El 2HDM tipo III y su impacto a los procesos $\gamma\gamma \to \phi_i\phi_j$.

J. Hernández-Sanchéz, C. G. Honorato, M. A. Pérez y J. J. Toscano.

En cuanto al modelo

- El potencial del modelo

$$
\begin{aligned}
V(\Phi_1, \Phi_2) \;=\; & \mu_1^2(\Phi_1^\dagger \Phi_1) + \mu_2^2(\Phi_2^\dagger \Phi_2) - \left(\mu_{12}^2(\Phi_1^\dagger \Phi_2) + \mathrm{H.c.}\right) + \frac{1}{2}\lambda_1(\Phi_1^\dagger \Phi_1)^2 + \frac{1}{2}\lambda_2(\Phi_2^\dagger \Phi_2)^2 + \lambda_3(\Phi_1^\dagger \Phi_1)(\Phi_2^\dagger \Phi_2) \\
& + \lambda_4(\Phi_1^\dagger \Phi_2)(\Phi_2^\dagger \Phi_1) + \left(\frac{1}{2}\lambda_5(\Phi_1^\dagger \Phi_2)^2 + \left(\lambda_6(\Phi_1^\dagger \Phi_1) + \lambda_7(\Phi_2^\dagger \Phi_2)\right)(\Phi_1^\dagger \Phi_2) + \mathrm{H.c.}\right),
\end{aligned}
$$

- Tendiendo un par de Higgses neutros *CP-even* (h, H), un neutro *CP-odd* (A) y un par de Higgses cargados.
- Después del rompimiento espontaneo de la simetría

Masas para los bosones de norma.

Como parámetros libres quedan:

M_h, M_H, M_A, M_H+, α y β

μ_{12}

λ_6 y λ_7

Sector de Yukawa

- El lagrangiano más general para este sector se puede escribir como sigue:

$$\begin{aligned}\mathcal{L} \quad = \quad & Y_1^u \bar{Q}'_L \widetilde{\Phi}_1 u'_R + Y_2^u \bar{Q}'_L \widetilde{\Phi}_2 u'_R + Y_1^d \bar{Q}'_L \Phi_1 d'_R + Y_2^d \bar{Q}'_L \Phi_2 d'_R \\ & + Y_1^l \bar{L}'_L \Phi_1 l'_R + Y_2^l \bar{L}'_L \Phi_2 l'_R + h.c.,\end{aligned}$$

- El modelo tipo I

$$\mathcal{L}^I = Y_2^u \bar{Q}'_L \widetilde{\Phi}_2 u'_R + Y_2^d \bar{Q}'_L \Phi_2 d'_R + Y_2^l \bar{L}'_L \Phi_2 l'_R + h.c.$$

$$u'_R, d'_R, l'_R \rightarrow -u'_R, -d'_R, -l'_R$$

- El modelo tipo II

$$\mathcal{L}^{II} = Y_2^u \bar{Q}'_L \widetilde{\Phi}_2 u'_R + Y_1^d \bar{Q}'_L \Phi_1 d'_R + Y_1^l \bar{L}'_L \Phi_1 l'_R + h.c.$$

$$u_R \rightarrow -u_R.$$

- El modelo tipo III

$$
\begin{aligned}
\mathcal{L} \;=\; & \frac{1}{\sqrt{2}}\Big\{\left[\bar{u}'_L(v_1 Y_1^u + v_2 Y_2^u)u'_R + \bar{d}'_L(v_1 Y_1^d + v_2 Y_2^d)d'_R + \bar{l}'_L(v_1 Y_1^l + v_2 Y_2^l)l'_R\right] \\
& + \bar{u}'_L(Y_1^u c_\alpha + Y_2^u s_\alpha)H u'_R + \bar{d}'_L(Y_1^d c_\alpha + Y_2^d s_\alpha)H d'_R + \bar{l}'_L(Y_1^l c_\alpha + Y_2^l s_\alpha)H l'_R \\
& + \bar{u}'_L(-Y_1^u s_\alpha + Y_2^u c_\alpha)h u'_R + \bar{d}'_L(-Y_1^d s_\alpha + Y_2^d c_\alpha)h d'_R + \bar{l}'_L(-Y_1^l s_\alpha + Y_2^l c_\alpha)h l'_R \\
& + i\bar{u}'_L(Y_1^u s_\beta - Y_2^u c_\beta)A u'_R + i\bar{d}'_L(-Y_1^d s_\beta + Y_2^d c_\beta)A d'_R + i\bar{l}'_L(-Y_1^l s_\beta + Y_2^l c_\beta)A l'_R \\
& + \bar{d}'_L(Y_1^u s_\beta - Y_2^u c_\beta)H^- u'_R + \bar{u}'_L(-Y_1^d s_\beta + Y_2^d c_\beta)H^+ d'_R + i\bar{\nu}'_L(-Y_1^l s_\beta + Y_2^l c_\beta)H^+ l'_R\Big\}
\end{aligned}
$$

Luego, la matriz de masa pude ser vista como

$$M_f = \frac{1}{\sqrt{2}}(v_1 Y_1^f + v_2 Y_2^f),$$

Después de diagonalizar la matriz de masa tenemos

$$\widetilde{M}_f = \frac{1}{\sqrt{2}}(v_1 \widetilde{Y}_1^f + v_2 \widetilde{Y}_2^f)$$

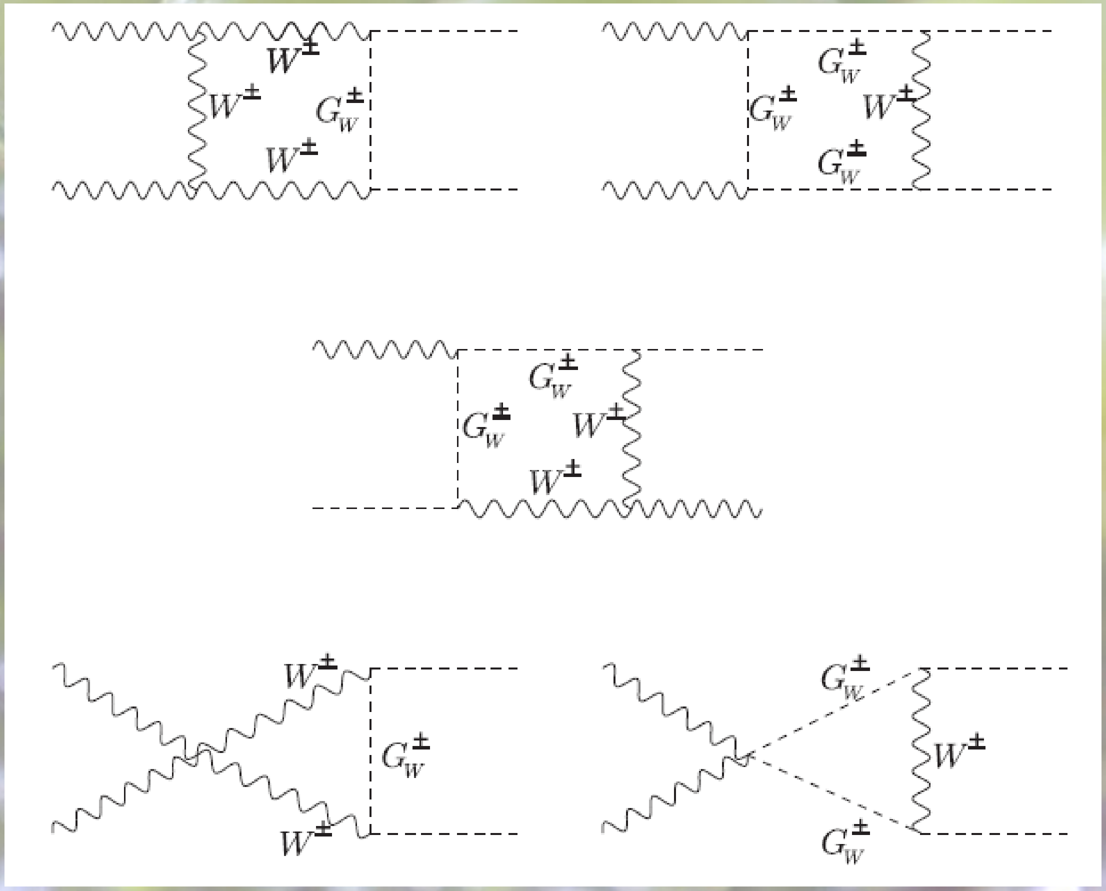
$$
\begin{aligned}
\widetilde{Y}_1^{l,d} &= \frac{\sqrt{2}}{v c_\beta}\widetilde{M}_{l,d} - t_\beta \widetilde{Y}_2^{l,d}, \\
\widetilde{Y}_2^{u} &= \frac{\sqrt{2}}{v s_\beta}\widetilde{M}_{u} - t_\beta^{-1} \widetilde{Y}_1^{u}.
\end{aligned}
$$

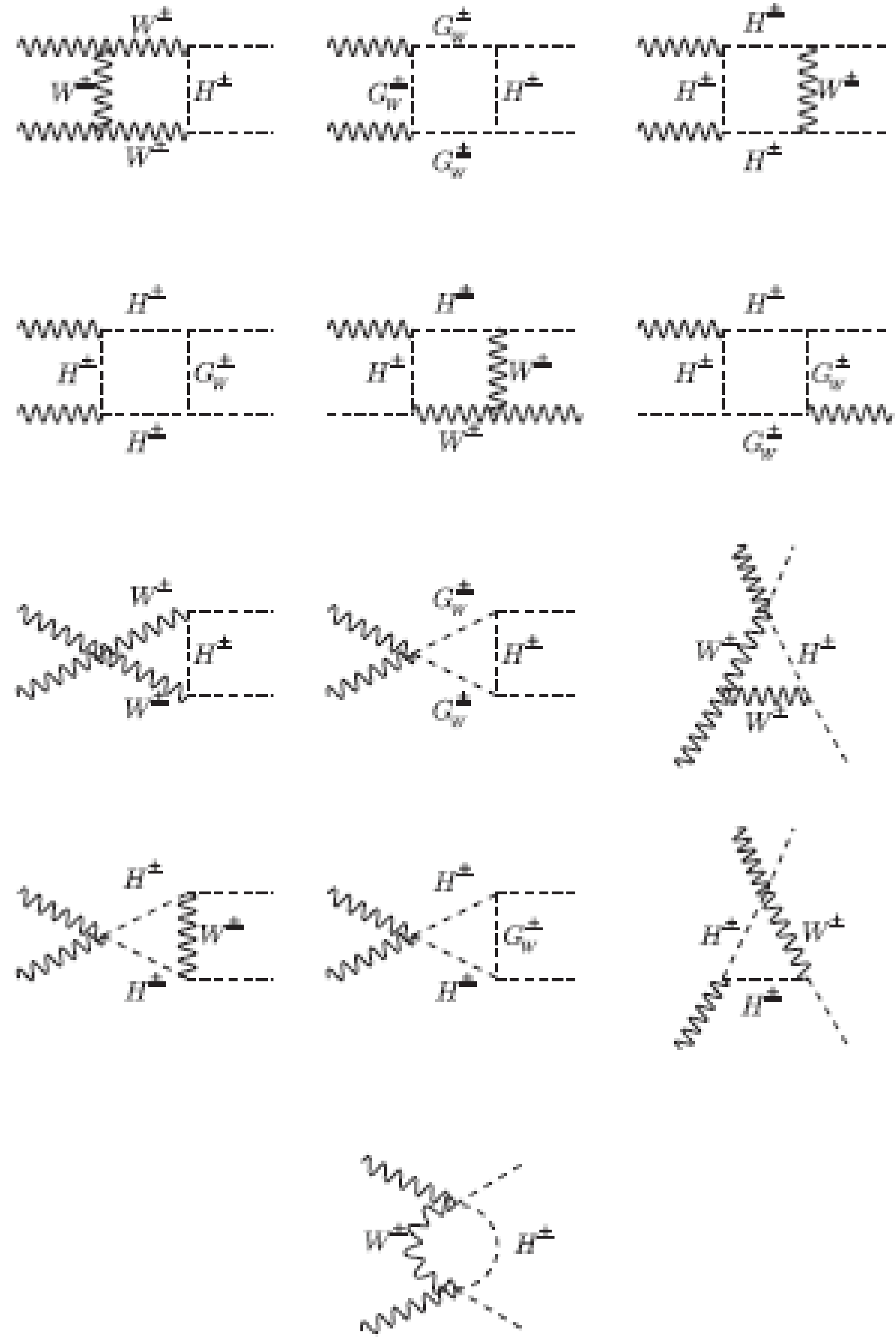
De esta manera, el lagrangiano relacionado con las corrientes neutras queda como sigue

$$
\begin{aligned}
\mathcal{L}^N \quad = \quad & m_{u_n}\bar{u}_n u_n + m_{d_n}\bar{d}_n d_n + m_{l_n}\bar{l}_n l_n \\
& + \frac{g}{2m_W}\Big\{ m_{u_n}\bar{u}_n\Big[\frac{s_\alpha}{s_\beta}\delta_{nm} - \frac{\sqrt{2}s_{\alpha-\beta}}{g s_\beta}\frac{m_W}{m_{u_n}}(\widetilde{Y}_1^u)_{nm}\Big]u_n H \\
& + m_{d_n}\bar{d}_n\Big[\frac{c_\alpha}{c_\beta}\delta_{nm} + \frac{\sqrt{2}s_{\alpha-\beta}}{g c_\beta}\frac{m_W}{m_{d_n}}(\widetilde{Y}_2^d)_{nm}\Big]d_n H \\
& + m_{l_n}\bar{l}_n\Big[\frac{c_\alpha}{c_\beta}\delta_{nm} + \frac{\sqrt{2}s_{\alpha-\beta}}{g c_\beta}\frac{m_W}{m_{l_n}}(\widetilde{Y}_2^l)_{nm}\Big]l_n H \\
& + m_{u_n}\bar{u}_n\Big[\frac{c_\alpha}{s_\beta}\delta_{nm} - \frac{\sqrt{2}c_{\alpha-\beta}}{g s_\beta}\frac{m_W}{m_{u_n}}(\widetilde{Y}_1^u)_{nm}\Big]u_n h \\
& + m_{d_n}\bar{d}_n\Big[-\frac{s_\alpha}{c_\beta}\delta_{nm} + \frac{\sqrt{2}c_{\alpha-\beta}}{g c_\beta}\frac{m_W}{m_{d_n}}(\widetilde{Y}_2^d)_{nm}\Big]d_n h \\
& + m_{l_n}\bar{l}_n\Big[-\frac{s_\alpha}{c_\beta}\delta_{nm} + \frac{\sqrt{2}c_{\alpha-\beta}}{g c_\beta}\frac{m_W}{m_{l_n}}(\widetilde{Y}_2^l)_{nm}\Big]l_n h \\
& + i m_{u_n}\bar{u}_n\Big[-t_\beta^{-1}\delta_{nm} + \frac{\sqrt{2}}{g s_\beta}\frac{m_W}{m_{u_n}}(\widetilde{Y}_1^u)_{nm}\Big]\gamma^5 u_n A \\
& + i m_{d_n}\bar{d}_n\Big[-t_\beta\delta_{nm} + \frac{\sqrt{2}}{g c_\beta}\frac{m_W}{m_{d_n}}(\widetilde{Y}_2^d)_{nm}\Big]\gamma^5 d_n A \\
& + i m_{l_n}\bar{l}_n\Big[-t_\beta\delta_{nm} + \frac{\sqrt{2}}{g c_\beta}\frac{m_W}{m_{l_n}}(\widetilde{Y}_2^l)_{nm}\Big]\gamma^5 l_n A + h.c.\Big\}.
\end{aligned}
$$

Los procesos $\gamma\gamma \to \phi_i\phi_j$.

Existen un conjunto de diagramas que resultan ser independientes del modelo, estos son:



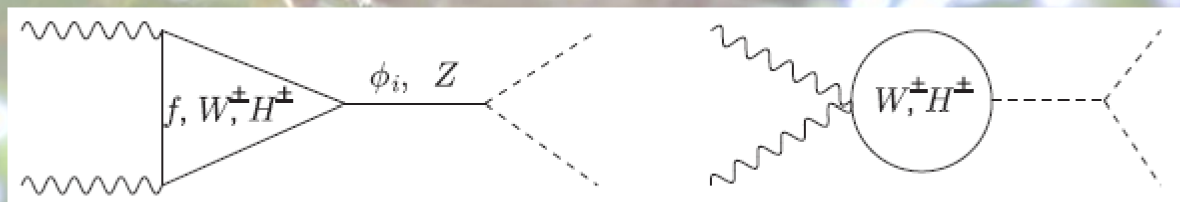


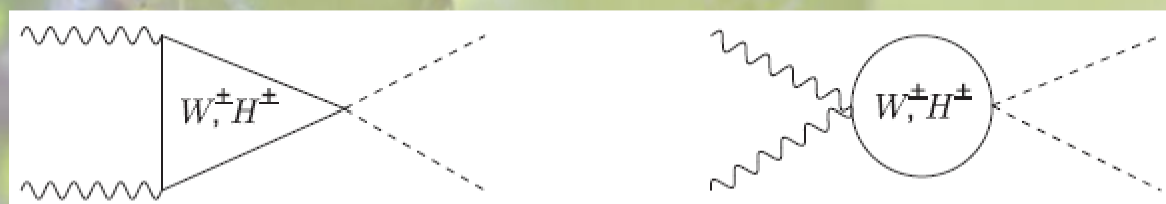
$W^{\pm}$
$W^{\pm}$
$H^{\pm}$
$W^{\pm}$
$G_w^{\pm}$
$G_w^{\pm}$
$H^{\pm}$
$G_w^{\pm}$
$H^{\pm}$
$H^{\pm}$
$W^{\pm}$
$H^{\pm}$
$H^{\pm}$
$H^{\pm}$
$G_w^{\pm}$
$H^{\pm}$
$H^{\pm}$
$H^{\pm}$
$W^{\pm}$
$W^{\pm}$
$H^{\pm}$
$H^{\pm}$
$G_w^{\pm}$
$G_w^{\pm}$
$W^{\pm}$
$H^{\pm}$
$W^{\pm}$
$G_w^{\pm}$
$H^{\pm}$
$G_w^{\pm}$
$W^{\pm}$
$H^{\pm}$
$W^{\pm}$
$H^{\pm}$
$W^{\pm}$
$H^{\pm}$
$H^{\pm}$
$G_w^{\pm}$
$H^{\pm}$
$H^{\pm}$
$W^{\pm}$
$H^{\pm}$
$W^{\pm}$
$H^{\pm}$

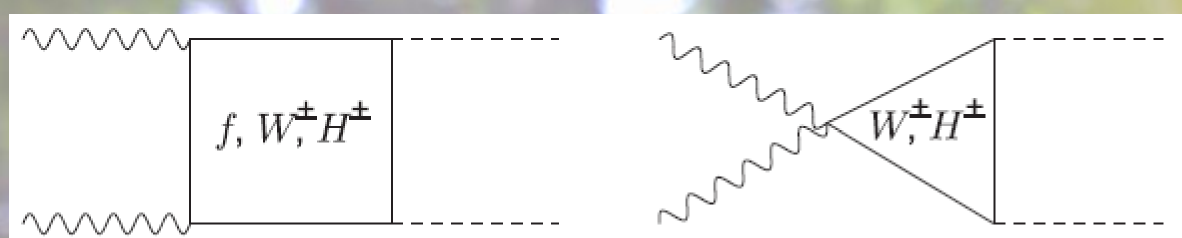
- Estos diagramas son independientes del tipo de modelo.
- Pero tiene una fuerte dependencia con respecto a la elección de la norma.
- Una norma covariante de tipo renormalizable permite eliminar

$WG_{W\gamma}$ $HWG_{W\gamma}$ $hWG_{W\gamma}$

- Los siguientes diagramas dependen tanto del sector de norma, como de los de Higgs y Yukawa.





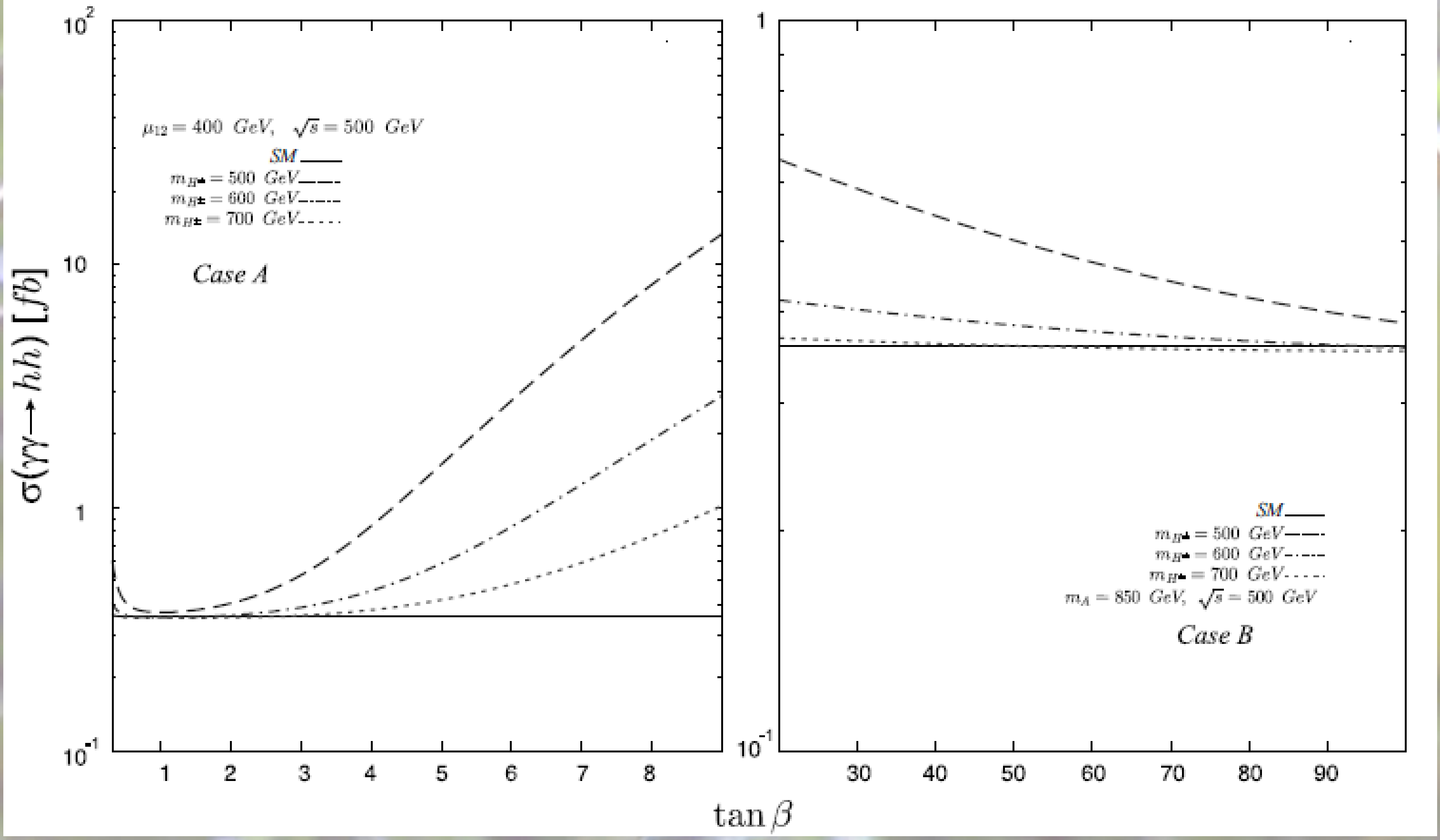


Autoacoplamientos de Higgs y acoplamientos de Yukawa.

Factor	
g_{hhh}	$\frac{3m_h^2(c_{\beta-3\alpha}+3c_{\beta-\alpha})}{m_W^2 s_{2\beta}} - \frac{24\mu_{12}^2 c_{\beta+\alpha}c_{\beta-\alpha}^2}{m_W^2 s_{2\beta}^2} + \frac{12\lambda_6 c_{\beta-\alpha}^3}{g^2 s_\beta^2} - \frac{12\lambda_7 c_{\beta-\alpha}^3}{g^2 c_\beta^2}$
g_{HHH}	$\frac{3m_H^2(s_{\beta-3\alpha}+3s_{\beta+\alpha})}{m_W^2 s_{2\beta}} - \frac{24\mu_{12}^2 s_{\beta+\alpha}s_{\beta-\alpha}^2}{m_W^2 s_{2\beta}^2} - \frac{12\lambda_6 s_{\beta-\alpha}^3}{g^2 s_\beta^2} + \frac{12\lambda_7 s_{\beta-\alpha}^3}{g^2 c_\beta^2}$
g_{hhH}	$\frac{-2(2m_h^2+m_H^2)c_{\beta-\alpha}s_{2\alpha}}{m_W^2 s_{2\beta}} - \frac{2\mu_{12}^2(s_{3\beta-\alpha}+3s_{\beta-3\alpha}-2s_{\beta+\alpha})}{m_W^2 s_{2\beta}^2} - \frac{12\lambda_6 c_{\beta-\alpha}^2 s_{\beta-\alpha}}{g^2 s_\beta^2} + \frac{12\lambda_7 c_{\beta-\alpha}^2 s_{\beta-\alpha}}{g^2 c_\beta^2}$
g_{HHh}	$\frac{-2(m_h^2+2m_H^2)s_{\beta-\alpha}s_{2\alpha}}{m_W^2 s_{2\beta}} - \frac{2\mu_{12}^2(c_{3\beta-\alpha}-3c_{\beta-3\alpha}+2c_{\beta+\alpha})}{m_W^2 s_{2\beta}^2} + \frac{12\lambda_6 c_{\beta-\alpha}s_{\beta-\alpha}^2}{g^2 s_\beta^2} - \frac{12\lambda_7 c_{\beta-\alpha}s_{\beta-\alpha}^2}{g^2 c_\beta^2}$
g_{hAA}	$\frac{4s_{2\beta}s_{\beta-\alpha}m_A^2+(c_{3\beta-\alpha}+3c_{\beta+\alpha})m_h^2}{m_W^2 s_{2\beta}} - \frac{8\mu_{12}^2 c_{\beta+\alpha}}{m_W^2 s_{2\beta}^2} + \frac{4\lambda_6 c_{\beta-\alpha}}{g^2 s_\beta^2} - \frac{4\lambda_7 c_{\beta-\alpha}}{g^2 c_\beta^2}$
g_{HAA}	$\frac{4s_{2\beta}c_{\beta-\alpha}m_A^2+(-s_{3\beta-\alpha}+3s_{\beta+\alpha})m_H^2}{m_W^2 s_{2\beta}} - \frac{8\mu_{12}^2 s_{\beta+\alpha}}{m_W^2 s_{2\beta}^2} - \frac{4\lambda_6 s_{\beta-\alpha}}{g^2 s_\beta^2} + \frac{4\lambda_7 s_{\beta-\alpha}}{g^2 c_\beta^2}$
$g_{hH^\pm H^\mp}$	$\frac{4s_{\beta-\alpha}m_{H^\pm}^2}{m_W^2} + \frac{(c_{3\beta-\alpha}+3c_{\beta+\alpha})m_h^2}{m_W^2 s_{2\beta}} - \frac{8\mu_{12}^2 c_{\beta+\alpha}}{m_W^2 s_{2\beta}^2} + \frac{4\lambda_6 c_{\beta-\alpha}}{g^2 s_\beta^2} - \frac{4\lambda_7 c_{\beta-\alpha}}{g^2 c_\beta^2}$
$g_{HH^\pm H^\mp}$	$\frac{4c_{\beta-\alpha}m_{H^\pm}^2}{m_W^2} + \frac{(-s_{3\beta-\alpha}+3s_{\beta+\alpha})m_H^2}{m_W^2 s_{2\beta}} - \frac{8\mu_{12}^2 s_{\beta+\alpha}}{m_W^2 s_{2\beta}^2} - \frac{4\lambda_6 s_{\beta-\alpha}}{g^2 s_\beta^2} + \frac{4\lambda_7 s_{\beta-\alpha}}{g^2 c_\beta^2}$

Factor	Type-I	Type-II	Type-III
g_{hll}, g_{hdd}	$\frac{c_\alpha}{s_\beta}$	$\frac{-s_\alpha}{c_\beta}$	$\frac{-s_\alpha}{c_\beta} + \frac{\sqrt{2}c_{\alpha-\beta}m_W}{gvc_\beta}\lambda_{dd}^2$
g_{huu}	$\frac{c_\alpha}{s_\beta}$	$\frac{c_\alpha}{s_\beta}$	$\frac{c_\alpha}{s_\beta} - \frac{\sqrt{2}c_{\alpha-\beta}m_W}{gvs_\beta}\lambda_{uu}^1$
g_{Hll},g_{Hdd}	$\frac{s_\alpha}{s_\beta}$	$\frac{c_\alpha}{c_\beta}$	$\frac{c_\alpha}{c_\beta} + \frac{\sqrt{2}s_{\alpha-\beta}m_W}{gvc_\beta}\lambda_{dd}^2$
g_{Huu}	$\frac{s_\alpha}{s_\beta}$	$\frac{s_\alpha}{s_\beta}$	$\frac{s_\alpha}{s_\beta} - \frac{\sqrt{2}s_{\alpha-\beta}m_W}{gvs_\beta}\lambda_{uu}^1$
g_{All},g_{Add}	t_β^{-1}	$-t_\beta$	$-t_\beta + \frac{\sqrt{2}m_W}{gvc_\beta}\lambda_{dd}^2$
g_{Auu}	$-t_\beta^{-1}$	$-t_\beta^{-1}$	$-t_\beta^{-1} + \frac{\sqrt{2}m_W}{gvc_\beta}\lambda_{uu}^1$

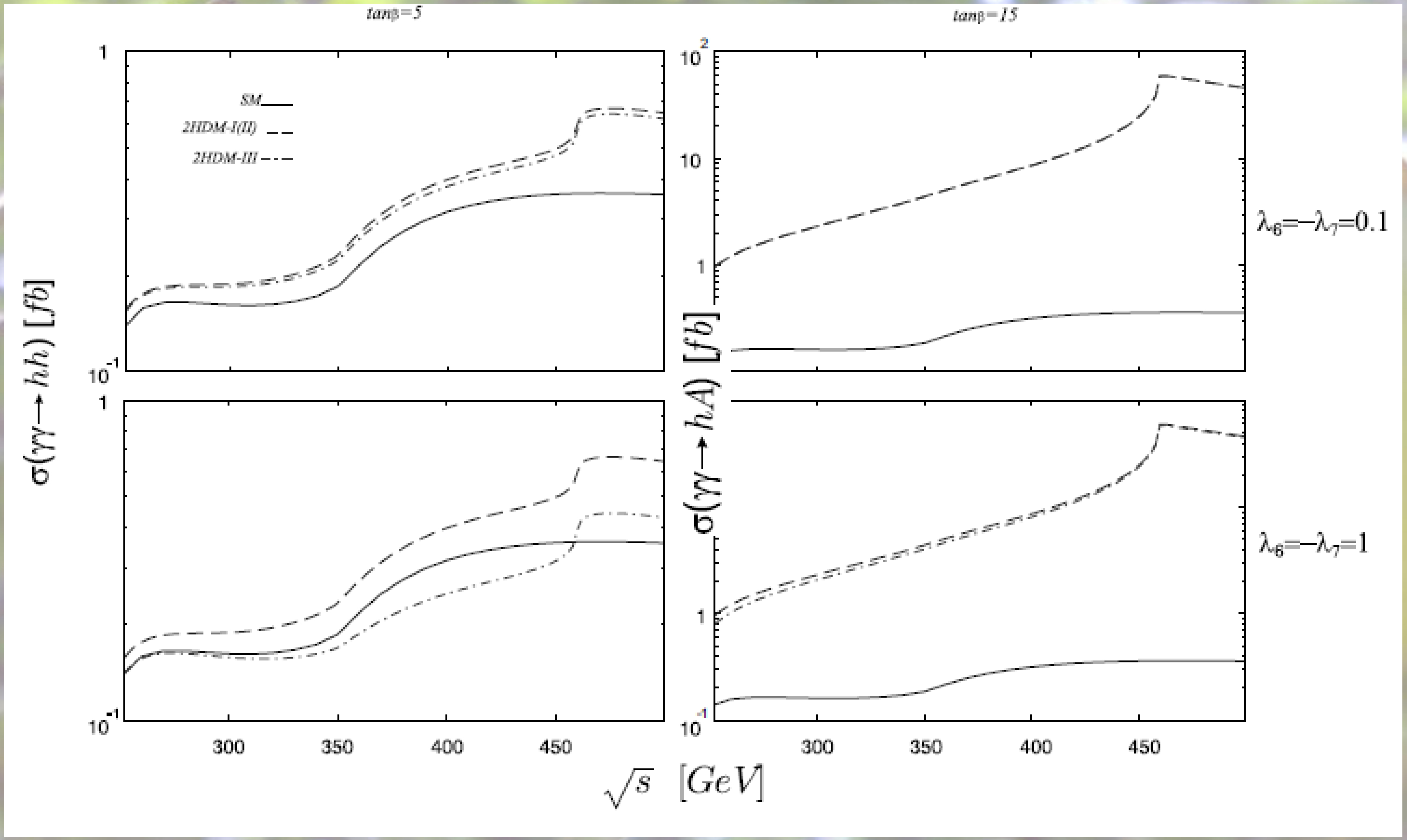
Límite de desacoplo



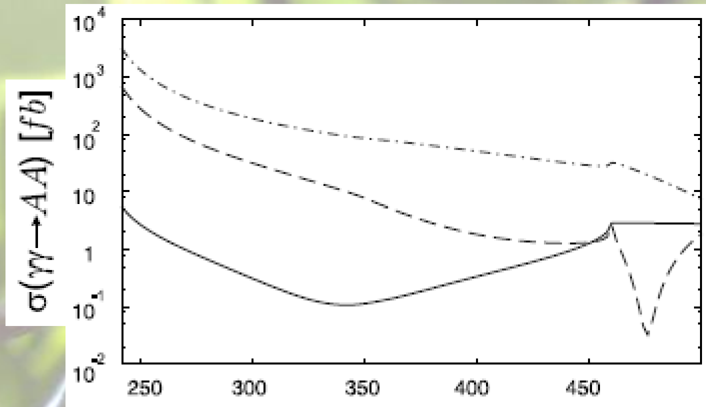
Case A $m_h = 120\ GeV$, $\alpha = \beta - \pi/2$, $\lambda_6 = \lambda_7 = 0$, $\mu_{12}^2 >> v^2$, and $m_H^+ >> m_h$.

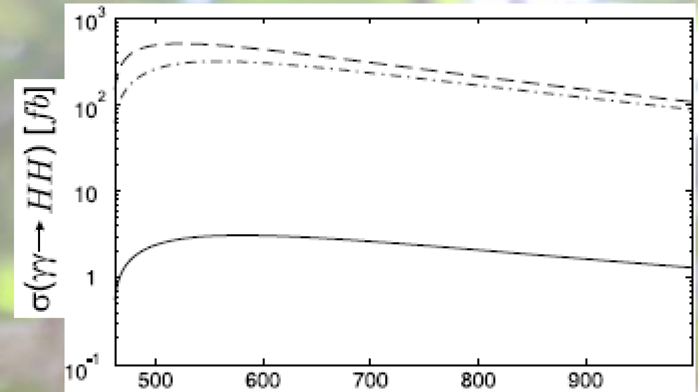
Case B $m_h = 120\ GeV$, $\alpha = \beta - \pi/2$, $\lambda_6 = -\lambda_7 = 0.1$, $\mu_{12}^2 \sim v^2$, and $m_H^+ >> m_h$.

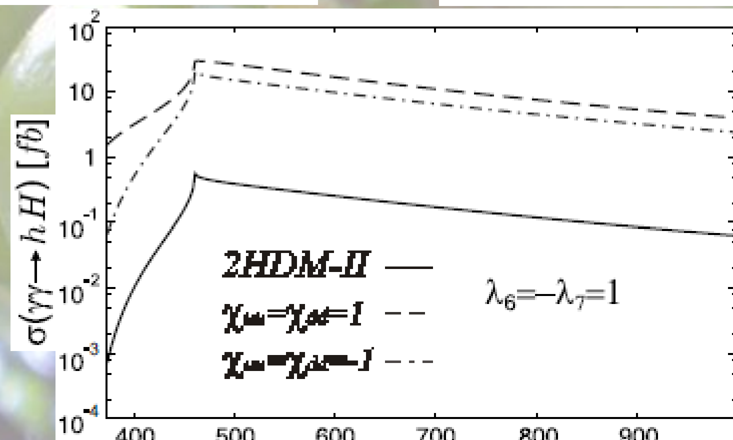
SM-like

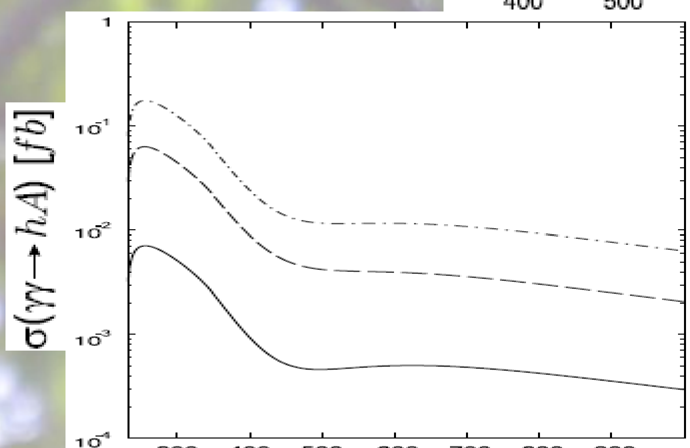


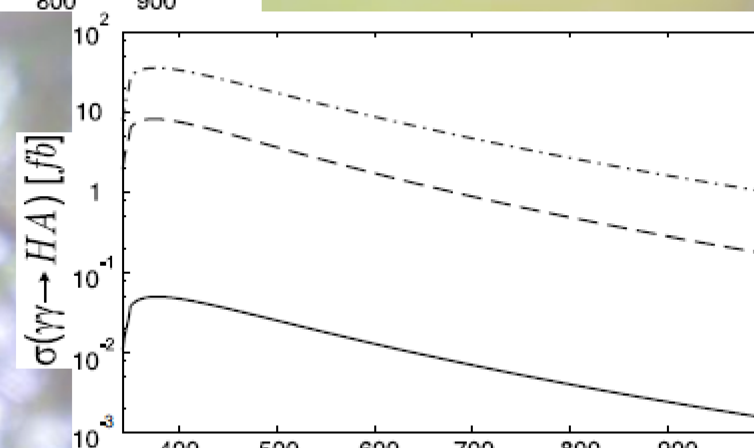
$m_h = 120$ GeV, $m_A = 110$ GeV, $\mu_{12} = 130$ GeV, $m_{H^\pm} \sim m_H \sim m_A + m_h$ GeV





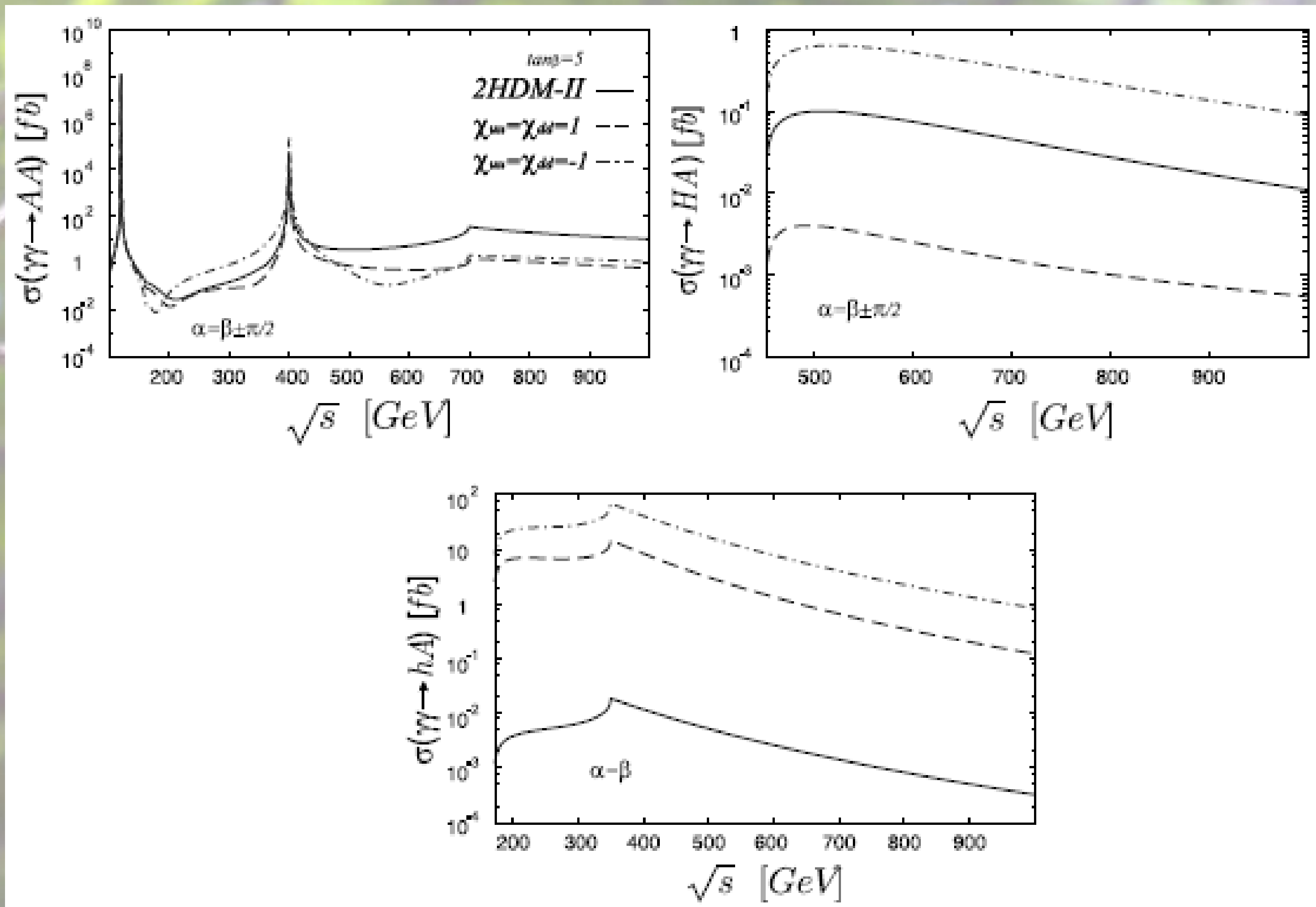






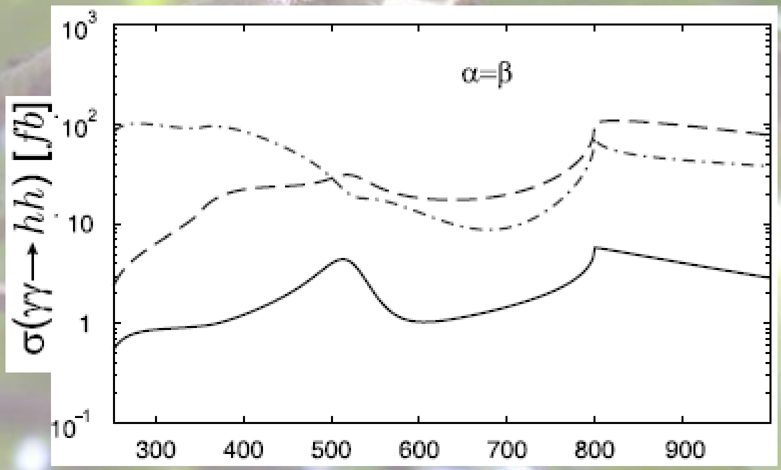
$m_h = 120$ GeV, $m_A = 110$ GeV, $\mu_{12} = 130$ GeV, $m_{H^\pm} \sim m_H \sim m_A + m_h$ GeV

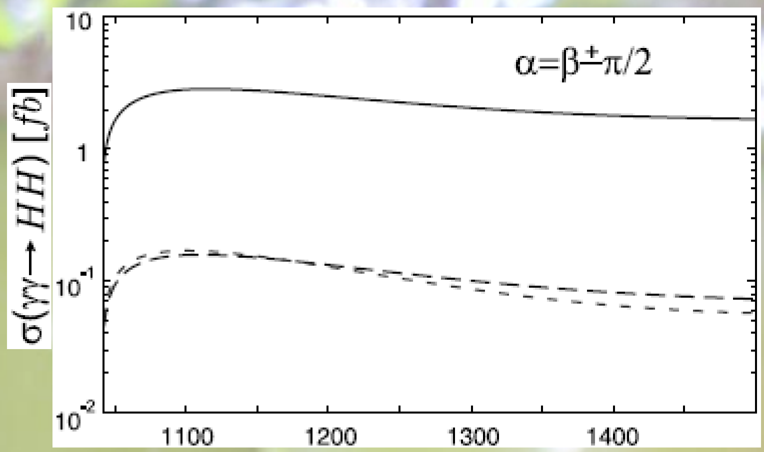
Caso general A-ligero

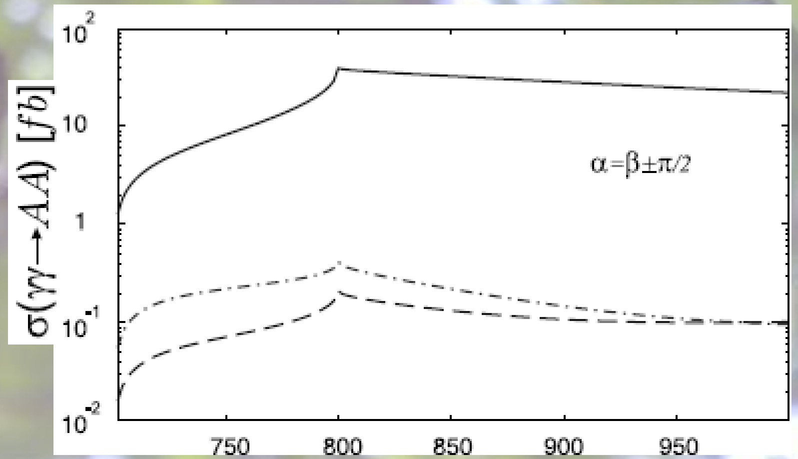


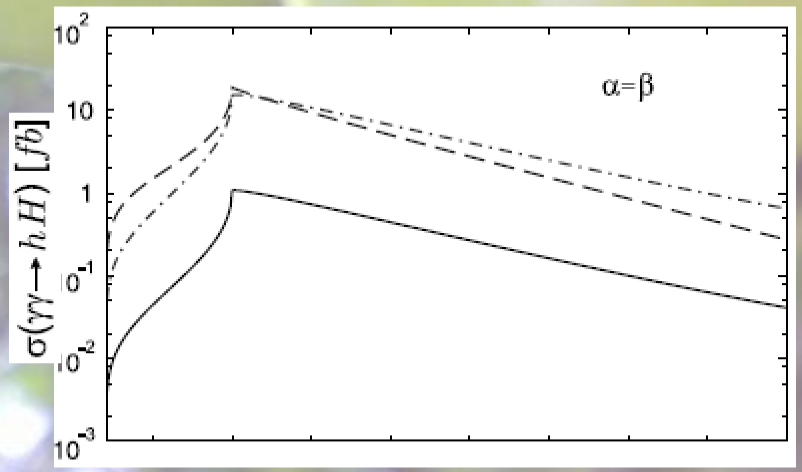
$m_A = 50$ GeV, $m_h = 120$ GeV, $m_{H^\pm} = 350$ GeV, $m_H = 400$ GeV, and $\mu_{12} = 70$ GeV

Caso General

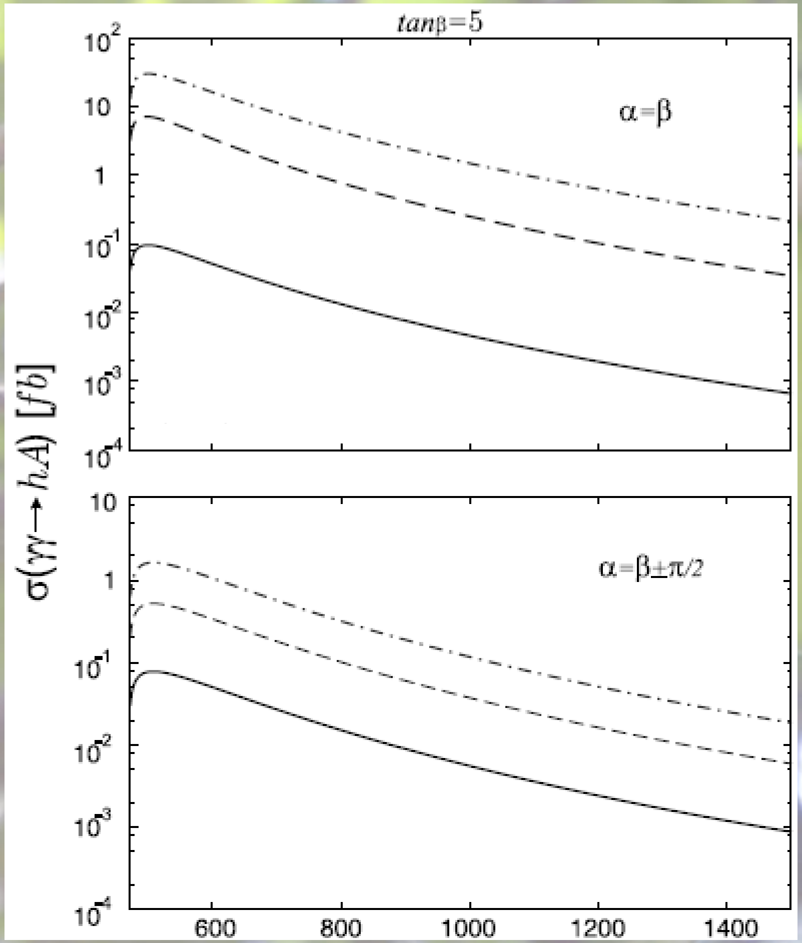


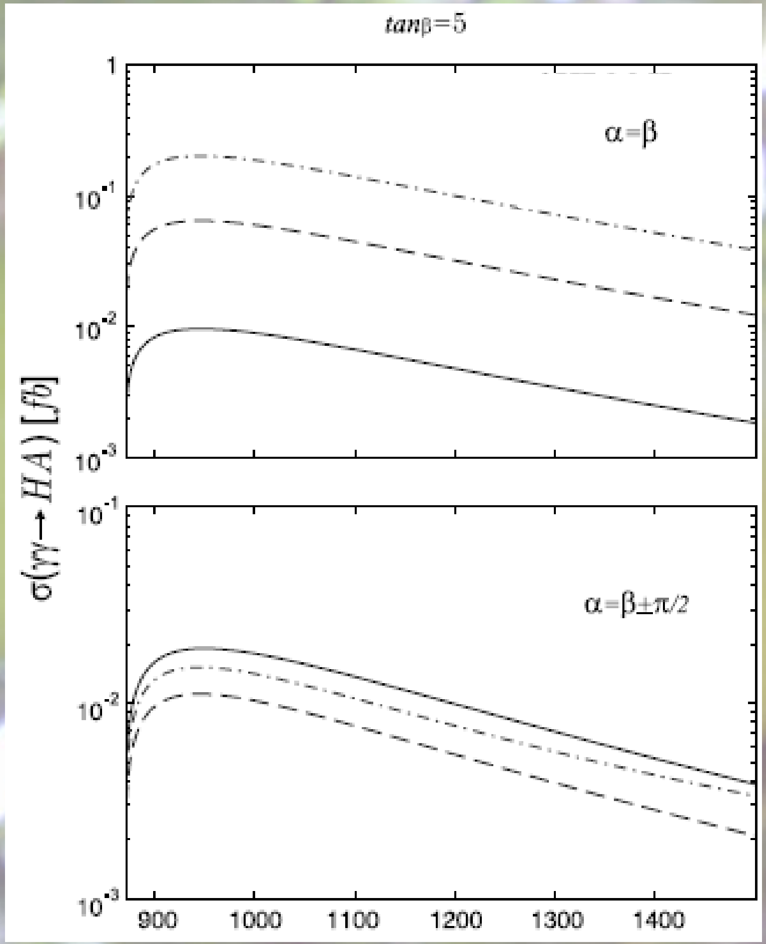






$m_{H^\pm} = 400$ GeV, $m_A = 350$ GeV, $M_H = 520$ GeV, $\mu_{12} = 120$ GeV, and $m_h = 120$ GeV


tanβ=5
σ(γγ→hA) [fb]
α=β
α=β±π/2
10²
10
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
600
800
1000
1200
1400


tanβ=5
σ(γγ→HA) [fb]
α=β
α=β±π/2
1
10⁻¹
10⁻²
10⁻³
900
1000
1100
1200
1300
1400

Conclusiones

- El considerar un modelo 2HDM-III permite el utilizar el potencial completo.
- El impacto de los parámetros propios del modelo tipo III producen importes realces a las secciones eficaces.
- El modelo tipo III permite observar el desacoplo del modelo mediante el parámetro *tan* β.