Interplay of Supersymmetry and Higgs Physics

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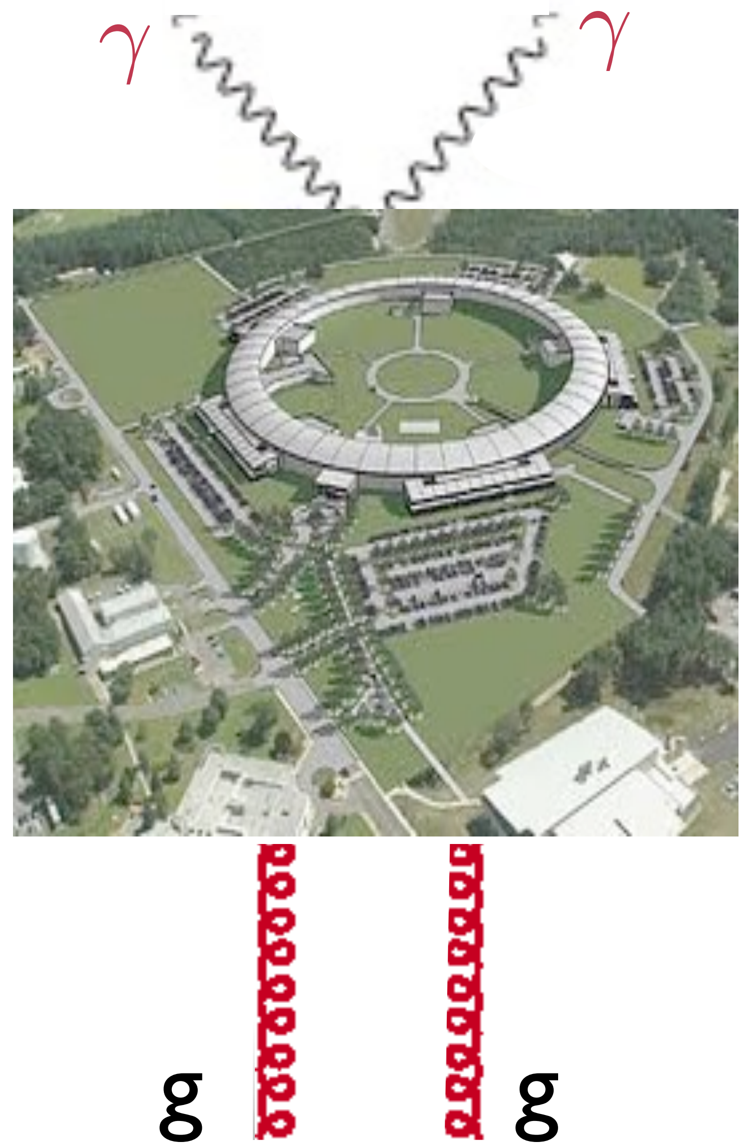


SUSY Workshop, BNL, May 2, 2012

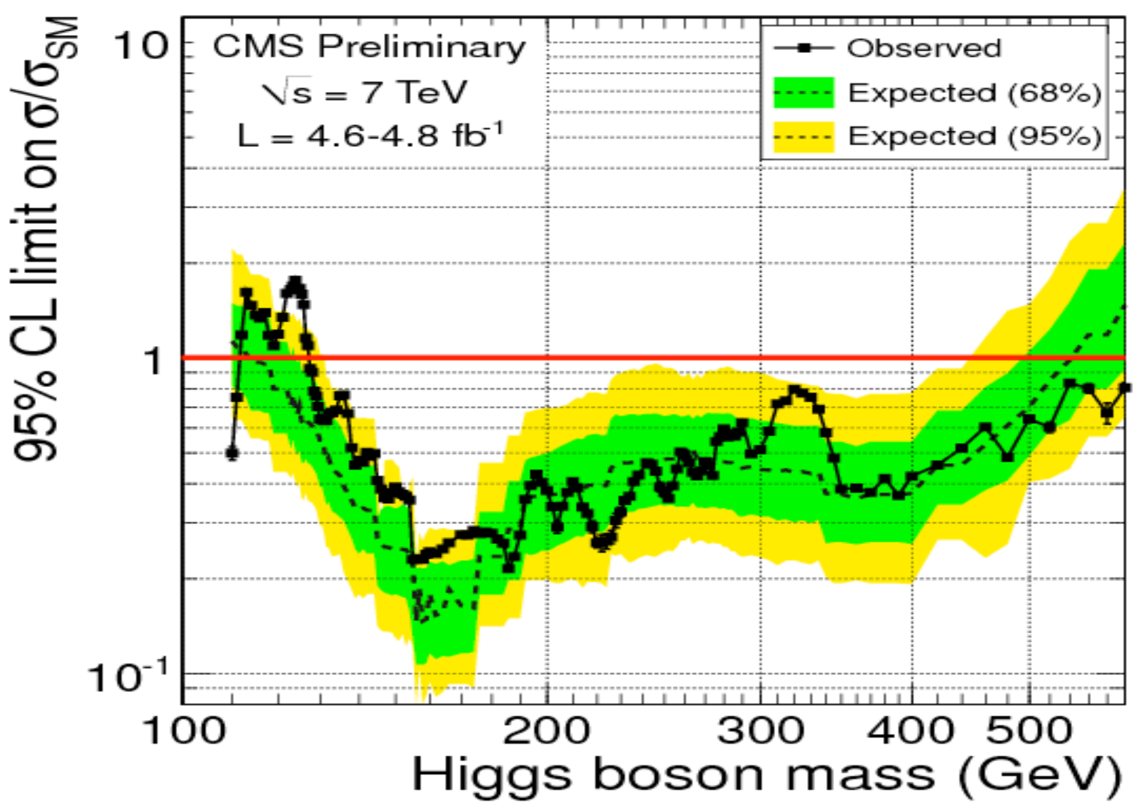
Based on the following works :

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, C.W., L.T. Wang, to appear

M. Carena, I. Low and C.E.M. Wagner, to appear

Full mass range



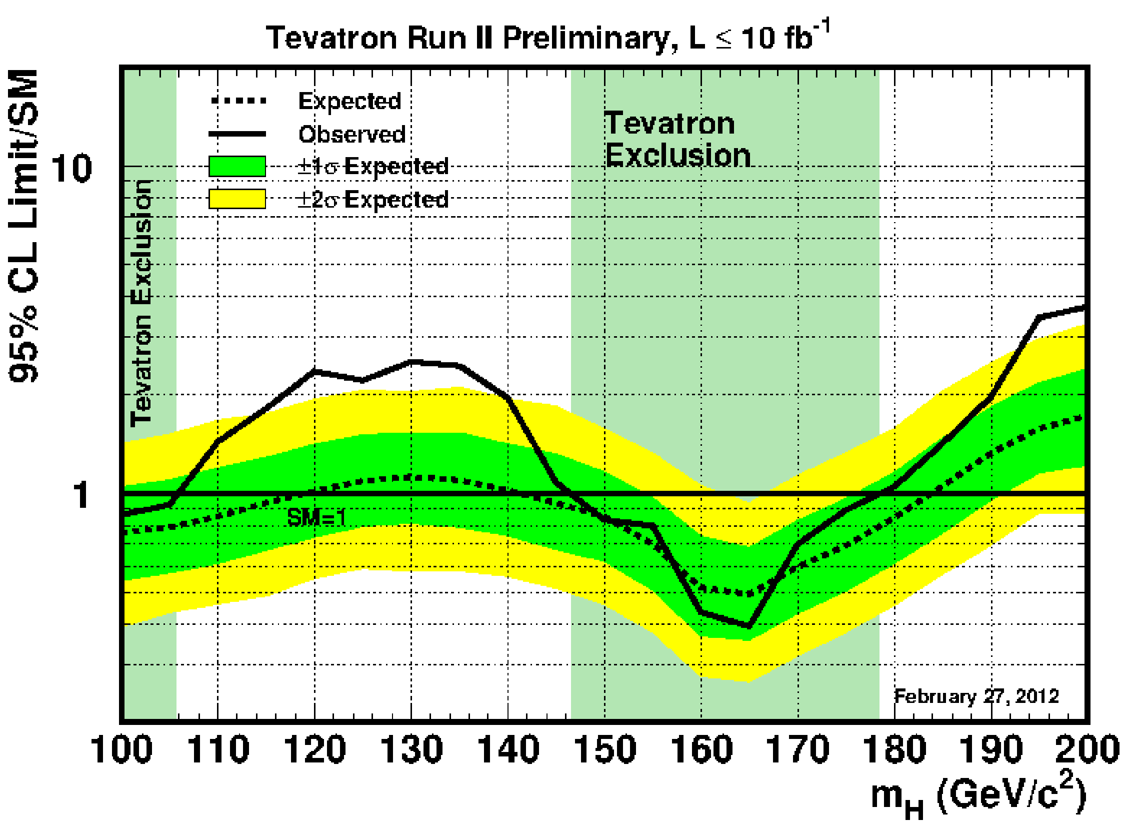
Observed: 95% exclusion M_H in [127.5-600] GeV

We are leaving in exciting times:

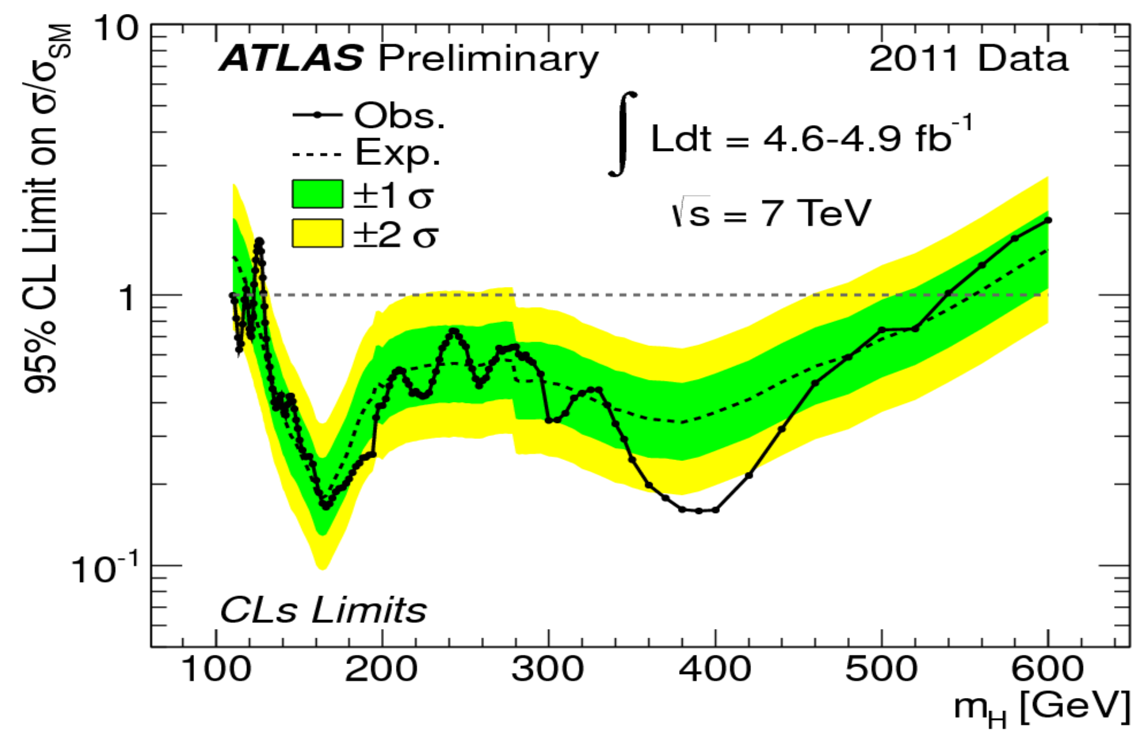
LHC and Tevatron Experiments are starting to test the SM Higgs above the LEP limit, leading to interesting exclusion bounds on its mass.

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.

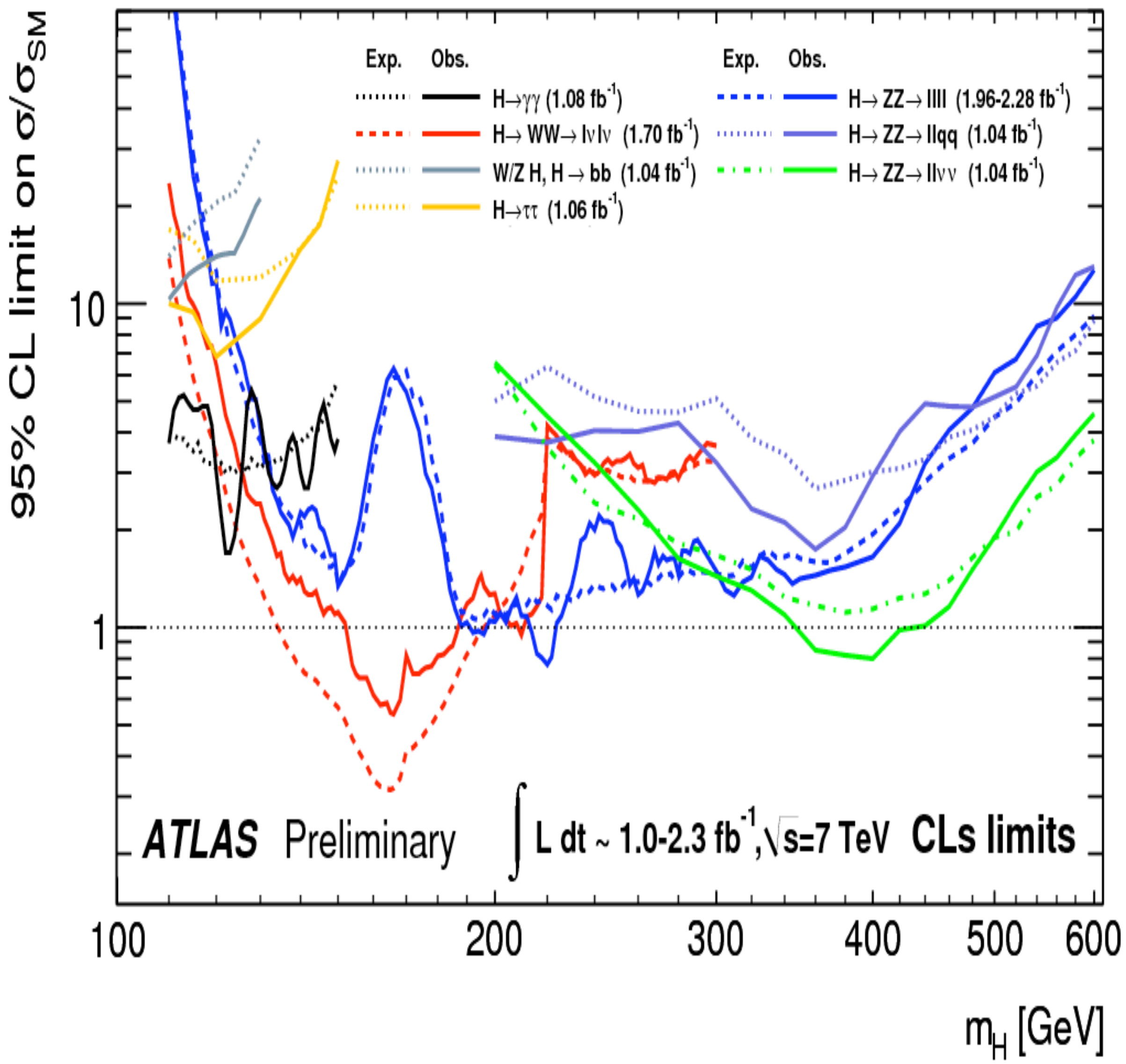


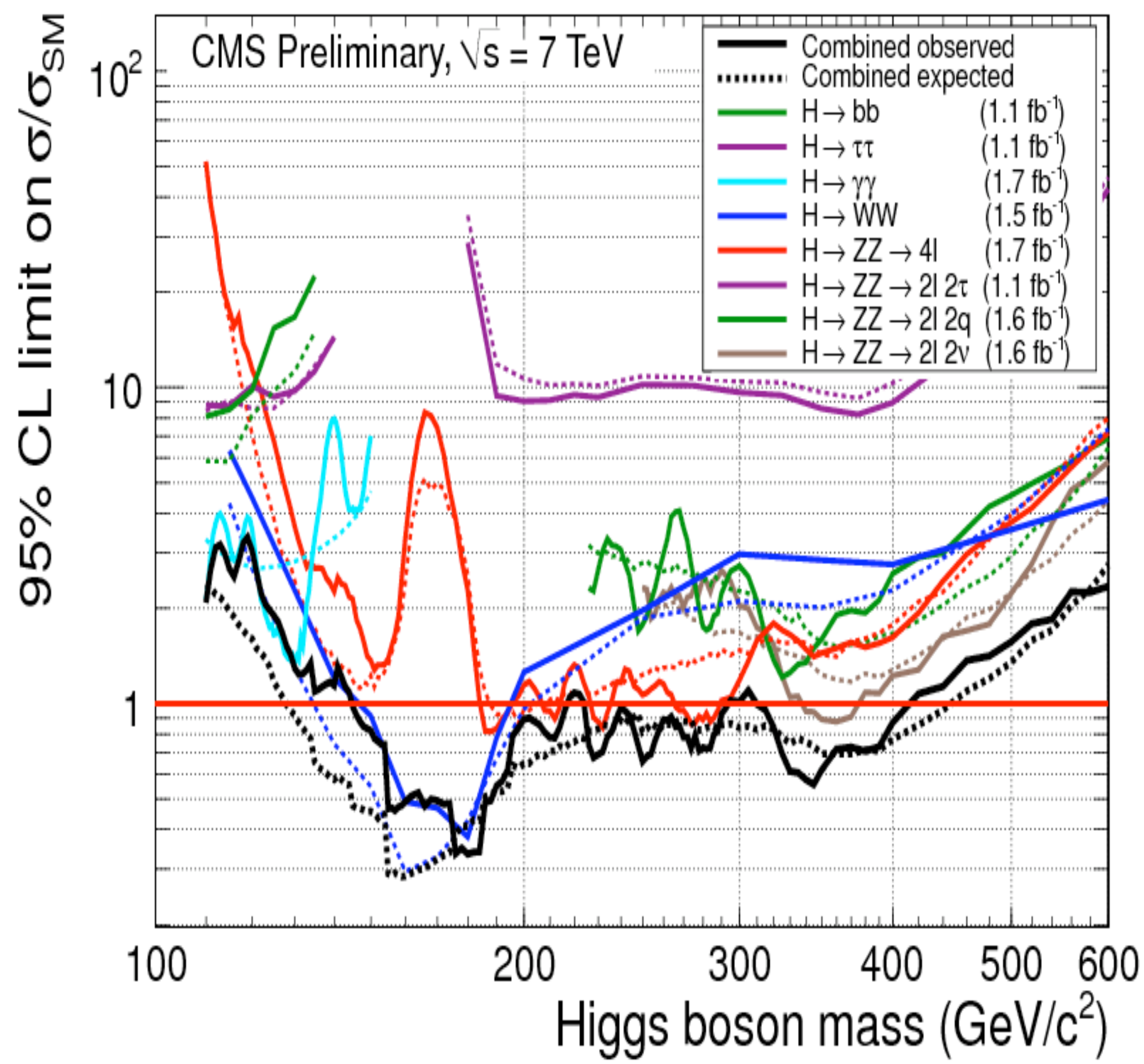
Observed exclusion: **100 < M_H < 106 GeV** 147 < M_H < 179 GeV



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

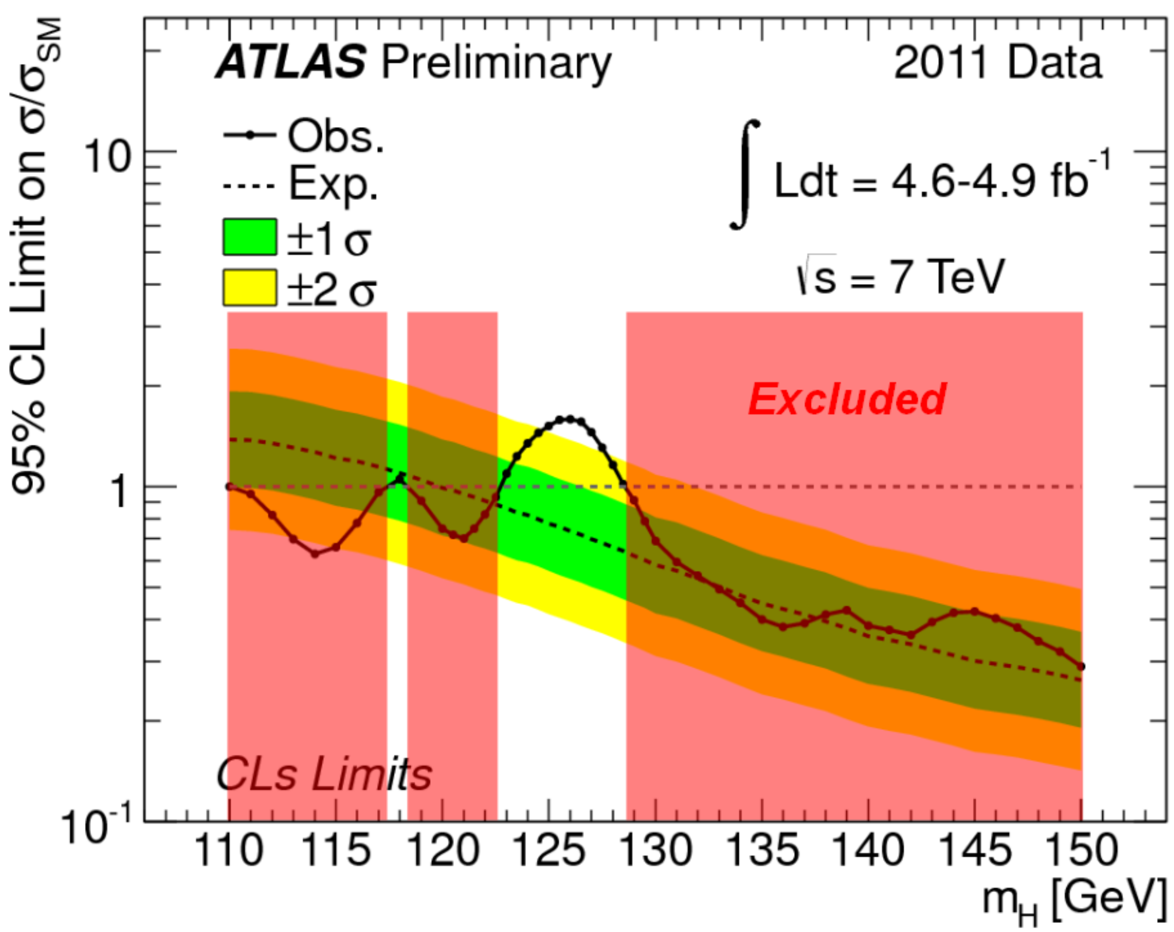
Higgs Limits at the LHC obtained by combination of multiple channels



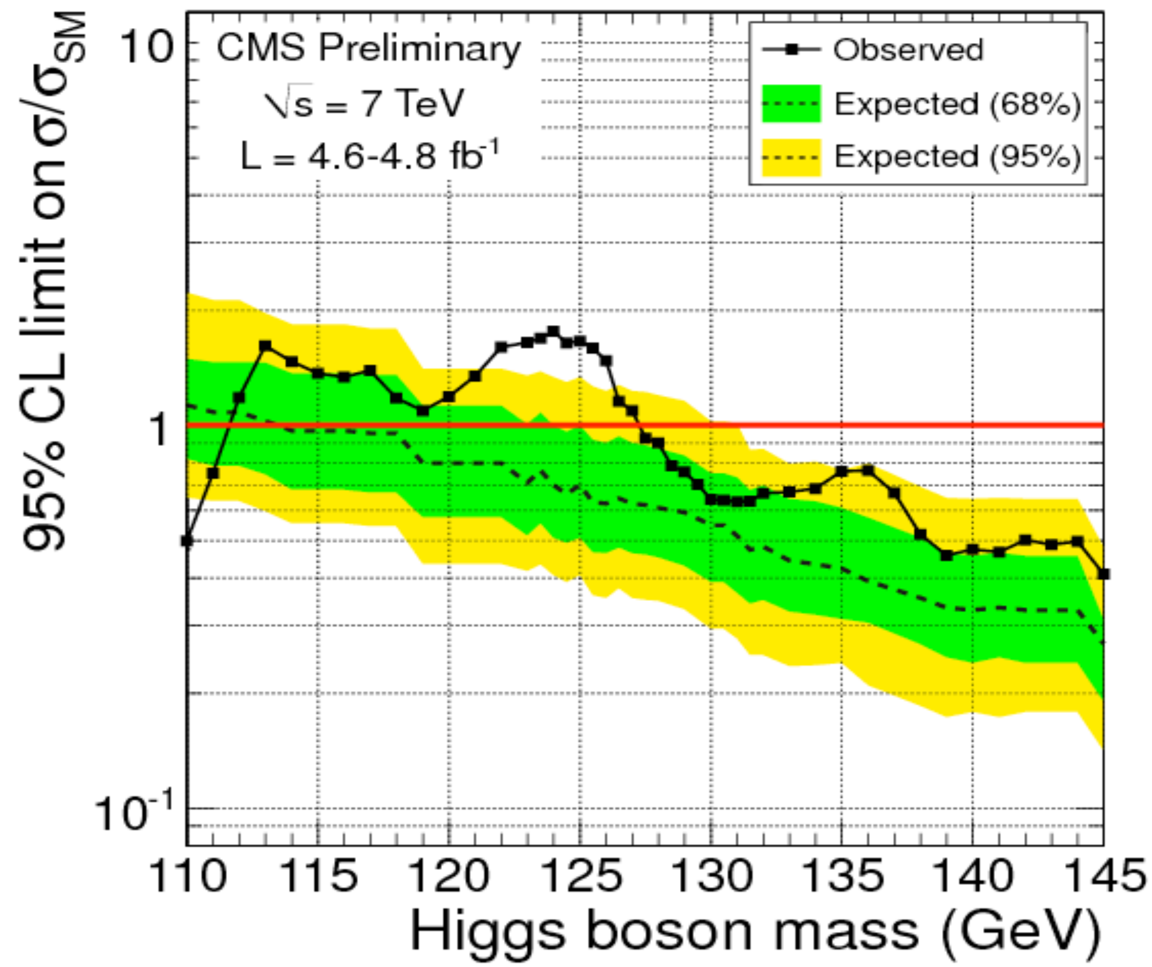


Zoom on the low Higgs Mass

Zoom in:

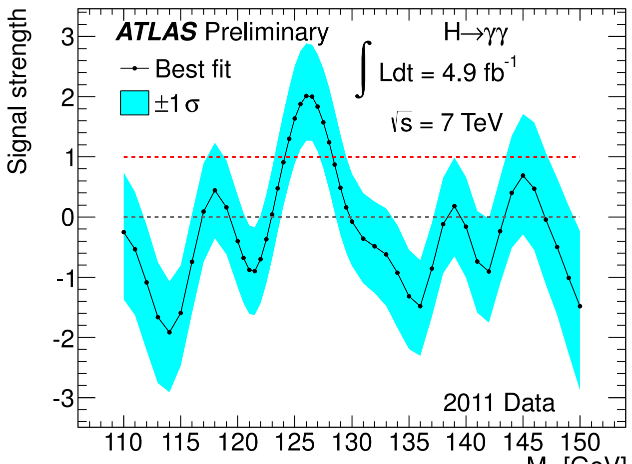


Low mass region

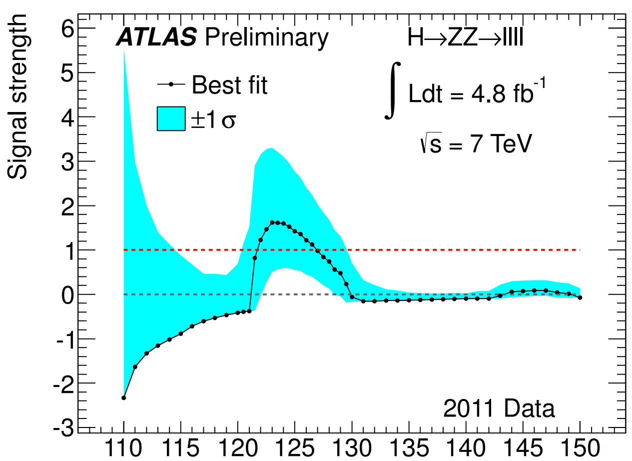


If the Higgs is SM-like, mass range between 115 GeV and 130 GeV is preferred both from direct searhes as well as from indirect precision tests. Interesting excess in the region of Higgs masses close to 125 GeV.

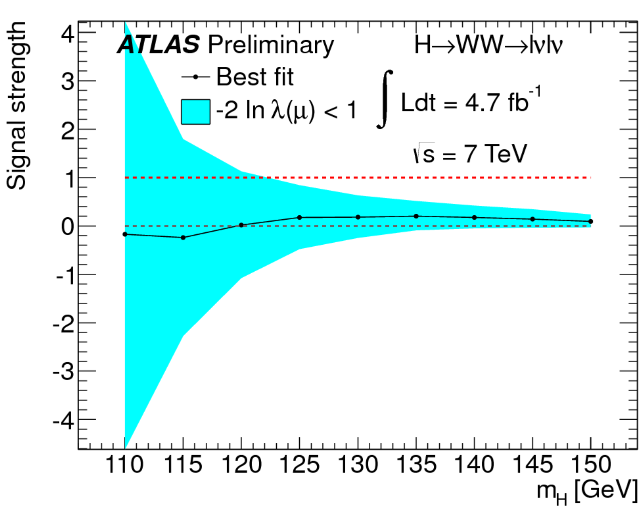
The photon rate looks somewhat high at this point, but more data are necessary in order to reach a robust conclusion on this relevant issue

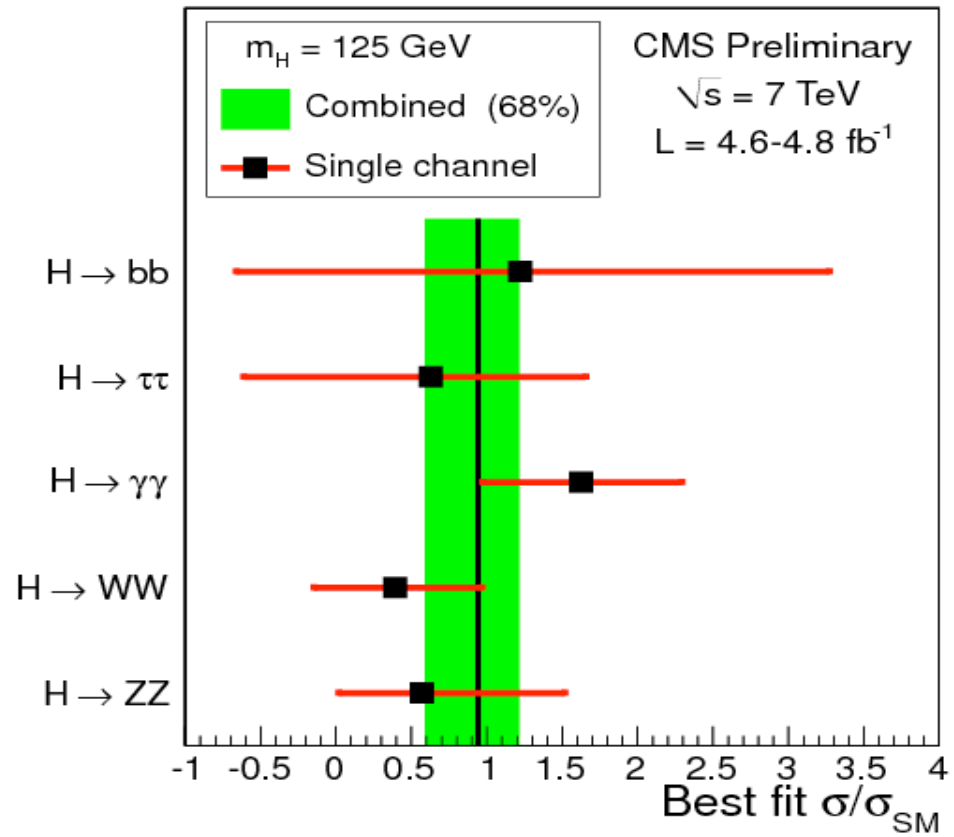


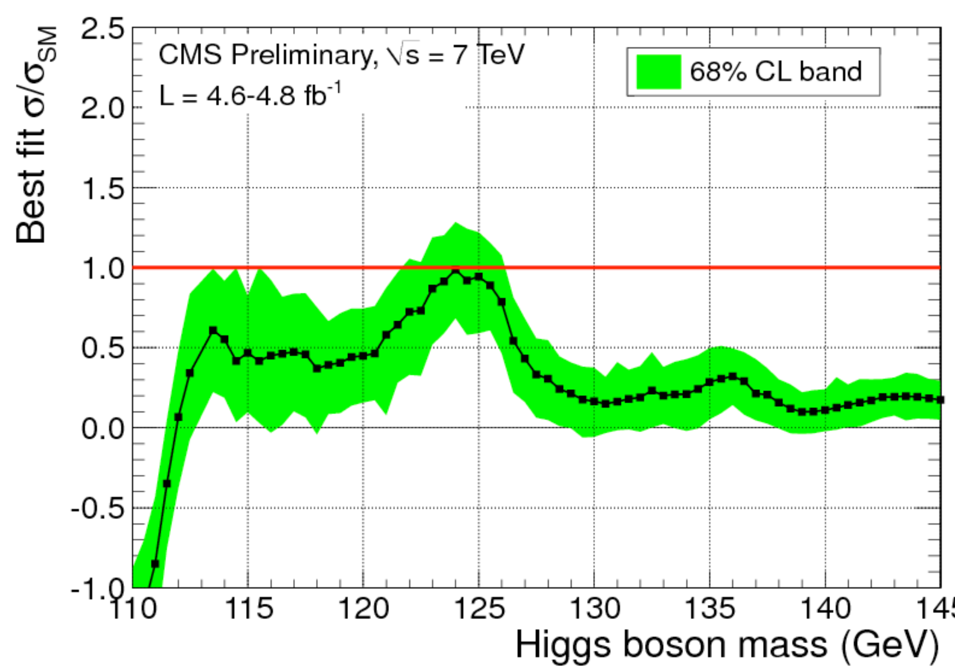
(a)



(b)







Supersymmetry

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

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

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

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

$$t = \log(M_{SUSY}^2 / m_t^2) \qquad \tilde{X}_t = \frac{2X_t^2}{M_{SUSY}^2}\left(1 - \frac{X_t^2}{12 M_{SUSY}^2}\right)$$

$X_t = A_t - \mu/\tan\beta \rightarrow$ LR stop mixing

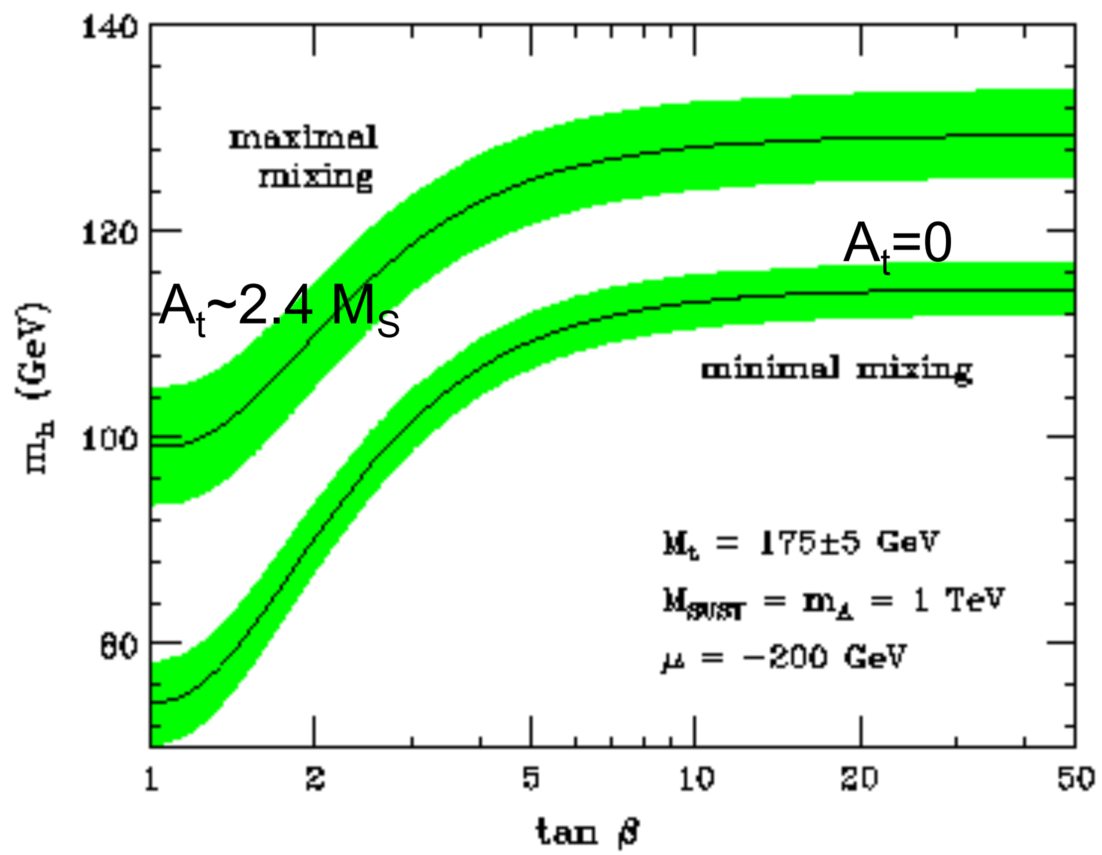
M.Carena, J.R. Espinosa, M. Quiros, C.W.'95
M. Carena, M. Quiros, C.W.'95

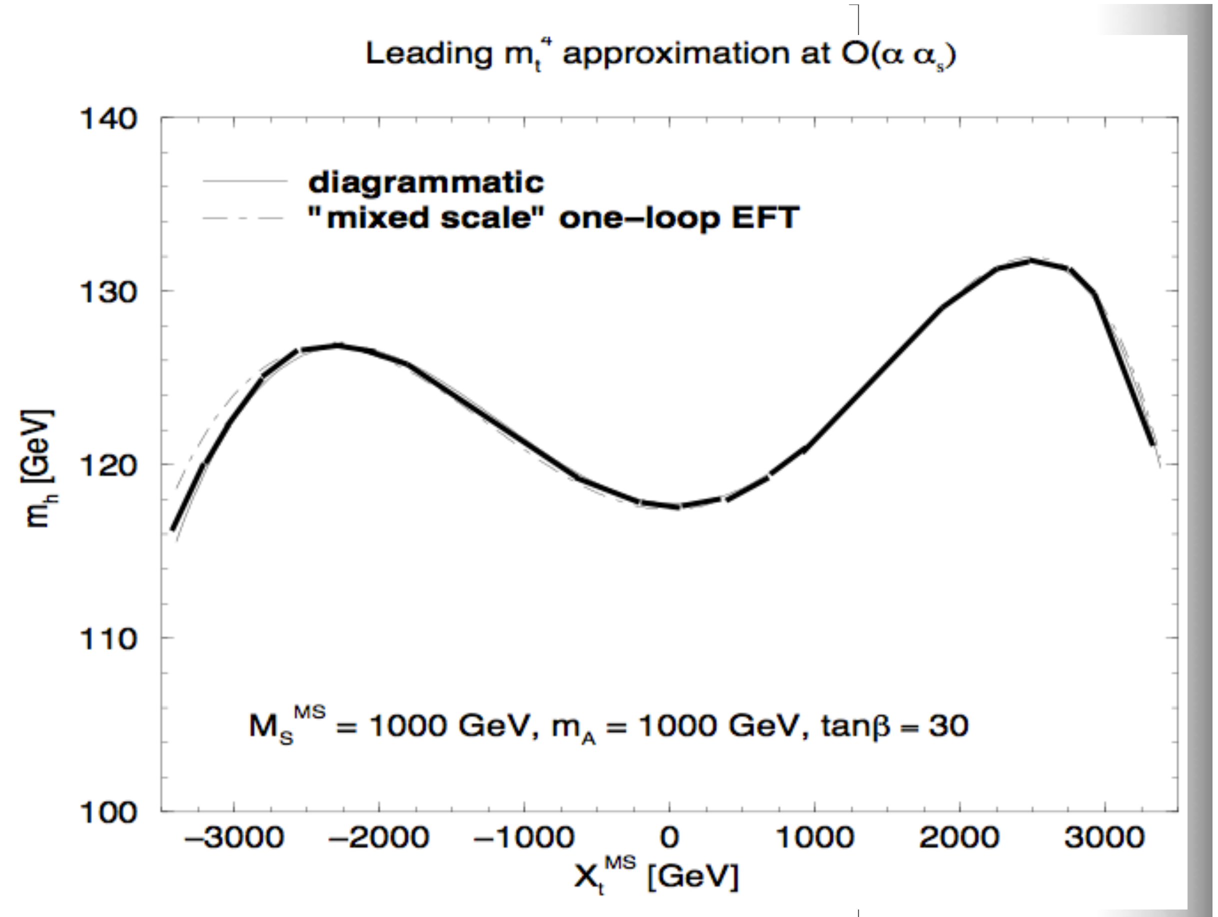
Analytic expression valid for $M_{SUSY} \sim m_Q \sim m_U$

Standard Model-like Higgs Mass

Long list of two-loop computations: Carena, Degrassi, Ellis, Espinosa, Haber, Harlander, Heinemeyer, Hempfling, Hoang, Hollik, Hahn, Martin, Pilaftsis, Quiros, Ridolfi, Rzehak, Slavich, C.W., Weiglein, Zhang, Zwirner

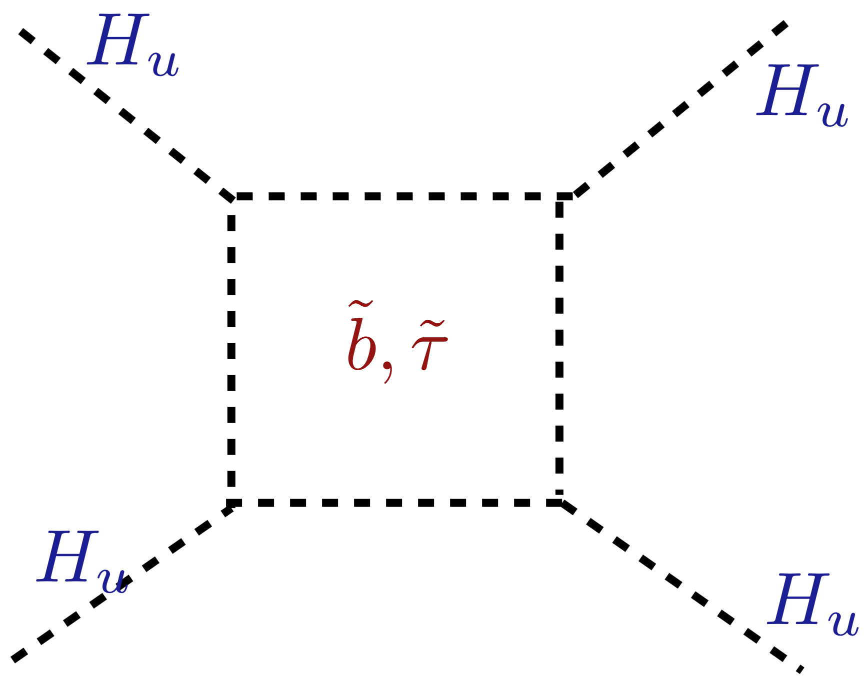
Carena, Haber, Heinemeyer, Hollik, Weiglein, C.W.'00





$$X_t = A_t - \mu/\tan\beta, \qquad X_t = 0 : \text{ No mixing;} \qquad X_t = \sqrt{6}M_S : \text{ Max. Mixing}$$

Large $\tan\beta$ corrections



Corrections from the sbottom sector :
Negative contributions to the Higgs mass

$$\Delta m_h^2 \simeq -\frac{h_b^4 v^2}{16\pi^2} \frac{\mu^4}{M_{\rm SUSY}^4}$$

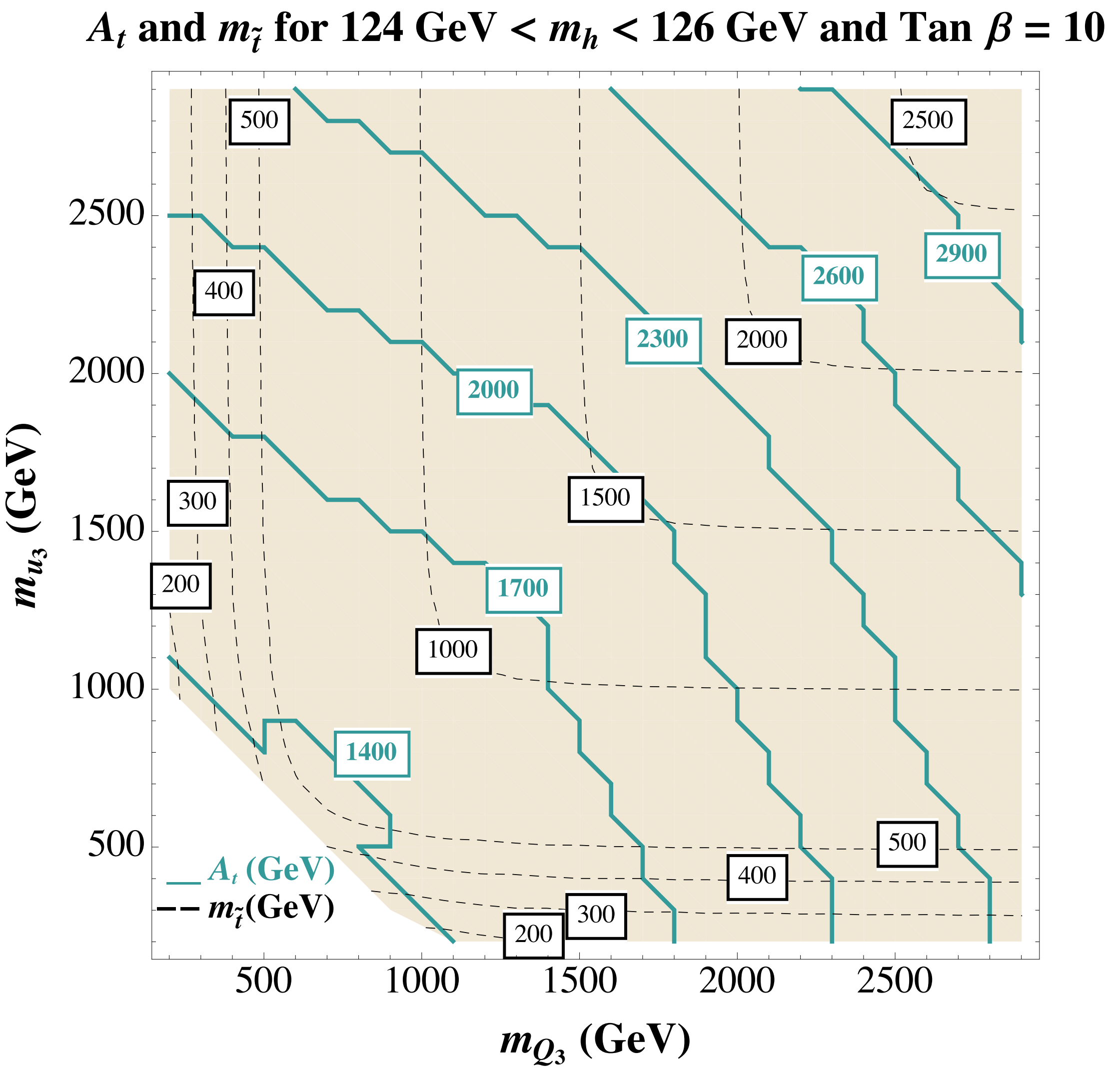
$$h_b \simeq \frac{m_b}{v\cos\beta(1+\tan\beta\Delta h_b)}$$

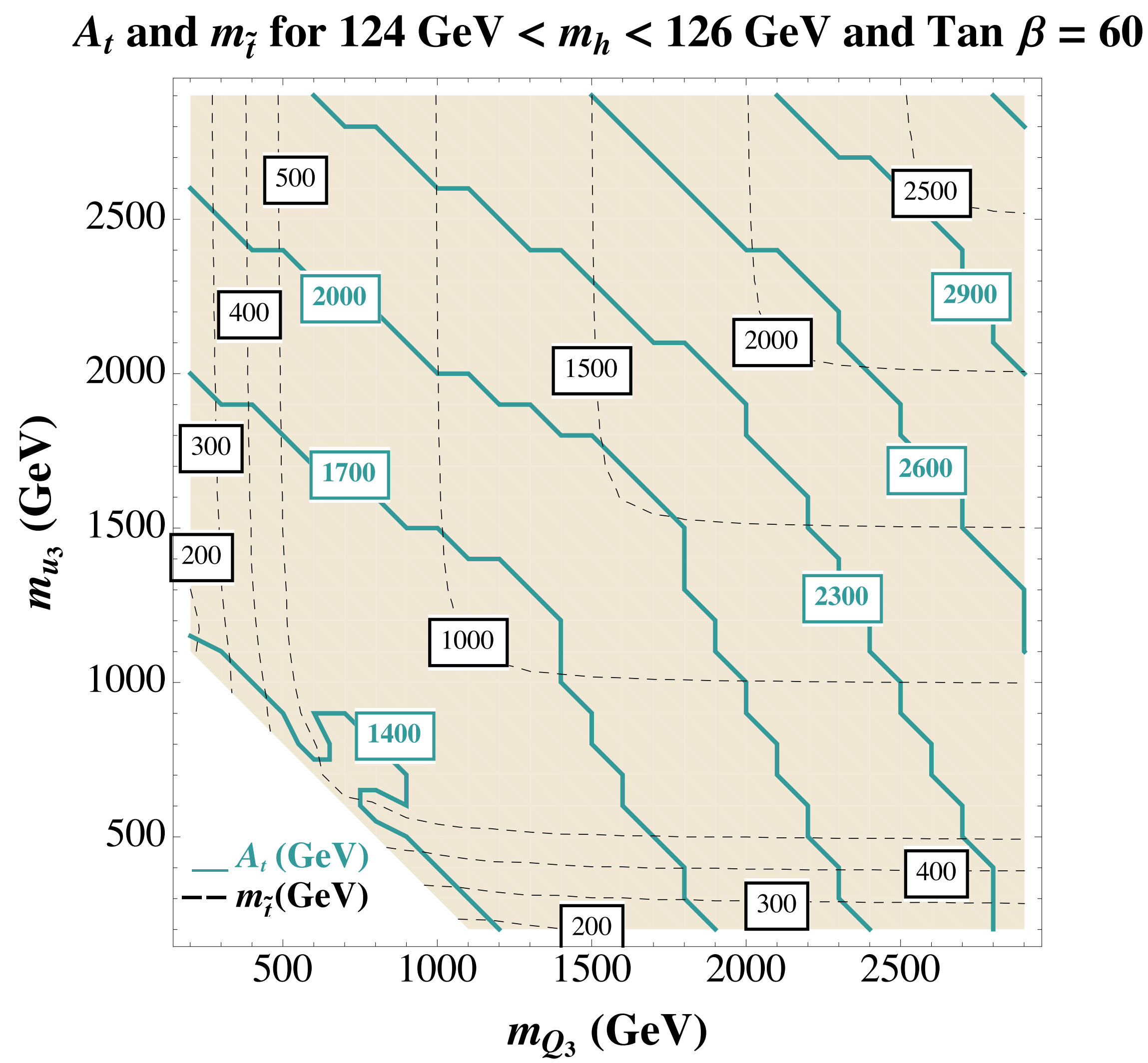
Similar negative corrections, often ignored,
appear from the stau sector

$$\Delta m_h^2 \simeq -\frac{h_\tau^4 v^2}{48\pi^2} \frac{\mu^4}{M_{\tilde{\tau}}^4}\,,$$

$$h_\tau \simeq \frac{m_\tau}{v\cos\beta(1+\tan\beta\Delta h_\tau)}$$

Soft supersymmetry Breaking Parameters





Stop mixing parameter $A_t \geq 1300$ GeV.
No hard bound on the lightest stop mass.

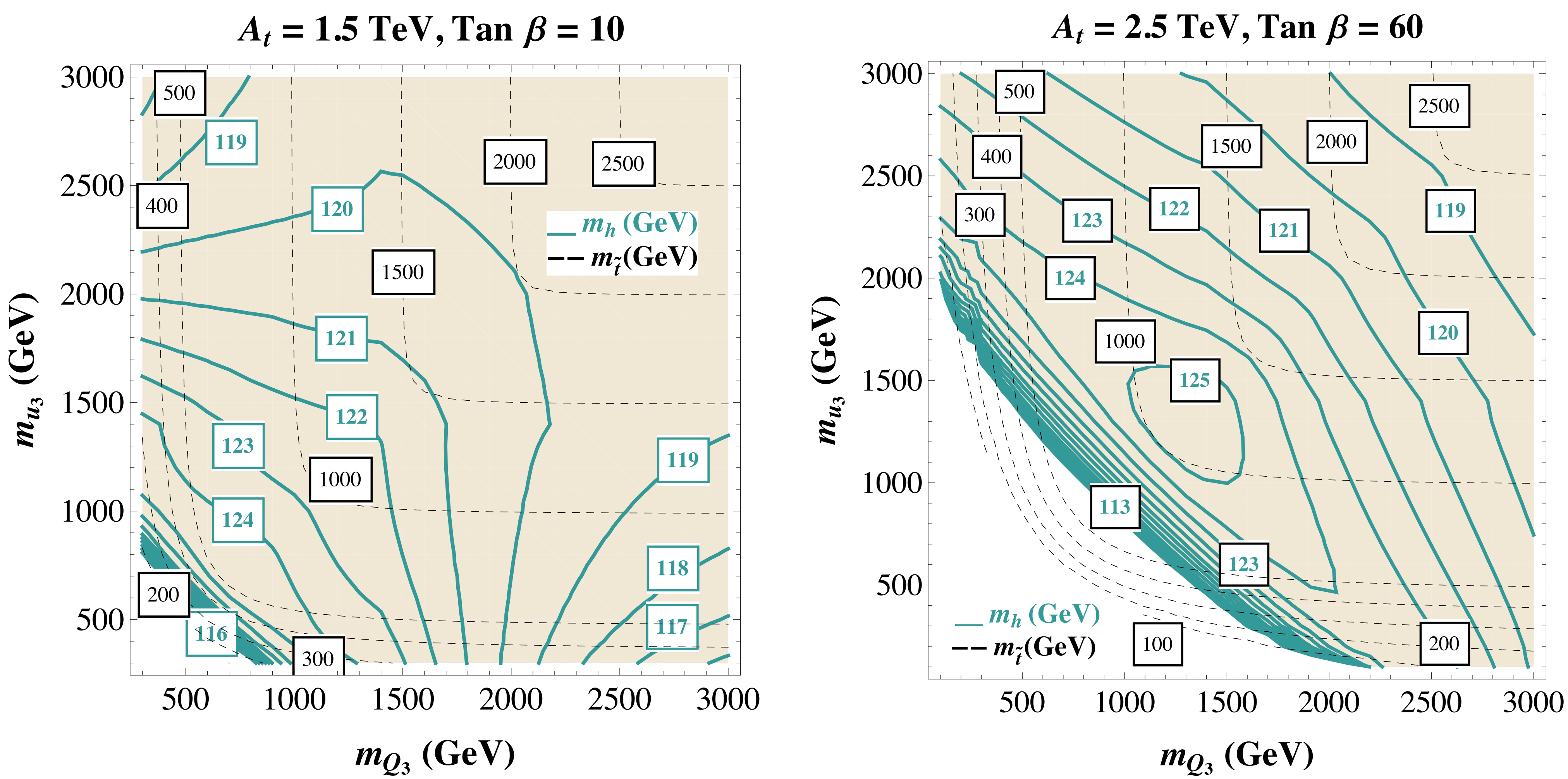
Both stops can have masses below 1 TeV
or one can be light and the other rather heavy.

Light staus of mass   100 GeV at $\tan\beta = 60$,
$m_{L_3} = m_{E_3} = 270$ GeV, $\mu = 650$ GeV

Gain in tree-level mass in going from $\tan\beta = 10$
to $\tan\beta = 60$ compensated by light stau effects

Light staus with larger soft breaking parameters
Stop spectrum and a 125 GeV Higgs boson

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



Light staus and large mixing at $\tan\beta = 60$.

$\mu = 1030$ GeV $\quad m_{e_3} = m_{L_3} = 340$ GeV

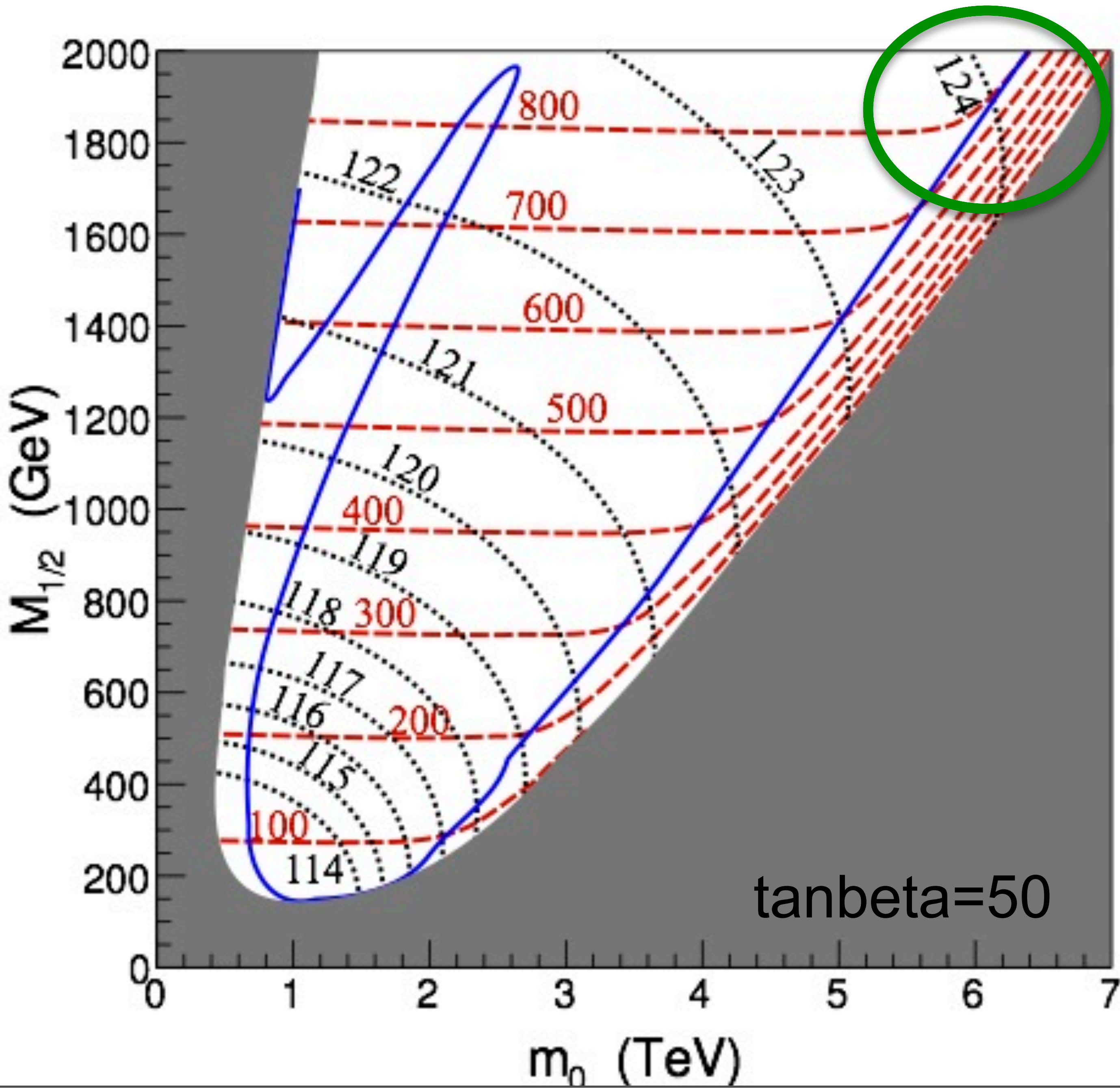
Large values of A_t preferred.

No hard bound on the lightest stop mass.

Alternative : Very heavy scalars

- **Focus Point SUSY ➔ SUSY scenario with heavy scalar super-partners**

For sizeable tanbeta and m_t ~ 170 -175 GeV, the Higgs mass parameter becomes insensitive to the squark mass parameter



Good agreement with null results for SUSY searches :(

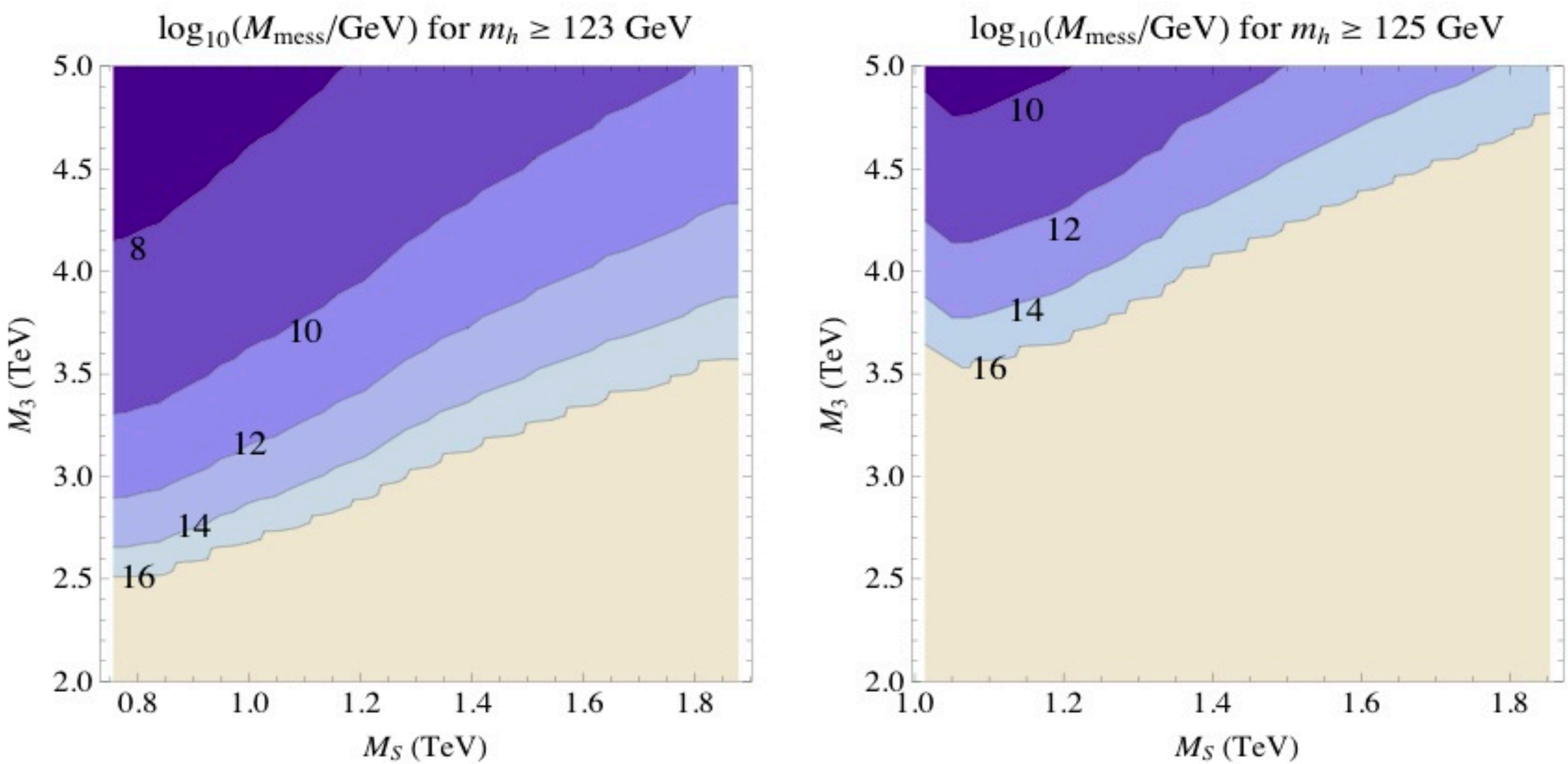
also with EDM's, B observables, DM density, DM and (g-2 of the muon)

Feng, Matchev, Sanford'11
Kane, Kumar, Lu, Zheng'11

Large Stop Mixing must be obtained via running in GM

- **Gauge mediation SUSY breaking**

Draper, Meade, Reece, Shih'11

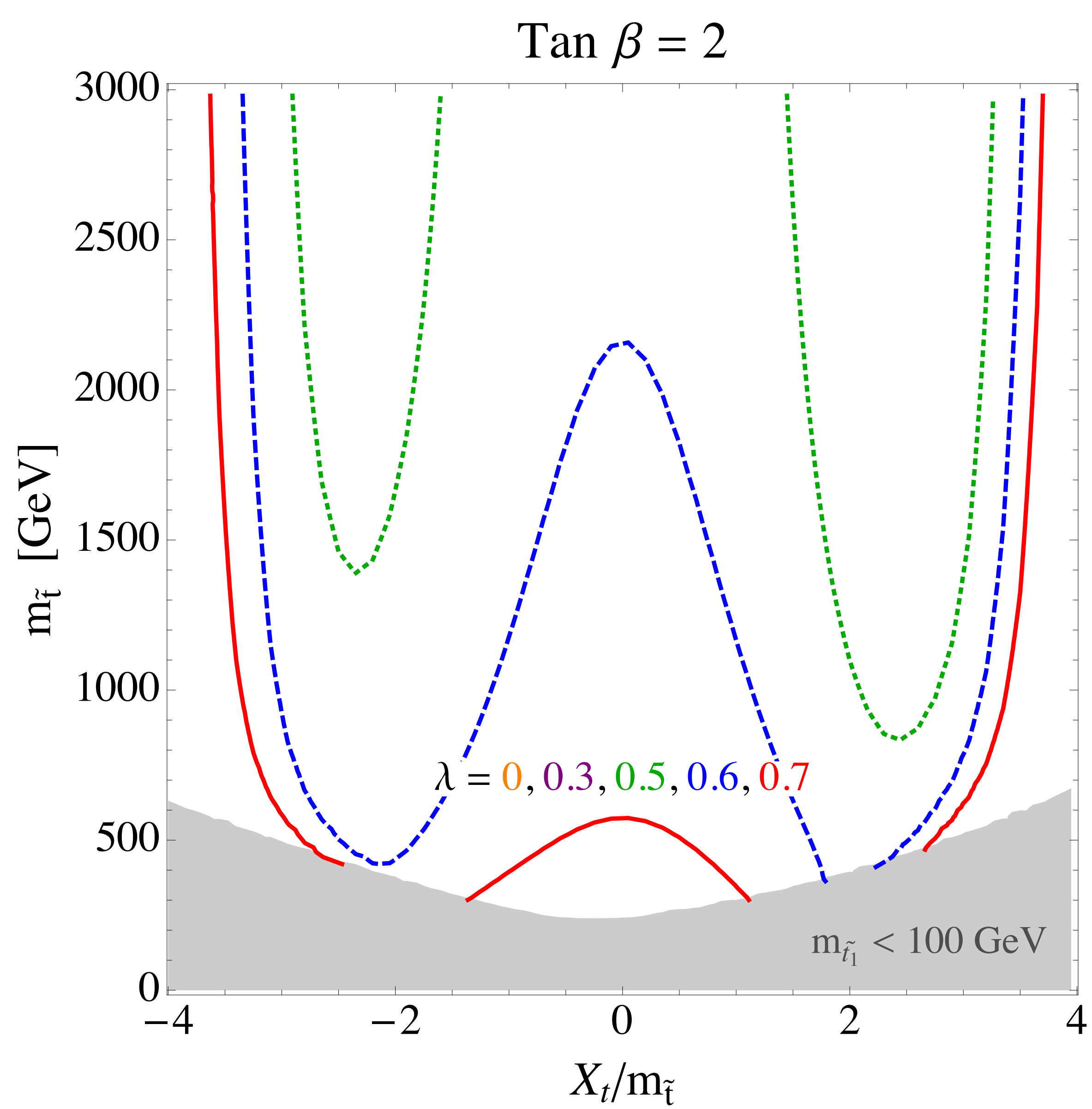


If SUSY partners at the reach of LHC

➔ Severe restrictions on the scale that SUSY is transmitted, M_{mess},

($M_{mess} > 10^7$ GeV implies a long lived NLSP)

Stop Mass requirements may be relaxed in the NMSSM



"More natural"

$$W = \lambda S H_u H_d$$

$$\Delta m_h^2 \propto \lambda^2 v^2 \sin^2 2\beta$$

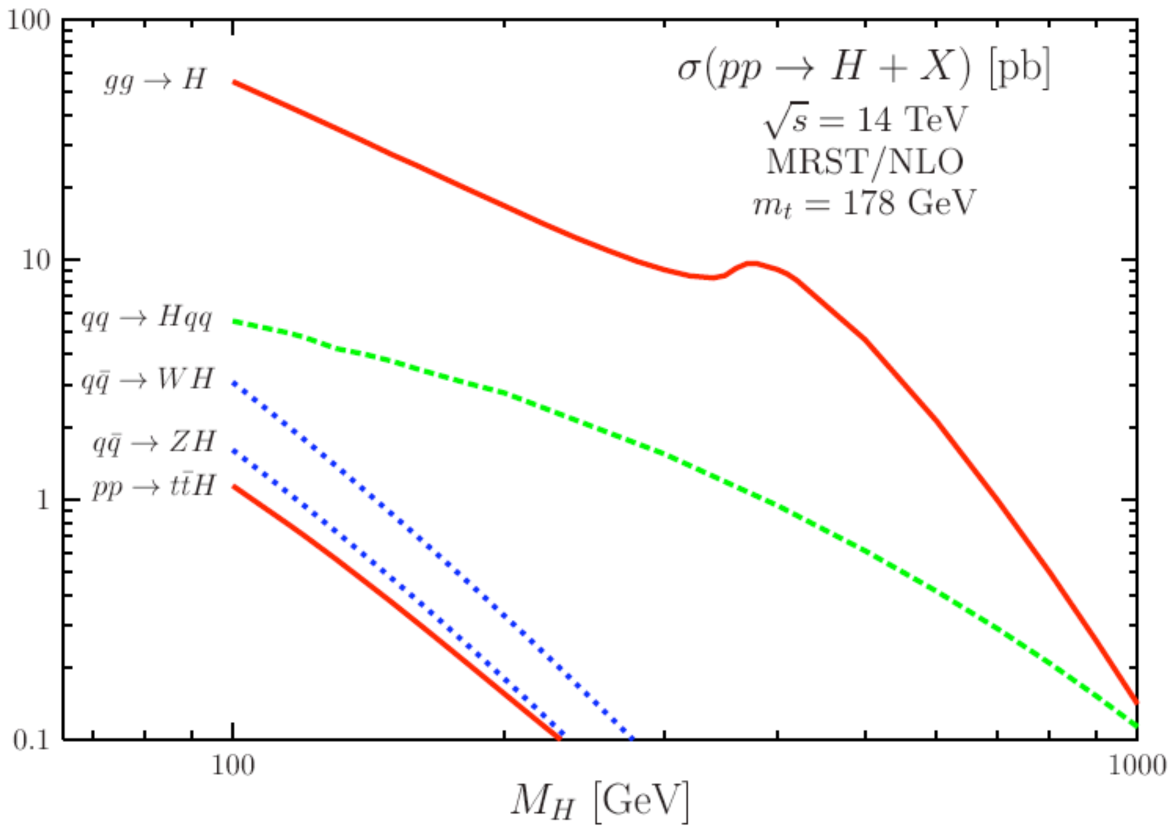
Hall, Pinner, Ruderman'11

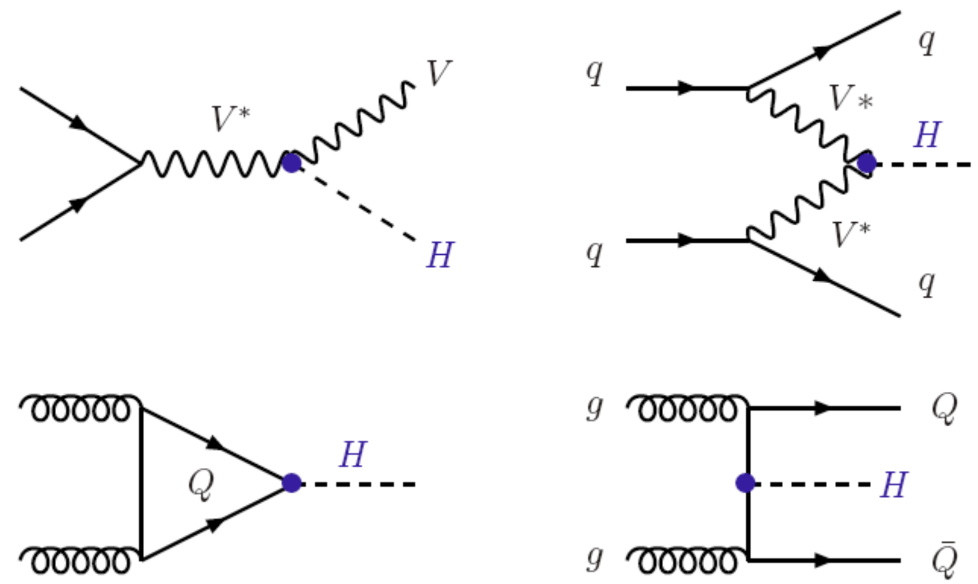
At low values of $\tan\beta$ and large values of λ singlet effects are relevant.

Reduced fine tuning can be obtained at the cost of accepting the additional singlet.
Mixing between CP-even states may be affected too.

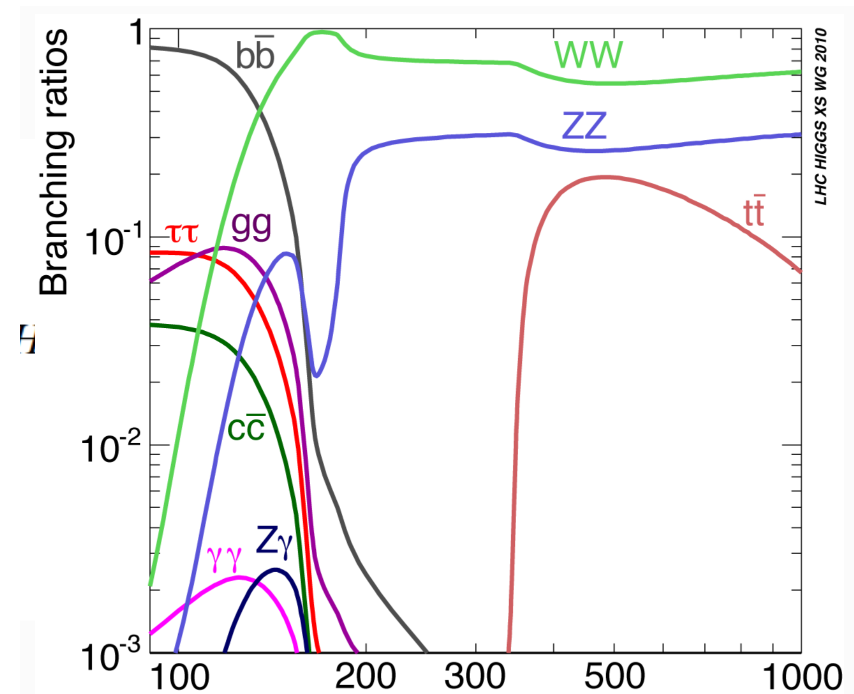
Ellwanger '11

Main Higgs Production channels at Hadron Colliders





A. Djouadi, 0503172



The event rate depends on three quantities

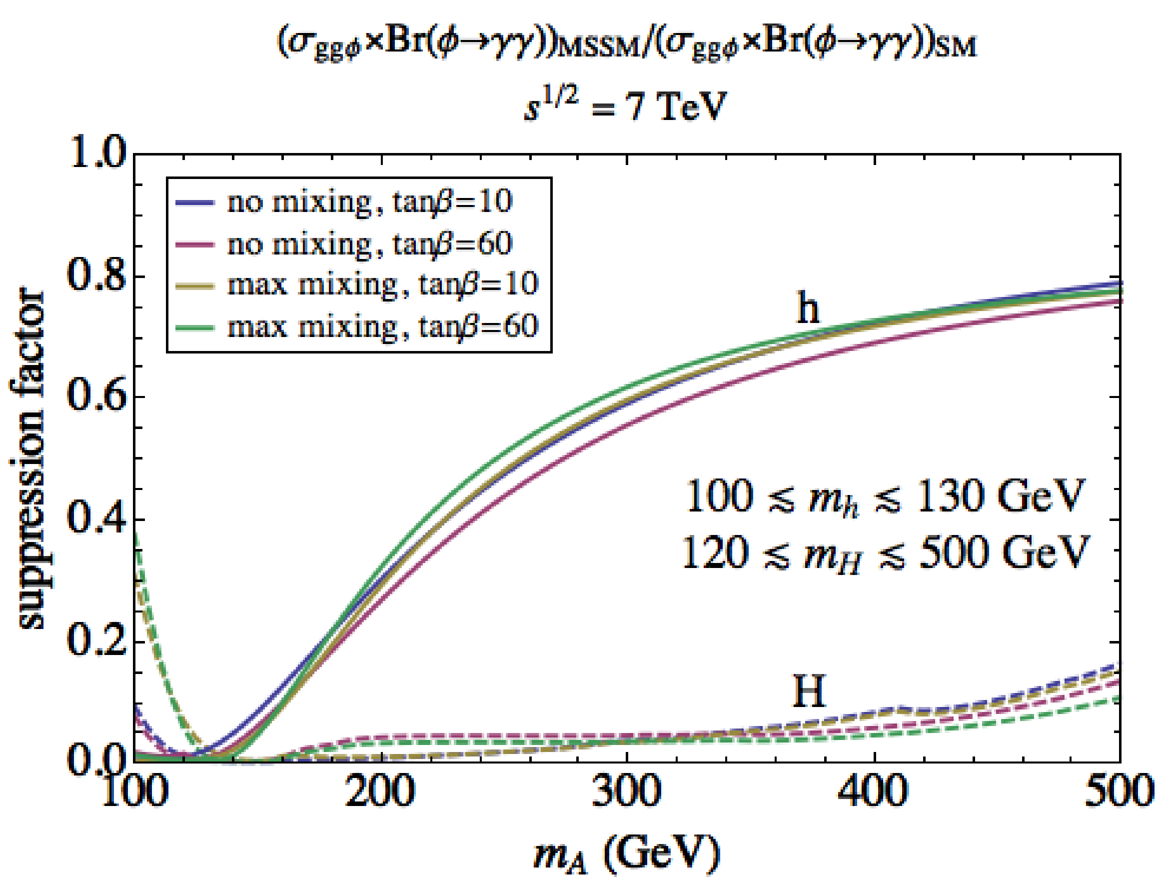
$$B\sigma(p\bar{p} \to h \to X_{\rm SM}) \equiv \sigma(p\bar{p} \to h)\frac{\Gamma(h \to X_{\rm SM})}{\Gamma_{\rm total}}$$

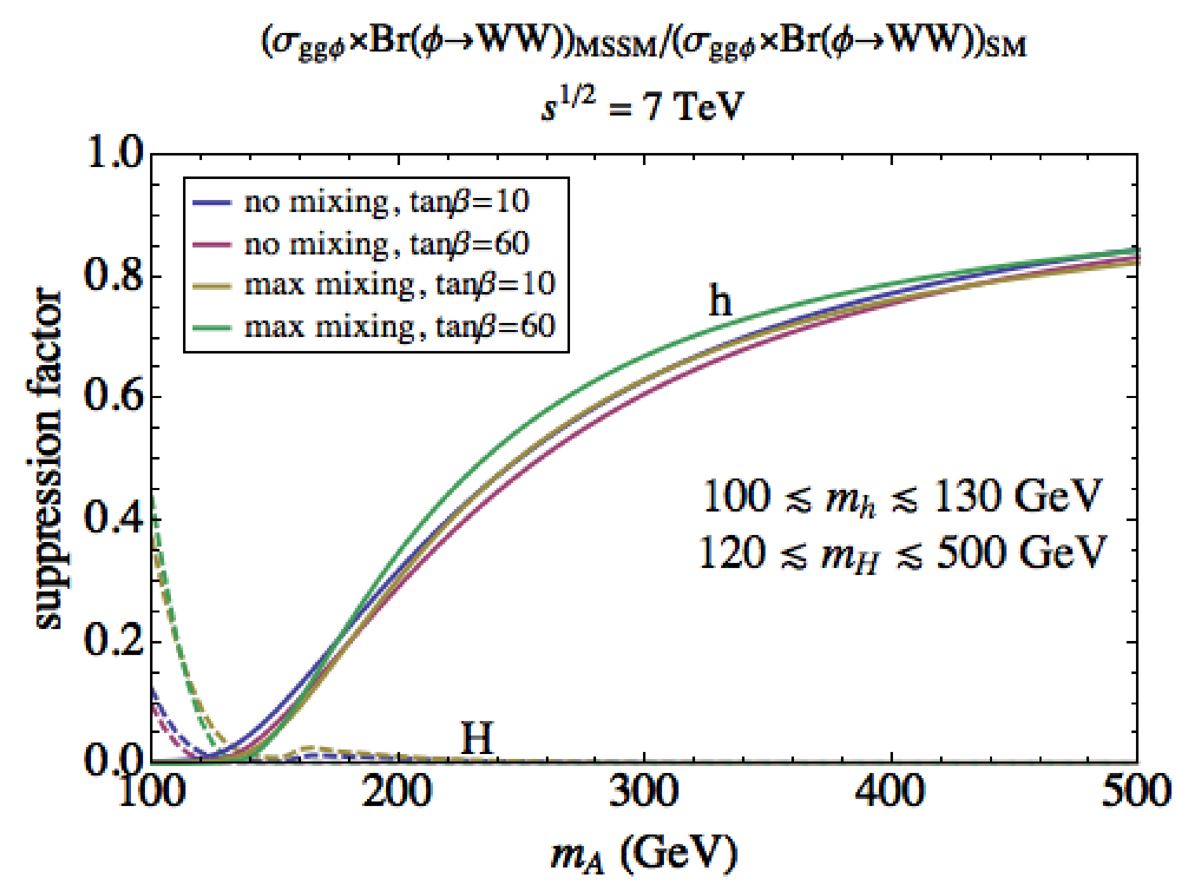
The three of them may be affected by the presence of new physics. If the SM rate is modified, of course, the total width is modified as well. This is particularly true for the WW rate at high Higgs masses and bb at low Higgs masses

Heavy Stops : MSSM SM-like Higgs Searches at the LHC

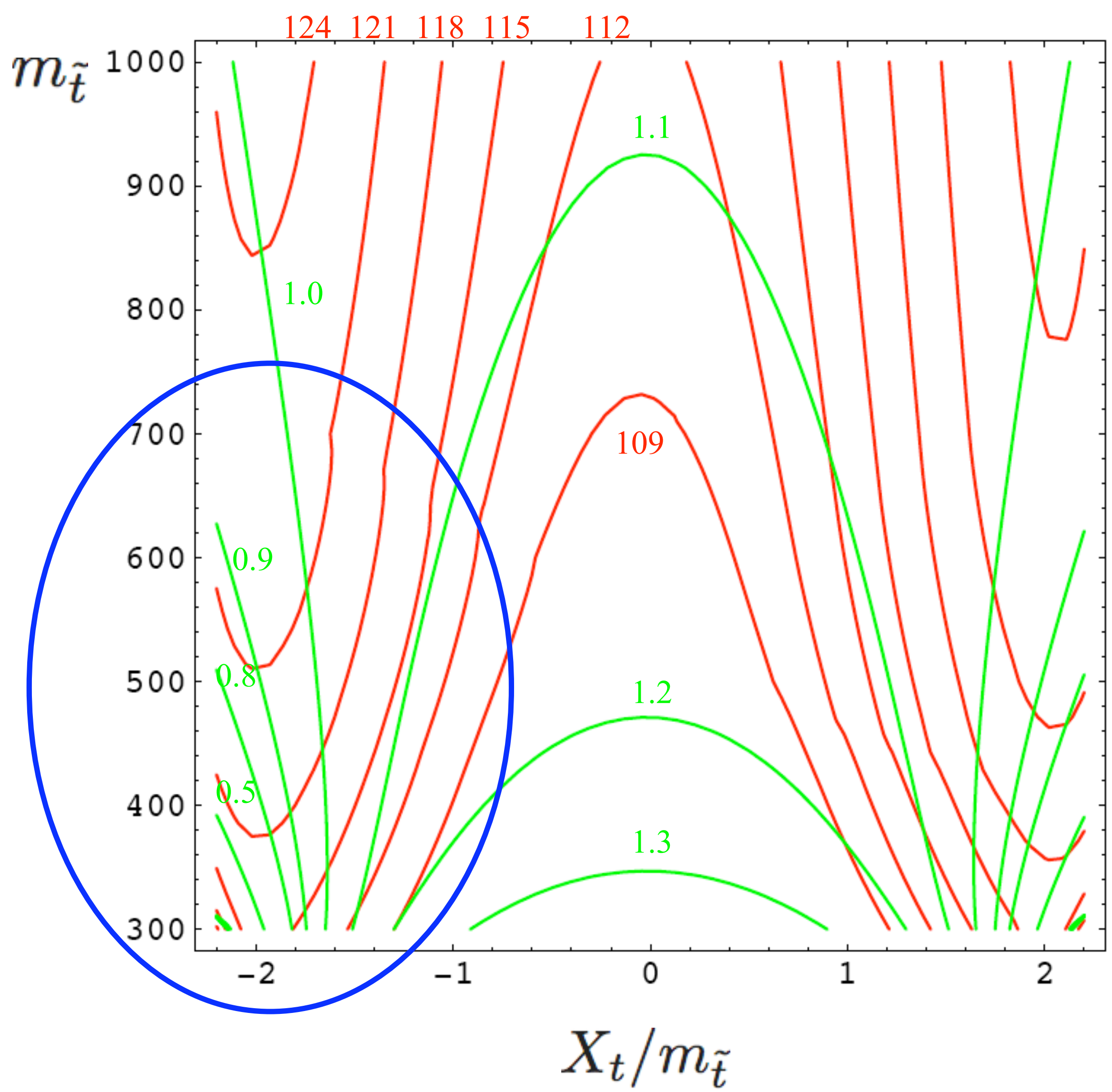
P. Draper, T. Liu, C. Wagner, **Phys.Rev.D81:015014,2010**; M. Carena, P. Draper, T. Liu, C. Wagner, arXiv:1107.4354

- In the MSSM, one of the Higgs bosons has standard model like couplings to the top and gauge bosons
- Relevant SM-like channels of production and/or decay are induced by loops, which are affected by new physics (mainly stops). We shall assume all relevant supersymmetric particles to be heavy, with masses of order 1 TeV.
- Moreover, the dominant width of Higgs decay into bottom quarks is enhanced due to mixing with non-standard Higgs bosons. Relatively large CP-odd Higgs mass preferred.





Gluon Fusion Production Rate in the MSSM



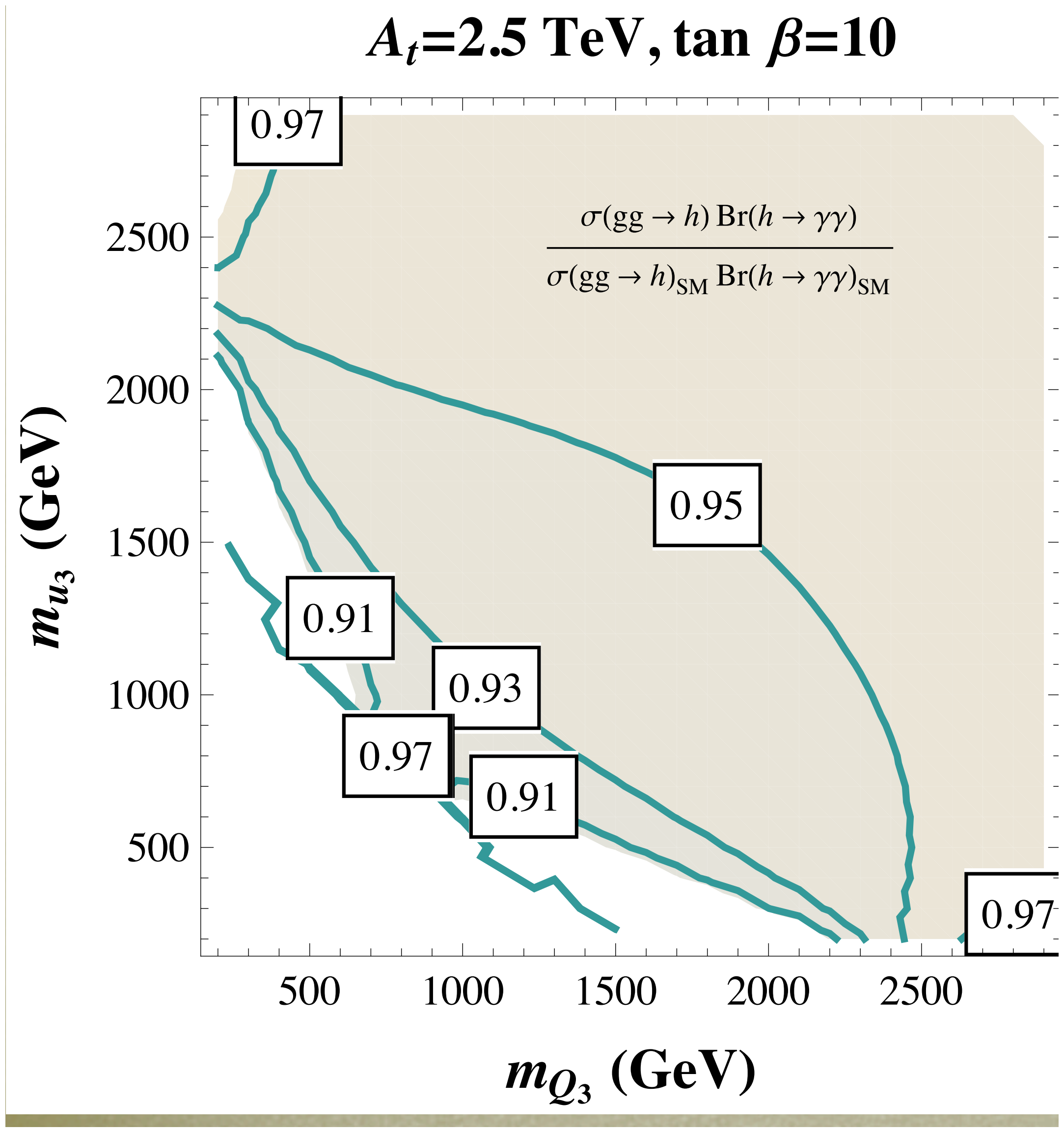
Rate may be modified for light stops and close to the large mixing senario.

For stop masses of order of 1 TeV the rate modifications tend to be small

Dermisek and Low, 0701235

LHC Bound on stop masses depends on gluino mass

Stop effects on diphoton rate



Heavy stops needed for a 125 GeV Higgs lead to small effects on diphoton rate.

For large mixing, enhancement of diphoton decay branching ratio compensated by production rate suppression.

Even for the case of one stop light, the effects tend to be small.

Explanation :

Coupling of light stop to Higgs is approximately given by

$$g_{h\tilde{t}\tilde{t}} \simeq h_t^2 \left(1 - \frac{A_t^2}{m_Q^2}\right)$$

But in this region, $m_Q \simeq A_t$ and coupling is suppressed

M. Carena, S. Gori, N. Shah, C.W., arXiv:1112.3336, JHEP 1203:014, 2012

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

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

$$A_1 \to -7 \, , \qquad N_c Q_t^2 \, A_{1/2} \to \frac{4}{3} N_c Q_t^2$$

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.

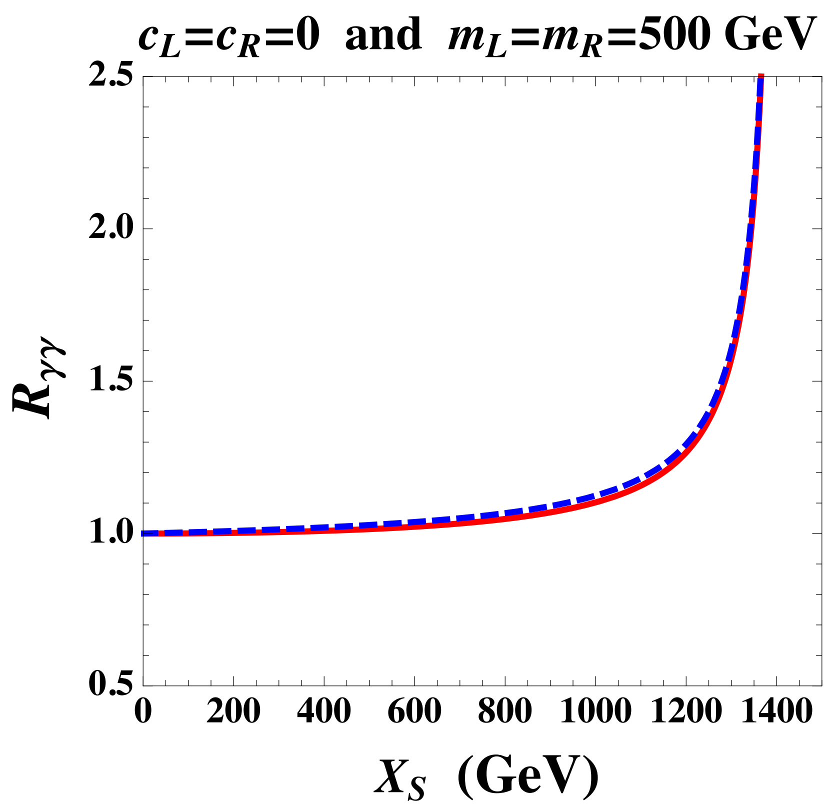
$$\mathcal{L}_{h\gamma\gamma} = -\frac{\alpha}{16\pi}\frac{h}{v}\left[\sum_i b_i \frac{\partial}{\partial \log v}\log\left(\det \mathcal{M}_i^\dagger \mathcal{M}_i\right)\right] F_{\mu\nu}F^{\mu\nu}$$

Ellis, Gaillard, Nanopoulos'76
Falkowski'07

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 visualization of when particles could lead to an enhanced diphoton rate !

Two Scalars with Mixing

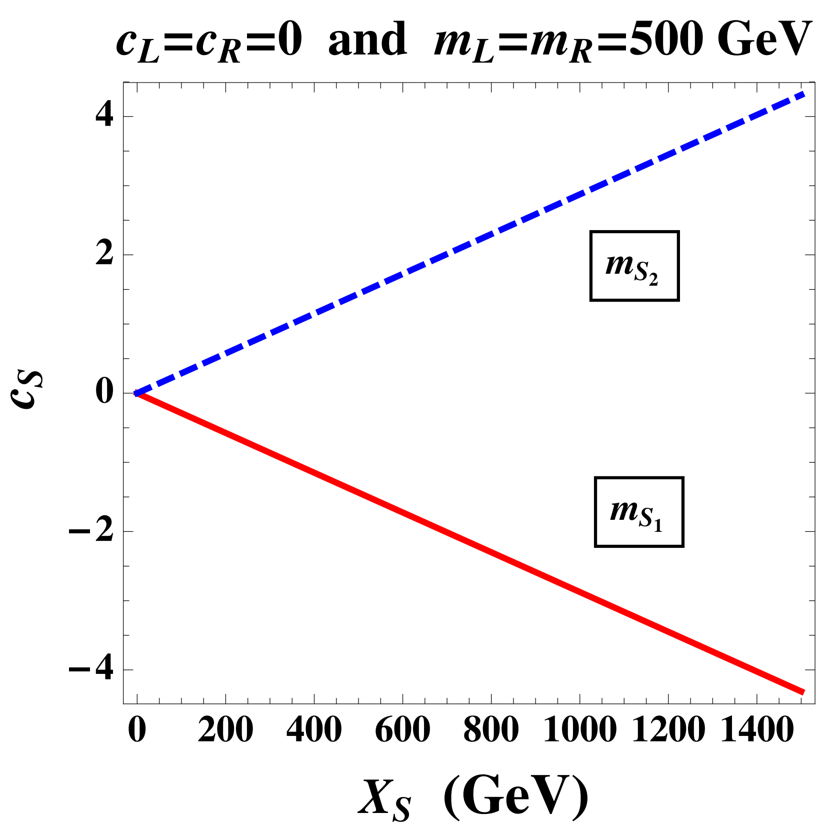
M. Carena, I. Low, C.W.'12

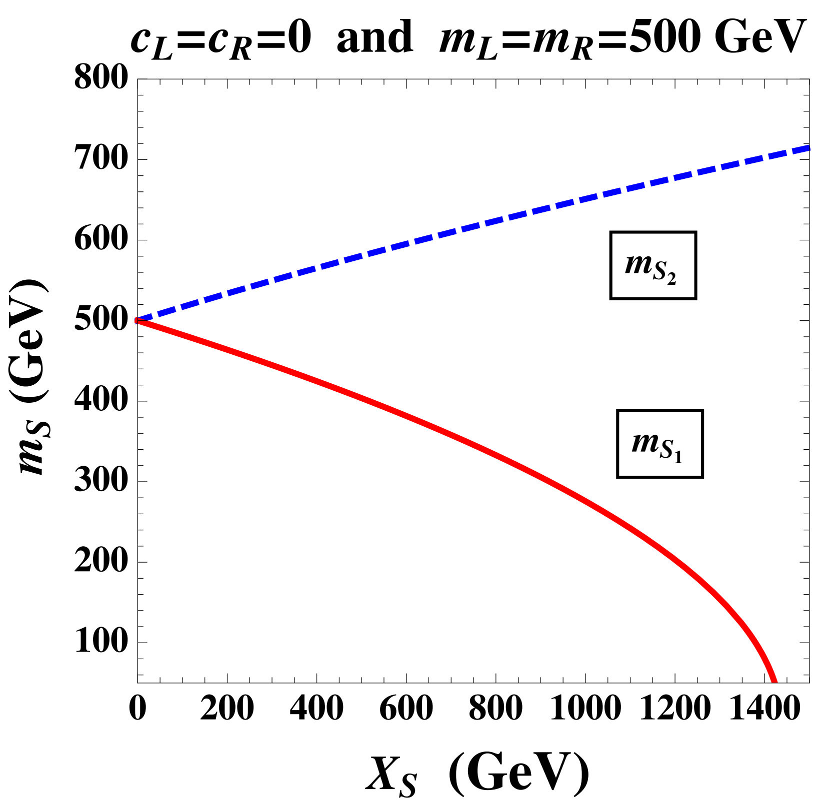


$$\mathcal{M}_S^2 = \begin{pmatrix} \tilde{m}_L(v)^2 & \frac{1}{\sqrt{2}} v X_S \\ \frac{1}{\sqrt{2}} v X_S & \tilde{m}_R(v)^2 \end{pmatrix}$$

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

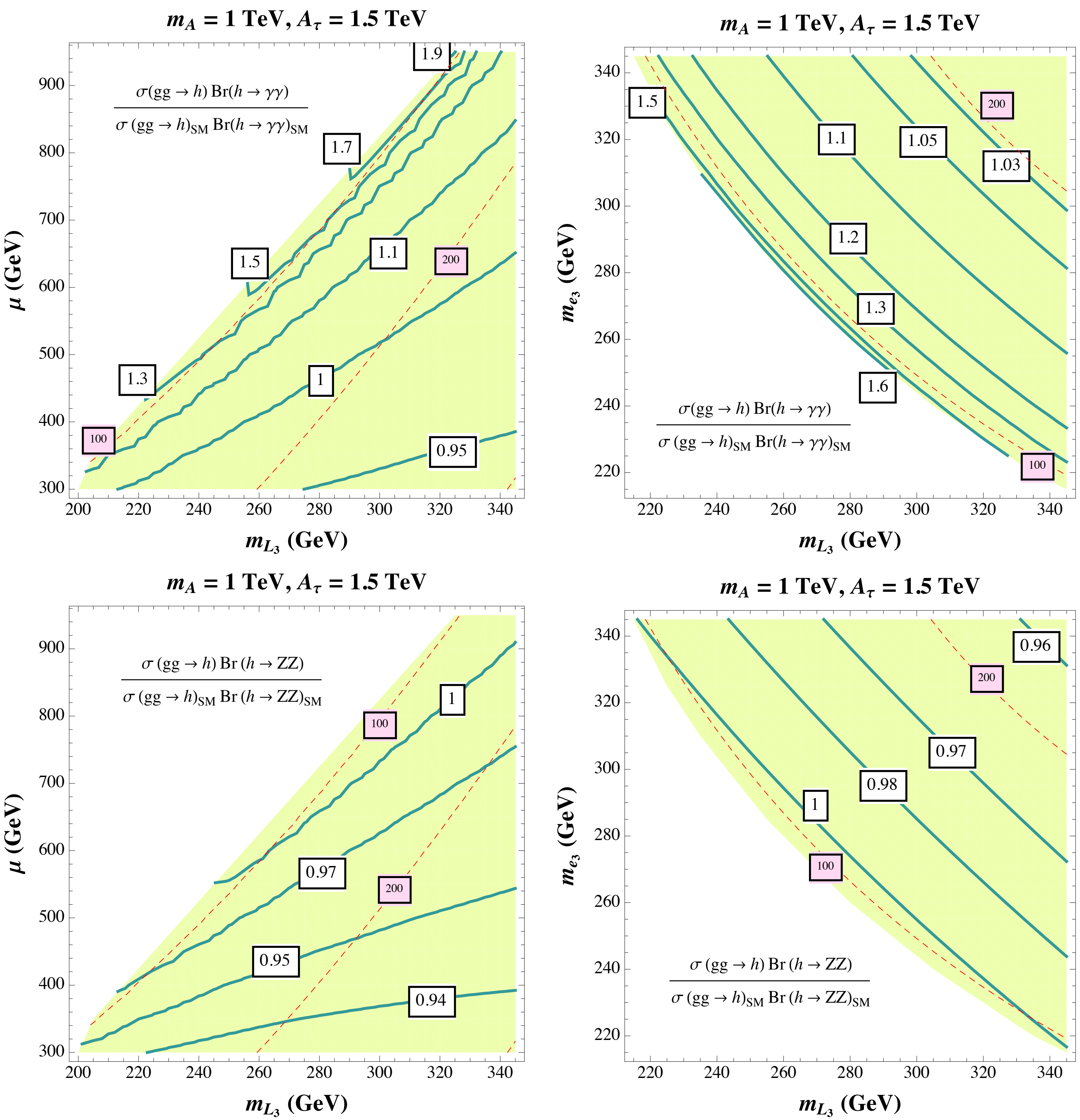
Large mixing and small value of the lightest scalar mass preferred





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

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



M. Carena, S. Gori, N. Shah, C.W., arXiv:1112.3336, JHEP 1203:014, 2012

Dashed lines represent the countors of equal stau mass

Left plots : $m_{L_3} = m_{E_3}$

Right plots : $\mu = 650$ GeV, $\tan\beta = 60$.

Smaller (larger) enhancements obtained for smaller (larger) μ and the same stau mass

Searches for non-standard Higgs bosons

QCD: S. Dawson, C.B. Jackson, L. Reina, D.Wackeroth '06
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.

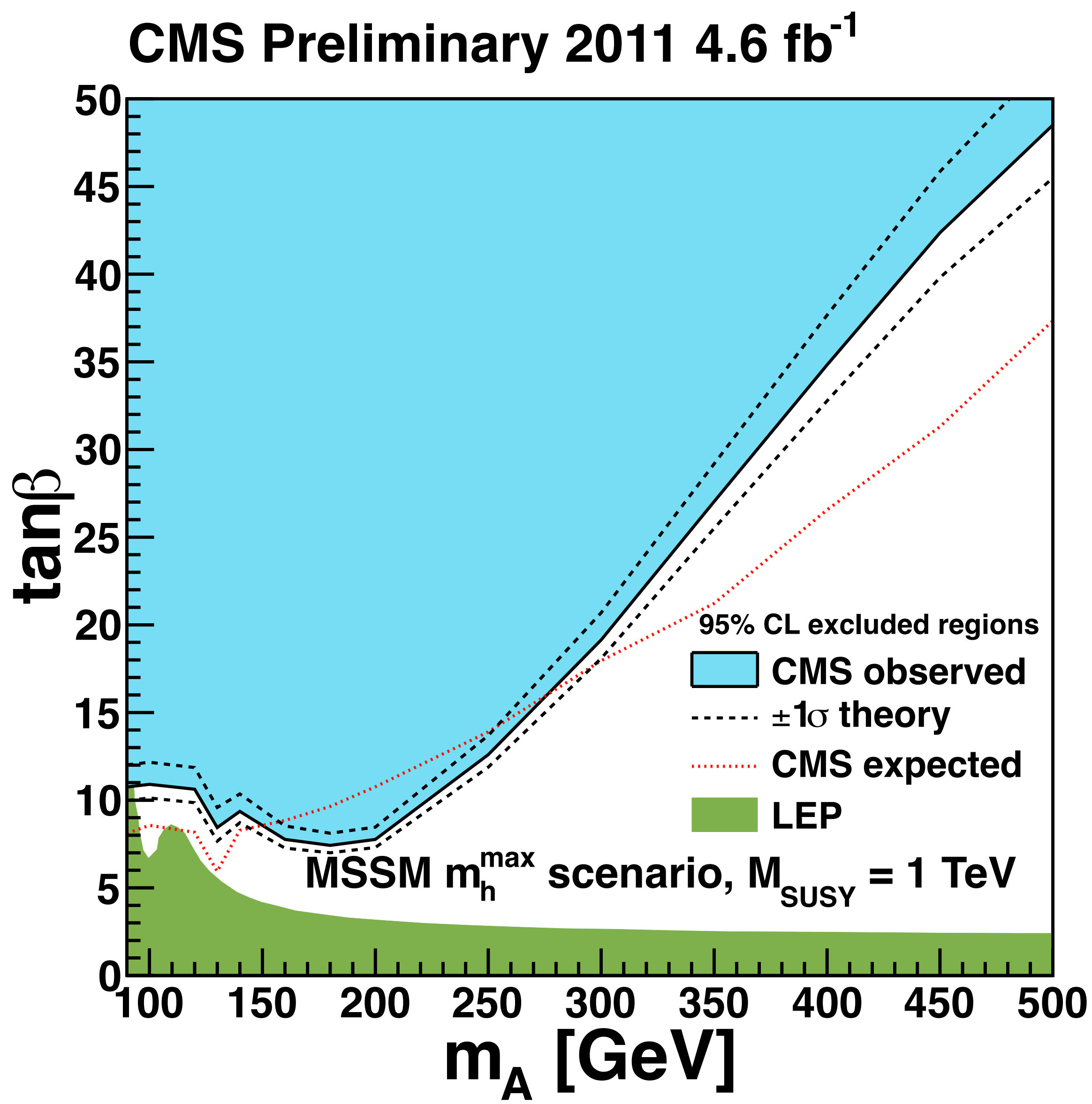
$$\sigma(b\bar{b}A) \times BR(A \to b\bar{b}) \simeq \sigma(b\bar{b}A)_{\rm SM} \frac{\tan^2\beta}{(1+\Delta_b)^2} \times \frac{9}{(1+\Delta_b)^2 + 9}$$

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

- 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. North and M. Spira, arXiv:0808.0087
Further work by Mhulleitner, Rzehak and Spira, 0812.3815, Dawson et al '10, Djouadi et al'11

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



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

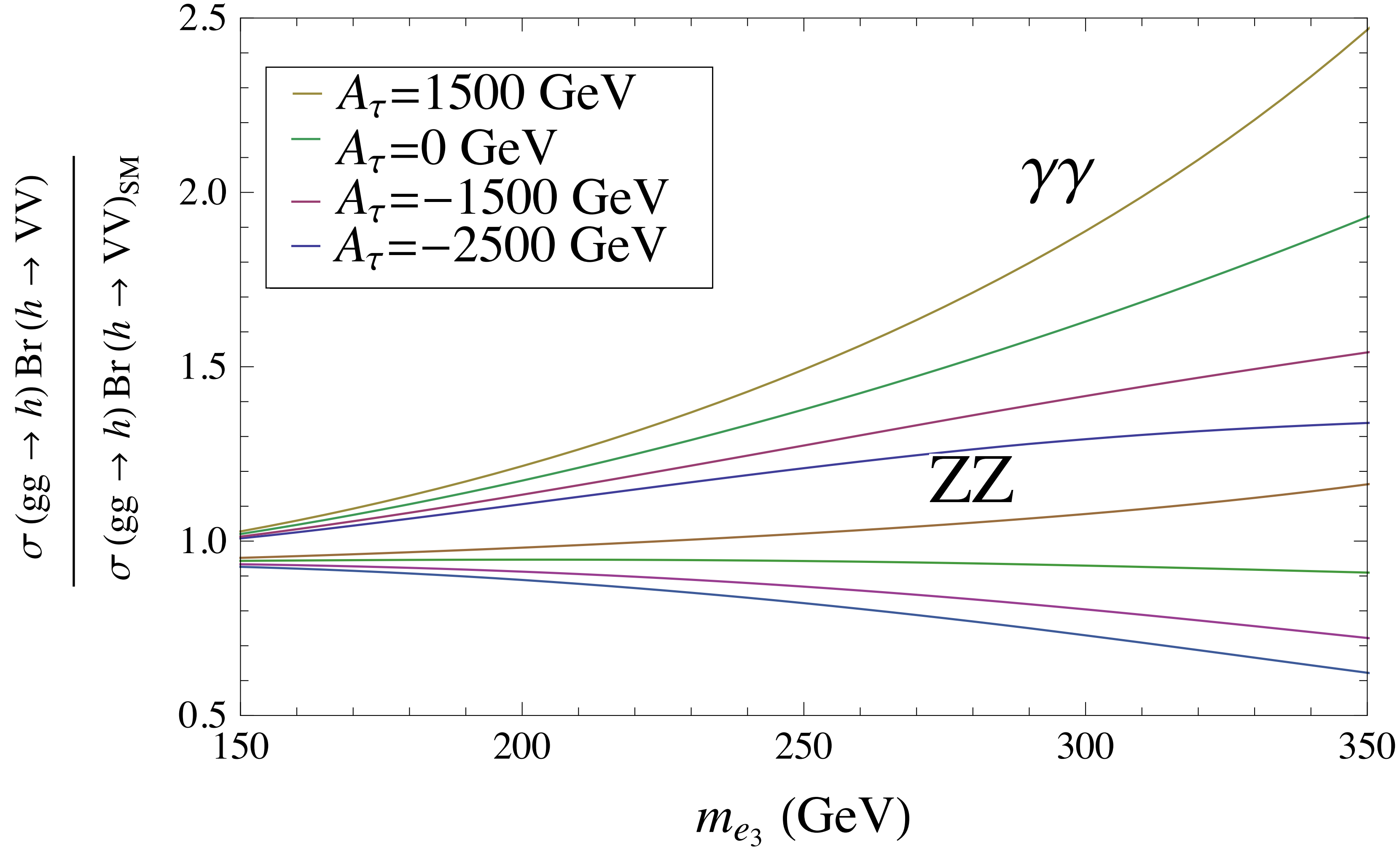
$$\sin(2\alpha) = \frac{2\,(\mathcal{M}_H^2)_{12}}{\sqrt{Tr[\mathcal{M}_H^2]^2 - det[\mathcal{M}_H^2]}}$$

$$hb\bar{b}: \quad -\frac{\sin\alpha}{\cos\beta} \left[1 - \frac{\Delta h_b \tan\beta}{1 + \Delta h_b \tan\beta} \left(1 + \frac{1}{\tan\alpha \tan\beta} \right) \right]$$

Large variation of the rates depending on soft parameters

$m_A = 1$ TeV

Carena, Gori, Shah,C.W. '11
Carena, Gori, Shah, Wang, C.W.'12

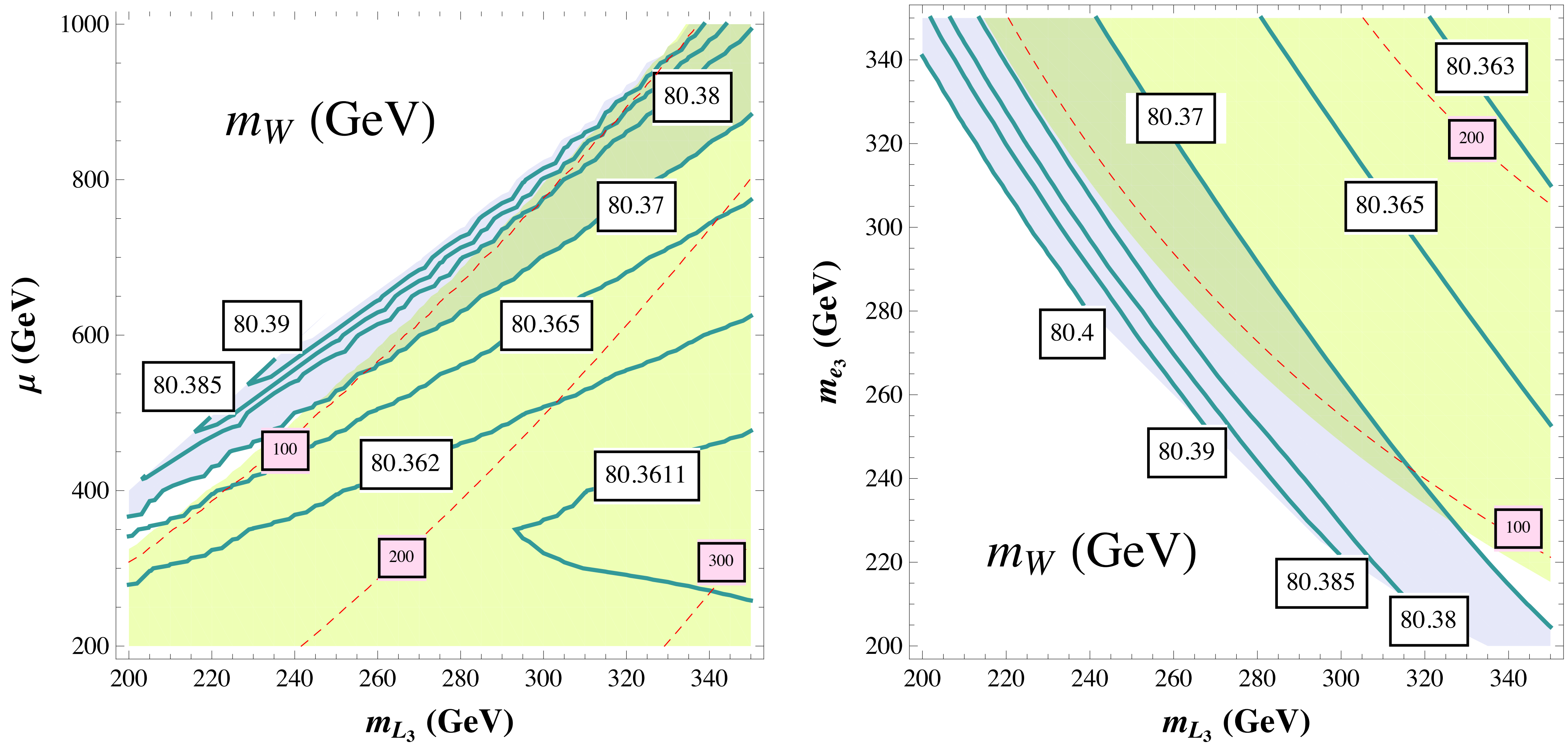


Positive (negative) A_τ are associated with smaller (larger) values of the bottom quark width

Precision Measurement and the Light Stau Scenario

Only moderate corrections to the precision electroweak observables

Carena, Gori, Shah, Wang, C.W.'12



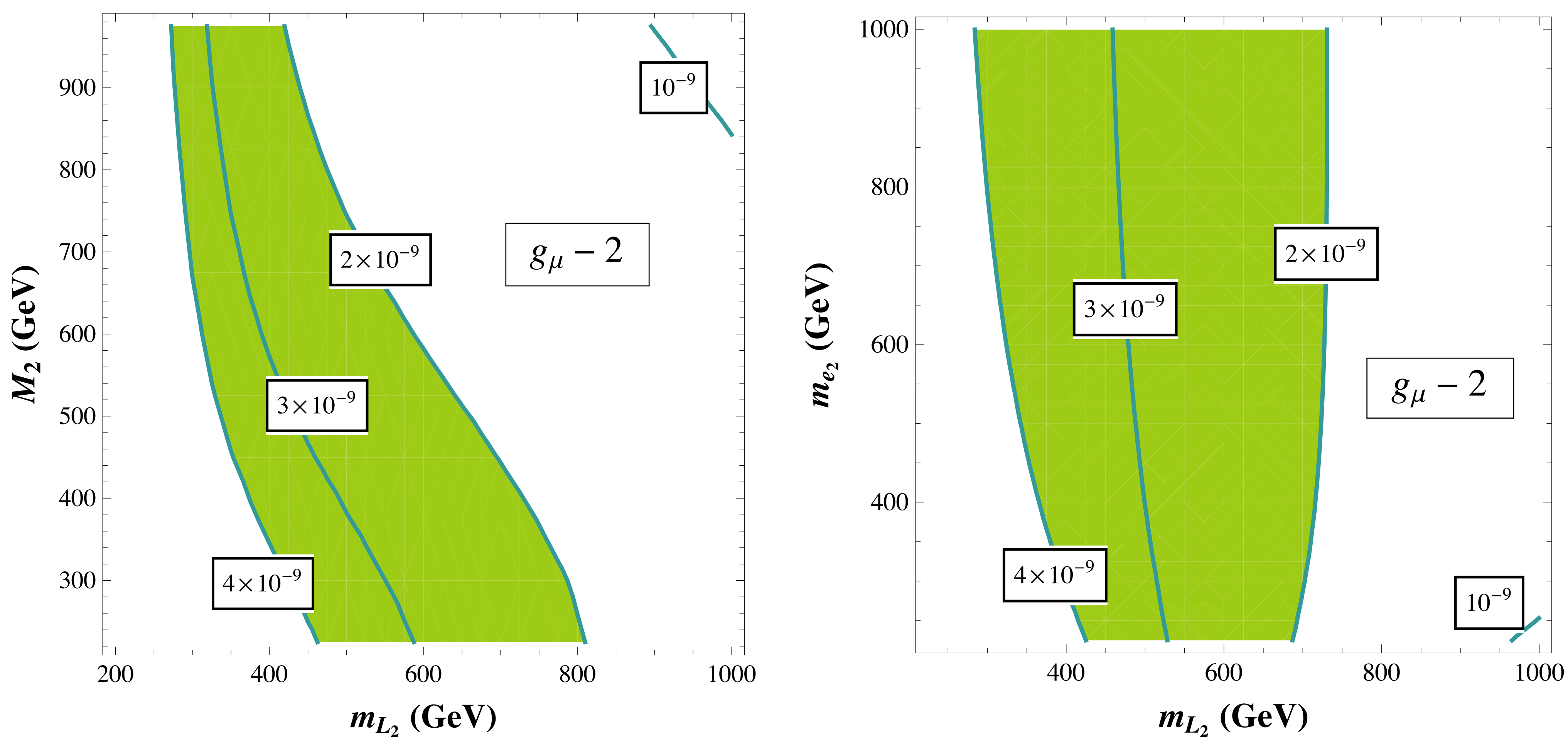
$m_{L_3} = m_{E_3}$

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

Muon Anomalous Magnetic Moment

Agreement within one standard deviation with experiment demands light left-handed sleptons of the second generation with mass of about 300 to 700 GeV

Carena, Gori, Shah, Wang, C.W.'12



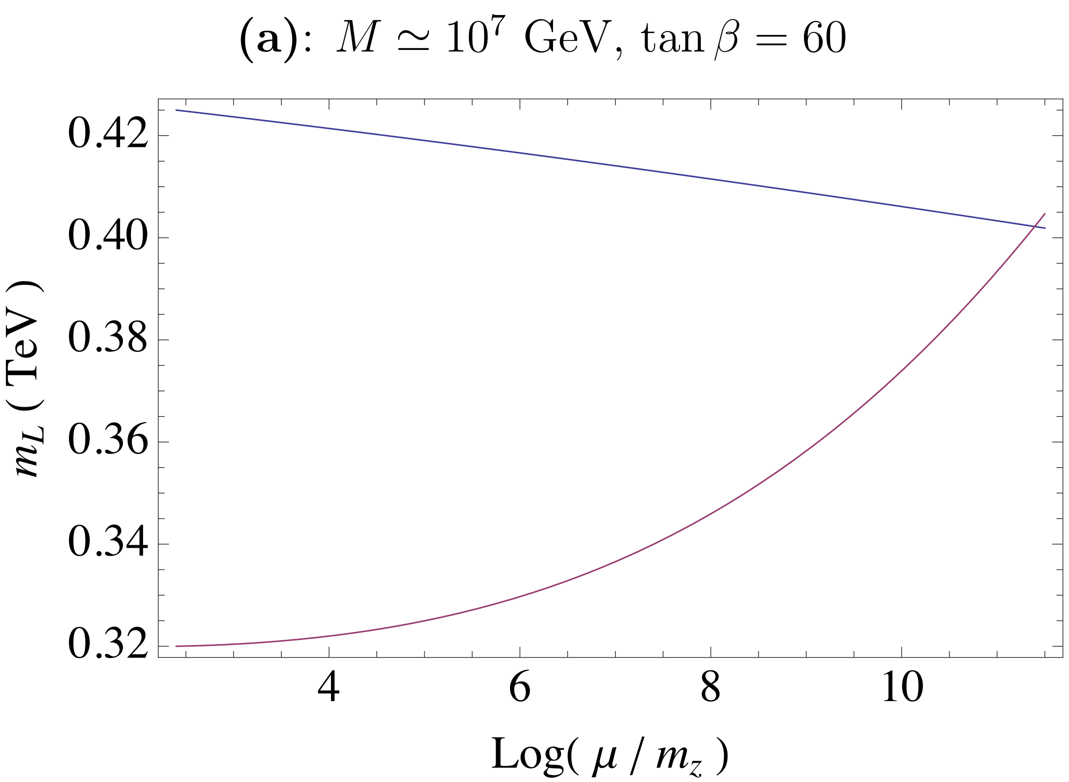
$$\mu \simeq 650 \text{ GeV}, \tan\beta = 60$$

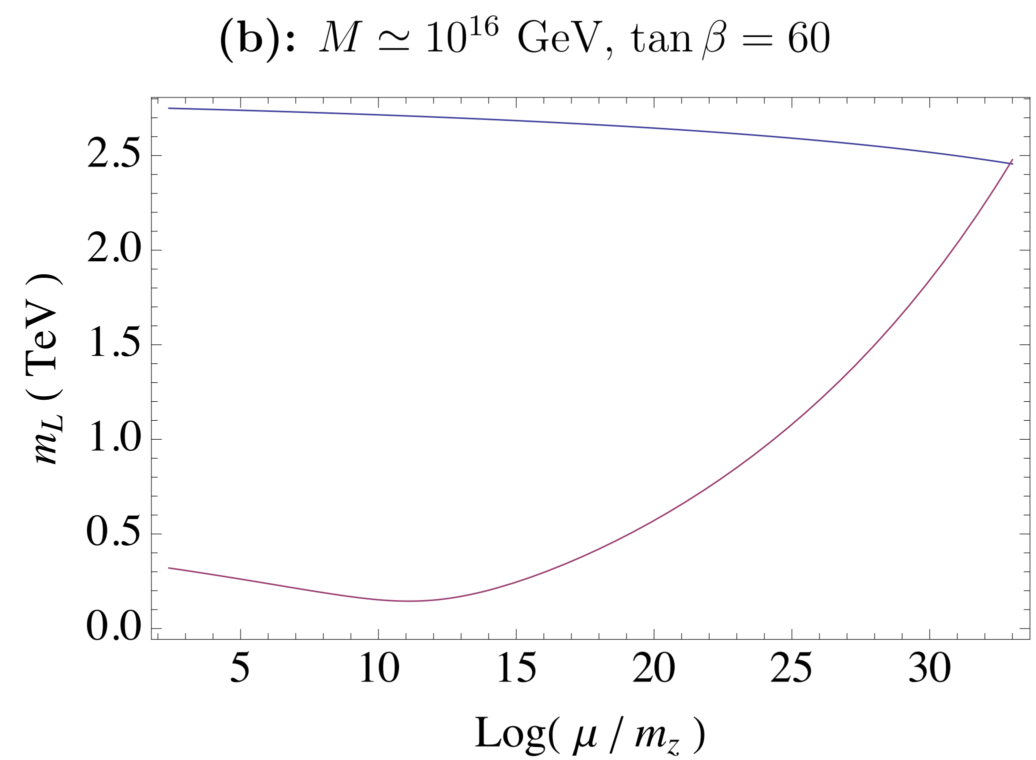
Not very sensitive to other choices of parameters with enhanced (1.5 to 2) diphoton rate

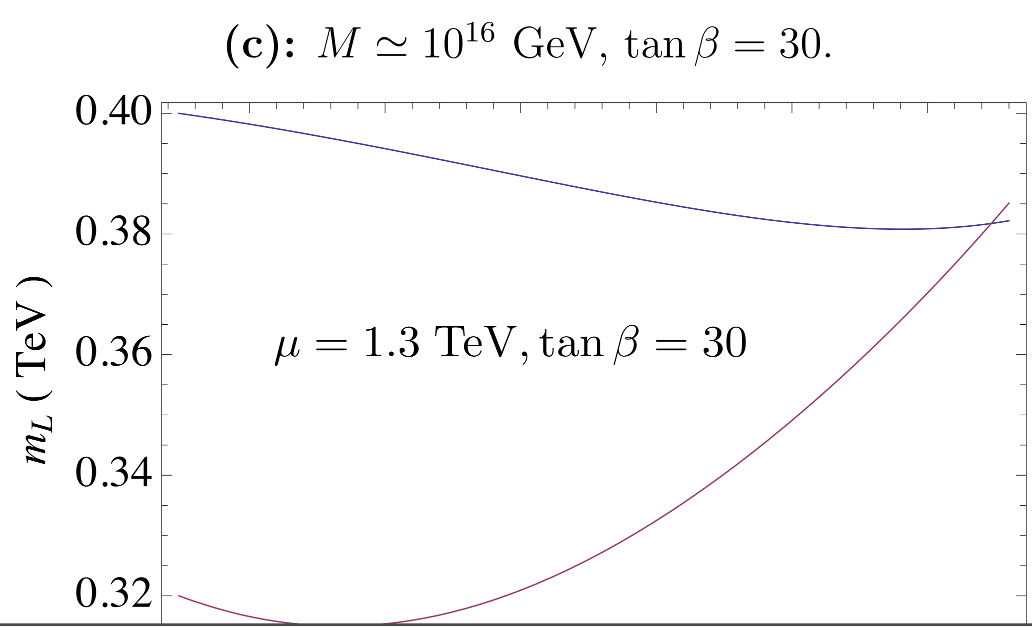
Running to high energies

$$\mu \simeq 650 \text{ GeV}, \ \tan\beta = 60$$

Carena, Gori, Shah, Wang, C.W.'12







Running depends on $\tan\beta$, but phenomenological properties depend on $\mu \tan\beta$.

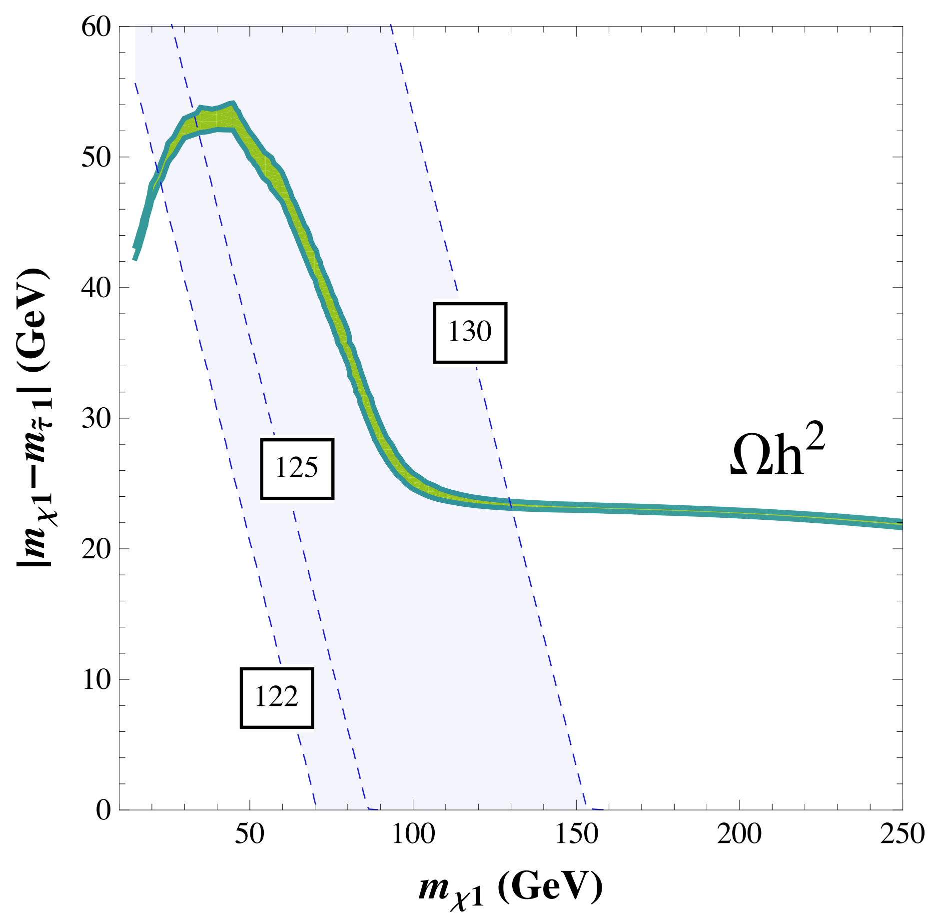
Consistency with $(g-2)_\mu$ and flavor independence at the messenger scale demands either low messenger scale or smaller $\tan\beta$ and larger μ.

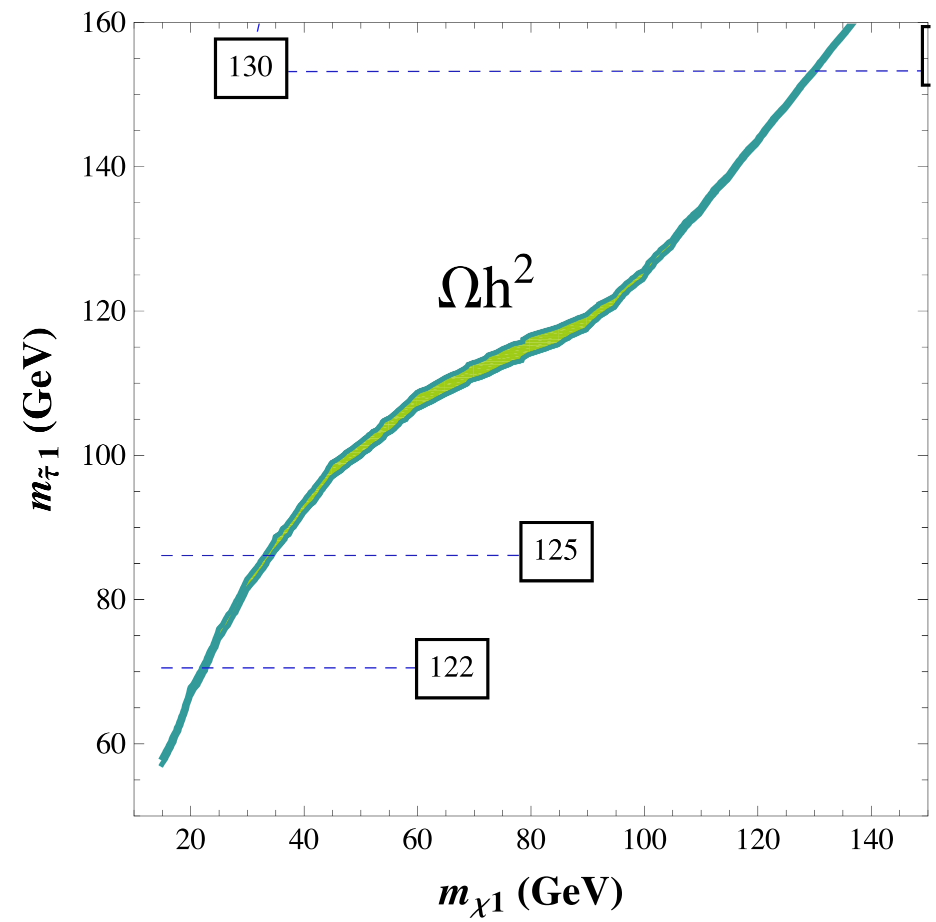
Wednesday, May 2, 2012

Dark Matter

Co-annihilation of neutralinos with staus, together with the s-channel Z and h induced diagrams can lead to a consistent Dark Matter density. For staus of mass 100 GeV, neutralinos in the 30--50 GeV mass range required. Relatively hard taus from stau decays

Carena, Gori, Shah, Wang, C.W.' 12





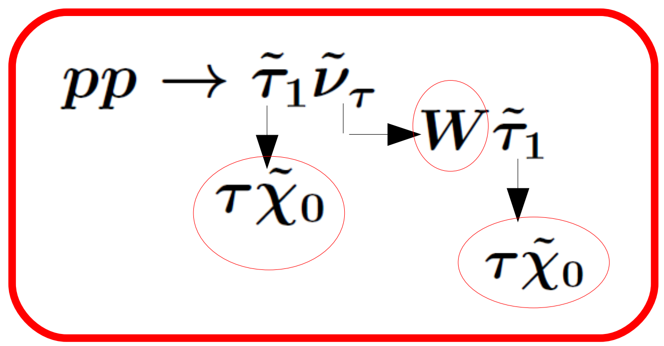
Large messenger scales or order MGUT assumed.
For smaller scales, the gravitino tends to be the LSP

Collider Physics

- LHC is looking for staus only if produced through Susy cascade decay

ATLAS-CONF-2012-005
ATLAS-CONF-2012-002

- Possible new interesting channel to look for:



Final signature:
Lepton, 2 taus, missing energy
(gravitino or neutralino)

- Main backgrounds:

Physical background: Wγ*, WZ*
Fake background: W+jets

S/B~1
even if low statistics
(~10 events with 30 fb^{-1})

- Set of cuts:

$$\not{E}_T > 70\,\mathrm{GeV}$$
$$p_T^{\tau,j} < 70\,\mathrm{GeV}$$
$$p_T^{\ell} > 70\,\mathrm{GeV}$$
$$70\,\mathrm{GeV} < m_{12} < 130\,\mathrm{GeV}$$

Rough analysis shows that hints of stau/sneutrino production may be obtained. More sophisticated analysis should be performed to validate these 8 TeV results.

Carena, Gori, Shah, Wang, C.W.'12

Conclusions

- Allowed SM-Higgs mass window at the LHC is consistent with precision measurements and with the extrapolation of SM description to very high energies.

- A 125 GeV Higgs boson is consistent with a stop spectrum of order 1 TeV and large stop mixing parameters. No hard bound on the lightest stop mass can be set.

- In the minimal supersymmetric model, rates may be modified by mixing or by presence of light sfermions.

- While in the region of parameters consistent with a 125 GeV Higgs, stops tend to slightly suppress the photon rate, light staus can enhance it without modifying the other rates in a significant way.

- They can also induce relevant mixing effects, which would lead to a suppression of the bottom quark rates and a further enhancement of the photon rate, as well as a less dramatic enhancement of the WW and ZZ rates.

- The combination of LHC and Tevatron results may provide a very relevant test for this scenario in the near future.

- There is an improvement of the relevant precision measurement variables. Dark Matter and g-2 improvements are easy to obtain in this region of parameters. Collider phenomenlogy is interesting.

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.

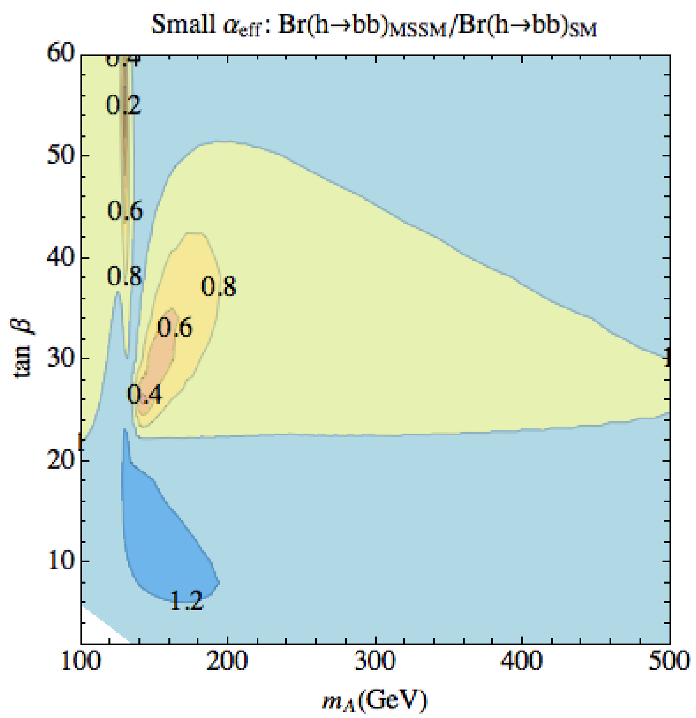
- Specifically, this happens when

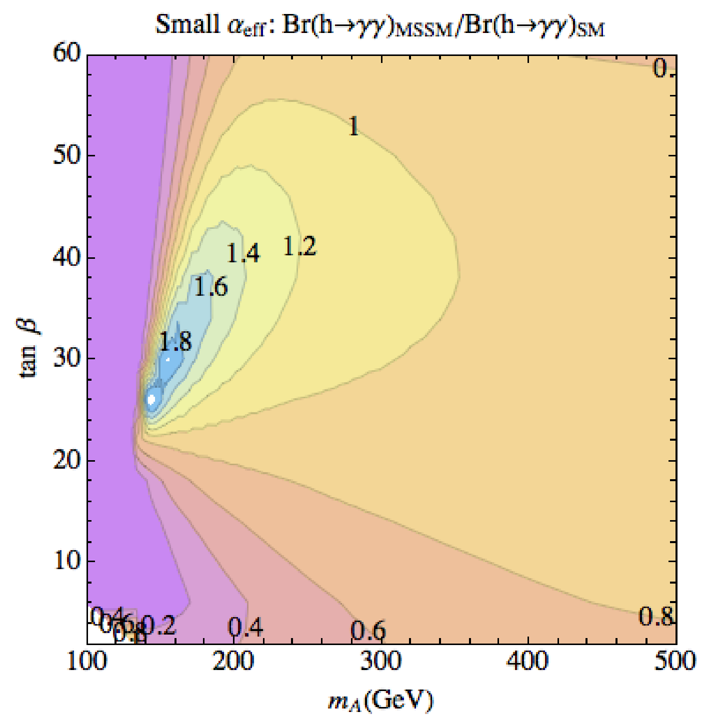
$$\frac{m_A^2}{M_Z^2} + \mathcal{O}(1) \simeq \tan\beta \frac{h_t^4 v^2}{16\pi^2 M_Z^2} \frac{\mu\, X_t}{M_S^2} \left(\frac{X_t^2}{6M_S^2} - 1 \right)$$

- 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



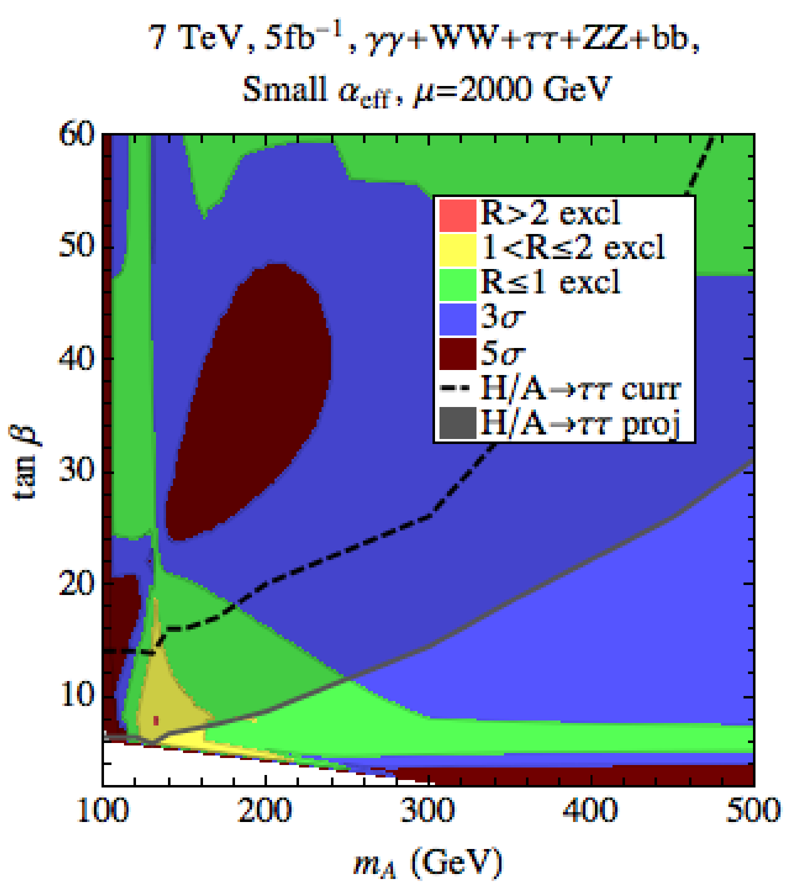


For large values of μ and A_t

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

Carena, Mrenna, Wagner'99

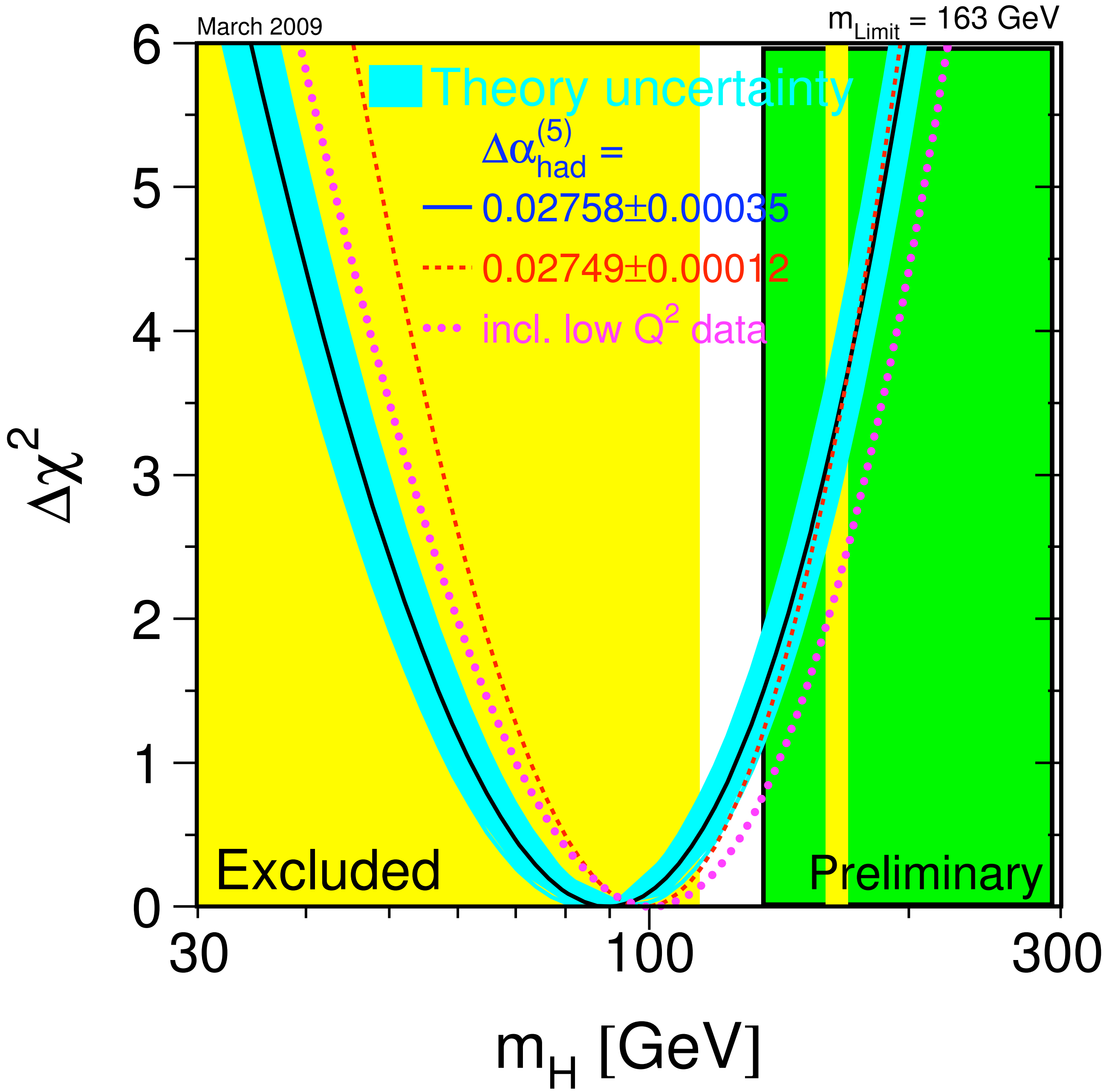
Carena, Heinemeyer, Wagner, Weiglein'02



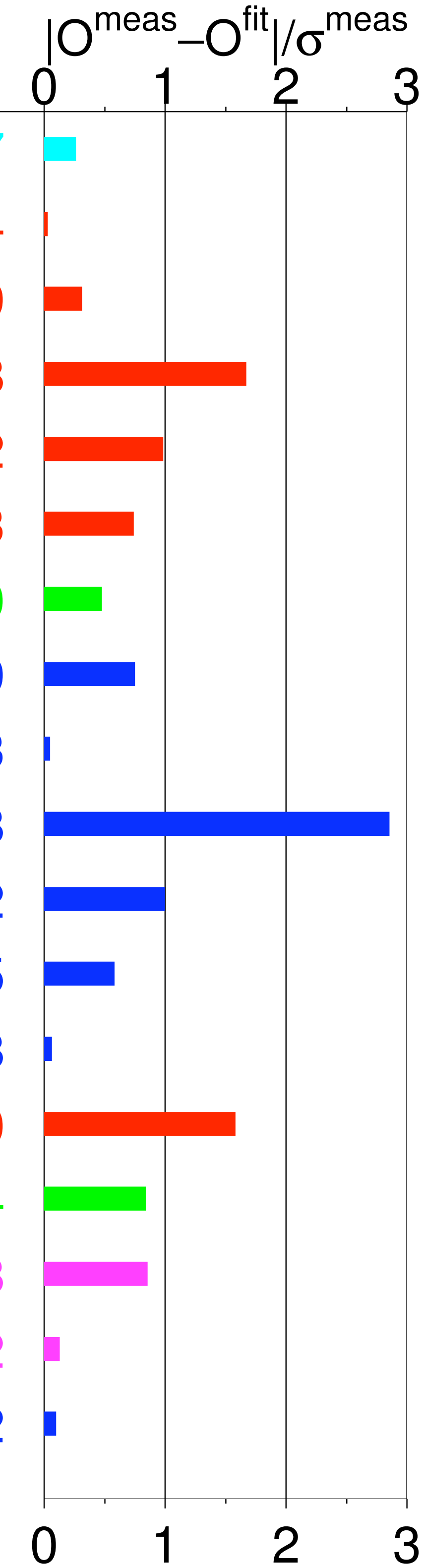
Such scenario, however, demands small values of the the CP-odd Higgs mass and large tanbeta and seems to be in conflict with non-standard Higgs boson searches

Carena, Draper, Liu, Wagner'11

Allowed region overlaps with the region preferred by SM Precision Electroweak Data

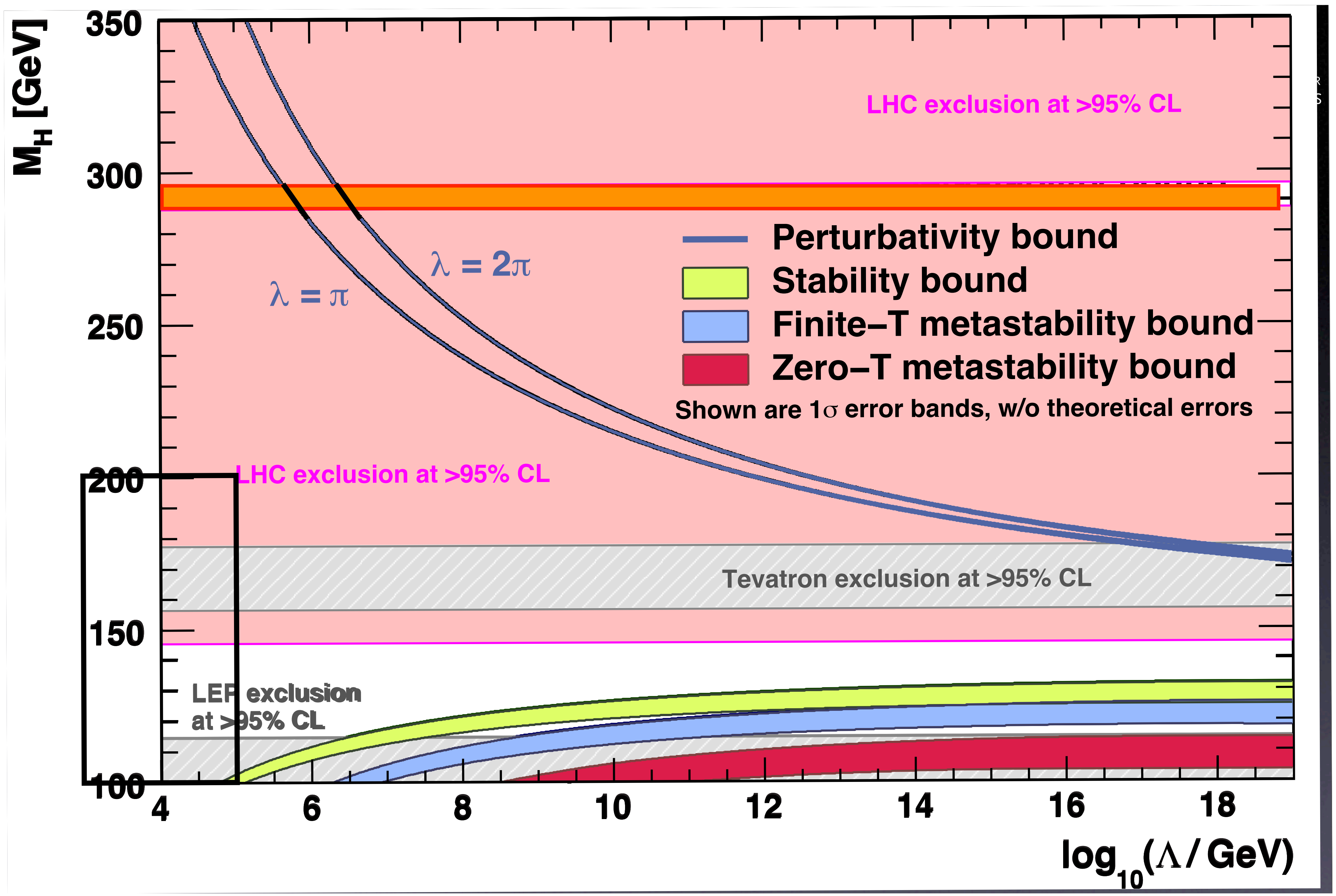


	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02767
m_Z [GeV]	91.1875 ± 0.0021	91.1874
Γ_Z [GeV]	2.4952 ± 0.0023	2.4959
σ^0_{had} [nb]	41.540 ± 0.037	41.478
R_l	20.767 ± 0.025	20.742
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01643
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1480
R_b	0.21629 ± 0.00066	0.21579
R_c	0.1721 ± 0.0030	0.1723
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1038
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1480
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.399 ± 0.025	80.378
Γ_W [GeV]	2.098 ± 0.048	2.092
m_t [GeV]	173.1 ± 1.3	173.2



March 2009

Allowed region consistent with extrapolation of the SM description until very high energies



J. Elias Miro et al'11
H. Murayama'11
C. Cheung et al'12

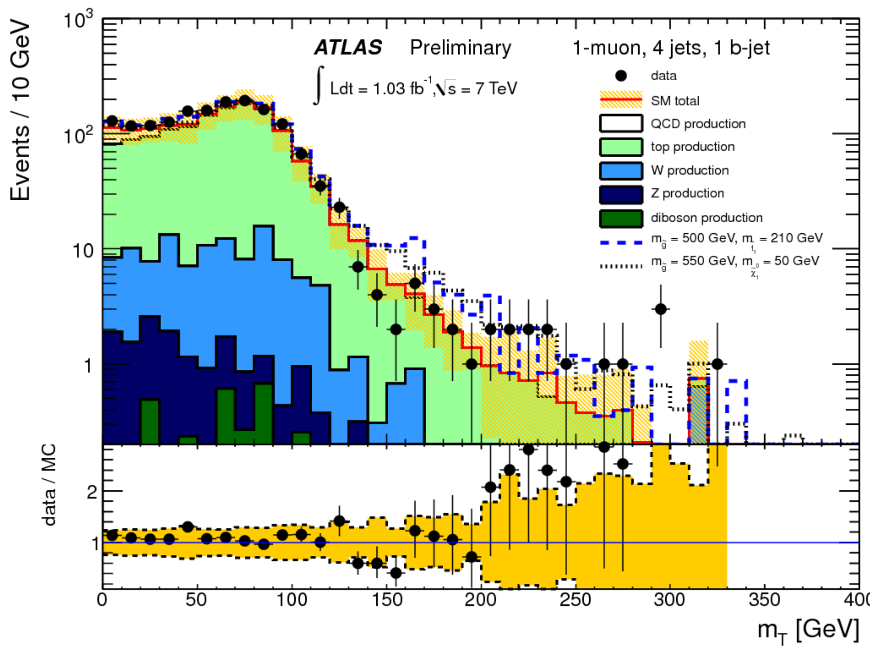
One Lepton + b-jets + Missing E_T

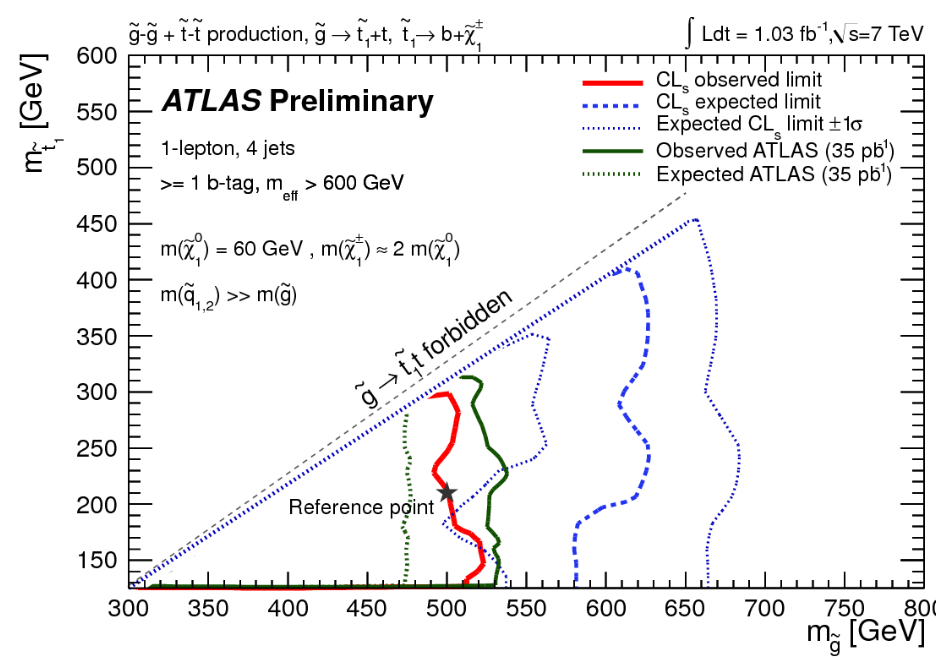
Update LP2011

- 3[rd] 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

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

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

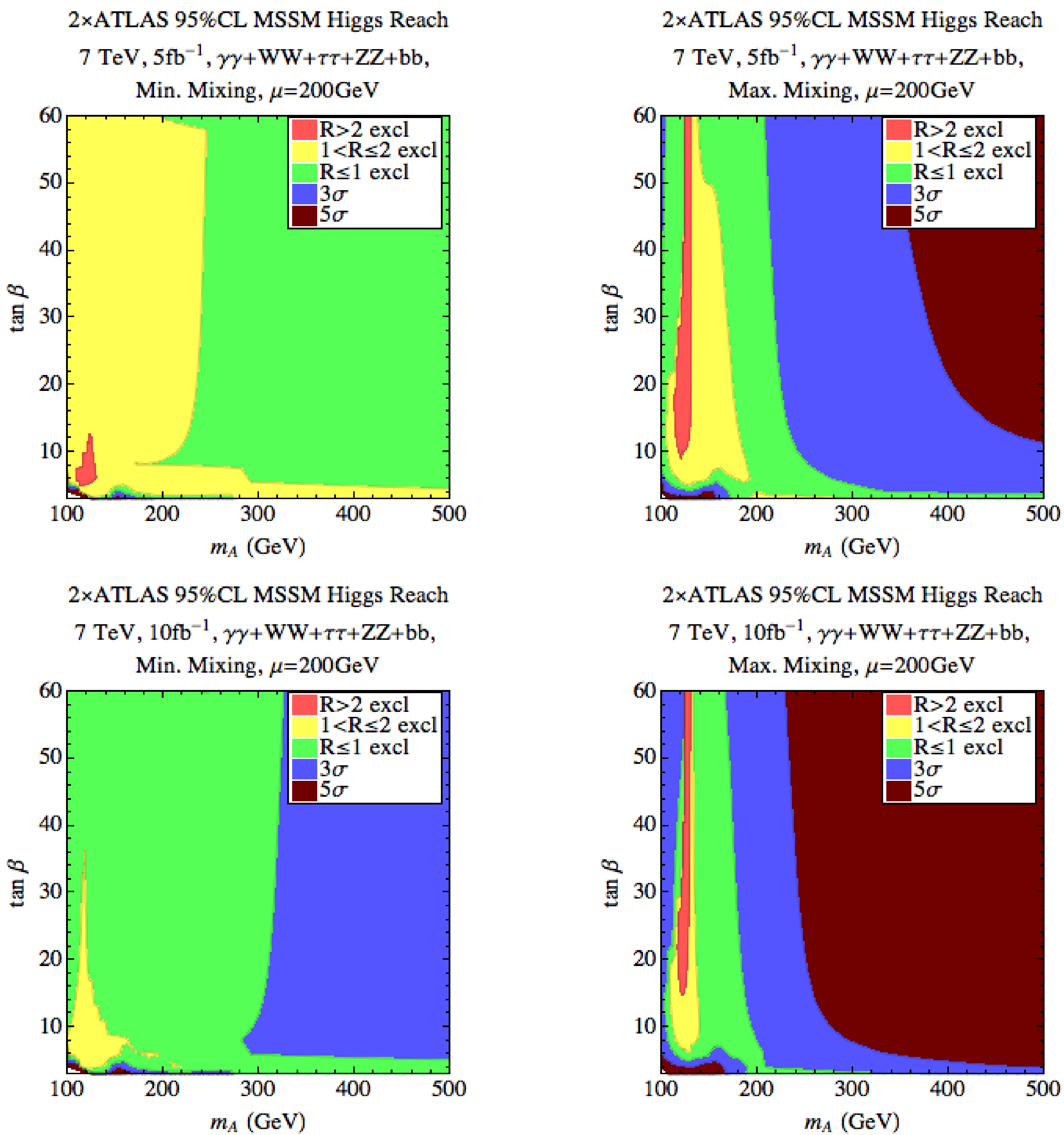
$$\begin{aligned} A_f(\tau) &= 2\left[\tau + (\tau-1)f(\tau)\right]\,\tau^{-2} \\ A_W(\tau) &= -\left[2\tau^2 + 3\tau + 3(2\tau-1)f(\tau)\right]\,\tau^{-2} \end{aligned}$$

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

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

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



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

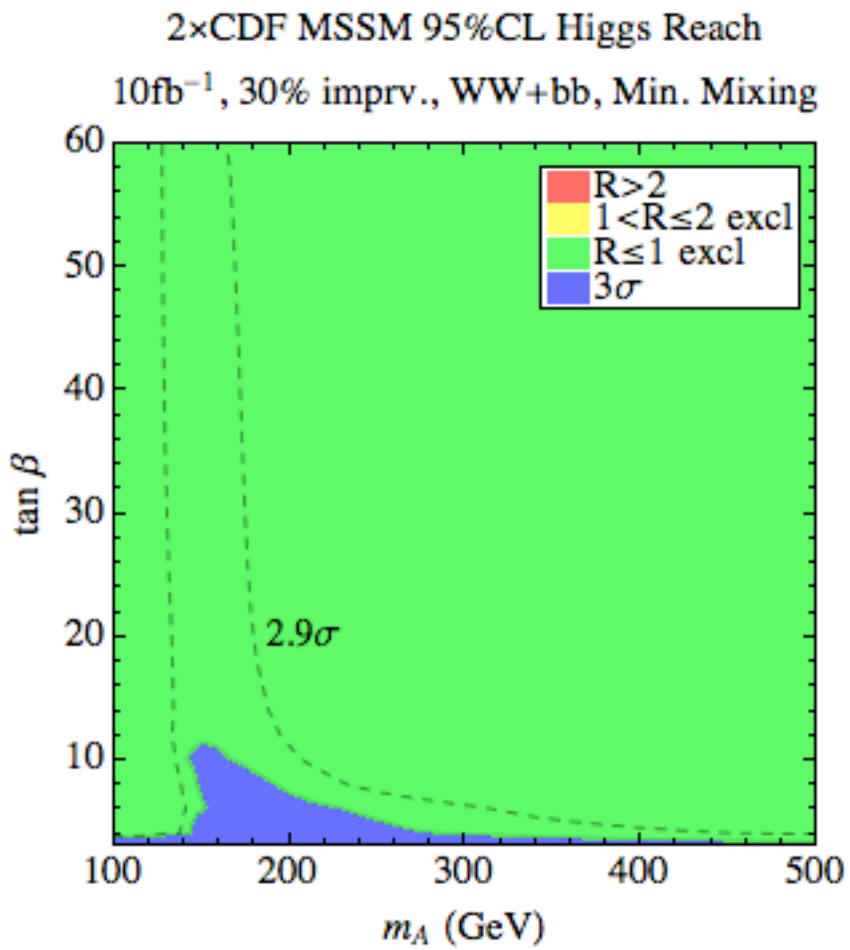
$Vh, h \to bb$

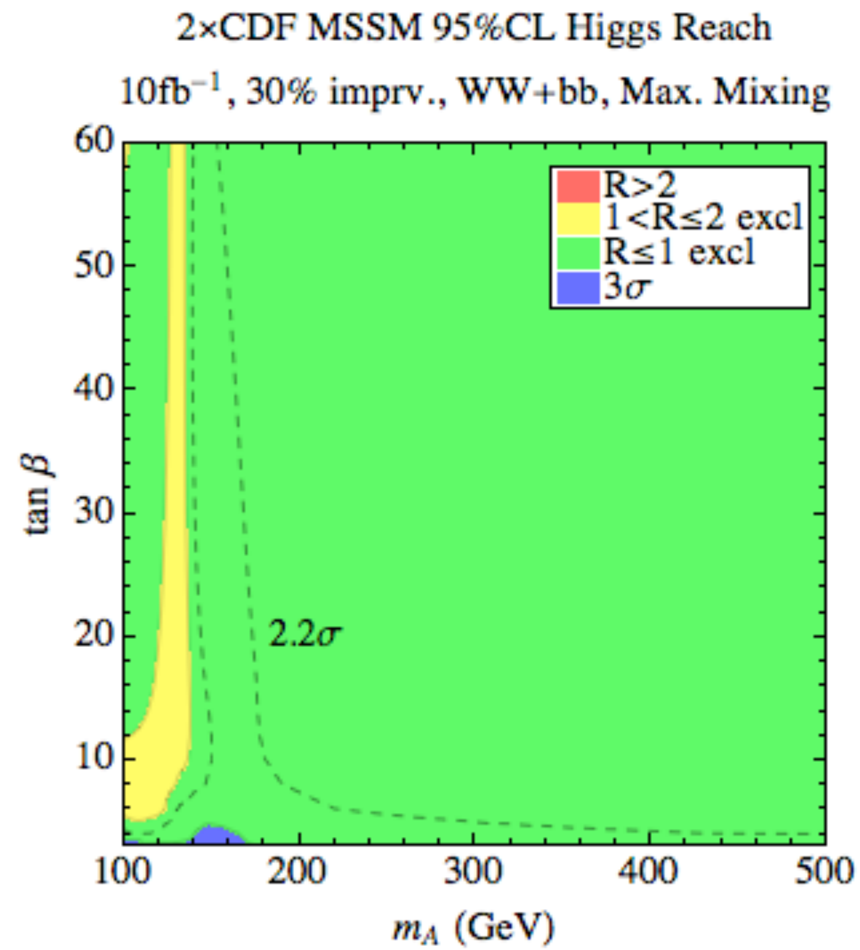
$\text{WBF}, h \to \tau\tau$

are helpful in partially reducing the reach suppression

Tevatron Reach

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

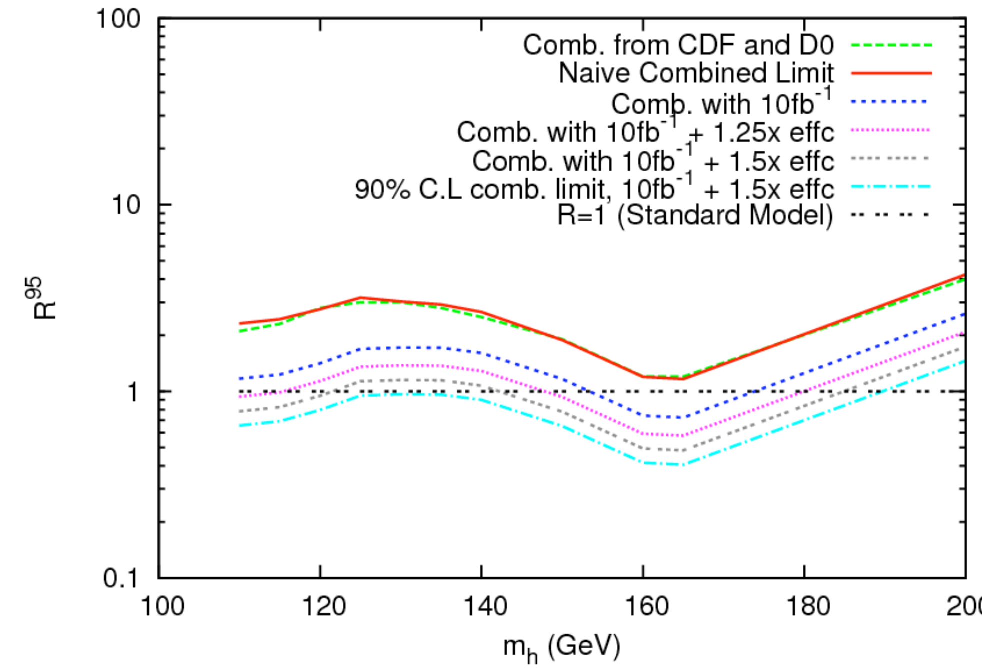




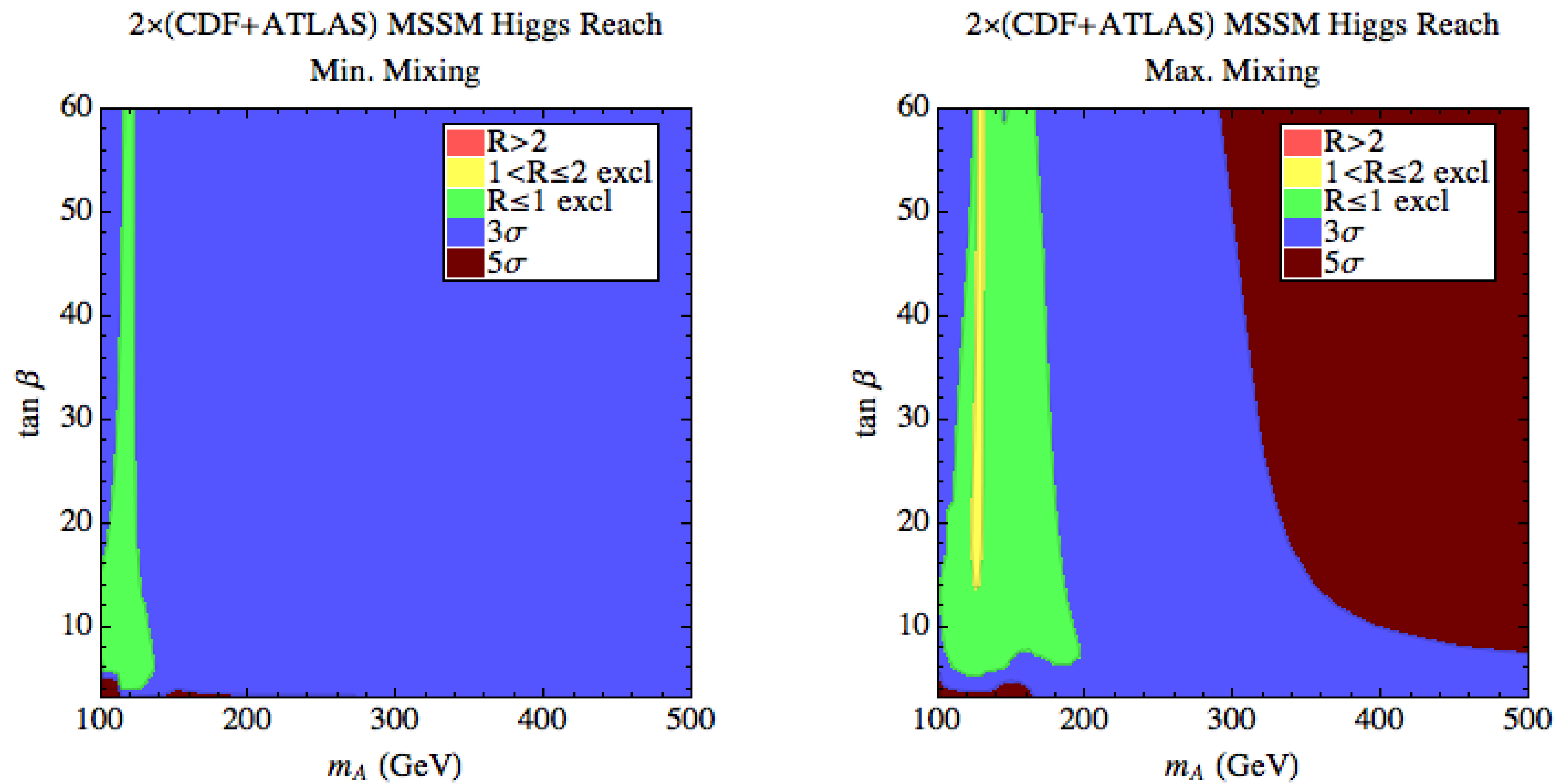
More than 2 standard deviations in most of the parameter space

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

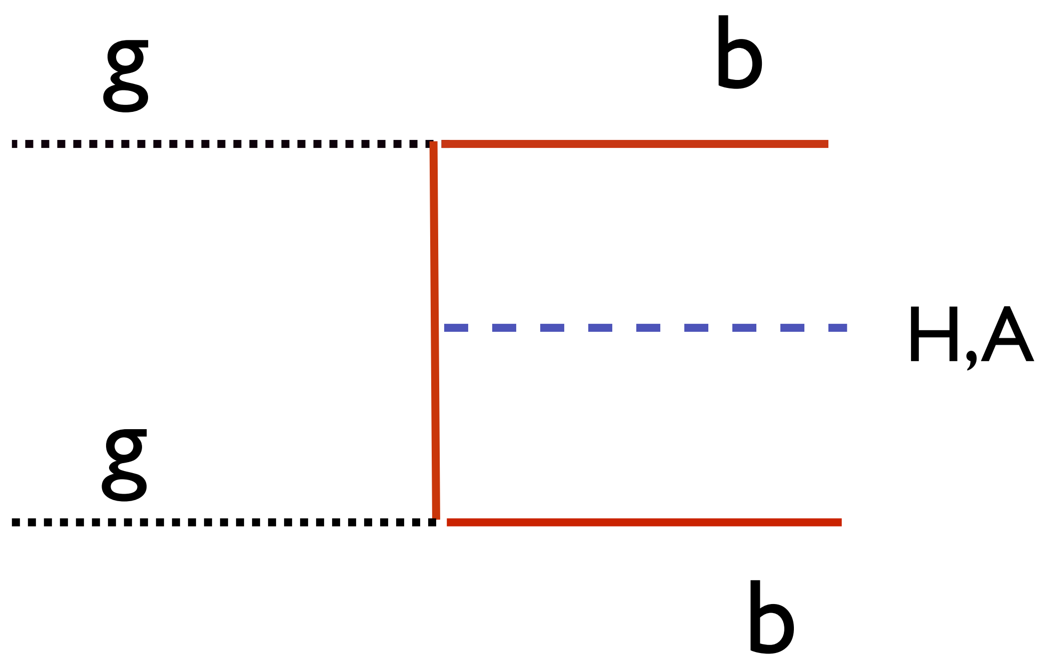


Combination of 5 inverse fb LHC with 10 inverse fb Tevatron data : Evidence of SM-like Higgs presence in almost all parameter space

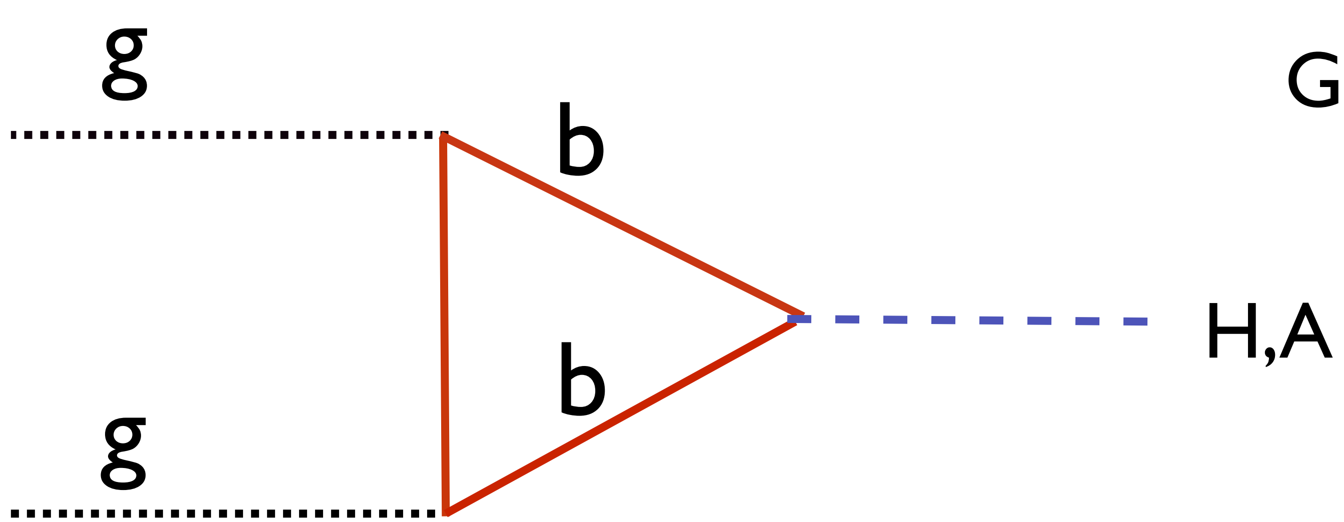
M. Carena, P. Draper, T. Liu, C.W.'11

Non-Standard Higgs Production

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



Associated Production



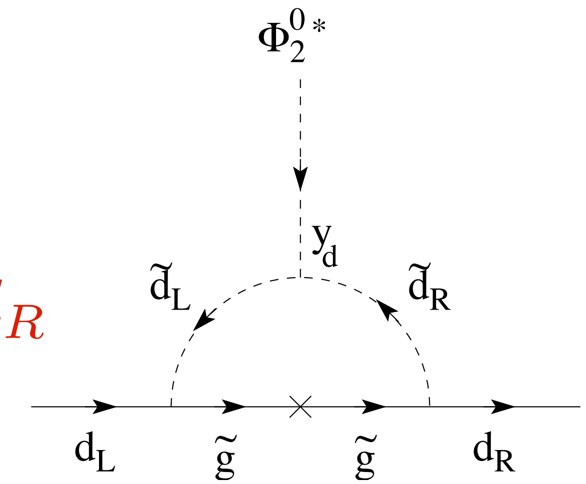
Gluon Fusion

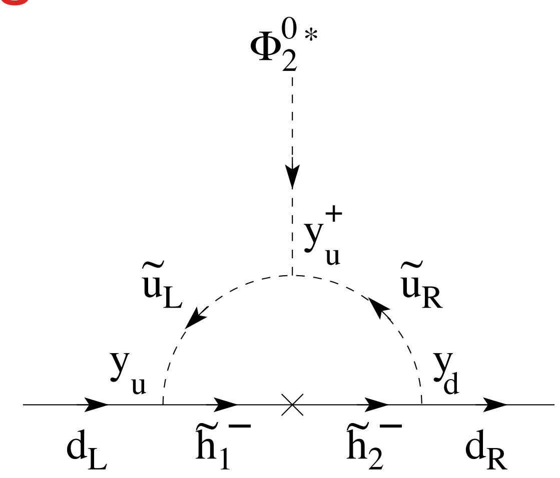
$$g_{Abb} \simeq g_{Hbb} \simeq \frac{m_b \tan\beta}{(1+\Delta_b)v}, \qquad g_{A\tau\tau} \simeq g_{H\tau\tau} \simeq \frac{m_\tau \tan\beta}{v}$$

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.

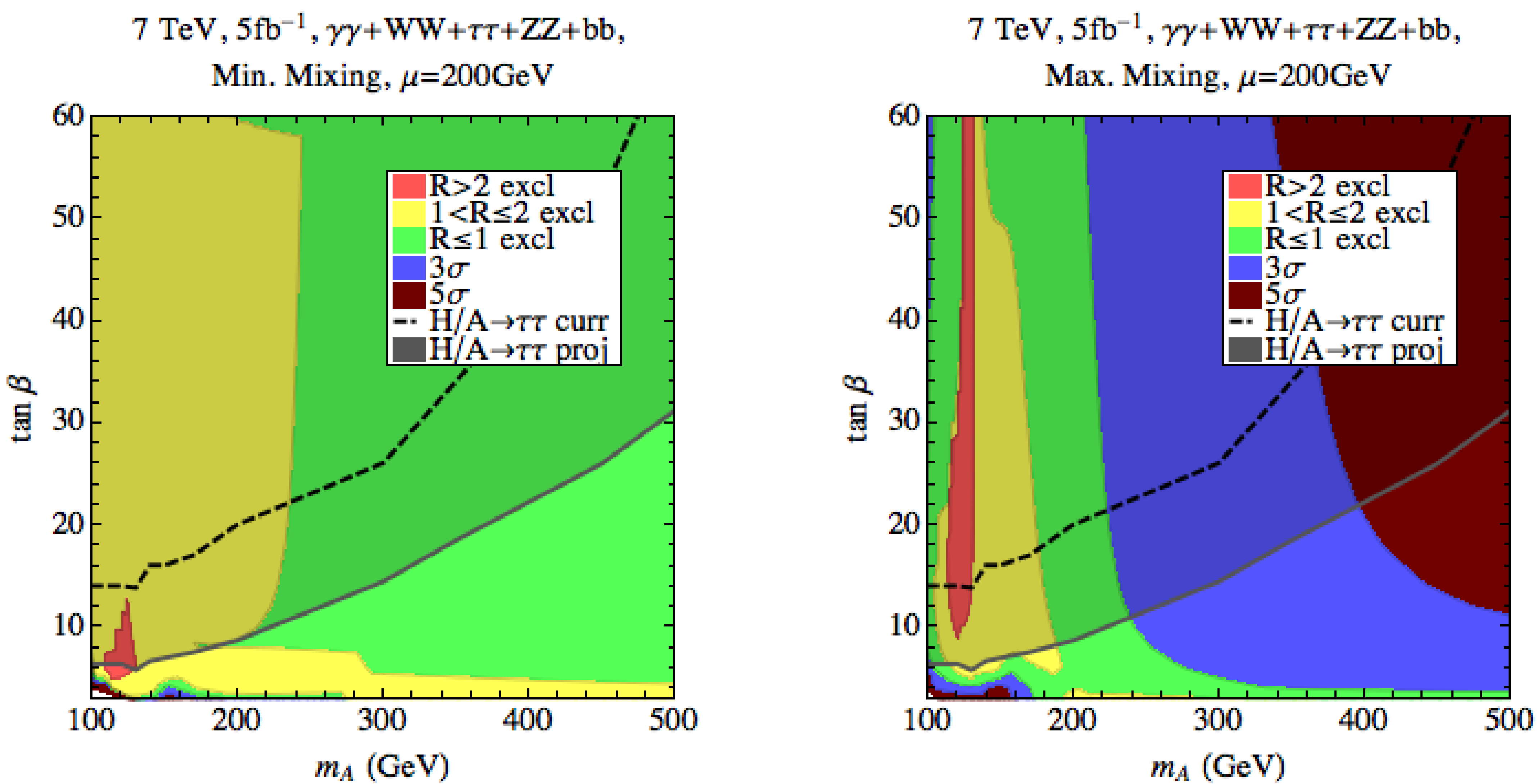
$$\sigma(b\bar{b}A) \times BR(A \to b\bar{b}) \simeq \sigma(b\bar{b}A)_{\rm SM} \frac{\tan^2\beta}{(1+\Delta_b)^2} \times \frac{9}{(1+\Delta_b)^2+9}$$

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

- 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