Charged Higgs production in association with W boson at photon colliders

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Based on collaboration with

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1. Introduction

Higgs sector of SM can be extended.

2 neutral Higgs bosons
a pair of charged Higgs bosons
for an additional doublet

Exploring Higgs sector

What members are included? (mass? charge? parity? CP property?)
What is the mass relation among the members like?
How many members are included?

gives us a clue to understand physics beyond SM.

In extended Higgs sector,

Higgs→Higgs+X is interesting
because we can observe 2 Higgs bosons simultaneously.

But it's hard to occur for heavy Higgs bosons in MSSM
due to the mass relation.

At tree level

$$m_H{}^2 = \frac{1}{2}\left[m_A{}^2 + m_Z{}^2 + \sqrt{\left(m_A{}^2 - m_Z{}^2\right)^2 + 4 m_A{}^2 m_Z{}^2 \sin^2 2\beta} \right]$$

$$m_{H^\pm}{}^2 = m_A{}^2 + m_W{}^2$$

$$\Rightarrow \quad \boxed{m_{H^\pm} \approx m_H \approx m_A}$$

in decoupling limit

In non-MSSM models,
large mass splittings among A , H and $H^\pm$
can be realized within constraints from $\left\{ \begin{array}{l} \text{pparameters} \\ \text{perturbative unitarity.} \end{array} \right.$

Model / Constraints	MSSM	THDM
pparamater	Automatically satisfied due to $m_{H^\pm} \approx m_H \approx m_A$	should be considered
perturbative unitarity	Automatically satisfied due to $\lambda_i \sim O(g^2)$	should be considered

$$
\begin{aligned}
V_{THDM} &= m_1^2 \left|\Phi_1\right|^2 + m_2^2 \left|\Phi_2\right|^2 - m_3^2 \left(\Phi_1^\dagger \Phi_2 + \Phi_2^\dagger \Phi_1\right) \\
&\quad + \frac{\lambda_1}{2} \left|\Phi_1\right|^4 + \frac{\lambda_2}{2} \left|\Phi_2\right|^4 + \lambda_3 \left|\Phi_1\right|^2 \left|\Phi_2\right|^2 \\
&\quad + \lambda_4 \left|\Phi_1^\dagger \Phi_2\right|^2 + \frac{\lambda_5}{2} \left\{ \left(\Phi_1^\dagger \Phi_2\right)^2 + \left(\Phi_2^\dagger \Phi_1\right)^2 \right\}
\end{aligned}
$$

Non-MSSM decay mode

$$H^0 \to A^0 A^0 \qquad \text{if } m_{H^0} \geq 2m_{A^0}$$

$$H^0 \to H^\pm H^\mp \qquad \text{if } m_{H^0} \geq 2m_{H^\pm}$$

$$H^0 \to H^\pm W^\mp \qquad \text{if } m_{H^0} \geq m_{H^\pm} + m_W$$

$$H^\pm \to H^0 W^\pm \qquad \text{if } m_{H^\pm} \geq m_{H^0} + m_W$$

$$A^0 \to H^\pm W^\mp \qquad \text{if } m_{A^0} \geq m_{H^\pm} + m_W$$

$$H^\pm \to A^0 W^\pm \qquad \text{if } m_{H^\pm} \geq m_{A^0} + m_W$$

$$H^0 \to A^0 Z \qquad \text{if } m_{H^0} \geq m_{A^0} + m_Z$$

$$A^0 \to H^0 Z \qquad \text{if } m_{A^0} \geq m_{H^0} + m_Z$$

At photon colliders,

kinematical reach for neutral Higgs bosons is much longer than for charged Higgs bosons.

Then, we consider

the process where charged Higgs bosons are produced in neutral Higgs boson decays.

$$\boxed{A \to H^{\pm} W^{\mp}}$$

Non-MSSM decay mode

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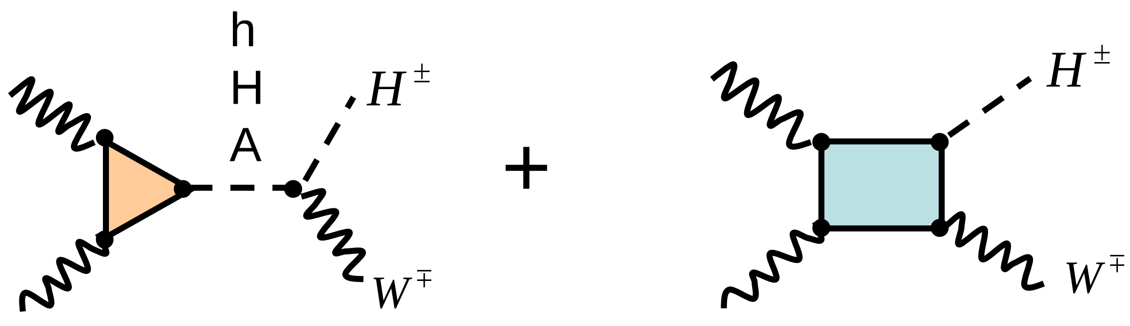
2. $\gamma\gamma \to W^{\pm}H^{\mp}$

This process is loop-induced one.



In general Two Higgs Doublet Model,

$$m_A \geq m_{H^\pm} + m_W \quad \text{is possible,}$$

$$V_{THDM} = m_1^2 |\Phi_1|^2 + m_2^2 |\Phi_2|^2 - m_3^2 \left(\Phi_1^\dagger \Phi_2 + \Phi_2^\dagger \Phi_1\right) + \frac{\lambda_1}{2}|\Phi_1|^4 + \frac{\lambda_2}{2}|\Phi_2|^4 + \lambda_3 |\Phi_1|^2 |\Phi_2|^2 + \lambda_4 \left|\Phi_1^\dagger \Phi_2\right|^2 + \frac{\lambda_5}{2}\left\{\left(\Phi_1^\dagger \Phi_2\right)^2 + \left(\Phi_2^\dagger \Phi_1\right)^2\right\}$$

because

$$m_A{}^2 - m_{H^\pm}{}^2 = \frac{v^2}{2}\left(\underline{\lambda_4} - \underline{\lambda_5}\right)$$

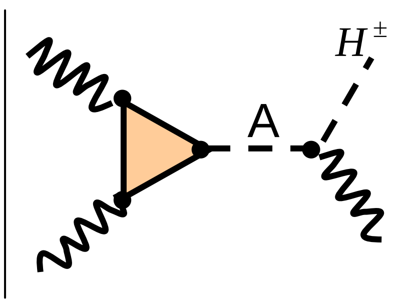
Free parameters

In MSSM

$$\lambda_4 = -\frac{1}{2} g^2, \quad \lambda_5 = 0$$

$$\Rightarrow \quad m_A{}^2 - m_{H^\pm}{}^2 = -m_W{}^2$$

In this case, around $\sqrt{s}_{\gamma\gamma} \simeq m_A$



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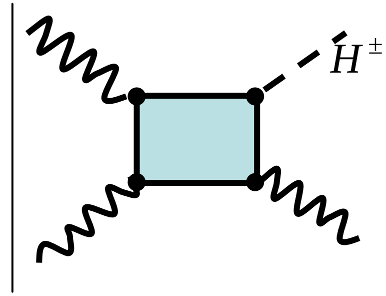
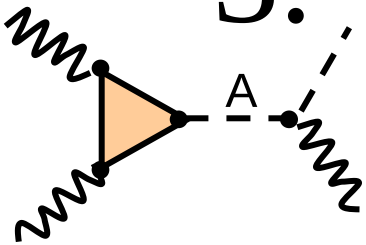


Resonant s-channel diagrams dominate over other diagrams.

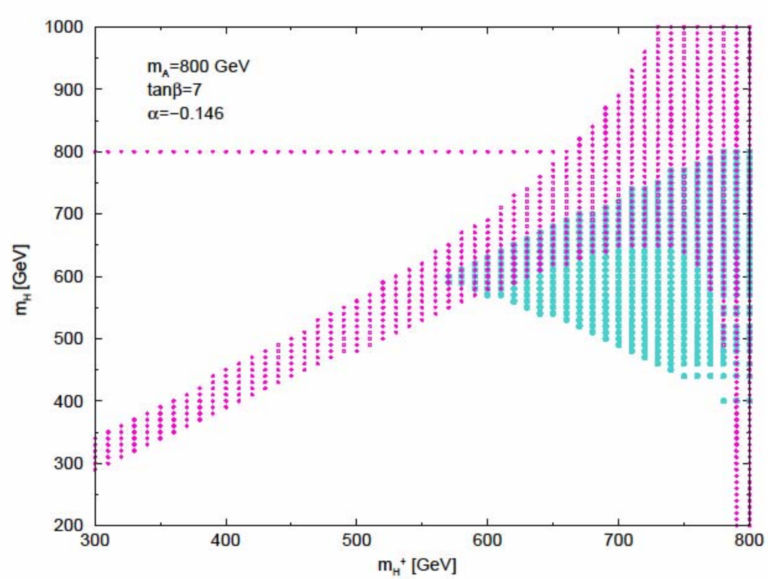
3. $\gamma\gamma \to A \to W^{\pm}H^{\mp}$



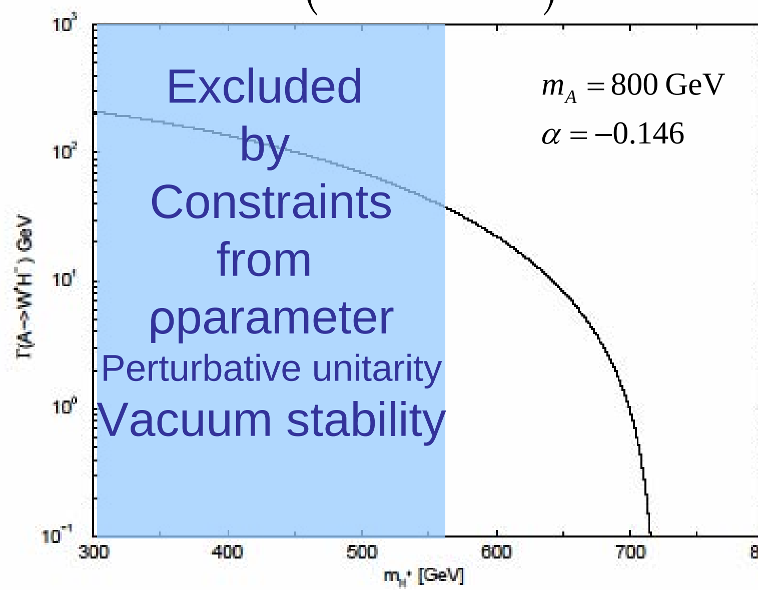
Partial decay width for $A \to W^{\pm}H^{\mp}$ can be large
and gives large contribution to <u>total decay width of A</u>
even if constraints from {ρ parameter, perturbative unitarity, vacuum stability} are considered.

$$\Gamma(A \to others) = 17.56\ \text{GeV}\,(\tan\beta = 1.5)$$
$$1.46\ \text{GeV}\,(\tan\beta = 7)$$
$$12.11\ \text{GeV}\,(\tan\beta = 30)$$
$$21.47\ \text{GeV}\,(\tan\beta = 40)$$

: allowed by ρ parameter
: allowed by theoretical constraints



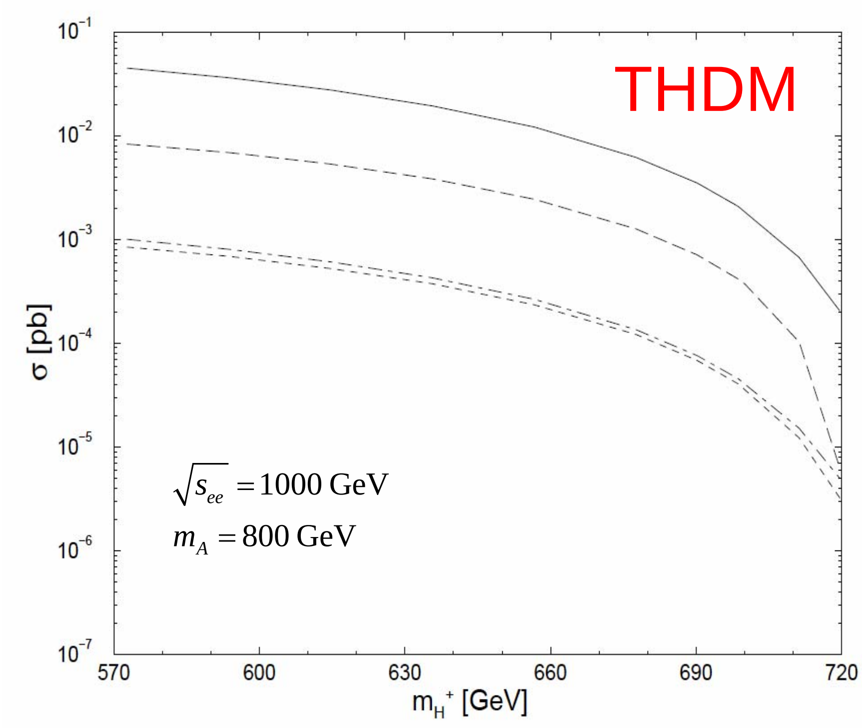
$\Gamma(A \to W^{\pm}H^{\mp})$

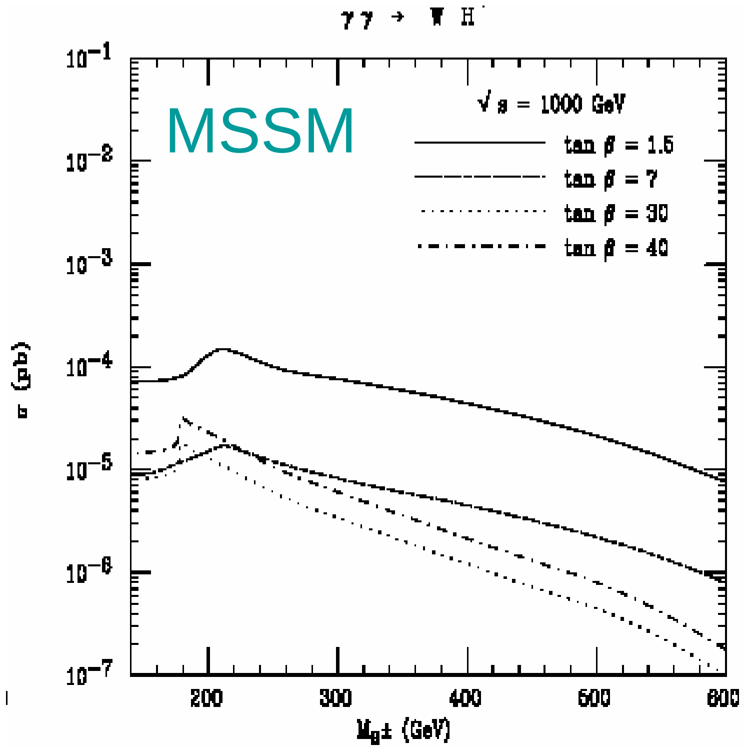


Resonant process

Non-Resonant process

$$\gamma\gamma \to A \to W^{\pm}H^{\mp}$$

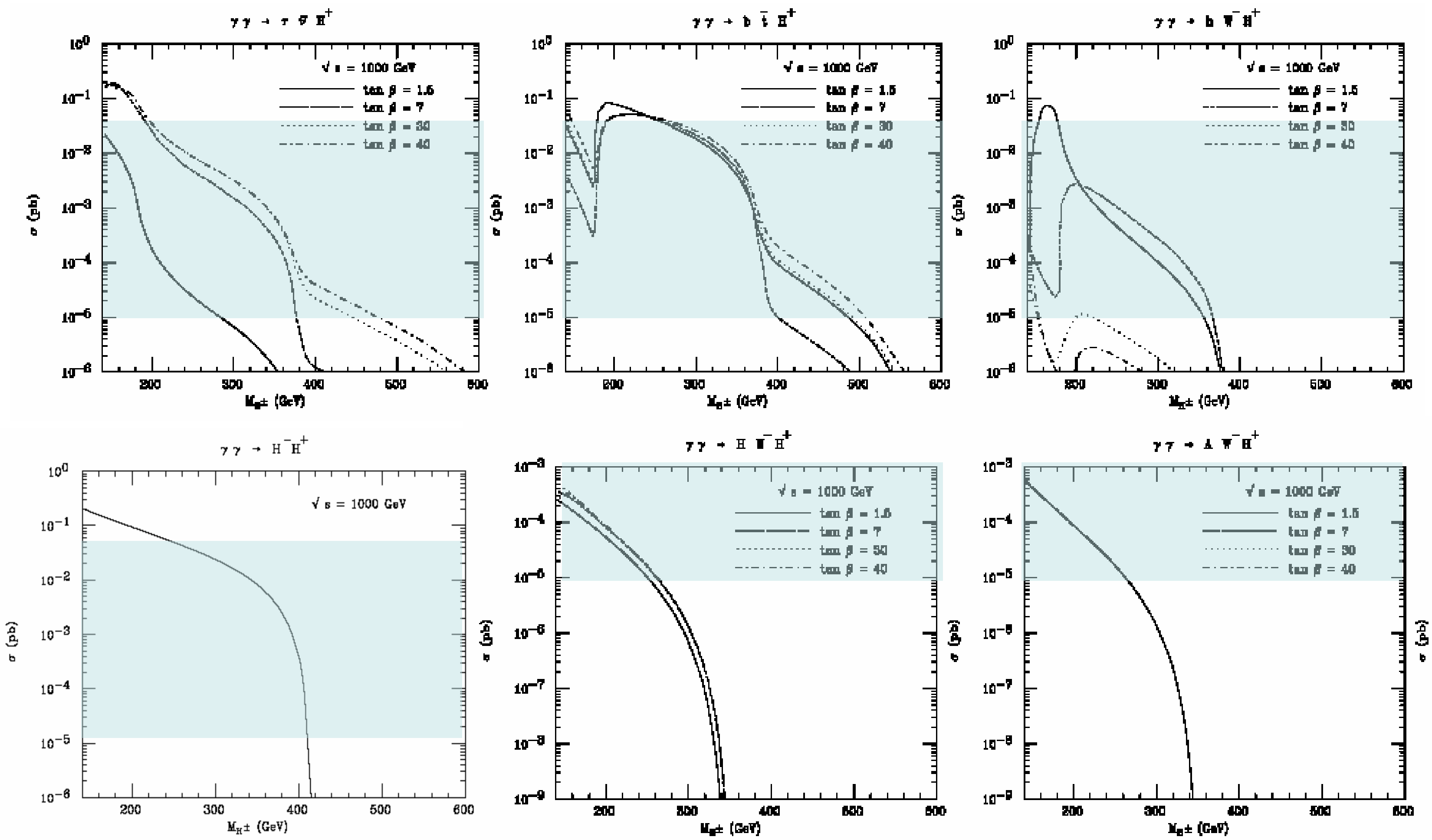




Moretti-Kanemura (02)

$$\sigma = \int d\sqrt{s}_{\gamma\gamma} \frac{1}{L_{ee}^{geom}} \frac{dL}{d\sqrt{s}_{\gamma\gamma}} \hat{\sigma}\left(\sqrt{s}_{\gamma\gamma}\right)$$

The cross section of $O(1)-O(10)$ fb ($O(10^{-3})-O(10^{-2})$ pb) is significant for charged Higgs production at PLC.

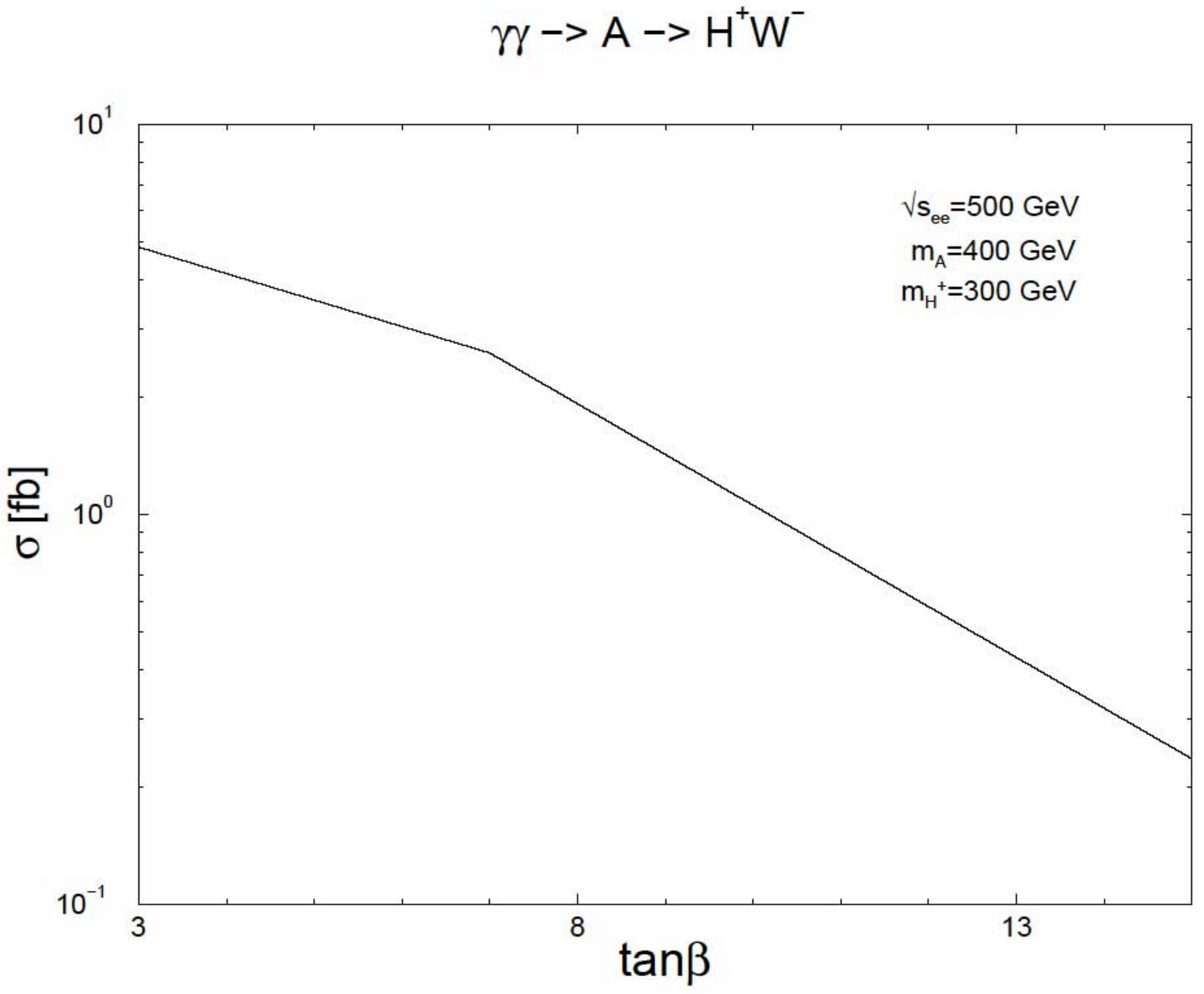


Moretti-Kanemura (02)

For $\sqrt{s}_{ee} = 500$ GeV,

Mass bound from b→sγ

$m_{H^{\pm}} \geq$ around 300 GeV



4. Summary

- $\text{Higgs}^{\text{heavy}} \to \text{Higgs}^{\text{heavy}}$ + X decay is possible in non-MSSM models. The decay modes are useful for distinguishing models and may affect Higgs detection strategy.

- We have studied the process $\gamma\gamma \to A \to W^{\pm}H^{\mp}$ in THDM.

- It has been shown that the cross section for $\gamma\gamma \to A \to W^{\pm}H^{\mp}$ can be significantly large for charged Higgs production at photon colliders.

Constraints from experimental aspects

ρ parameter: $\quad -0.0014 \leq \Delta\rho_{THDM} \leq +0.0023$

Constraints from theoretical aspects

Perturbative unitarity: |S-wave amplitudes| < 1/2

for

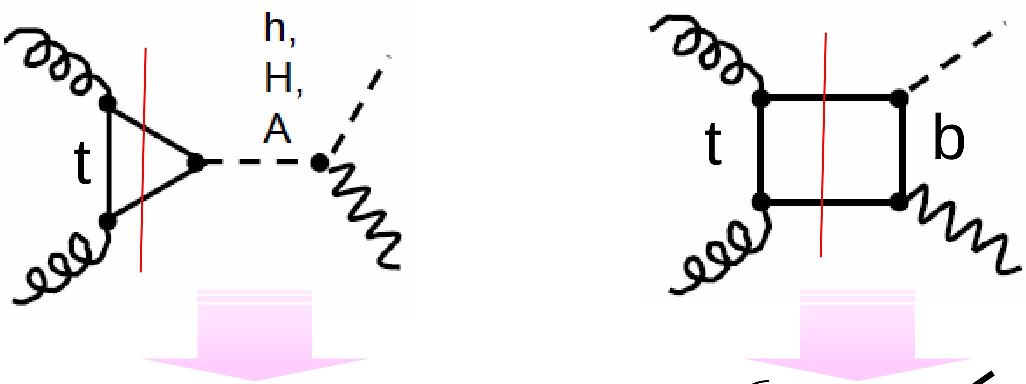
$$
\begin{aligned}
W_L^+ W_L^- &\to W_L^+ W_L^- \\
Z_L\, Z_L &\to Z_L\, Z_L \\
Z_L\, h &\to Z_L\, h \\
h\, h &\to h\, h \\
&\vdots
\end{aligned}
$$

Vacuum stability:

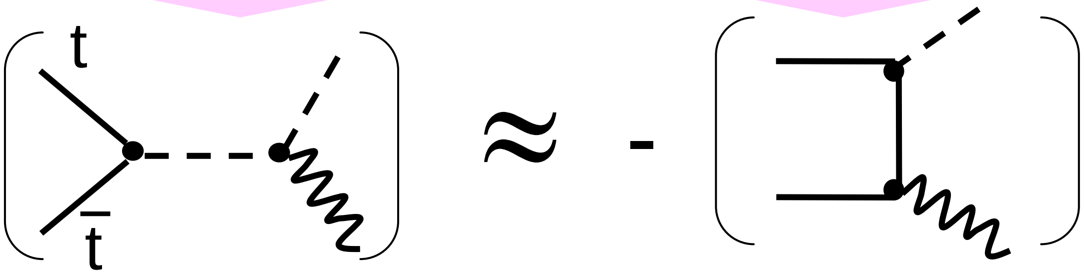
$$\lambda_1(\mu) > 0, \quad \lambda_2(\mu) > 0,$$

$$\sqrt{\lambda_1(\mu)\lambda_2(\mu)} + \lambda_3(\mu) + \min\left[0, \lambda_4(\mu) + \lambda_5(\mu), \lambda_4(\mu) - \lambda_5(\mu)\right] > 0$$

Dicus-Hewett-Kao-Rizzo (1989)



Sub-diagrams



$$m_{H,A} < m_{H^{\pm}} + m_W \leq \sqrt{s}$$

Gauge symmetry assures this cancellation
to satisfy unitarity at high energies.