Complementarity of Precision Higgs Measurements and direct Searches for non-standard Higgs Bosons

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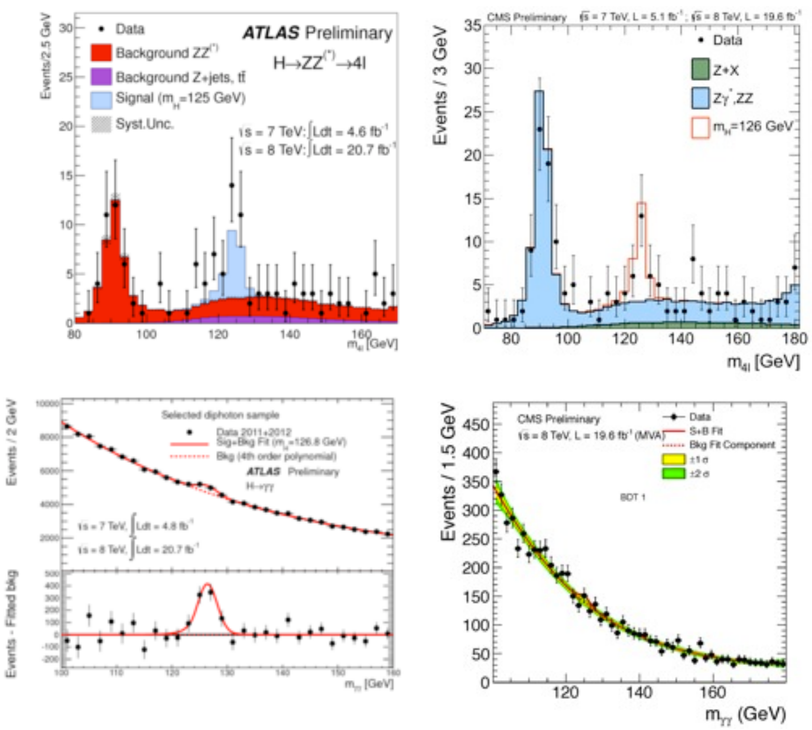
A Standard Model-like Higgs particle has been discovered by the ATLAS and CMS experiments at CERN



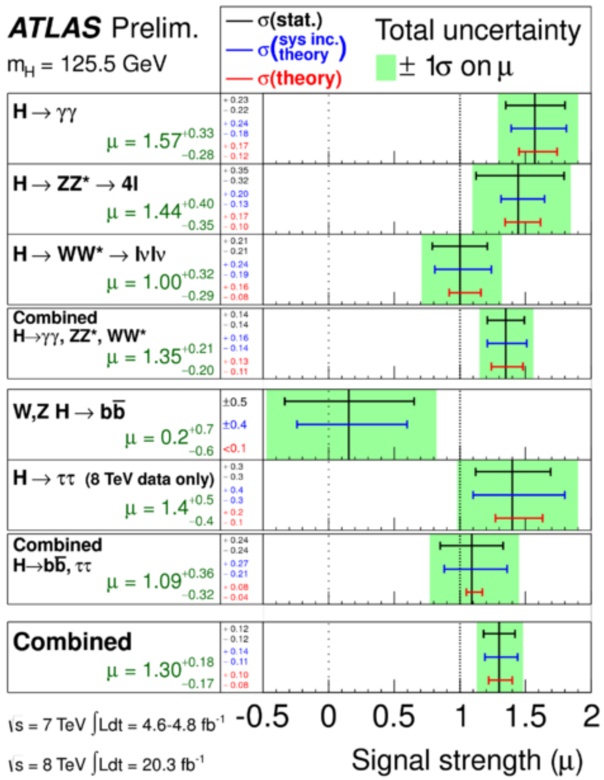
We see evidence
of this particle
in multiple channels.

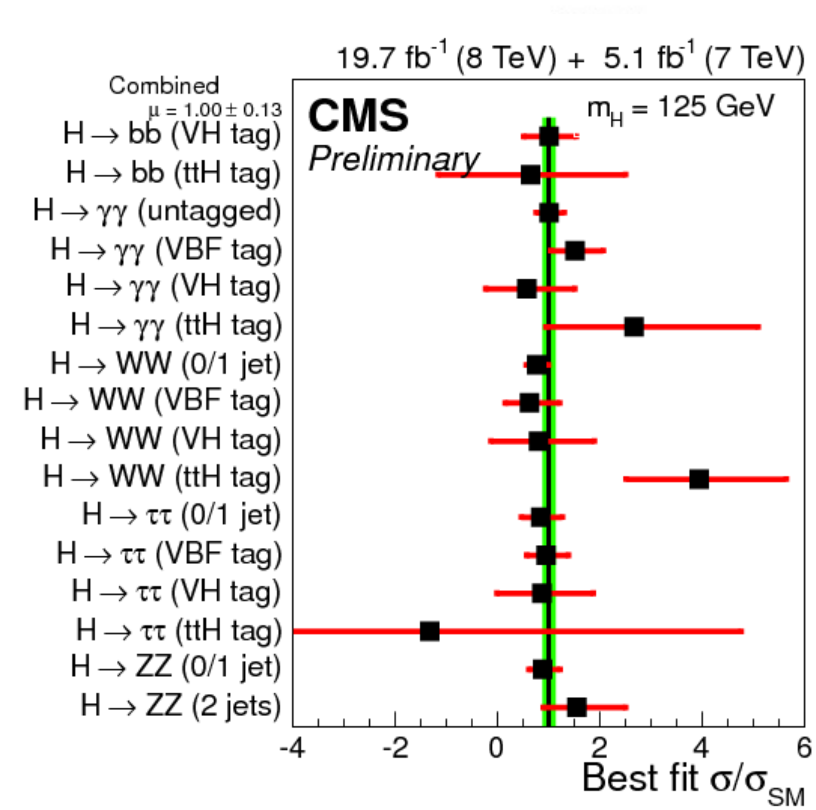
We can reconstruct
its mass and we know
that is about 125 GeV.

The rates are consistent
with those expected
in the Standard Model.

But we cannot determine the Higgs couplings very accurately

Variations of Higgs couplings are still possible





As these measurements become more precise, they constrain possible extensions of the SM, and they could lead to the evidence of new physics.

It is worth studying what kind of effects one could obtain in well motivated extensions of the Standard Model, like SUSY.

Going Beyond the SM : Two Higgs Doublet Models

- The simplest extension of the SM is to add one Higgs doublet, with the same quantum numbers as the SM one.

- Now, we will have contributions to the gauge boson masses coming from the vacuum expectation value of both fields

$$(\mathcal{D}\phi_i)^\dagger \mathcal{D}\phi_i \to g^2 \phi_i^\dagger T^a T^b \phi_i A_\mu^a A^{\mu,b}$$

- Therefore, the gauge boson masses are obtained from the SM expressions by simply replacing

$$v^2 \to v_1^2 \; + \; v_2^2$$

- There is then a free parameter, that is the ratio of the two vacuum expectation values, and this is usually denoted by

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

- The number of would-be Goldstone modes are the same as in the SM, namely 3. Therefore, there are still 5 physical degrees of freedom in the scalar sector which are a charged Higgs, a CP-odd Higgs and two CP-even Higgs bosons.

CP-even Higgs Bosons

- There is no symmetry argument and in general these two Higgs boson states will mix. The mass eigenvalues, in increasing order of mass, will be

$$\sqrt{2}\ h = -\sin\alpha\ \mathrm{Re}H_1^0 + \cos\alpha\ \mathrm{Re}H_2^0$$
$$\sqrt{2}\ H = \cos\alpha\ \mathrm{Re}H_1^0 + \sin\alpha\ \mathrm{Re}H_2^0$$

- From here one can easily obtain the coupling to the gauge bosons. This is simply given by replacing in the mass contributions

$$v_i \to v_i + ReH_i^0$$

- This leads to a coupling proportional to

$$v_i\ \mathrm{Re}H_i^0$$

- Hence, the effective coupling of h is given by

$$hVV = (hVV)^{\mathrm{SM}}(-\cos\beta\sin\alpha + \sin\beta\cos\alpha) = (hVV)^{\mathrm{SM}}\sin(\beta-\alpha)$$
$$HVV = (hVV)^{\mathrm{SM}}(\cos\beta\cos\alpha + \sin\beta\sin\alpha) = (hVV)^{\mathrm{SM}}\cos(\beta-\alpha)$$

- These proportionality factors are nothing but the projection of the Higgs mass eigenstates into the one acquiring a vacuum expectation value.

Fermion Masses and Flavor

- Similarly to the gauge boson masses, the fermion masses are obtain from the some of the contributions of both Higgs fields.

- For instance, the down-quark mass matrix is given by

$$M_d^{ij} = h_{d,1}^{ij} \frac{v_1}{\sqrt{2}} + h_{d,2}^{ij} \frac{v_2}{\sqrt{2}}$$

- The interaction of the two CP-even scalars with fermions is given, instead, by

$$g_{hd_i d_j} \propto h_{d,1}^{ij}(-\sin\alpha) + h_{d,2}^{ij}(\cos\alpha)$$
$$g_{Hd_i d_j} \propto h_{d,1}^{ij}(\cos\alpha) + h_{d,2}^{ij}(\sin\alpha)$$

- So, contrary to the SM, the rotation that diagonalizes the mass matrix does not diagonalize the couplings. This in general leads to large Higgs mediated Flavor changing processes, that are in conflict with experiment.

- One solution is to make the non-standard Higgs bosons very heavy, going close to the SM. Another natural solution is to restrict the couplings of each fermion sector to only one of the two Higgs doublets. This is what happens to a good approximation in supersymmetry.

Low Energy Supersymmetry : Type II Higgs doublet models

- In Type II models, the Higgs H1 would couple to down-quarks and charge leptons, while the Higgs H2 couples to up quarks and neutrinos. Therefore,

$$g_{hff}^{dd,ll} = \frac{\mathcal{M}_{dd,ll}^{\rm diag}}{v} \frac{(-\sin\alpha)}{\cos\beta}, \qquad g_{Hff}^{dd,ll} = \frac{\mathcal{M}_{dd,ll}^{\rm diag}}{v} \frac{\cos\alpha}{\cos\beta}$$

$$g_{hff}^{uu} = \frac{\mathcal{M}_{uu}^{\rm diag}}{v} \frac{(\cos\alpha)}{\sin\beta}, \qquad g_{Hff}^{uu} = \frac{\mathcal{M}_{uu}^{\rm diag}}{v} \frac{\sin\alpha}{\sin\beta}$$

- If the mixing is such that

$$\sin\alpha = -\cos\beta,$$
$$\cos\alpha = \sin\beta$$

then the coupling of the lightest Higgs to fermions and gauge bosons is SM-like. This limit is called decoupling limit. Is it possible to obtain similar relations for lower values of the CP-odd Higgs mass ? We shall call this situation ALIGNMENT

- Observe that close to the decoupling limit, the lightest Higgs couplings are SM-like, while the heavy Higgs couplings to down quarks and up quarks are enhanced (suppressed) by a $\tan\beta$ factor. We shall concentrate on this case.

- It is important to stress that the coupling of the CP-odd Higgs boson

$$g_{Aff}^{dd,ll} = \frac{\mathcal{M}_{\rm diag}^{\rm dd}}{v} \tan\beta, \qquad g_{Aff}^{uu} = \frac{\mathcal{M}_{\rm diag}^{\rm uu}}{v \tan\beta}$$

Alignment in General two Higgs Doublet Models

H. Haber and J. Gunion'03

$$
\begin{aligned}
V &= m_{11}^2 \Phi_1^\dagger \Phi_1 + m_{22}^2 \Phi_2^\dagger \Phi_2 - m_{12}^2 (\Phi_1^\dagger \Phi_2 + \mathrm{h.c.}) + \frac{1}{2}\lambda_1 (\Phi_1^\dagger \Phi_1)^2 + \frac{1}{2}\lambda_2 (\Phi_2^\dagger \Phi_2)^2 \\
&\quad + \lambda_3 (\Phi_1^\dagger \Phi_1)(\Phi_2^\dagger \Phi_2) + \lambda_4 (\Phi_1^\dagger \Phi_2)(\Phi_2^\dagger \Phi_1) \\
&\quad + \left\{ \frac{1}{2}\lambda_5 (\Phi_1^\dagger \Phi_2)^2 + [\lambda_6 (\Phi_1^\dagger \Phi_1) + \lambda_7 (\Phi_2^\dagger \Phi_2)] \Phi_1^\dagger \Phi_2 + \mathrm{h.c.} \right\} ,
\end{aligned}
$$

- From here, one can minimize the effective potential and derive the expression for the CP-even Higgs mass matrix in terms of a reference mass, that we will take to be mA

$$
\mathcal{M} = \begin{pmatrix} \mathcal{M}_{11} & \mathcal{M}_{12} \\ \mathcal{M}_{12} & \mathcal{M}_{22} \end{pmatrix} \equiv m_A^2 \begin{pmatrix} s_\beta^2 & -s_\beta c_\beta \\ -s_\beta c_\beta & c_\beta^2 \end{pmatrix} + v^2 \begin{pmatrix} L_{11} & L_{12} \\ L_{12} & L_{22} \end{pmatrix}
$$

$$
\begin{aligned}
L_{11} &= \lambda_1 c_\beta^2 + 2\lambda_6 s_\beta c_\beta + \lambda_5 s_\beta^2 , \\
L_{12} &= (\lambda_3 + \lambda_4) s_\beta c_\beta + \lambda_6 c_\beta^2 + \lambda_7 s_\beta^2 , \\
L_{22} &= \lambda_2 s_\beta^2 + 2\lambda_7 s_\beta c_\beta + \lambda_5 c_\beta^2 .
\end{aligned}
$$

CP-even Higgs Mixing Angle and Alignment

M. Carena, I. Low, N. Shah, C.W.', arXiv:1310.2248

$$\sin\alpha = \frac{\mathcal{M}_{12}^2}{\sqrt{\mathcal{M}_{12}^4 + \left(\mathcal{M}_{11}^2 - m_h^2\right)^2}}$$

$$-\tan\beta\ \mathcal{M}_{12}^2 = \left(\mathcal{M}_{11}^2 - m_h^2\right) \longrightarrow \sin\alpha = -\cos\beta$$

Condition independent of the CP-odd Higgs mass.

$$\begin{pmatrix} s_\beta^2 & -s_\beta c_\beta \\ -s_\beta c_\beta & c_\beta^2 \end{pmatrix} \begin{pmatrix} -s_\alpha \\ c_\alpha \end{pmatrix} = -\frac{v^2}{m_A^2} \begin{pmatrix} L_{11} & L_{12} \\ L_{12} & L_{22} \end{pmatrix} \begin{pmatrix} -s_\alpha \\ c_\alpha \end{pmatrix} + \frac{m_h^2}{m_A^2} \begin{pmatrix} -s_\alpha \\ c_\alpha \end{pmatrix}$$

M. Carena, I. Low, N. Shah, C.W.'13

Alignment Conditions

$$(m_h^2 - \lambda_1 v^2) + (m_h^2 - \tilde{\lambda}_3 v^2) t_\beta^2 = v^2 (3\lambda_6 t_\beta + \lambda_7 t_\beta^3) \ ,$$

$$(m_h^2 - \lambda_2 v^2) + (m_h^2 - \tilde{\lambda}_3 v^2) t_\beta^{-2} = v^2 (3\lambda_7 t_\beta^{-1} + \lambda_6 t_\beta^{-3})$$

- If fulfilled not only alignment is obtained, but also the right Higgs mass, $m_h^2 = \lambda_{\rm SM} v^2$, with $\lambda_{\rm SM} \simeq 0.26$ and $\lambda_3 + \lambda_4 + \lambda_5 = \tilde{\lambda}_3$

$$\lambda_{\rm SM} = \lambda_1 \cos^4\beta + 4\lambda_6 \cos^3\beta \sin\beta + 2\tilde{\lambda}_3 \sin^2\beta \cos^2\beta + 4\lambda_7 \sin^3\beta \cos\beta + \lambda_2 \sin^4\beta$$

- For $\lambda_6 = \lambda_7 = 0$ the conditions simplify, but can only be fulfilled if

$$\lambda_1 \ \geq \ \lambda_{\rm SM} \ \geq \ \tilde{\lambda}_3 \quad \text{and} \quad \lambda_2 \ \geq \ \lambda_{\rm SM} \ \geq \ \tilde{\lambda}_3 \ ,$$

or

$$\lambda_1 \ \leq \ \lambda_{\rm SM} \ \leq \ \tilde{\lambda}_3 \quad \text{and} \quad \lambda_2 \ \leq \ \lambda_{\rm SM} \ \leq \ \tilde{\lambda}_3$$

- Conditions not fulfilled in the MSSM, where both $\lambda_1, \tilde{\lambda}_3 < \lambda_{\rm SM}$

Deviations from Alignment

$$c_{\beta-\alpha} = t_\beta^{-1}\eta \ , \qquad s_{\beta-\alpha} = \sqrt{1 - t_\beta^{-2}\eta^2}$$

The couplings of down fermions are not only the ones that dominate the Higgs width but also tend to be the ones which differ at most from the SM ones

$$g_{hVV} \approx \left(1 - \frac{1}{2} t_\beta^{-2}\eta^2\right) g_V \ , \qquad g_{HVV} \approx t_\beta^{-1}\eta \ g_V \ ,$$

$$g_{hdd} \approx (1-\eta)\, g_f \ , \qquad g_{Hdd} \approx t_\beta(1 + t_\beta^{-2}\eta) g_f$$

$$g_{huu} \approx (1 + t_\beta^{-2}\eta)\, g_f \ , \qquad g_{Huu} \approx -t_\beta^{-1}(1-\eta) g_f$$

For small departures from alignment, the parameter η can be determined as a function of the quartic couplings and the Higgs masses

$$\eta = s_\beta^2 \left(1 - \frac{\mathcal{A}}{\mathcal{B}}\right) = s_\beta^2 \frac{\mathcal{B} - \mathcal{A}}{\mathcal{B}}, \qquad \mathcal{B} - \mathcal{A} = \frac{1}{s_\beta}\left(-m_h^2 + \tilde{\lambda}_3 v^2 s_\beta^2 + \lambda_7 v^2 s_\beta^2 t_\beta + 3\lambda_6 v^2 s_\beta c_\beta + \lambda_1 v^2 c_\beta^2\right)$$

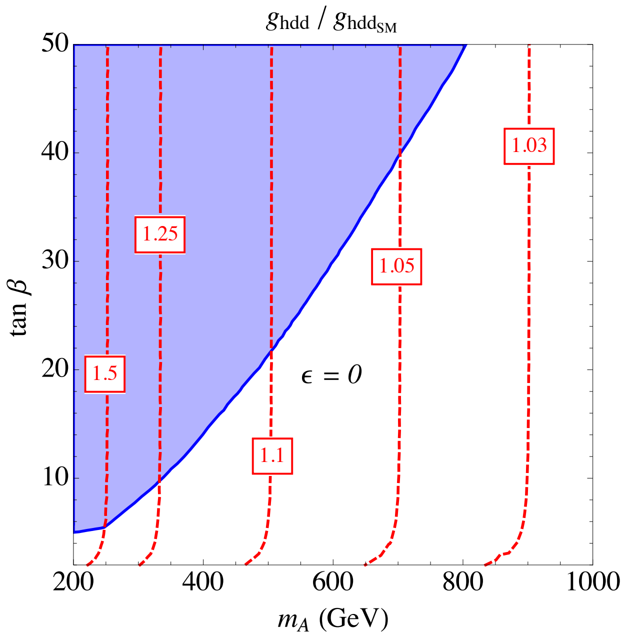
$$\mathcal{B} = \frac{\mathcal{M}_{11}^2 - m_h^2}{s_\beta} = \left(m_A^2 + \lambda_5 v^2\right) s_\beta + \lambda_1 v^2 \frac{c_\beta}{t_\beta} + 2\lambda_6 v^2 c_\beta - \frac{m_h^2}{s_\beta}$$

Down Couplings in the MSSM for low values of μ

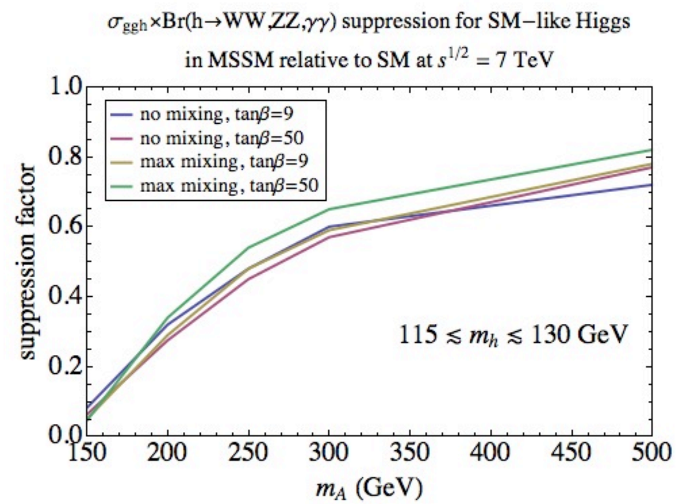
- In this regime,

$$\lambda_1 \simeq -\tilde{\lambda}_3 = \frac{g_1^2 + g_2^2}{4} = \frac{M_Z^2}{v^2} \simeq 0.125 \qquad \lambda^{\rm SM} \simeq 0.26$$

$$\lambda_2 \simeq \frac{M_Z^2}{v^2} + \frac{3}{8\pi^2} h_t^4 \left[\log\left(\frac{M_{\rm SUSY}^2}{m_t^2}\right) + \frac{A_t^2}{M_{\rm SUSY}^2}\left(1 - \frac{A_t^2}{12 M_{\rm SUSY}^2}\right)\right]$$



Carena, Low, Shah, C.W.'13

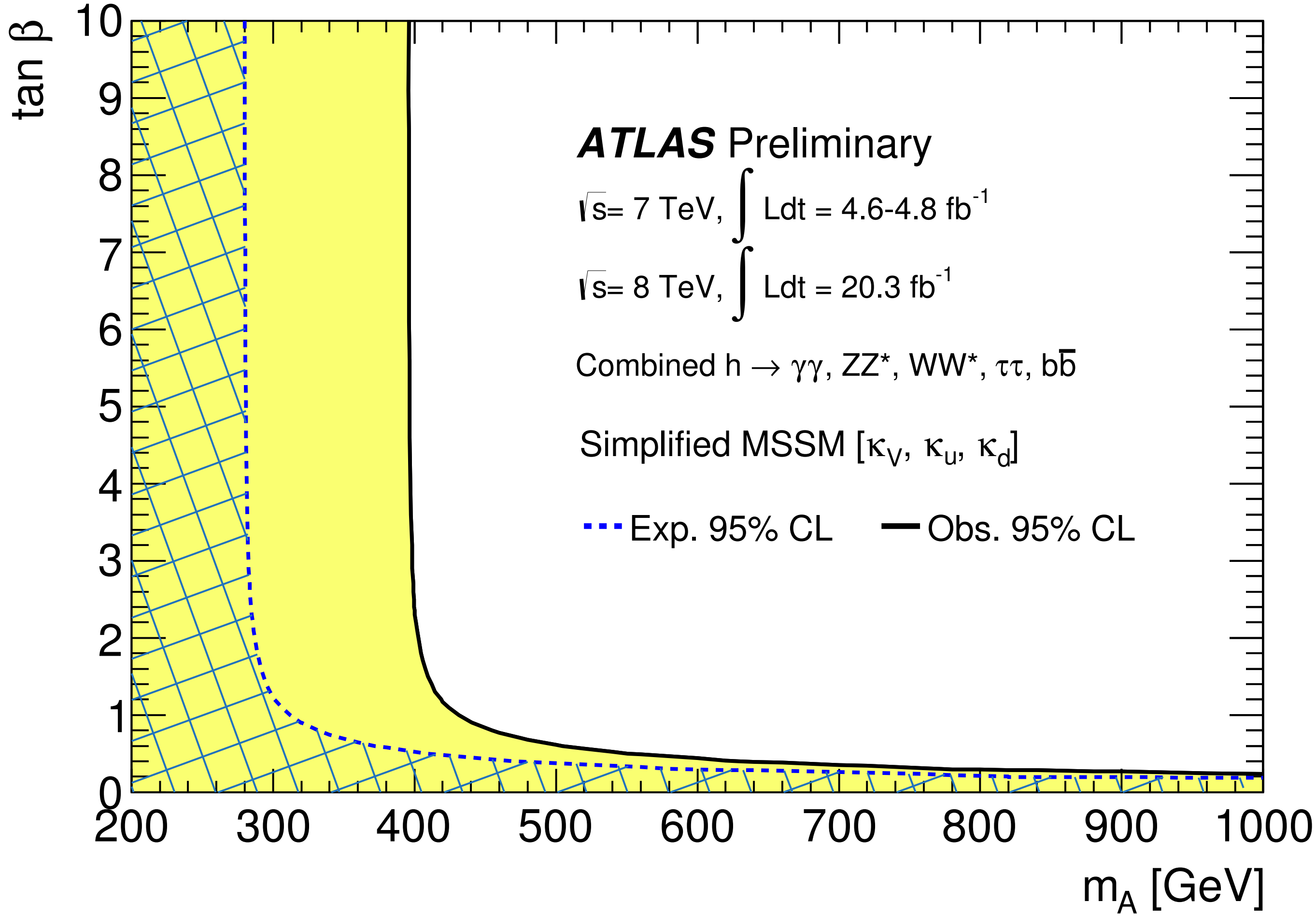


All vector boson branching ratios suppressed by enhancement of the bottom decay width

Enhancement of bottom quark and tau couplings independent of $\tan\beta$

Low values of μ similar to the ones analyzed by ATLAS

ATLAS-CONF-2014-010



Lightest SM-like Higgs mass strongly depends on:

* CP-odd Higgs mass m_A
* tan beta
* the top quark mass
* the stop masses and mixing

$$M_{\tilde{t}}^2 = \begin{pmatrix} m_Q^2 + m_t^2 + D_L & m_t X_t \\ m_t X_t & m_U^2 + m_t^2 + D_R \end{pmatrix}$$

M_h depends logarithmically on the averaged stop mass scale M_{SUSY} and has a quadratic and quartic dep. on the stop mixing parameter X_t. [and on sbotton/stau sectors for large tanbeta]

For moderate to large values of tan beta and large non-standard Higgs masses

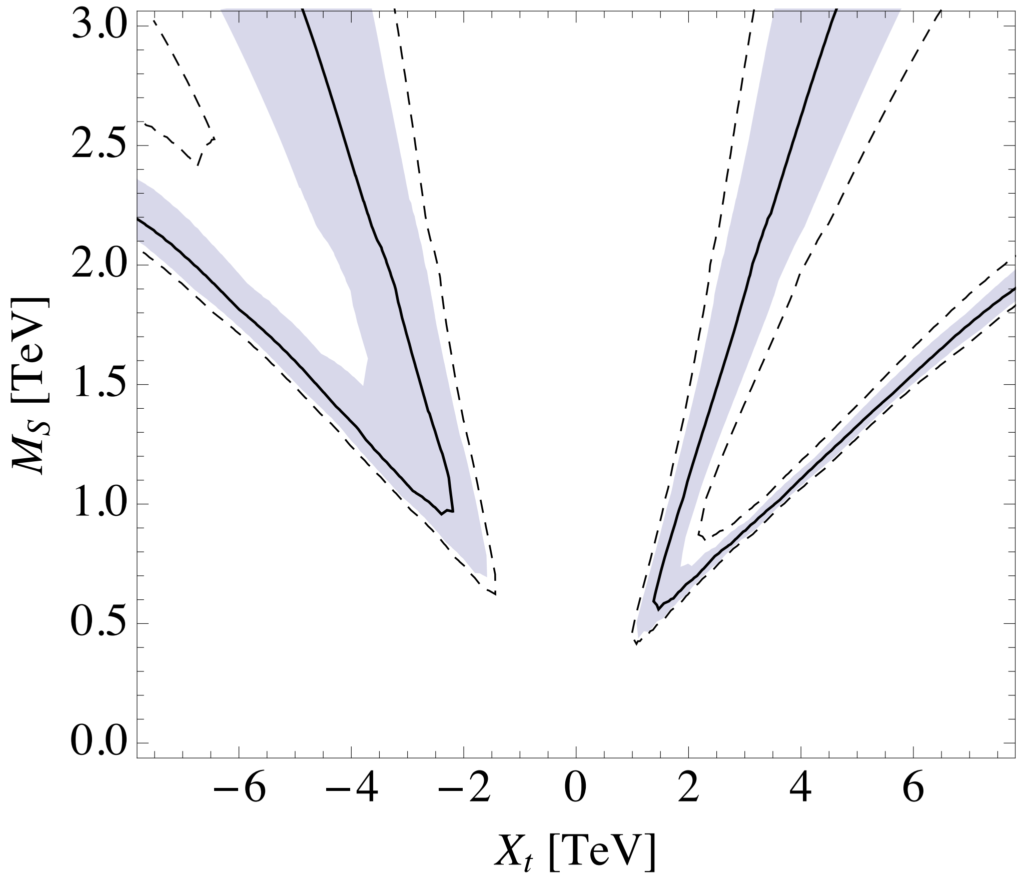
$$\boxed{m_h^2 \cong M_Z^2 \cos^2 2\beta + \frac{3}{4\pi^2}\frac{m_t^4}{v^2}\left[\frac{1}{2}\tilde{X}_t + t + \frac{1}{16\pi^2}\left(\frac{3}{2}\frac{m_t^2}{v^2} - 32\pi\alpha_3\right)\left(\tilde{X}_t t + t^2\right)\right]}$$

$$t = \log(M_{SUSY}^2/m_t^2) \qquad \tilde{X}_t = \frac{2X_t^2}{M_{SUSY}^2}\left(1 - \frac{X_t^2}{12 M_{SUSY}^2}\right) \qquad X_t = A_t - \mu/\tan\beta \rightarrow \text{LR stop mixing}$$

M.Carena, J.R. Espinosa, M. Quiros, C.W.'95
M. Carena, M. Quiros, C.W.'95

Analytic expression valid for $M_{SUSY} \sim m_Q \sim m_U$

Large Mixing in the Stop Sector Necessary



P. Draper, P. Meade, M. Reece, D. Shih'11
L. Hall, D. Pinner, J. Ruderman'11
M. Carena, S. Gori, N. Shah, C. Wagner'11
A. Arbey, M. Battaglia, A. Djouadi, F. Mahmoudi, J. Quevillon'11
S. Heinemeyer, O. Stal, G. Weiglein'11
U. Ellwanger'11

Down Couplings in the MSSM for large values of μ

- At large values of μ, corrections to the quartic couplings $\lambda_{5,6,7}$ become significant.

- For nonvanishing values of these couplings, a new condition of alignment at large $\tan\beta$ is obtained

$$\tan\beta = \frac{\lambda_{\rm SM} - \tilde{\lambda}_3}{\lambda_7}, \qquad \lambda_2 \simeq \lambda_{\rm SM}$$

- Alignment for $\tan\beta \simeq 10$ may be obtained, making difficult the test of the "wedge" by coupling variations.

M. Carena, I. Low, N. Shah, C.W.'13

Impact and Size of Loop Corrections

Considering

$$\Delta L_{12} = \lambda_7, \qquad \Delta \tilde{L}_{12} = \Delta\left(\lambda_3 + \lambda_4\right), \qquad \Delta L_{11} = \lambda_5, \qquad \Delta L_{22} = \lambda_2.$$

The condition of alignment reads

$$\tan\beta \simeq \frac{\lambda_{\rm SM} - \tilde{\lambda}_3^{\rm tree} - \Delta\tilde{\lambda}_3}{\lambda_7} = \frac{120 - 32\pi^2\left(\Delta L_{11} + \Delta\tilde{L}_{12}\right)}{32\pi^2 \Delta L_{12}}$$

where the loop corrections are approximately given by

$$v^2 \Delta L_{12} \simeq \frac{v^2}{32\pi^2}\left[h_t^4 \frac{\mu \tilde{A}_t}{M_{\rm SUSY}^2}\left(\frac{A_t \tilde{A}_t}{M_{\rm SUSY}^2} - 6\right) + h_b^4 \frac{\mu^3 A_b}{M_{\rm SUSY}^4} + \frac{h_\tau^4}{3}\frac{\mu^3 A_\tau}{M_{\tilde{\tau}}^4}\right],$$

$$v^2 \Delta\tilde{L}_{12} \simeq \frac{v^2}{16\pi^2}\left[h_t^4 \frac{\mu^2}{M_{\rm SUSY}^2}\left(3 - \frac{A_t^2}{M_{\rm SUSY}^2}\right) + h_b^4 \frac{\mu^2}{M_{\rm SUSY}^2}\left(3 - \frac{A_b^2}{M_{\rm SUSY}^2}\right) + h_\tau^4 \frac{\mu^2}{3M_{\tilde{\tau}}^2}\left(3 - \frac{A_\tau^2}{M_{\tilde{\tau}}^2}\right)\right].$$

$$v^2 \Delta L_{11} \simeq -\frac{v^2}{32\pi^2}\left(\frac{h_t^4 \mu^2 A_t^2}{M_{\rm SUSY}^4} + \frac{h_b^4 \mu^2 A_b^2}{M_{\rm SUSY}^4} + \frac{h_\tau^4 \mu^2 A_\tau^2}{3M_{\tilde{\tau}}^4}\right)$$

M. Carena, I. Low, N. Shah, C.W.'13

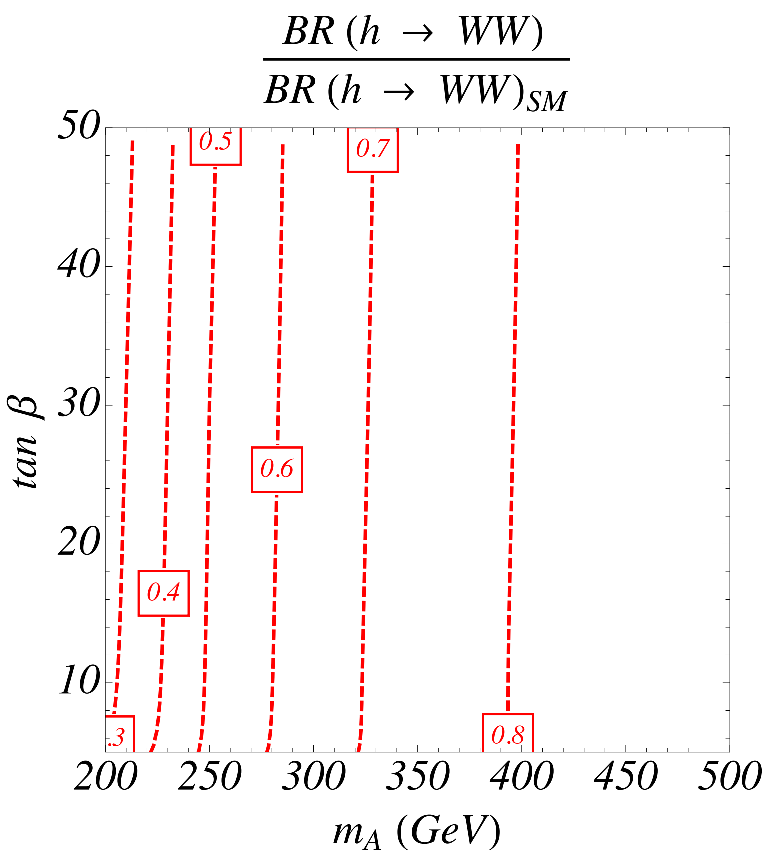
Carena, Haber, Low, Shah, C.W.'14

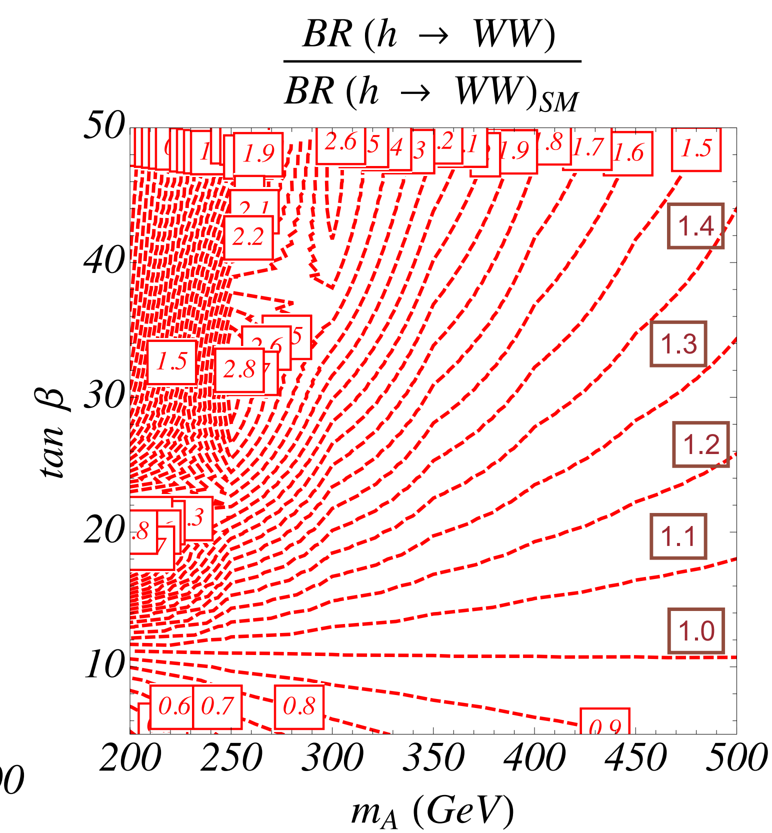
Higgs Decay into Gauge Bosons

Mostly determined by the change of width

Small μ

$\mu/M_{\rm SUSY} = 2, \qquad A_t/M_{\rm SUSY} \simeq 3$

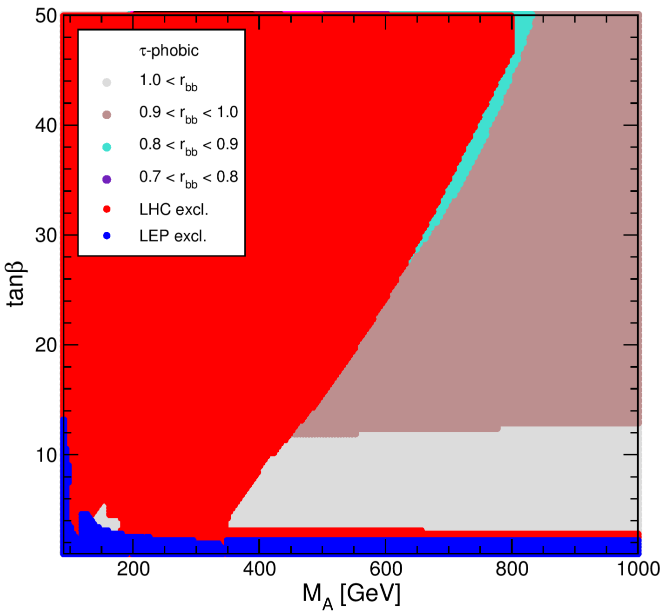


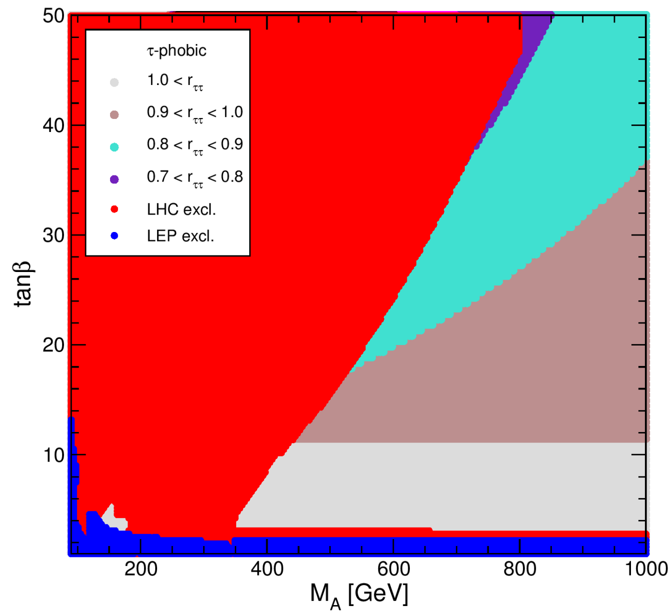


CP-odd Higgs masses of order 200 GeV and tanβ = 10 OK in the alignment case

The τ-phobic Higgs scenario

Suppression of down-type fermion couplings to the Higgs due to Higgs mixing effects. Staus play a relevant role. Decays into staus relevant for heavy non-standard Higgs bosons.





$$
\begin{aligned}
M_{\rm SUSY} &= 1500 \text{ GeV}, \\
\mu &= 2000 \text{ GeV}, \\
M_2 &= 200 \text{ GeV}, \\
X_t^{\rm OS} &= 2.45\, M_{\rm SUSY} \text{ (FD calculation)}, \\
X_t^{\overline{\rm MS}} &= 2.9\, M_{\rm SUSY} \text{ (RG calculation)}, \\
A_b &= A_\tau = A_t\ , \\
m_{\tilde g} &= 1500 \text{ GeV}, \\
M_{\tilde l_3} &= 500 \text{ GeV}\ .
\end{aligned}
$$

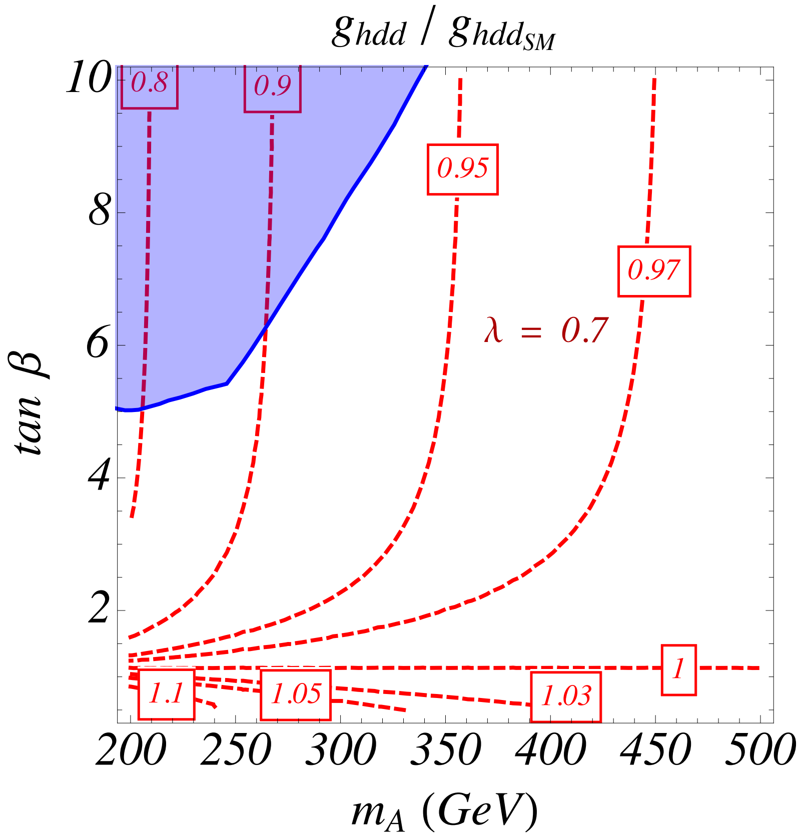
M. Carena, S. Heinemeyer, O. Stål, C.E.M. Wagner, G. Weiglein, arXiv:1302.7033

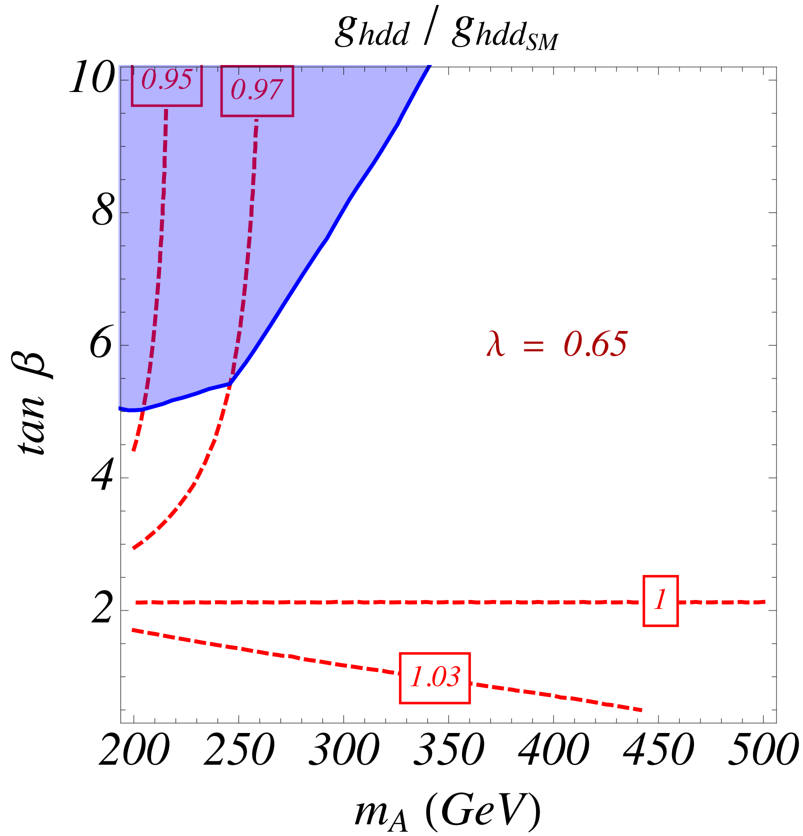
$$
\mathrm{Loop}_{12} = \frac{m_t^4}{16\pi^2 v^2 \sin^2\beta}\frac{\mu \tilde{A}_t}{M_{\rm SUSY}^2}\left[\frac{A_t \tilde{A}_t}{M_{\rm SUSY}^2} - 6\right] + \frac{h_b^4 v^2}{16\pi^2}\sin^2\beta\,\frac{\mu^3 A_b}{M_{\rm SUSY}^4} + \frac{h_\tau^4 v^2}{48\pi^2}\sin^2\beta\,\frac{\mu^3 A_\tau}{M_{\tilde\tau}^4}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

M. Carena, I. Low, N. Shah, C.W.'13

Down Fermion Couplings in the NMSSM

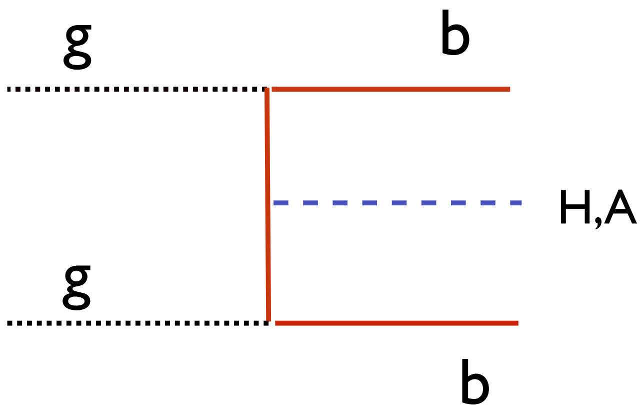
$$\lambda_2 - \lambda_{\rm SM} = \frac{\lambda_{\rm SM} - \tilde{\lambda}_3}{\tan^2\beta} = \frac{\lambda_1 - \lambda_{\rm SM}}{\tan^4\beta} \qquad \tilde{\lambda}_3 = -0.135 \ + \ \lambda^2$$



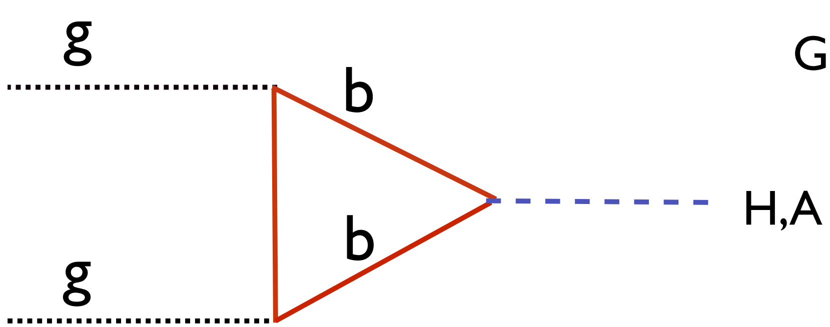


Non-Standard Higgs Production

QCD: S. Dawson, C.B. Jackson, L. Reina, D.Wackeroth, hep-ph/06031



Associated Production



Gluon Fusion

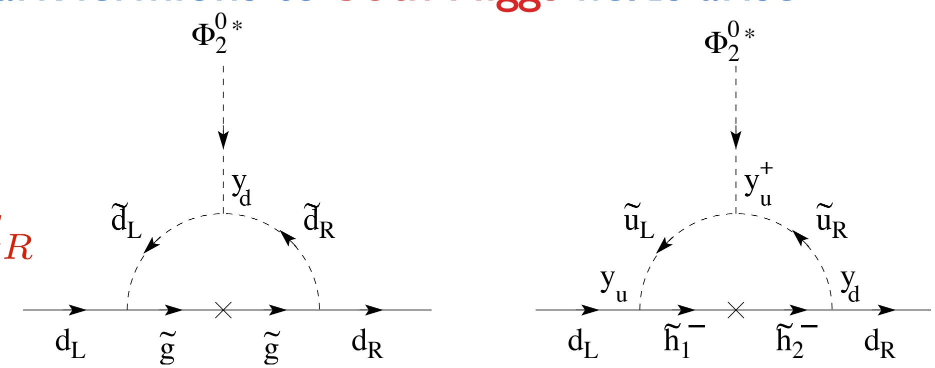
$$g_{Abb} \simeq g_{Hbb} \simeq \frac{m_b \tan\beta}{(1+\Delta_b)v}, \qquad g_{A\tau\tau} \simeq g_{H\tau\tau} \simeq \frac{m_\tau \tan\beta}{v}$$

Hempfling '93
Hall, Rattazzi, Sarid'93
Carena, Olechowski, Pokorski, C.W.'93

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

$$m_b = h_b v_1 \left(1 + \frac{\Delta h_b}{h_b} \tan\beta\right) \qquad \boxed{\tan\beta = \frac{v_2}{v_1}}$$

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

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

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.

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

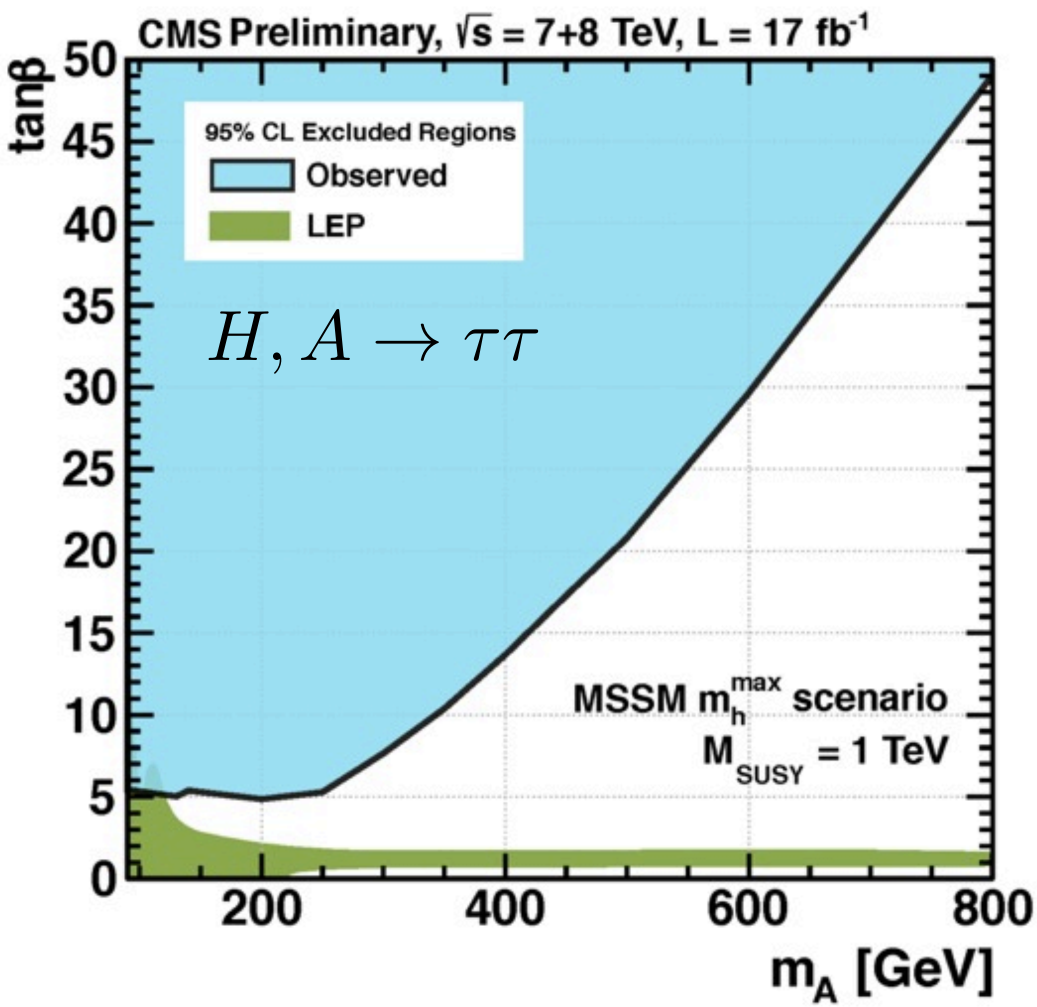
$$\sigma(b\bar{b}, gg \to A) \times BR(A \to \tau\tau) \simeq \sigma(b\bar{b}, gg \to A)_{\mathrm{SM}} \frac{\tan^2\beta}{(1+\Delta_b)^2+9}$$

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

- If charginos are light, they contribute to the total with, suppressing the BR.

$$\sigma(pp \to H, A \to \tau\tau) \propto \frac{\tan^2\beta}{\left[\left(3\frac{m_b^2}{m_\tau^2} + \frac{(M_W^2+M_Z^2)(1+\Delta_b)^2}{m_\tau^2\tan^2\beta}\right)(1+\Delta_\tau)^2 + (1+\Delta_b)^2\right]}$$

In the MSSM, non-standard Higgs may be produced via its large couplings to the bottom quark, and searched for in its decays into bottom quarks and tau leptons



How to test the region of low tanbeta and moderate mA ?

Decays of non-standard Higgs bosons into paris of standard ones, charginos and neutralinos may be a possibility.

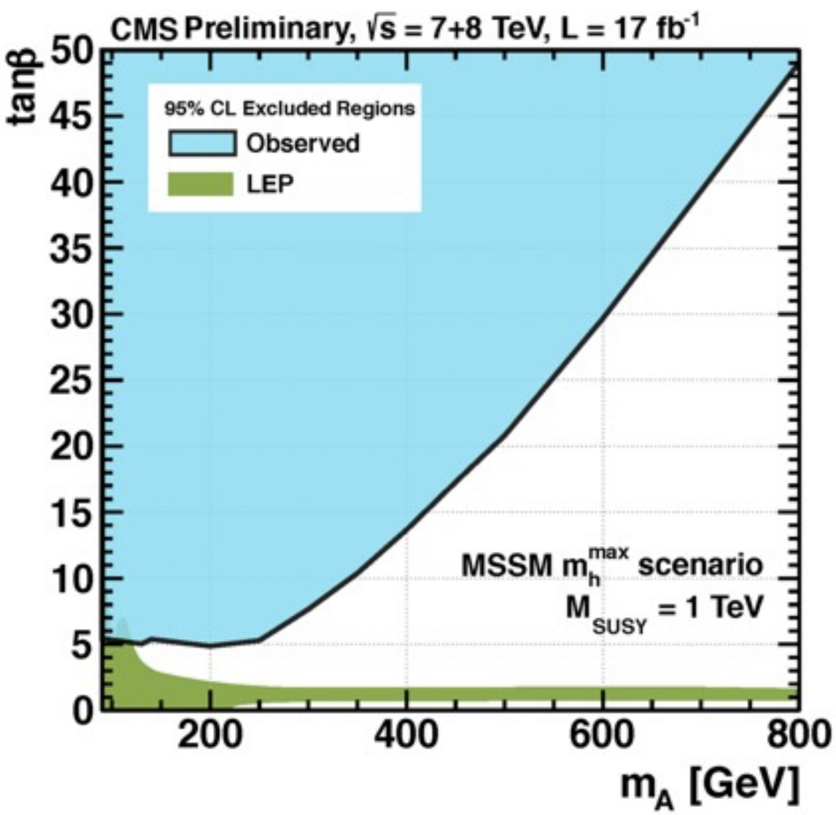
Can change in couplings help there ?

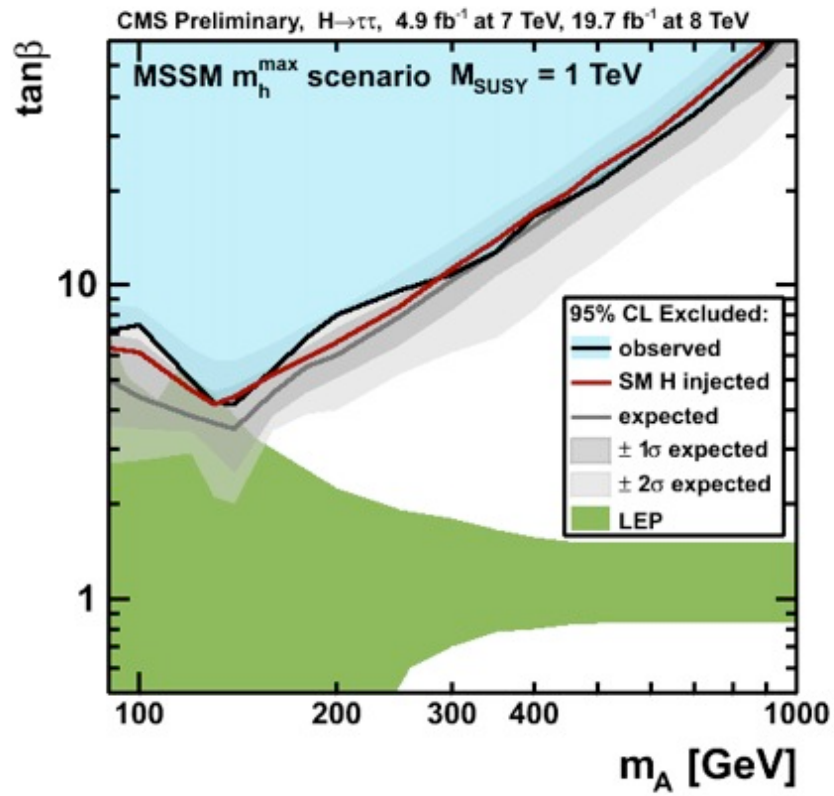
It depends on radiative corrections

See
Carena, Haber, Logan, Mrenna '01

Small differences in final analysis... Small excess at 200 GeV and tanβ of order 10 ?

Need to control the SM-like Higgs behavior !





Bounds used

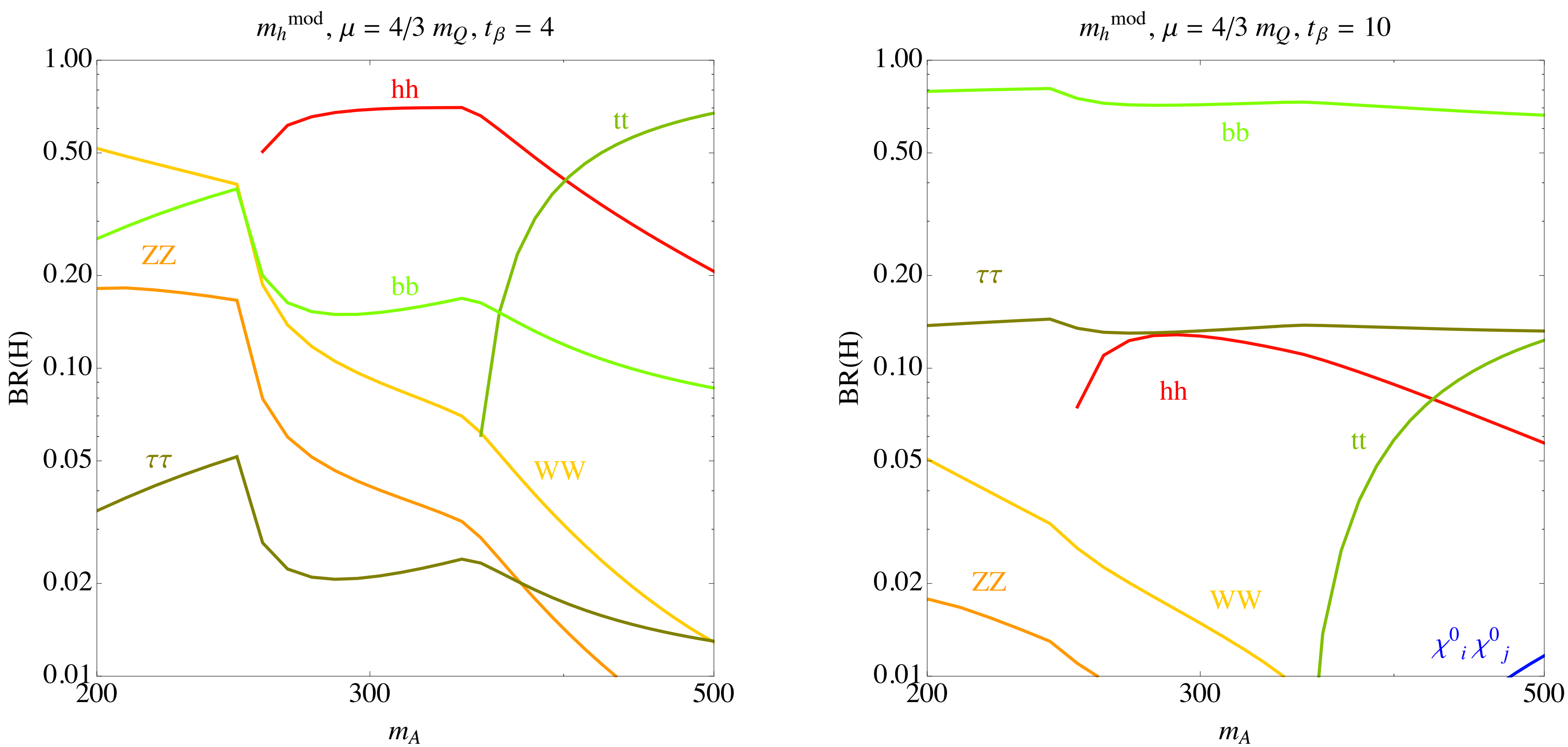
Final results

Heavy Supersymmetric Particles

A variety of decay Branching Ratios

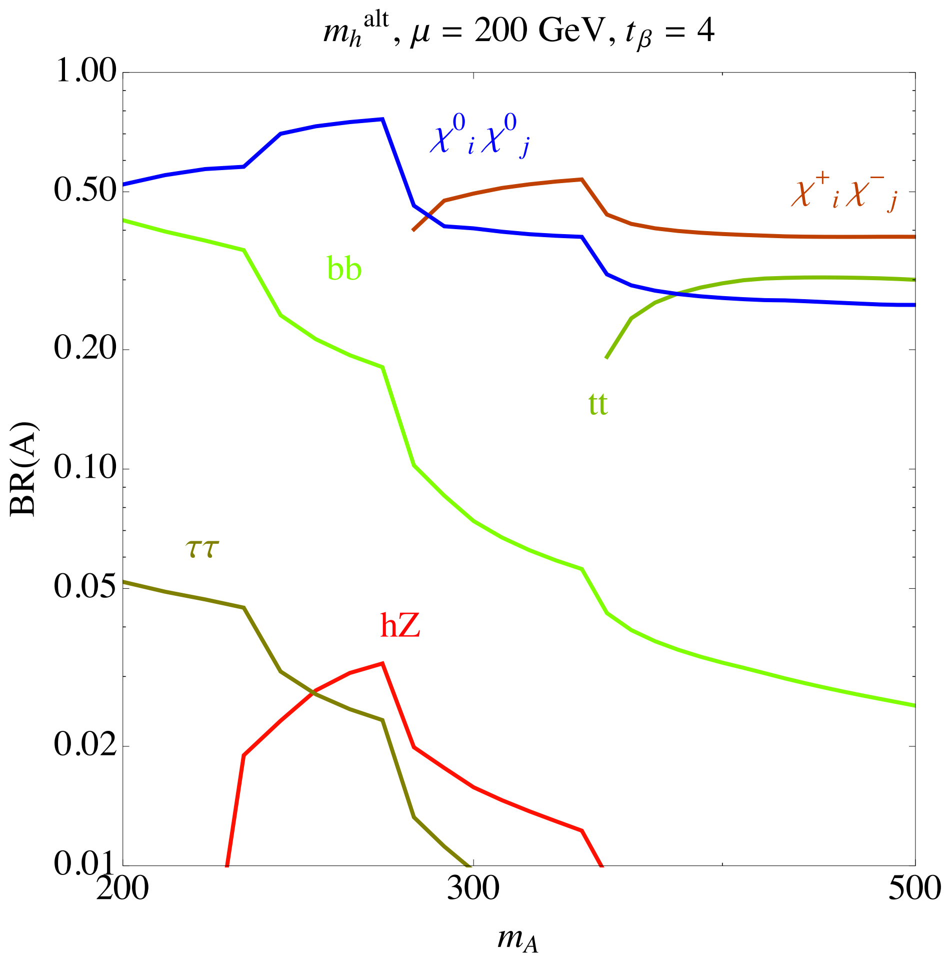
Carena, Haber, Low, Shah, C.W.'14

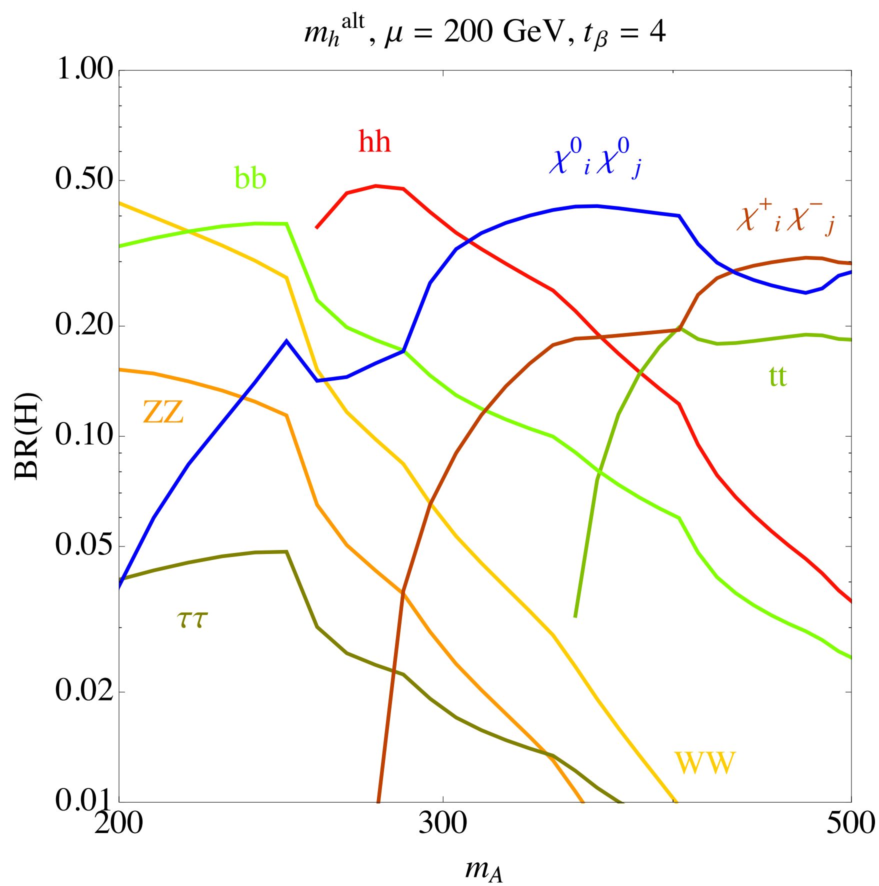
Depending on the values of mu and tanbeta different search strategies must be applied.



Light Charginos and Neutralinos can significantly modify M the CP-odd Higgs Decay Branching Ratios

Carena, Haber, Low, Shah, C.W.'14

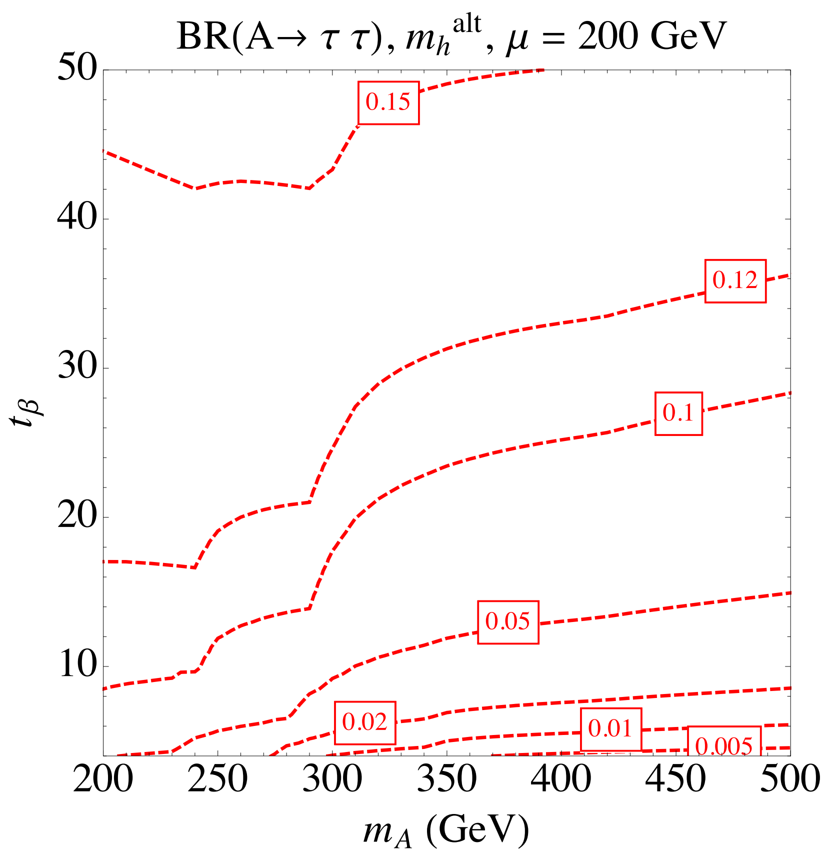


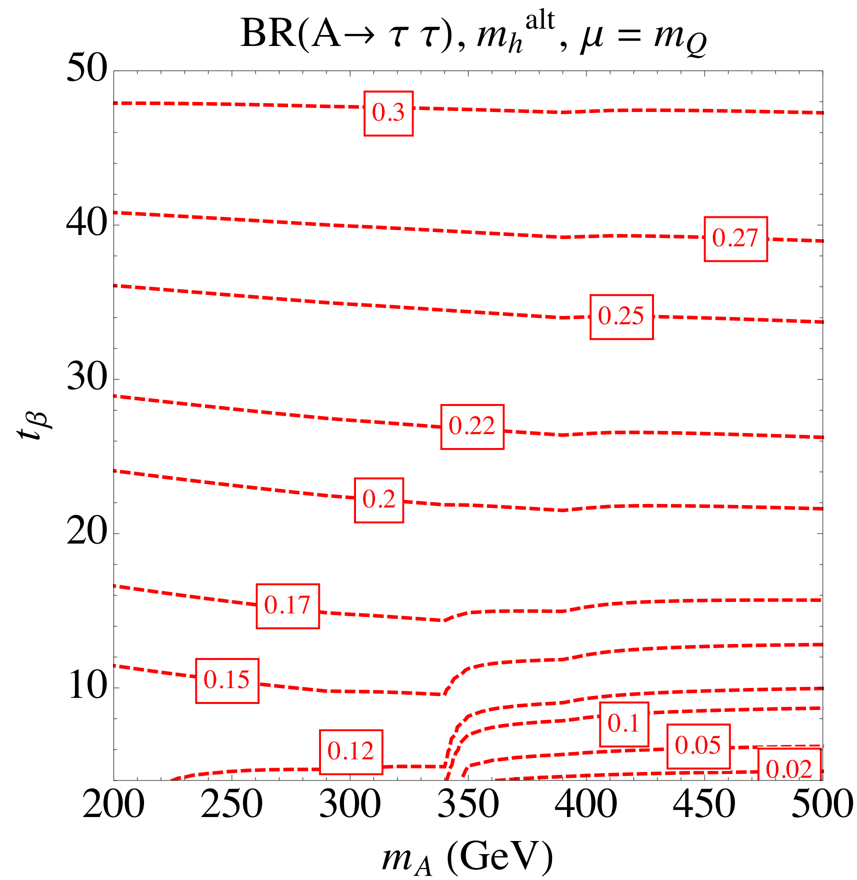


Carena, Haber, Low, Shah, C.W.'14

Variation of the CP-odd Higgs Decays with the value of μ

Strong suppression due to chargino contribution

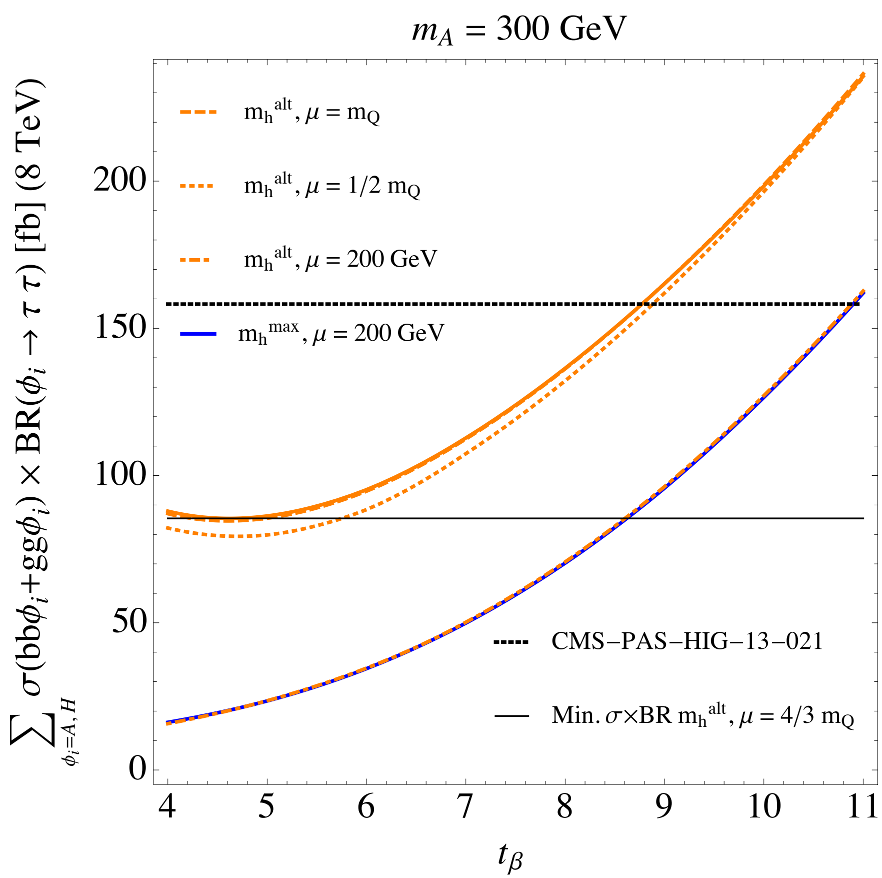


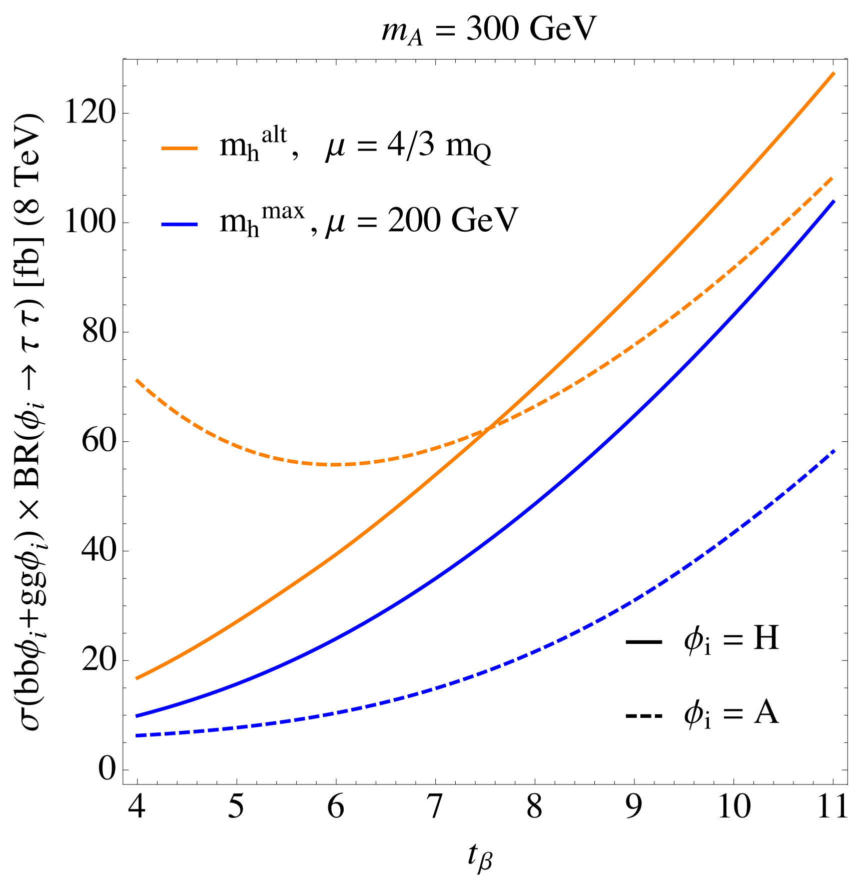


Decays into taus become prominent for heavy electroweakino masses (or suppressed couplings)

Change in bound of $\tan\beta$ due to variation of μ

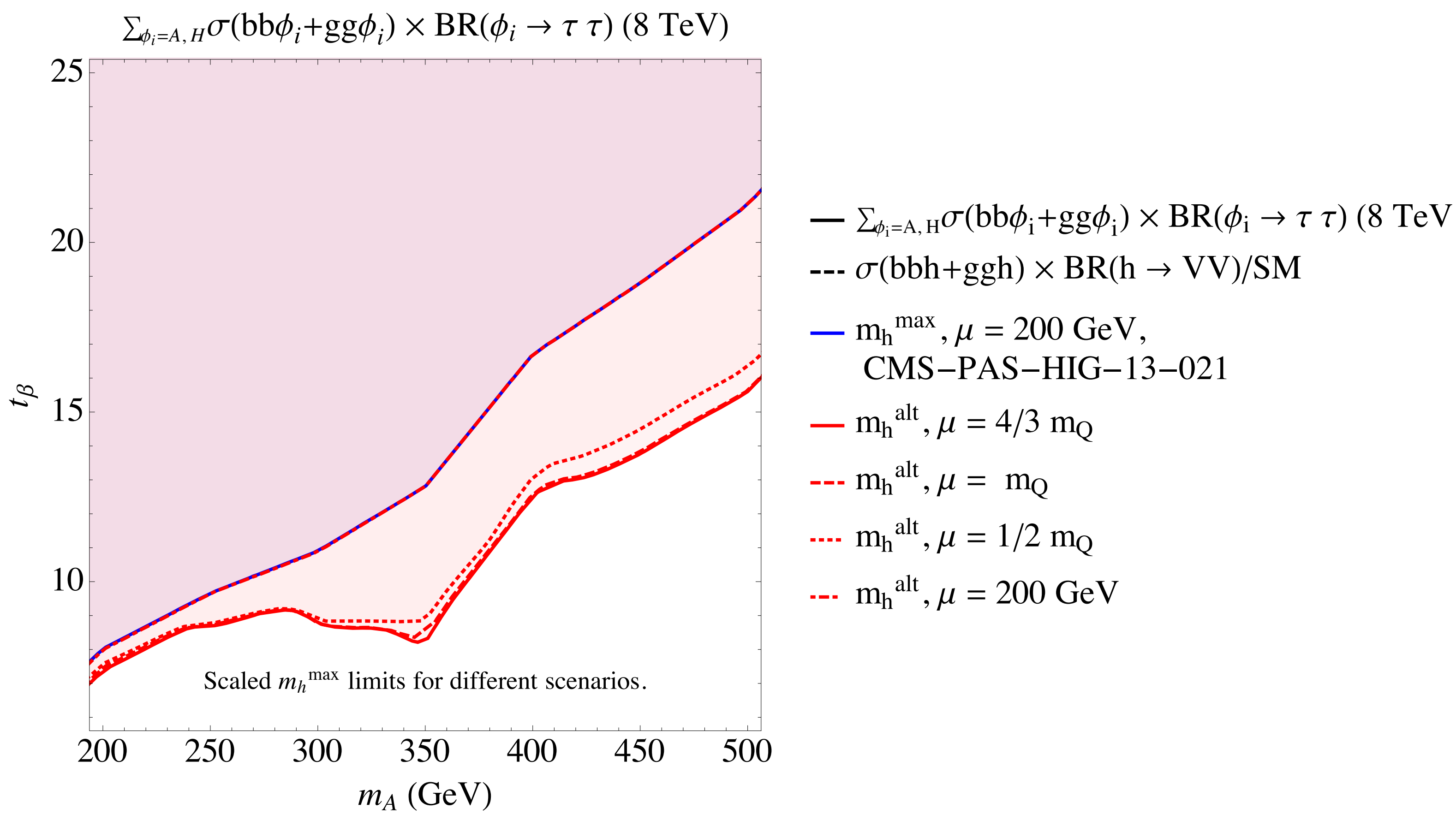
Carena, Haber, Low, Shah, C.W.'14





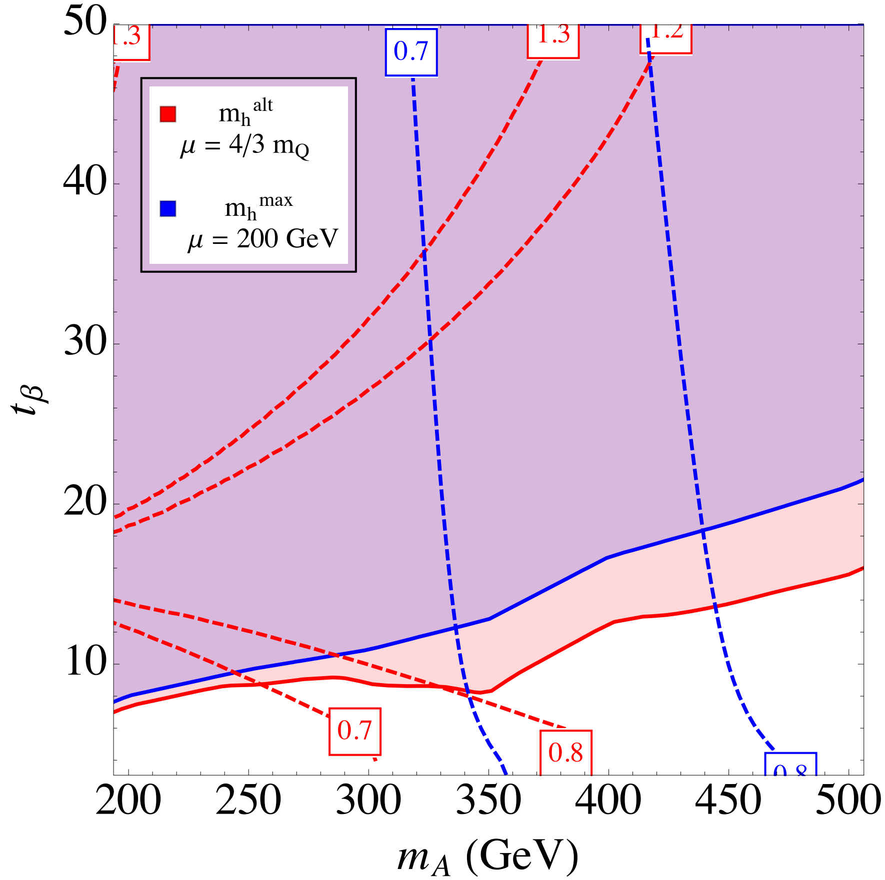
Variation of the Experimental Bound with the value of μ

Carena, Haber, Low, Shah, C.W.'14



Complementarity between different search channels

Carena, Haber, Low, Shah, C.W.'14



Limits coming from measurements of h couplings become weaker for larger values of μ

— $\sum_{\phi_i=A,H}\sigma(bb\phi_i+gg\phi_i) \times BR(\phi_i \to \tau\,\tau)$ (8 TeV)

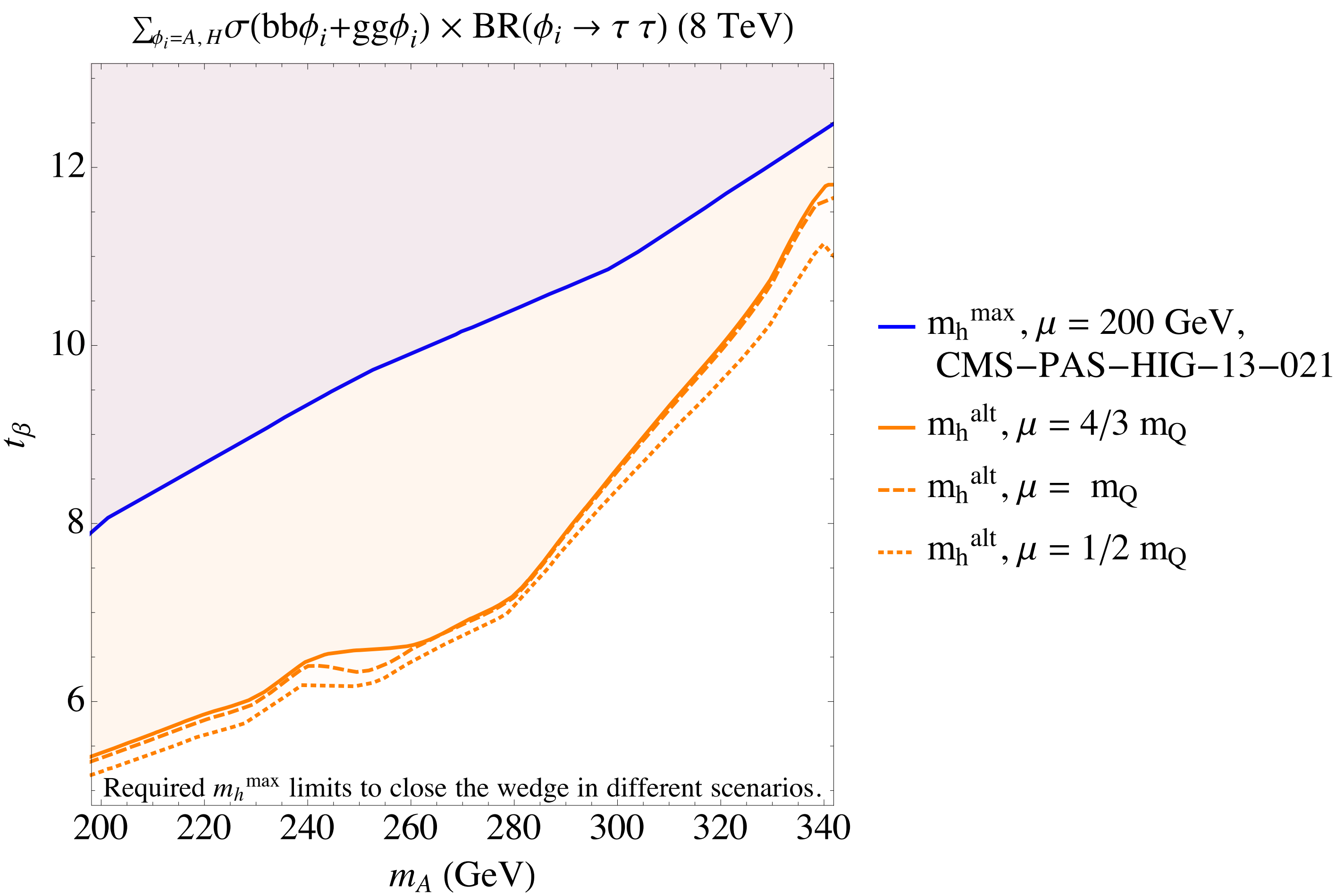
--- $\sigma(bbh+ggh) \times BR(h \to VV)/SM$

Limits coming from direct searches of $H, A \to \tau\tau$ become stronger for larger values of μ

Bounds on m_A are therefore dependent on the scenario and at present become weaker for larger μ

With a modest improvement of direct search limit one would be able to close the wedge, below top pair decay threshold

Limit in the mhmax scenario that would close the wedge for masses below 350 GeV



Conclusions

- The MSSM provides a very predictive framework for the computation of the Higgs phenomenology.
- The properties of the lightest and heavy Higgs bosons depend strongly on radiative corrections mediated by the stops
- In general, at low values of the CP-odd Higgs mass the lightest CP-even Higgs width increases, leading to a suppression of the other decay branching ratios (with the possible exception of loop induced couplings)
- Such suppressions are restricted by present measurements, and can only be avoided under the presence of alignment.
- Alignment in the MSSM appears for large values of mu, for which decays into electroweakinos are suppressed, making the bounds coming from decays into SM particles stronger.
- Bounds on the CP-odd Higgs mass are model dependent and should take into account this dependence.

Comparison of BR of decay into vector bosons and photons