Diphoton excess in extended Higgs models

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Based on JHEP 1204 ’12 , PRD84 ’11 , PRD85’12 in collaboration with

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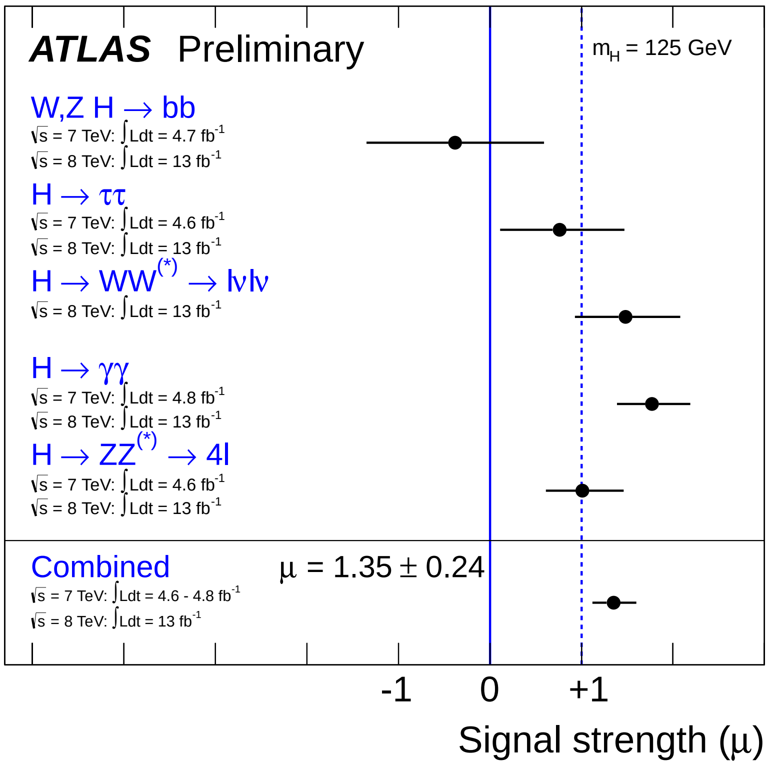
Outlines

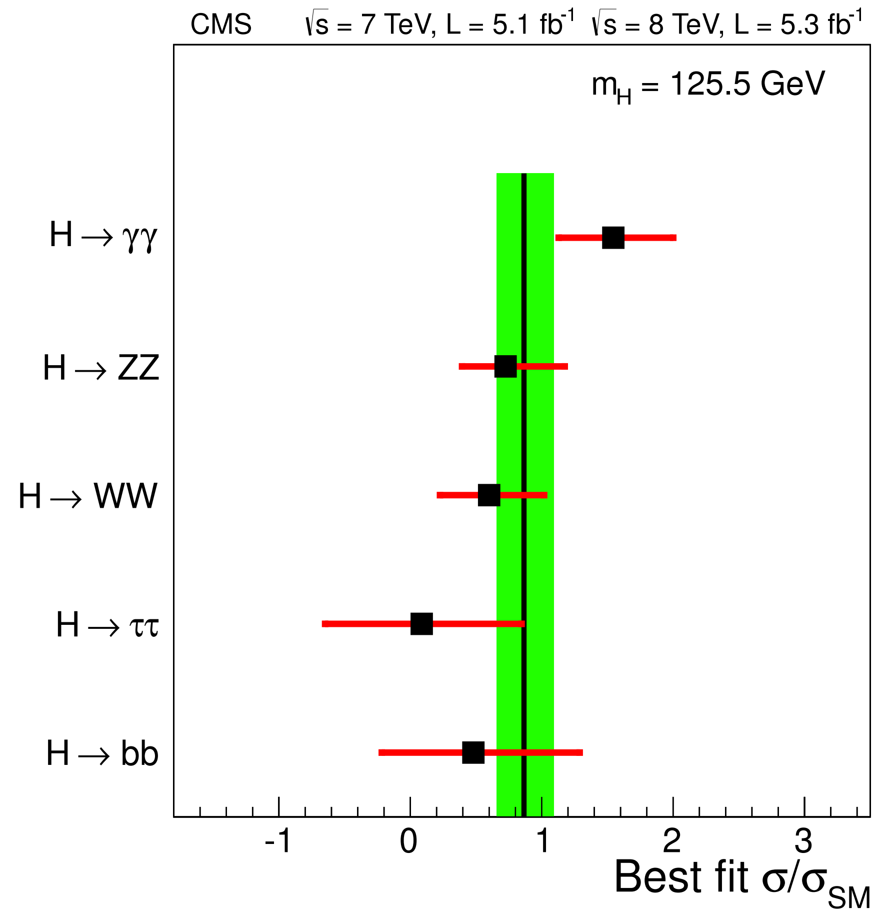
- Introduction and Motivations
- $h \to \gamma\gamma$ in the Higgs Triplet Model (HTM)
- $h \to \gamma\gamma$ vs $h \to Z\gamma$ in the Inert Higgs Doublet Model
- $h \to \gamma\gamma$, $h \to Z\gamma$ and $h \to b\bar{b}$ in the decoupling limit of the 2HDM
- Conclusions

Introduction: (Haber, Djouadi,Tanaka)

- After many years of investigations, a new boson was discovered on 4th July 2012 by ATLAS and CMS at CERN. [ATLAS PLB716'12 ; CMS PLB716'12]
- Both ATLAS and CMS reported a *clear excess in the two photon channel and in the ZZ^* channel*.
  The discovery is also confirmed, with less significance, in WW^* channel and also by Tevatron results.
- Since it decay to 2 photons, a boson with spin-1 is excluded, it is either spin-0 or spin-2.
- From 4-lepton and diphoton channels, both ATLAS and CMS updated their studies on spin and parity and a CP-even spin-0 state $J^P = 0^+$ seems to be preferred.
  CP-odd 0^- excluded with 96% ; 2^+ excluded with 91%
  ATLAS-CONF-2012-169 ; CMS-PAS-HIG-12-041

From experiments





The signal strength is consistent with the SM

$h \to \gamma\gamma$: ATLAS updates

- At ATLAS, $h \to \gamma\gamma$ with 7 and 8 TeV: a local significance of 6.1 standard deviations with $m_H = 126.5$ GeV [ATLAS-CONF-2012-170 (combined) and ATLAS-CONF-2012-168 ($H \to \gamma\gamma$)]
- CMS finds less, a local significance of 4.1 standard deviations with $m_H \approx 125$ GeV. [hep-ex/1207.7235]
- The best-fit signal strength for a SM Higgs boson mass hypothesis of ≈ 126 GeV is

$$\frac{\sigma}{\sigma_{SM}} = 1.8 \pm 0.5 \ \ (ATLAS)$$

- CMS limit on $h \to \gamma Z$; [CMS-HIG-12-049]

$$\frac{\sigma}{\sigma_{SM}} < 10 - 28$$

Motivations for Higgs Triplet (E.J. Chun)

- Neutrino masses: Type I , II , III seesaw models; Hybrid seesaw (I+III) ; Left-Right symmetric models (I+II) [Minkowski'77, Mohapatra, Senjanović'79,Yanagida'79, Glashow'79, Gell-Mann, Ramond, Slansky'79]; [Magg, Wetterich'80,Lazarides, Shafi, Wetterich '81, Mohapatra];[Foot, Lew, He, Joshi'89]; [Ma'98,B. Bajc and G. Senjanović'06, Fileviez Pérez'07]; [Mohapatra, Pati'75, Senjanović, Mohapatra'75]
- Real triplet $Y = 0$ Could be a candidate for dark matter M. Cirelli, N. Fornengo and A. Strumia, NPB 753(2006); M. Cirelli et al NPB 787(2007) ; F. Perez, Pavel et al. Phys.Rev. D79 (2009)

Motivations:

$$\mathcal{L}_{\rm Yukawa} \supset -Y_\nu L^T C \otimes i\sigma^2 \Delta L + {\rm h.c.} \Rightarrow m_\nu = Y_\nu v_\Delta$$

$$V(\Delta, H) = M_\Delta^2 Tr(\Delta^\dagger \Delta) + \mu(H^T i\tau_2 \Delta^\dagger H) \ ,$$

seesaw relation : $\boxed{m_\nu = Y_\nu \mu v_d^2 / M_\Delta^2}$

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- If $m_\nu \approx 1$ eV with $Y_\nu \approx 1$, then $M_\Delta \approx \mu \approx 10^{14-15}$ GeV not testable at the LHC
- If $m_\nu \approx 1$ eV and $M_\Delta \approx 1$ TeV , $Y_\nu \mu \approx 10^{-8}$ GeV
- small μ can be viewed as soft breaking term of lepton number

Higgs Triplet Model HTM

It consists of standard Higgs weak doublet H and a scalar field Δ transforming as a triplet under $SU(2)_L$ with $Y_\Delta = 2$
$H \sim (1,2,1)$ and $\Delta \sim (1,3,2)$ under $SU(3)_c \times SU(2)_L \times U(1)_Y$

$$\Delta = \begin{pmatrix} \delta^+/\sqrt{2} & \delta^{++} \\ \delta^0 & -\delta^+/\sqrt{2} \end{pmatrix} \quad \text{and} \quad H = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$$

$$\mathcal{L} = (D_\mu H)^\dagger (D^\mu H) + Tr(D_\mu \Delta)^\dagger (D^\mu \Delta) - V(H,\Delta) + \mathcal{L}_{\rm Yukawa}$$

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The most general renormalizable potential is:

$$V = M_\Delta^2 Tr\Delta^\dagger\Delta - m_H^2 H^\dagger H + \frac{\lambda}{4}(H^\dagger H)^2 + \lambda_1 (H^\dagger H) Tr(\Delta^\dagger \Delta)$$
$$+\lambda_2 (Tr\Delta^\dagger\Delta)^2 + \lambda_3 Tr(\Delta^\dagger\Delta)^2 + \lambda_4 H^\dagger \Delta\Delta^\dagger H + \mu H^T i\tau_2 \Delta^\dagger H + h$$

- The inclusion of the μ term eliminates the Majoron.

Electroweak symmetry breaking

$$\Delta = \begin{pmatrix} 0 & 0 \\ v_\Delta & 0 \end{pmatrix} \quad \text{and} \quad H = \begin{pmatrix} 0 \\ v_d \end{pmatrix}$$

one finds after minimization of the potential:

$$M_\Delta^2 = \frac{2\mu v_d^2 - \sqrt{2}(\lambda_1+\lambda_4)v_d^2 v_\Delta - 2\sqrt{2}(\lambda_2+\lambda_3)v_\Delta^3}{2\sqrt{2}v_\Delta}$$

$$m_H^2 = \frac{\lambda v_d^2}{4} - \sqrt{2}\mu v_\Delta + \frac{(\lambda_1+\lambda_4)}{2}v_\Delta^2$$

- After EWSB: 2 CP-even, h, H, one CP-odd A, a pair of $H^\pm$ and a pair of doubly charged Higgs $H^{\pm\pm}$
- 10-3 independents parameters: 5 masses, μ and v_Δ or λ , $\lambda_{1,2,3,4}$, μ and v_Δ

Doublet-Triplet mixing

- $H^{\pm\pm}$ is a pure triplet
- $H^{\pm}$ and A are dominated by the triplet δ fields,
  the mixing is small: $v_\Delta/v \le 0.03$
- h and H are mixtures of doublet ϕ and triplet δ fields,

$$\tan 2\alpha = \frac{2\mathcal{M}_{12}^2}{\mathcal{M}_{11}^2 - \mathcal{M}_{22}^2} \approx v_\Delta/v$$

maximal mixing is possible for $\mathcal{M}_{11}^2 = \mathcal{M}_{22}^2$
(when h and H are close to degenerate)

[A. Akeroyd and C.W.Chiang PRD'10]

[P. Dey, A.Kundu and B.Mukhopadhyaya, J.Phys'09]

Constraint from EWPO on triplet vev

$$M_Z^2 = \frac{(g^2+g'^2)(v_d^2+4v_\Delta^2)}{4} = \frac{g^2(v_d^2+4v_\Delta^2)}{4\cos^2\theta_W}$$

$$M_W^2 = \frac{g^2(v_d^2+2v_\Delta^2)}{4}$$

hence the modified form of the ρ parameter:

$$\rho_0 = \frac{M_W^2}{c_W^2 M_Z^2} = \frac{v_d^2+2v_\Delta^2}{v_d^2+4v_\Delta^2} \simeq 1 - 2\frac{v_\Delta^2}{v_d^2} \approx 1+\delta\rho$$

At the 2 σ level, $\rho_0 = 1.0004^{+0.0029}_{-0.0011}$ (or $\rho_0 = 1.0008^{+0.0017}_{-0.0010}$), one gets an upper bound on $v_\Delta \leq 2.5$–4.6 GeV.

- 1-loop analysis is done: [S. Kanemura, K.Yagyu PRD85'2012] Similar conclusions

Spectrum and constraints on μ

Absence of tachyonic modes:

$$m_A^2 = \frac{\mu(v_d^2 + 4v_\Delta^2)}{\sqrt{2}v_\Delta} \Rightarrow \mu > 0$$

$$m_{H^{\pm\pm}}^2 = \frac{\sqrt{2}\mu v_d^2 - \lambda_4 v_d^2 v_\Delta - 2\lambda_3 v_\Delta^3}{2v_\Delta} \Rightarrow \mu > \frac{\lambda_4 v_\Delta}{\sqrt{2}} + \sqrt{2}\frac{\lambda_3 v_\Delta^3}{v_d^2}$$

$$m_{H^\pm}^2 = \frac{(v_d^2 + 2v_\Delta^2)[2\sqrt{2}\mu - \lambda_4 v_\Delta]}{4v_\Delta} \Rightarrow \mu > \frac{\lambda_4 v_\Delta}{2\sqrt{2}}$$

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$$m_{H^\pm}^2 = \frac{(v_d^2 + 2v_\Delta^2)[2\sqrt{2}\mu - \lambda_4 v_\Delta]}{4v_\Delta} \Rightarrow \mu > \frac{\lambda_4 v_\Delta}{2\sqrt{2}}$$

From the CP-even sector, it is more involving:

$$(\lambda_{14}^2 - \lambda\lambda_{23})\,\frac{2\sqrt{2}}{\lambda}\frac{v_\Delta^3}{v_d^2} + \mathcal{O}(v_\Delta^4) < \mu < \frac{\lambda}{4\sqrt{2}}\frac{v_d^2}{v_\Delta} + \sqrt{2}\lambda_{14}v_\Delta + \mathcal{O}(v_\Delta^2).$$

with $\lambda_{ij} = \lambda_i + \lambda_j$

Boundedness From Bellow (BFB)

Stability of the vacuum ($V > V_{min}$) requires that the potential should be BFB. At large field values: $V \approx V^{(4)}(H,\Delta)$

$$V^{(4)}(H,\Delta) = \frac{\lambda}{4}(H^\dagger H)^2 + \lambda_1 (H^\dagger H) Tr(\Delta^\dagger \Delta) + \lambda_2 (Tr \Delta^\dagger \Delta)^2 + \lambda_3 Tr(\Delta^\dagger \Delta)^2 + \lambda_4 H^\dagger \Delta \Delta^\dagger H$$

- If we pick up neutral directions:

$$V_0^{(4)} = \frac{\lambda}{4}|\phi^0|^4 + (\lambda_2+\lambda_3)|\delta^0|^4 + (\lambda_1+\lambda_4)|\phi^0|^2|\delta^0|^2 =$$

$$[\frac{\sqrt{\lambda}}{2}|\phi^0|^2 - \sqrt{\lambda_2+\lambda_3}|\delta^0|^2]^2 + (\lambda_{14} + \sqrt{\lambda(\lambda_2+\lambda_3)})|\phi^0|^2|\delta^0|$$

- $\lambda > 0 \;\&\; \lambda_2 + \lambda_3 > 0 \;\&\; \lambda_1 + \lambda_4 + \sqrt{\lambda(\lambda_2+\lambda_3)} > 0$

- What about the other 10 directions: (ϕ^0 , δ^{++}), (ϕ^0 ,δ^+), (ϕ^0 , ϕ^+), (δ^+ , ϕ^+) ...

BFB: General proof

$$r \equiv \sqrt{H^\dagger H + Tr\Delta^\dagger\Delta} > 0$$

$$H^\dagger H \equiv r^2 \cos^2\gamma$$

$$Tr(\Delta^\dagger\Delta) \equiv r^2 \sin^2\gamma \quad ; \quad -\frac{\pi}{2} < \gamma < +\frac{\pi}{2}$$

$$Tr(\Delta^\dagger\Delta)^2/(Tr\Delta^\dagger\Delta)^2 \equiv \zeta \in [\frac{1}{2}, 1]$$

$$(H^\dagger\Delta\Delta^\dagger H)/(H^\dagger H Tr\Delta^\dagger\Delta) \equiv \xi \in [0, 1]$$

$$V_0^{(4)} = \frac{r^4\cos^4\gamma}{4}(\lambda + 4(\lambda_1 + \xi\lambda_4)\tan^2\gamma + 4(\lambda_2 + \zeta\lambda_3)\tan^4\gamma)$$

$$V(\chi) = a|\phi^0|^4 + b|\phi^0|^2|\delta^0|^2 + c|\delta^0|^4 \quad , \; \chi = |\phi^0|/|\delta^0|$$

$$= a + b\chi^2 + c\chi^4 = (\sqrt{a} - \sqrt{c}\chi^2)^2 + (b + 2\sqrt{ac})\chi^2 \Rightarrow a > 0 \;\&\; c > 0 \;\&\; b + 2\sqrt{ac} > 0$$

$$\lambda > 0 \;\&\; \lambda_2 + \zeta\lambda_3 > 0 \;\&\; \lambda_1 + \xi\lambda_4 + \sqrt{\lambda(\lambda_2 + \zeta\lambda_3)} > 0 \;\forall \zeta \in [\frac{1}{2}, 1], \xi \in$$

BFB: General proof

$$\lambda > 0 \ \& \ \lambda_2 + \zeta\lambda_3 > 0 \ \ \& \ \lambda_1 + \xi\lambda_4 + \sqrt{\lambda(\lambda_2 + \zeta\lambda_3)} > 0$$

$$\forall\zeta \in [\frac{1}{2}, 1], \forall\xi \in [0, 1]$$

which gives

$$\lambda > 0 \ \ \& \ \ \lambda_2 + \lambda_3 > 0 \ \ \& \ \ \lambda_2 + \frac{\lambda_3}{2} > 0$$

$$\& \ \ \lambda_1 + \sqrt{\lambda(\lambda_2 + \lambda_3)} > 0 \ \ \& \ \ \lambda_1 + \sqrt{\lambda(\lambda_2 + \frac{\lambda_3}{2})} > 0$$

$$\& \ \ \lambda_1 + \lambda_4 + \sqrt{\lambda(\lambda_2 + \lambda_3)} > 0 \ \ \& \ \ \lambda_1 + \lambda_4 + \sqrt{\lambda(\lambda_2 + \frac{\lambda_3}{2})} > 0$$

Perturbative unitarity

In the HTM: the scattering amplitude is 35×35 matrix which can be cast to 7 sub-matrix:

- $S_1(6 \times 6)$, $S_2(7 \times 7)$, $S_3(2 \times 2)$, (0-charge channels): $\delta^0\delta^0$, $\phi^+\phi^-$, $\delta^{++}\delta^{--}$
- $S_{(4)}(10 \times 10)$: (1-charge channels) : $\delta^0\phi^+$
- $S_{(5)}(7 \times 7)$: (2-charge channels) : $\phi^+\phi^+$
- $S_{(6)}(2 \times 2)$: (3-charge channels): $\delta^{++}\phi^+$
- $S_{(7)}(1 \times 1)$: (4-charge channels): $\delta^{++}\delta^{++}$

Unitarity

$$|\lambda_1+\lambda_4| \leq \kappa\pi \quad ; \quad |\lambda_1| \leq \kappa\pi \quad ; \quad |2\lambda_1+3\lambda_4| \leq 2\kappa\pi$$

$$|\lambda| \leq 2\kappa\pi \quad ; \quad |\lambda_2| \leq \frac{\kappa}{2}\pi \quad ; \quad |\lambda_2+\lambda_3| \leq \frac{\kappa}{2}\pi$$

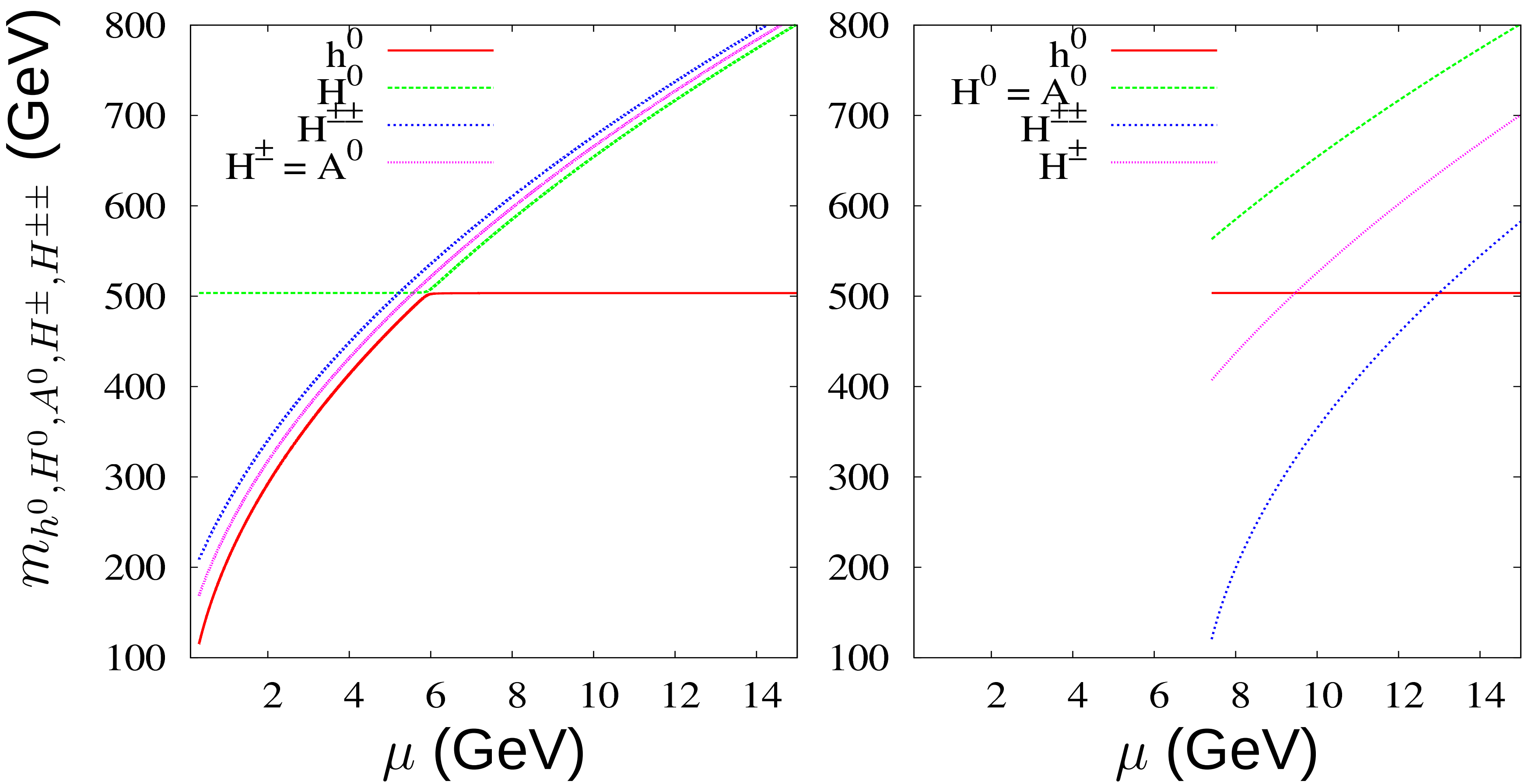
$$|2\lambda_1-\lambda_4| \leq 2\kappa\pi \quad ; \quad |2\lambda_2-\lambda_3| \leq \kappa\pi$$

$$|\lambda+4\lambda_2+8\lambda_3 \pm \sqrt{(\lambda-4\lambda_2-8\lambda_3)^2+16\lambda_4^2}\,| \leq 4\kappa\pi$$

$$|3\lambda+16\lambda_2+12\lambda_3 \pm \sqrt{(3\lambda-16\lambda_2-12\lambda_3)^2+24(2\lambda_1+\lambda_4)^2}\,| \leq 4\kappa\pi$$

$\kappa = 16$ or 8, depending on : $|a_0| < 1$ or $|\Re a_0| < \frac{1}{2}$

$$M_{H^{\pm\pm}} > m_{H^{\pm}} > m_A \quad , \qquad m_A > m_{H^{\pm}} > m_{H^{\pm\pm}}$$



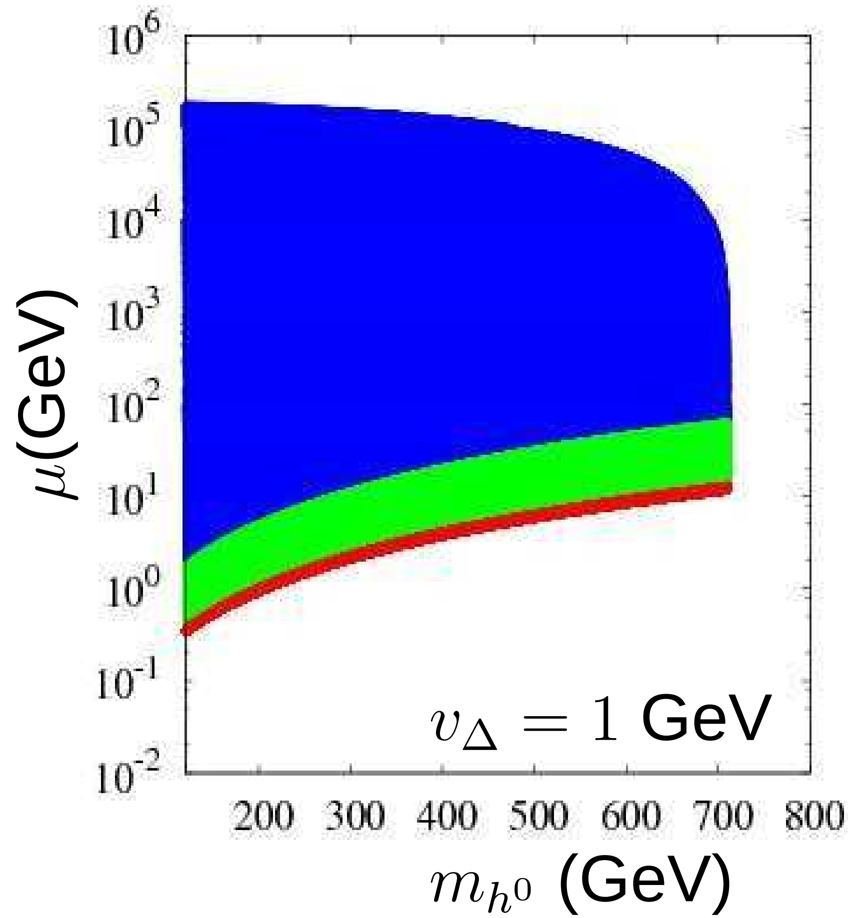
Higgs boson masses as a function of μ with $v_\Delta = 1$ GeV, $\lambda = 8\pi/3$, $\lambda_1 = 0.5$, $\lambda_2 = \lambda_3 = 0.1$, $\lambda_4 = -1$ (left) and $\lambda_4 = 10$ (right)

$$m^2_{H^\pm} - m^2_{H^{\pm\pm}} \approx m^2_{H^0} - m^2_{H^\pm} \approx \lambda_4\, v_d^2/4$$

mixing pattern: h or H SM-like

$h = \cos\alpha \Re(\phi^0) + \sin\alpha \Re(\delta^0) \approx \Re(\phi^0)$: SM-like for $\sin\alpha \to 0$

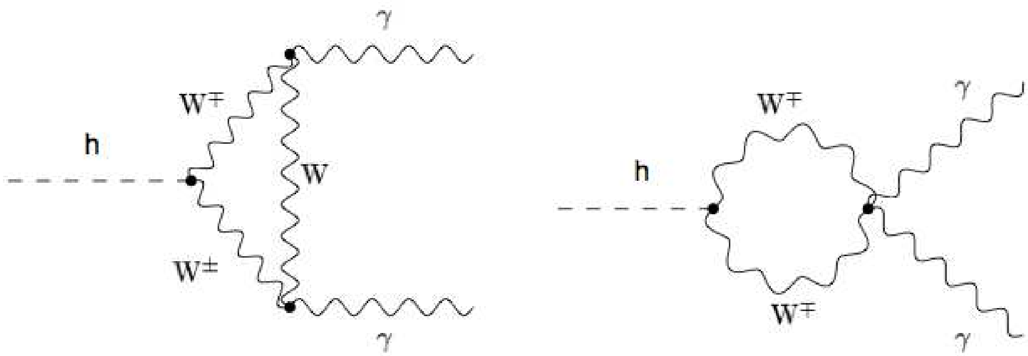
$H = -\sin\alpha \Re(\phi^0) + \cos\alpha \Re(\delta^0) \approx \Re(\delta^0)$: triplet for $\sin\alpha \to 0$



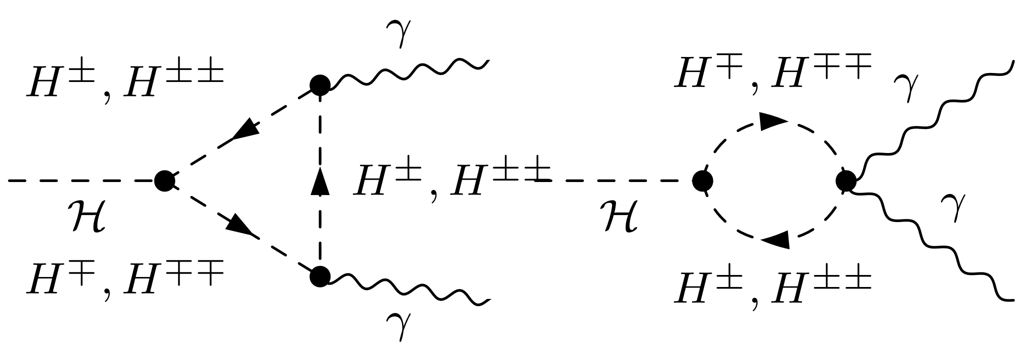
Correlation between μ and m_{h^0}, with $0.44 \leq \lambda \leq 16\pi/3$ $10^{-1} \leq s_\alpha \leq 1$, $10^{-2} \leq s_\alpha \leq 10^{-1}$, $10^{-3} \leq s_\alpha \leq 10^{-2}$ $\lambda_1 = -\lambda_4 = 1$, $\lambda_2 = \lambda_3 = 0$

$h \to \gamma\gamma$

- $h \to \gamma\gamma$ is loop-induced process: new physics can easily affect it.
- In the SM, $h \to \gamma\gamma$ is dominated by W loops



- $H^{\pm\pm}$ and $H^{\pm}$ loops can interfere constructively or destructively with W loops



$h \to \gamma\gamma$ amplitude

$$\Gamma(h^0 \to \gamma\gamma) = \frac{G_F \alpha^2 M_h^3}{128\sqrt{2}\pi^3} \Bigg| \sum_f N_c Q_f^2 g_{hff} A_{1/2}(\tau_f) + g_{hWW} A_1(\tau_W)$$

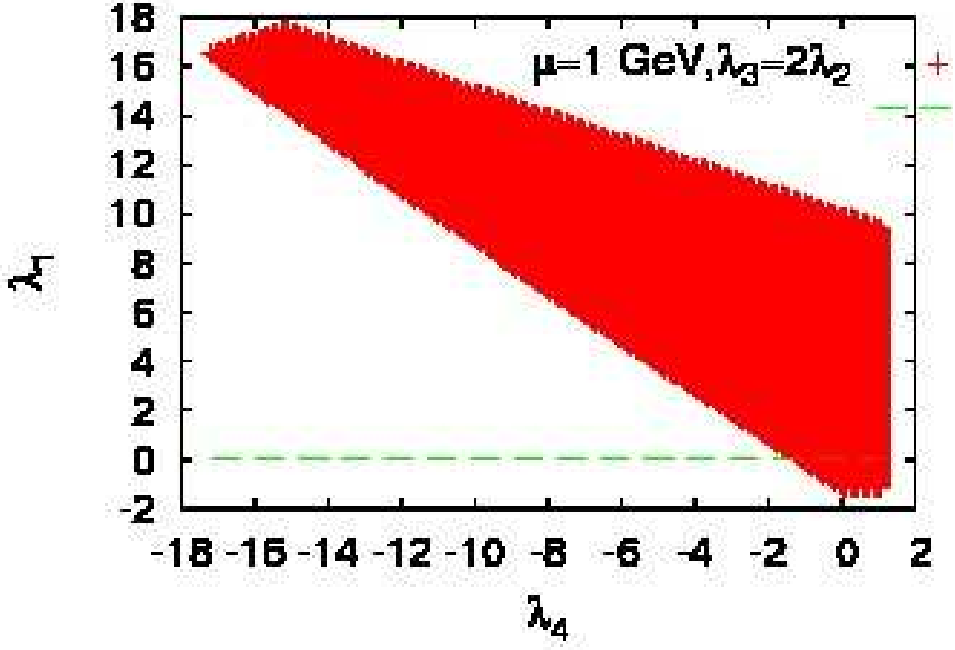
$$- \frac{M_W}{g} \Big(\frac{g_{hH^\pm H^\mp}}{m_{H^\pm}^2} A_0(\tau_{H^\pm}) + 4 \frac{g_{hH^{\pm\pm} H^{\mp\mp}}}{m_{H^{\pm\pm}}^2} A_0(\tau_{H^{\pm\pm}}) \Big)$$

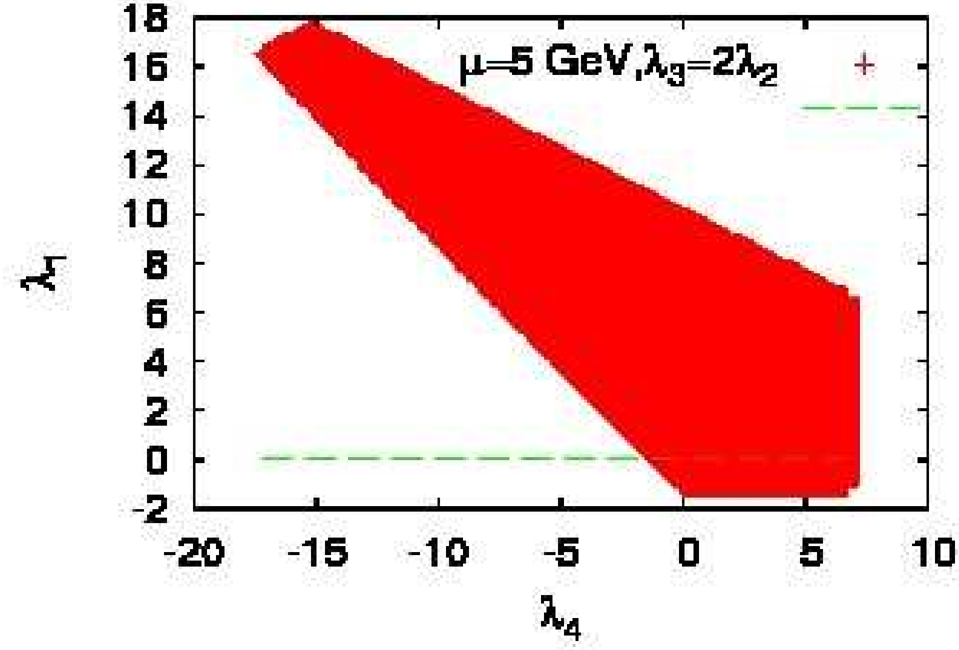
with

$$g_{h^0 H^{++} H^{--}} = -2(\lambda_2 v_\Delta s_\alpha + \lambda_1 v_d c_\alpha) \approx -\lambda_1 v_d + \ldots$$

$$g_{h^0 H^+ H^-} = -\frac{1}{2}(2\lambda_1 + \lambda_4) v_d + \ldots$$

What sign of λ_1 is prefered by constraints?



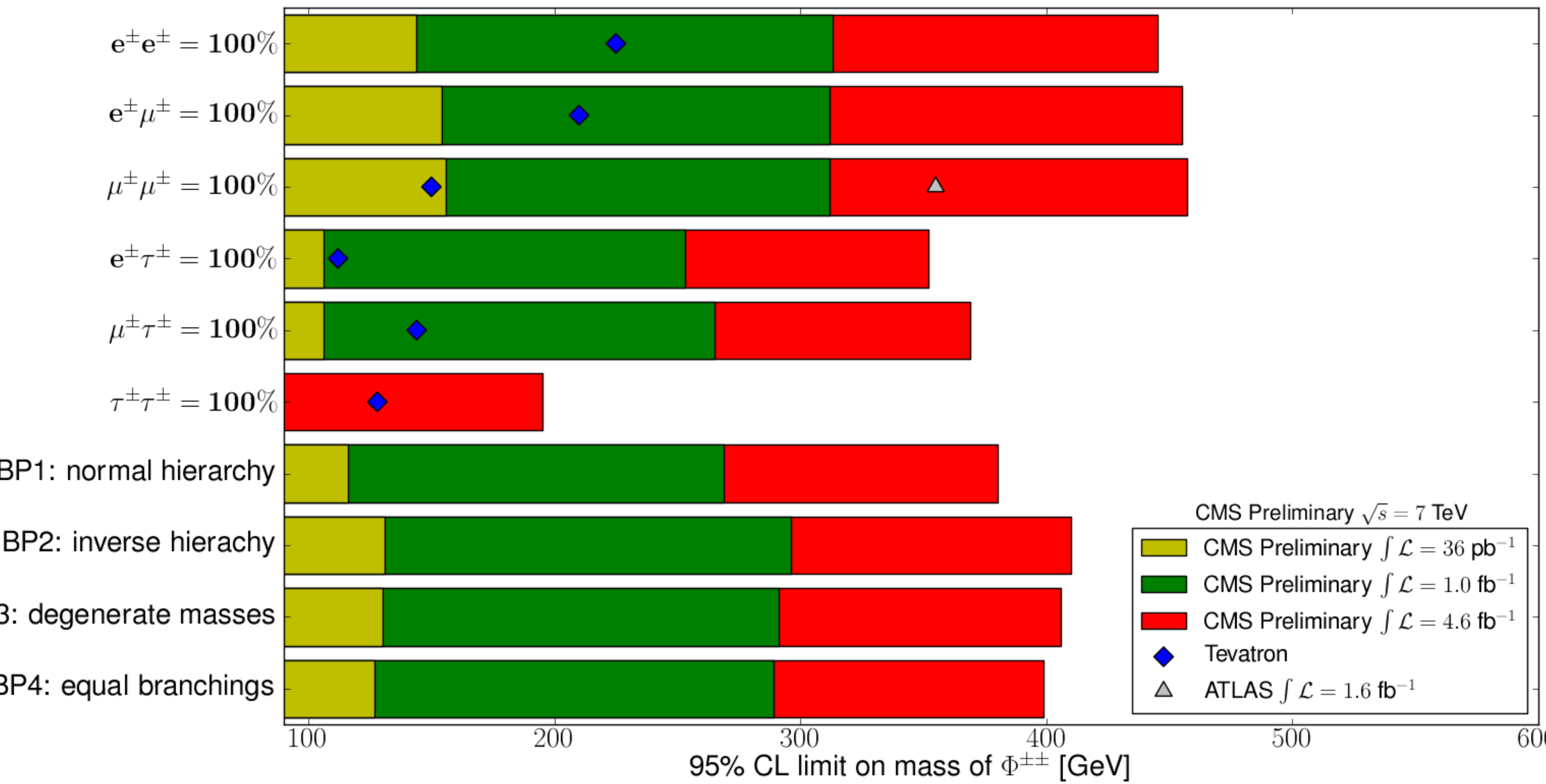


$\lambda_3 = 2\lambda_2 \;\; , \;\; \lambda_2 \in [-8\pi, 8\pi]$

It is possible to have both $hH^{\pm\pm}H^{\mp\mp} \approx -\lambda_1 v_d$ and $hH^{\pm}H^{\mp} \approx -(2\lambda_1 + \lambda_4)v_d > 0$ and then $H^{\pm\pm}$ and $H^{\pm}$ contribute constructively with W loops.

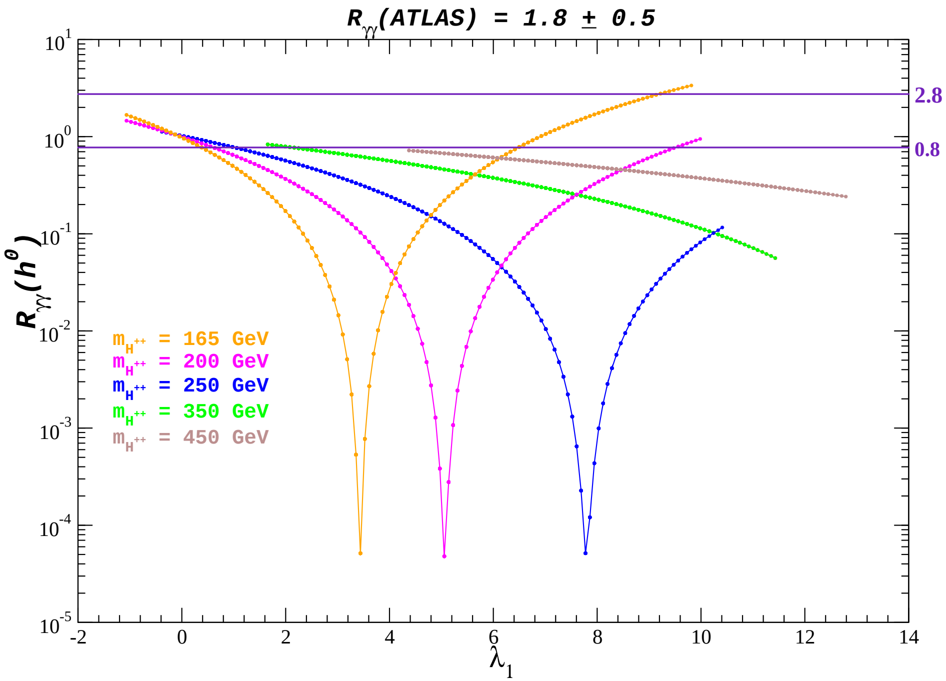
A. Akeroyd, S. Moretti, Phys.Rev. D86'12

ATLAS and CMS limits on $H^{\pm\pm}$



This bound can be avoided if $H^{\pm\pm} \to W^\pm W^{\pm *}$ or $H^{\pm\pm} \to H^\pm W^\pm$ dominates

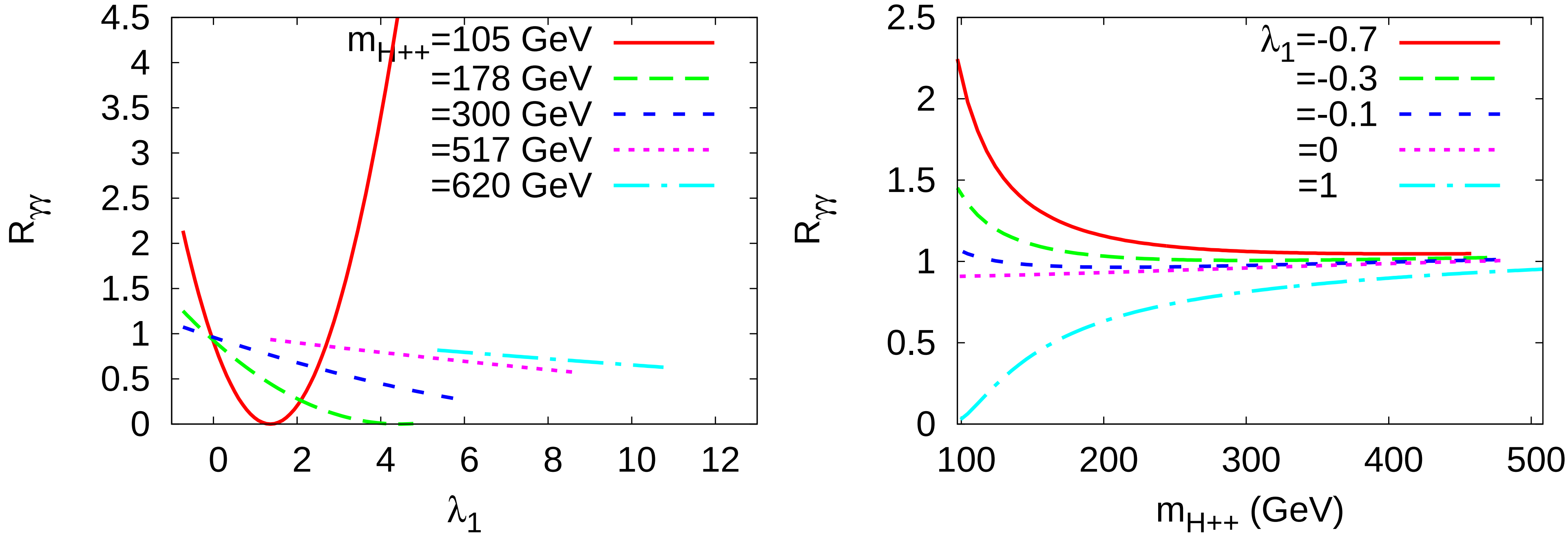
$R_{\gamma\gamma}$ results



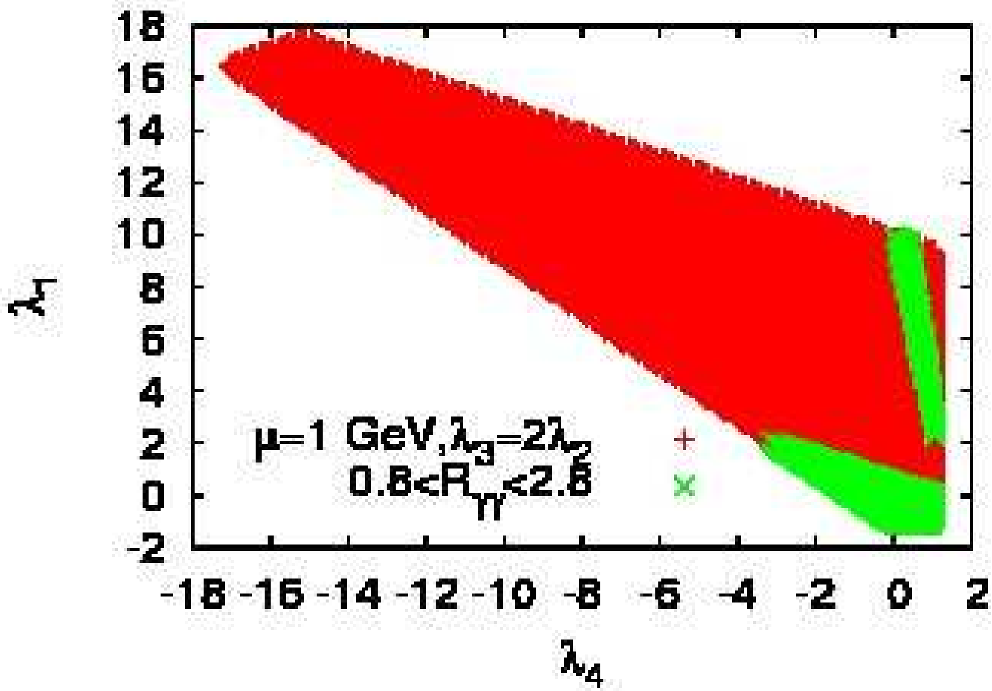
$\lambda_3 = 2\lambda_2 = 0.2$, $m_h = 126$ GeV

$$R_{\gamma\gamma} = \frac{\sigma(gg \to h) \times Br(h \to \gamma\gamma)}{\sigma^{SM}(gg \to h) \times Br^{SM}(h \to \gamma\gamma)}$$

$R_{\gamma\gamma}$



$R_{\gamma\gamma}$ constraint

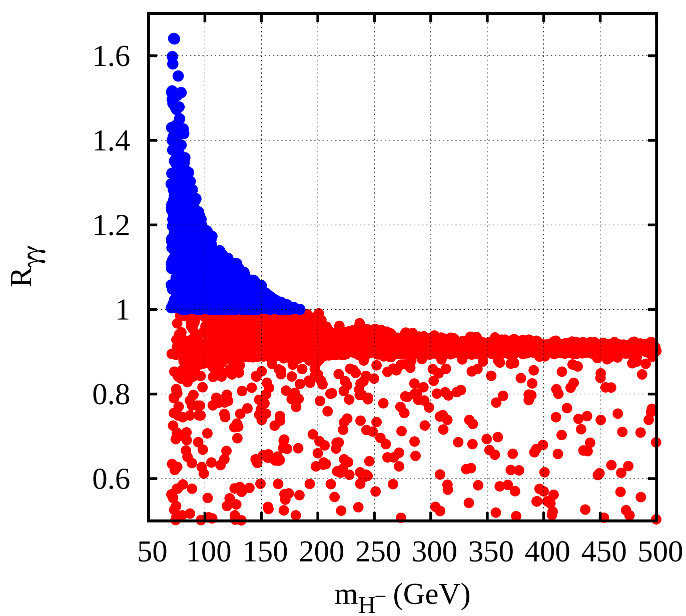


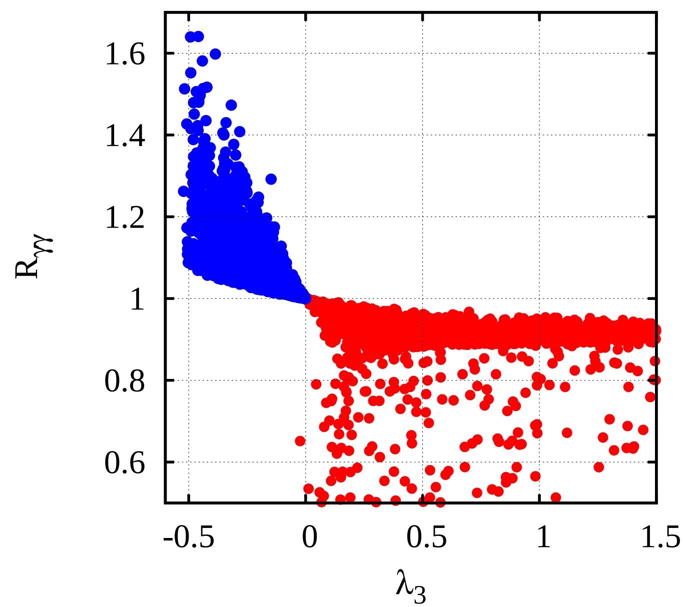
$\lambda_3 = 2\lambda_2$; $\lambda_2 \in [-8\pi, 8\pi]$; $\mu = v_t = 1GeV$; $m_h = 125 - 126$ GeV

ATLAS: $R_{\gamma\gamma} = 1.8 \pm 0.5$

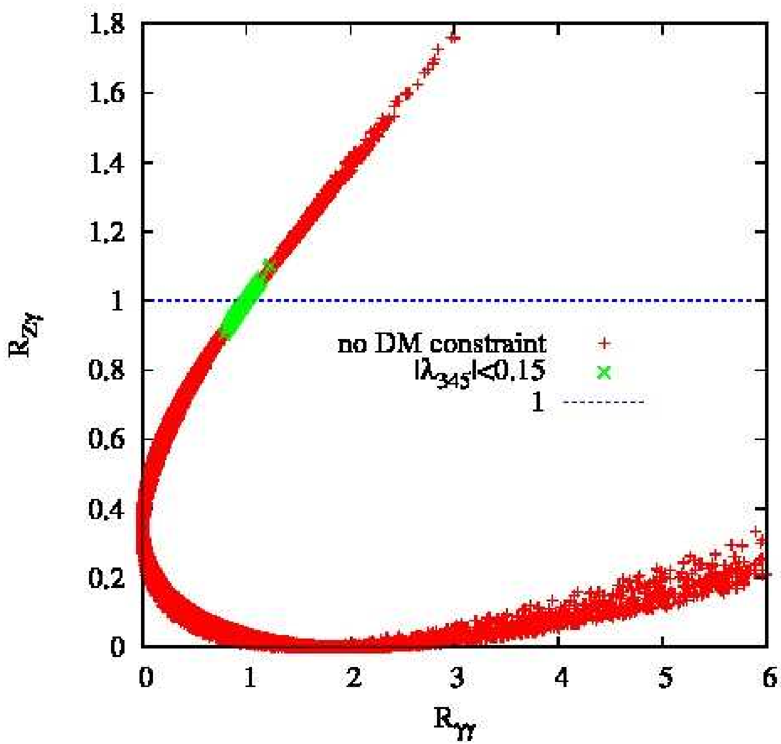
$h \to \gamma\gamma$ vs $h \to Z\gamma$ in the inert Model (Krawczyk)

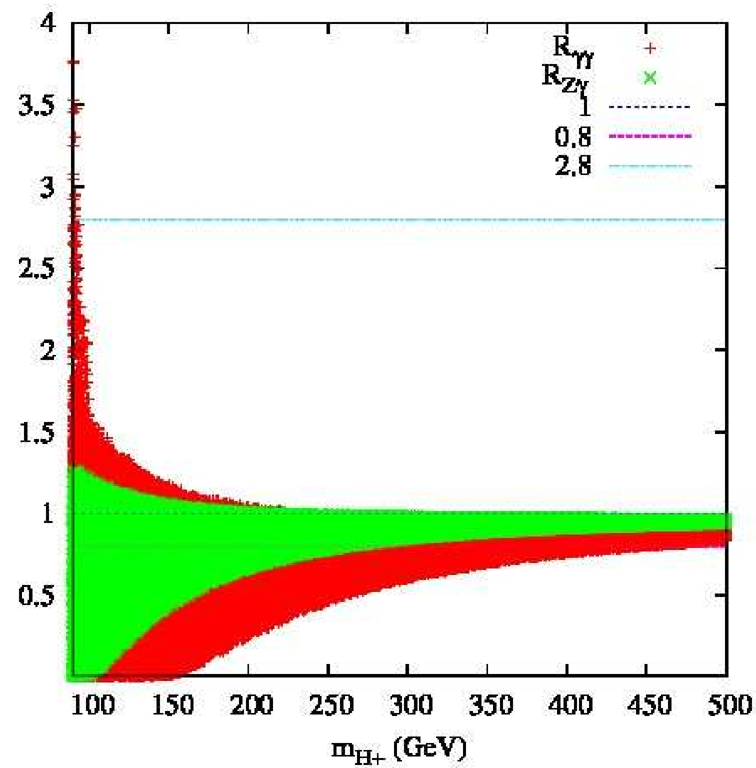
- $R_{\gamma\gamma} = \frac{Br(h \to \gamma\gamma)^{IDM}}{Br(h \to \gamma\gamma)^{SM}}$, $R_{Z\gamma} = \frac{Br(h \to Z\gamma)^{IDM}}{Br(h \to Z\gamma)^{SM}}$
- $hH^+H^- = -2\frac{m_W s_W}{e}\lambda_3 = -4\frac{m_W s_W}{ev^2}(m_{H^\pm}^2 - \mu_2^2)$





$h \to \gamma\gamma$ vs $h \to Z\gamma$ in the inert Model





$h \to \gamma\gamma$ vs $h \to Z\gamma$ in the 2HDM-II in the decoupling limit

(A. A; W. Hollik, S. Penaranda, PLB'2003)
In the decoupling limit:

$$
\begin{aligned}
m^2_{H^\pm} &= M^2_{12} - (\lambda_4 + \lambda_5)(v_1^2 + v_2^2), \to M^2_{12} \ (\text{for } \mathrm{M}_{12} \to \infty) \\
m^2_A &= M^2_{12} - \lambda_5(v_1^2 + v_2^2), \to M^2_{12} \quad , \quad m^2_H \to M^2_{12} \\
m^2_h &\to \lambda(v_1^2 + v_2^2) \quad , \quad M^2_{12} = m^2_{12}/s_\beta c_\beta
\end{aligned}
$$

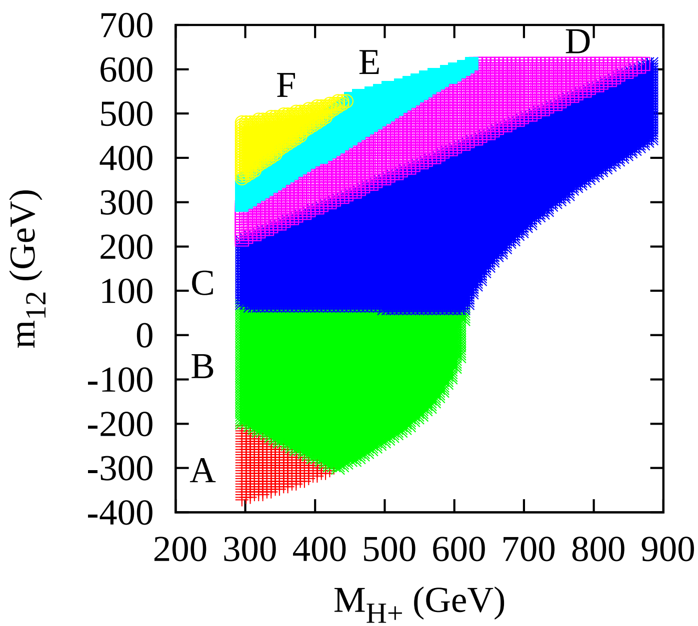
If $M^2_{12} \to \infty$, $\tan 2(\alpha - \beta) \to 0$: $\sin(\alpha - \beta) \to 1$, $\cos(\alpha - \beta) \to 0$
In this case: $\alpha \to \beta - \pi/2$,

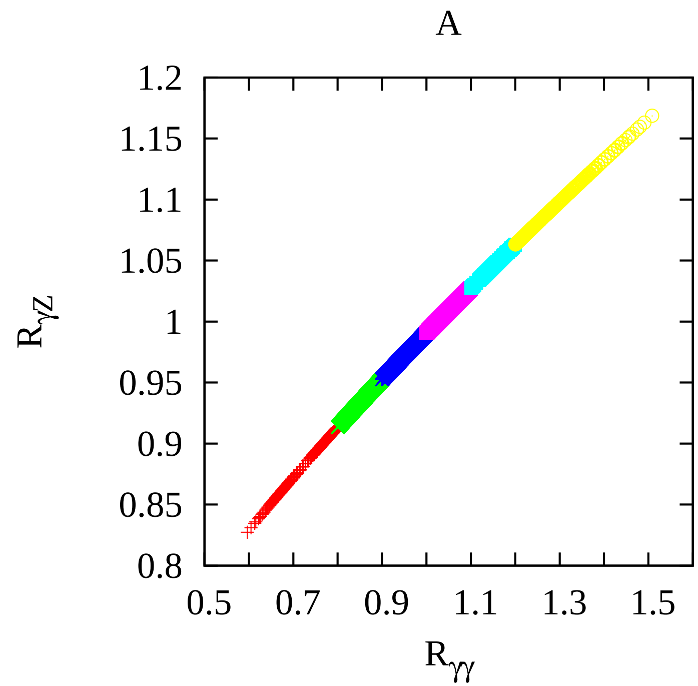
$$
h^0VV/(h_{SM}VV) = \sin(\beta - \alpha) \to 1
$$

$$
h^0 b\bar{b}/h_{SM}b\bar{b} = -\frac{\sin\alpha}{\cos\beta} \to 1 \ , \ (h^0\bar{t}t)/h_{SM}t\bar{t} = \frac{\cos\alpha}{\sin\beta} \to 1
$$

$$
g[h^0H^+H^-] = -\frac{g}{2M_W}\{M^2_{h^0} + 2(M^2_{H^\pm} - M^2_{12})\}
$$

$h^0 \to \gamma\gamma$: $R_{V\gamma} = \left| \frac{\Gamma(h\to V\gamma)^{2HDM} - \Gamma(h\to V\gamma)^{SM}}{\Gamma(h\to V\gamma)^{SM}} \right|$, $V = \gamma$, Z



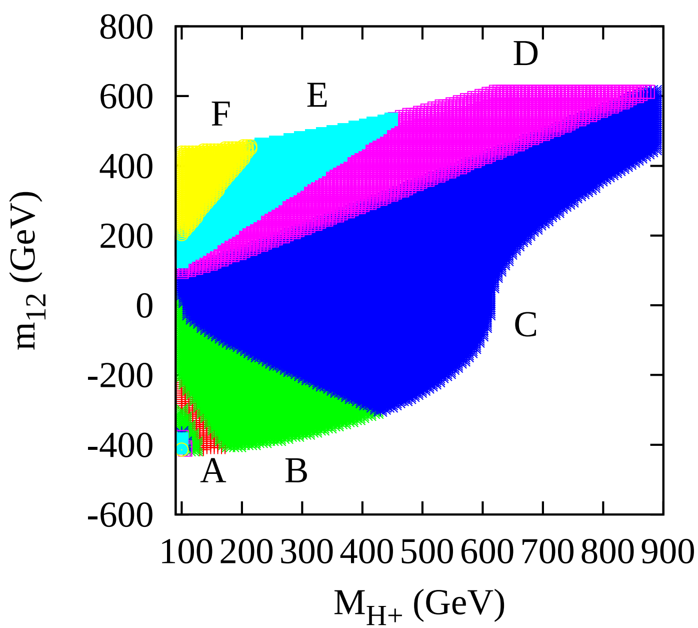


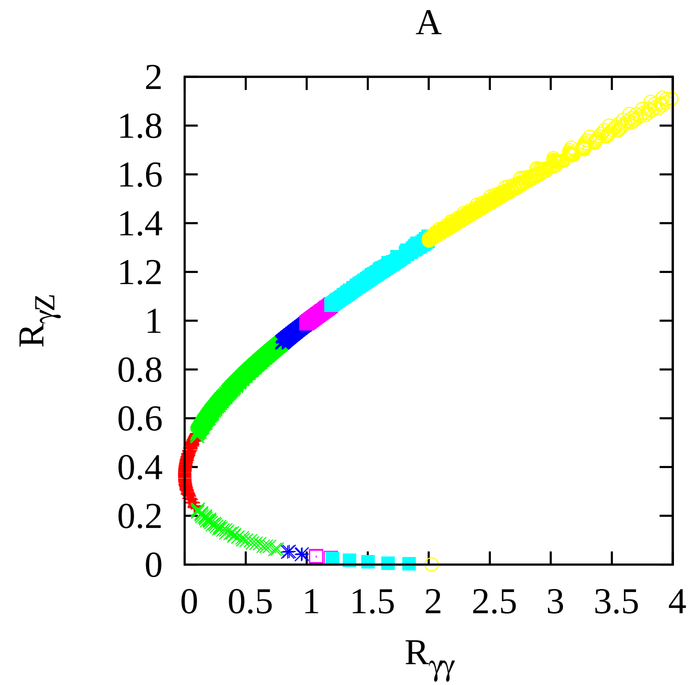
The regions A, B,C, D, E and F are as follow: $R_{\gamma\gamma} < 0.8$, $0.8 < R_{\gamma\gamma} < 0.9$, $0.9 < R_{\gamma\gamma} < 1$, $1 < R_{\gamma\gamma} < 1.1$, $1.1 < R_{\gamma\gamma} < 1.2$ and $R_{\gamma\gamma} > 1.2$. D,E,F violate vaccum stability constraints.

(Right) correlation between $R_{\gamma\gamma}$ and $R_{\gamma Z}$

$h \to \gamma\gamma$ vs $h \to Z\gamma$ in the 2HDM-I

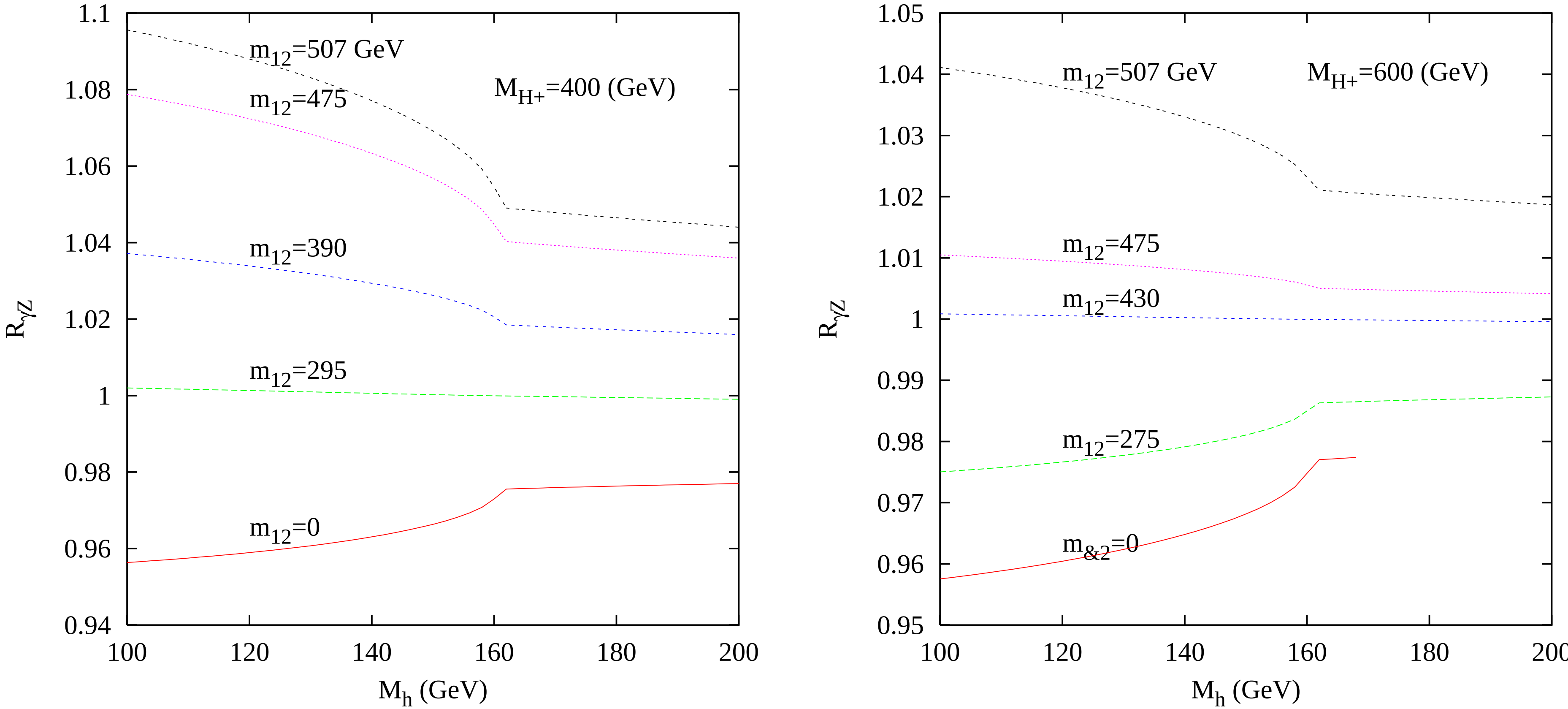
$h^0 \to V\gamma$: $R_{V\gamma} = |\frac{\Gamma(h\to V\gamma)^{2HDM} - \Gamma(h\to V\gamma)^{SM}}{\Gamma(h\to V\gamma)^{SM}}|$



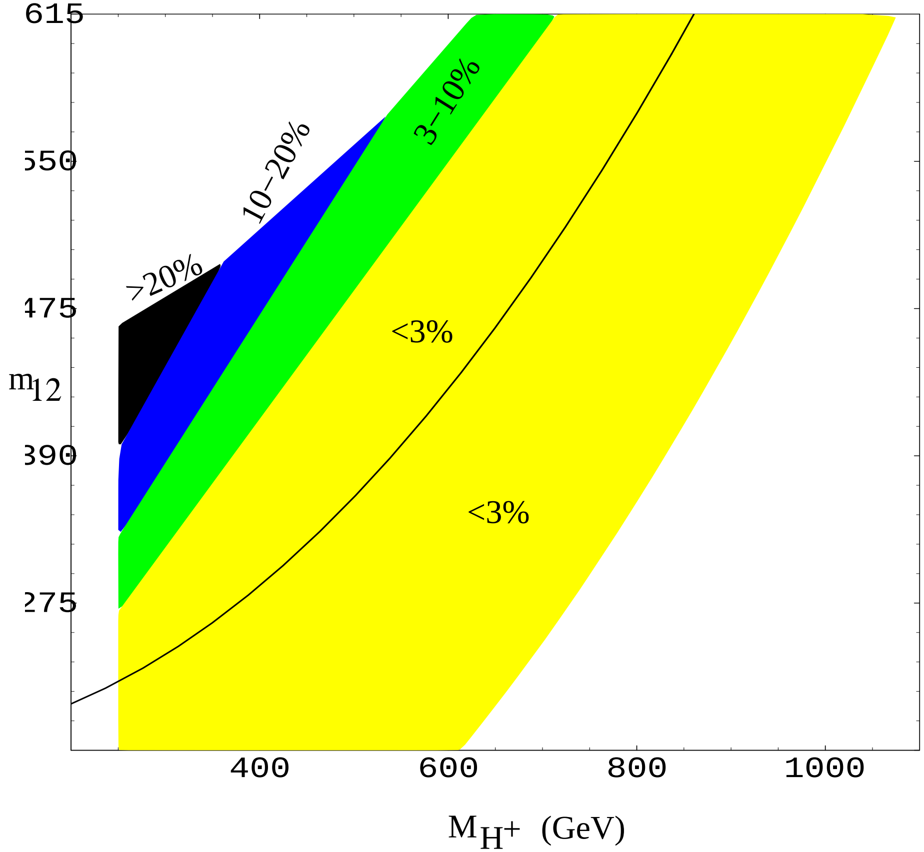


The regions A, B,C, D, E and F are as follow: $R_{\gamma\gamma} < 0.8$, $0.8 < R_{\gamma\gamma} < 0.9$, $0.9 < R_{\gamma\gamma} < 1$, $1 < R_{\gamma\gamma} < 1.1$, $1.1 < R_{\gamma\gamma} < 1.2$ and $R_{\gamma\gamma} > 1.2$. D,E,F violate vaccum stability constraints. (Right) correlation between $R_{\gamma\gamma}$ and $R_{\gamma Z}$

$h \to \gamma Z$: $R_{\gamma Z} = |\frac{\Gamma(h \to \gamma Z)^{2HDM}}{\Gamma(h \to \gamma Z)^{SM}}|$



$$h \to b\bar{b}\text{: } \Delta_{bb} = \left|\frac{\Gamma(h\to bb)^{2HDM} - \Gamma(h\to bb)^{SM}}{\Gamma(h\to bb)^{SM}}\right|$$



Summary

- Higgs Triplet Model (HTM) is consistent with 125 GeV higgs, it can fit the data even much better than SM
- We derive the full set of tree level perturbative unitarity and boundedness from below constraints for HTM
- Unitarity on the SM Higgs is ≤ 700 GeV, while the other states $H^{\pm}$, H^{0}, $H^{\pm\pm}$ is very large (≈ 90 TeV)
- $h \to \gamma\gamma$ is very sensitive charged particles and can be used to set limits on the parameter space of the model.
- $h \to \gamma\gamma$ and $h \to Z\gamma$ can be correlated or anti-correlated both in HTM and IDM