جامعة القاضي عياض

LABORATOIRE DE PHYSIQUE DES HAUTES ENERGIES ET ASTROPHYSIQUE

Diphoton channel in the Higgs Triplet Model

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Based on : A. Arhrib et al., Phys. Rev. D 84 (2011) 095005 [arXiv:1105.1925]
A. Arhrib et al., JHEP (2012) [arXiv:1112.5453]

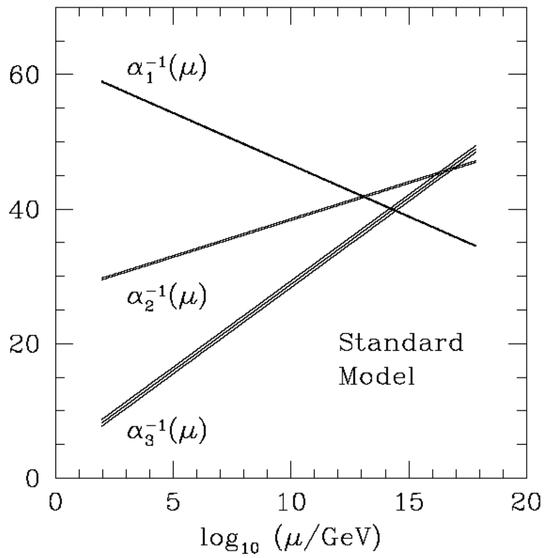
Questions Beyond the SM ……

❖ 19 free parameters : unexplained

❖ Electroweak breaking mechanism still mysterious ?

the Higgs boson is missing?

❖ No unification of coupling constants



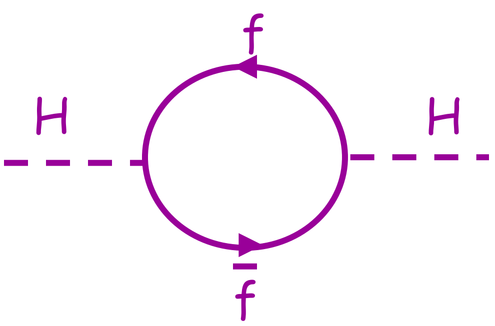
❖ Does not describe gravitation

Significant at the Planck scale Λp (~1019 GeV)

❖ Problem of hierarchy and naturalness

- ❑ 17 Orders of magnitude between Mw et ΛP
- ❑ radiative corrections ⇒ fine adjustment

$$\Delta m_H^2 = \frac{|\lambda_f|^2}{16\pi^2}\left[-2\Lambda_{UV}^2 + 6m_f^2 \ln\left(\frac{\Lambda_{UV}}{m_f}\right) + \ldots\right]$$



❖ Neutrino mass

- ○ neutrino oscillations indicate a non-zero mass (although very small) for neutrino
- ○ first direct indication of physics beyond the SM.

Lagrangian and scalar potential V(H,Δ)

Scalar Lagrangian

$$\mathcal{L} = (D_\mu H)^\dagger (D^\mu H) + Tr(D_\mu \Delta)^\dagger (D^\mu \Delta) + \mathcal{L}_Y - V(H;\Delta)$$

$$D_\mu H = \partial_\mu H + i g T^a W^a_\mu H + i\frac{g'}{2} B_\mu H$$

$$D_\mu \Delta = \partial_\mu \Delta + i g [T^a W^a_\mu ; \Delta] + i g' \frac{Y}{2} B_\mu \Delta$$

Scalar Potential

$$\begin{aligned} V(H;\Delta) = & -m_H^2 H^\dagger H + M_\Delta^2 Tr(\Delta^\dagger \Delta) \\ & + \frac{\lambda}{4}(H^\dagger H)^2 + \lambda_1 (H^\dagger H) Tr(\Delta^\dagger \Delta) \\ & + \lambda_2 (Tr\Delta^\dagger \Delta)^2 + \lambda_3 Tr(\Delta^\dagger \Delta)^2 \\ & + \lambda_4 H^\dagger \Delta \Delta^\dagger H + [\mu (H^T i\tau_2 \Delta^\dagger H) + \mathrm{hc}] \end{aligned}$$

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

$$\Delta^{\pm\pm} = H^{\pm\pm}$$

$$\begin{pmatrix} h \\ \xi^0 \end{pmatrix} = \mathcal{R}_\alpha \begin{pmatrix} h^0 \\ H^0 \end{pmatrix}$$

$$\begin{pmatrix} \phi^\pm \\ \delta^\pm \end{pmatrix} = \mathcal{R}_{\beta'} \begin{pmatrix} H^\pm \\ G^\pm \end{pmatrix}$$

$$\begin{pmatrix} Z_1 \\ Z_2 \end{pmatrix} = \mathcal{R}_\beta \begin{pmatrix} A^0 \\ G^0 \end{pmatrix}$$

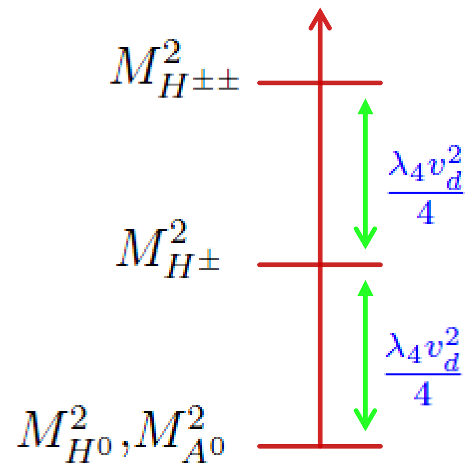
$$M^2_{H^{\pm\pm}} \simeq \frac{\mu v_d}{\sqrt{2}\epsilon} - \frac{\lambda_4 v_d^2}{2} + \mathcal{O}(\epsilon^2)$$

$$M^2_{H^\pm} \simeq \frac{\mu v_d}{\sqrt{2}\epsilon} + \sqrt{2}\mu v_d \epsilon - \frac{\lambda_4 v_d^2}{4} + \mathcal{O}(\epsilon^2)$$

$$M^2_{A^0} \simeq \frac{\mu v_d}{\sqrt{2}\epsilon} + 2\sqrt{2}\mu v_d \epsilon + \mathcal{O}(\epsilon^2)$$

$$M^2_{H^0} \simeq \frac{\mu v_d}{\sqrt{2}\epsilon} + 2\sqrt{2}\mu v_d \epsilon + \mathcal{O}(\epsilon^2)$$

$$M^2_{h^0} \simeq \frac{\lambda v_d^2}{2} - 2\sqrt{2}\mu v_d \epsilon + \mathcal{O}(\epsilon^2)$$



Constraints in the HTM

Unitarity & $\mathcal{BFB}$

Working out analytically these two sets of BFB and unitarity constraints, one can reduce them to a more compact system where the allowed ranges for λ's are easily identified. We find [1],

$$0 \leq \lambda \leq \frac{2}{3}\kappa\pi$$

$$\lambda_2 + \lambda_3 \geq 0 \;\;\&\;\; \lambda_2 + \frac{\lambda_3}{2} \geq 0$$

$$\lambda_2 + 2\lambda_3 \leq \frac{\kappa}{2}\pi$$

$$4\lambda_2 + 3\lambda_3 \leq \frac{\kappa}{2}\pi$$

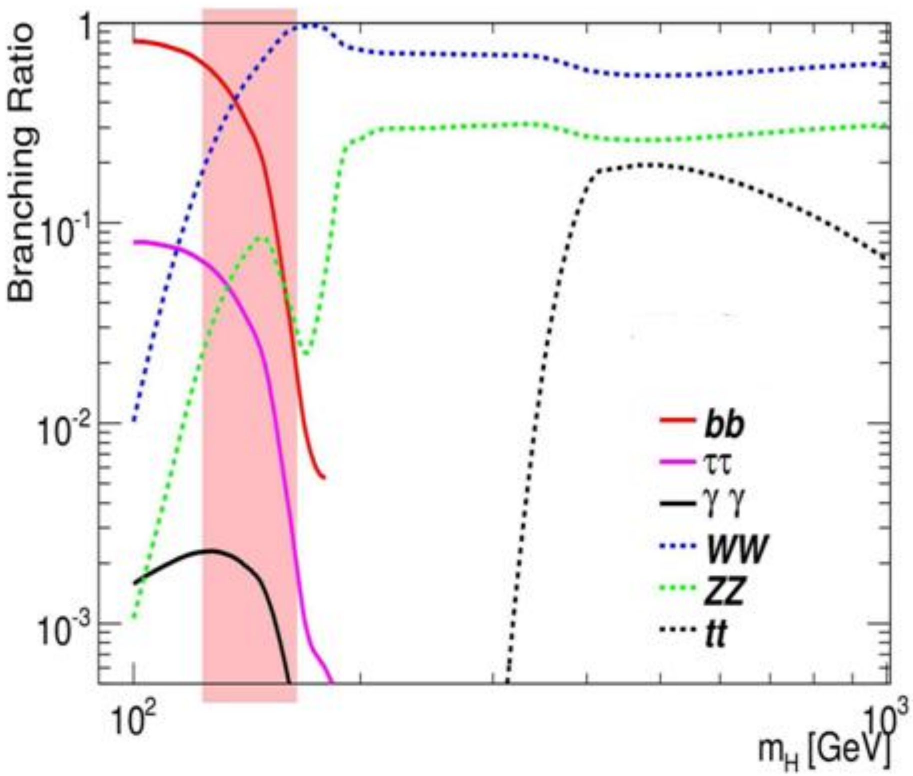
$$2\lambda_2 - \lambda_3 \leq \kappa\pi$$

$$|\lambda_4| \leq \min \sqrt{(\lambda \pm 2\kappa\pi)(\lambda_2 + 2\lambda_3 \pm \frac{\kappa}{2}\pi)}$$

$$|2\lambda_1 + \lambda_4| \leq \sqrt{2(\lambda - \frac{2}{3}\kappa\pi)(4\lambda_2 + 3\lambda_3 - \frac{\kappa}{2}\pi)}$$

Overview to H—>γγ search

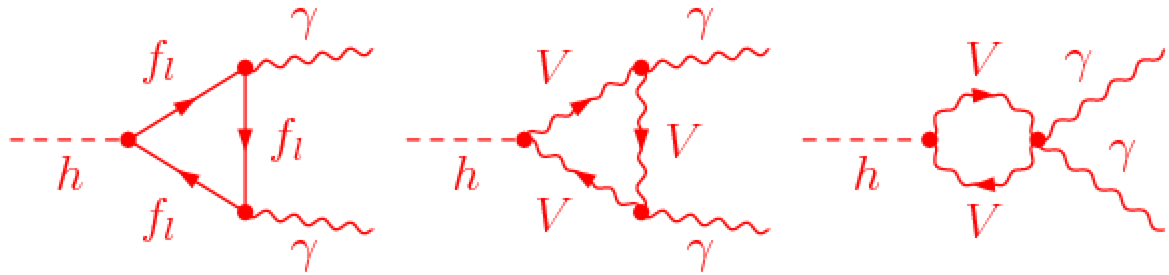
- One goal of the LHC and ATLAS is the discovery of the Higgs boson.
- H —> γγ is one of the most promising discovery channels for a SM Higgs boson in the region of low mass (114 < mH < 140 GeV).



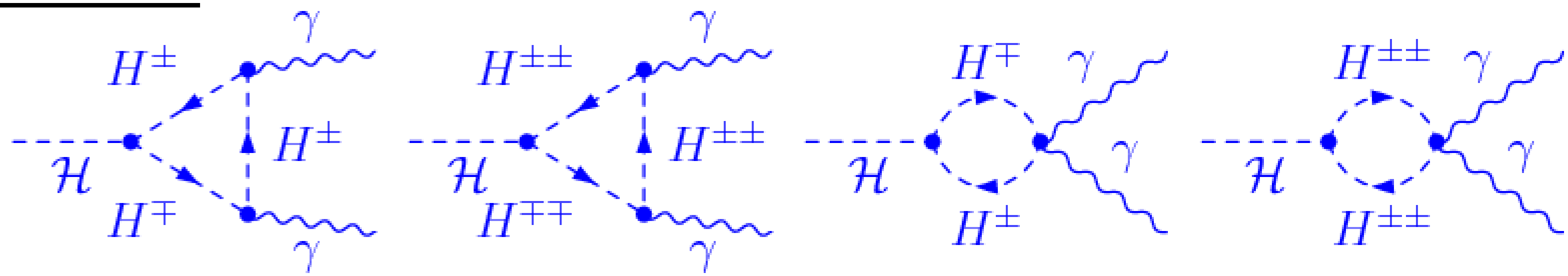
- Small branching ratios (≈ 2.10^{-3} pour mH=120 GeV)
- But …
- Simple & clean signature compared to b b-bar (no jet)
- Good resolution in mass (≈1.5 GeV)
- Two photon signature study very useful in next generation colliders

Decay into 2 photons in the HTM

In the SM



In the HTM



Partial Width

$$\Gamma(\mathcal{H} \to \gamma\gamma) = \frac{G_F \alpha^2 M_{\mathcal{H}}^3}{128\sqrt{2}\pi^3} \Bigg| \sum_f N_c Q_f^2 \tilde{g}_{\mathcal{H}ff} A_{1/2}^{\mathcal{H}}(\tau_f) + \tilde{g}_{\mathcal{H}WW} A_1^{\mathcal{H}}(\tau_W)$$

$$+ \tilde{g}_{\mathcal{H}H^\pm H^\mp} A_0^{\mathcal{H}}(\tau_{H^\pm}) + 4\tilde{g}_{\mathcal{H}H^{\pm\pm}H^{\mp\mp}} A_0^{\mathcal{H}}(\tau_{H^{\pm\pm}}) \Bigg|^2$$

$$\tilde{g}_{\mathcal{H}H^{++}H^{--}} = \frac{s_W}{e}\frac{m_W}{m_{H^{\pm\pm}}^2}\lambda_1 v_d$$

$$\tilde{g}_{\mathcal{H}H^{+}H^{-}} = \frac{s_W}{e}\frac{m_W}{m_{H^{\pm}}^2}\left(\lambda_1 + \frac{\lambda_4}{2}\right)v_d$$

$\mathcal{H}$	$\tilde{g}_{\mathcal{H}\bar{f}f}$	$\tilde{g}_{\mathcal{H}W^+W^-}$
h^0	$c_\alpha / c_{\beta'}$	$+e(c_\alpha v_d + 2 s_\alpha v_t)/(2 s_W m_W)$
H^0	$-s_\alpha / c_{\beta'}$	$-e(s_\alpha v_d - 2 c_\alpha v_t)/(2 s_W m_W)$

Decay into 2 photons in the HTM

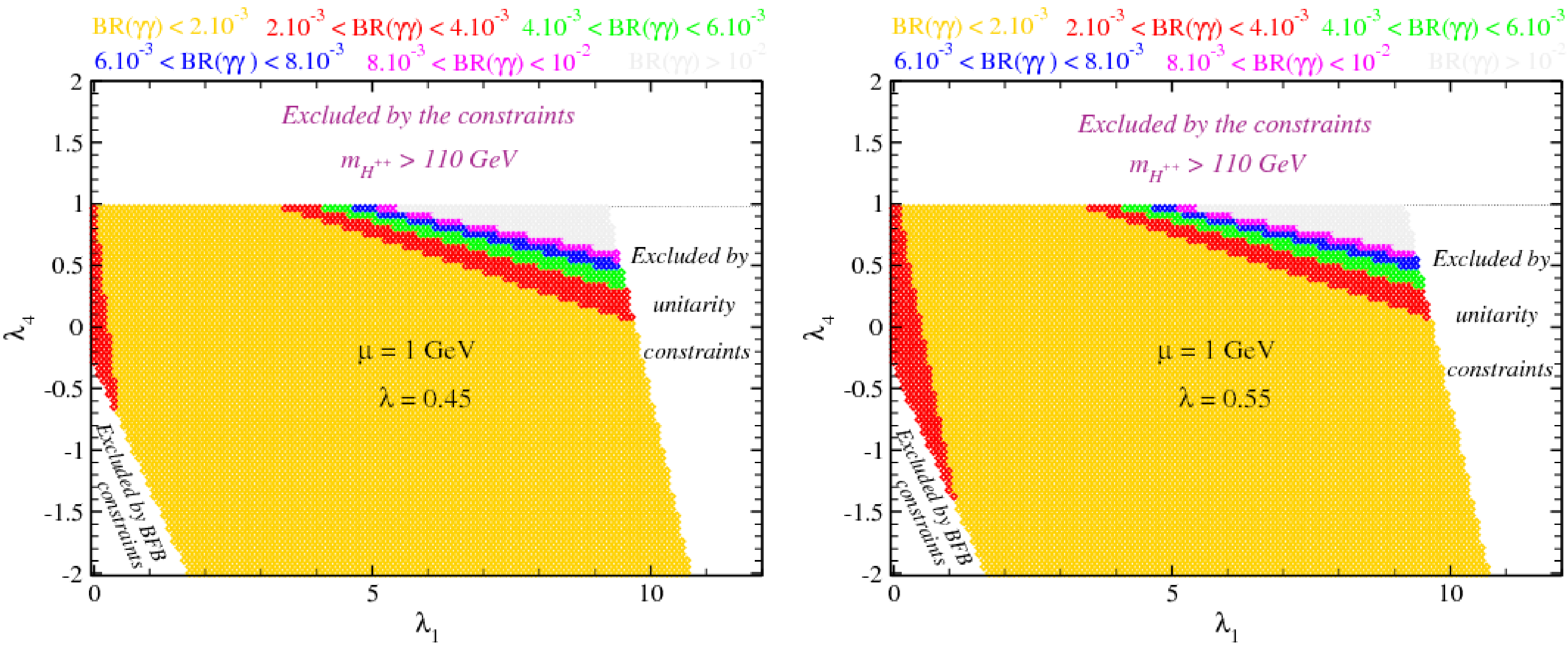


Fig : Scatter plot in the $[\lambda_1, \lambda_4]$ plane showing the branching ratios for $H \to \gamma\gamma$.

In both panels the SM-like Higgs is h^0, with $\lambda = 0.45$, $m_{h^0} \approx 125$ GeV (left panel) and $\lambda = 0.55$, $m_{h^0} \approx 127$ GeV (right panel), $\lambda_3 = 2\lambda_2 = 0.2$ and $\mu = \upsilon_t = 1$ GeV

Decay into 2 photons in the HTM

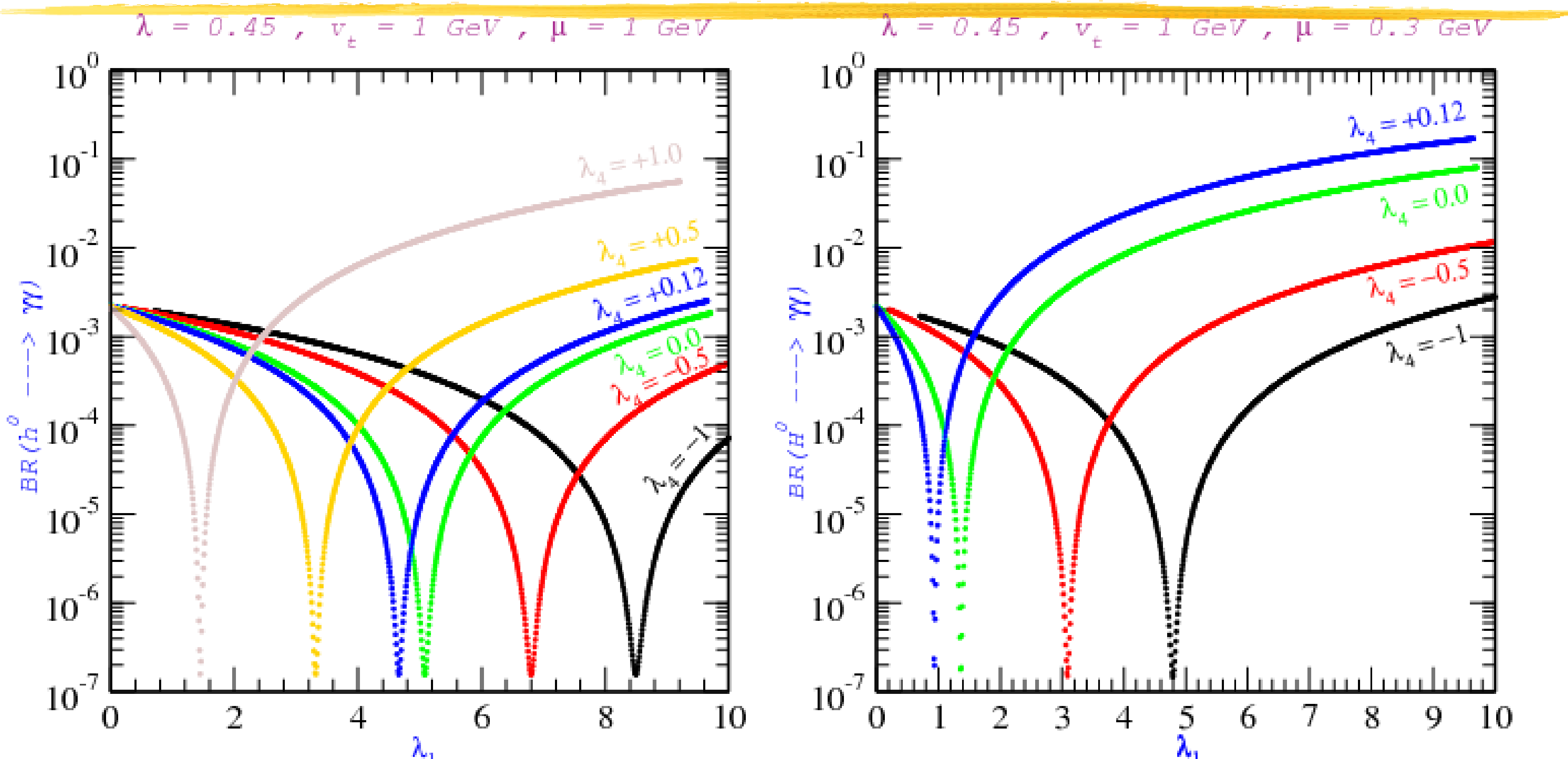


Fig : The branching ratios for $H \to \gamma\gamma$ *as a function of* λ_1 *for various values of* λ_4 *with* $\lambda = 0.45, \lambda_3 = 2\lambda_2 = 0.2$ *and* $\upsilon_t = 1$ *GeV.*

Left panel : $\mu = 1\,GeV, h^0$ *is SM – like with* $m_{h^0} = 114 - 115\,GeV$

Right panel : $\mu = 0.3\,GeV, H^0$ *is SM – like with* $m_{H^0} = 115 - 123\,GeV$

Decay into 2 photons in the HTM

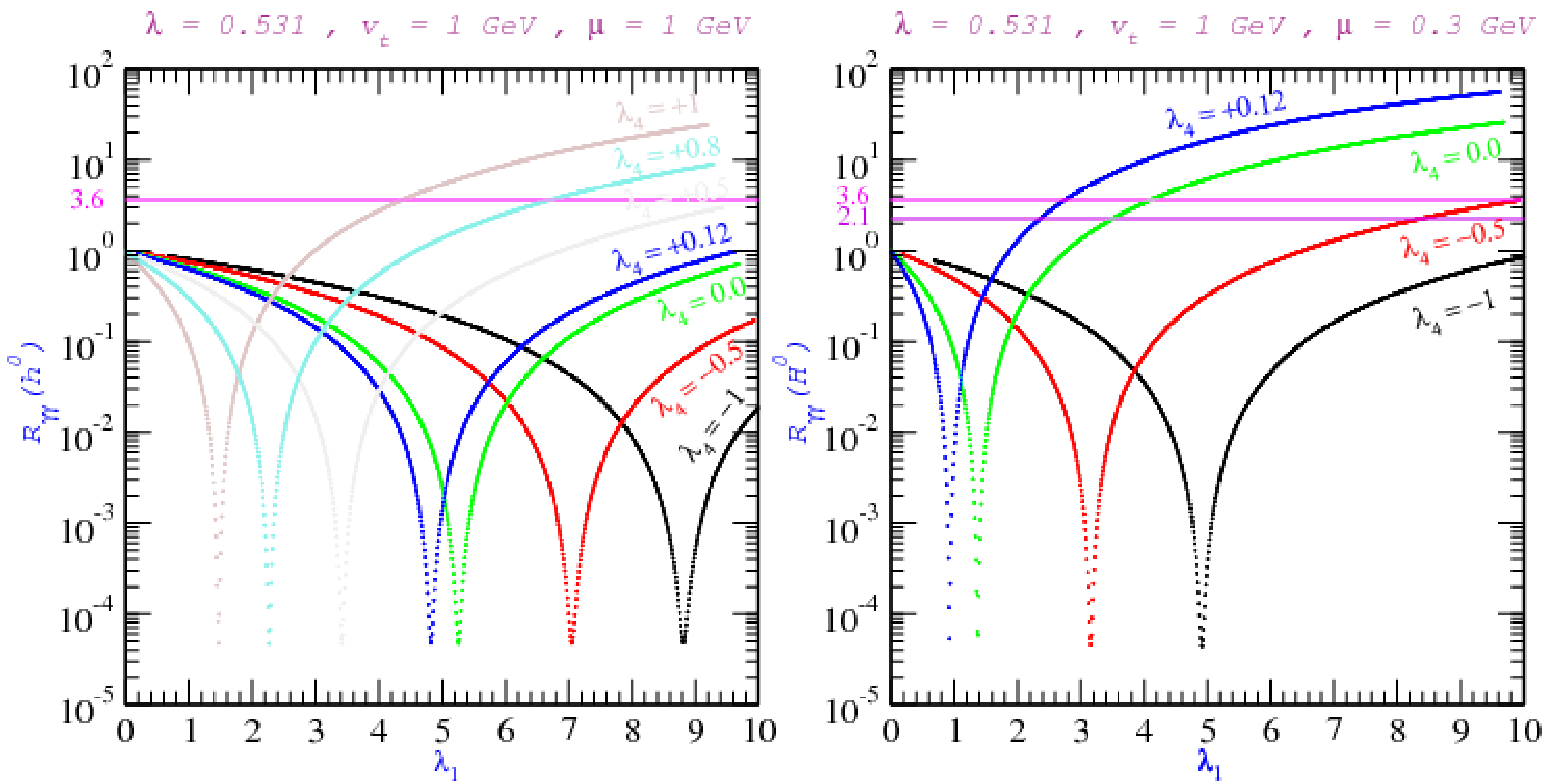
In the SM-like regime of HTM, the branching ratios of all Higgs decays channels are the same as in the SM, except for $H \to \gamma\gamma$ and $H \to \gamma Z$, where they can significantly differ but remain very small compared to the other decay channels

Besides the branching ratios of $H \to \gamma\gamma$, we will consider the observable [2] :

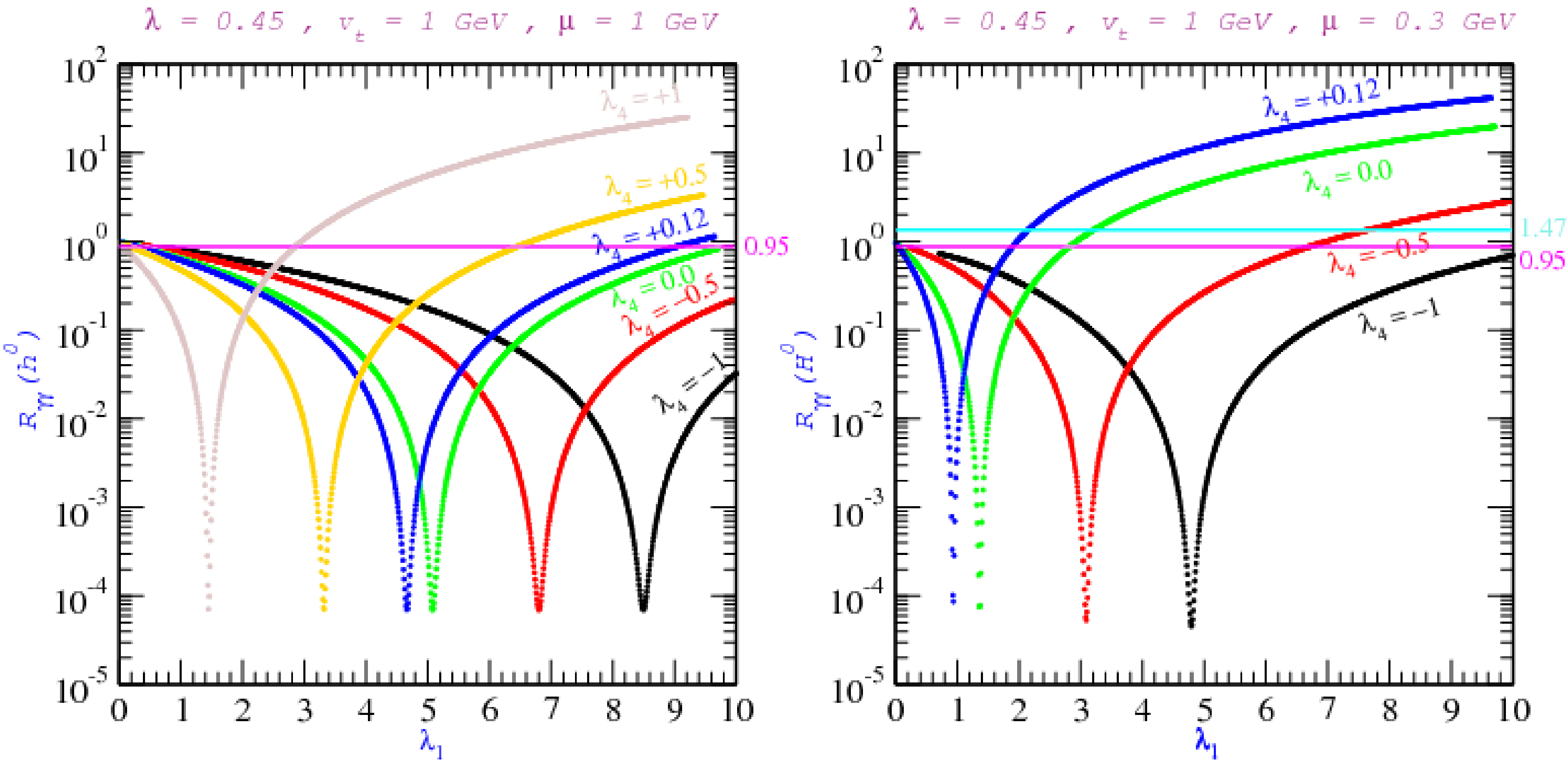
$$R_{\gamma\gamma}(H) = \frac{\{\sigma(gg \to H) \times Br(H \to \gamma\gamma)\}^{DTHM}}{\{\sigma(gg \to H) \times Br(H \to \gamma\gamma)\}^{MSM}}$$

which can be viewed as an estimate of the ratio of HTM to SM of the gluon fusion Higgs production cross section with a Higgs decaying into a photon pair.

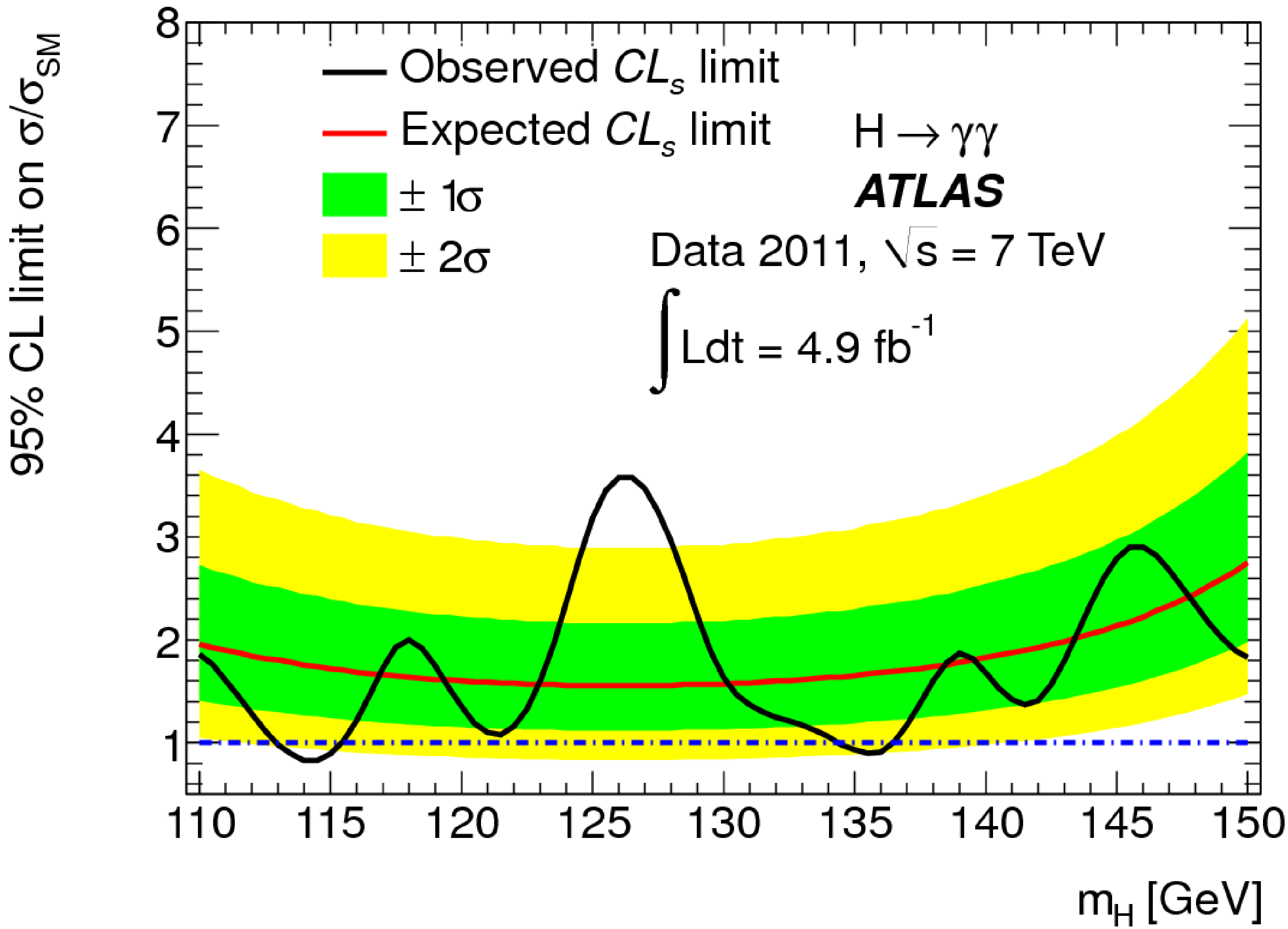
Decay into 2 photons in the HTM



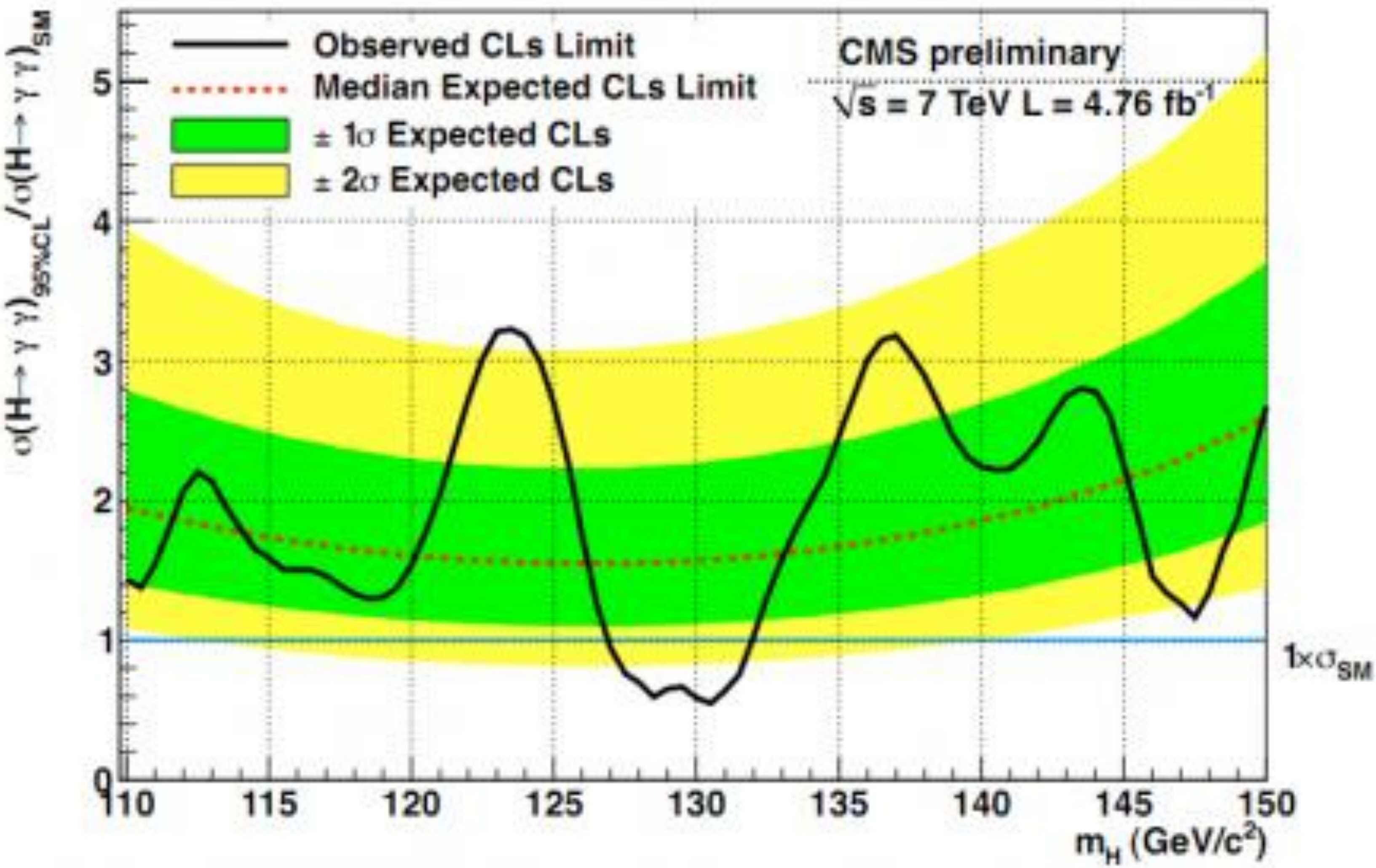
Decay into 2 photons in the HTM



Diphoton channel : ATLAS



Diphoton channel : CMS



Summary

- HTM is motived by neutrino masses and involves only a few model parameters in the Higgs sector, rendering the model relatively predictive.
- The HTM potential is described by 7 parameters
- We derive the full set of tree level unitarity and BFB constraints.
- HTM is still survay and is not excluded by the experimental data.
- We have studied the phenomenology of the HTM model by examining the diphoton channel decay, and it branching ratio taking into account the latest experimental limits and results.
- Possibility that the $H^\circ \rightarrow h^\circ h^\circ$ process take place for some regions in the space parameters.

bibliography

[1] A. Arhrib et al., Phys. Rev. D 84 (2011) 095005 [arXiv:1105.1925]
[2] A. Arhrib et al., JHEP (2012) [arXiv:1112.5453]