Implications of an Enhanced Diphoton Decay Width of the Higgs

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International Conference on New Frontiers in Physics, Crete, June 11,2012

Based on the following works :

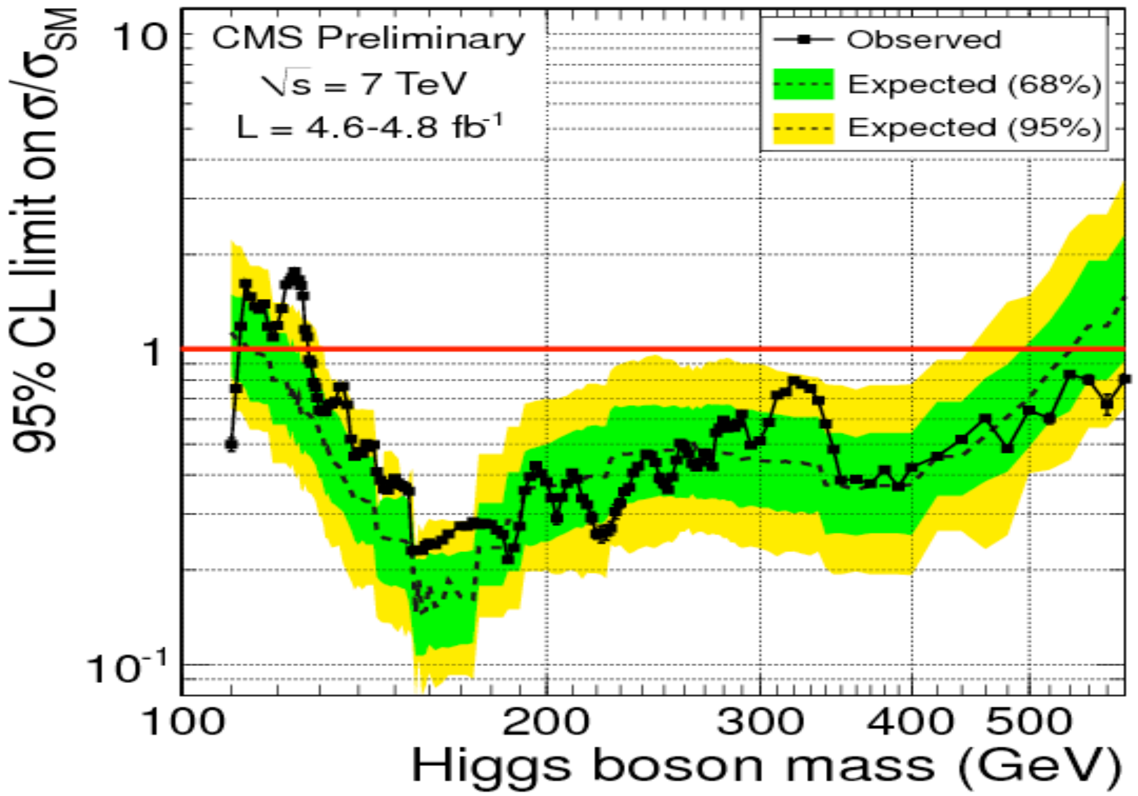
M. Carena, I. Low and C.E.M. Wagner, arXiv:1206.1082

M. Carena, S. Gori, N. R. Shah and C.E.M. Wagner, arXiv:1112.3336, JHEP 1203:014,2012.

M. Carena, S. Gori, N.R. Shah, L.T. Wang and C.W. , arXiv:1205.5842

P. Schwaller, A. Joglekar and C.E.M. Wagner, to appear

Full mass range



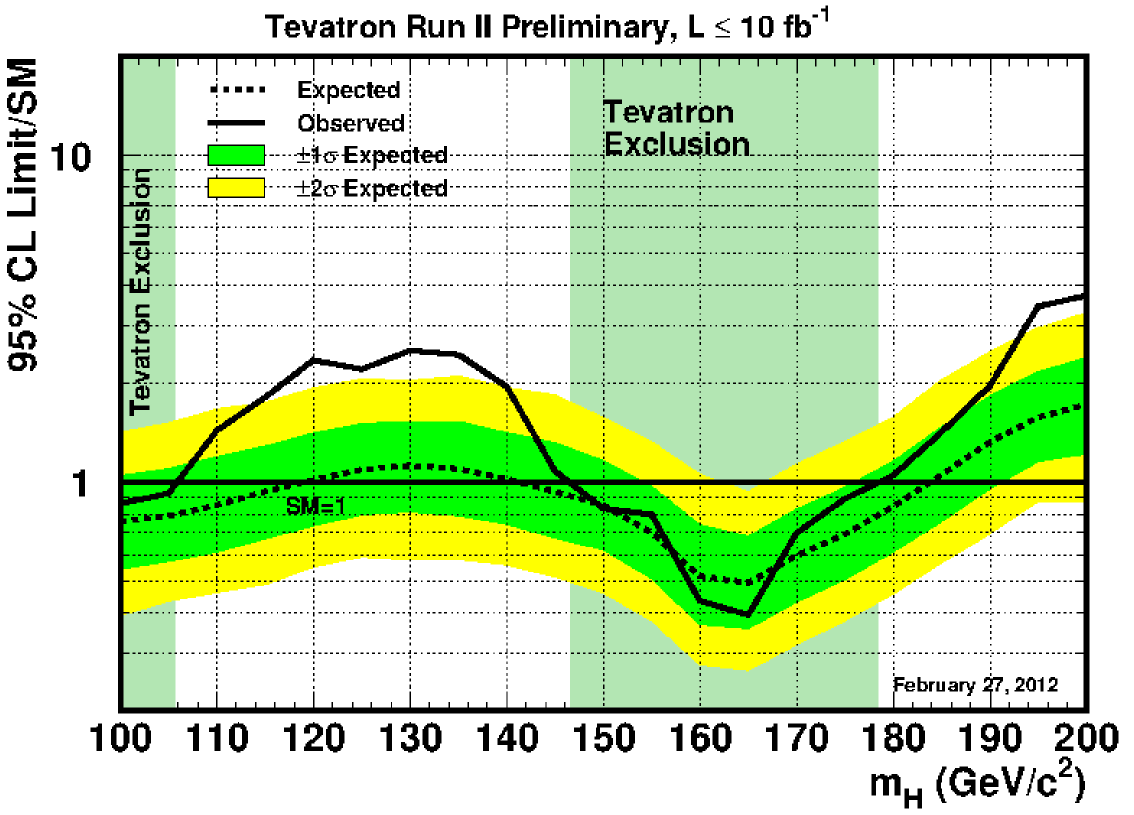
Observed: 95% exclusion M_H in [127.5-600] GeV

We are living in exciting times:

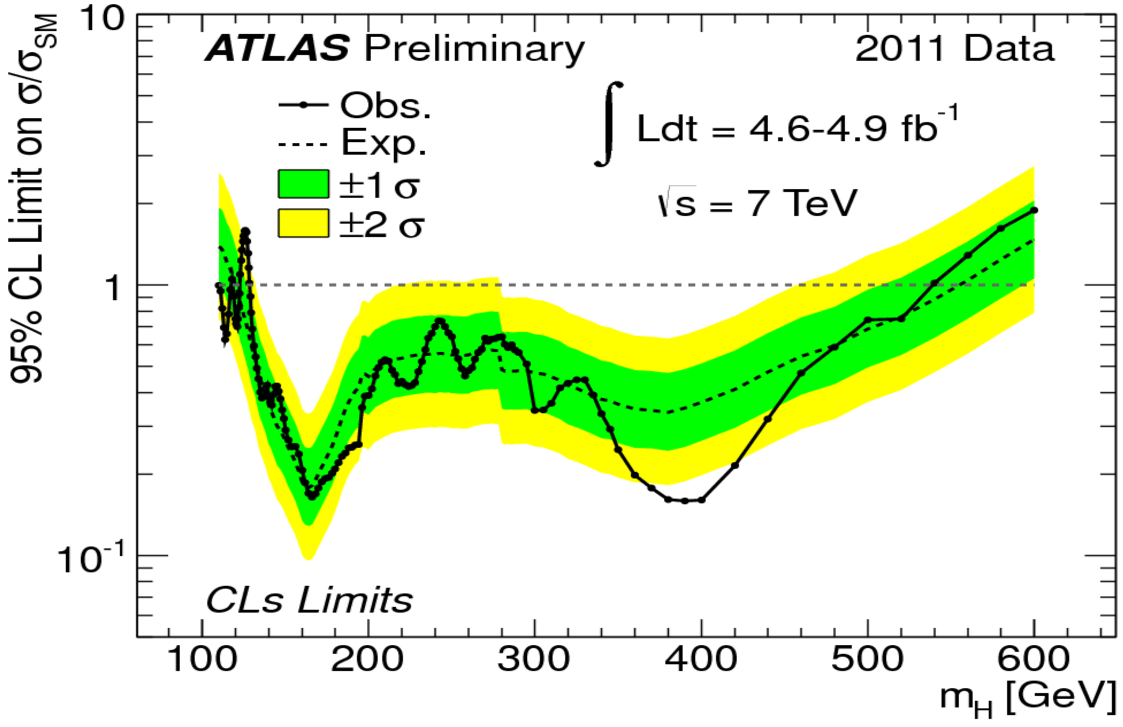
LHC and Tevatron Experiments are starting to test the SM Higgs above the LEP limit, leading to interesting exclusion bounds on its mass.

Strong limits are being set on a moderately heavy SM-like Higgs.

A light SM-like Higgs, is beginning to be probed by present data.



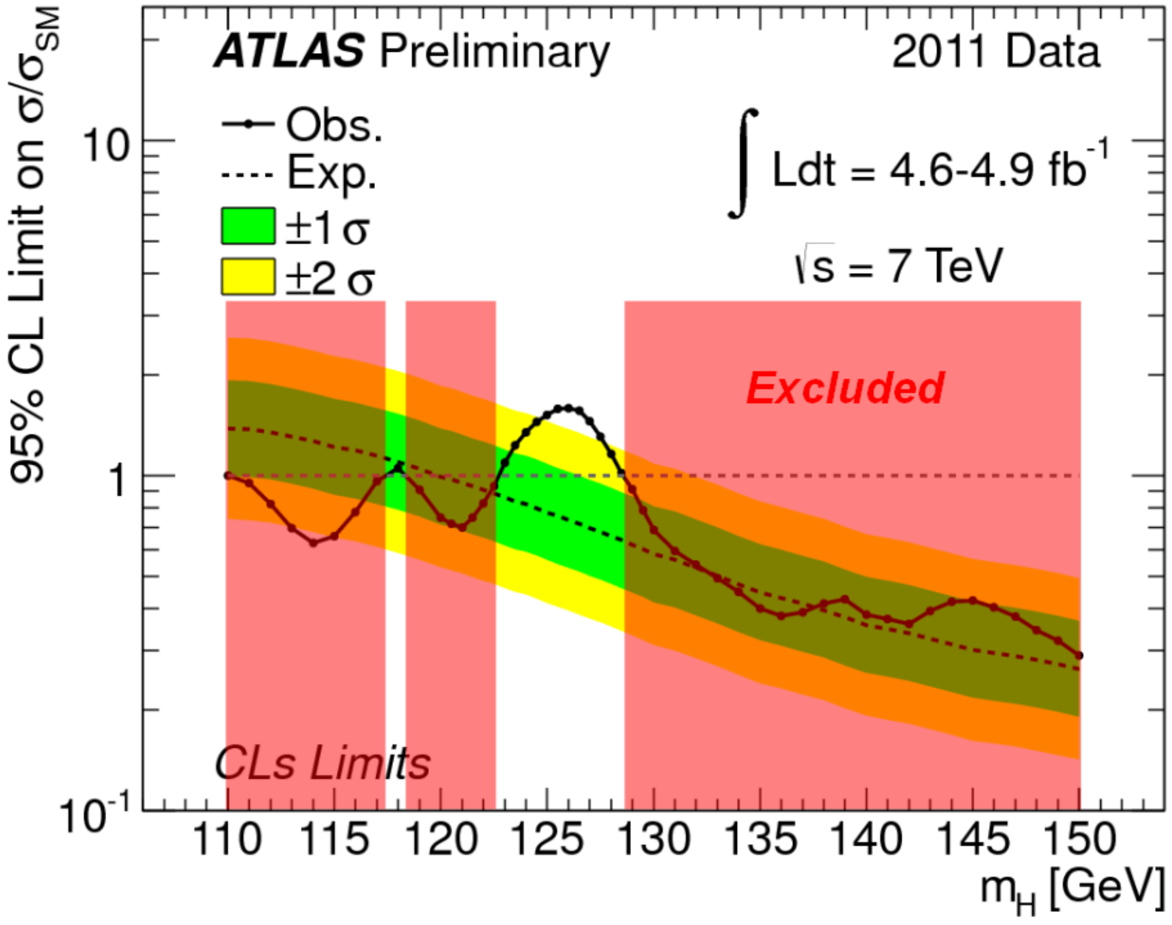
Observed exclusion: **100 < M_H < 106 GeV** 147 < M_H < 179 GeV



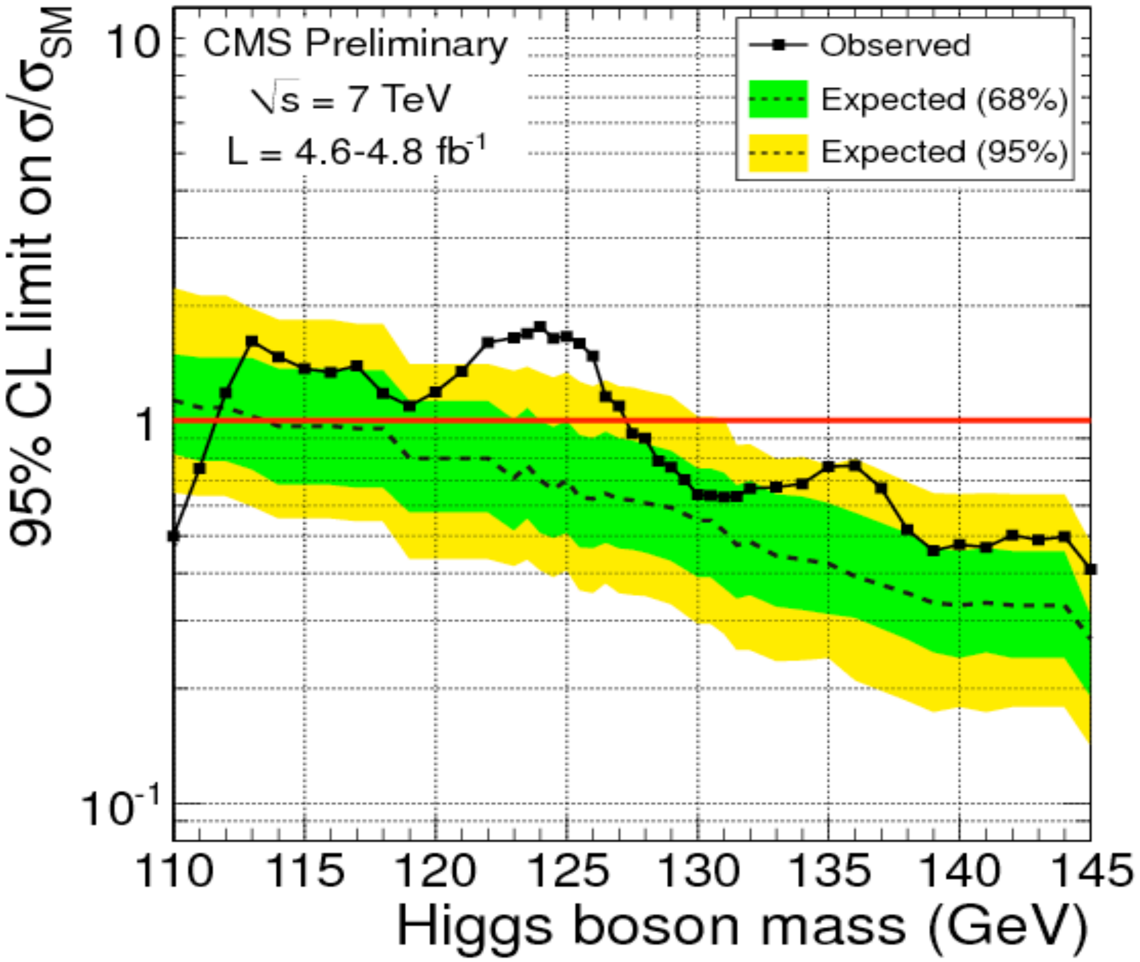
Observed exclusion at 95% CL: 110-117.5, 118.5-122.5, 129-539 GeV

Zoom on the low Higgs Mass

Zoom in:

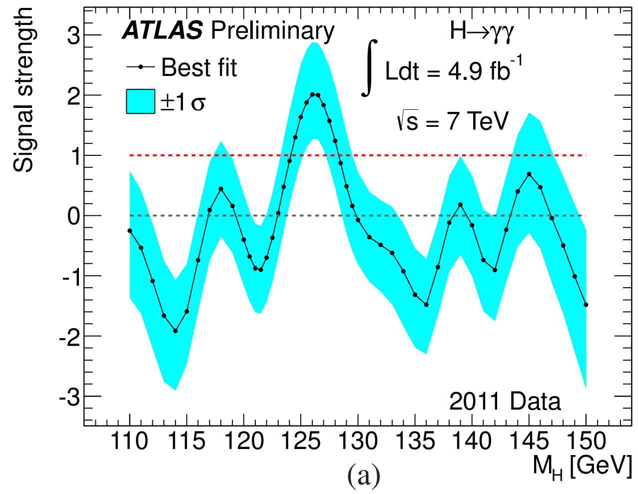


Low mass region

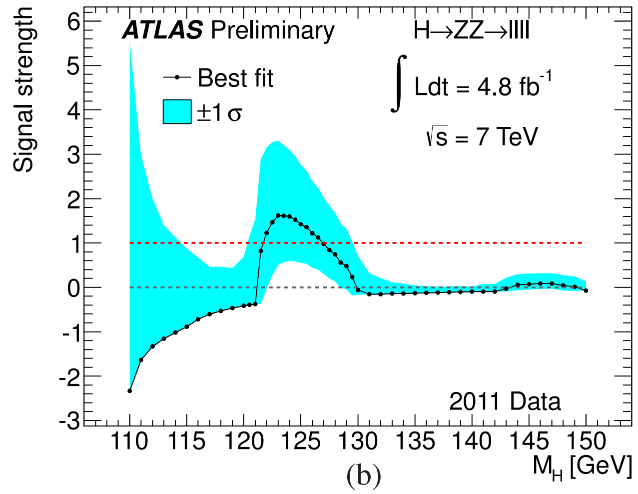


If the Higgs is SM-like, mass range between 115 GeV and 130 GeV is preferred both from direct searhes as well as from indirect precision tests. Interesting excess in the region of Higgs masses close to 125 GeV.

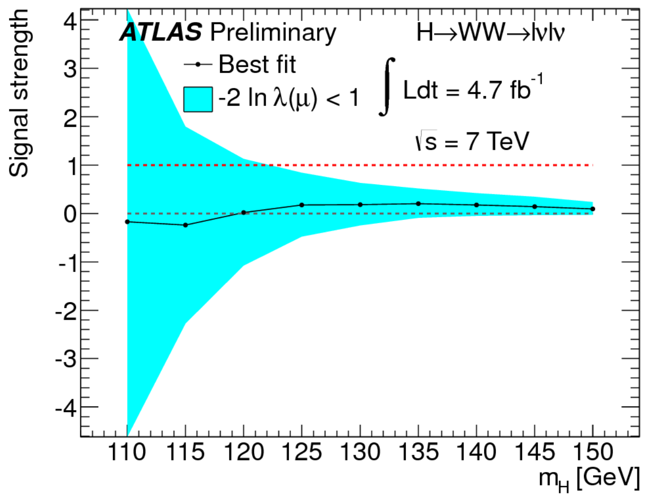
The diphoton rate looks somewhat high at this point, but more data are necessary in order to reach a robust conclusion on this relevant issue

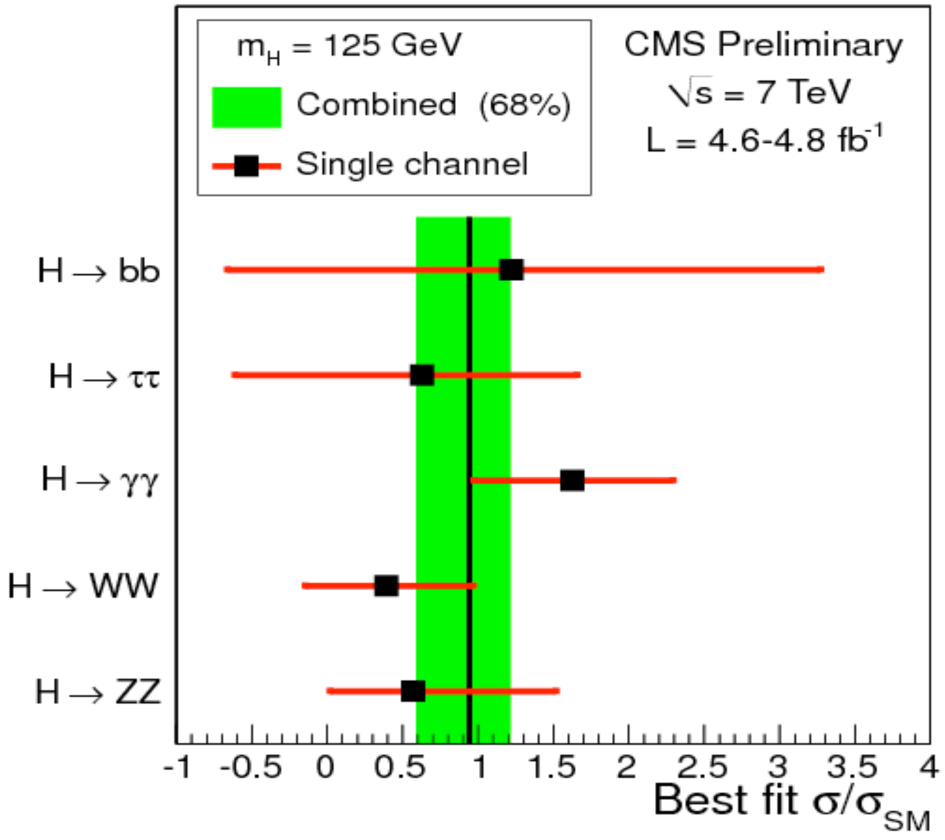


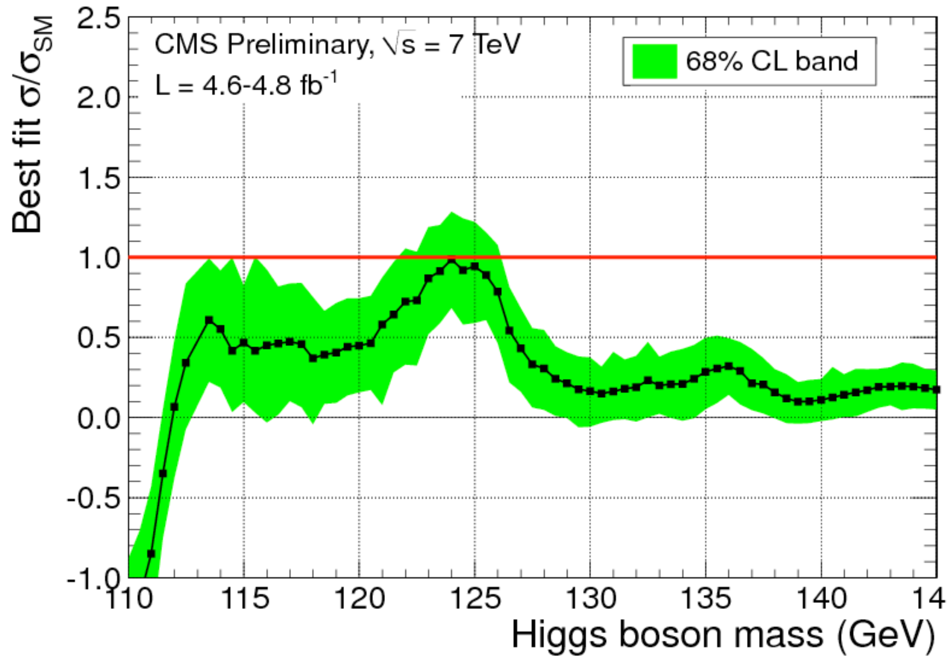
(a)



(b)

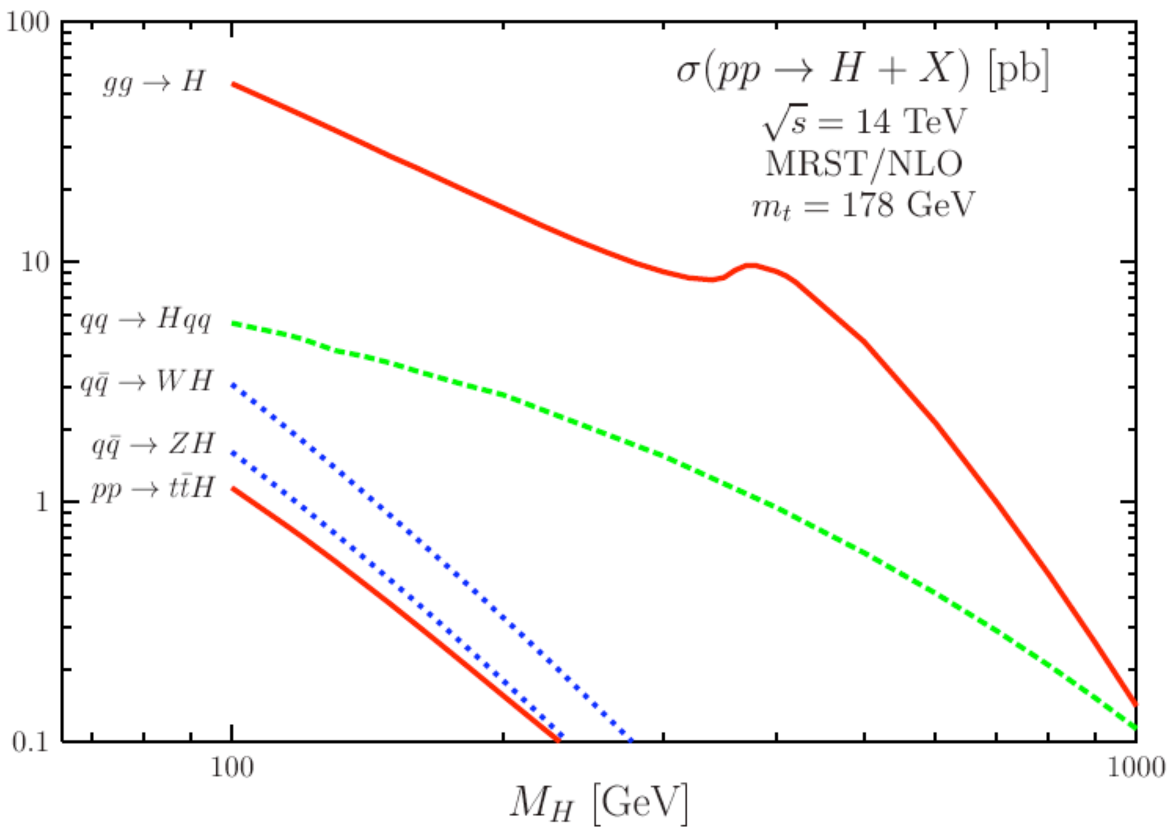


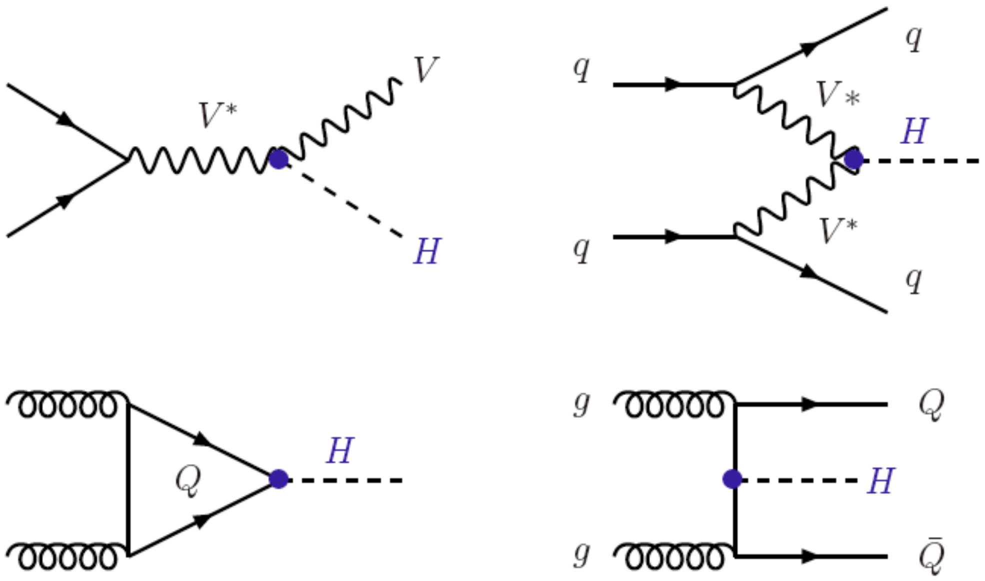




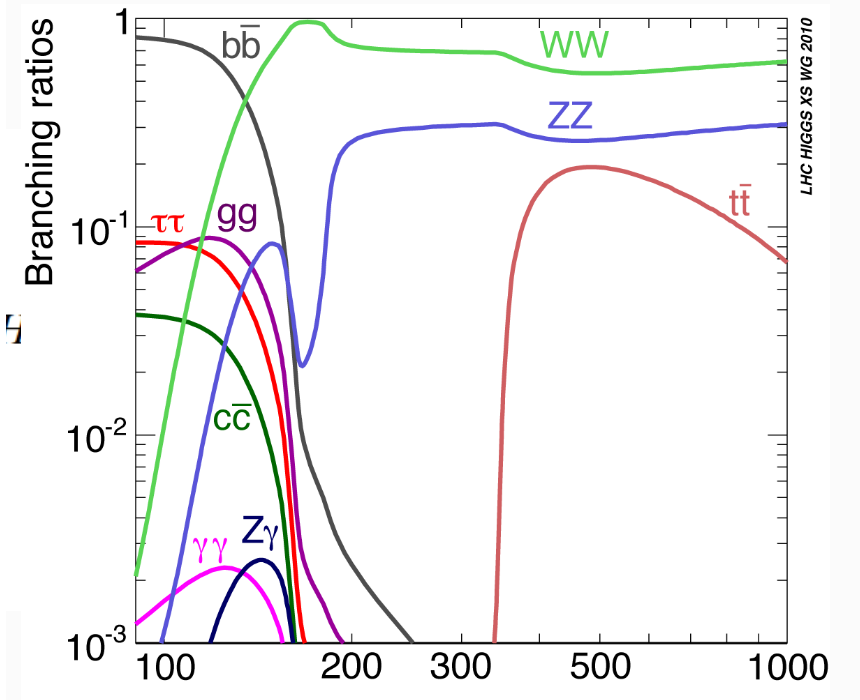
What would be the Implications of an Enhanced Diphoton Production Rate ?

Main Higgs Production channels at Hadron Colliders





A. Djouadi, 0503172

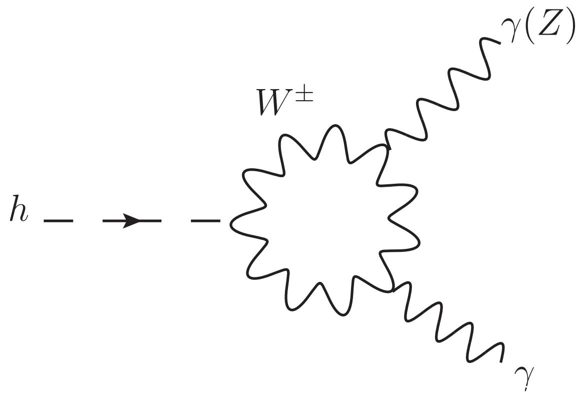


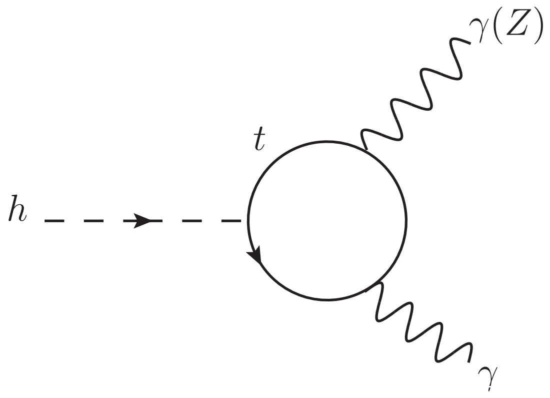
The event rate depends on three quantities

$$B\sigma(p\bar{p} \to h \to X_{\rm SM}) \equiv \sigma(p\bar{p} \to h)\frac{\Gamma(h \to X_{\rm SM})}{\Gamma_{\rm total}}$$

In this talk, we shall concentrate on diphoton rate enhancement induced by a modified width of the Higgs decaying to diphotons.

Dominant Contributions to the Diphoton Width in the Standard Model





Similar corrections appear from other scalar, fermion or vector particles. Clearly, similarly to the top quark, chiral fermions tend to reduce the vector boson contributions

Higgs Diphoton Decay Width in the SM

$$\Gamma(h \to \gamma\gamma) = \frac{G_F \alpha^2 m_h^3}{128\sqrt{2}\pi^3} \left| A_1(\tau_w) + N_c Q_t^2 A_{1/2}(\tau_t) \right|^2 \qquad \tau_i \equiv 4m_i^2/m_h^2$$

A. Djouadi'05

For particles much heavier than the Higgs boson

$$A_1 \to -7\ , \qquad N_c Q_t^2\, A_{1/2} \to \frac{4}{3} N_c Q_t^2 \ \simeq 1.78, \quad \text{for } N_c = 3, Q_t = 2/3$$

In the SM, for a Higgs of mass about 125 GeV

$$m_h = 125 \ \ \text{GeV}: \ A_1 = -8.32\ , \quad N_c Q_t^2 A_{1/2} = 1.84$$

Dominant contribution from W loops. Top particles suppress by 40 percent the W loop contribution. One can rewrite the above expression in terms of the couplings of the particles to the Higgs as :

$$\Gamma(h \to \gamma\gamma) = \frac{\alpha^2 m_h^3}{1024\pi^3} \left| \frac{g_{hWW}}{m_W^2} A_1(\tau_w) + \frac{2 g_{ht\bar{t}}}{m_t} N_c Q_t^2 A_{1/2}(\tau_t) + N_c Q_S^2 \frac{g_{hSS}}{m_S^2} A_0(\tau_S) \right|^2$$

Inspection of the above expressions reveals that the contributions of particles heavier than the Higgs boson may be rewritten as

$$\mathcal{L}_{h\gamma\gamma} = -\frac{\alpha}{16\pi}\frac{h}{v}\left[\sum_i 2b_i \frac{\partial}{\partial \log v}\log m_i(v)\right] F_{\mu\nu}F^{\mu\nu}$$

$$\left\{ \begin{array}{lll} b & = \frac{4}{3}N_c Q^2 & \text{for a Dirac fermion ,} \\ b & = -7 & \text{for the } W \text{ boson ,} \\ b & = \frac{1}{3}\,N_c Q_S^2 & \text{for a charged scalar .} \end{array} \right.$$

where in the Standard Model

$$\frac{g_{hWW}}{m_W^2} = \frac{\partial}{\partial v}\log m_W^2(v)\ , \qquad \frac{2g_{ht\bar{t}}}{m_t} = \frac{\partial}{\partial v}\log m_t^2(v)$$

This generalizes for the case of fermions with contributions to their masses independent of the Higgs field. The couplings come from the vertex and the inverse dependence on the masses from the necessary chirality flip (for fermions) and the integral functions.

$$\mathcal{L}_{h\gamma\gamma} = \frac{\alpha}{16\pi}\frac{h}{v}\left[\sum_i b_i \frac{\partial}{\partial \log v}\log\left(\det \mathcal{M}_{F,i}^{\dagger}\mathcal{M}_{F,i}\right) + \sum_i b_i \frac{\partial}{\partial \log v}\log\left(\det \mathcal{M}_{B,i}^2\right)\right] F_{\mu\nu}F^{\mu\nu}$$

Ellis, Gaillard, Nanopoulos'76, Shifman, Vainshtein, Voloshin, Zakharov'79

For bosons one simply replaces the square of the mass matrix by the mass matrix of the square masses ! Since the Higgs is light and charged particles are constrained by LEP to be of mass of order of, or heavier than the Higgs, this expression provides a good understanding of when particles could lead to an enhanced diphoton rate.

A New Scalar with Q = 1

New charged scalars, with significant couplings to the Higgs may also contribute to the loop

Battel, Gori, Wang'11

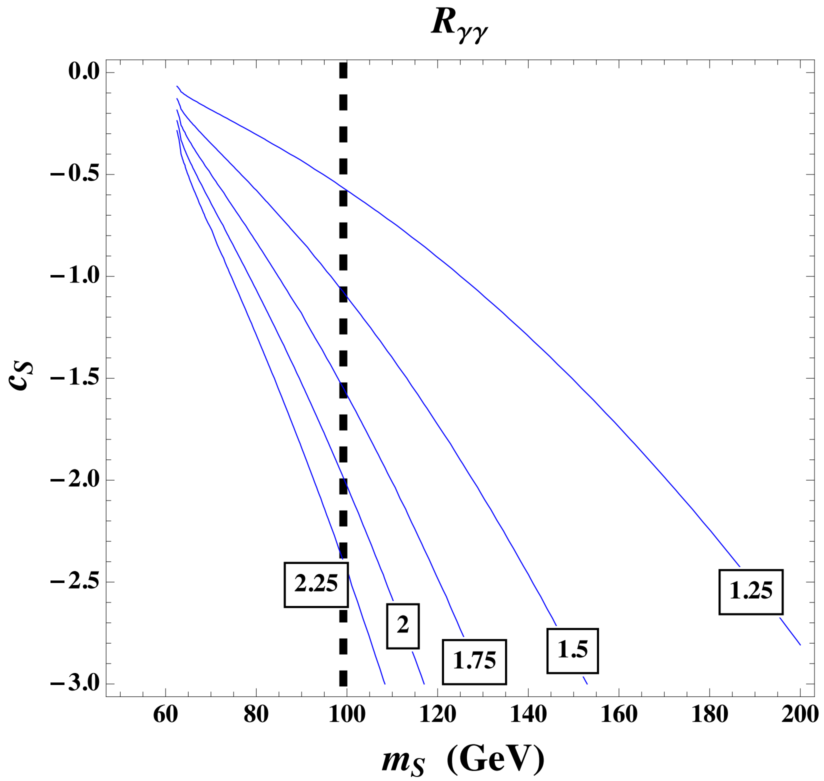
$$m_S^2 = m_{S0}^2 + \frac{1}{2} c_S\, v^2 \qquad \mathcal{O}_S = c_S H^\dagger H\, |S|^2$$

For a single scalar, if one does the ratio of the diphoton width to the SM one, one gets

$$R_{\gamma\gamma} = \left| 1 + \frac{c_S}{2} \frac{v^2}{m_S^2} \frac{A_0(\tau_S)}{A_1(\tau_w) + N_c Q_t^2\, A_{1/2}(\tau_t)} \right|^2$$

Negative values of the effective coupling c_S are necessary

M. Carena, I. Low, C.W., arXiv:1206.1082



$$R_{\gamma\gamma} \simeq \left| 1 - \frac{c_S}{39} \frac{v^2}{m_S^2} \right|^2$$

For scalars heavier than the Higgs. Coefficient 1/39 grows for lighter scalars, up to a value of about 1/30 for mS about 100 GeV

Enhancements of order fifty percent to factor 2 can be obtained for light particles.

Scalar Mass Bounds

The mass of the scalar necessary to produce a given enhancement depends on its charge and on the number of degrees of freedom. Due to the weak dependence of the amplitudes with the mass, it approximately scales like

$$m_S^2 \simeq \sqrt{\tilde{N}_{c,S}}\, |Q_S| \left(m_S^2\right)_{\tilde{N}_c = Q_S = 1} .$$

Vacuum Stability

Negative couplings induce new charge color minima in the potential

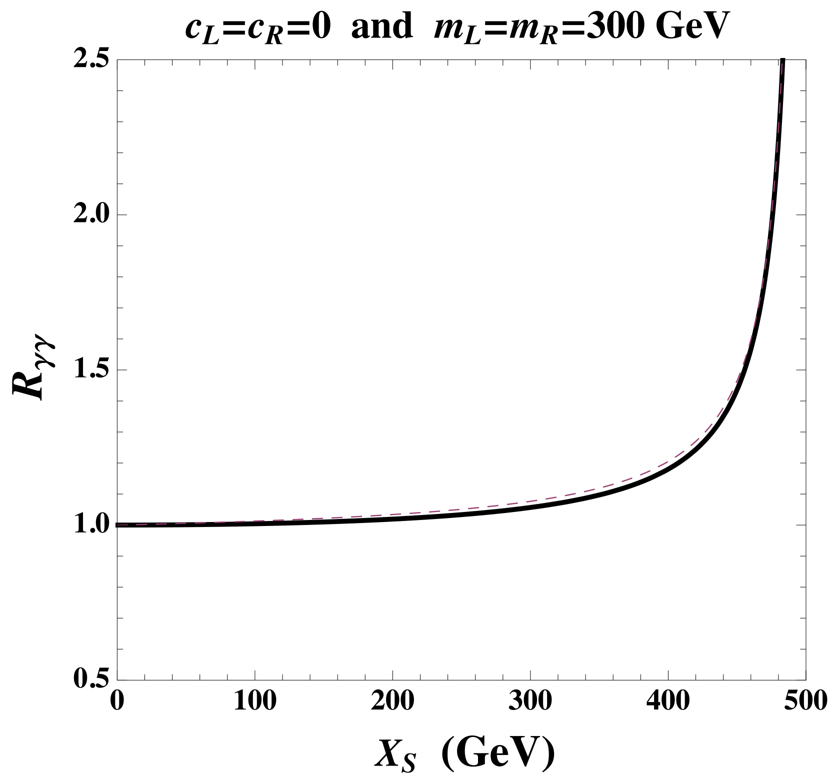
$$V(S,H) \supset -|c_S||H^\dagger H||S^\dagger S| + \frac{\lambda}{2}|H^\dagger H|^2 + \frac{\lambda_S}{2}|S^\dagger S|^2$$

For instance, the renormalizable potential becomes unbounded from below if.

$$|c_S|^2 < \lambda_S \lambda$$

Therefore, values of c_S larger than one may lead to unstable or metastable vacuua.

Two Scalars with Mixing


$c_L = c_R = 0$ and $m_L = m_R = 300$ GeV

Similar to light stau scenario,

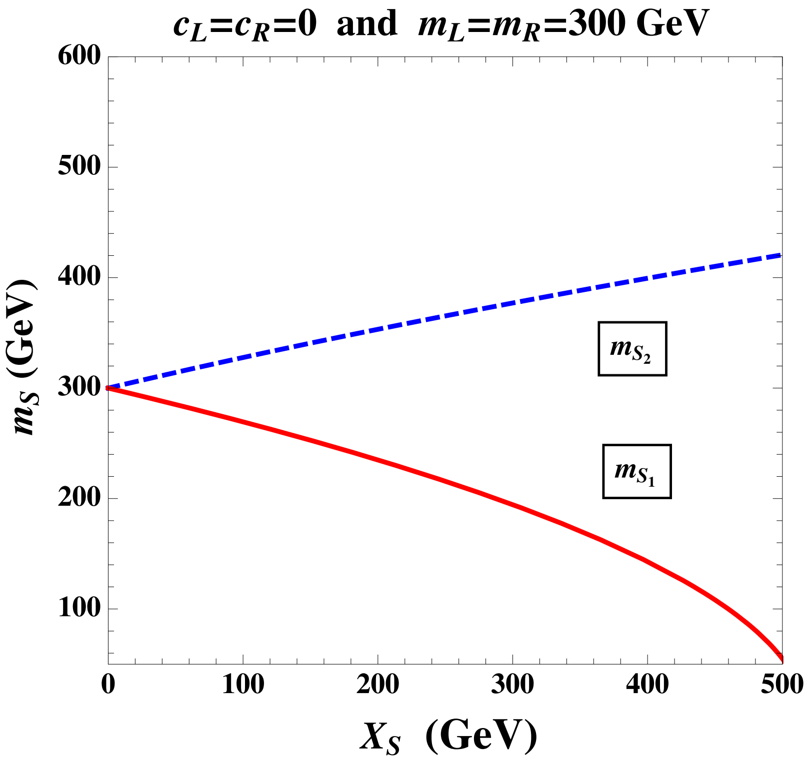
M. Carena, S. Gori, N. Shah, C.W., arXiv: 1112.3336,
M. Carena, S. Gori, N. Shah, C.W., L.T. Wang, arXiv:1205.5842

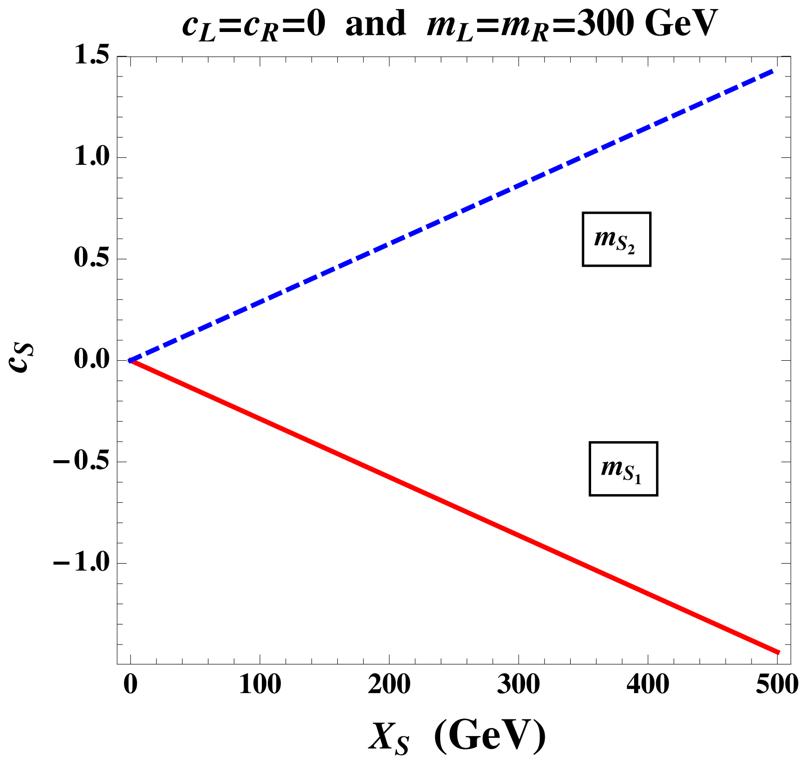
$$\mathcal{M}_S^2 = \begin{pmatrix} \tilde{m}_L(v)^2 & \frac{1}{\sqrt{2}} v X_S \\ \frac{1}{\sqrt{2}} v X_S & \tilde{m}_R(v)^2 \end{pmatrix}$$

$$\frac{\partial \log(\mathrm{Det} M_S^2)}{\partial v} \simeq -\frac{X_S^2 v}{m_{S_1}^2 m_{S_2}^2}$$

Negative Effective Coupling of lightest scalar

Large mixing and small value of the lightest scalar mass preferred


$c_L = c_R = 0$ and $m_L = m_R = 300$ GeV


$c_L = c_R = 0$ and $m_L = m_R = 300$ GeV

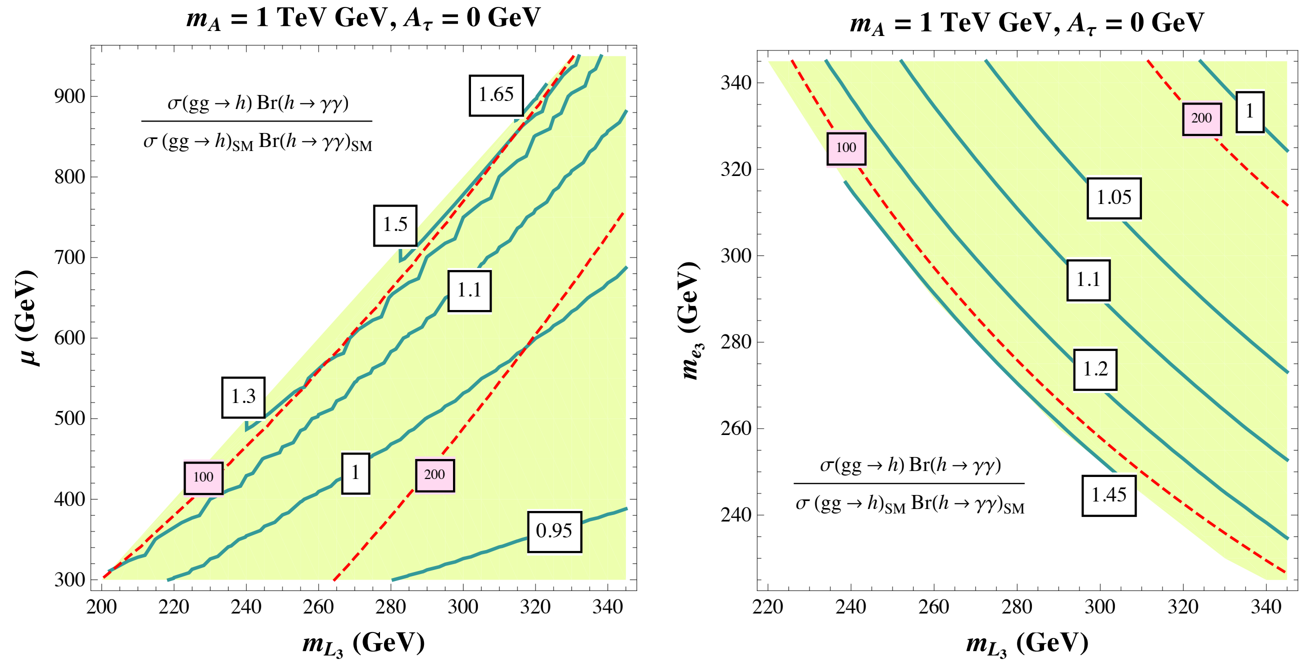
Lightest scalar, with mass below 200 GeV gives the dominant contribution in this case.

M. Carena, I. Low, C.W., arXiv:1206.1082

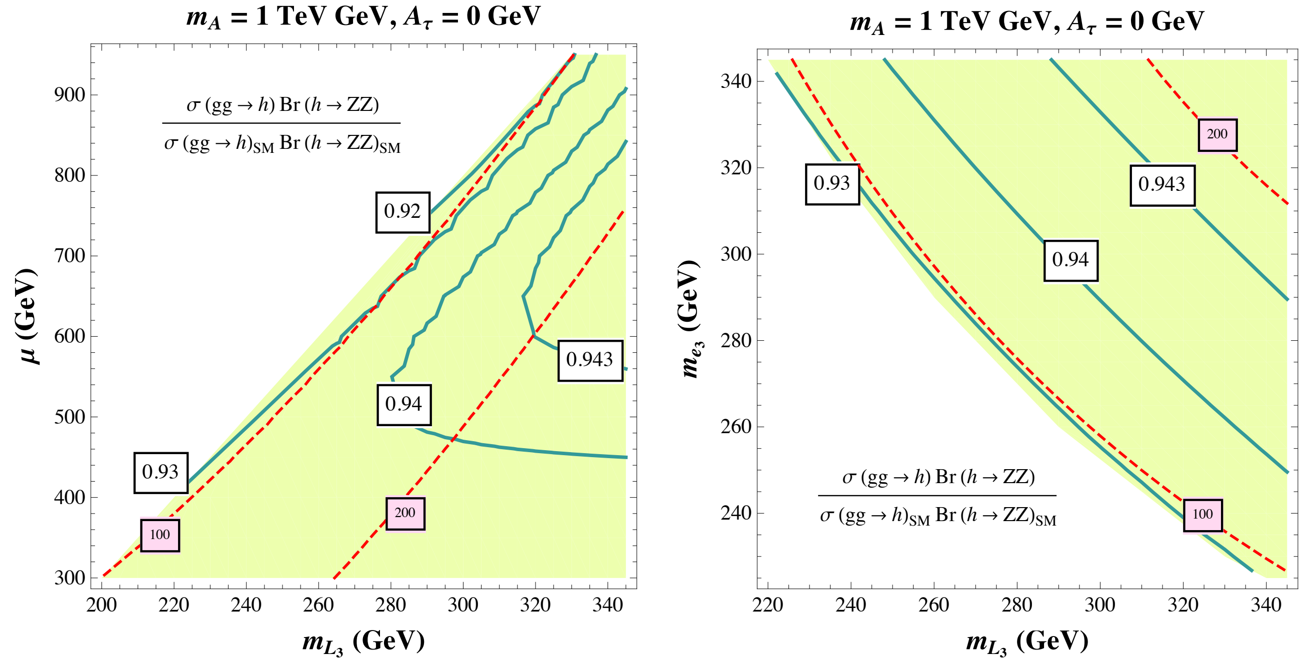
Light Staus, large $\tan\beta$ and the BR($h \to \gamma\gamma$)

M. Carena, S. Gori, N. Shah, C.W., arXiv:1112.3336

Light staus, with large mixing, may induce a relevant enhancement of the branching ratio of the decay of a the SM-like Higgs into two photons, without affecting other decays



$\mu = 650$ GeV, $\tan\beta = 60$



Dashed lines represent the countors of equal stau mass

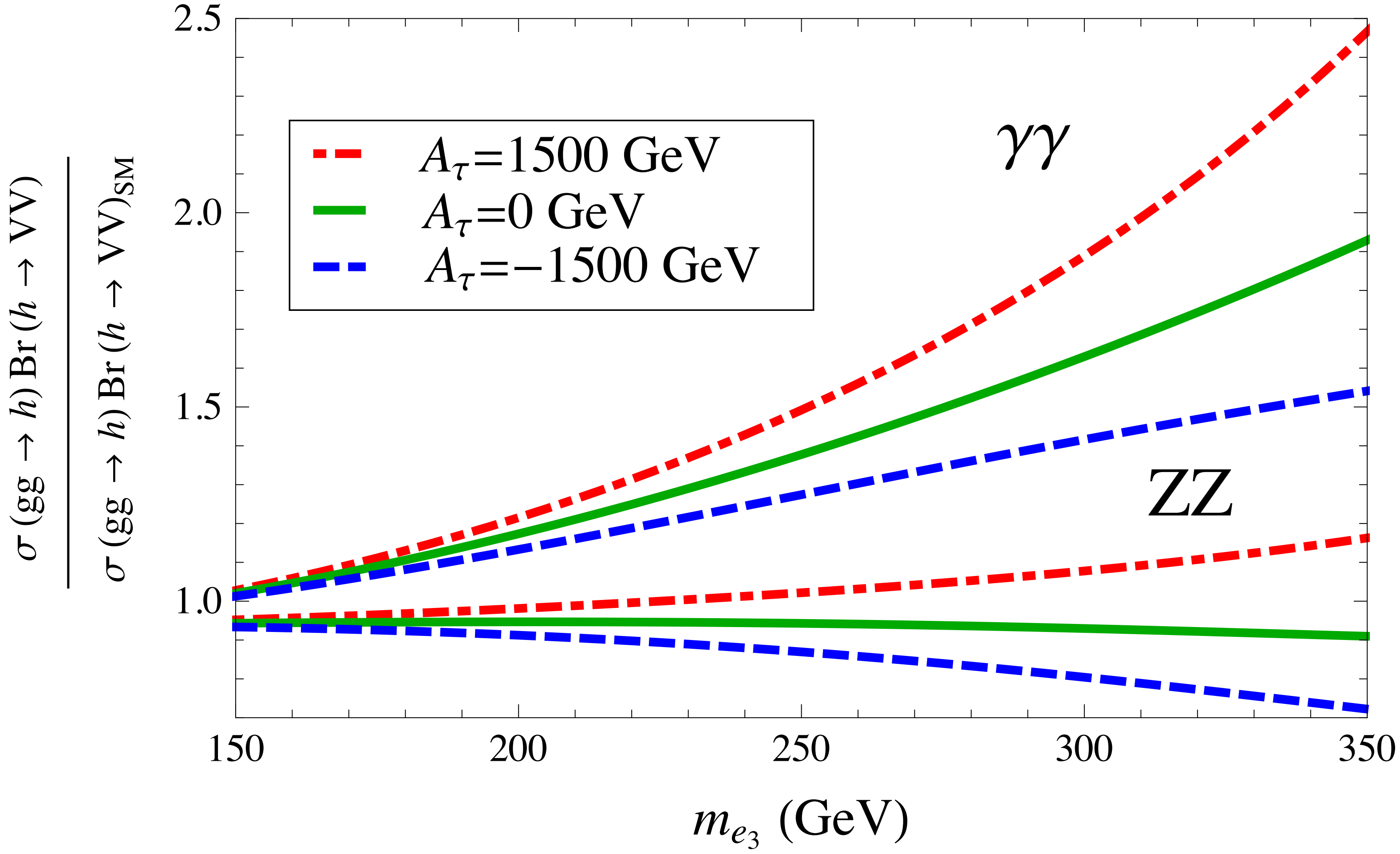
M. Carena, S. Gori, N. Shah, C.W., L.T.Wang, arXiv:1205.5842

M. Carena's talk

Combination with Modified bottom quark width Correlation with other channels.

$m_A = 1\text{TeV}$

M. Carena, S. Gori, N. Shah, C.W., L.T. Wang, arXiv:1205.5842



Depending on the values of the CP-odd Higgs mass, models with enhanced Higgs diphoton and slightly (bottom) and suppressed ZZ and W rates may be obtained.

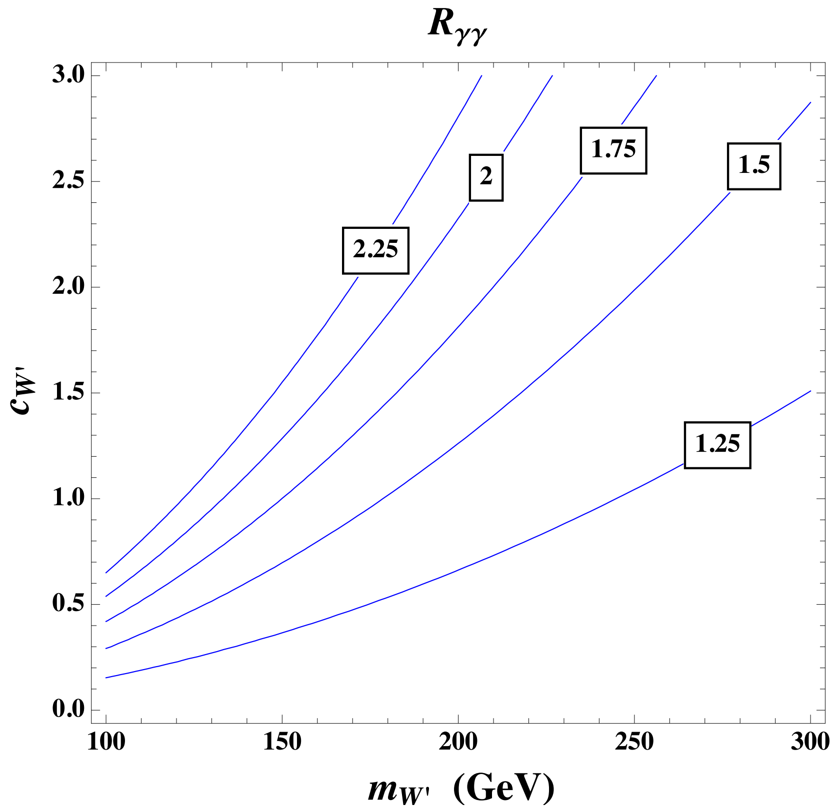
A new W' Gauge Boson

The simplest way of enhancing the rate, although strongly constrained phenomenologically, is a new charged gauge boson with mass :

$$m_{W'}(v)^2 = m_{W0}^2 + c_{W'}\, m_W^2 \ , \qquad c_{W'} > 0$$

M. Carena, I. Low, C.W., arXiv:1206.1082

$$\mathcal{O}_{W'} = \frac{1}{2} c_{W'} g^2 H^\dagger H\, W'^{+}_{\mu} W'^{-\mu} \ .$$



Relatively light gauge bosons with couplings significantly larger than the SM ones are required. Coupling of quarks and leptons would rule out these gauge bosons.

A "parity" could be imposed, disallowing linear couplings of these gauge bosons. Precision measurements would still demand new physics for these bosons to be allowed.

New, Vector like Fermion

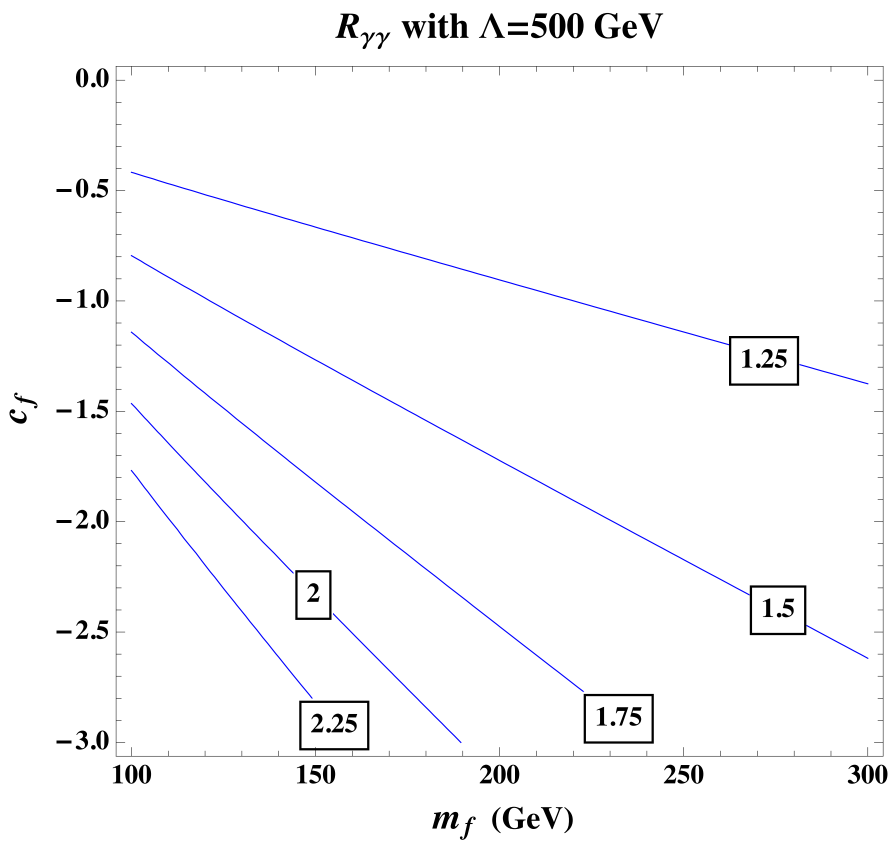
Let us parametrize the mass by

$$m_f = m_{f0} + c_f \frac{v^2}{2\Lambda}$$

Negative effective couplings are necessary (as obtained from the integration of heavy fermion)

M. Carena, I. Low, C.W., arXiv:1206.1082

$$R_{\gamma\gamma} = \left| 1 + c_f \frac{v^2}{\Lambda m_f} \frac{A_{1/2}(\tau_f)}{A_1(\tau_w) + N_c Q_t^2 \, A_{1/2}(\tau_t)} \right|^2$$



$$R_{\gamma\gamma} \simeq \left| 1 - \frac{8 c_f}{39} \frac{v^2}{m_f \Lambda} \right|^2$$

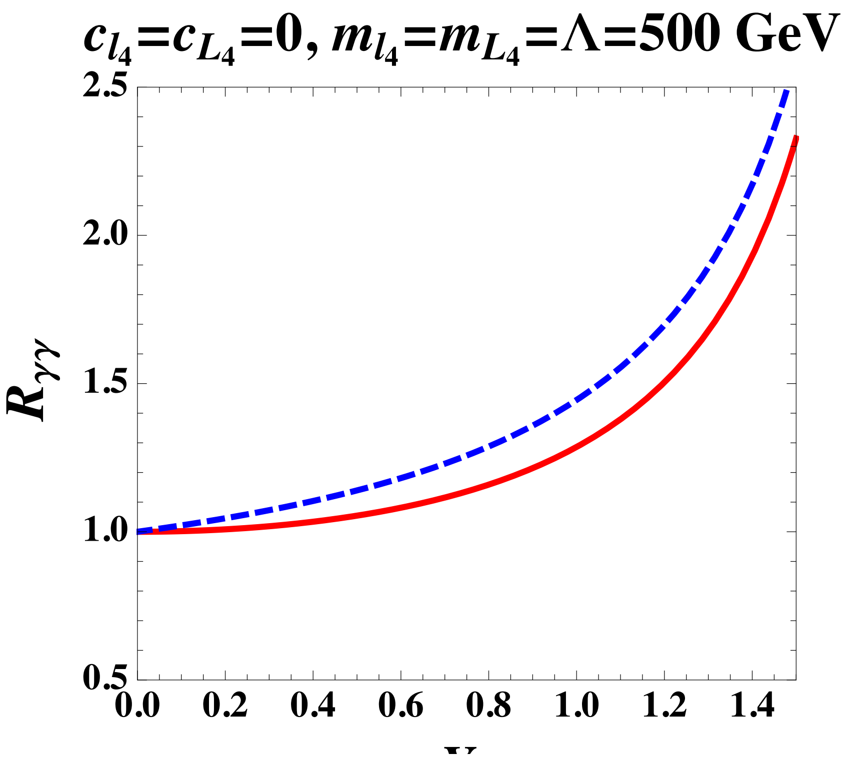
For fermions heavier than the Higgs. Coefficient only 10 percent larger for a fermion with mass about 100GeV.

Again, relatively large effective couplings and light fermions necessary in order to enhance the diphoton width in a significant way.

Vector pair of Doublets and Singlets

M. Carena, I. Low, C.W., arXiv:1206.1082

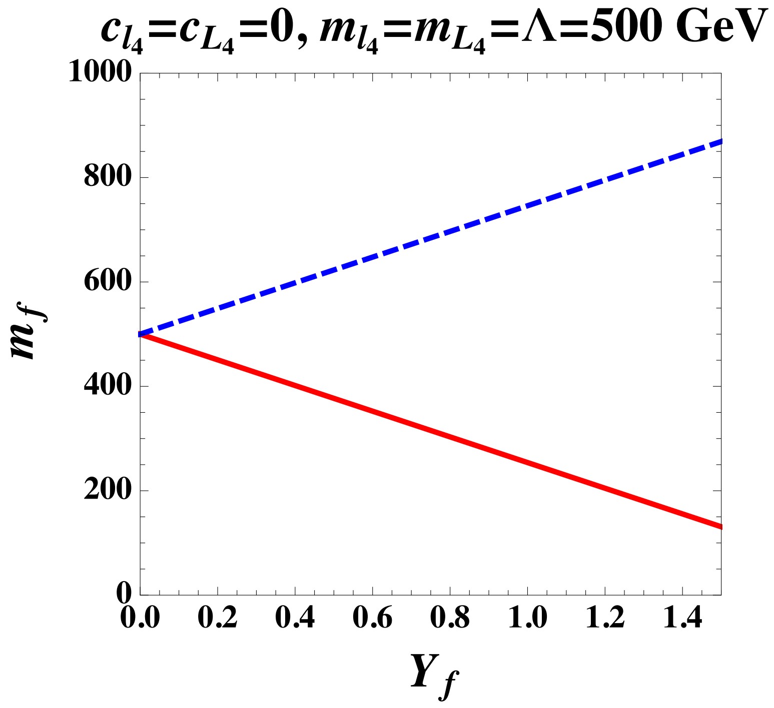
One can make the contribution of the extra fermions explicit.

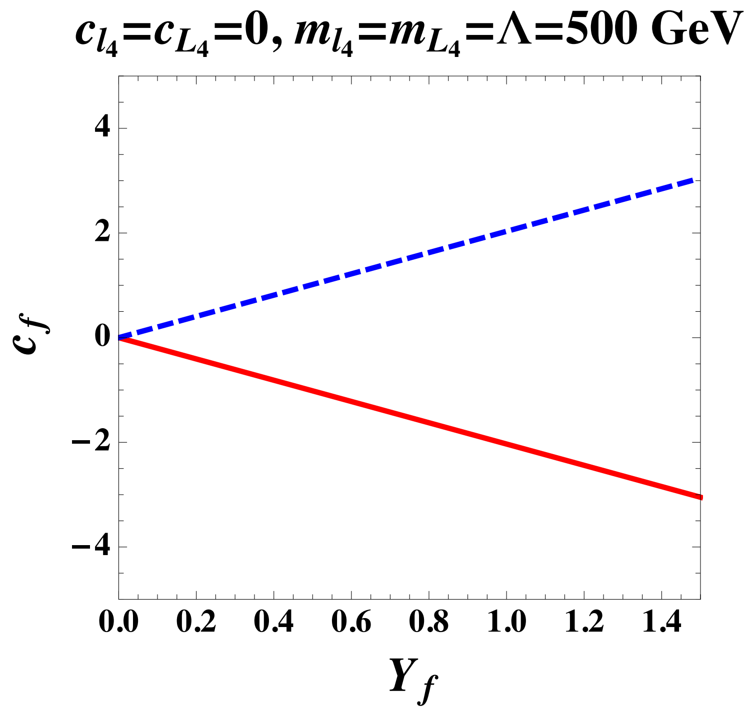


$$m_{\ell_4}(v) = m_{\ell_4 0} + c_{\ell_4}\frac{v^2}{2\Lambda}\ , \qquad m_{L_4}(v) = m_{L_4 0} + c_{L_4}\frac{v^2}{2\Lambda}$$

$$(\ell_4^c, L_4^c)\begin{pmatrix} m_{\ell_4}(v) & Y_f v \\ Y_f v & m_{L_4}(v) \end{pmatrix}\begin{pmatrix} \ell_4 \\ L_4 \end{pmatrix}$$

Lighter fermion contribution dominant

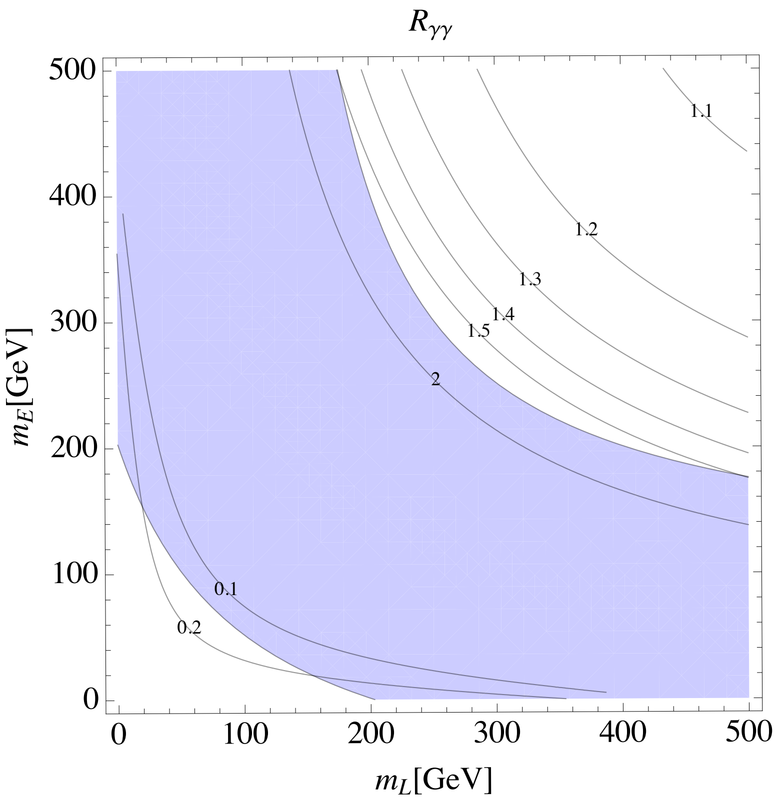




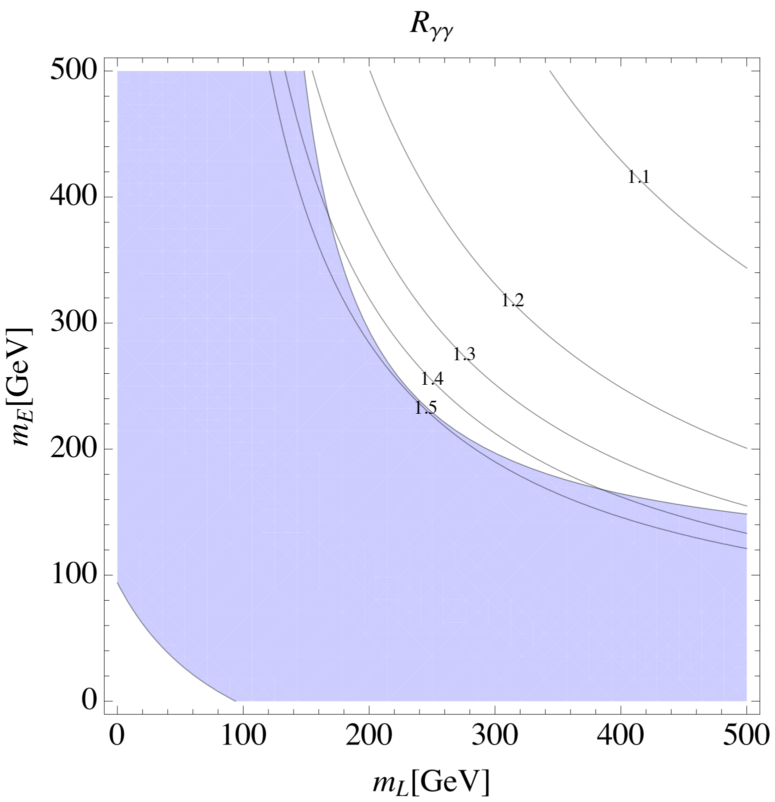
Model with a four generation leptons and their vector pairs.

Model can lead to the presence of Dark Matter and an enhanced diphoton rate

A. Joglekar, P. Schwaller, C.W.'12



$Y_C' = Y_C" = 1$



$Y_C' = Y_C" = 0.8$

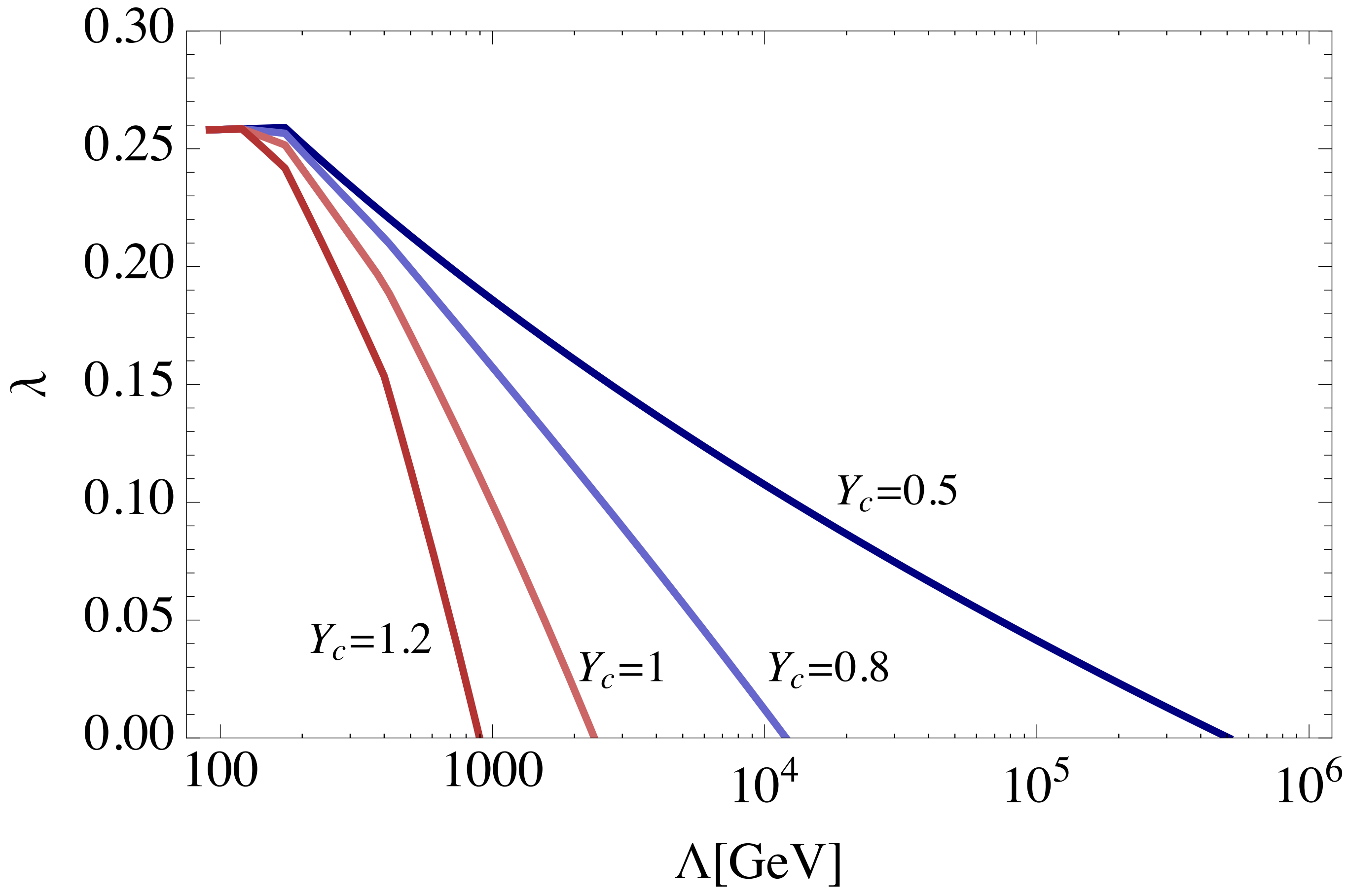
$$\mathcal{M} = \begin{pmatrix} Y_c' v & m_L \\ m_E & Y_c'' v \end{pmatrix}$$

$$\frac{\partial \log(\mathrm{Det} M_f)}{\partial v} \simeq -2 \frac{Y_C' Y_C" v}{m_L m_E - Y_C' Y_C" v^2}$$

Vacuum Stability Constraints

As happens with the top quark, once one adds further fermions with relevant couplings to the Higgs the quartic coupling becomes negative at high scales and new minima develop

A. Joglekar, P. Schwaller, C.W.'12



The scales at which
the instabilities occur
are somewhat small,
meaning that an ultratiolet
completion (SUSY ?) is
necessary at small scales

The Higgs $Z\gamma$ width

Correlation with Higgs Z photon width

There is an interesting correlation between this width and the diphoton one.

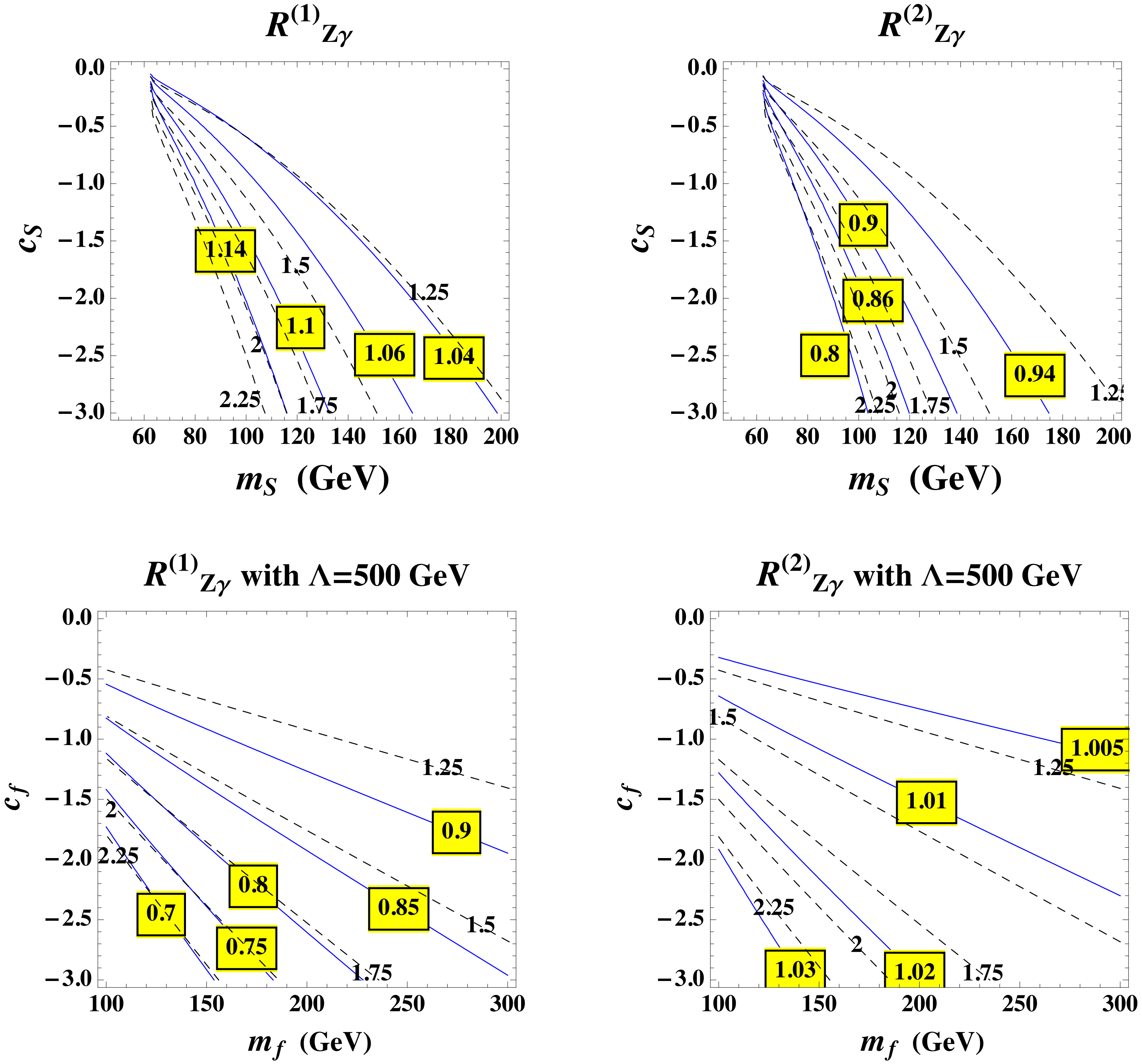
However, the coupling of scalars and fermions to the Z gauge boson is proportional to

$$T_3 - Q\sin^2\theta_W$$

which shows that unless the isospin quantum numbers are non-trivial the contribution is small.

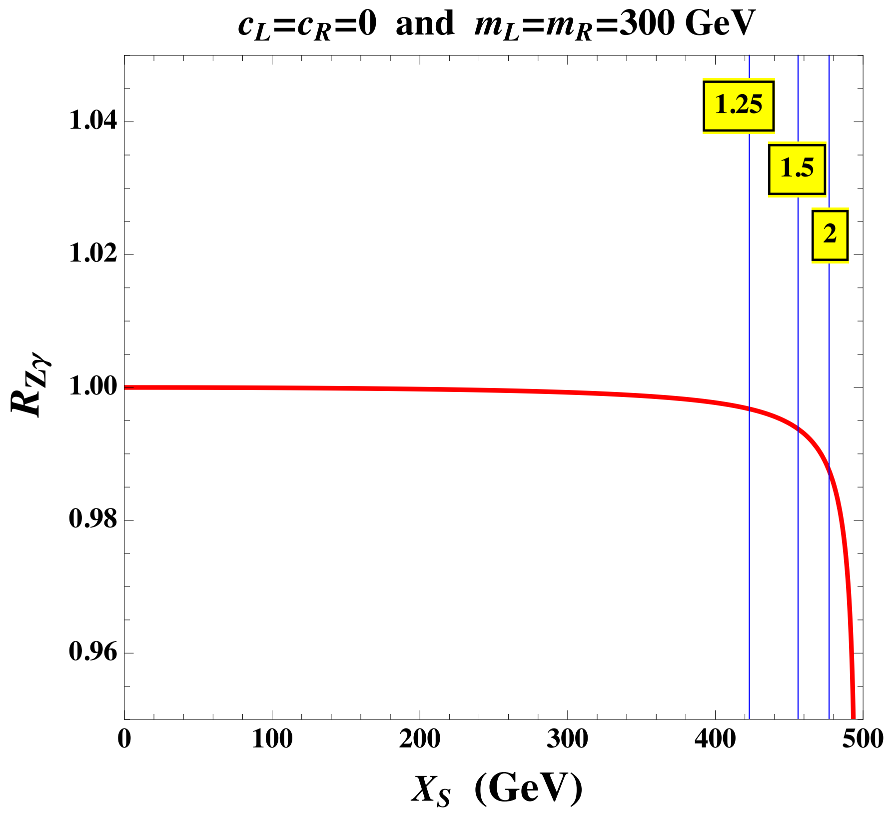
This is particularly true for models with standard scalars or (vector-like) fermions which transform as singlets and doublets of SU(2) and that mix via the Higgs v.e.v.

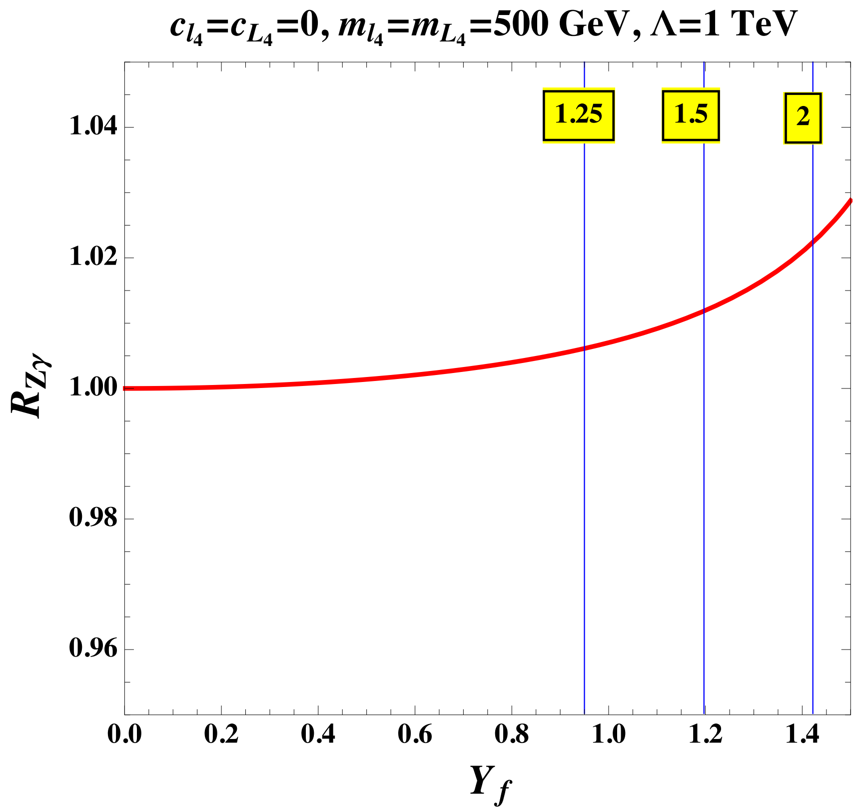
Here we show both for the models we analyze before.



M. Carena, I. Low, C.W., arXiv:1206.1082

and the same happens in the case of non-trivial mixing...

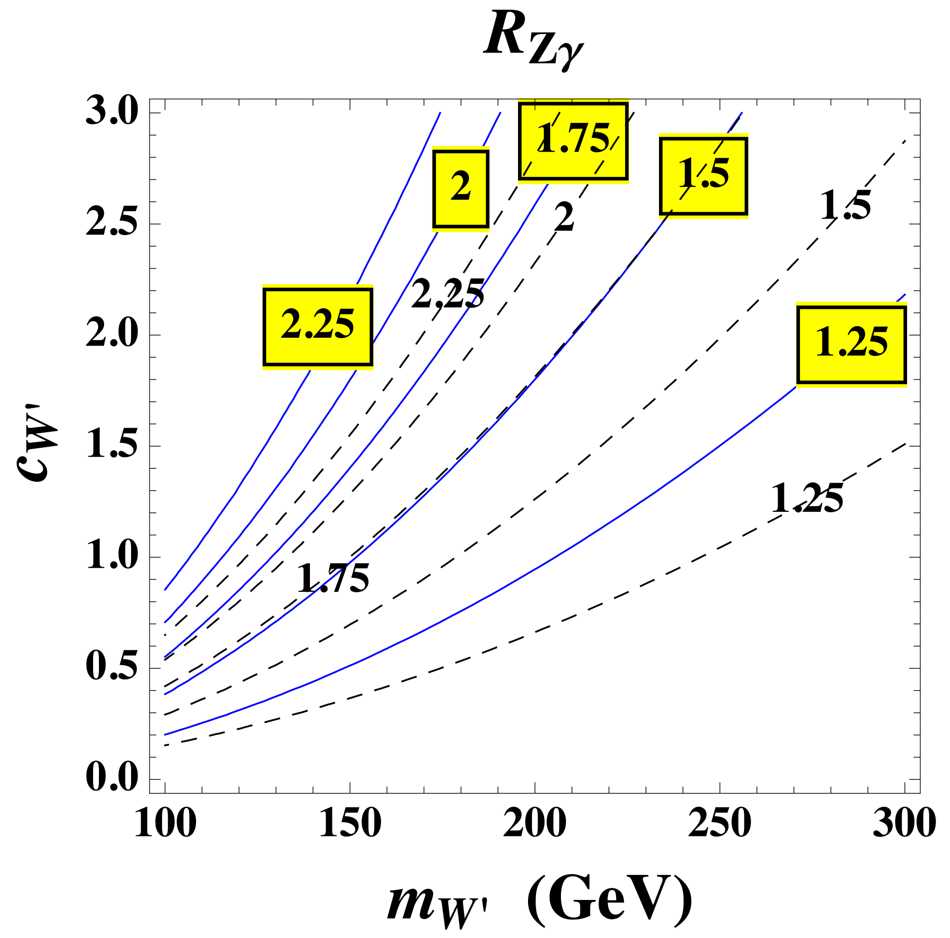




M. Carena, I. Low, C.W., arXiv:1206.1082

An exception to the rule would be the case of the W', transforms as a triplet of SU(2) (example : SU(2)_w proceeds from diagonal group in SU(2)xSU(2))

M. Carena, I. Low, C.W., arXiv:1206.1082



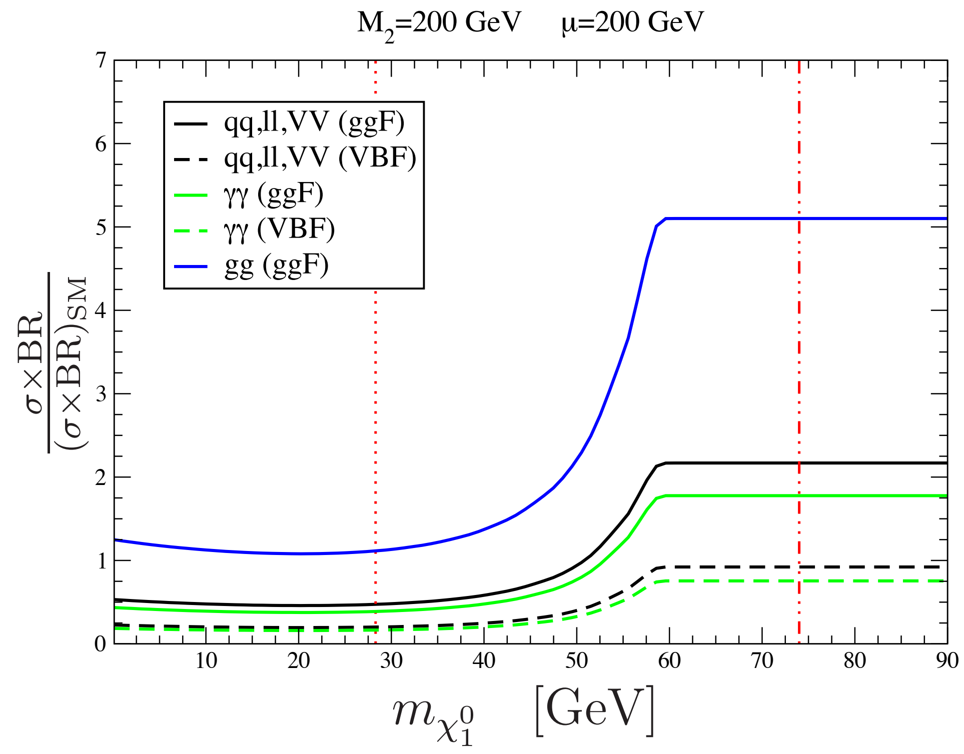
So, if one can measure this rate (for a discussion see the article by J. Gainer, W.Y. Keung, I. Low and P. Schwaller, arXiv:1112.1405) and determine an enhanced rate, similar to the diphoton one, a way of achieving this is by the presence of extra gauge bosons.

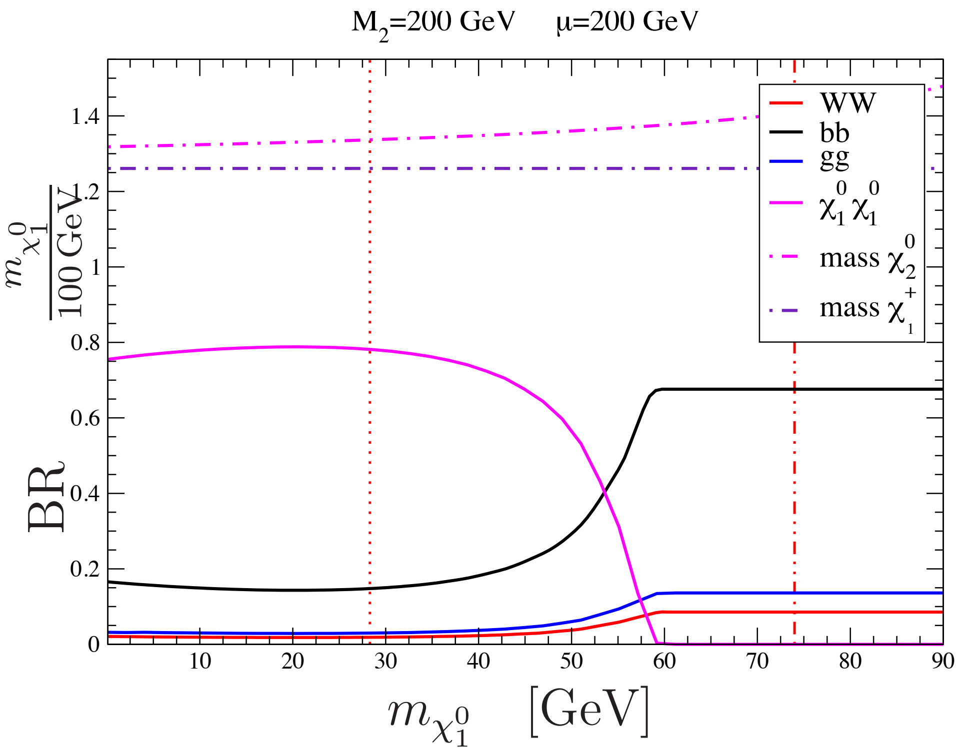
Comment on Scenarios with Enhanced Production rates or suppressed Higgs decay into bottom quarks. Example : Electroweak Baryogenesis

Models of the kind that tend to enhance both the photon as well as the ZZ and WW widths. If enhancements are significant, then models are disfavored.

EWBG within the MSSM, where the light stop enhances the gluon fusion rate is strongly constrained by this property, unless new decay modes are present. An example are light neutralinos. Three body decay channel of stop should be dominant.

M. Carena, G. Nardini, M. Quiros, C.W.' 12





Proper Dark Matter density may be obtained in the same region of parameters where gluon fusion induced processes become SM-like

Conclusions

- Allowed SM-Higgs mass window at the LHC is consistent with SM descriptionHiggs diphoton rate is somewhat large and it is interesting to study possible ways of enhancing it
- We have studied the properties that should be fulfilled for this rate to be enhanced in the presence of new scalar, vector and fermion particles
- In general, for couplings of order one, particles of mass of order of a few hundred GeV are necessary
- Scalars with negative couplings induced, for instance by large mixing effects lead to an enhanced photon rate. A well motivated example is the case of light staus !
- Vector light fermions, with explicit masses and couplings are another simple example. Large Yukawa coupling make the Higgs potential unstable.
- We studied precision electroweak constraint on specific new scalar and fermion models. No serious constraints imposed.
- New light gauge bosons, if allowed phenomenologically, are another example, and (the only among the ones analyzed here) that can lead to an enhanced Z photon rate, with interesting phenomenological consequences.

Backup Slides

Higgs Mixing Cancellation

- For large values of the Higgsino mass and (negative) stop mixing parameters, the off-diagonal element of the CP-even Higgs boson mass matrix is suppressed at low values of mA and tanbeta.

- Specifically, this happens when

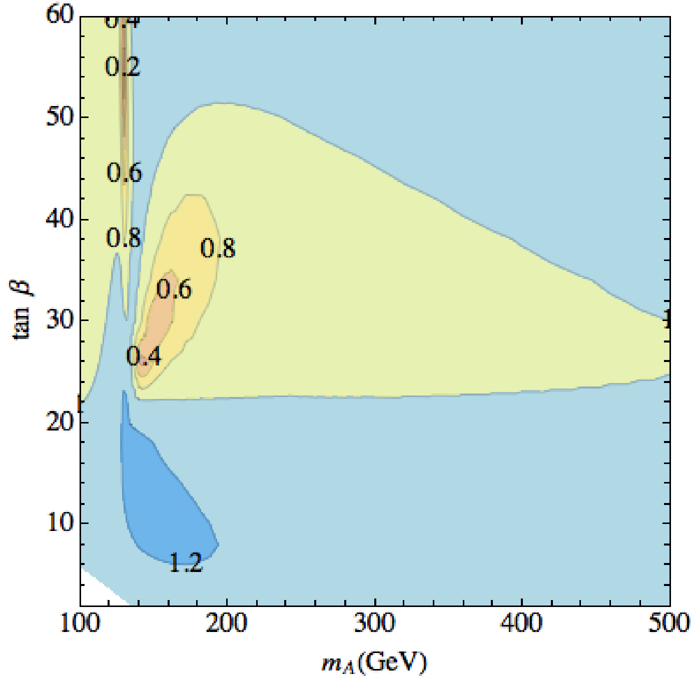
$$\frac{m_A^2}{M_Z^2} + \mathcal{O}(1) \simeq \tan\beta \frac{h_t^4 v^2}{16\pi^2 M_Z^2} \frac{\mu \, X_t}{M_S^2} \left(\frac{X_t^2}{6 M_S^2} - 1 \right)$$

- This means that the mass eigenstate couples has reduced couplings to the down sector (taus and bottoms).

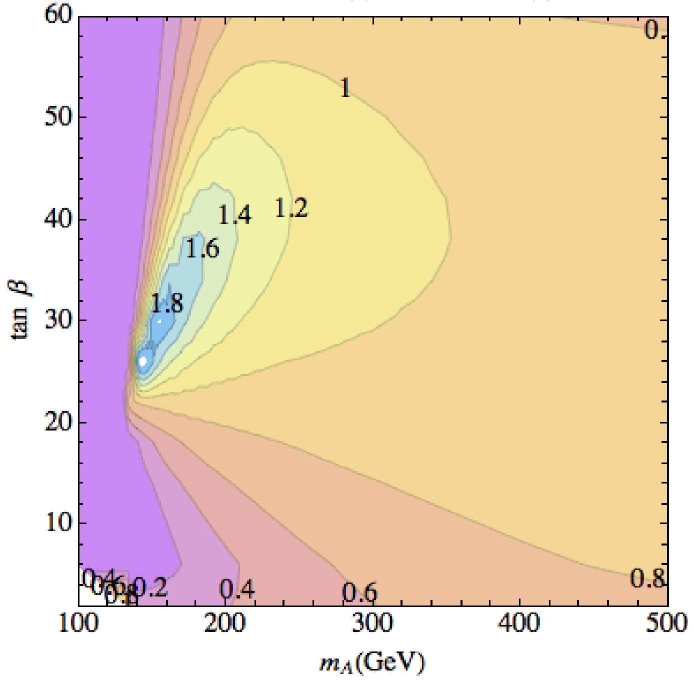
- We shall take $\mu = 2.5 M_S \quad \text{and} \quad X_t = -1.5 M_S$

Carena, Mrenna, C.W. '98
Carena, Heinemeyer, Weiglein, C.W. '02

Small $\alpha_{\rm eff}$: $\mathrm{Br}(h\to bb)_{\rm MSSM}/\mathrm{Br}(h\to bb)_{\rm SM}$



Small $\alpha_{\rm eff}$: $\mathrm{Br}(h\to\gamma\gamma)_{\rm MSSM}/\mathrm{Br}(h\to\gamma\gamma)_{\rm SM}$

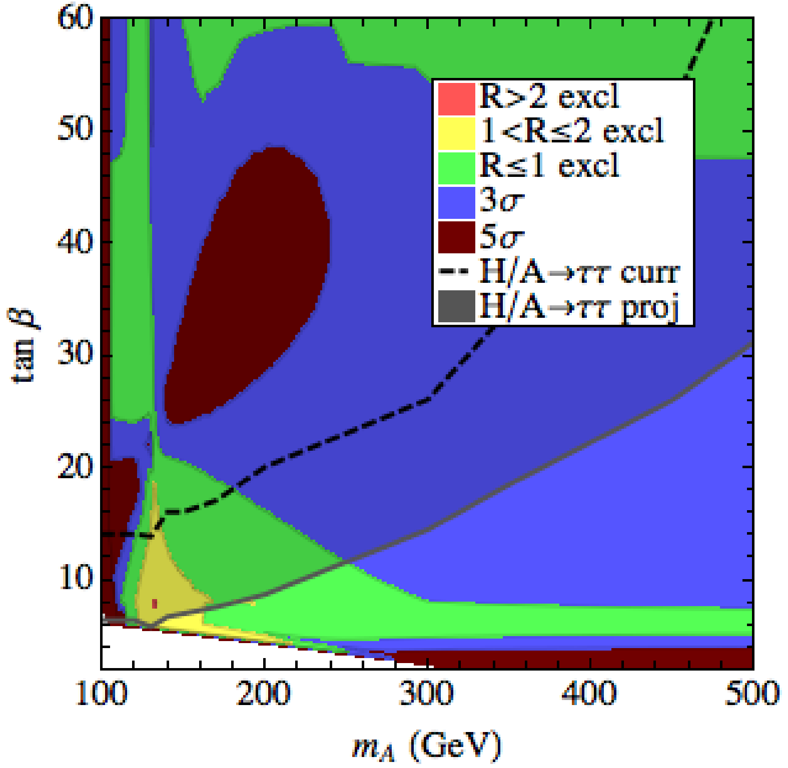


For large values of μ and A_t

one can get suppression of the Higgs decay into bottom quarks and therefore enhancement of photon decay branching ratio

Carena, Mrenna, Wagner'99
Carena, Heinemeyer, Wagner, Weiglein'02

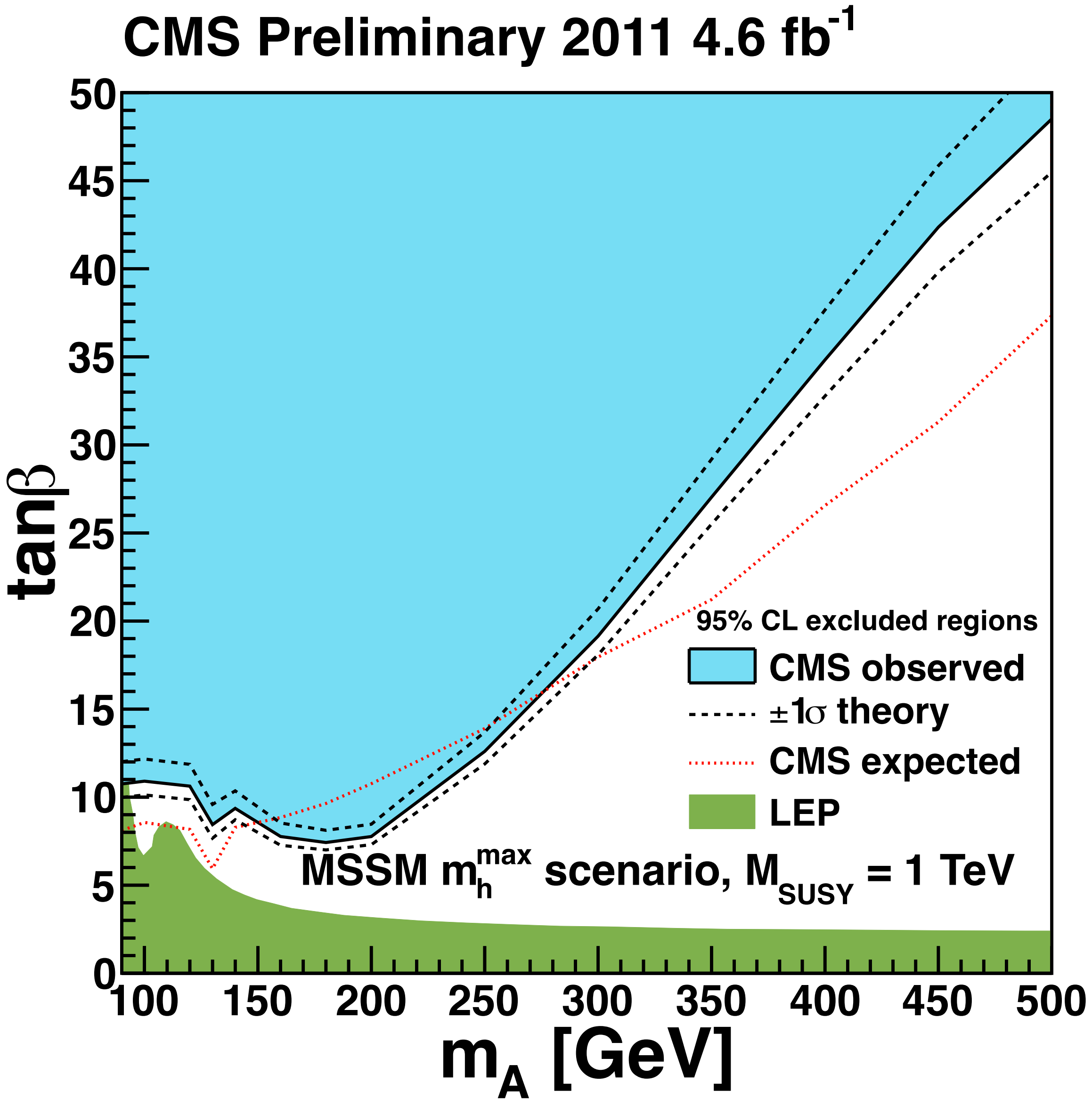
7 TeV, 5fb^{-1}, $\gamma\gamma$+WW+$\tau\tau$+ZZ+bb,
Small $\alpha_{\rm eff}$, μ=2000 GeV



Such scenario, however, demands small values of the the CP-odd Higgs mass and large tanbeta and seems to be in conflict with non-standard Higgs boson searches

Carena, Draper, Liu, Wagner'11

Results did not change significantly with the datea update. Interestingly, the observed limit is somewhat weaker than the expected one.



More on the CP-even Higgs boson Mixing

The neutral CP-even Higgs mass matrix is approximately given by

$$\mathcal{M}_H^2 = \begin{bmatrix} m_A^2 \sin^2\beta + M_Z^2 \cos^2\beta & -(m_A^2 + M_Z^2)\sin\beta\cos\beta + \mathrm{Loop}_{12} \\ -(m_A^2 + M_Z^2)\sin\beta\cos\beta + \mathrm{Loop}_{12} & m_A^2 \cos^2\beta + M_Z^2 \sin^2\beta + \mathrm{Loop}_{22} \end{bmatrix}$$

Mixing is very sensitive to off diagonal terms. The tree-level effects may be suppressed for moderate CP-odd Higgs masses. The dominant loop effects are given by

$$\mathrm{Loop}_{12} = \frac{m_t^4}{16\pi^2 v^2 \sin^2\beta} \frac{\mu \tilde{A}_t}{M_{\mathrm{SUSY}}^2} \left[\frac{A_t \tilde{A}_t}{M_{\mathrm{SUSY}}^2} - 6 \right] + \frac{h_b^4 v^2}{16\pi^2} \sin^2\beta \frac{\mu^3 A_b}{M_{\mathrm{SUSY}}^4} + \frac{h_\tau^4 v^2}{48\pi^2} \sin^2\beta \frac{\mu^3 A_\tau}{M_{\tilde{\tau}}^4}$$

From where the mixing angle, controlling the down fermion couplings is obtained

$$\sin(2\alpha) = \frac{2\,(\mathcal{M}_H^2)_{12}}{\sqrt{Tr[\mathcal{M}_H^2]^2 - det[\mathcal{M}_H^2]}} \qquad hb\bar{b}: \quad -\frac{\sin\alpha}{\cos\beta}\left[1 - \frac{\Delta h_b \tan\beta}{1 + \Delta h_b \tan\beta}\left(1 + \frac{1}{\tan\alpha\tan\beta}\right)\right]$$

Light Stau Effects on CP-even Higgs boson Mixing

M. Carena, S. Gori, N. Shah, C.W., arXiv:1112.3336

Light staus not only affect the photon rate, but they can also induce relevant Higgs mixing effects. For instance, for

$$\tan\beta = 60, \; A_\tau \simeq 1500 \; \text{GeV}, \; m_A \simeq 700 \; \text{GeV},$$

$$\mu = 1030 \; \text{GeV} \qquad m_{e_3} = m_{L_3} = 340 \; \text{GeV}$$

$m_{\tilde{\tau}_1} \simeq 105 \; \text{GeV}$ and the mixing effects lead to a reduced bottom rate

$$\text{BR}(h \to b\bar{b}) \simeq 0.8\text{BR}(\text{h} \to \text{b}\bar{\text{b}})_{\text{SM}}$$

The consequence is a further enhancement of the photon rate, together with an enhancement of all other gauge boson rates !

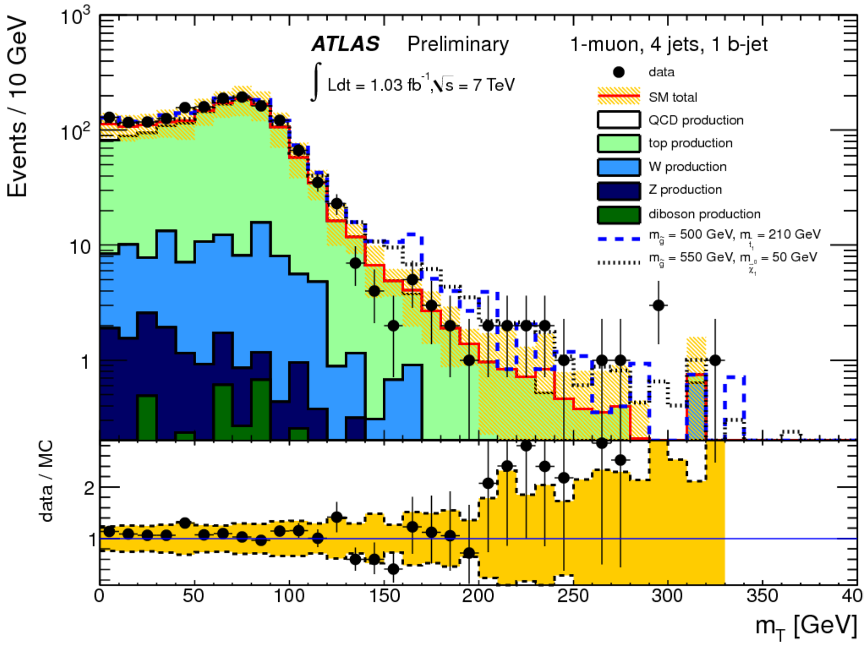
$$\frac{\sigma(gg \to h)}{\sigma(gg \to h)_{\text{SM}}} \frac{\text{BR}(h \to \gamma\gamma)}{\text{BR}(h \to \gamma\gamma)_{\text{SM}}} = 1.96$$

$$\frac{\sigma(gg \to h)}{\sigma(gg \to h)_{\text{SM}}} \frac{\text{BR}(h \to VV^*)}{\text{BR}(h \to VV^*)_{\text{SM}}} = 1.25 \qquad (V = W, Z)$$

One Lepton + b-jets + Missing E_T

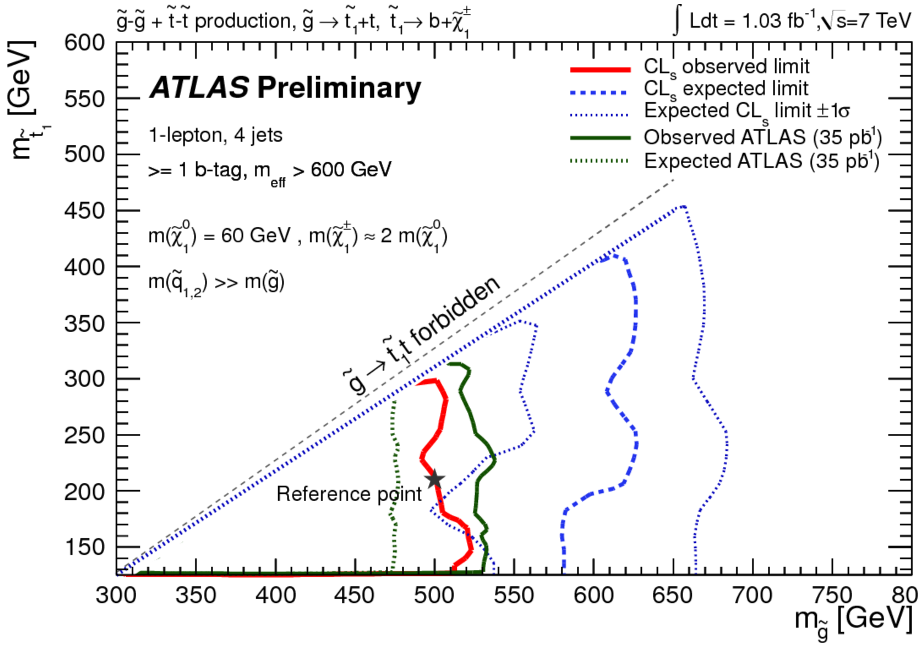
Update LP2011

- 3rd generation is special: has to be light to stabilize the Higgs
- selection similar to one lepton + 4 jets + missing E_T plus 1 b-tags
- signal region defined by missing E_T > 80 GeV, m_T> 100 GeV and m_{eff} > 600 GeV



Phenomenological MSSM:

$BR(g \to t_1 t \to tb\chi^{\pm}_1) = 100\%$



Relatively light stops are naturally there, they can raise sufficiently the Higgs mass and are not ruled out by current data !

They should be a priority in LHC searches (in all possible stop decay channels)

Loop induced gluon and gamma widths

$$\Gamma_{H\to gg} = \frac{G_\mu \alpha_s^2 m_H^3}{36\sqrt{2}\pi^3} \left| \frac{3}{4} \sum_f A_f(\tau_f) \right|^2$$

$$\Gamma_{H\to\gamma\gamma} = \frac{G_\mu \alpha^2 m_H^3}{128\sqrt{2}\pi^3} \left| \sum_f N_c Q_f^2 A_f(\tau_f) + A_W(\tau_W) \right|^2$$

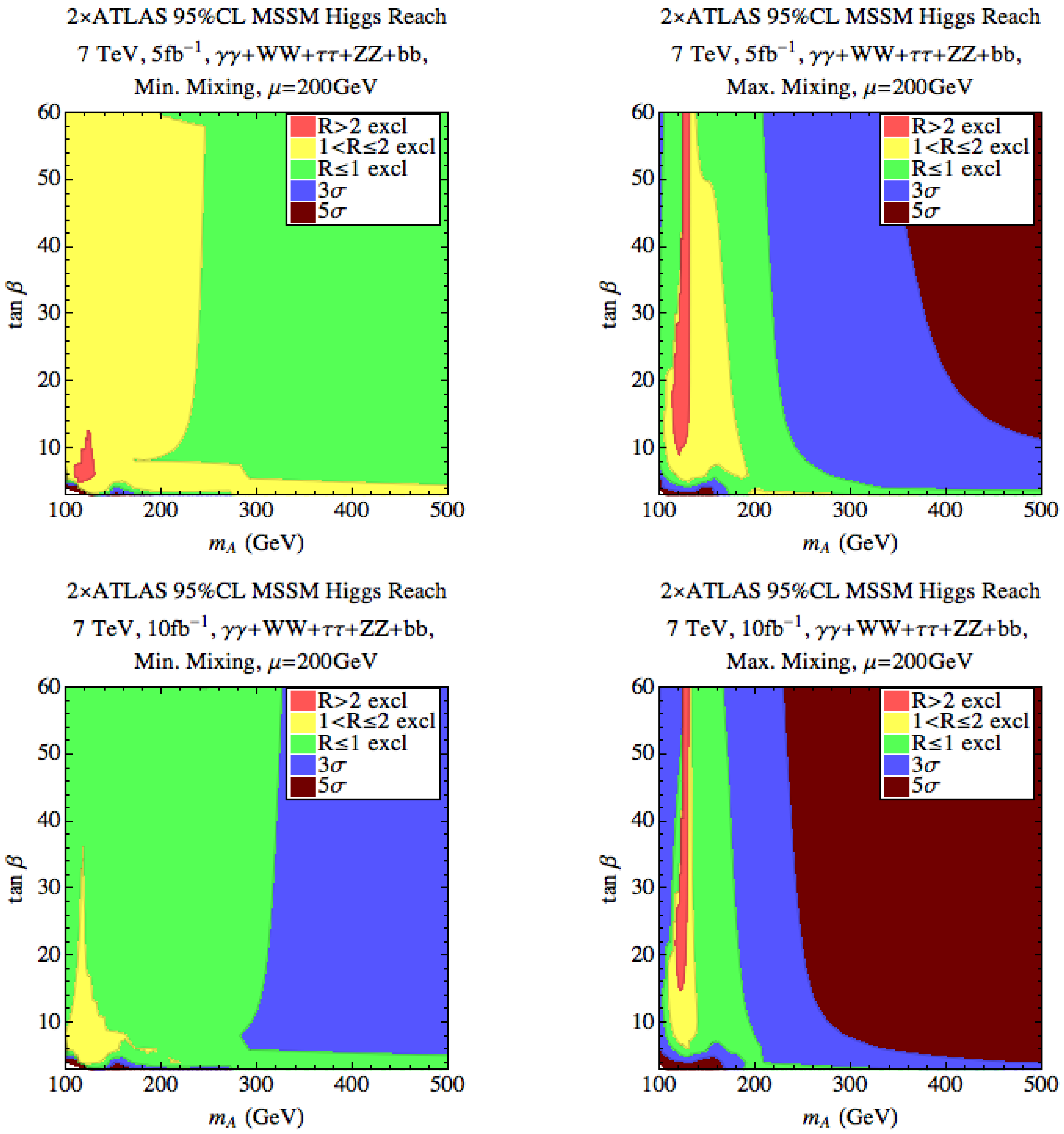
$$\begin{aligned} A_f(\tau) &= 2\left[\tau + (\tau-1)f(\tau)\right]\,\tau^{-2} \\ A_W(\tau) &= -\left[2\tau^2 + 3\tau + 3(2\tau-1)f(\tau)\right]\,\tau^{-2} \end{aligned}$$

$$f(\tau) = \begin{cases} \arcsin^2\sqrt{\tau} & \tau \le 1 \\ -\frac{1}{4}\left[\ln\frac{1+\sqrt{1-\tau^{-1}}}{1-\sqrt{1-\tau^{-1}}} - i\pi\right]^2 & \tau > 1 \end{cases}$$

7 TeV LHC MSSM Higgs Reach

P. Draper, T. Liu, C. Wagner, **Phys.Rev.D81:015014,2010**; M. Carena, P. Draper, T. Liu, C. Wagner, arXiv:1107.4354

$m_h \simeq 115\text{GeV}$ $m_h \simeq 130\text{ GeV}$



Suppression of

$BR(h \to \gamma\gamma)$

leads to reduced reach at low values of the CP-odd Higgs mass

$\text{Significance}(\sigma) = 2/R$

At sufficiently large luminosity

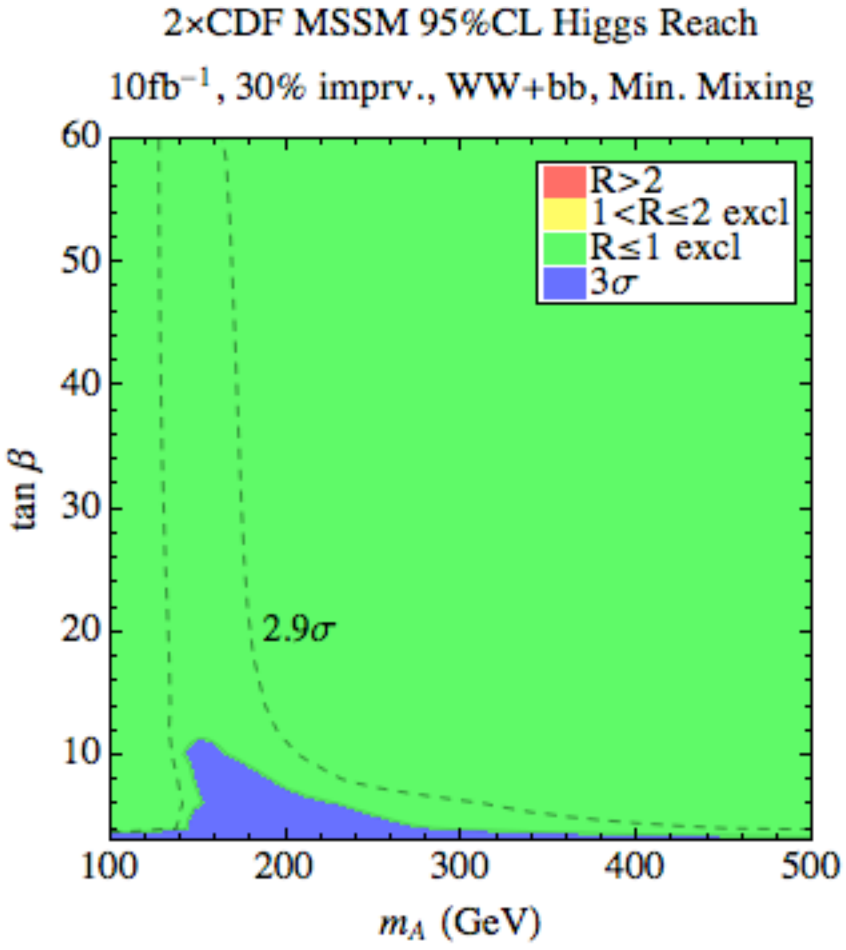
$Vh, h \to bb$

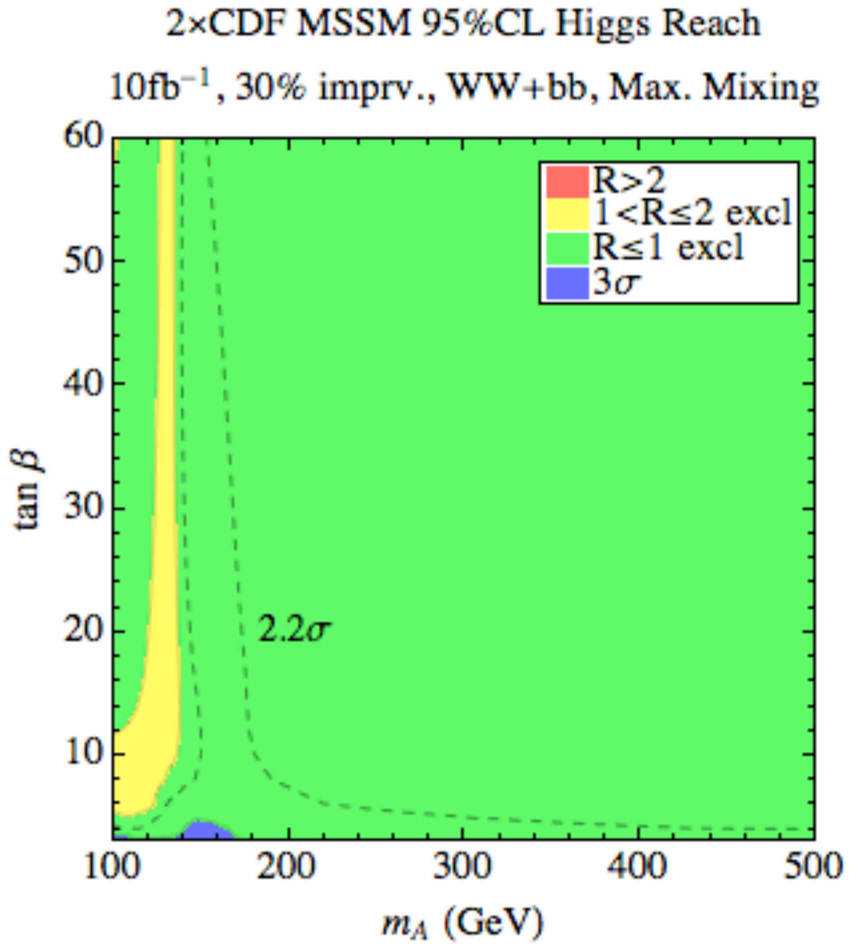
$\text{WBF}, h \to \tau\tau$

are helpful in partially reducing the reach suppression

Tevatron Reach

Conservative Estimate of 10 inverse fb combination of the two Experiments data

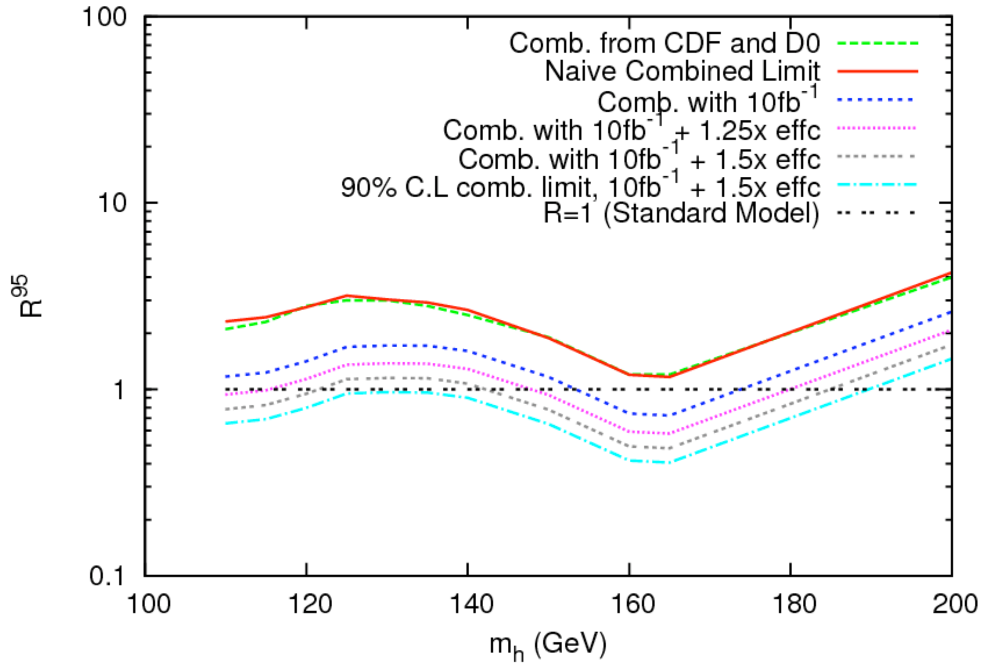




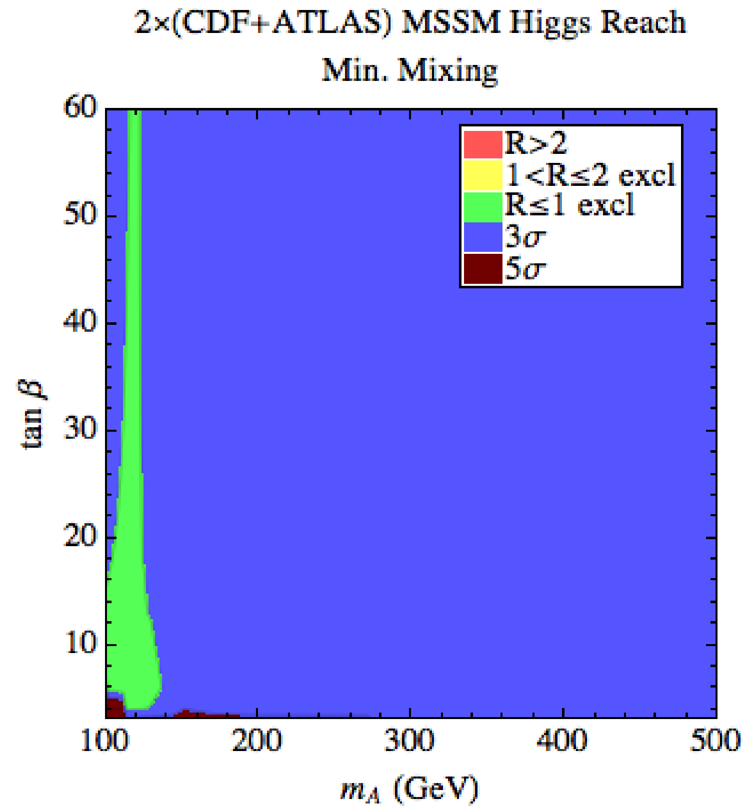
More than 2 standard deviations in most of the parameter space

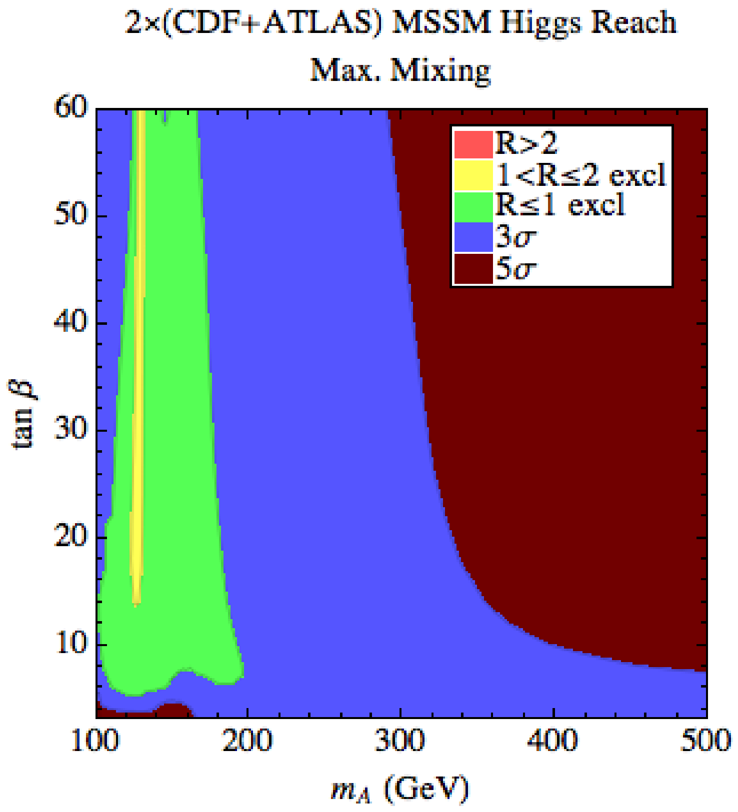
The LHC sensitivity is somewhat complementary to that of the Tevatron, which becomes more sensitive for low Higgs masses.

Combination of data from experiments at the end of 2011 may be useful to find evidence for Higgs at an early stage.



P. Draper, T. Liu and C. Wagner'09



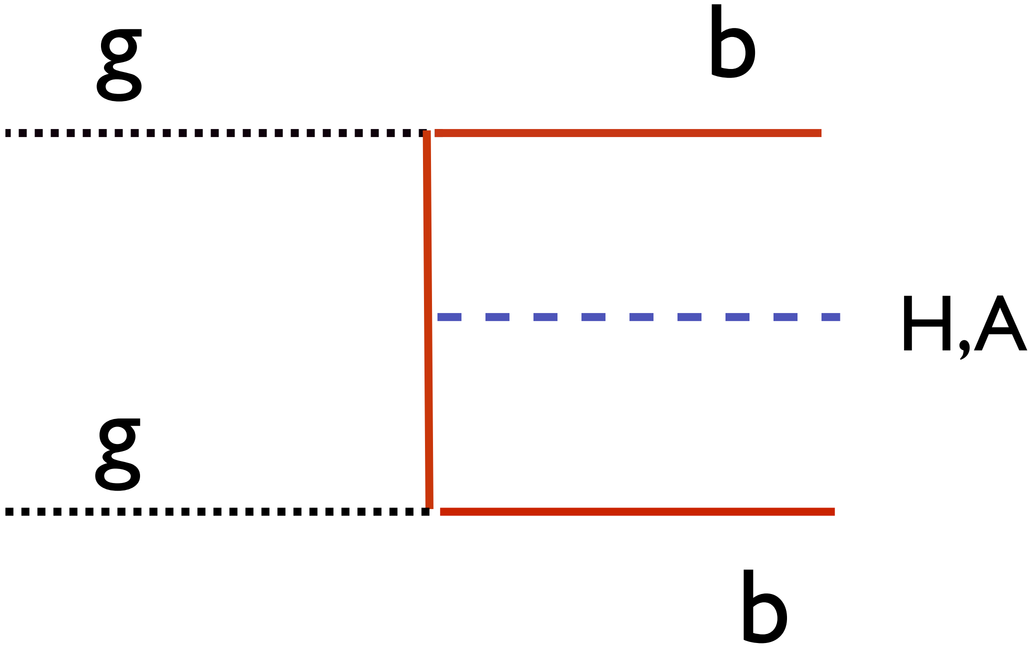


Combination of 5 inverse fb LHC with 10 inverse fb Tevatron data :
Evidence of SM-like Higgs presence in almost all parameter space

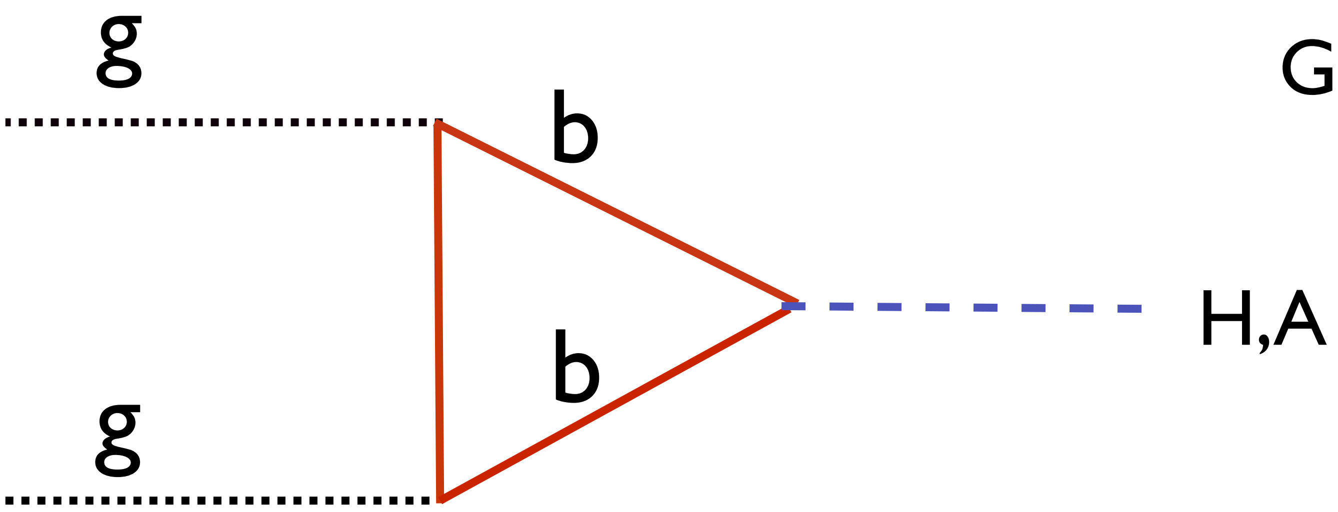
M. Carena, P. Draper, T. Liu, C.W.'11

Non-Standard Higgs Production

QCD: S. Dawson, C.B. Jackson, L. Reina, D. Wackeroth, hep-ph/0603112



Associated Production



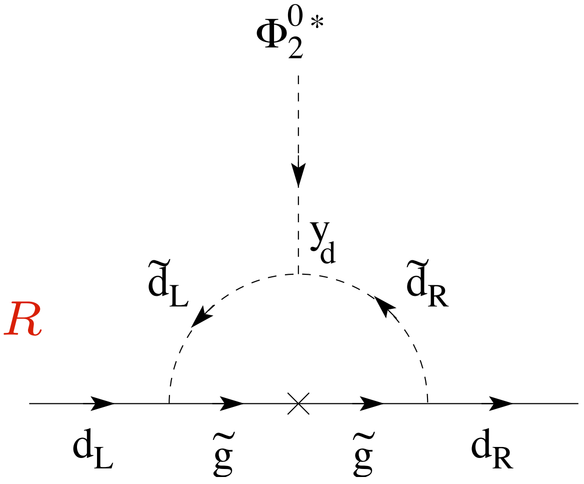
Gluon Fusion

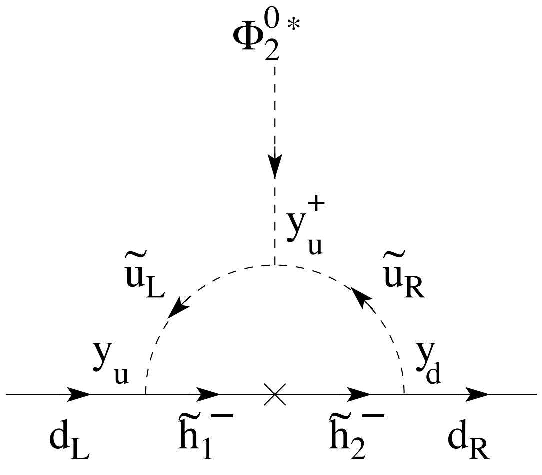
$$g_{Abb} \simeq g_{Hbb} \simeq \frac{m_b \tan\beta}{(1+\Delta_b)v}, \qquad g_{A\tau\tau} \simeq g_{H\tau\tau} \simeq \frac{m_\tau \tan\beta}{v}$$

Radiative Corrections to Flavor Conserving Higgs Couplings

- Couplings of down and up quark fermions to both Higgs fields arise after radiative corrections.

$$\mathcal{L} = \bar{d}_L (h_d H_1^0 + \Delta h_d H_2^0) d_R$$





- The radiatively induced coupling depends on ratios of supersymmetry breaking parameters

$$m_b = h_b v_1 \left(1 + \frac{\Delta h_b}{h_b} \tan\beta \right)$$

$$\boxed{\tan\beta = \frac{v_2}{v_1}}$$

$$\frac{\Delta_b}{\tan\beta} = \frac{\Delta h_b}{h_b} \simeq \frac{2\alpha_s}{3\pi} \frac{\mu M_{\tilde{g}}}{\max(m_{\tilde{b}_i}^2, M_{\tilde{g}}^2)} + \frac{h_t^2}{16\pi^2} \frac{\mu A_t}{\max(m_{\tilde{t}_i}^2, \mu^2)}$$

$$X_t = A_t - \mu / \tan\beta \simeq A_t \qquad \Delta_b = (E_g + E_t h_t^2) \tan\beta$$

Resummation : Carena, Garcia, Nierste, C.W.'00

Searches for non-standard Higgs bosons

M. Carena, S. Heinemeyer, G.Weiglein,C.W, EJPC'06

- Searches at the Tevatron and the LHC are induced by production channels associated with the large bottom Yukawa coupling.

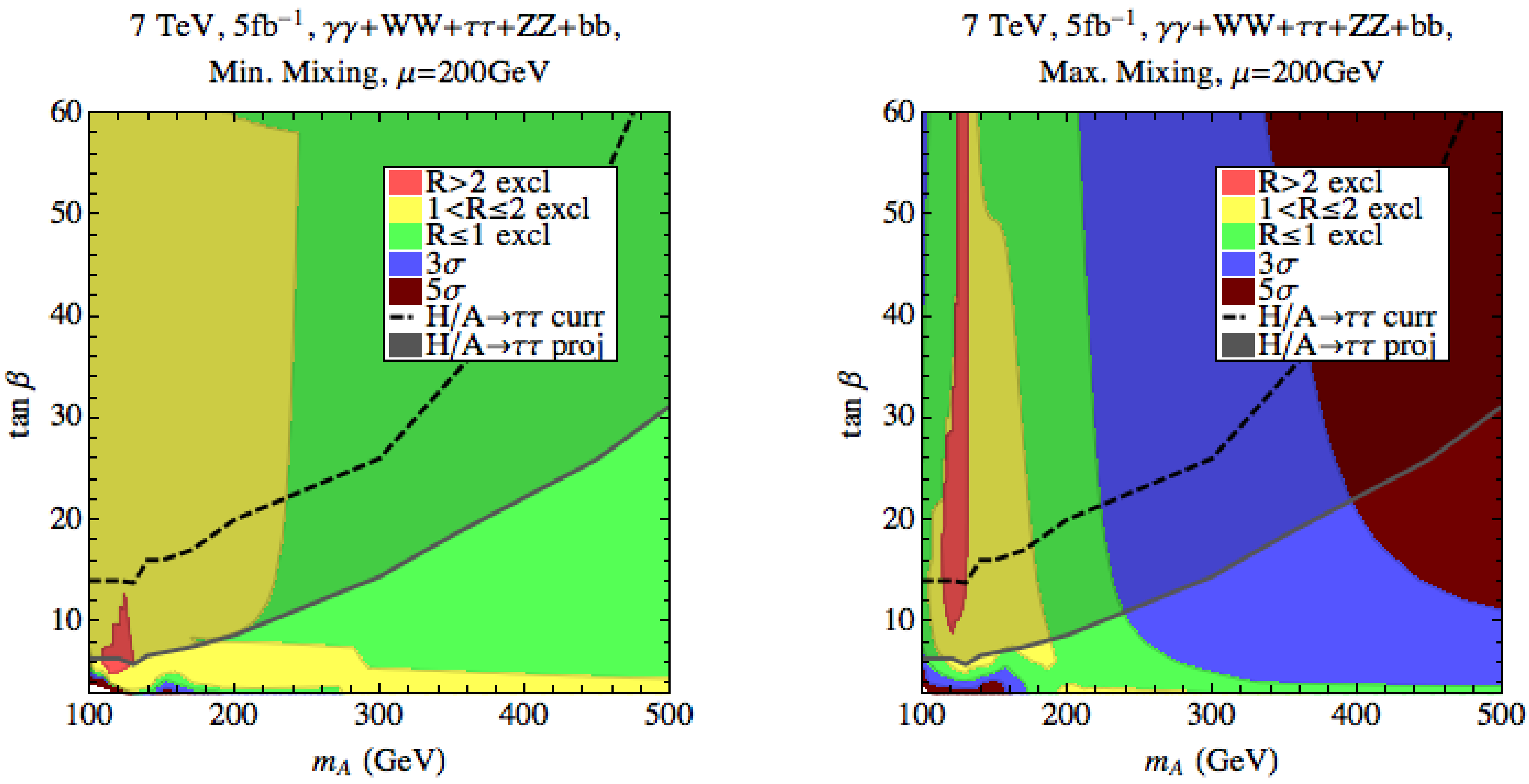
$$\sigma(b\bar{b}A) \times BR(A \to b\bar{b}) \simeq \sigma(b\bar{b}A)_{\mathrm{SM}} \frac{\tan^2\beta}{(1+\Delta_b)^2} \times \frac{9}{(1+\Delta_b)^2+9}$$

$$\sigma(b\bar{b}, gg \to A) \times BR(A \to \tau\tau) \simeq \sigma(b\bar{b}, gg \to A)_{\mathrm{SM}} \frac{\tan^2\beta}{(1+\Delta_b)^2+9}$$

- There may be a strong dependence on the parameters in the bb search channel, which is strongly reduced in the tau tau mode.

Validity of this approximation confirmed by NLO computation by D. Noth and M. Spira, arXiv:0808.0087
Further work by Muhlleitner, Rzehak and Spira, 0812.3815

Complementarity with LHC non-standard Higgs searches



M. Carena, P. Draper, T. Liu, C.W.' 11

Non-standard Higgs searches allow to probe part of the parameter space for which standard reach is suppressed. An excess at small CP-odd Higgs masses would mean a weaker reach for SM-like Higgs boson

Higgs Couplings to fermions

- At tree level, only one of the Higgs doublets couples to down-quarks and leptons, and the other couples to up quarks

$$\mathcal{L} = \bar{\Psi}^i_L \left(h_{d,ij} H_1 d_R + h_{u,ij} H_2 u_R\right) + h.c.$$

- Since the up and down quark sectors are diagonalized independently, the interactions remain flavor diagonal.

$$\bar{d}_L \frac{\hat{m}_d}{v} \left(h + \tan\beta \, (H + iA)\right) d_R + h.c.$$

- h is SM-like, while H and A have enhanced couplings to down quarks

Sensitivity to SM Higgs