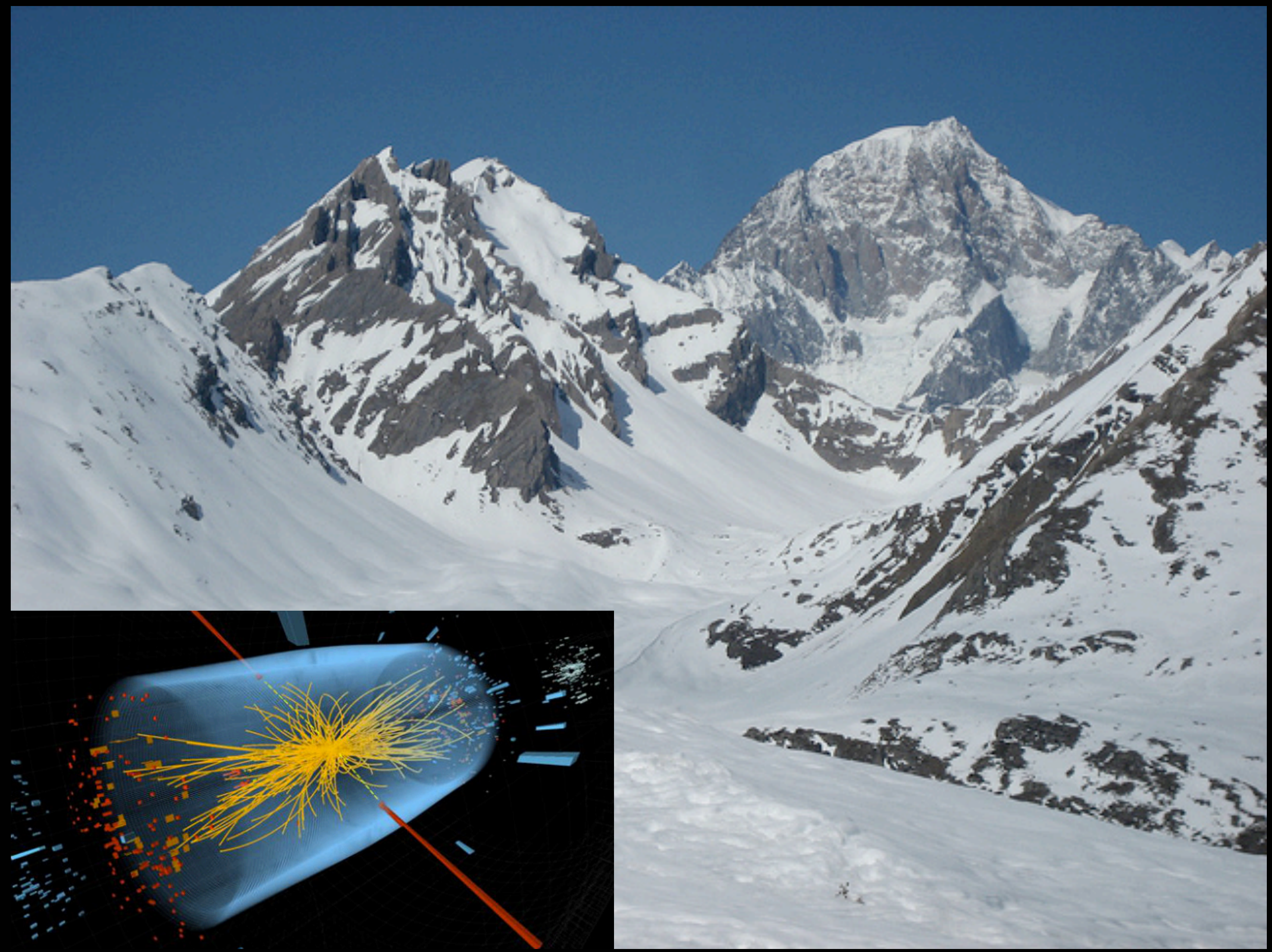
SUSY and the source of EWSB



Marcela Carena
Fermilab and U. of Chicago.

Rencontres de Moriond, Electroweak Interactions and Unified Theories
La Thuile, March 7, 2013

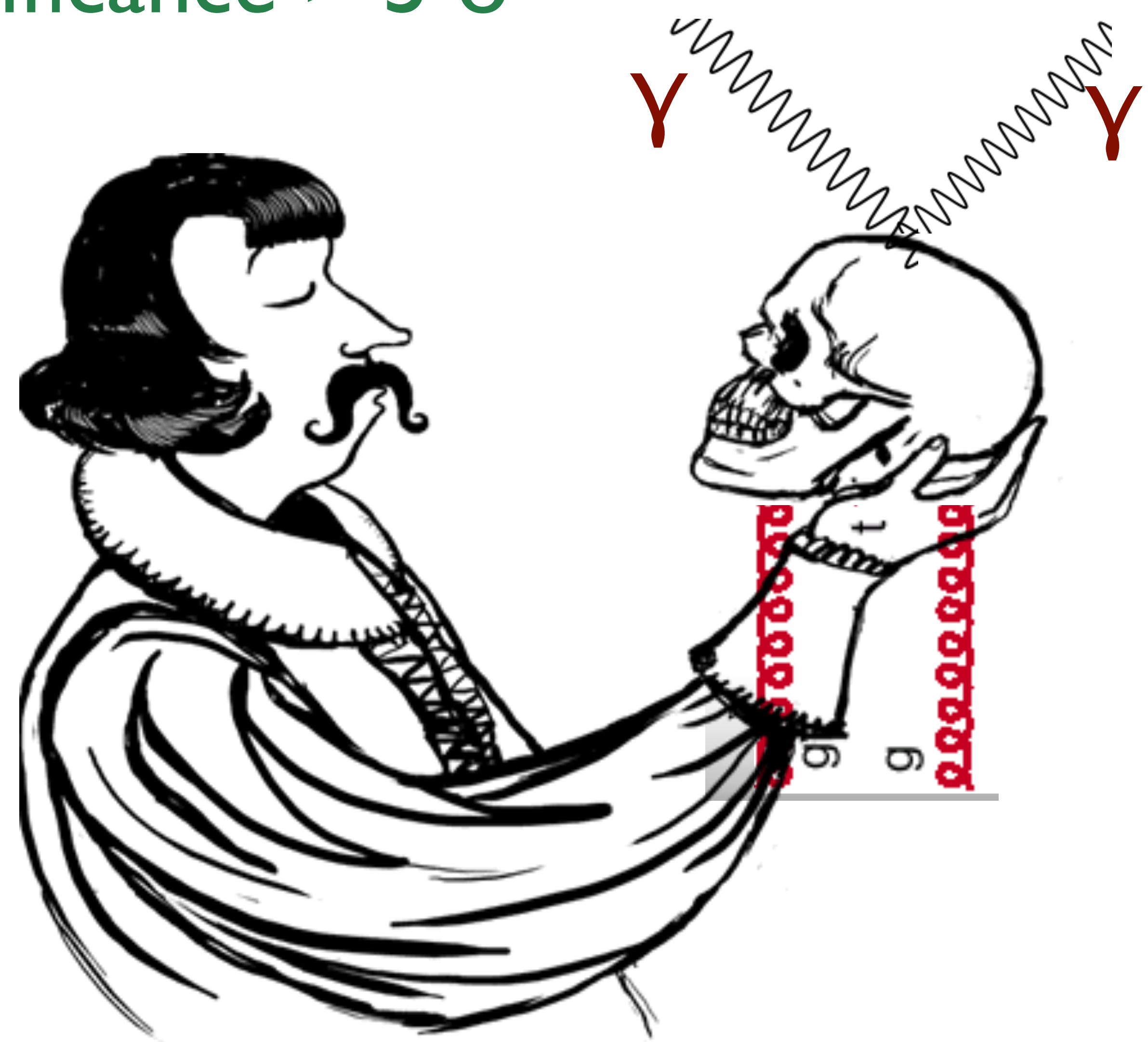
2012-2013: an amazing time for HEP:

“The” Standard Model Scalar Boson, or not ....

CMS: $m_h \sim 125.8$ GeV (in ZZ); $m_h = 124.9.$ GeV (in $\gamma\gamma$)

ATLAS: $m_h = 124.3$ GeV (in ZZ); $m_h = 126.8$ GeV (in $\gamma\gamma$)

Observation with a significance > 5 σ



In the ZZ channel

$$\mu = 1.7\,^{+0.5}_{-0.4}\ \text{ATLAS} \quad \mu = 0.91\,^{+0.3}_{-0.24}\ \text{CMS}$$

In the WW channel ($m_h \sim 125$ GeV)

$$\mu = 1.5 \pm 0.6\ \text{ATLAS} \quad \mu = 0.76 \pm 0.21\ \text{CMS}$$

In the $\gamma\gamma$ channel

$$\mu = 1.65 \pm 0.24\,^{+0.25}_{-0.18}\ \text{ATLAS}$$

$$\mu \approx 1.6 \pm 0.4\ \text{CMS (July 4th)}$$

The Discovery of a Scalar boson like particle puts the final piece of the Standard Model in place

and marks the birth of the hierarchy problem: one of the main motivations for physics beyond the SM

The SM works beautifully,
no compelling hints for deviations

But many questions remain unanswered:

Dynamical Origin of electroweak symmetry breaking

Origin of generations and structure of Yukawa interactions

Matter-antimatter asymmetry

Unification of forces

Neutrino masses

Dark matter and dark energy

Hence, the "prejudice" (the hope) that there must be "New Physics"

What if the newly discovered particle is not *the* SM Scalar?

- it can still be the scalar boson responsible for EWSB -

The SM Scalar Boson:

Spin 0

Neutral CP even component of a complex $SU(2)_L$ doublet with Y=1

Singlet under the residual SU(2) custodial symmetry after EWSB

==> $g_{WWH}/g_{ZZH} = m_W^2/m_Z^2$ at tree level

Couplings to SM fermions proportional to fermion masses

Self-coupling strength determined in terms of its mass and v = 246 GeV

A *SM-like* Scalar Boson:

Could be a mixture of CP even and CP odd states

Could have non-SM couplings to vector bosons and fermions

==> non-SM decay widths and production cross sections in many/all channels

Could have decays into new particles

Could be partly singlet or triplet instead of an $SU(2)_L$ doublet ?

Could be composite

How well can the Scalar Boson properties be resolved at the LHC?

Effective Theory Analyses

Chiral Lagrangian for a light SM-like scalar boson

see Eboli's and Azatov's talks

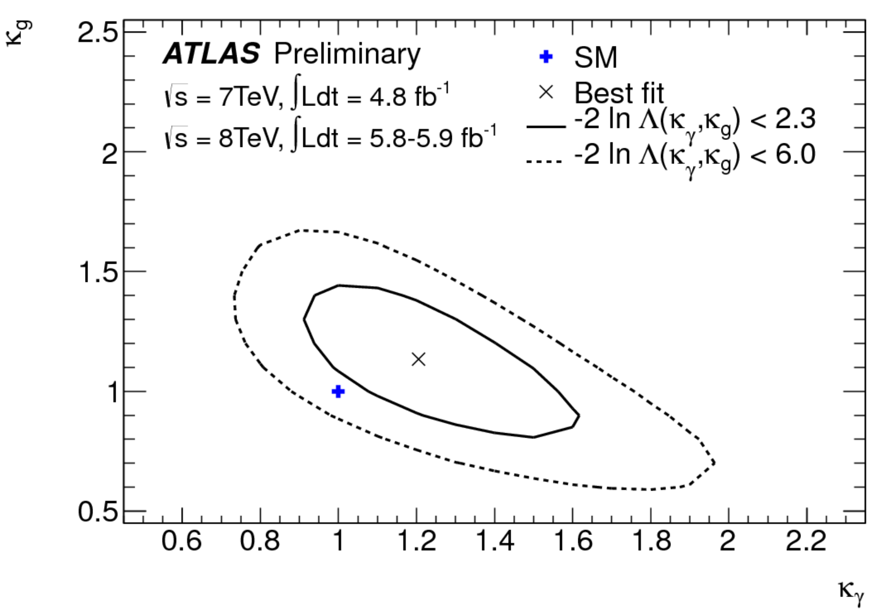
$$\mathcal{L} = \frac{1}{2}(\partial_\mu h)^2 - \frac{1}{2}m_h^2 h^2 - \frac{d_3}{6}\left(\frac{3m_h^2}{v}\right)h^3 - \frac{d_4}{24}\left(\frac{3m_h^2}{v^2}\right)h^4 \dots$$

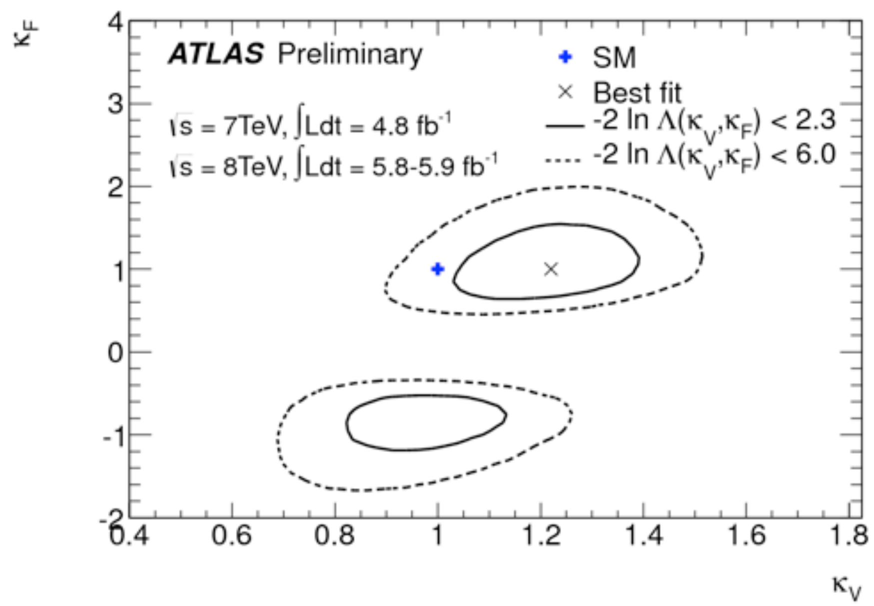
$$-\left(m_W^2\, W_\mu W_\mu + \frac{1}{2}m_Z^2\, Z_\mu Z_\mu\right)\left(1 + 2a\frac{h}{v} + b\frac{h^2}{v^2} + \dots\right)$$

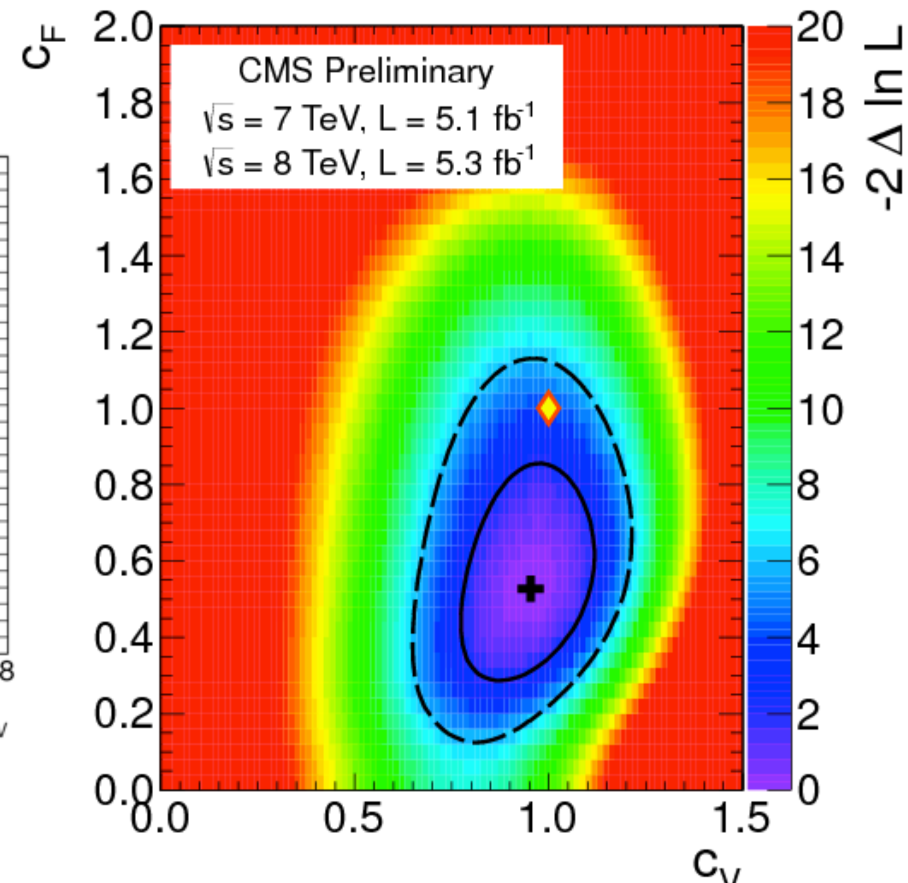
$$-\sum_{\psi=u,d,l} m_{\psi^{(i)}}\,\bar{\psi}^{(i)}\psi^{(i)}\left(1 + c_\psi\frac{h}{v} + c_{2\psi}\frac{h^2}{v^2} + \dots\right)$$

+ dimension 6 operators

In the SM: $a=b=c=d_3=d_4=1$
all h.d.o. coefficients are 0







Official results differ in each experiment due to different results in WW/ZZ/di-taus

(Results before March 6, 2013)

What does a 125 GeV Scalar Boson mean for Supersymmetric Models?

- **Minimal** Scalar Boson Sector: Two Scalar Boson doublets

$$\tan\beta = v_2/v_1$$

2 CP-even h (SM-like), H with mixing angle α
+ 1 CP-odd A + 1 charged pair H^{+-}

$$\Rightarrow v = \sqrt{v_1^2 + v_2^2} = 246 \text{ GeV}$$

- One Scalar boson doublet couples to up quarks, the other to down quarks/leptons only

Scalar Boson interactions are flavor diagonal if SUSY preserved

- Quartic couplings determined by SUSY as a function of the gauge couplings

  -- lightest (SM-like) scalar boson strongly correlated to Z mass (naturally light!)

  -- other scalar bosons can be as heavy as the SUSY breaking scale

- Important quantum corrections to the lightest Scalar boson mass due to incomplete cancellation of top and stop contributions in the loops

  -- also contributions from sbottoms and staus for large tan beta --

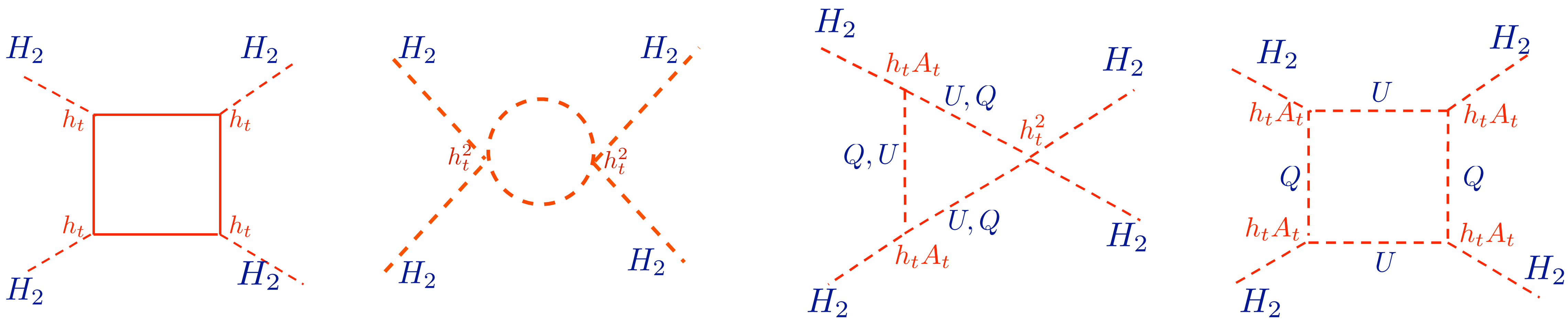
Lightest SM-like Scalar boson mass strongly depends on:

CP-odd mass m_A, $\tan\beta$,

M_{top}

Stop masses and mixing

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



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

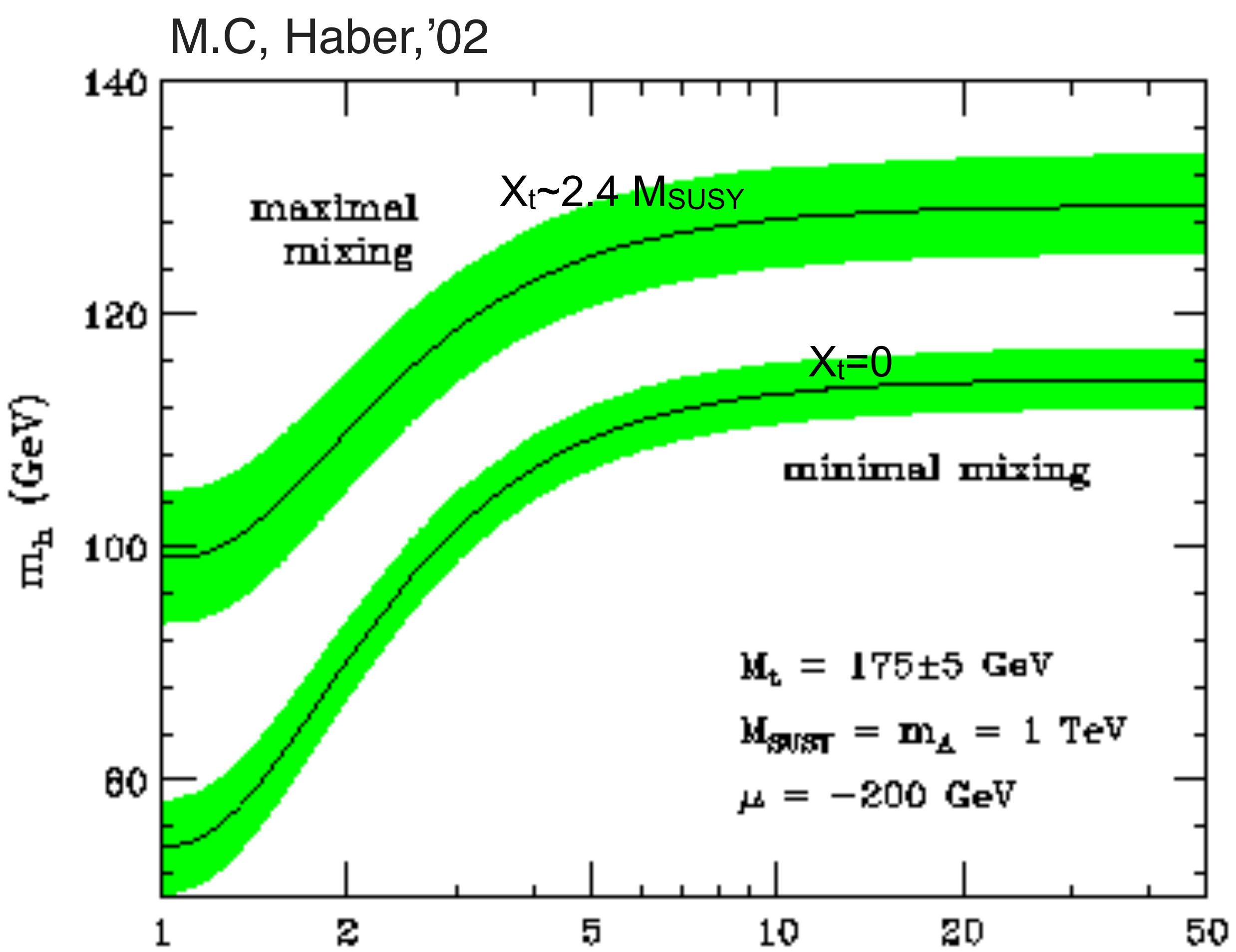
$$\boxed{m_h^2 \cong M_Z^2 \cos^2 2\beta + \frac{3}{4\pi^2}\frac{m_t^4}{\mathrm{v}^2}\left[\frac{1}{2}\tilde X_t + t + \frac{1}{16\pi^2}\left(\frac{3}{2}\frac{m_t^2}{\mathrm{v}^2} - 32\pi\alpha_3\right)\left(\tilde X_t t + t^2\right)\right]}$$

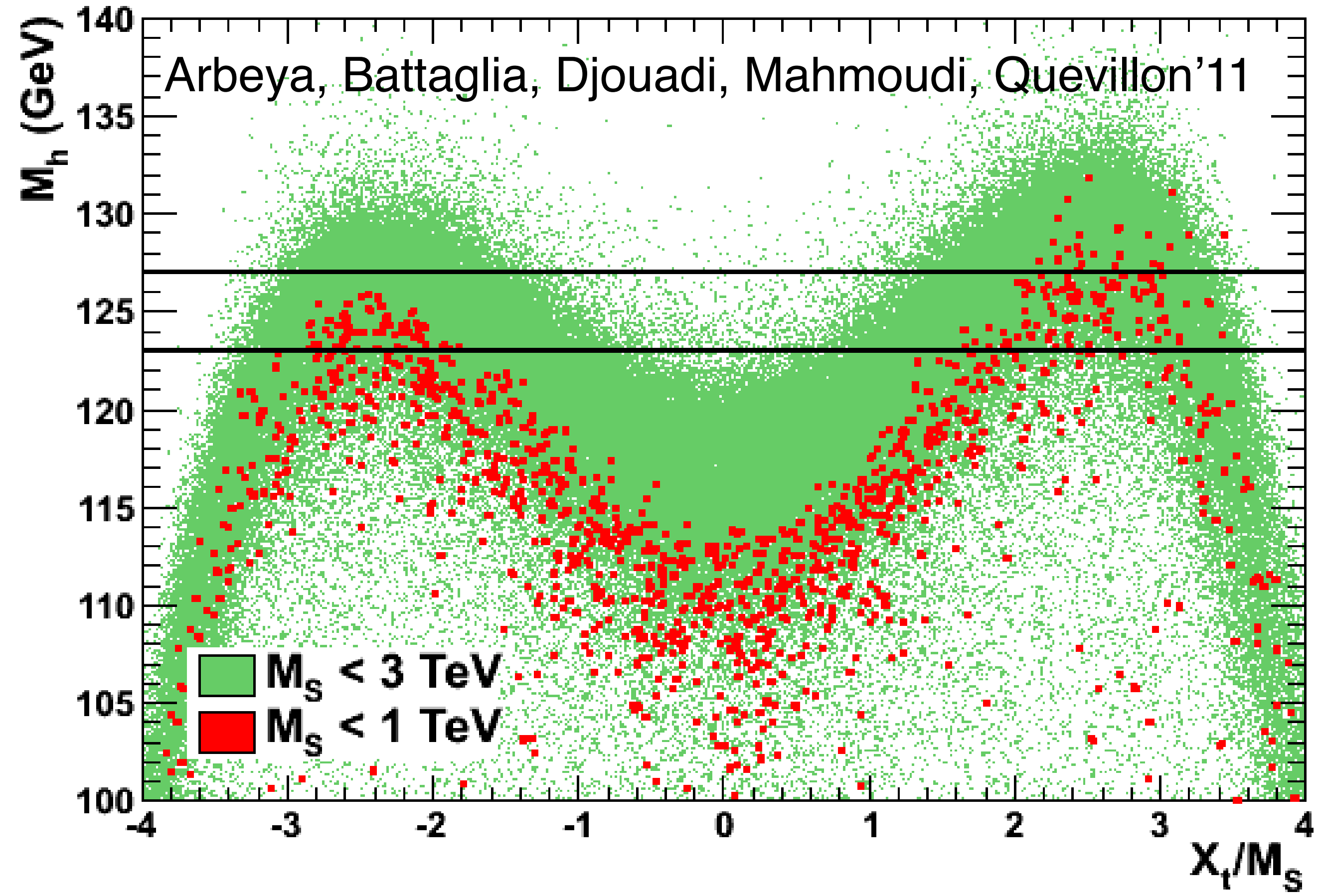
$$t = \log(M_{SUSY}^2 / m_t^2) \qquad \tilde X_t = \frac{2X_t^2}{M_{SUSY}^2}\left(1 - \frac{X_t^2}{12 M_{SUSY}^2}\right) \qquad \underline{X_t = A_t - \mu/\tan\beta} \rightarrow \text{LR stop mixing}$$

$M_{SUSY} \sim m_Q \sim m_U$

M.C. Espinosa, Quiros, Wagner '95; M.C. Quiros, Wagner '95; Haber, Hempfling, Hoang '96

SM-like MSSM Scalar Boson Mass:





$$\boxed{m_h \leq 130 \text{ GeV}}$$

(for sparticles of ~ 1 TeV)

Many contributions to two-loop calculations

Brignole, M.C., Degrassi, Diaz, Ellis, Haber, Hempfling, Heinemeyer, Hollik, Espinosa, Martin, Quiros, Ridolfi, Slavich, Wagner, Weiglein, Zhang, Zwirner, …

Given the Discovery of a SM-like Scalar boson particle with mass ~ 125 GeV

- Do we still expect SUSY (some type of low energy SUSY) ?

- If yes, what does it imply for SUSY models?

large mixing in the stop sector

or

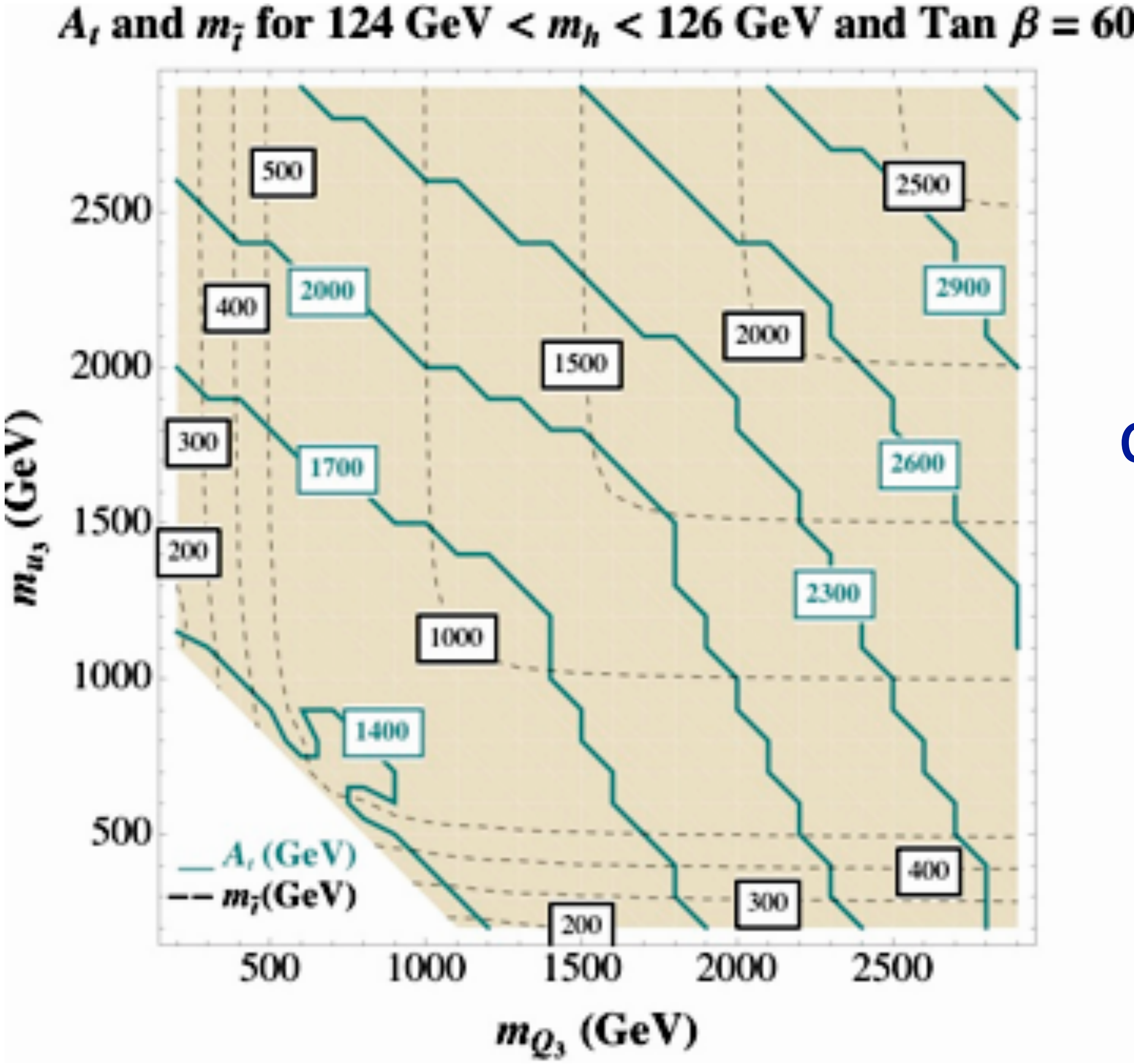
new matter or gauge superfields

Both alternatives have important implications for the Higgs production and decay rates

They also have implications for the flavor-Higgs connection within assumption of MFV at the SUSY breaking scale

DM constraints less strongly correlated since predictions depend strongly on gaugino soft masses, not very relevant for Higgs rad. corrections.

Soft supersymmetry Breaking Parameters in the MSSM



Large stop sector mixing
A_t > 1 TeV

No lower bound on the lightest stop
One stop can be light and the other heavy
or
in the case of similar stop soft masses.
both stops can be below 1TeV

Large mixing also constrains SUSY breaking model building

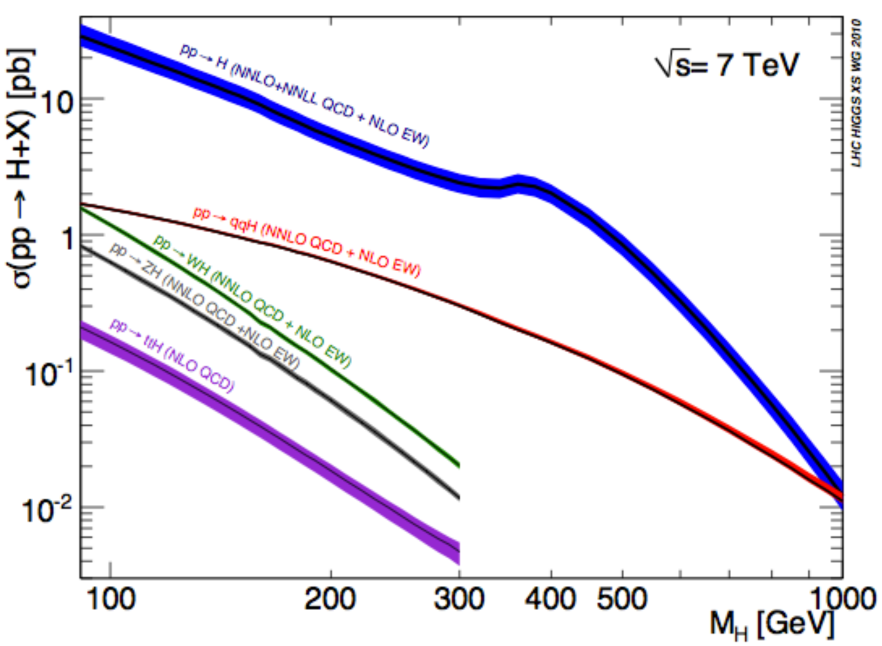
M. C., S. Gori, N. Shah, C.Wagner '11
+L.T.Wang '12

Similar results from
Arbey, Battaglia, Djouadi, Mahmoudi, Quevillon '11
Draper Meade, Reece, Shih'11
Shirman et al.

Can departures from the SM in the production/decay rates at the LHC disentangle among different SUSY spectra?

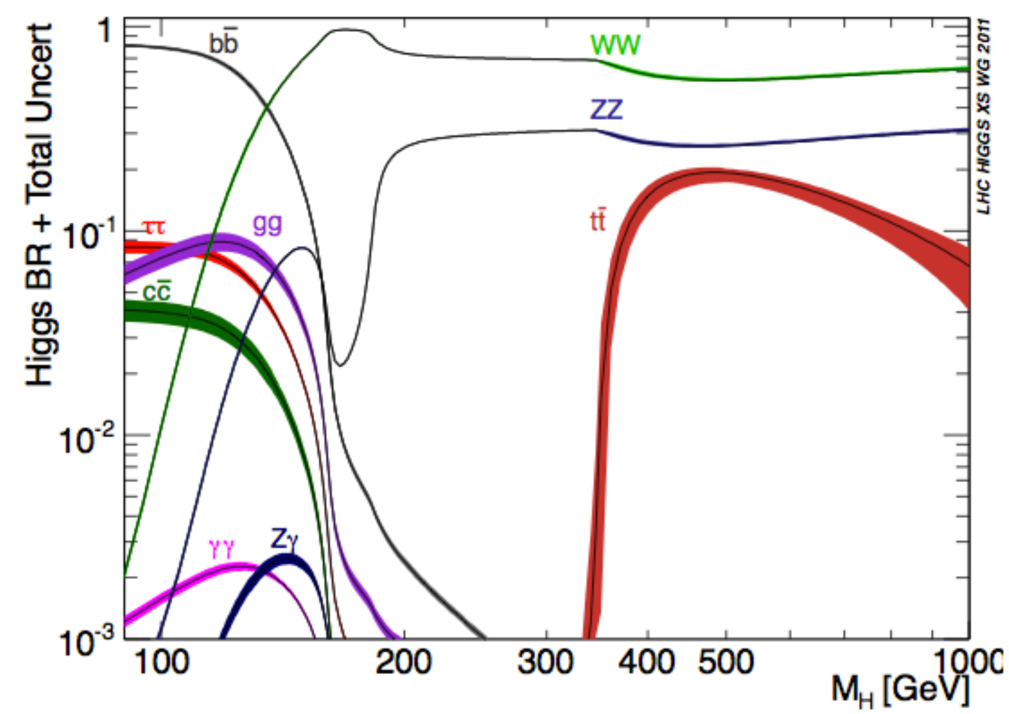
The event rates: $$B\sigma(p\bar{p} \to h \to X_{\rm SM}) \equiv \sigma(p\bar{p} \to h)\frac{\Gamma(h \to X_{\rm SM})}{\Gamma_{\rm total}}$$

- All three quantities may be affected by new physics.
- If one partial width is modified, the total width is modified as well, modifying all BR's.



Main production channel:
Gluon Fusion

Main/first search modes:
decay into γγ/ZZ/WW



How much can we perturb the gluon production mode?

Is it possible to change WW and ZZ decay rates independently?

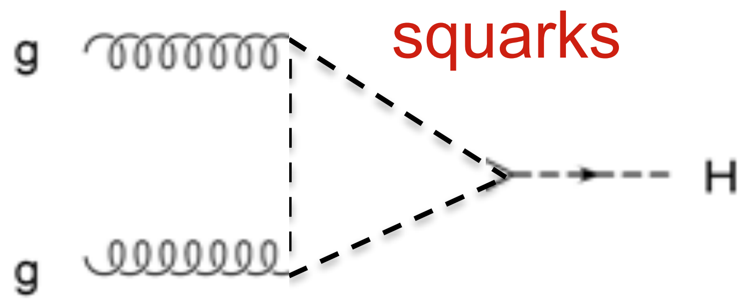
Can we vary the Higgs rate into di-photons independently from the rate into WW/ZZ?

Can we change the ratio of b-pair to tau pair decay rates?

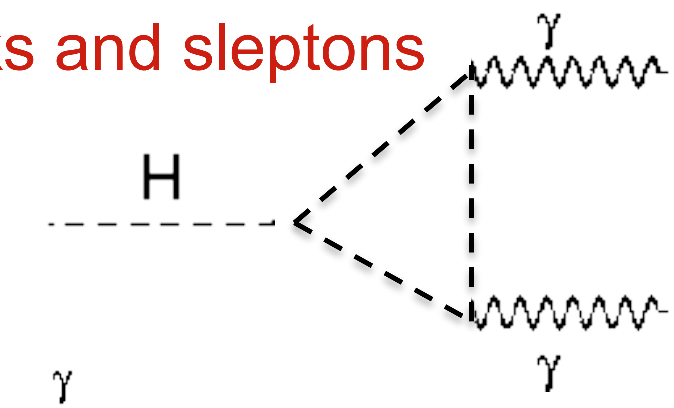
Possible departures in the production and decay rates at the LHC

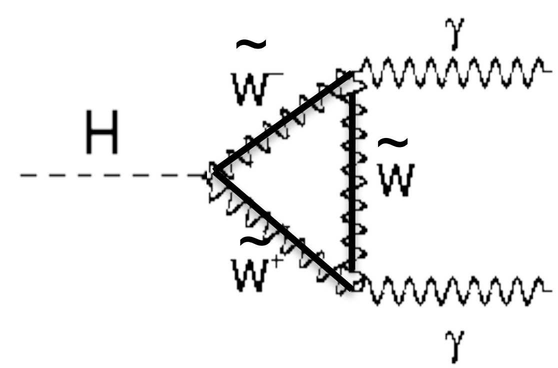
- Through SUSY particle effects in loop induced processes

squarks



squarks and sleptons





charginos

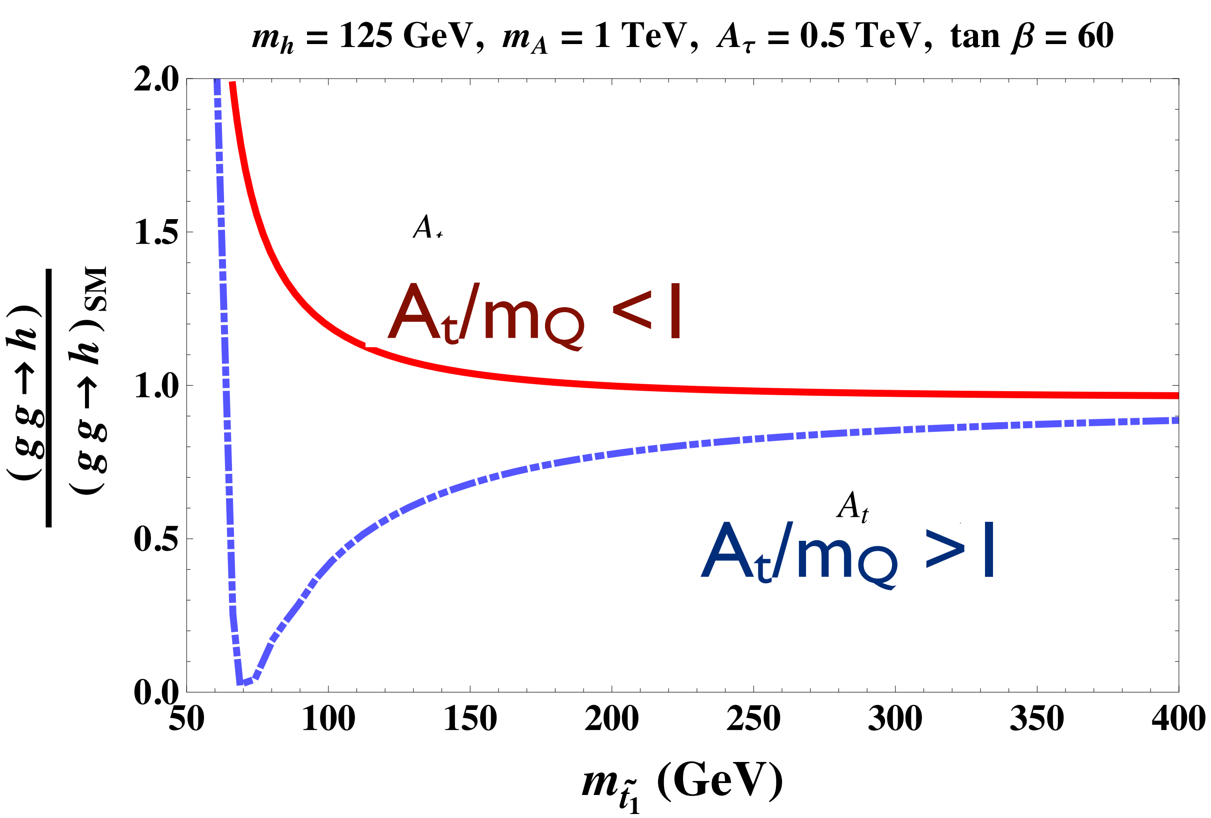
❖ Through enhancement/suppression of the Hbb and Hττ coupling strength via mixing in the scalar boson sector :
This affects in similar manner BR's into all other particles

❖ Through vertex corrections to Yukawa couplings: different for bottoms and taus
This destroys the SM relation $BR(h \rightarrow bb)/BR(h \rightarrow \tau\tau) \sim m_b^2/m_\tau^2$

❖ Through decays to new particles (including invisible decays)
This affects in similar manner BR's to all SM particles

Gluon Fusion in the MSSM

Light stops can increase the gluon fusion rate, but for large stop mixing X_t as required for m_h~125 GeV mostly leads to moderate suppression
[light sbottoms lead to suppression for large tanβ]



M.C.,Gori, Shah, Wagner, Wang
See also Dermisek, Low'07.
Natural SUSY fit: Espinosa, Grojean, Saenz, Trotta '12

$$\delta A^{\tilde{t}}_{\gamma\gamma,gg} \propto \frac{m_t^2}{m^2_{\tilde{t}_1} m^2_{\tilde{t}_2}}\left[m^2_{\tilde{t}_1} + m^2_{\tilde{t}_2} - X_t^2\right]$$

Ellis, Gaillard, Nanopoulos '76
Shifman, Vainshtein, Voloshin, Zakharov'79; MC. Low, Wagner'12

If one stop much heavier: $m_Q >> m_U$ and large tanβ

$$\delta A^{\tilde{t}}_{\gamma\gamma,gg} \propto \frac{m_t^2}{m^2_{\tilde{t}_1}}\left[1 - \frac{A_t^2}{m_Q^2}\right]$$

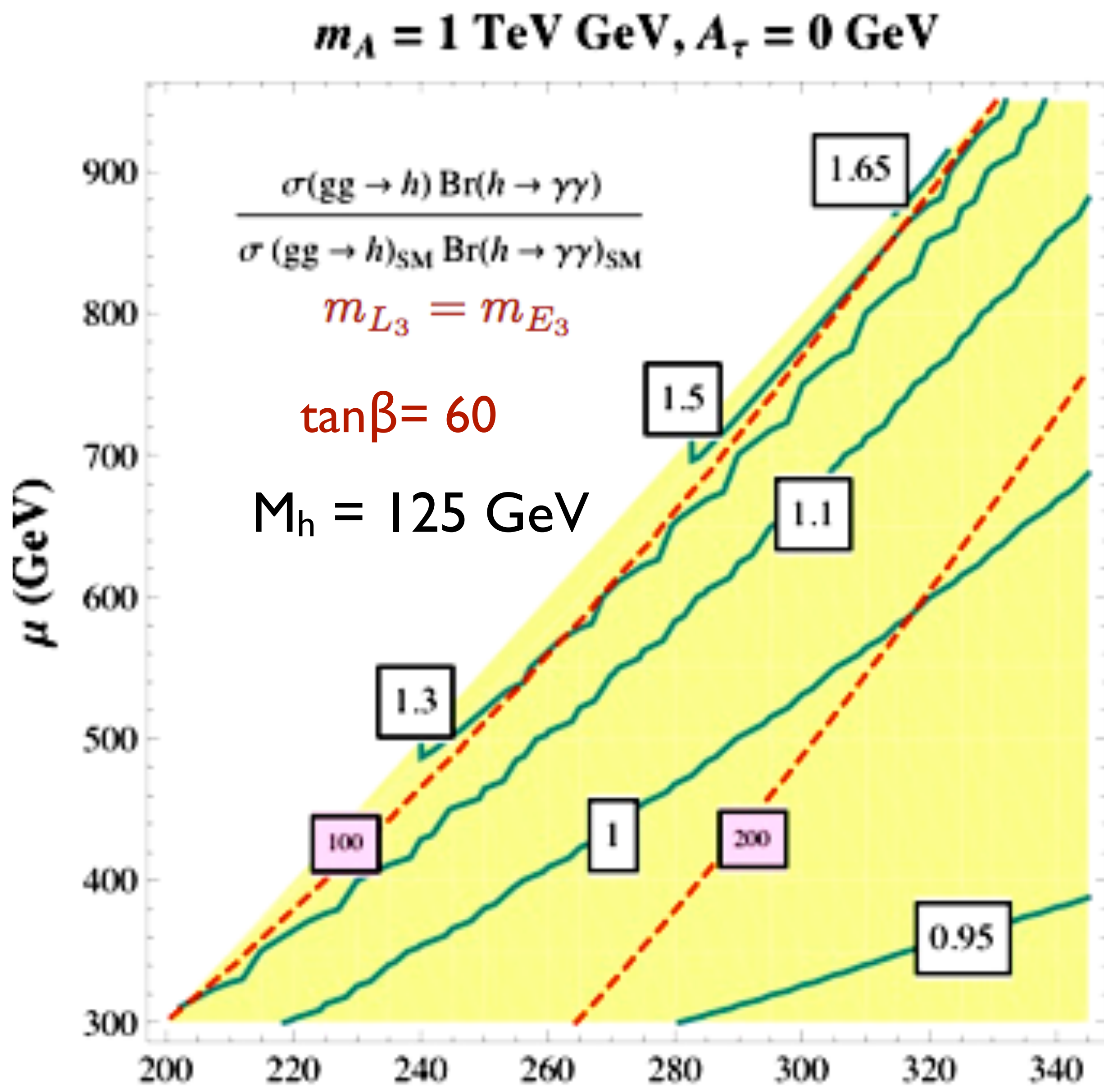
$$\frac{\sigma(gg\to h)BR(h\to\gamma\gamma)}{\sigma(gg\to h)_{SM}BR(h\to\gamma\gamma)_{SM}} < (>) 1$$

Squark effects in gluon fusion overcome opposite effects in di-photon decay rate:

$$\mathrm{If}\ \frac{\sigma(\mathrm{gg}\to\mathrm{h})}{\sigma(\mathrm{gg}\to\mathrm{h})_{\mathrm{SM}}} < (>) 1$$

Higgs Production in the di-photon channel in the MSSM

Charged scalar particles with no color charge can change di-photon rate without modification of the gluon production process



M. C, S. Gori, N. Shah, C. Wagner,'11 +L.T.Wang'12

$$\mathcal{M}^2_{\tilde{\tau}} \simeq \begin{bmatrix} m^2_{L_3} + m^2_\tau + D_L & h_\tau v(A_\tau \cos\beta - \mu \sin\beta) \\ h_\tau v(A_\tau \cos\beta - \mu \sin\beta) & m^2_{E_3} + m^2_\tau + D_R \end{bmatrix}$$

$$\delta A_{h\gamma\gamma} \propto -\frac{m_\tau^2}{m^2_{\tilde{\tau}_1} m^2_{\tilde{\tau}_2}} (m^2_{\tilde{\tau}_1} + m^2_{\tilde{\tau}_2} - \chi^2_\tau)$$

Light staus with large mixing

[sizeable μ and tan beta]:

➔ **enhancement of the Higgs to di-photon decay rate**

- up to 50 % with SM-like ZZ/WW -

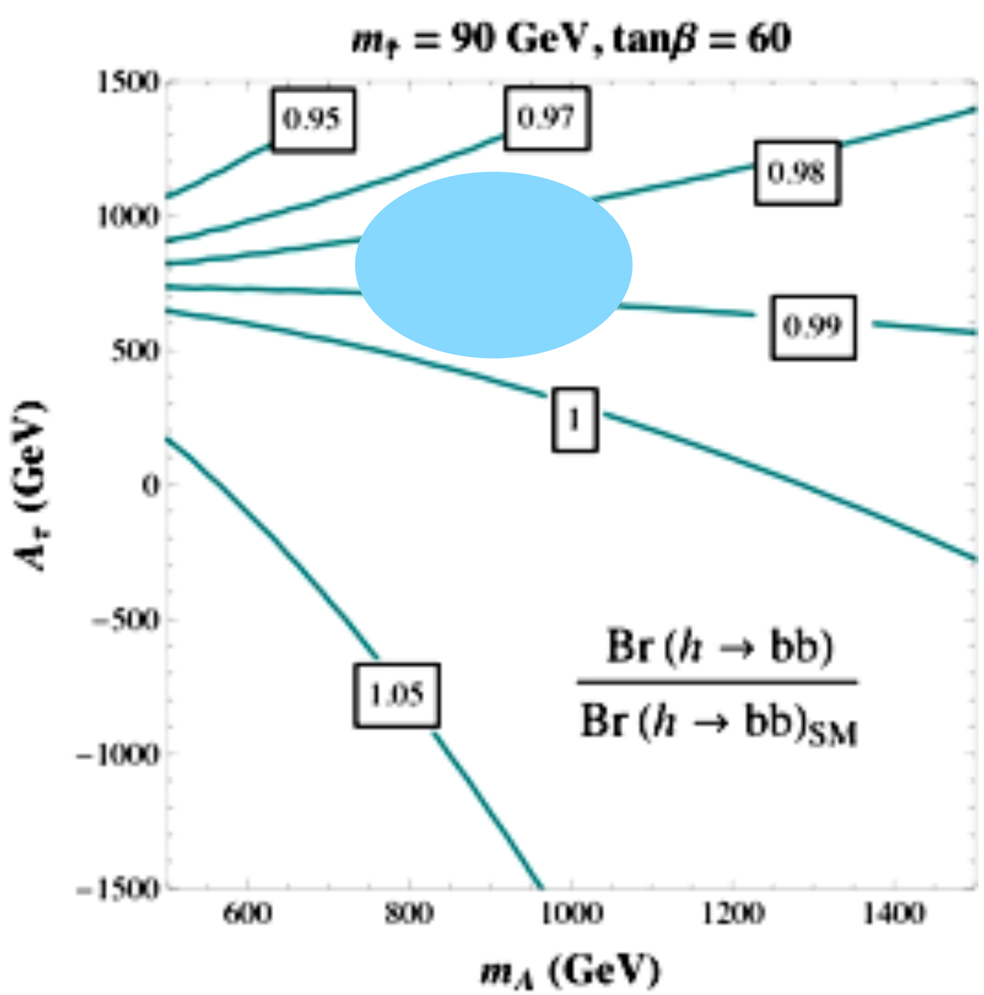
For a generic discussion of modified γγ and Zγ widths by new charged particles, see M. C. ,Low and C. Wagner'12; for specific connection with light staus: Giudice, Paradisi,Strumia'12

MSSM scan: Benbrik, Gomez Bock, Heinemeyer, Stal, Weigein, Zeune'12

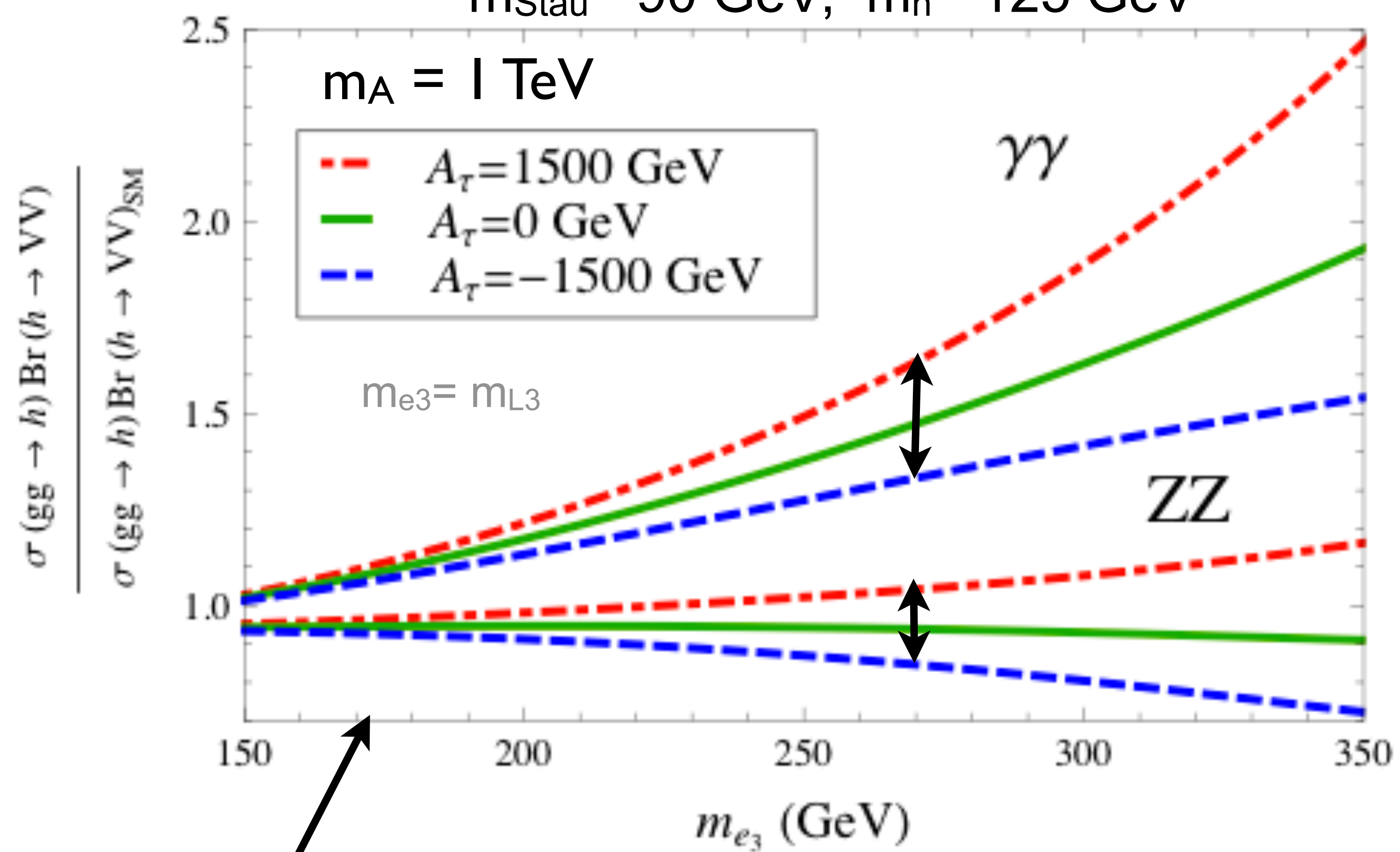
Additional modifications of the Higgs rates into gauge bosons via stau induced mixing effects in the Higgs sector

Important A_τ induced radiative corrections to the mixing angle α

$$g_{h\bar{b}b,h\tau^+\tau^-} \propto -\sin\alpha/\cos\beta$$



mStau~ 90 GeV; mh~ 125 GeV



Values of the soft parameters larger than ~ 250 GeV tend to lead to vacuum stability problems

M. C. Gori, Shah, Wagner,'11 + Wang'12

Small variations in BR [H to bb] induce significant variations in the other Higgs BR's

Similar results for example within pMSSM/MSSM fits: Arbey, Battaglia, Djouadi, Mahmoudi '12
Benbrik, Gomez Bock, Heinemeyer, Stal, Weiglein, Zeune'12

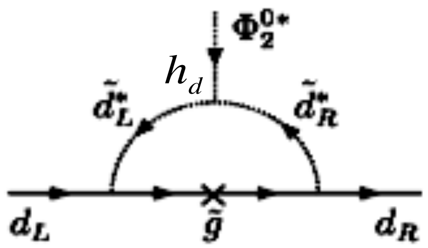
Suppression of the h to taus to h to b's ratio

due to different radiative SUSY corrections to higgs-fermion couplings

$$m_{b,\tau} \simeq \frac{h_{b,\tau} v}{\sqrt{2}} \cos\beta \left(1 + \frac{\Delta h_{b,\tau}}{h_{b,\tau}} \tan\beta\right)$$

$\Delta_{b,\tau}$

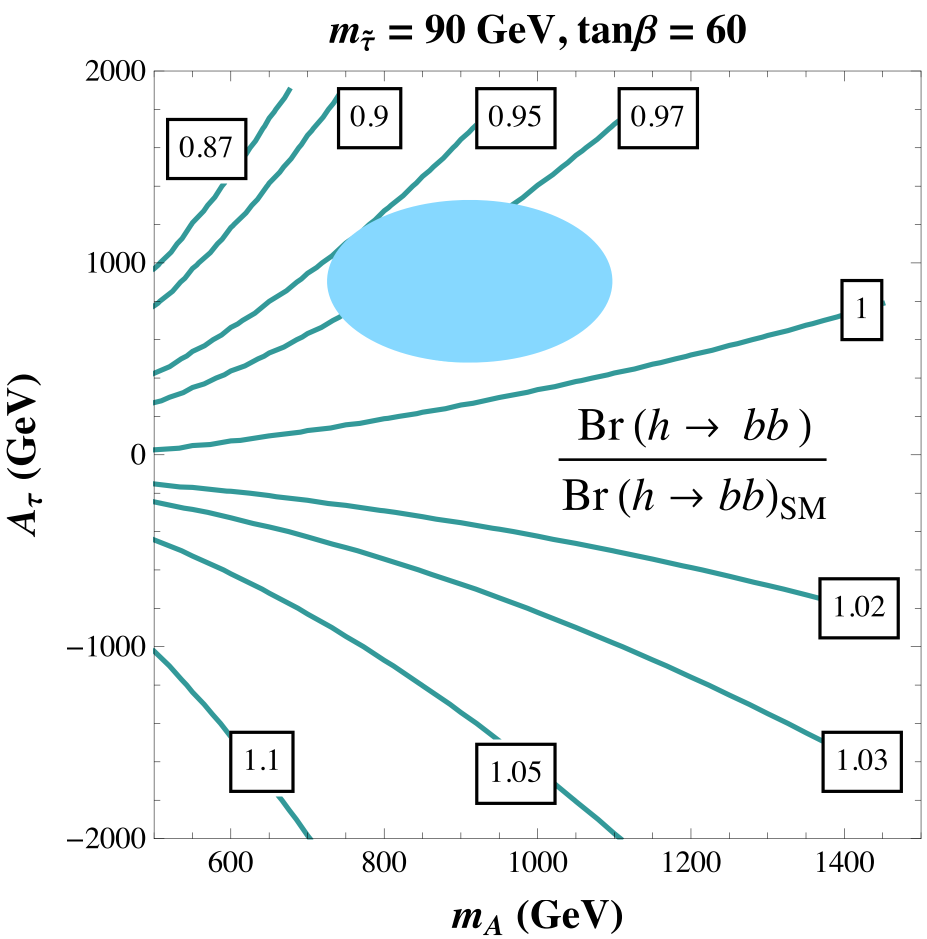
$$g_{hbb,h\tau\tau} = -\frac{m_{b,\tau} \sin\alpha}{v\cos\beta(1+\Delta_{b,\tau})}\left[1 - \frac{\Delta_{b,\tau}}{\tan\beta\tan\alpha}\right]$$

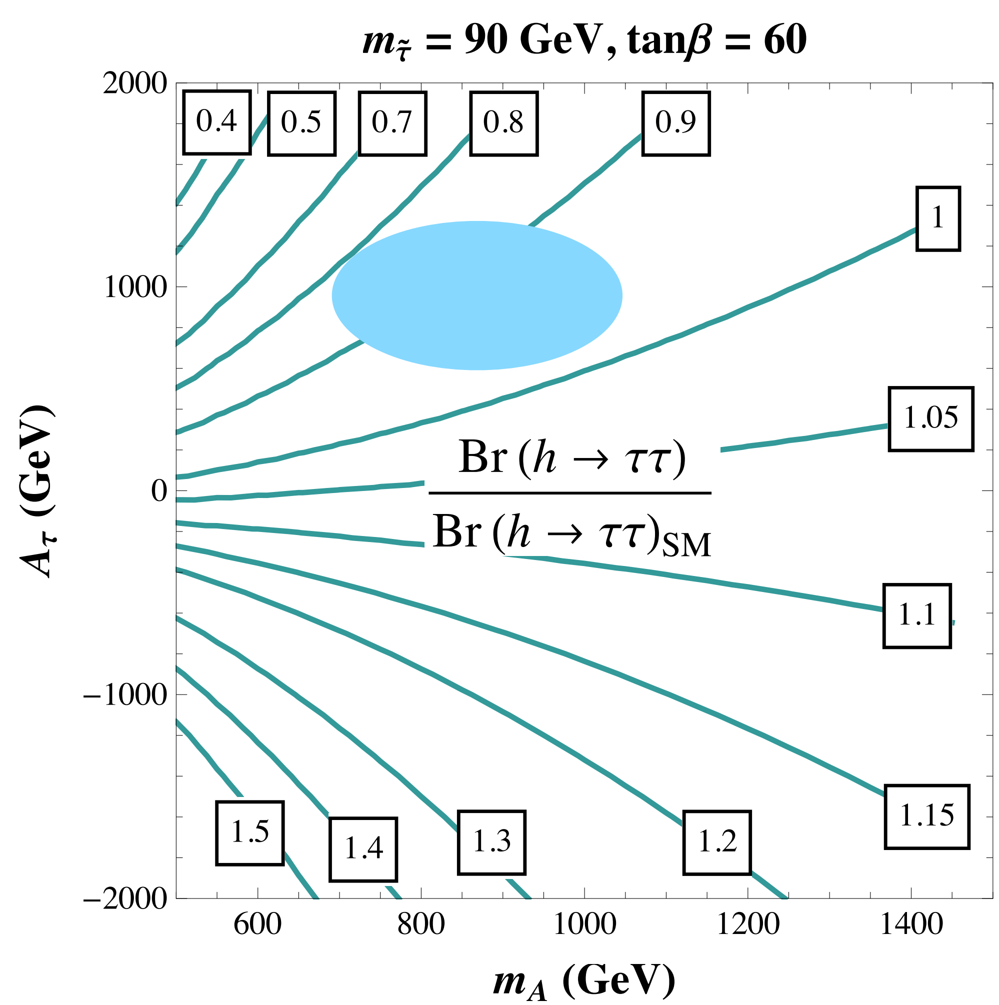


destroy basic relation

$g_{h,H,Abb}/g_{h,H,A\,\tau\tau} \propto m_b/m_\tau$

M.C. Mrenna, Wagner '98
Haber,Herrero, Logan, Penaranda, Rigolin, Temes '00





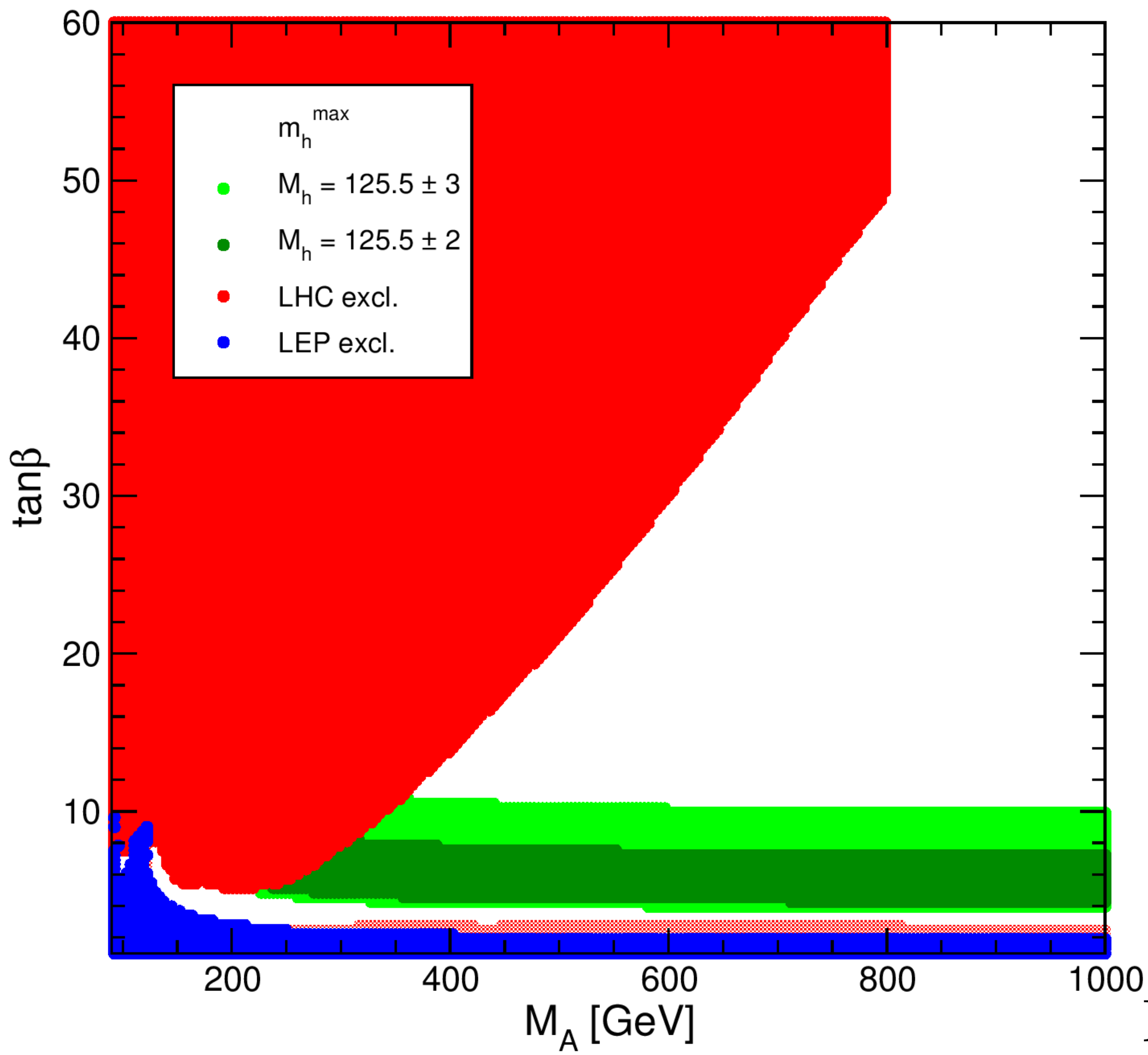
Suppression of di-tau rate not larger than 10% due to metastability constraints

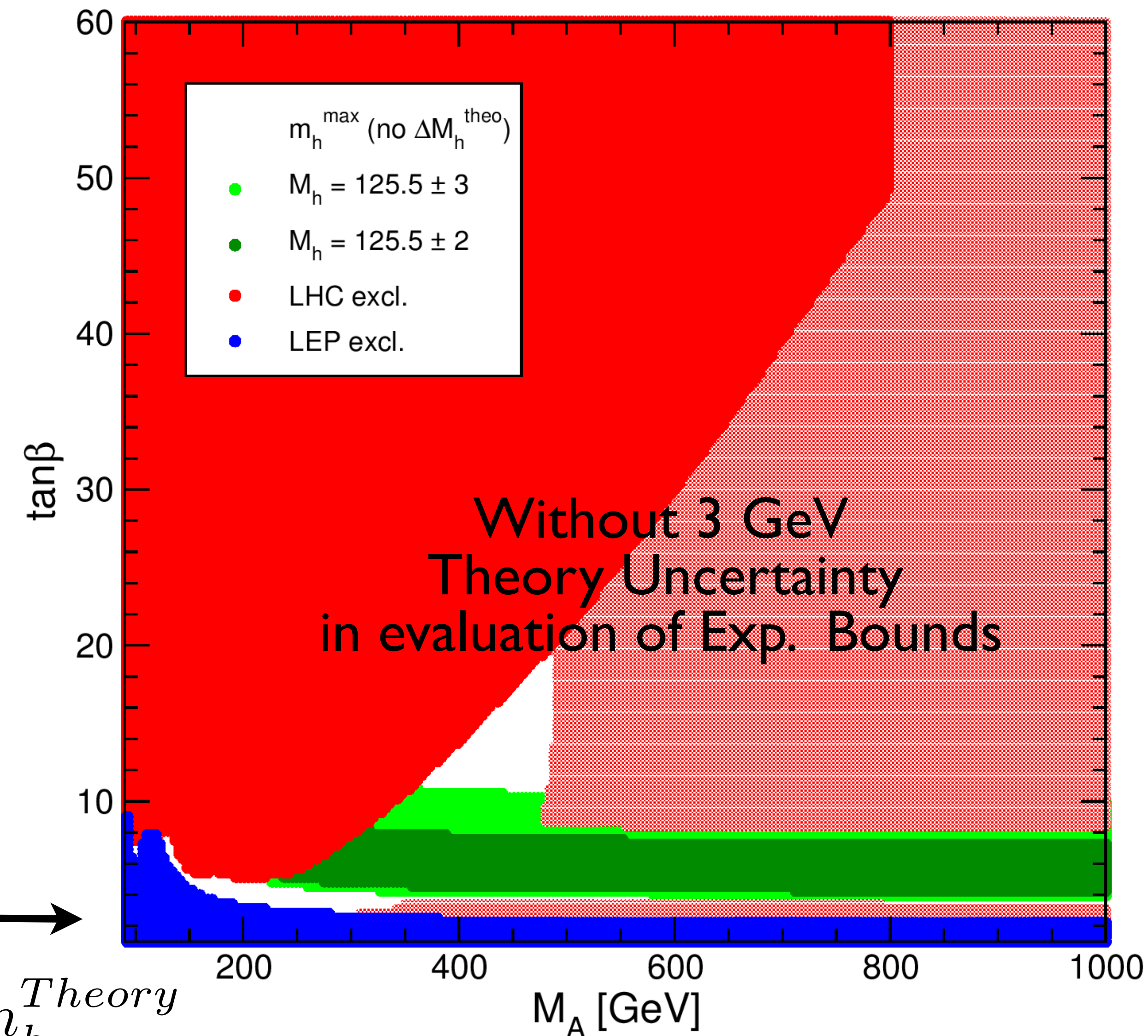
M. C., Gori, Shah, Wagner, Wang'12

Benchmark Scenarios for the Search of MSSM Scalar Bosons

with 125.5 GeV signal interpreted as h (or H)

m_h^{max} scenario (updated with M_{gluino} = 1.5 TeV, m_t = 173.2 GeV)





No Δm_h^{Theory}

Green region favored by LHC observation

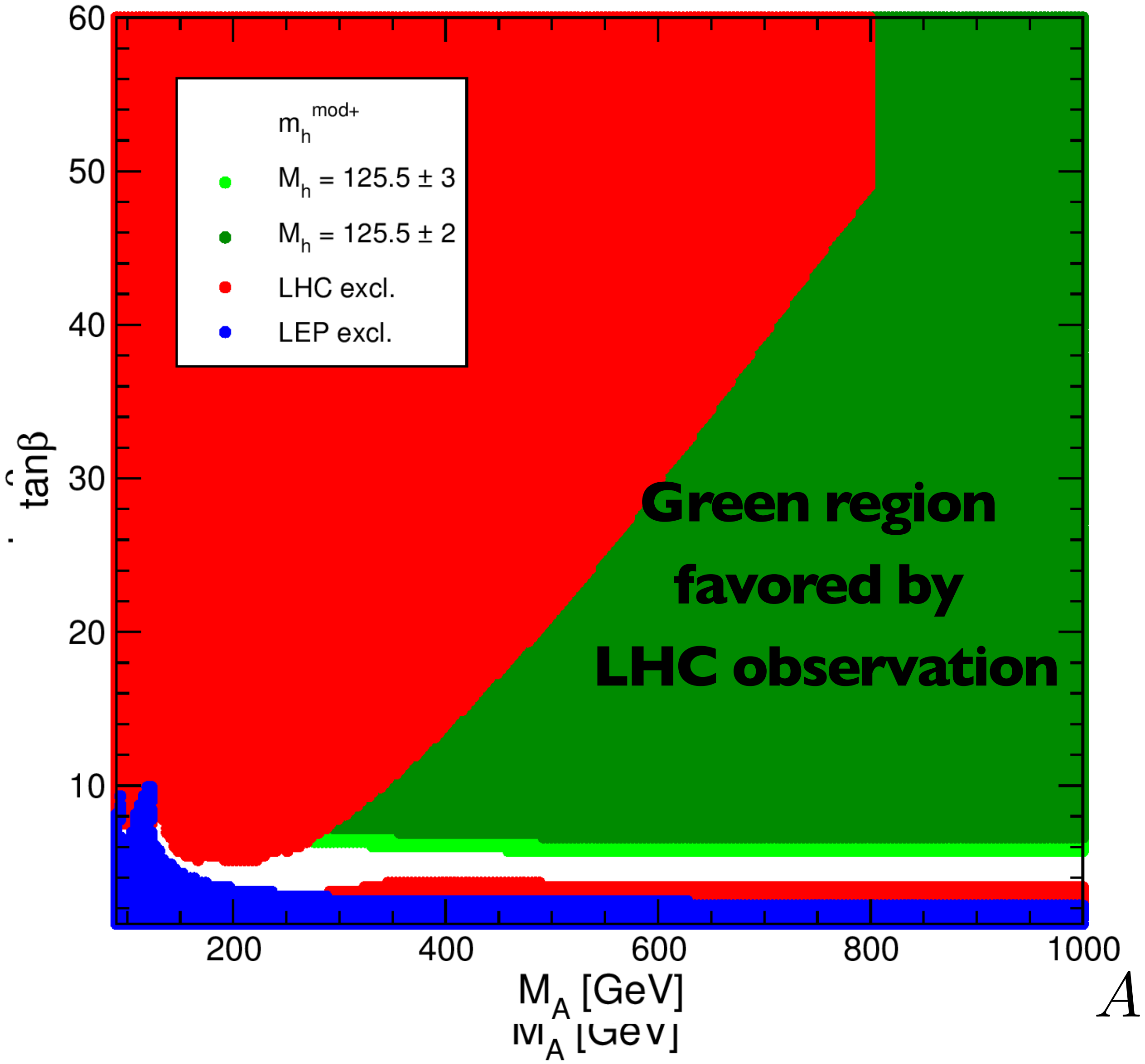
Lower bound on tanβ, M_A and M_{H+}
(slightly relaxed if M_{SUSY} ~ 2TeV)

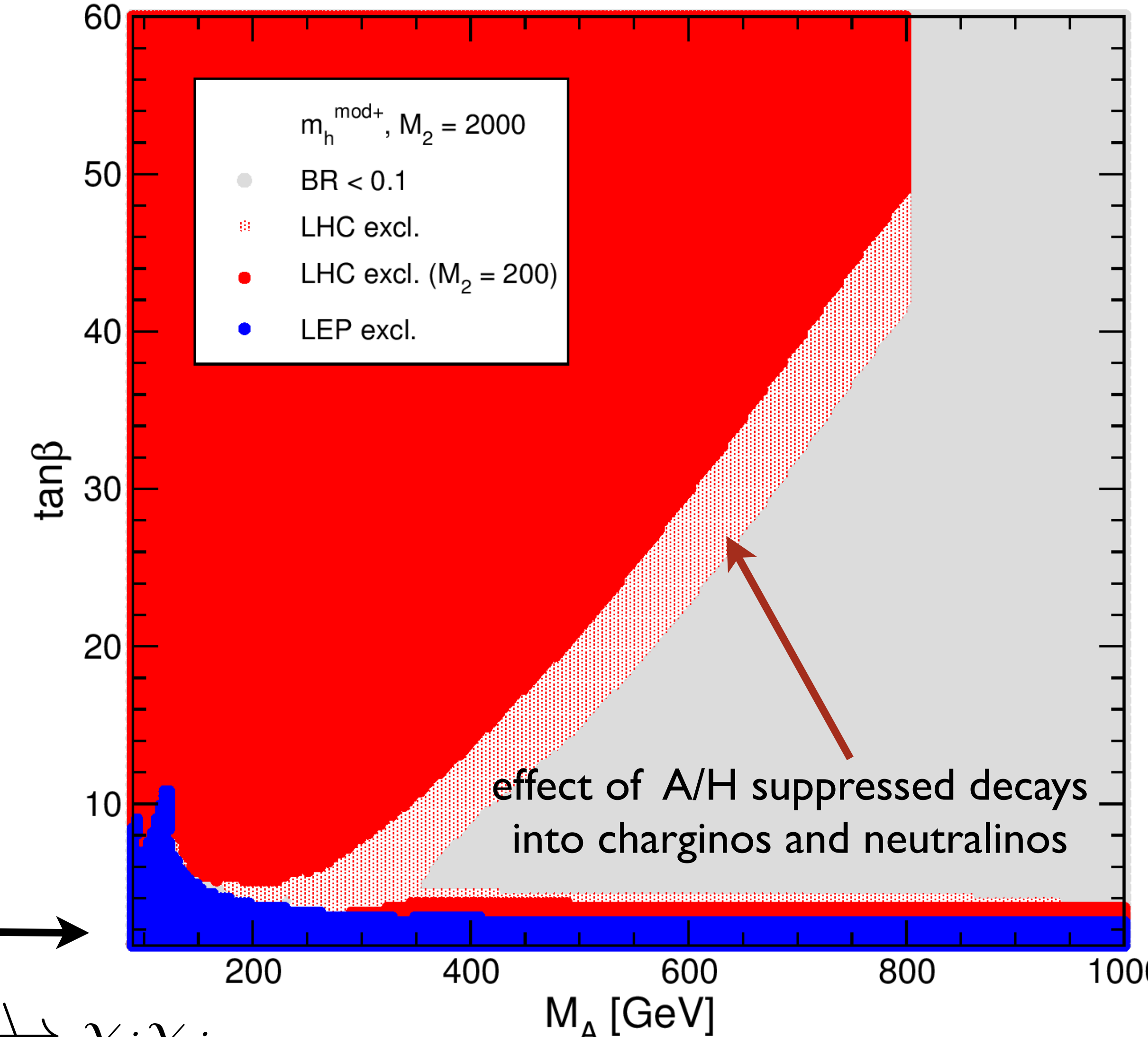
M.C., Heinemeyer, Stal, Wagner, Weiglein '13

Benchmark Scenarios for the Search of MSSM Scalar Bosons

with 125.5 GeV signal interpreted as h (or H)

m_h^{mod} scenario (moderate stop mixing scenario)





$A/H \not\to \chi_i \chi_j$

M.C., Heinemeyer, Stal, Wagner, Weiglein '13

Additional Benchmark Scenarios:

Light stops, Light staus, τ-phobic and SM-like H with m_H ~125 GeV with interesting phenomenology for the MSSM scalar boson sector

Many Minimal SUSY models can produce m_h=125 GEV

see Ellwanger's talk

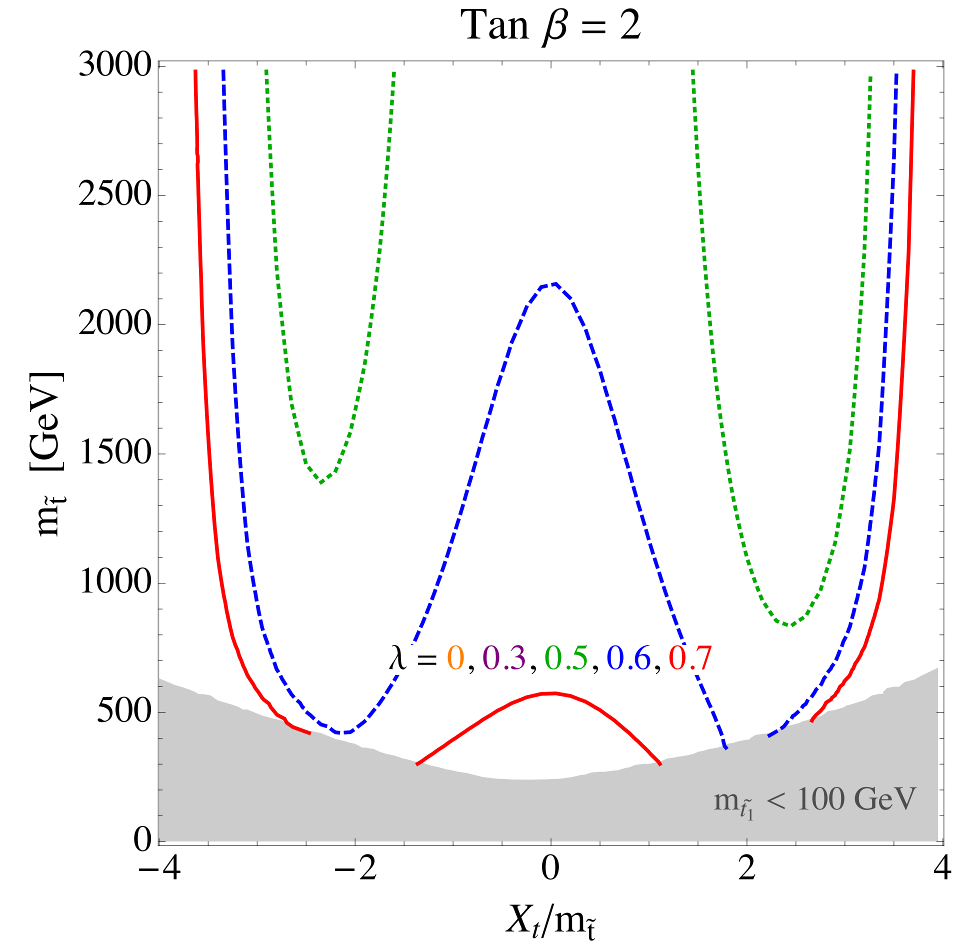
Extra singlet S with extra parameter λ

$$W \supset \lambda S H_u H_d + \hat{\mu} H_u H_d + \frac{M}{2} S^2 + \frac{\kappa}{3} \hat{S}^3 + \ldots$$

$$m_h^2 = M_Z^2 \cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta + \text{rad. corrections}$$

SM + singlet limit

$$\mathcal{M}^2 = \begin{pmatrix} \lambda^2 v^2 \sin^2 2\beta + M_Z^2 \cos^2 2\beta & \lambda v(\mu, M_S, A_\lambda) \\ \lambda v(\mu, M_S, A_\lambda) & m_S^2 \end{pmatrix}$$



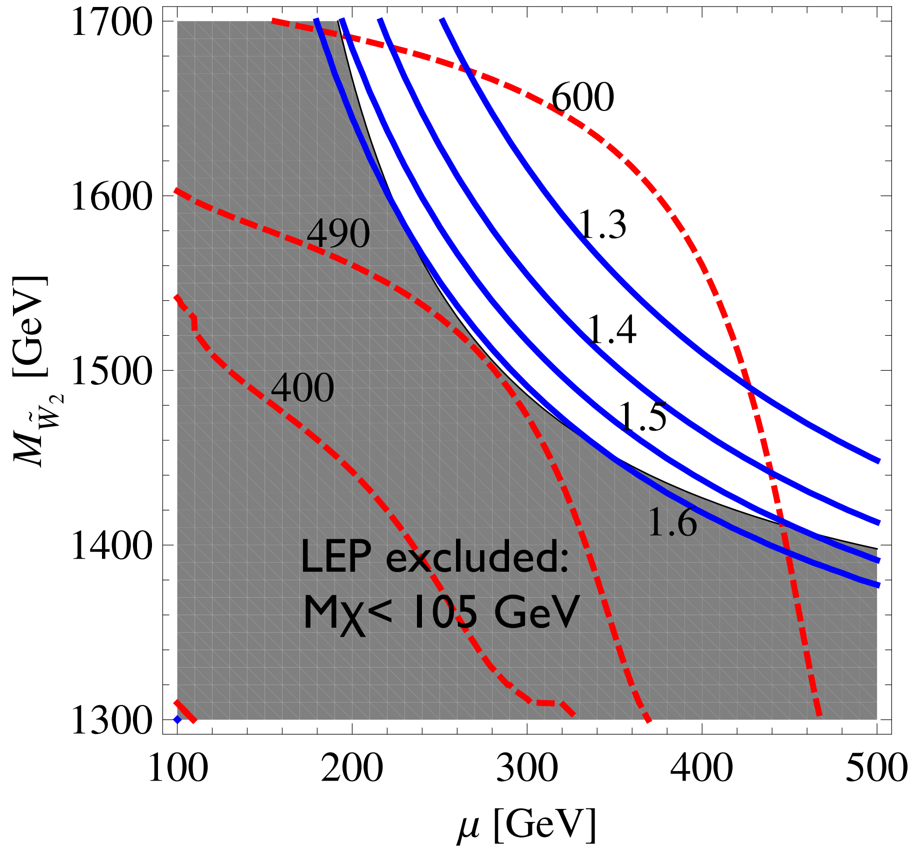
Hall, Pinner, Ruderman'11

NMSSM : At low tan beta, trade requirement on large stop mixing by sizeable trilinear Higgs-Higgs singlet coupling λ ⟶ more freedom on gluon fusion production

- **Higgs mixing effects can be also triggered by extra new parameter λ**
- Higgs-Singlet mixing ==> wide range of ZZ/WW and Diphoton rates
- Light staus cannot enhance the di-photon rate (at low tanβ stau mixing is negligible)
- Light chargino at low tanβ can contribute to enhance the di-photon rate

Ellwanger' 12; Benbrik, Bock, Heinemeyer, Stal, Weiglein,Zeune'12; Gunion, Jiang, Kraml '12

Extensions with extra gauge groups: 125 GeV Higgs mass from D terms plus chargino contribution to the quartic (plus usual top-stop)



SU(2) x SU(2) Extension of the weak interactions

Third generation and Higgs charged under strongly coupled SU(2)

Enhancement of γγ rate from new (strong) charginos (~60% max. to avoid too large Higgs mass)

Huo, Lee, Thalapillil, Wagner'12

Models with mixtures of singlets, W' Z', triplets:

look at specific models

or consider an EFT approach if new physics beyond direct reach

Dine, Seiberg, Thomas; Antoniadis, Dudas, Ghilencea, Tziveloglou
M.C, Kong, Ponton, Zurita

Split SUSY: (no extra light scalars below 100-1000 TeV)

→ diphoton rate constrained to be about the SM value

Arkani Hamed et al. '12

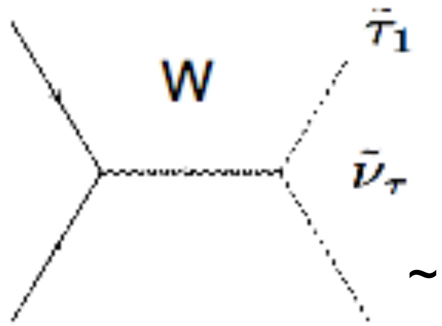
How are m_h~125 GeV SUSY scenarios constrained by data?

--- Third generation direct particle searches (**stau, stops**, sbottoms, charginos)

more experimental efforts needed in these direction

- LHC looks for staus produced through SUSY cascade decays
- LHC looks at long-lived staus
- Interesting channel to look for:

M. C., Gori, Shah, Wagner, Wang



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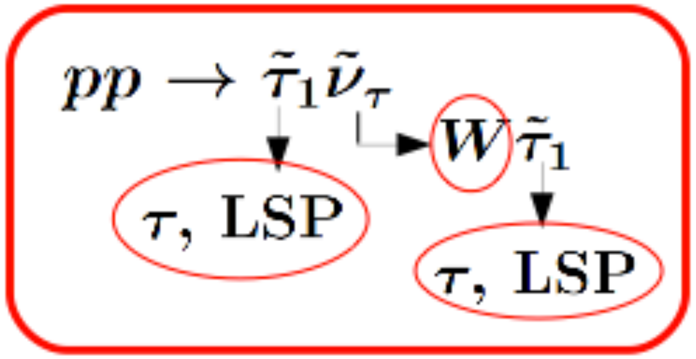


signature:
Lepton, 2 taus, missing energy

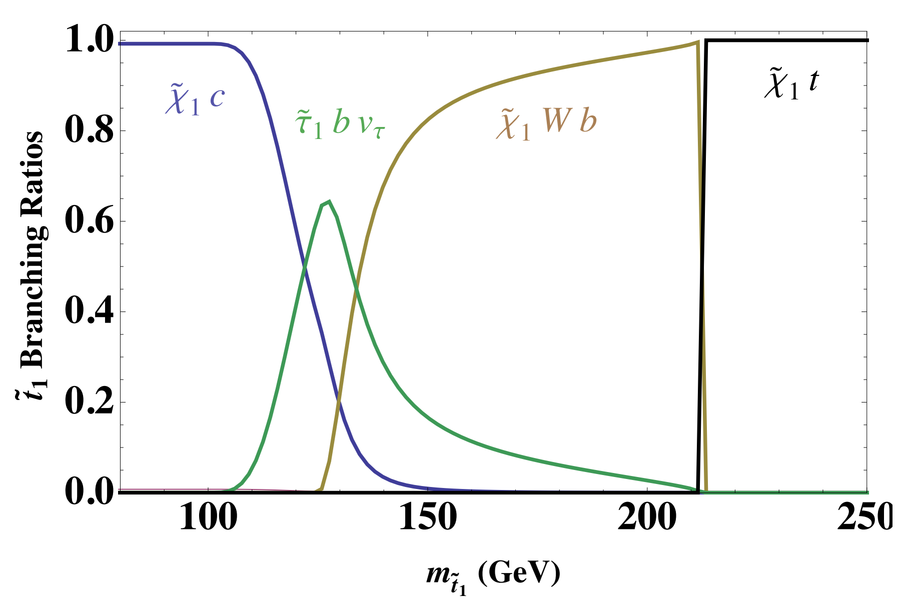
Physical background: Wγ*, WZ*Final
Fake background: W+jets

Estimation at the parton level shows promising results at 8 TeV LHC

- In principle also $pp \to \tilde{\tau}_1 \tilde{\tau}_1 \to (\tau\, \mathrm{LSP})(\tau\, \mathrm{LSP})$ can be interesting, but more challenging

- Another interesting possibility: Staus in "light" Stop decays

$$\tilde{t}_1 \to b\tilde{\chi}^+ \to b\tilde{\tau}\nu$$



How are m_h~125 GeV SUSY scenarios constrained by data?

--- Direct searches of other SUSY Higgs particles

more comprehensive searches/decay modes need to be considered

Example:

-- Strong constraints in MSSM on m_A-tan beta from A/H to $\tau\tau$, however, change of analysis/results if other channels open up; A/H to charginos/staus/...

-- NMSSM; many possible Higgs decay chains H_i to A A (Ellwanger's talk)

-- other extensions with different relations among Higgs masses
The channels A/H to hh and H+ to hW+ replaced by h/H to AA and H+ to AW+ in BMSSM

-- spectra with quasi degenerate Higgs bosons?

- How to disentangle between SUSY Higgs vs 2HDM's in the absence of obvious SUSY partner effects?

CP-violation in the Higgs sector:

MSSM: Upper bound on Higgs mass same as in the CP conserving case
Similar requirement on the SUSY parameters
harder to achieve enhanced di-photon rate (?)

Other extensions: CP violation at tree level

Strong bounds on CP phases from EDM's

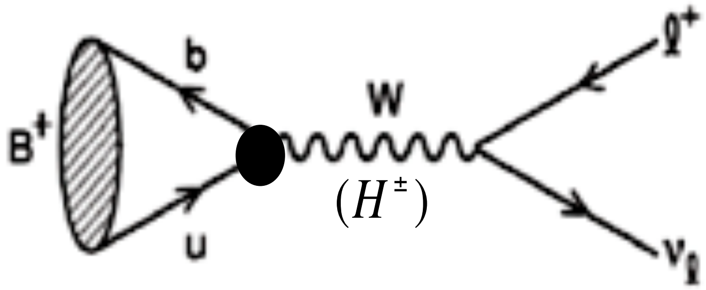
Interplay between collider and EDM's/MDM's data
(only in model dependent scenarios) ?

The Higgs discovery and

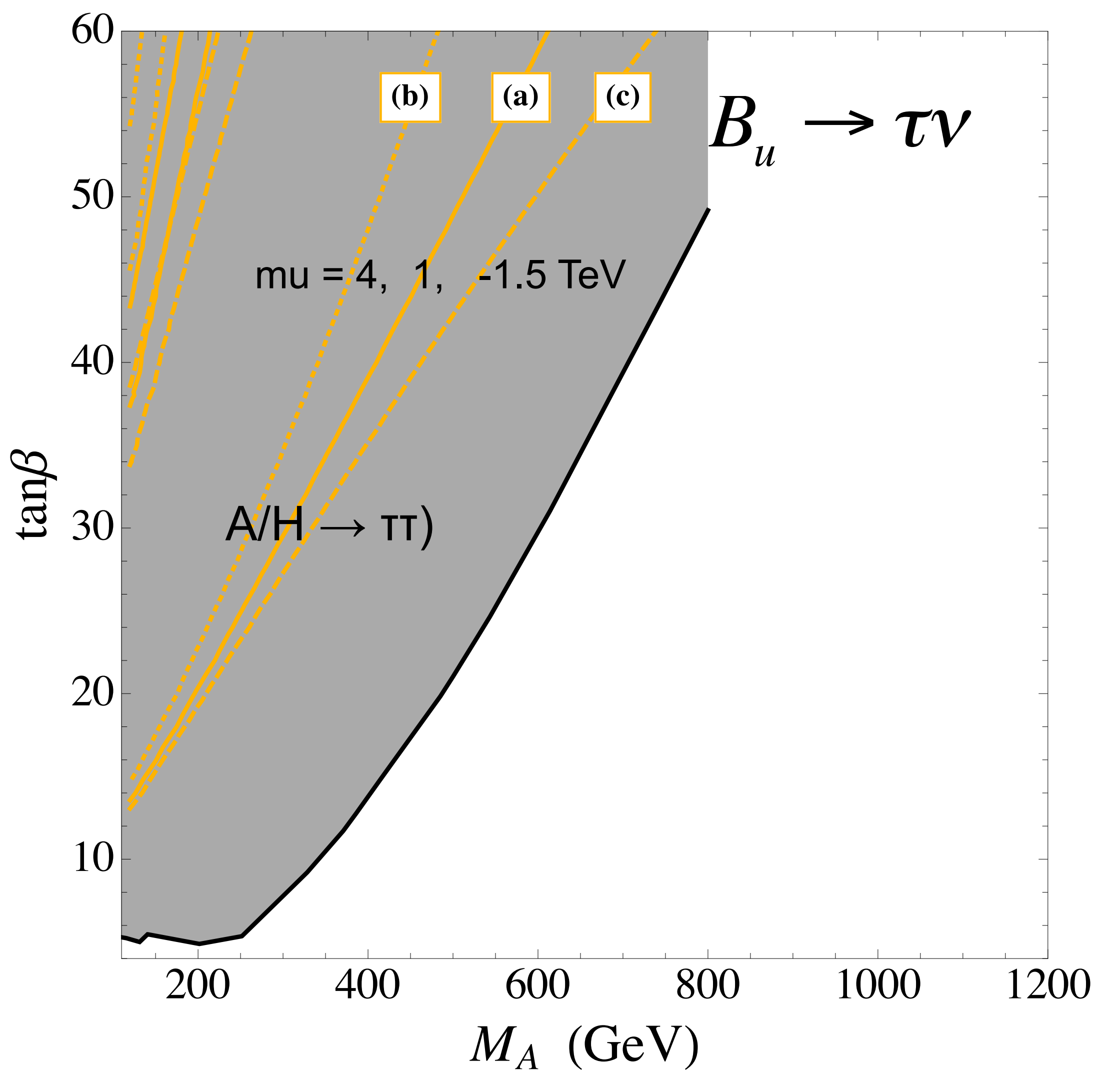
the Higgs-flavor connection in the MFV MSSM

M_h ~ 125 GeV and flavor in the MSSM

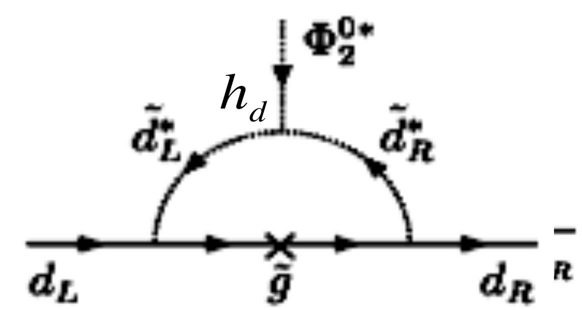
- $B_u \to \tau\nu$ **transition** MSSM charged Higgs & SM contributions interfere destructively



$$R_{B_u \to \tau\nu} = \frac{\mathrm{BR}(B_u \to \tau\nu)^{MSSM}}{\mathrm{BR}(B_u \to \tau\nu)^{SM}} = \left[1 - \left(\frac{m_B^2}{m_{H^\pm}^2}\right)\frac{\tan\beta^2}{(1+\varepsilon_0^3\tan\beta)}\right]^2$$



$$\varepsilon_0^i \approx \frac{2\alpha_s}{3\pi}\frac{\mu^* M_{\tilde{g}}^*}{\max\left[m_{\tilde{d}_1^i}^2, m_{\tilde{d}_2^i}^2, M_{\tilde{g}}^2\right]}$$



Independent on stop mixing
Almost independent of
SUSY breaking scale

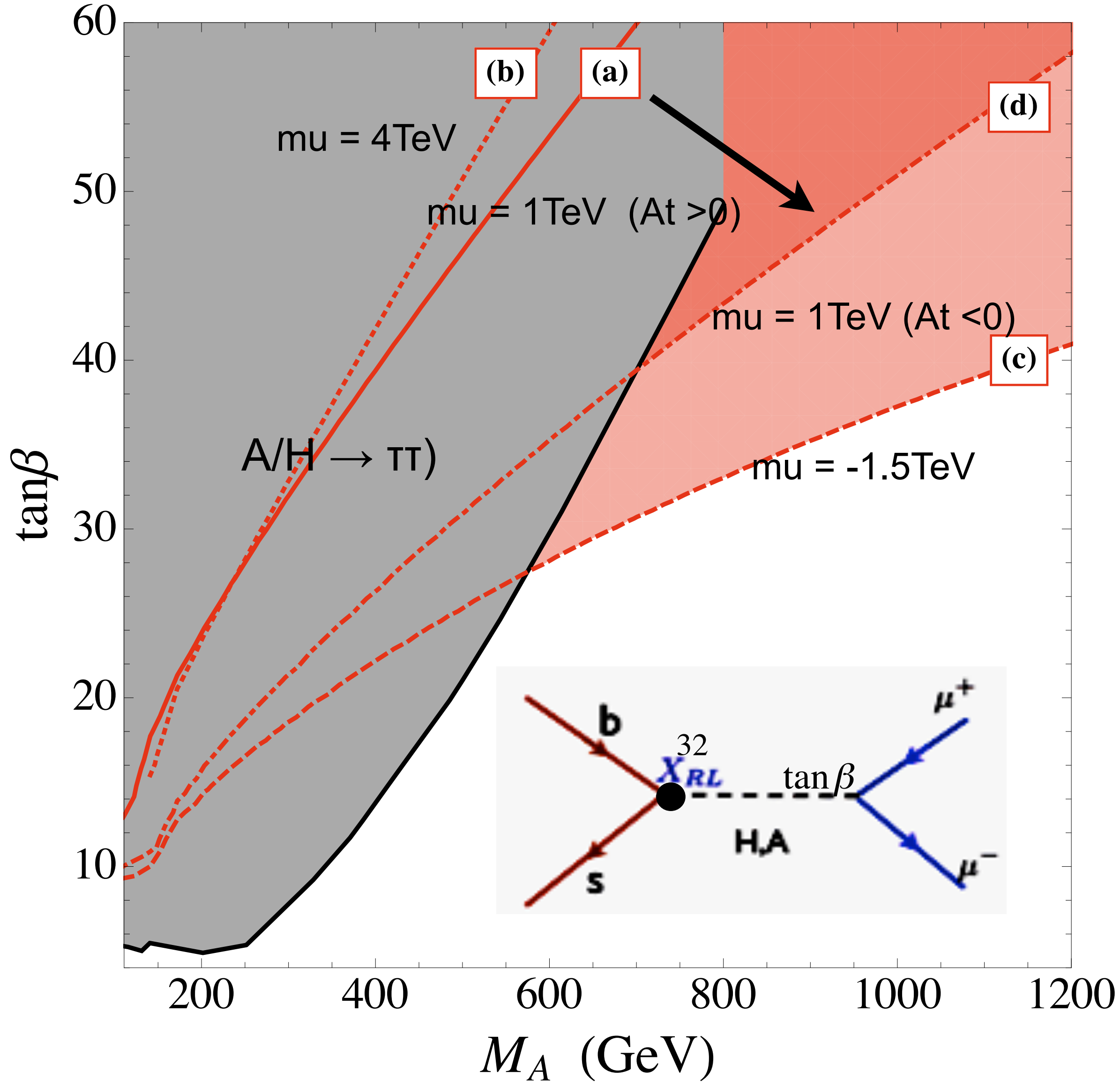
it became less powerful than direct
Heavy Higgs searches for large tanβ

Altmannshofer, MC, Shah,Yu ’12.

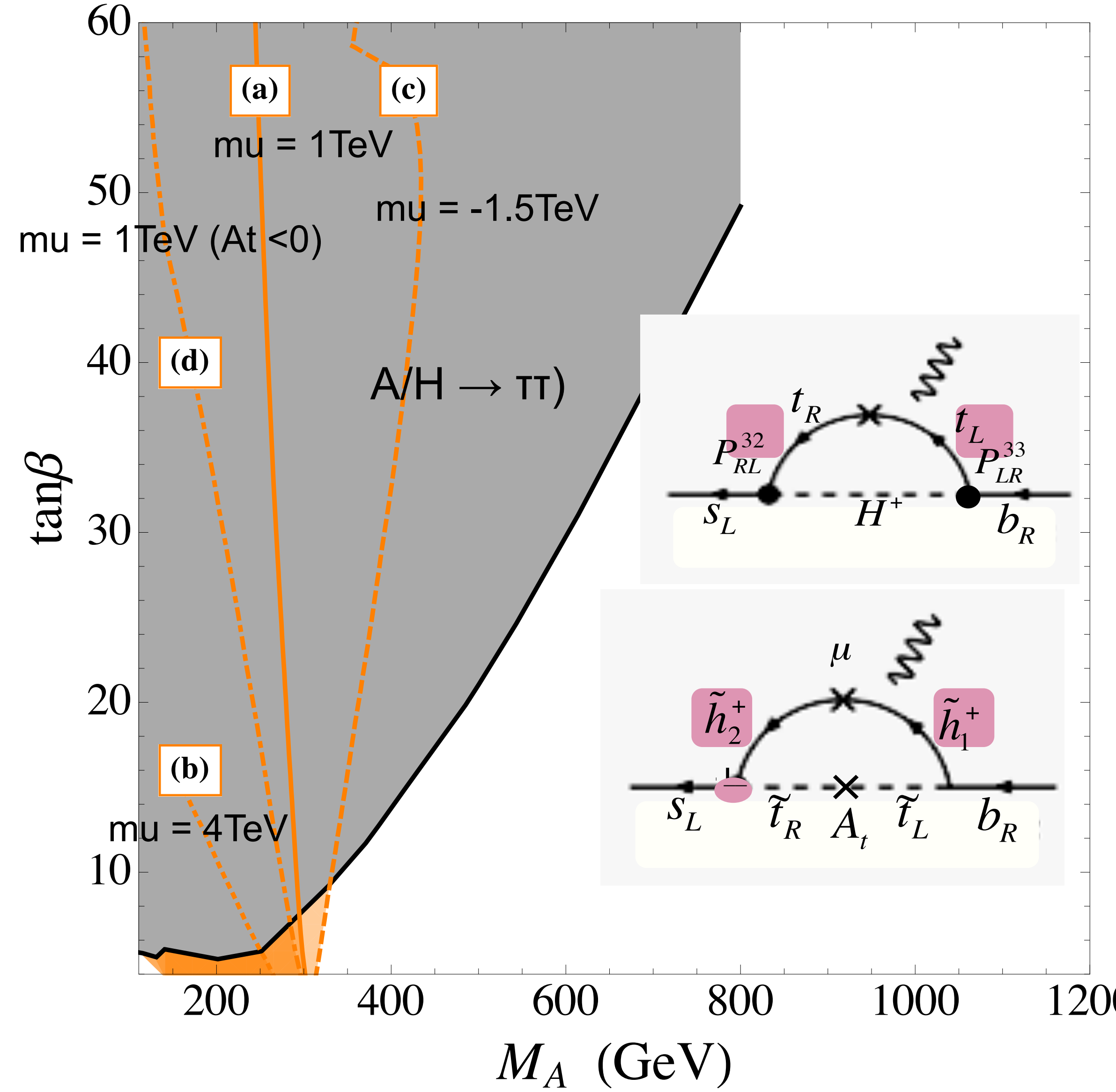
M_h ~125 GeV and Higgs-flavor connection in the MFV MSSM

Altmannshofer, MC, Shah,Yu '12

Bounds from $B_s \to \mu^+\mu^-$



Bounds from $B_s \to X_s\, \gamma$



SUSY effects intimately connected to the structure of the squark mass matrices

Positive values of A_t less constraining for sizeable m_A and large tan beta

Conclusions:

The Higgs discovery is of paramount importance

but

We need more precise measurements of Higgs properties

and/or

direct observation of new physics

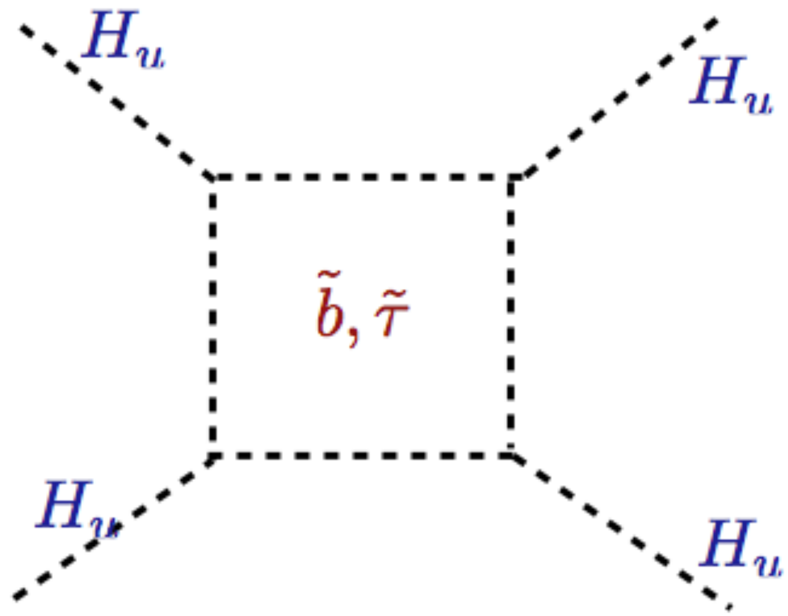
to further advance in our understanding of EWSB

Extras

Additional effects at large tan beta from sbottoms:

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

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



receiving one loop corrections that depend on the sign of $\mu M_{\tilde{g}}$

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

with $h_\tau \simeq \dfrac{m_\tau}{v\cos\beta(1+\tan\beta\Delta h_\tau)}$ Dep. on the sign of μM_2

Both corrections give negative contributions to the Higgs mass
hence smaller values of μ and positive values of μM_2 and $\mu M_{\tilde{g}}$ enhance the value of the Higgs mass

Maximal effect: lower m_h by several GeV

Mixing Effects in the CP- even Higgs Sector

can have relevant effects in the production and decay rates

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

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

Radiative corrections to the CP-even mass matrix
affect the mixing angle alpha
that governs couplings of Higgs to fermions

$$\sin\alpha\cos\alpha = M_{12}^2 / \sqrt{\left(\mathrm{Tr}\, M^2\right)^2 - 4 \det M^2}$$

Normalized to SM ones

$$g_{hu\bar{u},Hu\bar{u},Au\bar{u}} \to \cos\alpha/\sin\beta, \quad \sin\alpha/\sin\beta, \quad 1/\tan\beta$$

$$g_{hb\bar{b},Hb\bar{b},Ab\bar{b}} \to -\sin\alpha/\cos\beta, \quad \cos\alpha/\cos\beta, \quad \tan\beta$$ (same for leptons)

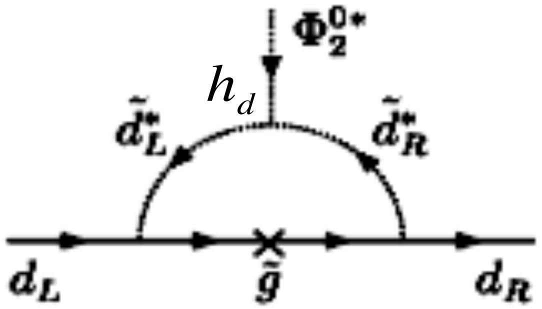
If off diagonal elements **suppressed/enhanced**: same occurs for sinα or cosα

==> **suppression/enhancement** of SM-like Higgs coupling to bb and ττ

leads to enhancement/suppression of BR(h/H to WW/ZZ/γγ) for $m_{h/H}$ < 135 GeV

After SUSY breaking all fermions couple to both Higgs Doublets

$$g_{hbb,h\tau\tau} = -h_{b,\tau}\sin\alpha + \Delta h_{b,\tau}\cos\alpha$$



can change the relative strength of Higgs decays to b and tau pairs

Modification of the tree level relation between $h_{b,\tau}$ and $m_{b,\tau}$

$$m_{b,\tau} \simeq \frac{h_{b,\tau} v}{\sqrt{2}} \cos\beta \left(1 + \frac{\Delta_{h_{b,\tau}}}{h_{b,\tau}} \tan\beta\right)$$

$\Delta_{b,\tau}$

$$g_{hbb,h\tau\tau} = -\frac{m_{b,\tau}\sin\alpha}{v\cos\beta(1+\Delta_{b,\tau})}\left[1 - \frac{\Delta_{b,\tau}}{\tan\beta\tan\alpha}\right]$$

destroy basic relation

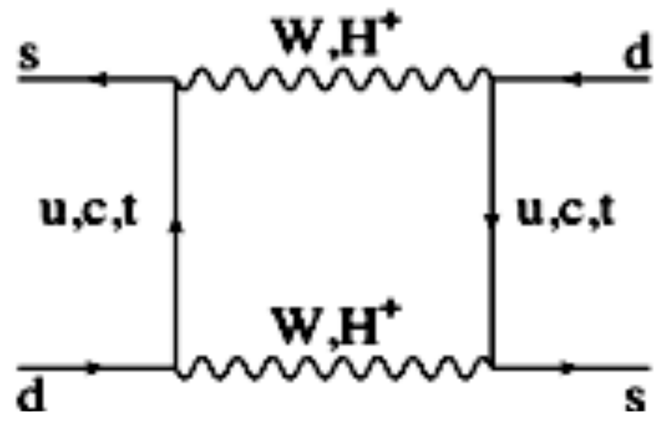
$g_{h,H,Abb}/g_{h,H,A\,\tau\tau} \propto m_b/m_\tau$

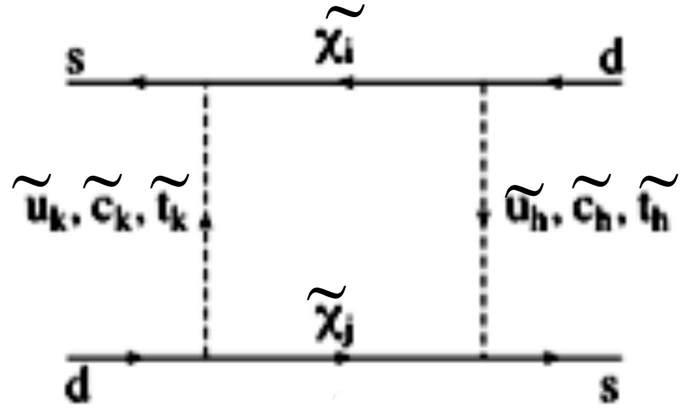
M.C. Mrenna, Wagner '98
Haber,Herrero, Logan, Penaranda, Rigolin, Temes '00

Radiative corrections ==> main decay modes of the SM-like MSSM Higgs into b- and tau-pairs can be drastically changed

Minimal Flavor Violation

- At tree level: the quarks and squarks diagonalized by the same matrices $\tilde{D}_{L,R} = D_{L,R};\quad \tilde{U}_{L,R} = U_{L,R}$

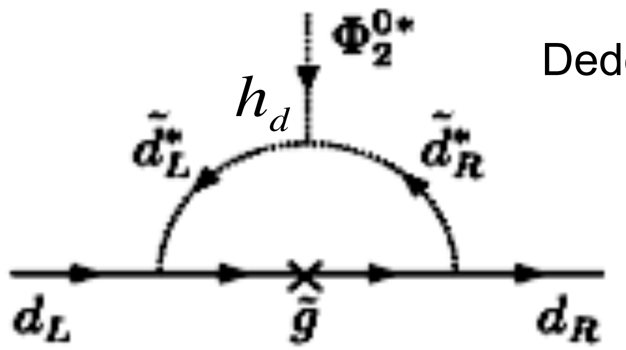




Hence, in the quark mass eigenbasis the only FC effects arise from charged currents via V_{CKM} as in SM.

Isidori, Retico: Buras et al.

- At loop level: FCNC generated by two main effects:



Dedes, Pilaftsis

1) Both Higgs doublets couple to up and down sectors

==> important effects in the B system at large tan beta

2) Soft ~~SUSY~~ parameters obey RG equations:

given their values at the ~~SUSY~~ scale, they change significantly at low energies

==> RG evolution adds terms prop. to $h_d h_d^+$ and $h_u h_u^+$, and h.c.

In both cases the effective coupling governing FCNC processes

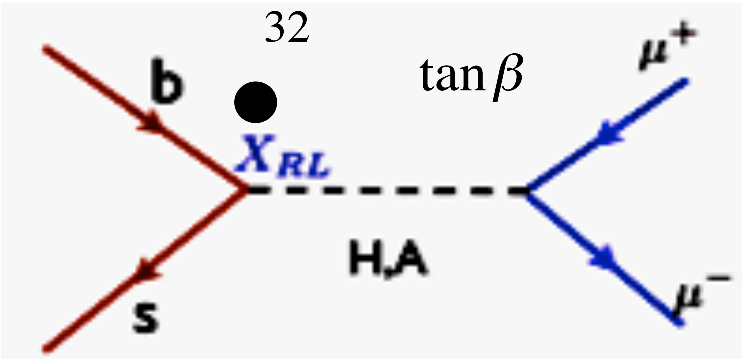
$$(X_{FC})_{ij} = (h_u^+ h_u)_{ij} \propto m_t^2 \, V_{3i}^{CKM*} V_{3j}^{CKM} \quad \text{for } i \neq j$$

D'Ambrosio, Giudice, Isidori, Strumia

M_h ~ 125 GeV and Minimal Flavor Violation in the MSSM

- **Loop-induced A/H contributions to** $B_s \to \mu^+\mu^-$

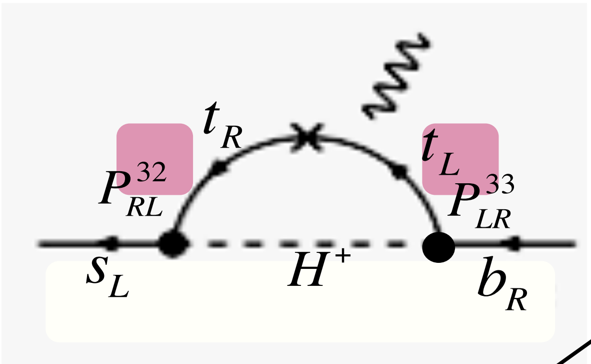
$$BR(B_S \to \mu^+\mu^-)^{SUSY} \propto \frac{\left|X_{RL}^{32}\right|^2 \tan\beta^2}{m_A^4} \propto \frac{\left|\mu A_t\right|^2 \tan\beta^6}{m_A^4}$$



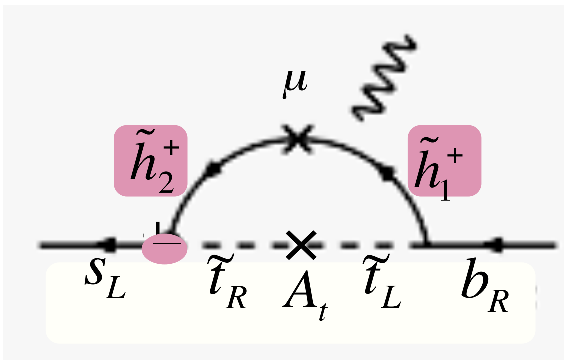
with $$\left(X_{RL}^{H/A}\right)^{bs} \approx -\frac{m_b}{v}\frac{h_t^2\ \varepsilon_Y\ \tan\beta^2}{\left(1+\varepsilon_0^3\tan\beta\right)\left(1+\Delta_b\right)} V_{CKM}^{tb^*} V_{CKM}^{ts}$$

$$\varepsilon_Y \approx \frac{\mu^* A_t^*}{16\pi^2 \max\left[m_{\tilde{t}_1}^2, m_{\tilde{t}_2}^2, \mu^2\right]} \qquad \Delta_b = \left(\varepsilon_0^3 + \varepsilon_y h_t^2\right)\tan\beta$$

- **Charged Higgs and chargino-stop contributions to** $BR(B \to X_S\gamma)$



$$\delta h_t \propto h_t \frac{2\alpha_S}{3\pi}\mu^* M_{\tilde{g}}$$



$$A_{H^+} \propto \frac{(h_t - \delta h_t \tan\beta)\ m_b}{\left(1+\Delta_b\right)} g[m_t, m_{H^+}]\ V_{ts}$$

$$A_{\chi^+} \propto \frac{\mu A_t \tan\beta\ m_b}{\left(1+\Delta_b\right)} h_t^2 f[m_{\tilde{t}_1}, m_{\tilde{t}_2}, \mu]\ V_{ts}$$

FCNC and the scale of SUSY Breaking

- FCNC's induced by Higgs-squark loops depend on the flavor structure of the squark soft SUSY breaking parameters

- **If ~~SUSY~~ is transmitted to the observable sector at high energies M~M_{GUT}**

even starting with universal masses (MFV) in the supersymmetric theory:

Ellis, Heinemeyer, Olive, Weiglein
M.C, Menon, Wagner

Due to RG effects:

1) The effective FC strange-bottom-neutral Higgs is modified: $B_s \to \mu^+\mu^-$

$$\left(X_{RL}^{H/A}\right)^{bs} \approx -\frac{m_b}{v}\frac{(\varepsilon_0^3 - \varepsilon_0^{1,2} + h_t^2\varepsilon_Y)\ \tan\beta^2}{\left(1+\varepsilon_0^3\tan\beta\right)\left(1+\Delta_b\right)} V_{CKM}^{tb^*} V_{CKM}^{ts}$$

$\varepsilon_0^3 - \varepsilon_0^{1,2} > 0$ and proportional to $\mu M_{\tilde{g}}$

If $\mu A_t < 0$ and $\mu M_{\tilde{g}} > 0$

possible cancellation of effects

2) Flavor violation in the gluino sector induces relevant contributions to $b \to s\gamma$

$$A_{\tilde{g}} \propto \alpha_S(m_0^2 - m_{Q_3}^2) M_{\tilde{g}}\mu\ \tan\beta\ F(m_0, m_R, m_{\tilde{b}_i}, m_{\tilde{d}_i}, M_{\tilde{g}})$$

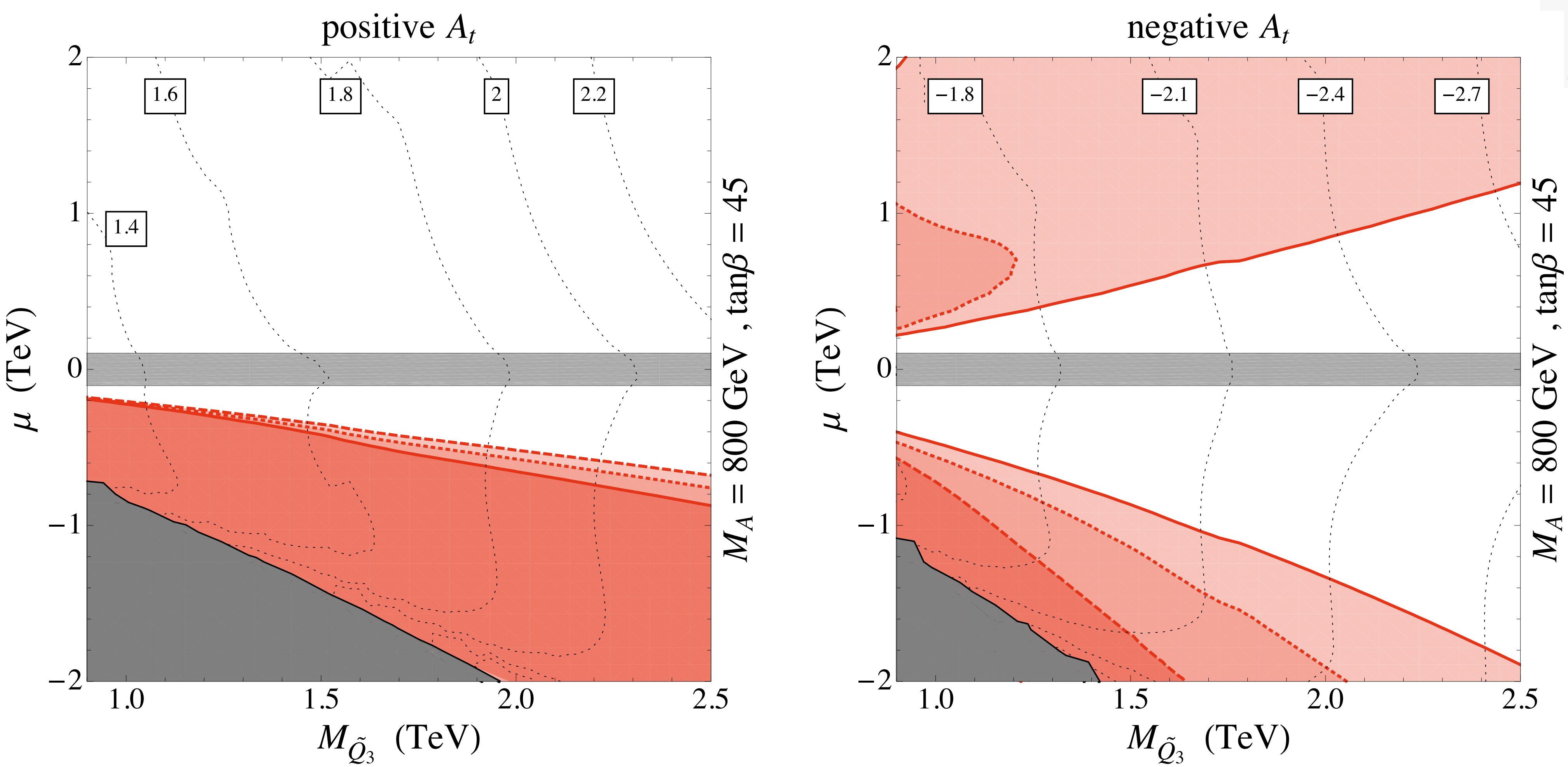
Borzumati, Bertolini, Masiero,Ridolfi

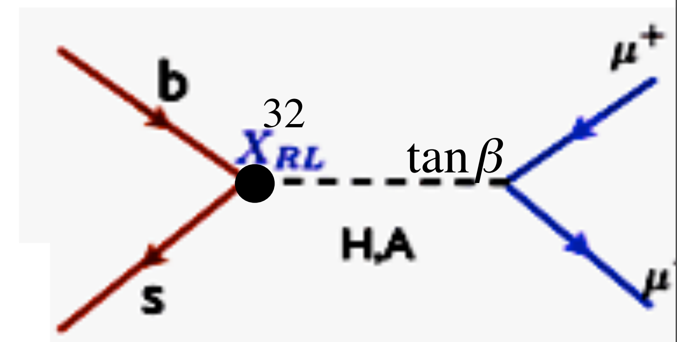
- **If ~~SUSY~~ is transmitted at low energies: M~ M_{SUSY}**,

Squark mass matrices approx. block diag, only FC effects in the chargino-stop& H^+ loops

M_h ~ 125 GeV and flavor in the MSSM

Bounds from $B_s \to \mu^+\mu^-$





Loop-induced A/H mediated FCNC's

intimately connected to the structure of the squark mass matrices

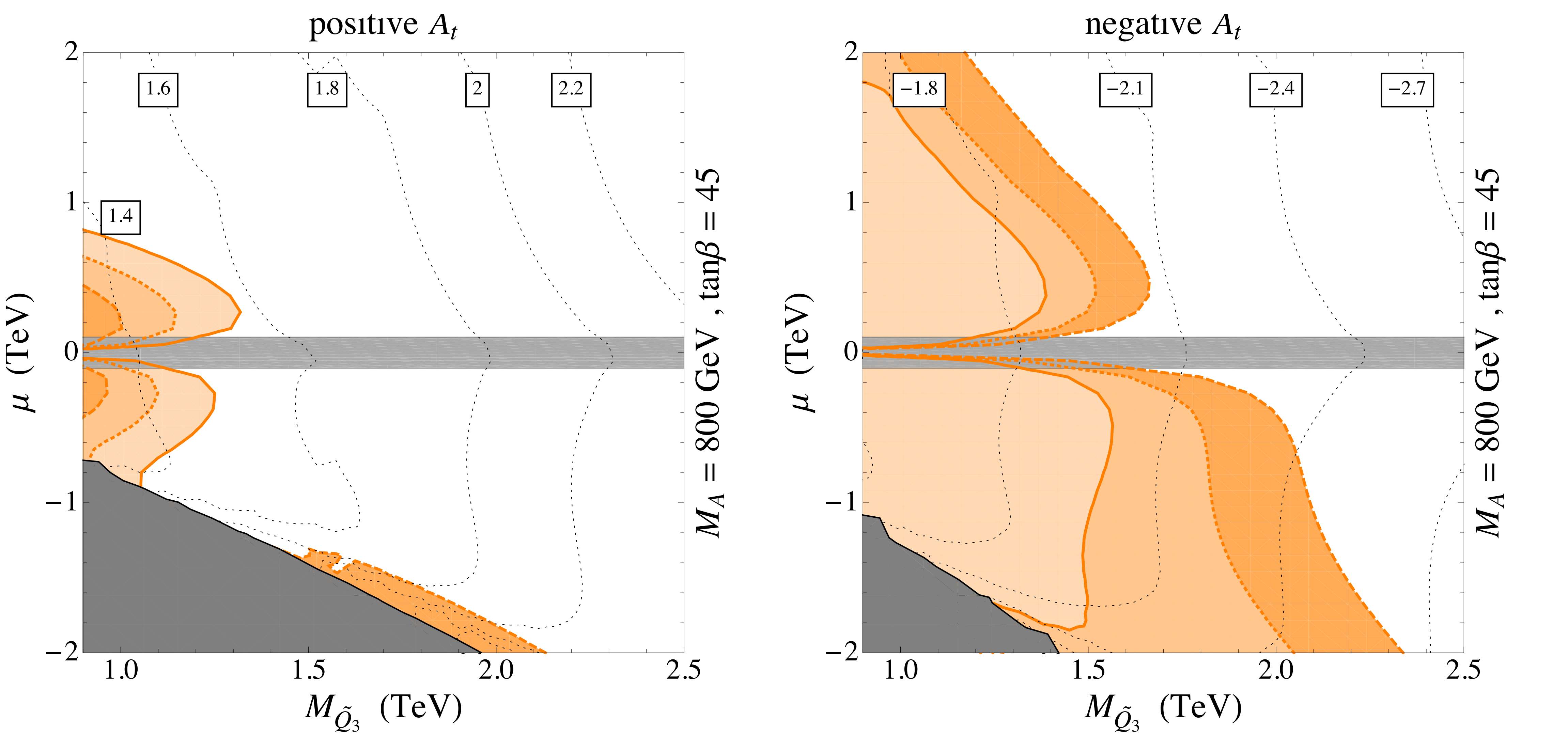
Altmannshofer, MC, Shah,Yu '12

Red solid line: $B_s \to$ mu$^+$mu$^-$ with low energy SUSY breaking effects
Red dashed (dotted) line has high energy MFV with running of all (1st-,2nd vs 3rd gen.) parameters

Positive values of A_t and μ less constraining for sizeable m_A and large tan be

M_h ~ 125 GeV and flavor in the MSSM

Bounds from $B_s \to X_s \gamma$



Altmannshofer, MC, Shah,Yu

Orange solid line from B X_s gamma with low energy SUSY breaking effects

Orange dashed (dotted) line has high energy MFV with running of all (1st-,2nd vs 3rd generation) parameters