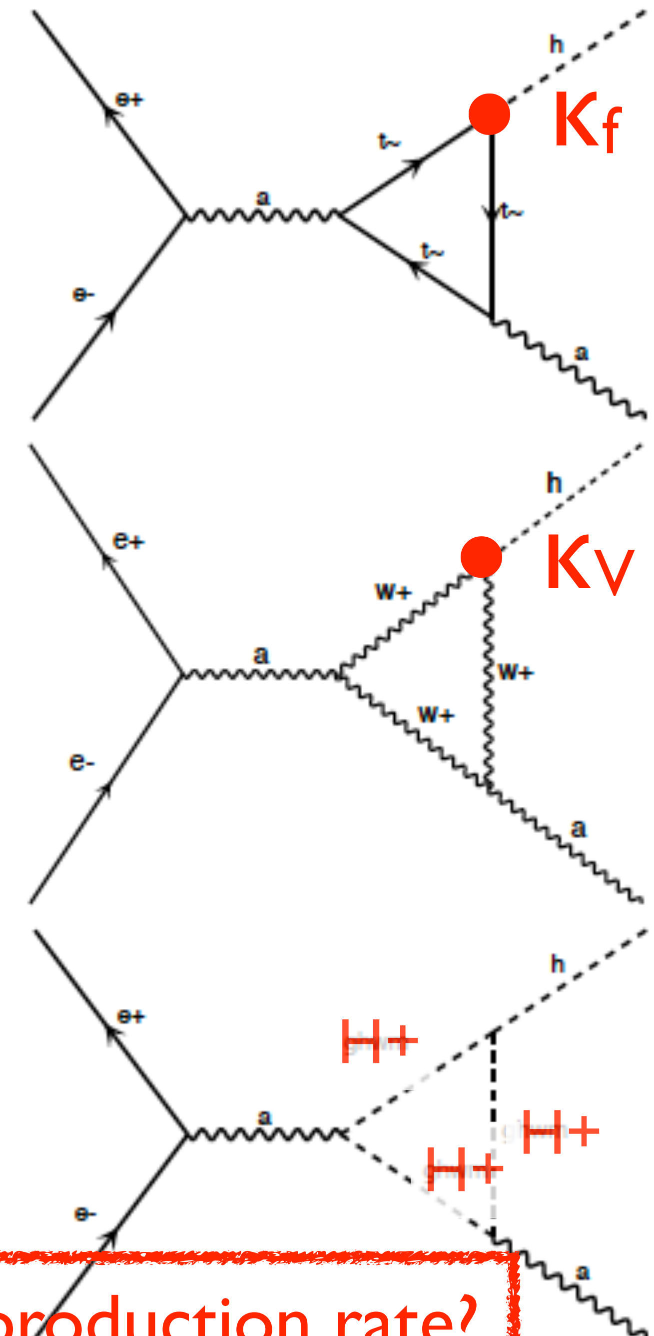
Unfortunate destructive interference among the different contributions…

$$\kappa_X = \frac{g_{hXX}^{\mathrm{NP}}}{g_{hXX}^{\mathrm{SM}}}$$

$e^+e^- \to h\gamma$ in extended Higgs models



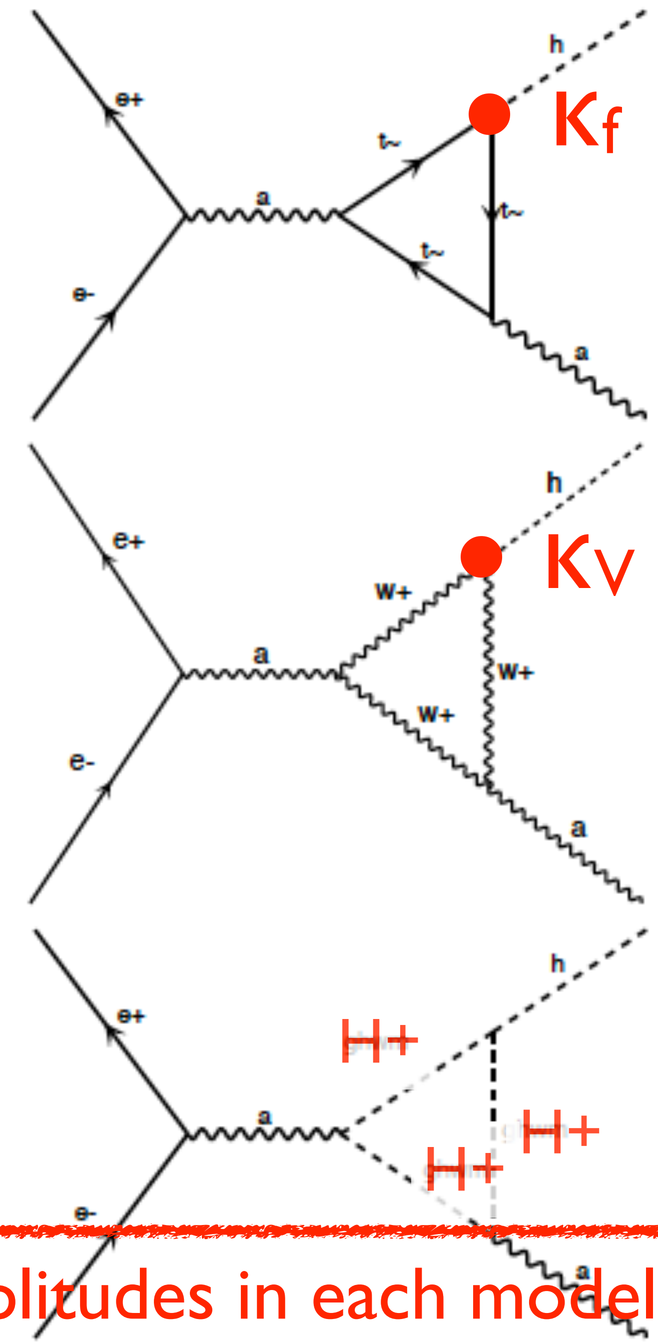




How much can new physics enhance (or reduce) the production rate?

3 benchmark extended Higgs models

	κ_f (=t)	κ_V	H^+	H^{++}
IDM (Inert doublet model)	1	1	○	×
ITM (Y=1) (Inert triplet model)	1	1	○	○
THDM (Two Higgs doublet model)	$s_{\beta-\alpha}$ $-c_{\beta-\alpha}/t_\beta$	$s_{\beta-\alpha}$	○	×

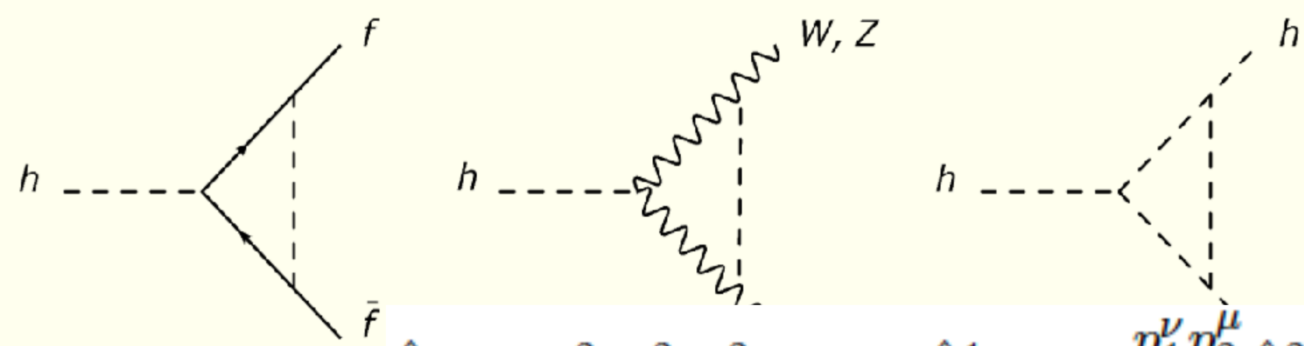


We employ the H-COUP program to compute the loop amplitudes in each model.

Kanemura, Kikuchi, Sakurai, Yagyu [1710.04603, CPC] www-het.phys.sci.osaka-u.ac.jp

H-COUP

＊See Kei Yagyu's talk and Kodai Sakurai's poster



$$\hat{\Gamma}^{\mu\nu}_{hVV}(p_1^2, p_2^2, q^2) = g^{\mu\nu}\hat{\Gamma}^1_{hVV} + \frac{p_1^\nu p_2^\mu}{m_V^2}\hat{\Gamma}^2_{hVV} + i\epsilon^{\mu\nu\rho\sigma}\frac{p_{1\rho}p_{2\sigma}}{m_V^2}\hat{\Gamma}^3_{hVV}$$

H-COUP is a calculation tool composed of a set of Fortran codes to compute the renormalized Higgs boson couplings with radiative corrections in various non-minimal Higgs models, such as the Higgs singlet model, four types of two Higgs doublet models and the inert doublet model. The impolved on-shell renormalization scheme is adopted, where the gauge depdence is eliminated.

Authors: Shinya Kanemura, Mariko Kikuchi, Kodai Sakurai and Kei Yagyu +K. Mawatari

The manual for H-COUP version 1.0 can be taken on arXiv:1710.04603 [hep-ph].

Loop effects on the Higgs decay widths
in extended Higgs models [1803.01456, PLB]

Downloads

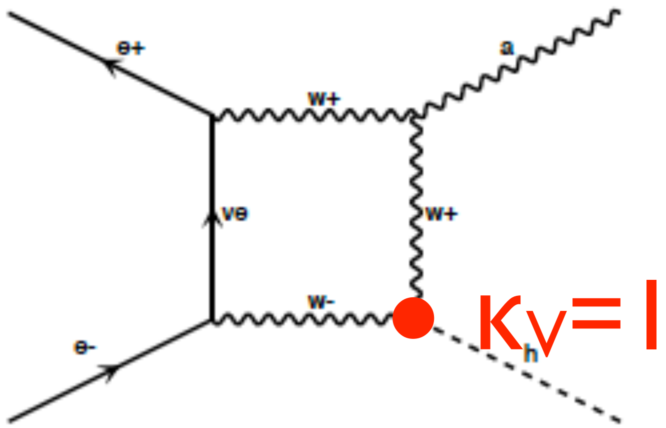
- H-COUP version 1.0 : [HCOUP-1.0.zip] [The manual is here]

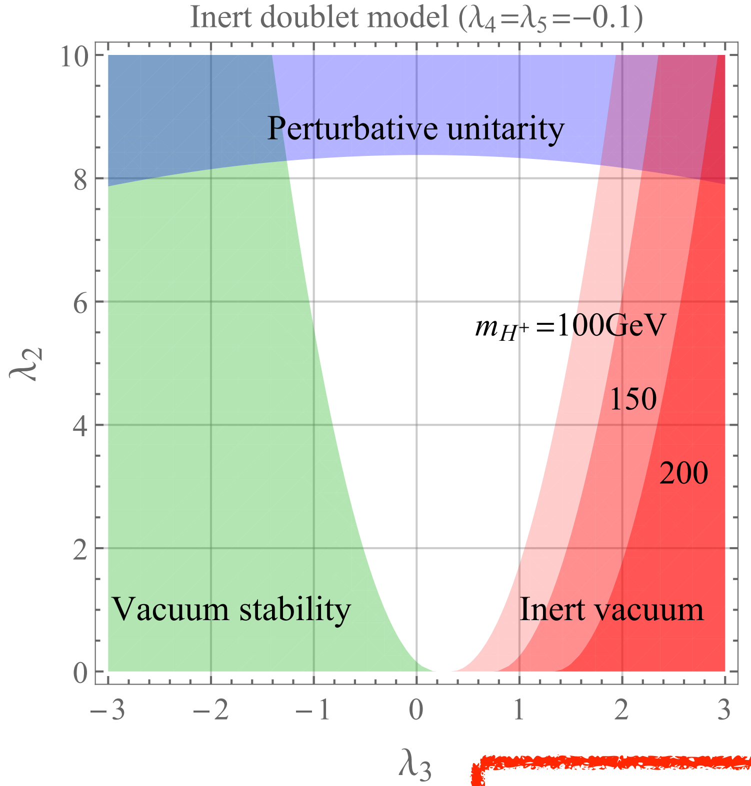
* An additional Higgs doublet with an exact Z_2 symmetry

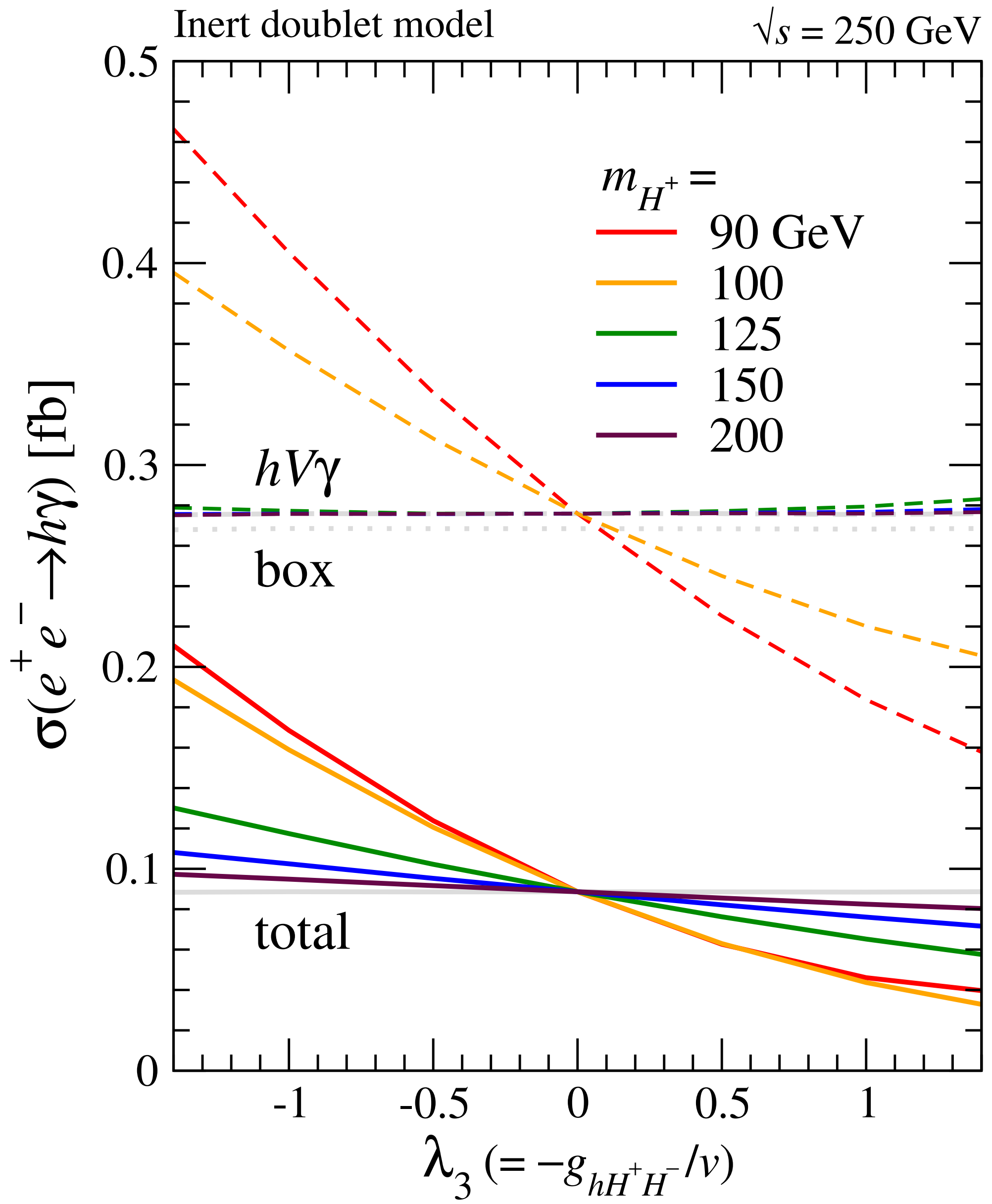
$e^+e^- \to h\gamma$ in the IDM

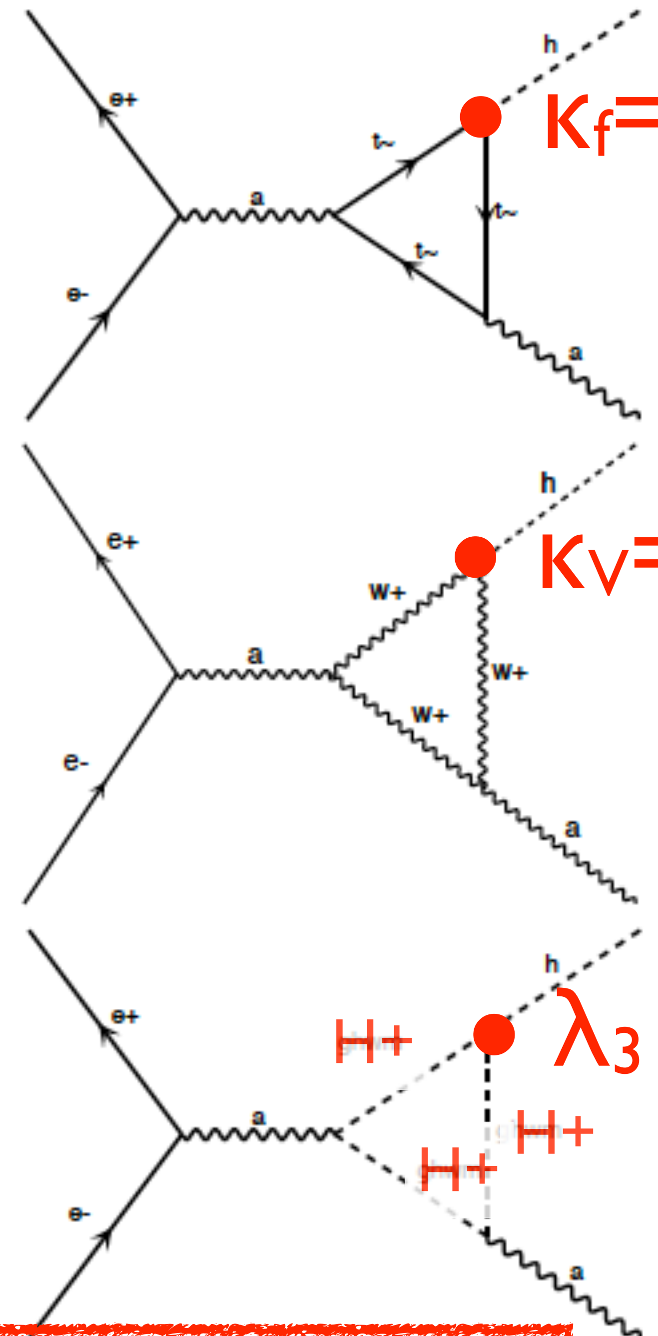
Arhrib, Benbrik, Yuan
[1401.6698, EPJC]

$$V = \mu_1^2|\Phi_1|^2 + \mu_2^2|\Phi_2|^2 + \frac{1}{2}\lambda_1|\Phi_1|^4 + \frac{1}{2}\lambda_2|\Phi_2|^4 + \lambda_3|\Phi_1|^2|\Phi_2|^2 + \lambda_4|\Phi_1^\dagger\Phi_2|^2 + \frac{1}{2}\lambda_5\{(\Phi_1^\dagger\Phi_2)^2 + \text{h.c.}\}$$





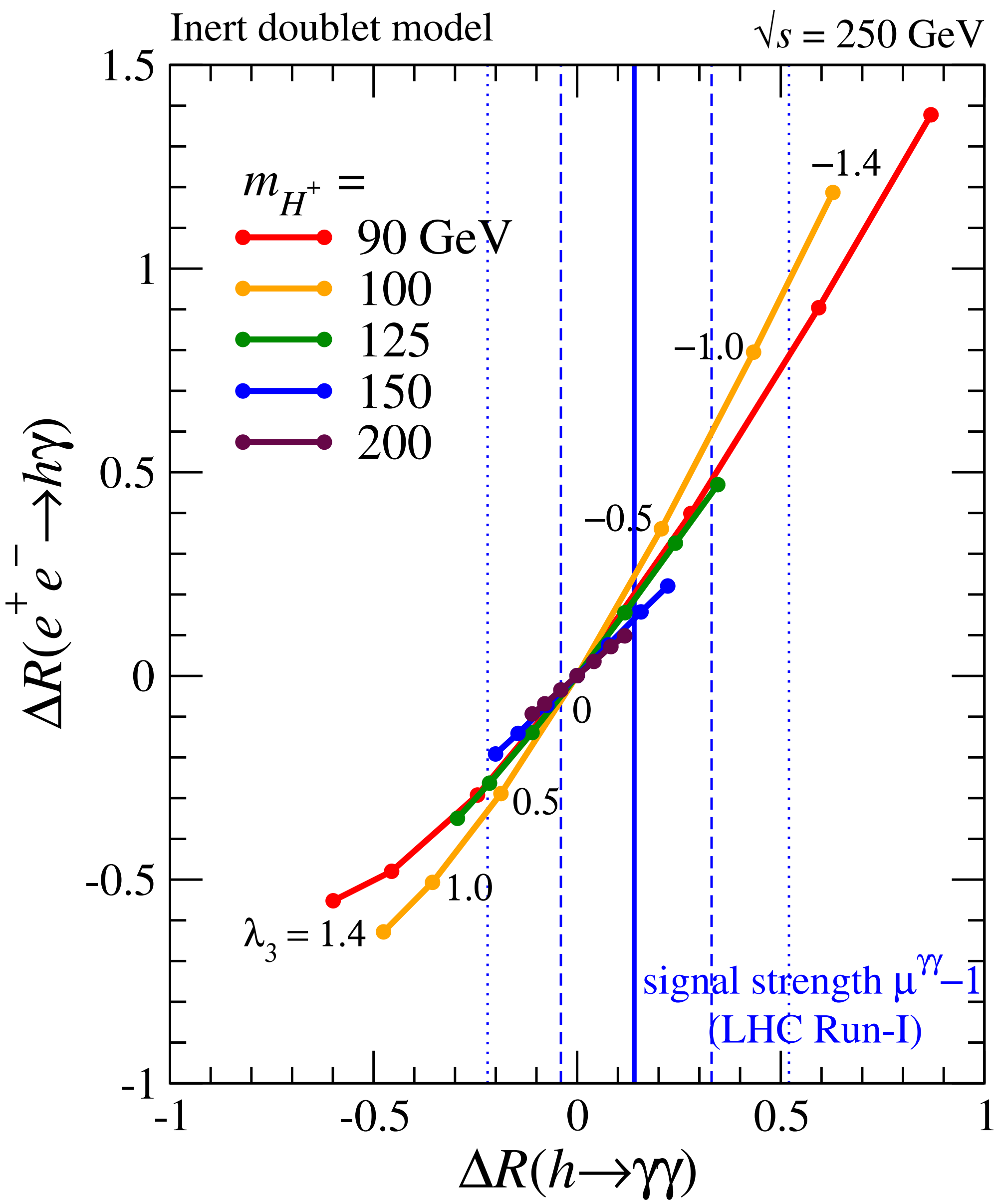




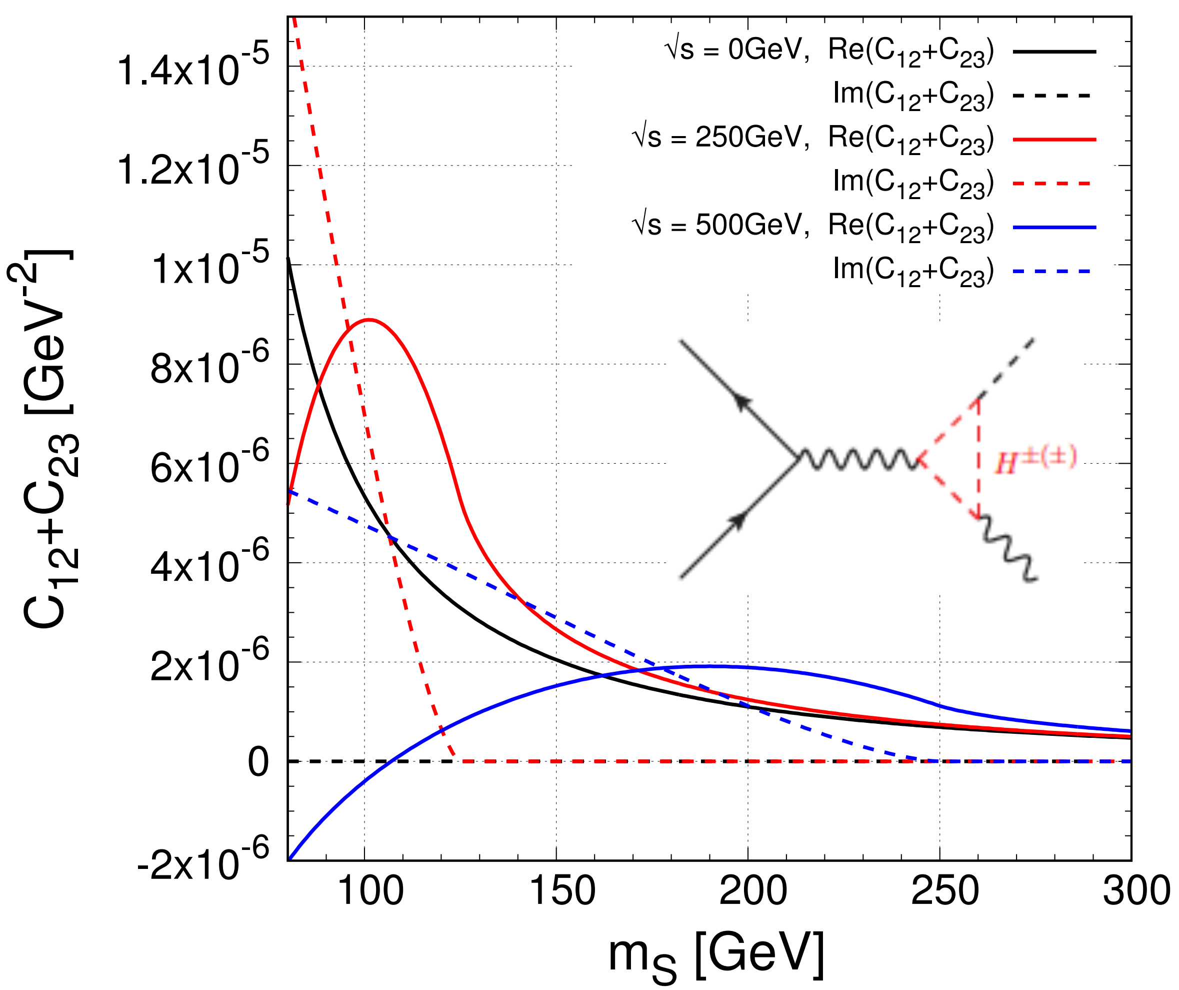
Lighter charged scalars with a negative λ_3 can enhance the production rate.

$$\Delta R(e^+e^- \to h\gamma) = \frac{\sigma_{NP}(e^+e^- \to h\gamma)}{\sigma_{SM}(e^+e^- \to h\gamma)} - 1, \quad \Delta R(h \to \gamma\gamma) = \frac{\Gamma_{NP}(h \to \gamma\gamma)}{\Gamma_{SM}(h \to \gamma\gamma)} - 1$$

$(e^+e^- \to h\gamma)$ vs. $(h \to \gamma\gamma)$ in the IDM



$$\Gamma^{2,1PI}_{h\gamma\gamma}(p_1^2, p_2^2, p_h^2)_S = -\frac{8e^2}{16\pi^2} \sum_S g_{hSS^*} Q_S^2 [C_{12}(S,S,S) + C_{23}(S,S,S)]$$

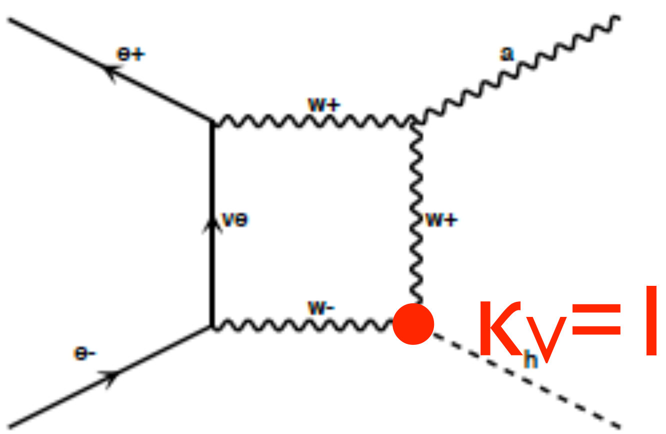


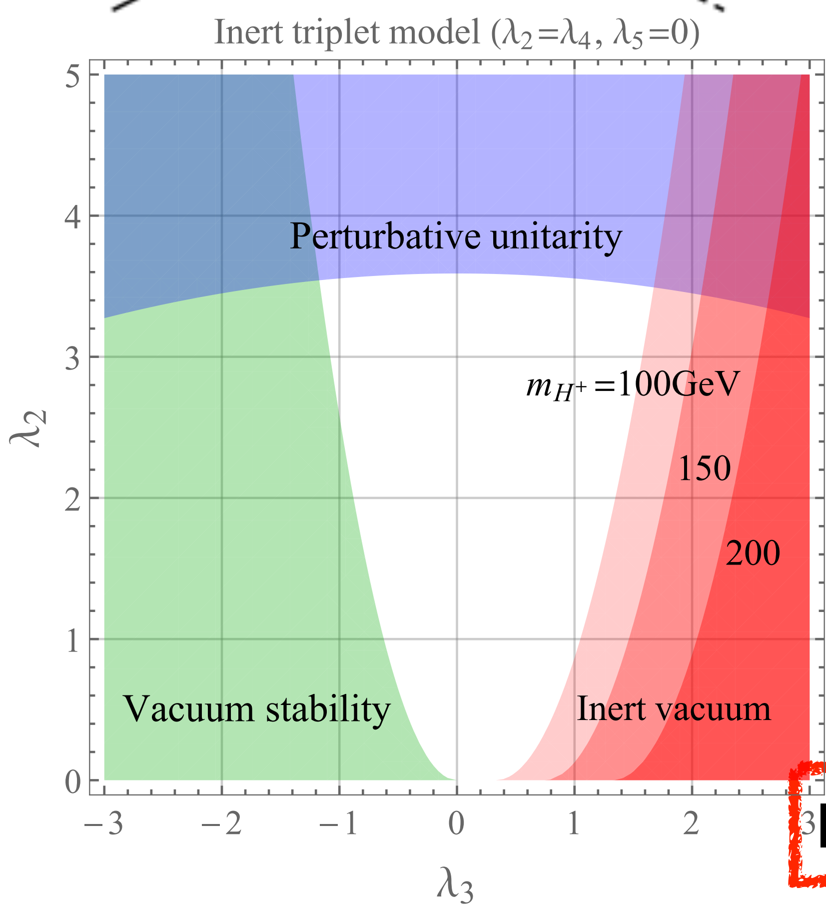
- Strong positive correlation.
- Stronger constraints for light H^+ by the Higgs measurement.

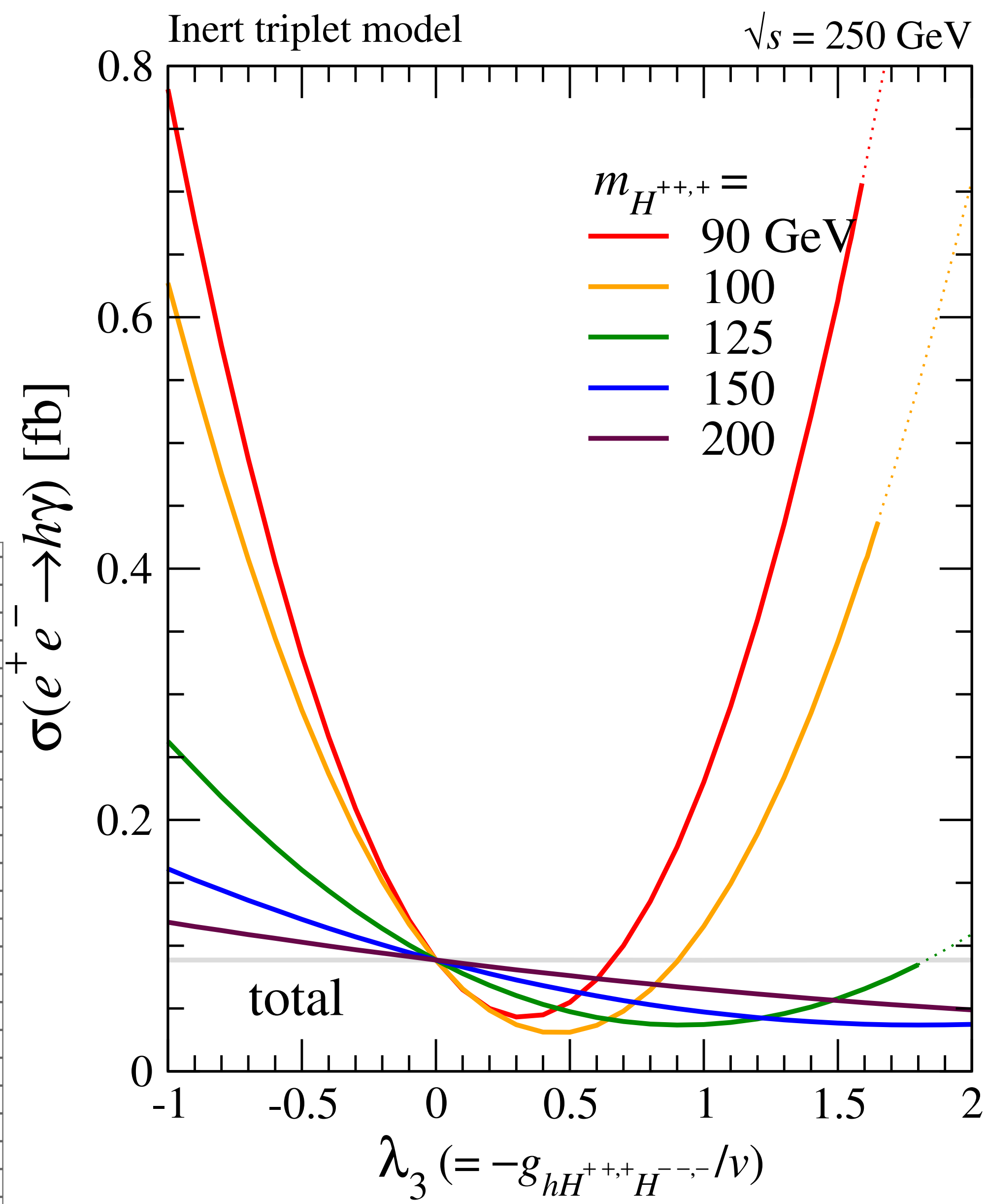
* An additional Higgs triplet with an exact Z_2 symmetry

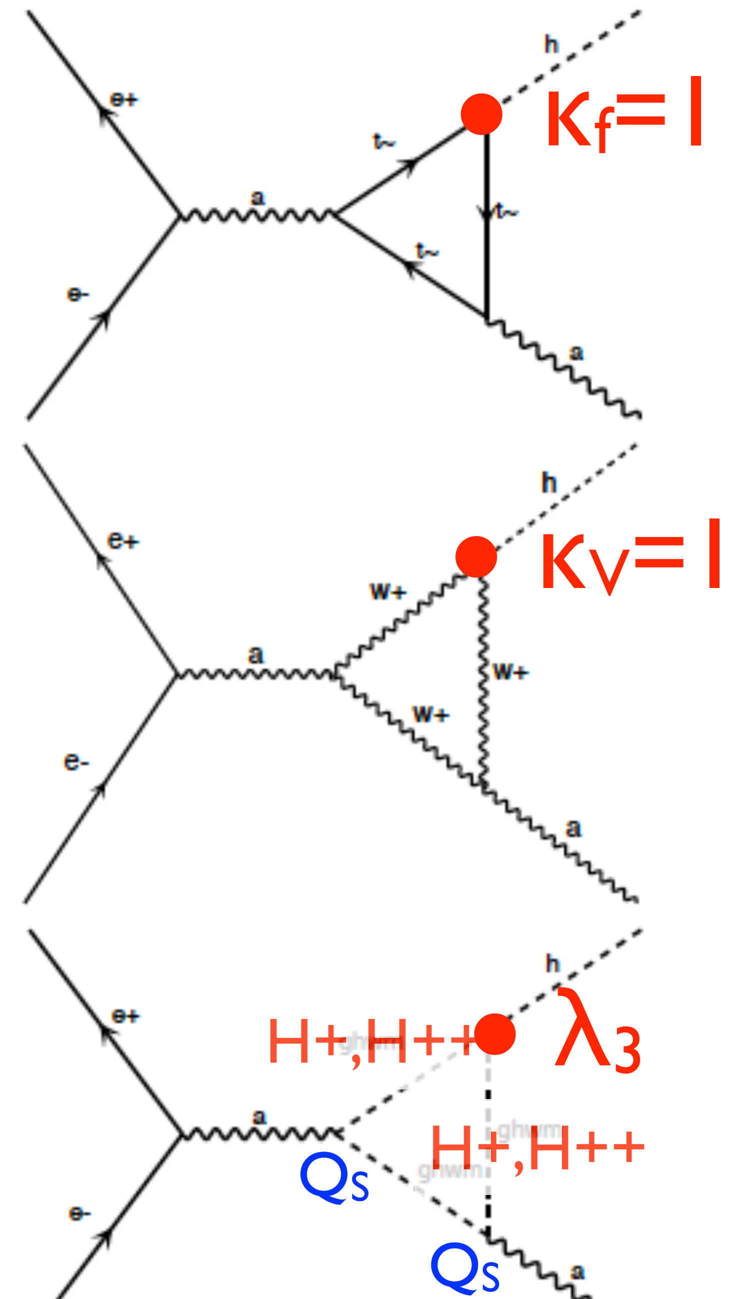
$e^+e^- \to h\gamma$ in the ITM

$$
\begin{aligned}
V = {} & \mu_1^2|\Phi|^2 + \mu_2^2\mathrm{Tr}[\Delta^\dagger\Delta] \\
& + \frac{1}{2}\lambda_1|\Phi|^4 + \frac{1}{2}\lambda_2(\mathrm{Tr}[\Delta^\dagger\Delta])^2 \\
& + \lambda_3|\Phi|^2\mathrm{Tr}[\Delta^\dagger\Delta] + \frac{1}{2}\lambda_4\mathrm{Tr}[(\Delta^\dagger\Delta)^2] \\
& + \lambda_5\Phi^\dagger\Delta\Delta^\dagger\Phi
\end{aligned}
$$





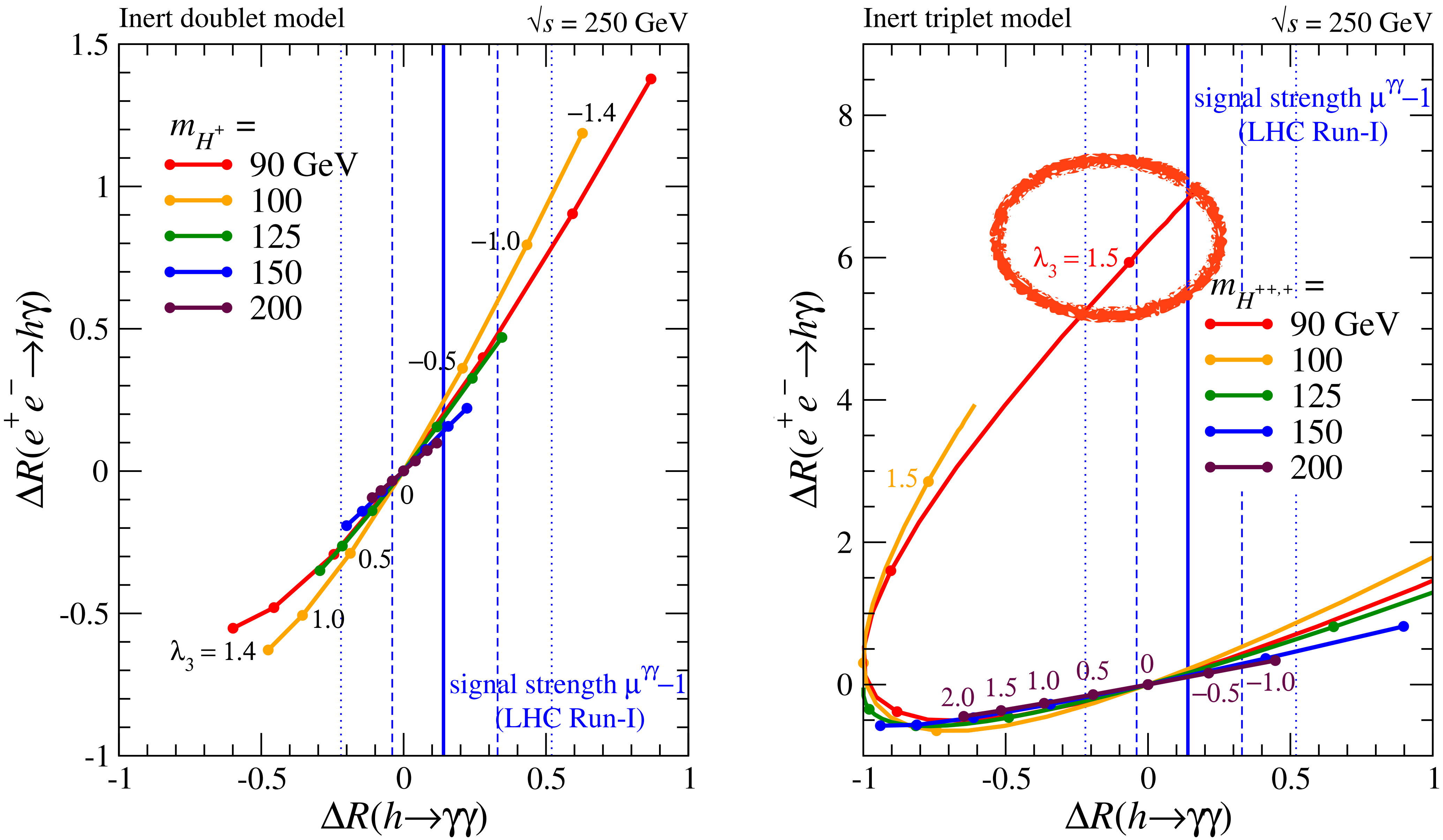




If $m_H^{++,+} \sim$ 100GeV, a positive λ_3 can also enhance the production rate.

$$\Delta R(e^+e^- \to h\gamma) = \frac{\sigma_{\rm NP}(e^+e^- \to h\gamma)}{\sigma_{\rm SM}(e^+e^- \to h\gamma)} - 1, \quad \Delta R(h \to \gamma\gamma) = \frac{\Gamma_{\rm NP}(h \to \gamma\gamma)}{\Gamma_{\rm SM}(h \to \gamma\gamma)} - 1$$

$(e^+e^- \to h\gamma)$ vs. $(h \to \gamma\gamma)$ in the IDM/ITM

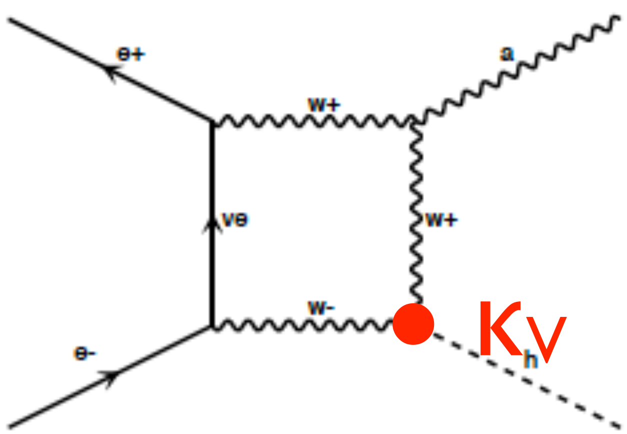


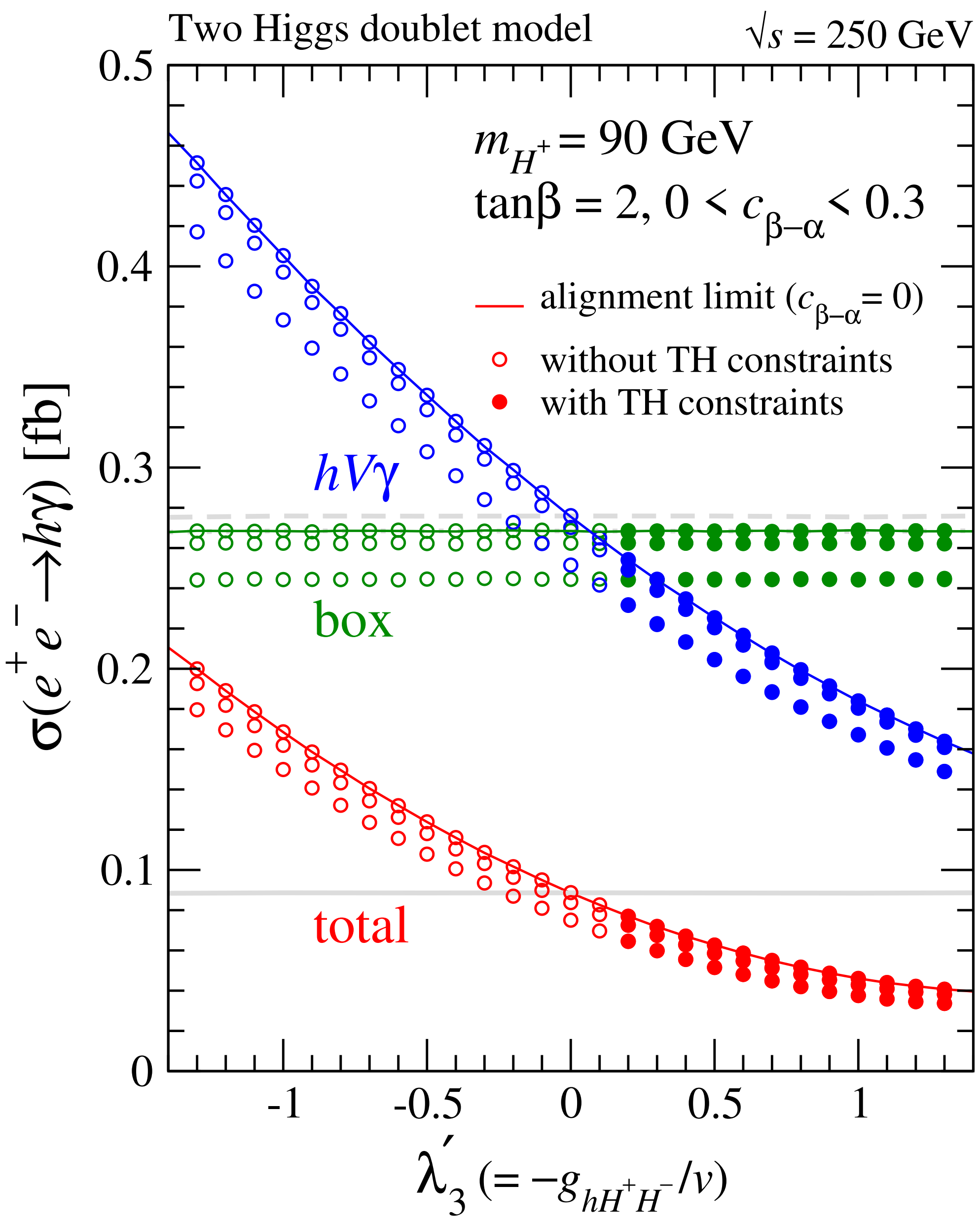
In the ITM, we can find a particular parameter region where the hγ production significantly increases, but the h→γγ decay still remains as in the SM.

$$V = m_1^2|\Phi_1|^2 + m_2^2|\Phi_2|^2 - m_3^2(\Phi_1^\dagger\Phi_2 + \text{h.c.}) + \frac{1}{2}\lambda_1|\Phi_1|^4 + \frac{1}{2}\lambda_2|\Phi_2|^4 + \lambda_3|\Phi_1|^2|\Phi_2|^2 + \lambda_4|\Phi_1^\dagger\Phi_2|^2 + \frac{1}{2}\lambda_5\{(\Phi_1^\dagger\Phi_2)^2 + \text{h.c.}\}$$

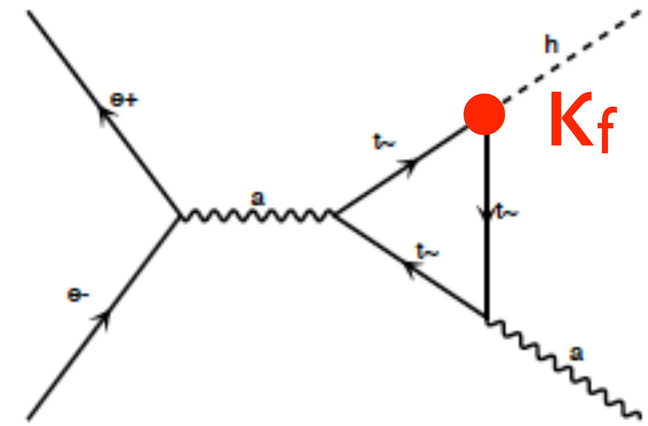
* An additional Higgs doublet with a softly broken Z_2 symmetry

$e^+e^- \to h\gamma$ in the THDM

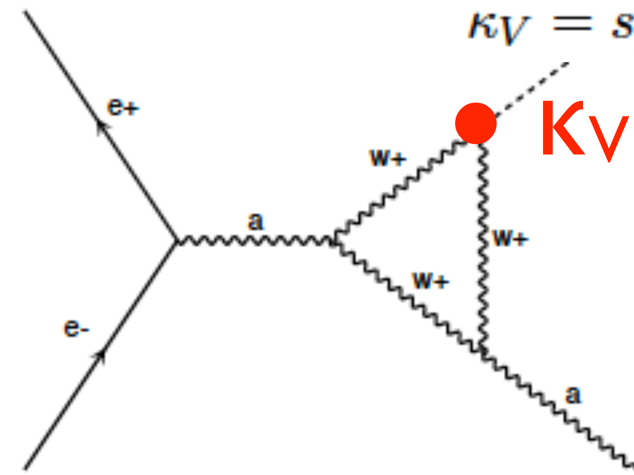


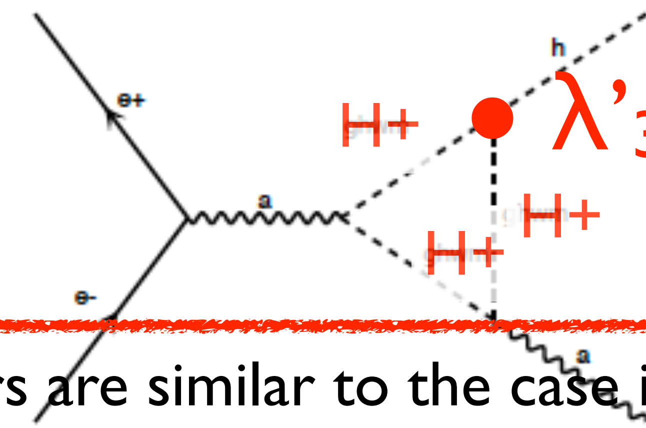


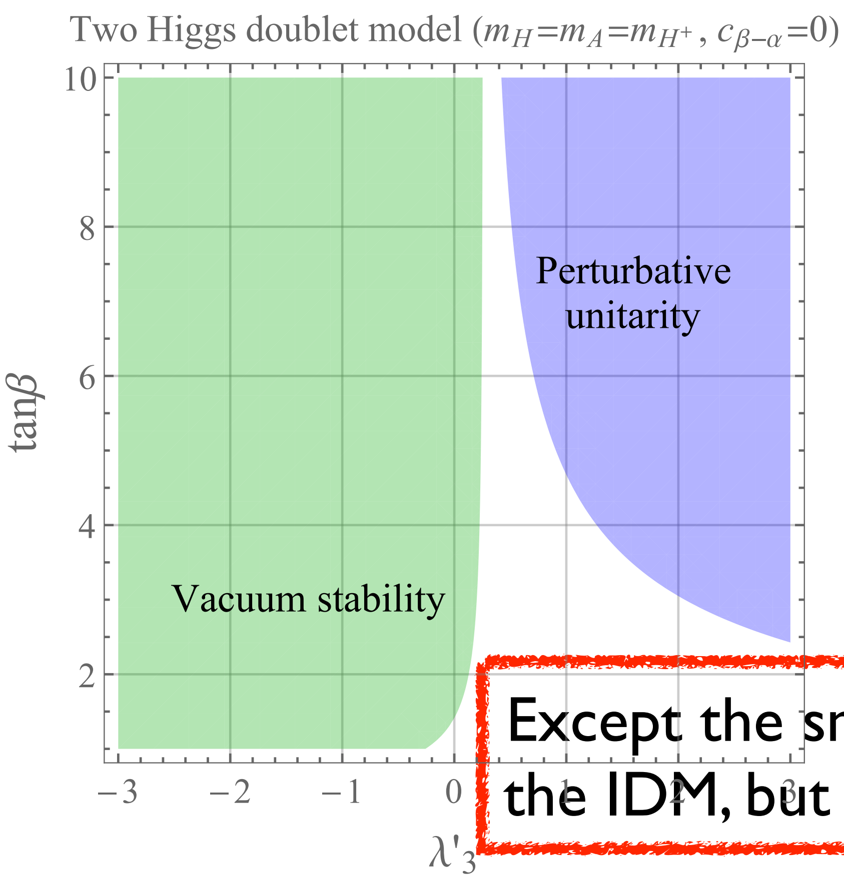
$\kappa_f = s_{\beta-\alpha} + \zeta_f c_{\beta-\alpha}$



$\kappa_V = s_{\beta-\alpha}$



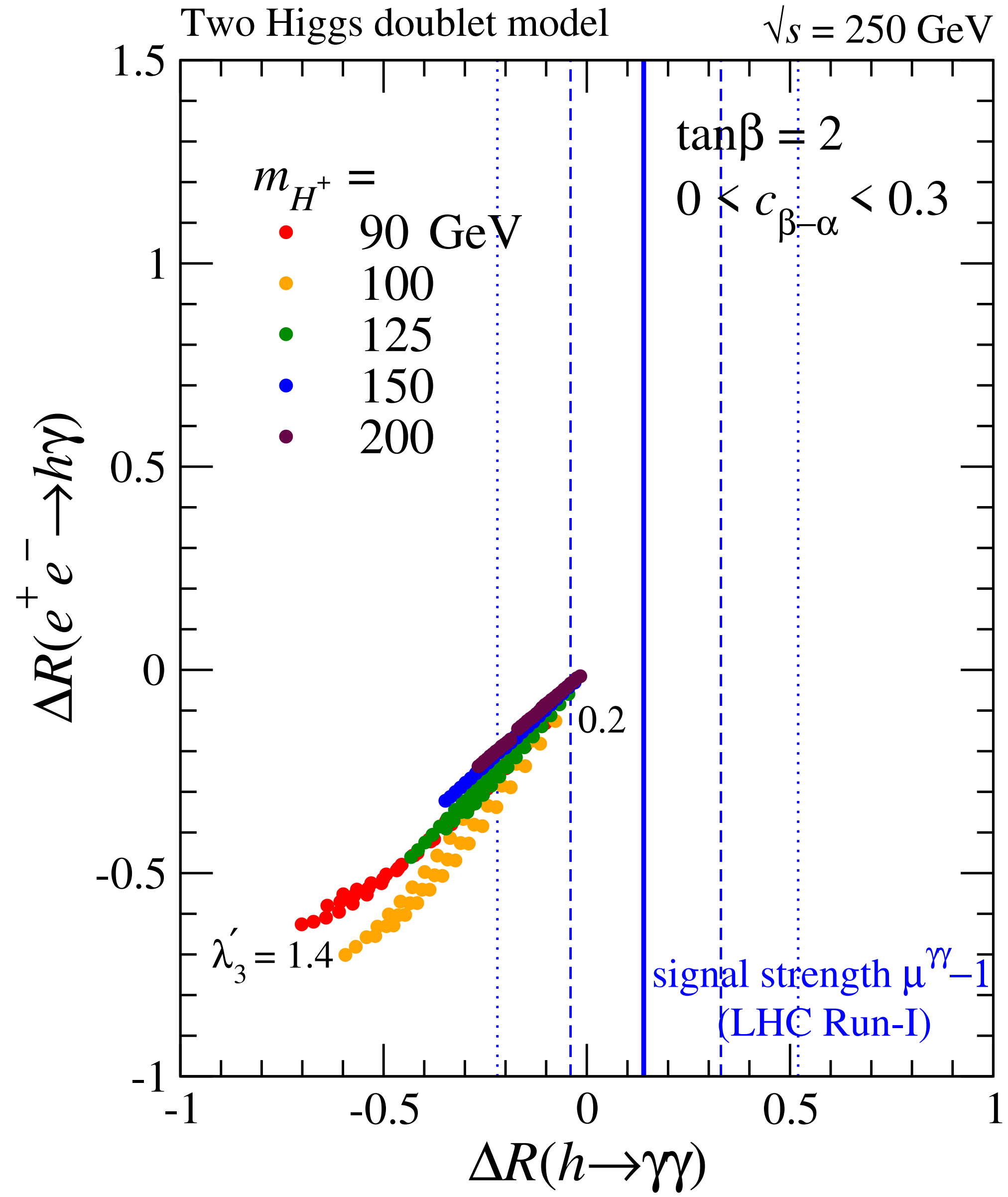




Except the small mixing effects, the qualitative behaviors are similar to the case in the IDM, but the enhanced parameter region is excluded by the TH constraints…

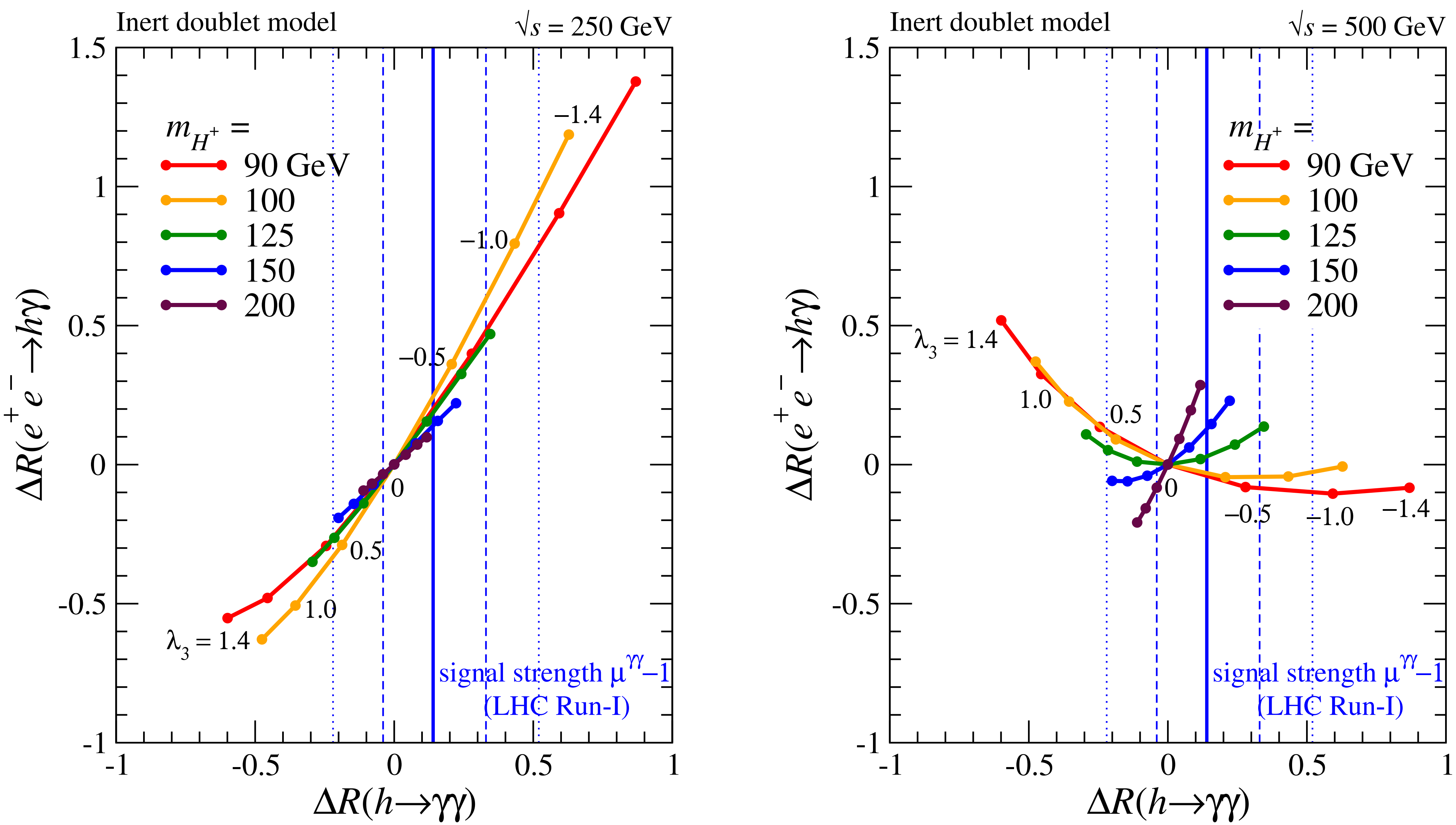
$$\Delta R(e^+e^- \to h\gamma) = \frac{\sigma_{\rm NP}(e^+e^- \to h\gamma)}{\sigma_{\rm SM}(e^+e^- \to h\gamma)} - 1, \quad \Delta R(h \to \gamma\gamma) = \frac{\Gamma_{\rm NP}(h \to \gamma\gamma)}{\Gamma_{\rm SM}(h \to \gamma\gamma)} - 1$$

($e^+e^- \to h\gamma$) vs. ($h \to \gamma\gamma$) in the THDM



Possible deviations from the SM prediction are minor in the viable parameter space.

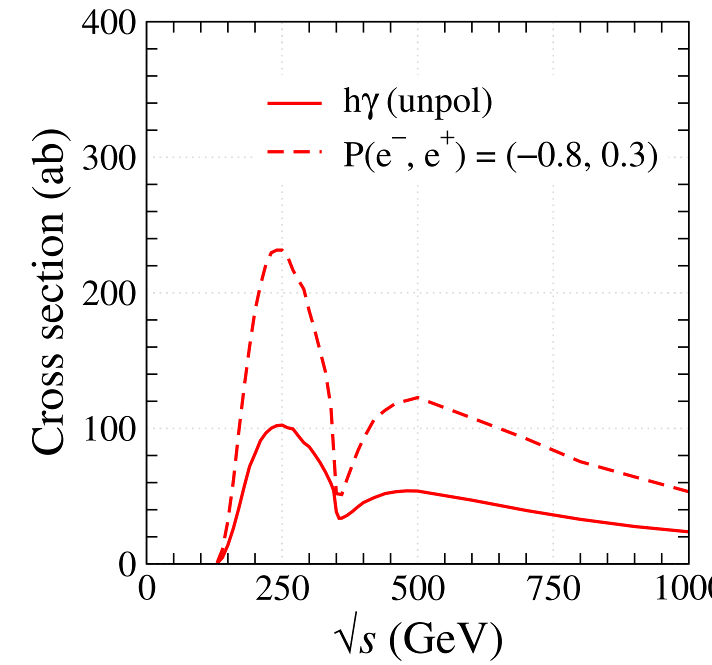
250 GeV vs. 500 GeV (IDM)



The correlations are different. ➡ A possibility to access more information on the Higgs sector!

Summary

- hγ production at lepton colliders:
  - The cross section is peaked at E=250GeV.
  - Beam polarization can enhance the cross section.
  - The signal is clean and very sensitive to New Physics.
  - Background study is needed. Aoki, Fujii, Jung, Lee, Tian, Yokoya "Study of the hγZ coupling" [1902.06029]



- With help from the H-COUP program, we studied the process in the benchmark extended Higgs models, such as IDM/ITM/THDM, systematically.
  - Light charged scalars (m_{H^+}〜100GeV) can enhance the event rates by a factor of 2 at most under the theoretical and experimental constraints.
  - In the ITM, thanks to doubly charged Higgs bosons, we can also find a particular parameter region where the hγ production significantly increases, but the h→γγ decay still remains as in the SM.