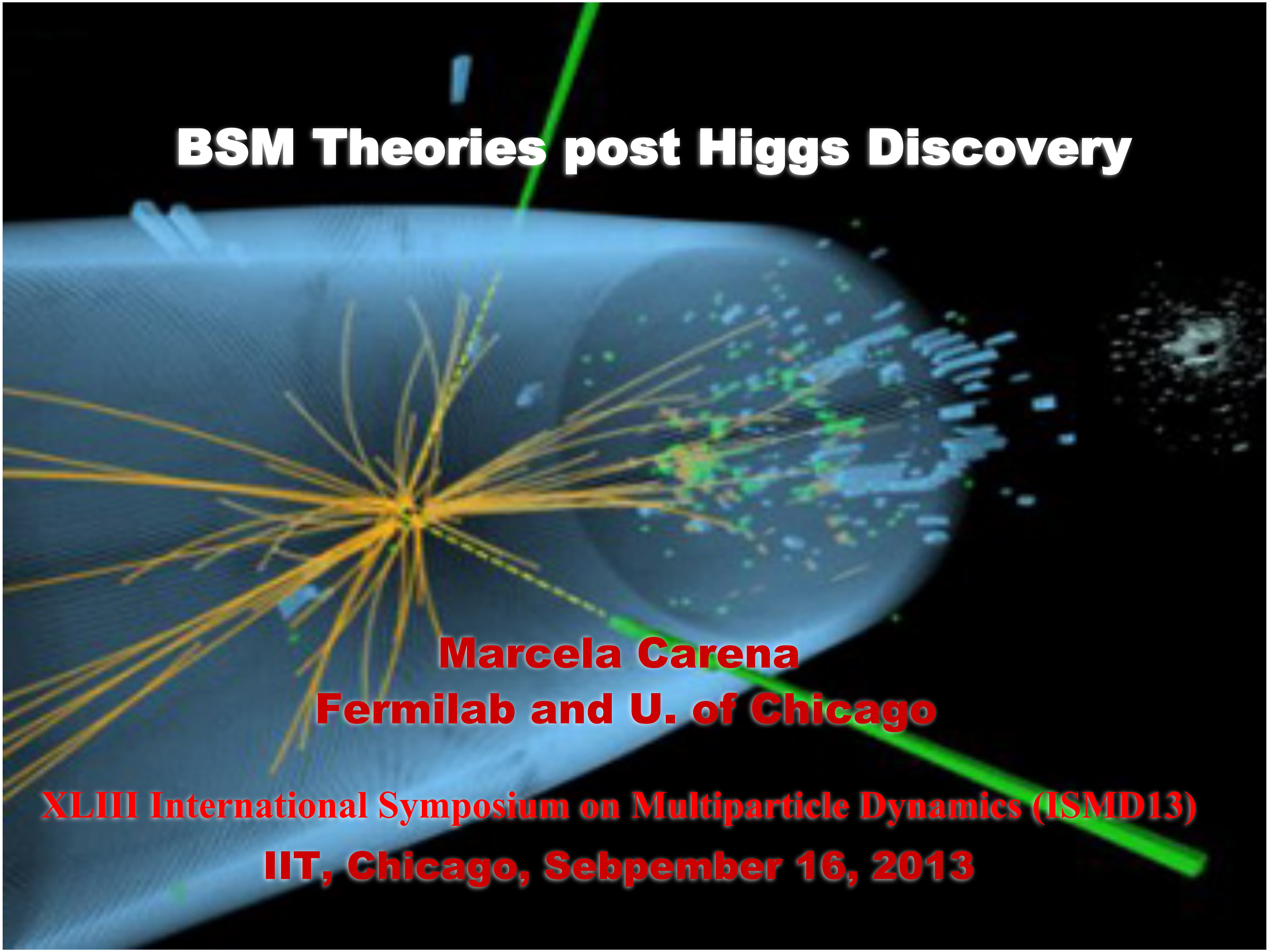


BSM Theories post Higgs Discovery

Marcela Carena
Fermilab and U. of Chicago

XLIII International Symposium on Multiparticle Dynamics (ISMD13)

IIT, Chicago, Sebpember 16, 2013

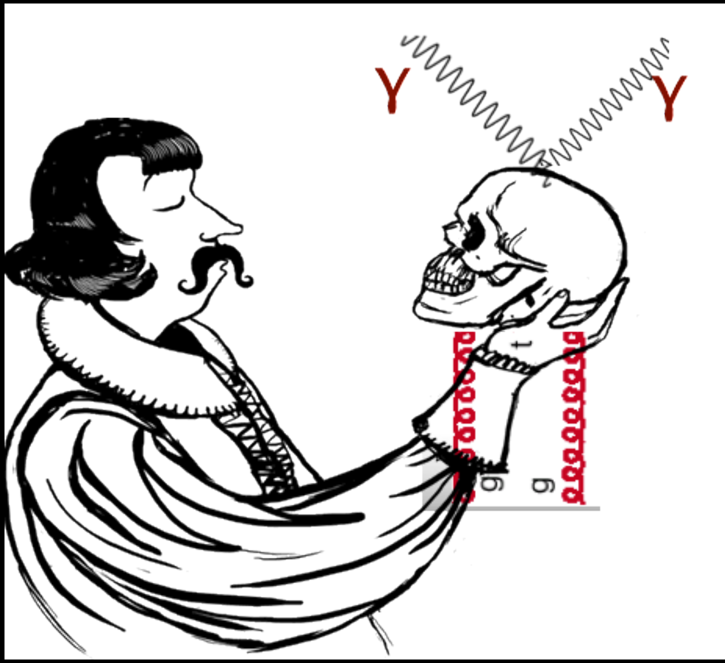
2012-2013: a revolutionary year for Physics

•Discovery of a new type of particle
• Discovery of a new type of force
• Start of a new era for particle physics at cosmology

- The PARTICLE of the July 4 discovery: is it THE HIGGS BOSON that explains the mass of fundamental particles?

~1% of all the visible mass

- Is it THE STANDARD MODEL HIGGS, just a close relative or an impostor?



"The" SM Scalar Boson, or not ….

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

What if the newly discovered *scalar* has non-SM properties?

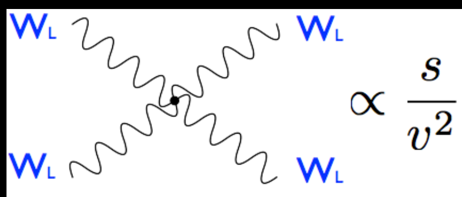
Could be a mixture from more than one Higgs Field
Could be a mixture of CP even and CP odd
Could be a composite particle
Could be partly a singlet or a triplet instead of an SU(2) doublet
Could have enhanced/suppressed coupling to photons or gluons if there are exotic heavy charged or colored particles
Could decay to exotic particles, e.g. dark matter
May not couple to matter particles proportional to their masses

it can still be the scalar boson responsible for EWSB -

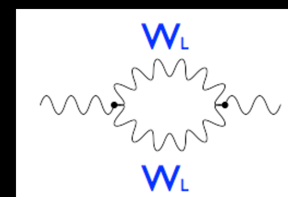
Why to expect New Physics beyond the Higgs at all?

The Higgs is special:

Without the Higgs, the calculability power of the SM is spoiled



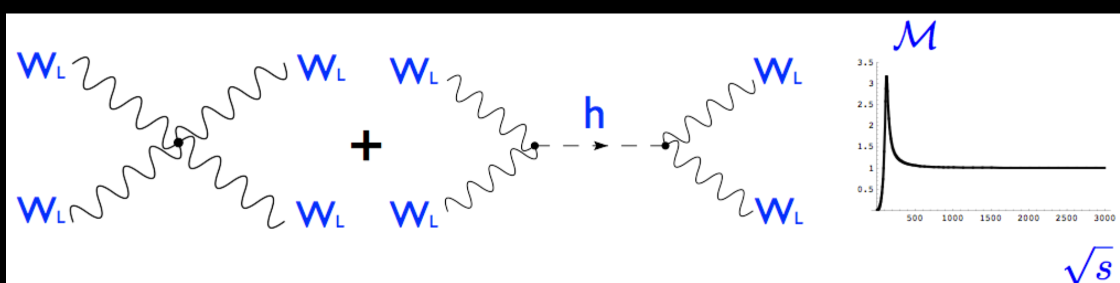
Unitarity lost at high energies

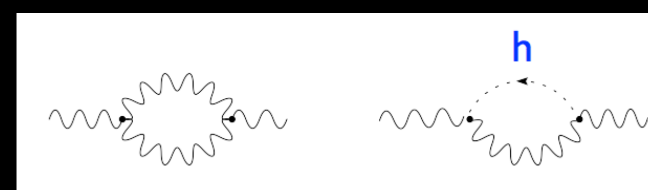


Loops are not finite

New Physics is needed at the EW scale

With the SM Higgs calculability is recovered (m_H<170 GeV)





Loops are finite

New Physics only needed to explain gravity

Why to expect New Physics beyond the Higgs at all?

The Higgs is special: it is a scalar

Scalar masses are not protected by gauge symmetries: $\mathcal{L} \propto \mu^2 |\phi|^2$

At quantum level scalar masses have quadratic sensitivity to UV physics

$$\delta\mu^2 \to \delta m_H^2 \qquad m_H^2(Q) = m_H^2(\mu) \pm \frac{3m_{F,B}^2}{8\pi^2}\lambda_{F,B}^2 \ln(\mu^2/Q^2)$$

Although the SM with the Higgs is a consistent theory,
light scalars like the Higgs cannot survive
in the presence of heavy states at GUT/String/Planck scales

Fine tuning $\longleftrightarrow$ Naturalness problem

Two possible Solutions:

Supersymmetry: a fermion-boson symmetry

The Higgs remains elementary but its mass is protected by the new fermion-boson symmetry

Composite Higgs Models:

The Higgs does not exist above a certain scale, at which new strong dynamics takes place

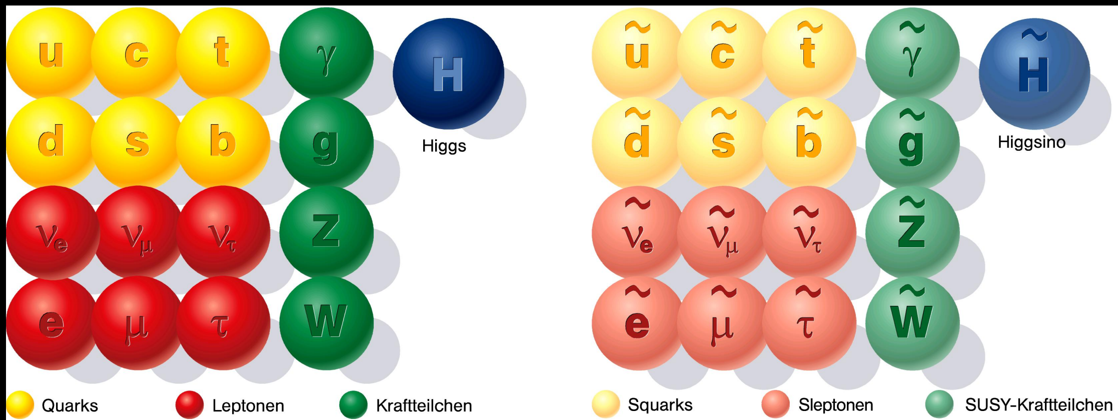
Both options imply changes in the Higgs phenomenology

Also the Higgs role in unitarization is shared by other particles: additional Higgs, strong sector

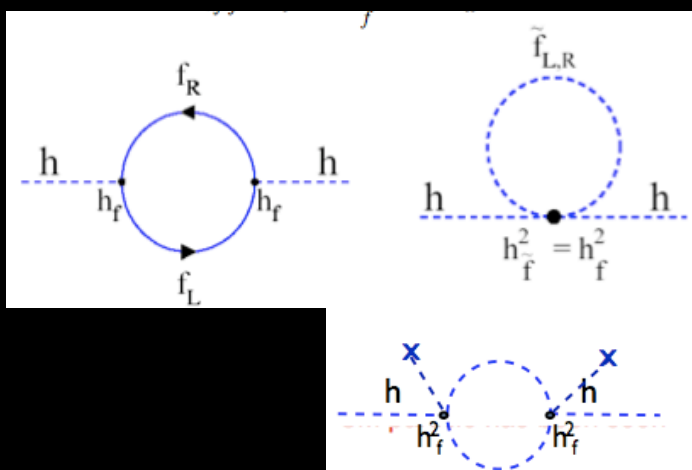
A third option: Higgsless models…in bad shape after Higgs discovery

Light dilaton, Goldstone of SB of scale invariance: a Higgs impostor?

SUPERSYMMETRY



For every fermion there is a boson with equal mass & couplings



$$\delta m_H^2 = \frac{3\lambda_F^2}{8\pi^2}[m_F^2 - m_B^2]\ln(\mu^2/Q^2)$$

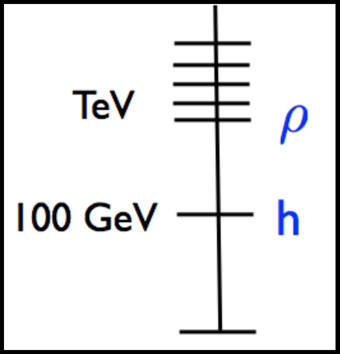
In SUSY, $\delta m_H^2 = 0$

Automatic cancellation of loop corrections to the Higgs mass parameter

No SUSY particles at LHC yet ➔SUSY broken in nature: $m_F - m_B \sim O(M_{SUSY})$

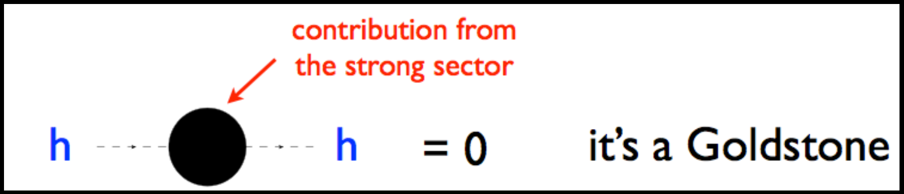
Stop mass value measures the degree of fine tuning

Composite Higgs



Higgs is light because is the Pseudo Goldstone Boson of a global symmetry
-- like pions of a new strong sector (QCD inspired) --

Higgs mass protected by global symmetry



Generated at one loop: breaking of global symmetry due to SM couplings

Higgs mass difficult to compute due to strong dynamics behavior

$$m_H^2 \approx m_t^2 M_T^2 / f^2$$

Higgs couplings to W/Z determine by the gauge groups involved
i.e. MCHM_X ➔ SO(5)/SO(4)

Higgs couplings to SM fermions depend on fermion embedding X

Non SM Couplings ➔ Unitarization requires effects from new strong states

Why to expect New Physics beyond the Higgs at all? (Part 2)

It may help explain:

- ** Dark Matter
- ** Neutrino masses
- ** dynamical origin of EWSB
- ** Matter-antimatter asymmetry
- ** Observed flavor structure
- ** Unification of forces

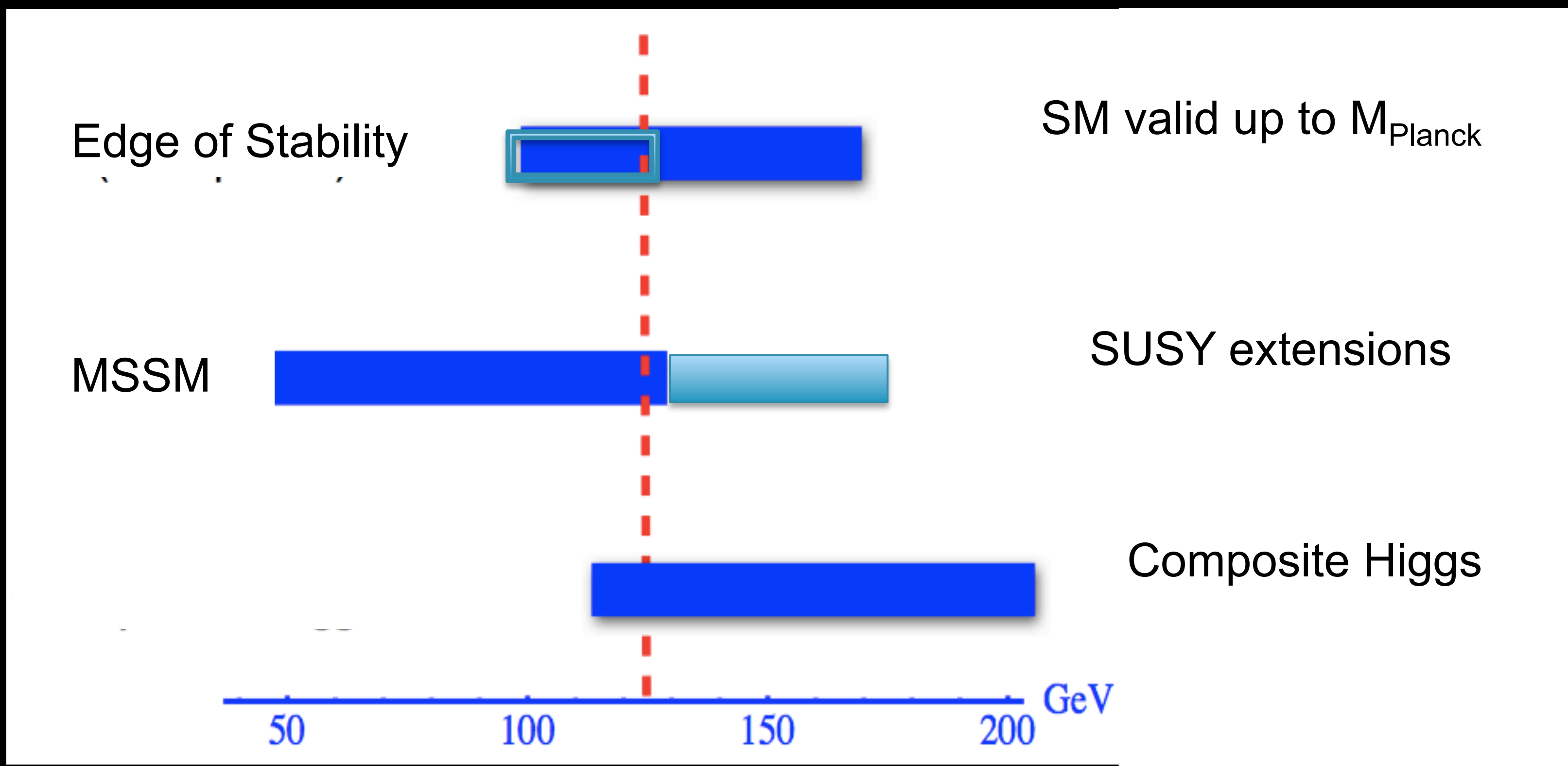
Hence the prejudice (the hope) that there must be NP

Back to the Higgs: the BASIC & the BIG questions

Are the Higgs couplings to matter particles prop. to their masses?
Does the Higgs talk to particles we have not seen?
How many Higgs bosons are there?

Is there a Higgs portal to DM?
Does the Higgs trigger the genesis of matter?
How does it talk to neutrinos?
Does the Higgs make the universe unstable?

What does a 125 GeV Higgs tell us?

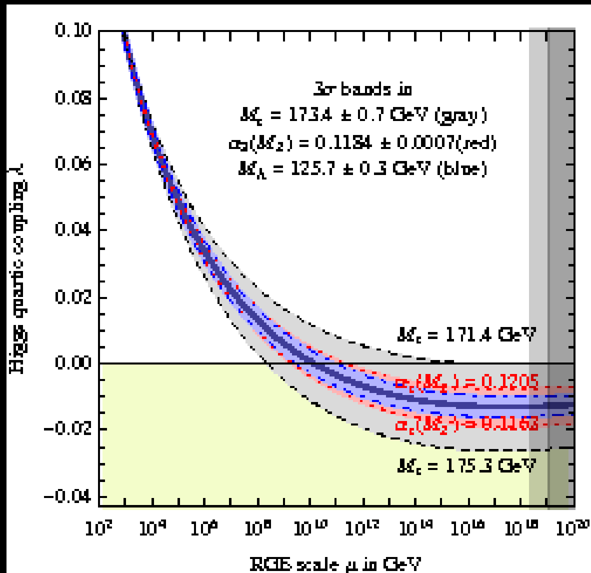


In the SM: $V(\Phi) = \mu^2|\Phi|^2 + \lambda\,(\Phi^+\Phi)^2$ and $m_H^2 = 2\,\lambda v^2$

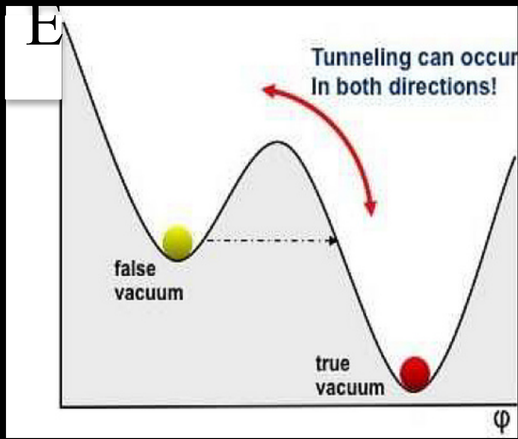
Hence, $\lambda \sim 0.13$ and $|\mu|^2 \sim 88$ GeV (with v = 246 GeV)

λ evolves with energy

- It remains perturbative all the way up to M_{Planck}
- It becomes negative at energies ~ $10^{10\text{-}12}$ GeV



The EW vacuum is metastable



Slow evolution of λ at high energies saves the EW vacuum from early collapse

The peculiar behavior of λ is
a coincidence, some special dynamics/new symmetry at high energies?
Or not there at all ? ➔ new physics at low energy scale

Why SUSY?

- Helps stabilize the weak scale-Planck scale hierarchy

- SUSY algebra contains the generator of space translations

  $\longrightarrow$ necessary ingredient of theory of quantum gravity

- Allows for Gauge Coupling Unification at a scale $\sim 10^{16}$ GeV

- Starting from positive Higgs mass parameters at high energies, induces electroweak symmetry breaking radiatively.

- Provides a good Dark matter candidate:
  The Lightest SUSY Particle (LSP)

- Provides possible solutions to the baryon asymmetry of the universe.

What does a 125 GeV Higgs implies in SUSY?

Multiple Higgs particles necessary: New Higgs bosons at LHC reach or only one SM-like Higgs and the rest heavy

Minimal Higgs Sector: Two SU(2) doublets H_d and H_u

➔required by SUSY/gauge invariance and to secure anomaly cancellations

One doublet is the SM one:

$$H_{SM} = \mathrm{Re}(H^o_d)\cos\beta + \mathrm{Re}(H^o_u)\sin\beta \qquad \tan\beta = v_u/v_d$$

And the orthogonal combination involves the CP-even, CP-odd and charged Non-SM Higgs H, A and H^{+-}

Strictly speaking, the CP-even modes mix and none behaves like the SM one

$$h = -\sin\alpha\,\mathrm{Re}(H^o_d) + \cos\alpha\,\mathrm{Re}(H^o_u) \qquad H = \cos\alpha\,\mathrm{Re}(H^o_d) + \sin\alpha\,\mathrm{Re}(H^o_u)$$

In the decoupling limit, the non-SM Higgs bosons are heavy, $\sin\alpha = -\cos\beta$ and one recovers the SM as an effective theory.

SM-like Higgs boson mass in the Minimal SUSY SM extension

depends on: **CP-odd mass m_A, tanβ, M_t** **and Stop masses & mixing**

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

For large m_A

$$m_h^2 = \underbrace{M_Z^2 \cos^2 2\beta}_{< (91\ \mathrm{GeV})^2} + \Delta m_h^2$$

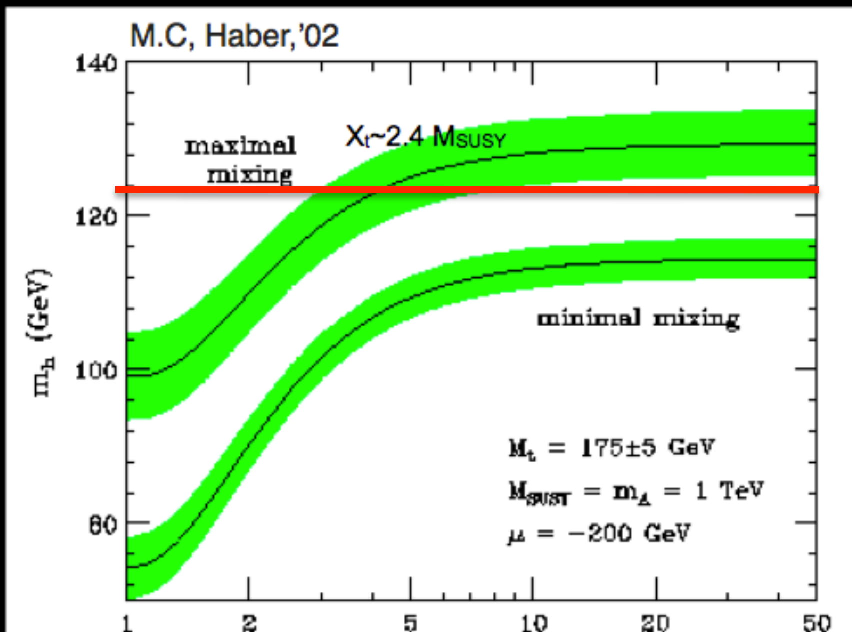
$$\Delta m_h^2 = \frac{3}{4\pi^2}\frac{m_t^4}{v^2}\left[\frac{1}{2}\tilde{X}_t + t + \frac{1}{16\pi^2}\left(\frac{3}{2}\frac{m_t^2}{v^2} - 32\pi\alpha_3\right)\left(\tilde{X}_t t + t^2\right)\right]$$

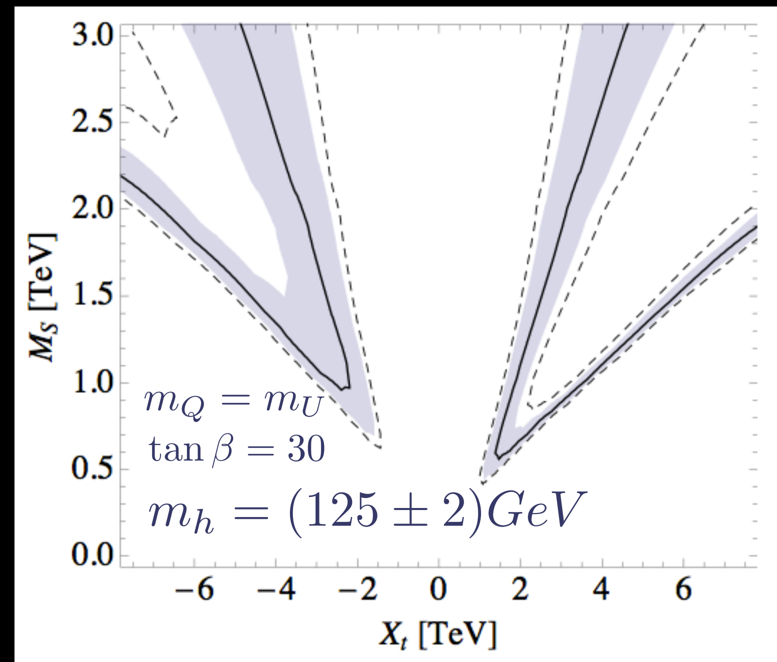
m_h depends logarithmically on the averaged stop mass scale **$M_{SUSY} \sim m_Q \sim m_U$**
and has a quadratic and quartic dep. on the stop mixing parameter X_t.
[and on sbottom/stau sectors for large tan beta]

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

Two-loop computations: Brignole, M.C, Degrassi, Diaz, Ellis, Espinosa, Haber, Harlander, Heinemeyer, Hempfling, Hoang, Hollik, Hahn, Martin, Pilaftsis, Quiros, Ridolfi, Rzehak, Slavich, Wagner,Weiglein, Zhang, Zwirner

SM-like MSSM Higgs Boson Mass:





$m_h \leq 130$ GeV

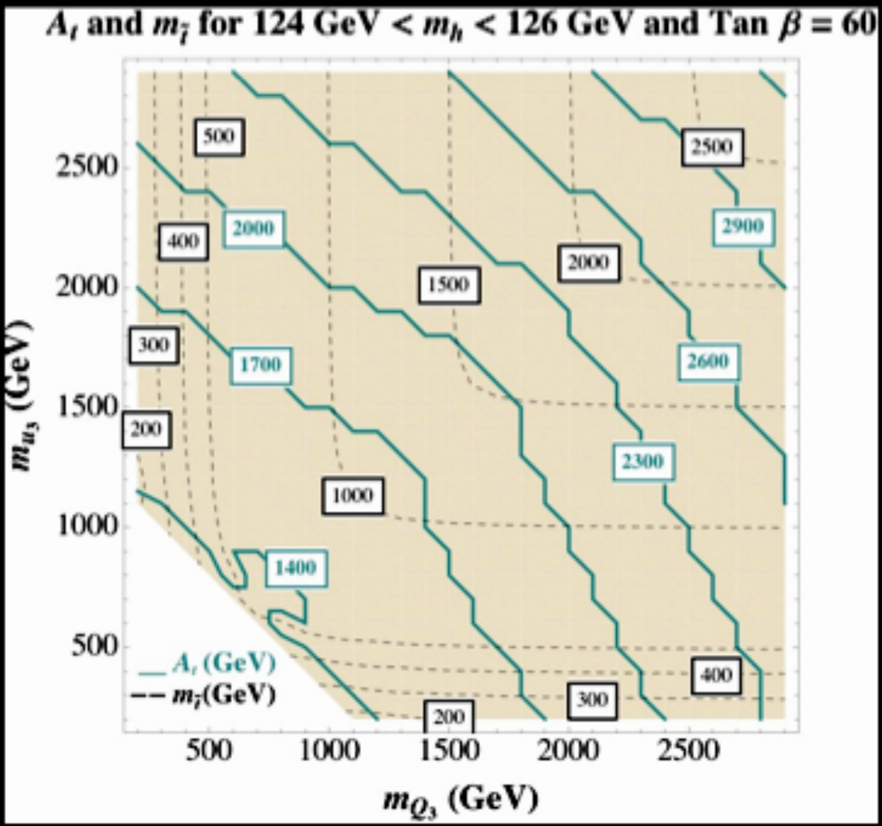
(for sparticles of ~ 1 TeV)

M.C. Espinosa, Quiros, Wagner '95;
M.C. Quiros, Wagner '95; Haber, Hempfling, Hoang '96
M.C. Haber, Heinemeyer, Hollik, Weiglein, Wagner'00

Mh ~ 125 GeV ➔ Large Mixing in the stop sector necessary

Draper, Meade, Reece, Shih'11
Hall, Pinner, Ruderman'11
M. Carena, S. Gori, N. Shah, C.Wagner'11
Arbey, Battaglia, Djouadi, Mahmoudi, Quevillon'11
Heinemeyer, Stal, Weiglein'11
Elwanger'11

Soft supersymmetry Breaking Parameters in the MSSM



Large stop sector mixing
A_t > 1 TeV
[Unless stop very heavy (5-10 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

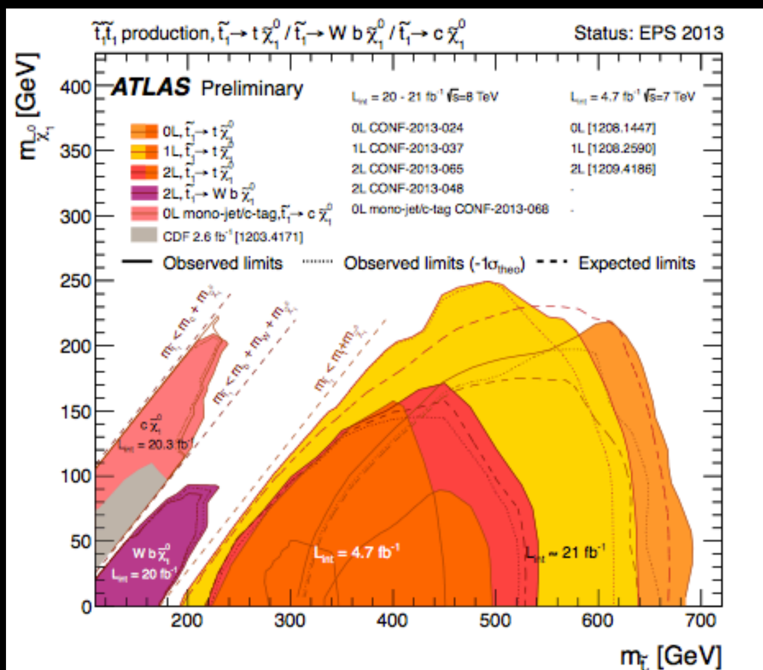
Similar results from
Arbey, Battaglia, Djouadi, Mahmoudi, Quevillon
Draper Meade, Reece, Shih
Shirman et al.

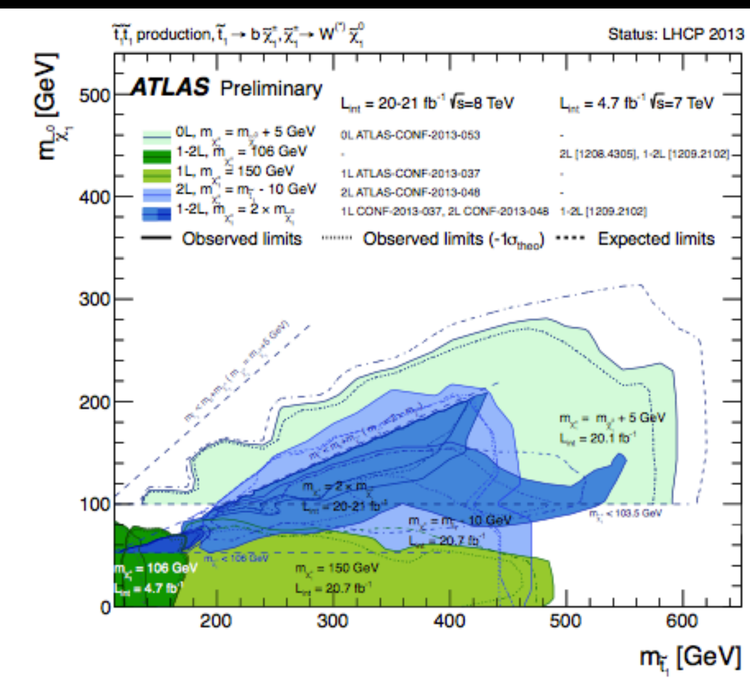
A 125 GeV Higgs and light stops

Light stop coupling to the Higgs $$m_Q \gg m_U; \qquad m_{\tilde{t}_1}^2 \simeq m_U^2 + m_t^2 \left(1 - \frac{X_t^2}{m_Q^2}\right)$$

Lightest stop coupling to the Higgs approximately vanishes for Xt ~m_Q
Higgs mass pushes us in that direction
Modification of the gluon fusion rate mild due to this reason.

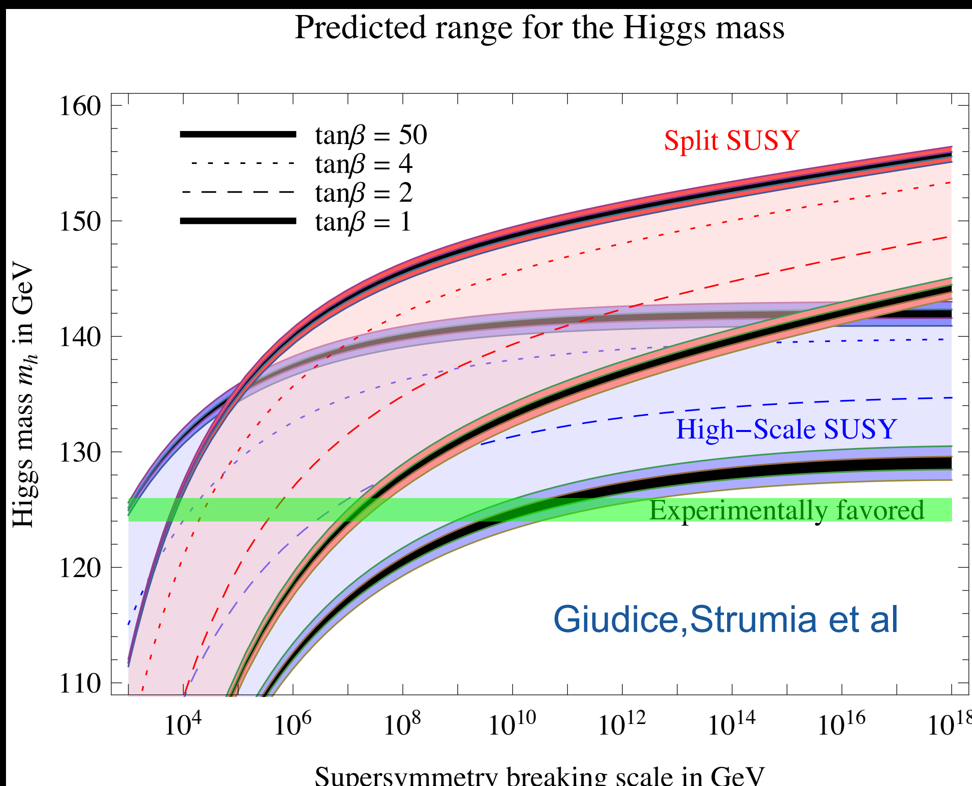
Limits on the Stop Mass



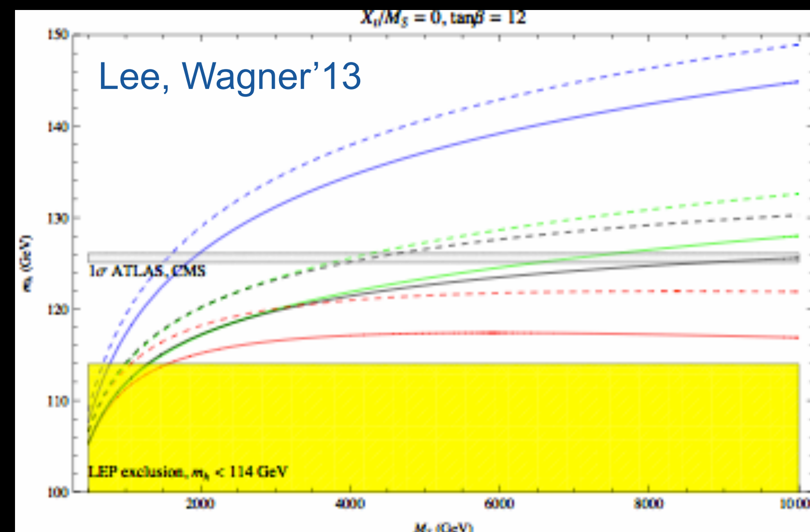


A 125 GeV Higgs and very heavy stops?

An upper bound on the SUSY scale [stop masses < 10-30 TeV]
if tanβ moderate or large (> 5)]



Recalculation of RG prediction with 4 loops in RG expansion.



The importance of higher order loops computations

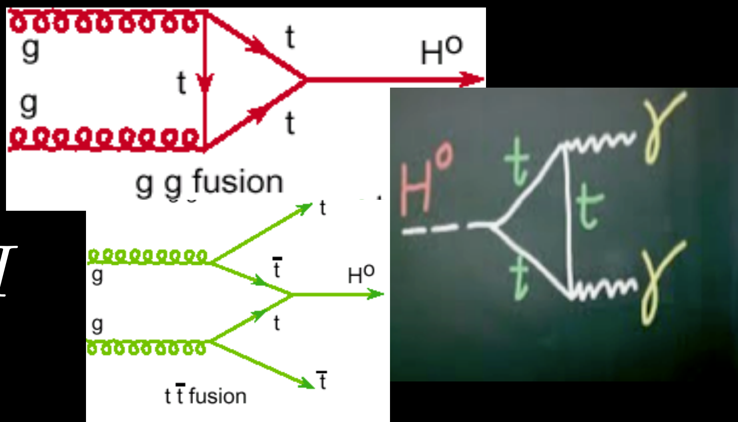
See also G. Kane, P. Kumar, R. Lu, B. Zheing '12
A.Arvanitaki, N. Craig, S. Dimoupoulos, G.Villadoro'12

See also. Martin'07; Kant, Harlander, Mihalla, Steinhauser; *Feng, Kant,. Profumo,. Sanford.*

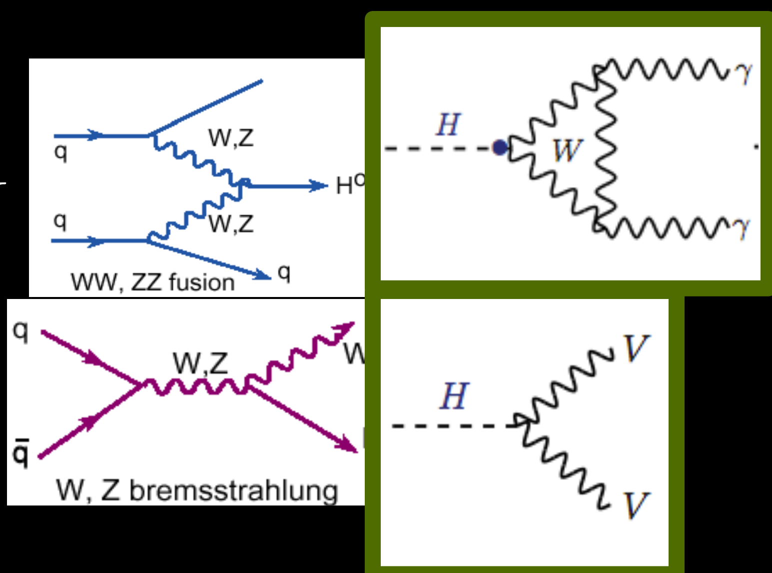
What do the Higgs Production and Decays tell us?

Many different pieces of information: $B\sigma(p\bar{p} \to h \to X_{\mathrm{SM}}) \equiv \sigma(p\bar{p} \to h)\,\frac{\Gamma(h \to X_{\mathrm{SM}})}{\Gamma_{\mathrm{total}}}$

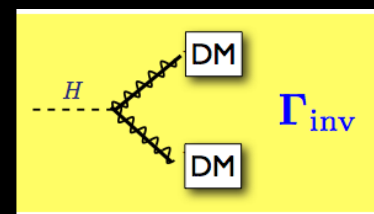
$t\bar{t}H$



VVH



also $H \to b\bar{b}, \tau^{+}\tau^{-}$



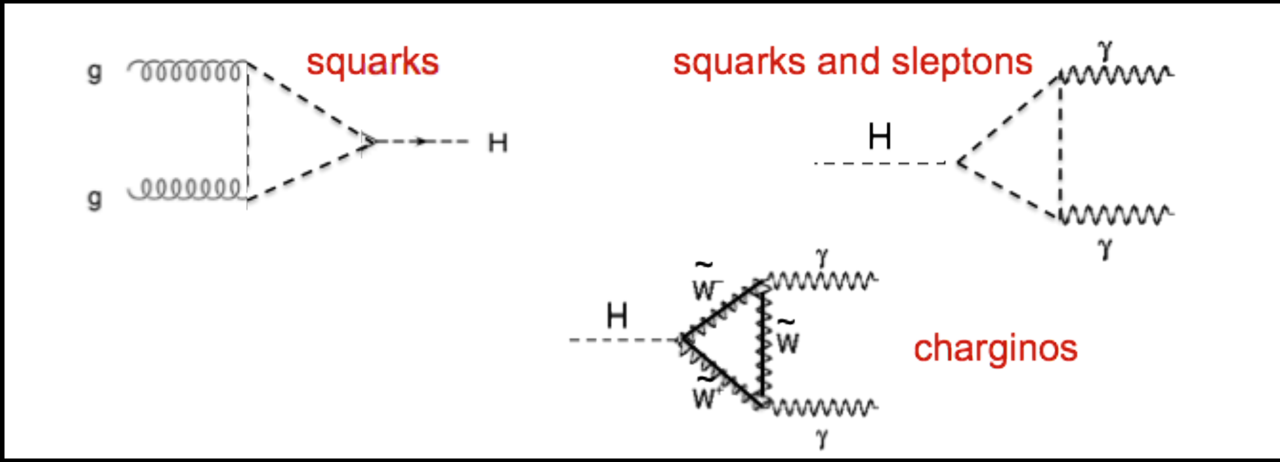
Different patterns of deviations from SM couplings if:

- New light charged or colored particles in loop-induced processes
- Modification of tree level couplings due to mixing effects
- Decays to new or invisible particles

crucial info on NP from Higgs precision measurements

Possible departures in the production and decay rates at the LHC in SUSY

- Through SUSY particle effects in loop induced processes



- 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

Loop induced Couplings of the Higgs to Gauge Boson Pairs

Low energy effective theorems relate a heavy particle contribution
to loop induced Higgs couplings to gauge bosons,
to that particle contribution to the two point function of the gauge bosons

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

M. C, I. Low, Wagner '12 Ellis, Gaillard, Nanopoulos'76, Shifman,Vainshtein,Voloshin, Zakharov'79

Similarly for the Higgs-gluon gluon coupling

Hence, W (gauge bosons) contribute negatively to Hγγ,
while top quarks (matter particles) contribute positively to Hgg and Hγγ

- New chiral fermions will enhance Hgg and suppress hγγ
- To reverse this behavior matter particles need to have negative values for

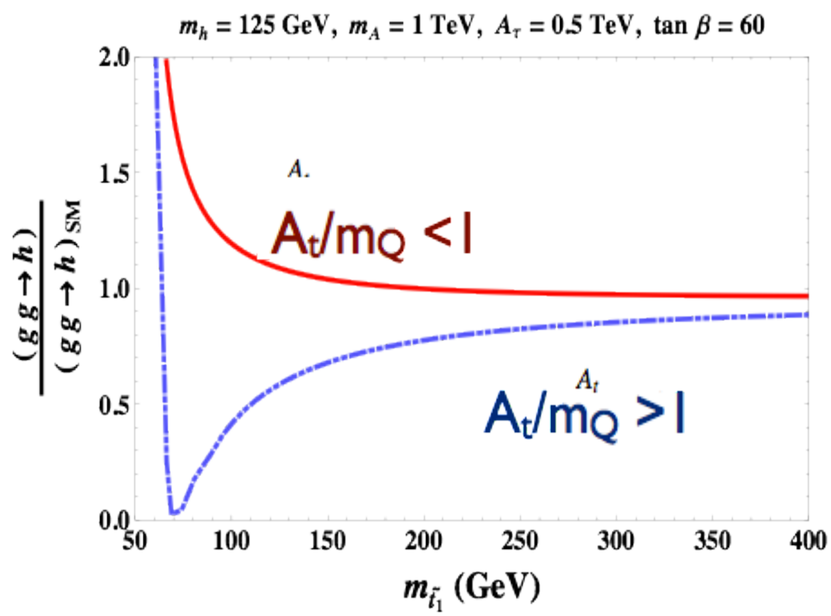
$$\frac{\partial}{\partial \log v}\log\left(\det \mathcal{M}^\dagger_{F,i}\mathcal{M}_{F,i}\right) \qquad \frac{\partial}{\partial \log v}\log\left(\det \mathcal{M}^2_{B,i}\right)$$

For a study considering CP violating effects and connection with EDM's and MDM's see
Altmannshofer, Bauer, MC'13; Voloshin'12

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

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

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

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

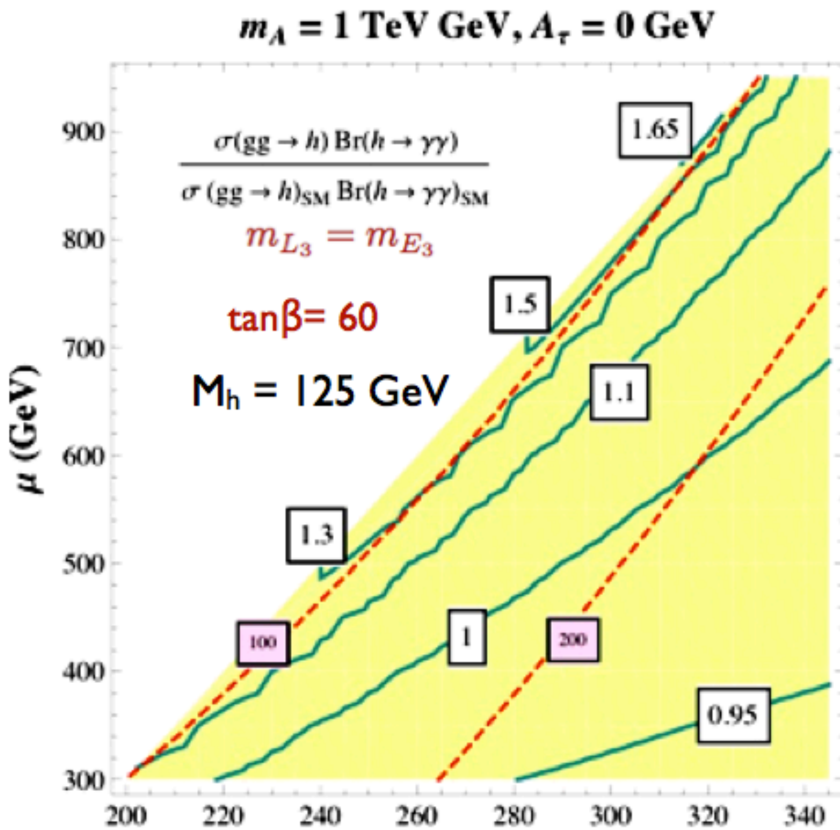
$$\frac{\sigma(gg \to h) BR(h \to \gamma\gamma)}{\sigma(gg \to h)_{SM} BR(h \to \gamma\gamma)_{SM}} < (>) 1$$

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

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

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

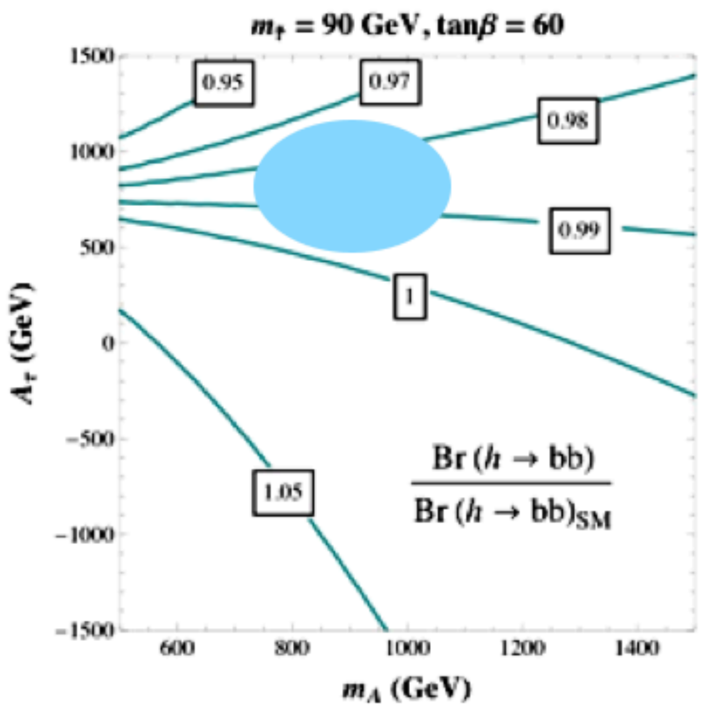
MSSM scan: Benbrik, Gomez Bock, Heinemeyer, Stal, Weigein, Zeune'12

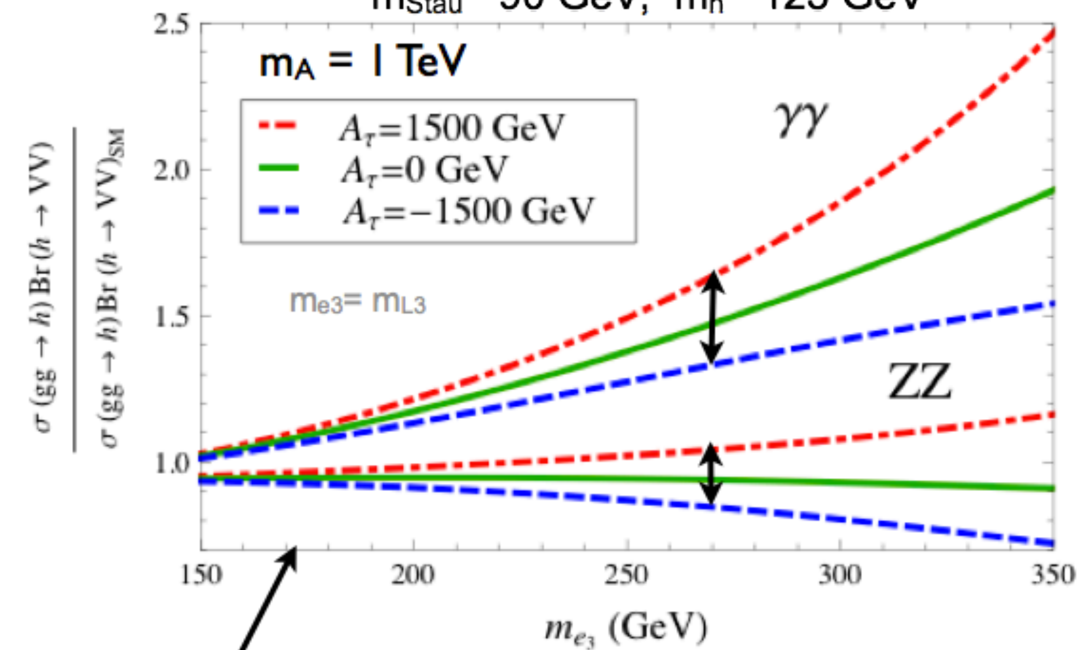
Additional modifications of the Higgs rates into gauge bosons via stau induced mixing effects in the Higgs sector

Important A_τ induced radiative corrections to the mixing angle α

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

$m_{Stau} \sim 90$ GeV; $m_h \sim 125$ 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, Battagllia, Djouadi, Mahmoudi '12
Benbrik, Gomez Bock, Heinemeyer, Stal, Weiglein, Zeune'12

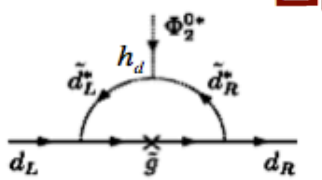
Suppression of the h to taus to h to b's ratio

due to different radiative SUSY corrections to higgs-fermion couplings

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

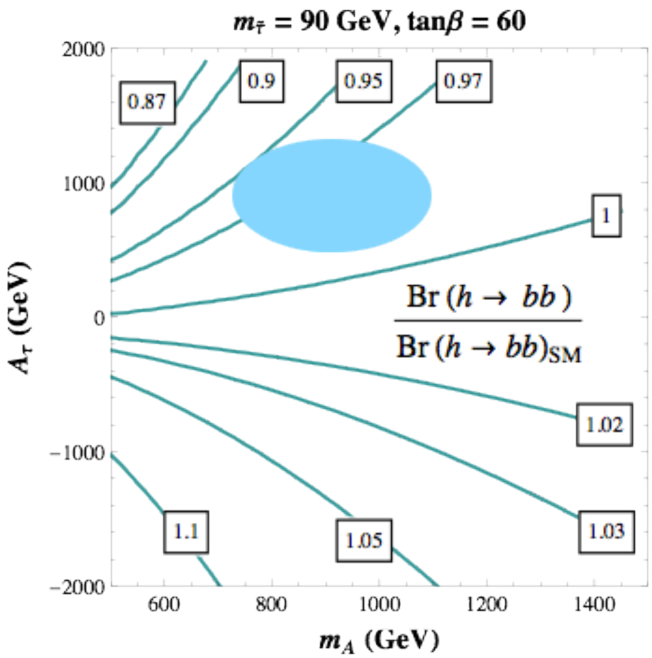
$\Delta_{b,\tau}$

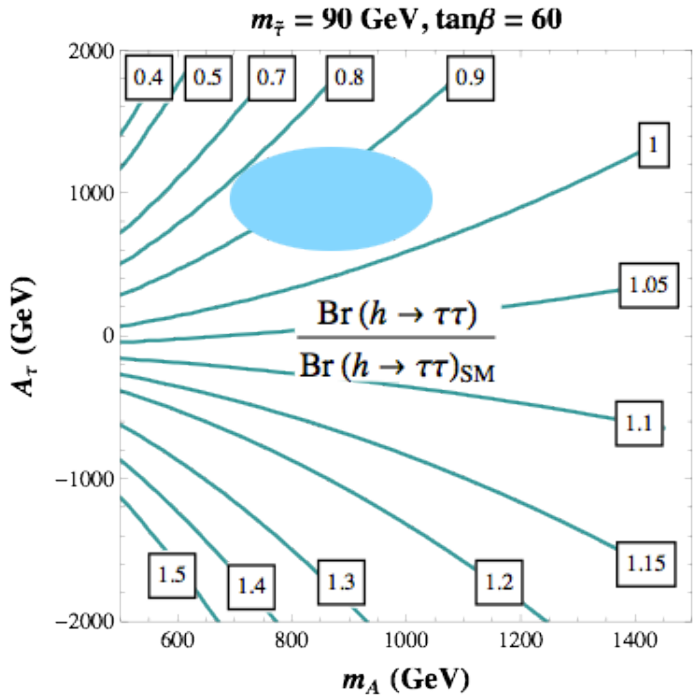
$$g_{hbb,h\tau\tau} = -\frac{m_{b,\tau} \sin\alpha}{v \cos\beta (1 + \Delta_{b,\tau})} \left[1 - \frac{\Delta_{b,\tau}}{\tan\beta \tan\alpha}\right]$$



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

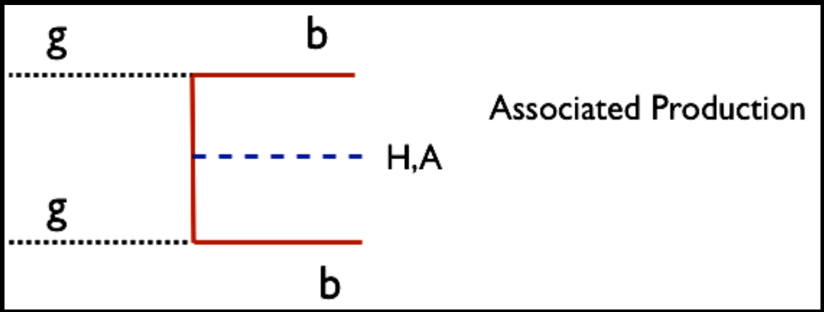
Searches for non-Standard Higgs bosons at LHC

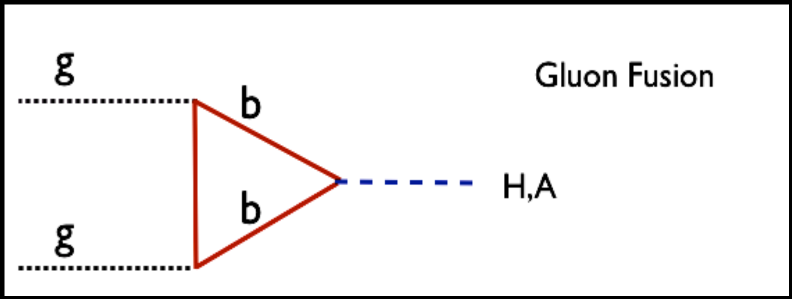
•Enhanced couplings to bottom quarks and tau-leptons

$$g_{Abb} \simeq g_{Hbb} \simeq \frac{m_b \tan\beta}{(1+\Delta_b)v}$$

$$g_{A\tau\tau} \simeq g_{H\tau\tau} \simeq \frac{m_\tau \tan\beta}{v}$$

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





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

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

Strong dependence on the SUSY parameters in the bb channel.

Robust predictions in the tau-tau channel

Excellent LHC coverage in the di-tau inclusive channel

M.C, Heinemeyer, Weiglein, Wagner

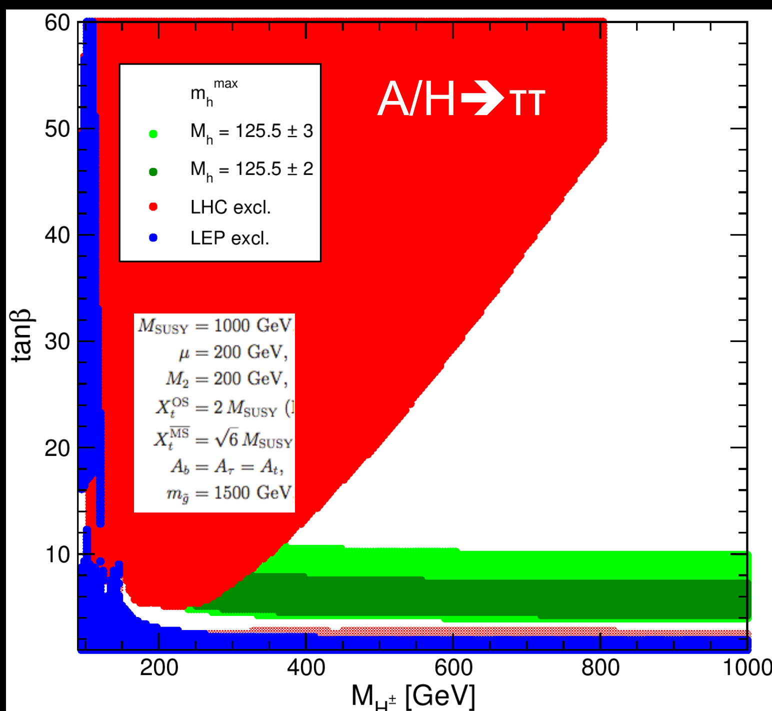
Benchmark Scenarios for the Search of MSSM Higgs Bosons

with 125.5 GeV signal interpreted as h (or H)

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

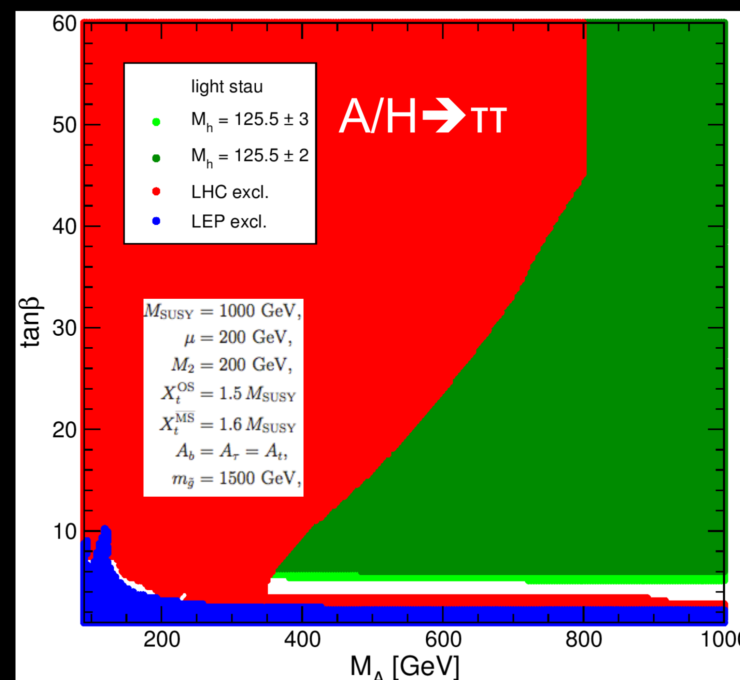
m_h^{max} scenario

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



m_h^{mod} scenario

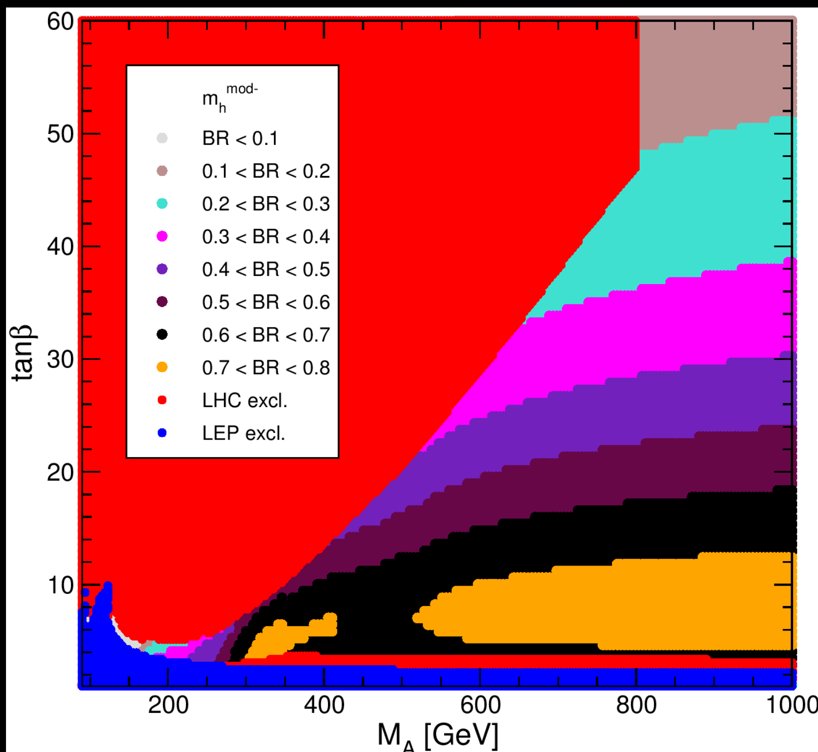
Moderate stop mixing: large region in tanβ-mA plane compatible with Higgs signal

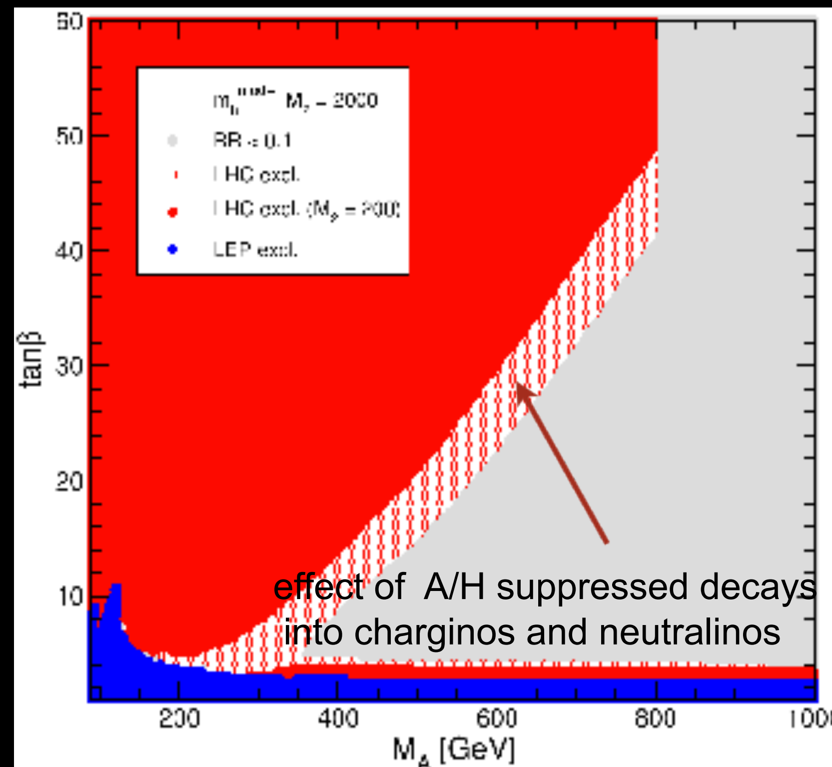


Green region favored by LHC observation

Decay of Non Standard MSSM Higgs Bosons in electroweakinos

m_h^{mod} scenario





Reach of non-standard Higgs bosons in tau decays modified.
Opportunity to search for these new decays
Also H➔hh relevant at low tanβ

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

Many Minimal SUSY models can produce m_h=125 GEV

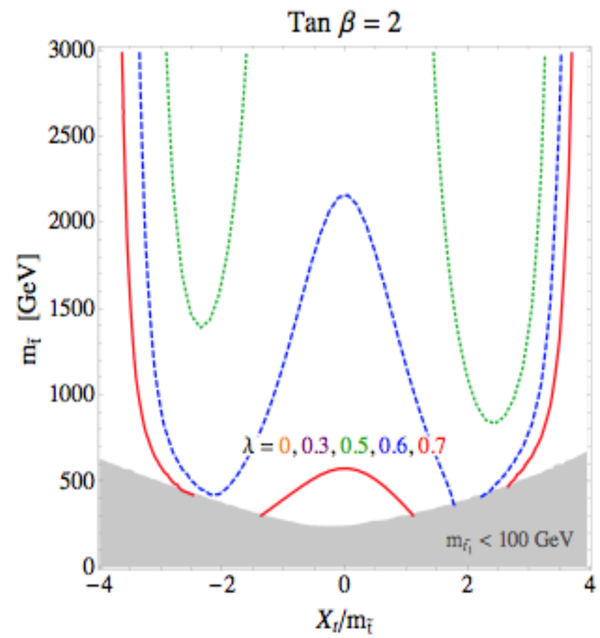
Extra singlet S with extra parameter λ

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

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

SM + singlet limit

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



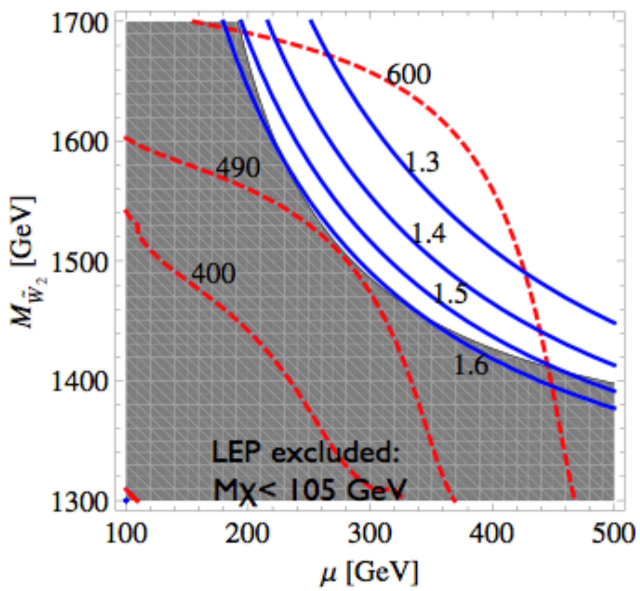
Hall, Pinner, Ruderman'11

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

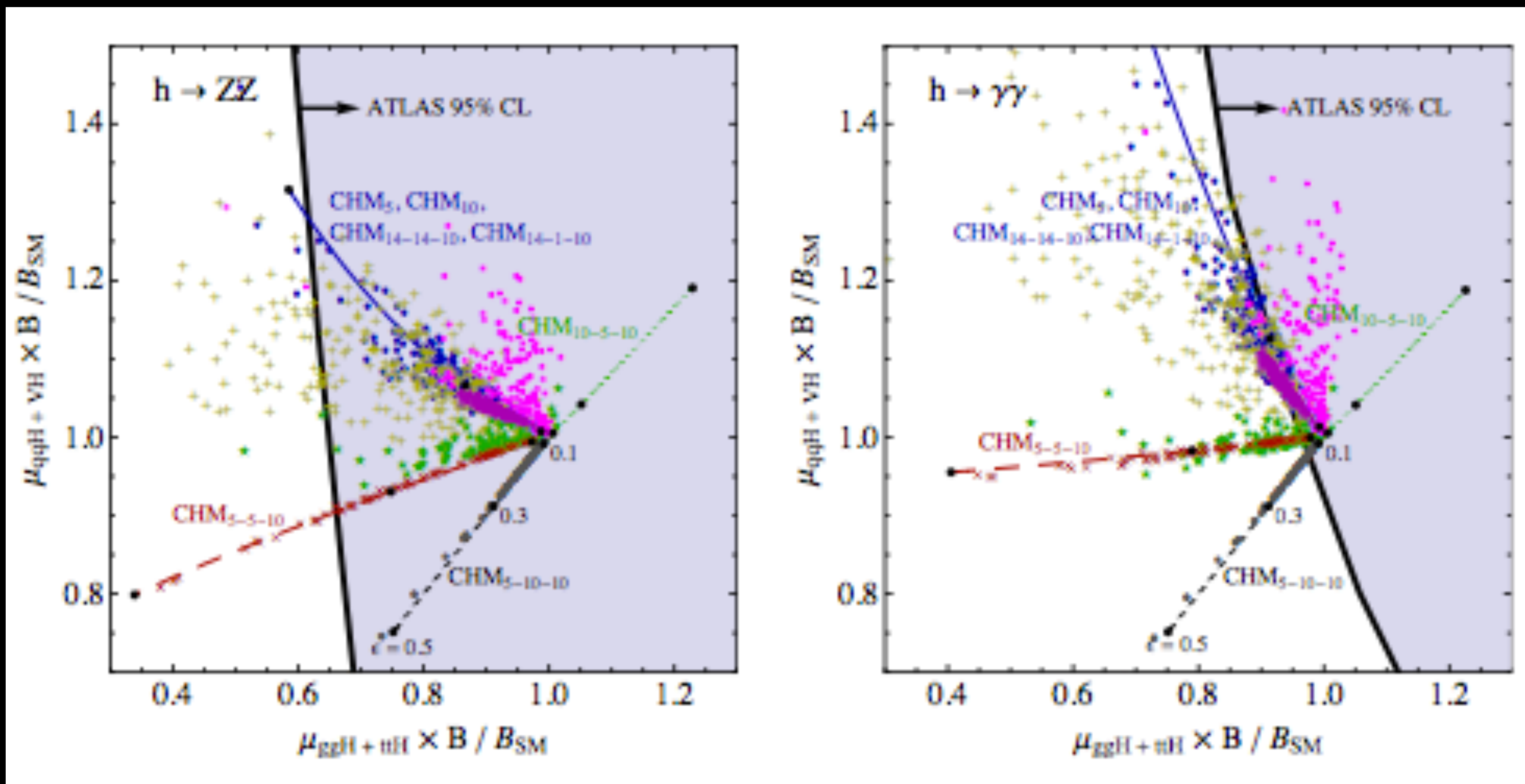
Dine, Seiberg, Thomas; Antoniadis, Dudas, Ghilencea, Tziveloglou
M.C, Kong, Ponton, Zurita

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

→ diphoton rate constrained to be about the SM value

Arkani Hamed et al. '12

Minimal Composite Higgs models confronting data



Effects from {
- New colored and em charged fermions in the loops
- Mixing between new fermions and SM fermions
- Mixing between new guage bosons and SM ones

M.C., Da Rold, Ponton, Preliminary

Effective Theory Analyses

Chiral Lagrangian for a light SM-like scalar boson

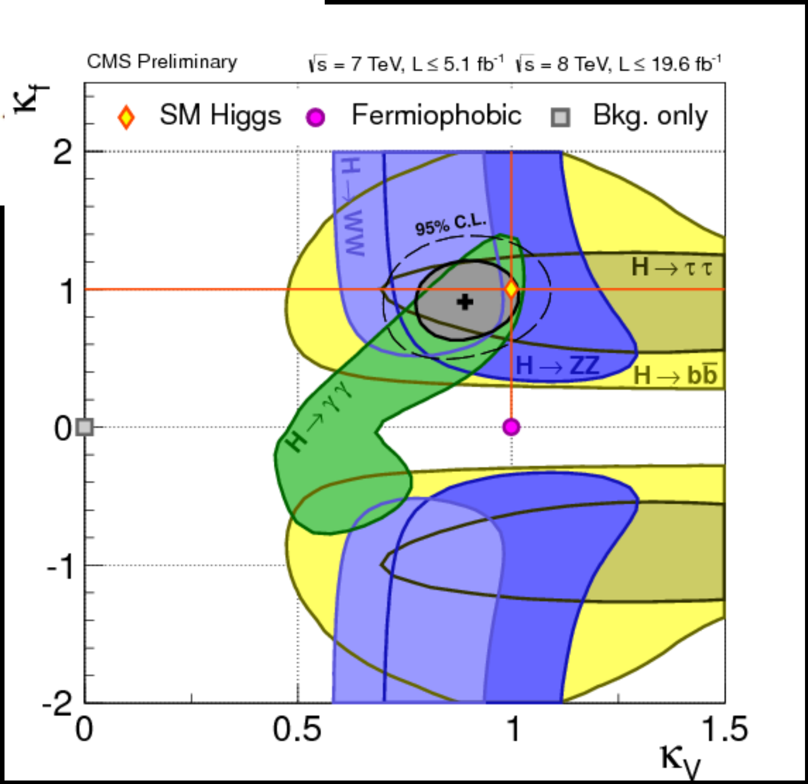
$$\mathcal{L} = \frac{1}{2}(\partial_\mu h)^2 - \frac{1}{2}m_h^2 h^2 - \frac{d_3}{6}\left(\frac{3m_h^2}{v}\right)h^3 - \frac{d_4}{24}\left(\frac{3m_h^2}{v^2}\right)h^4 \ldots$$

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

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

+ dimension 6 operators

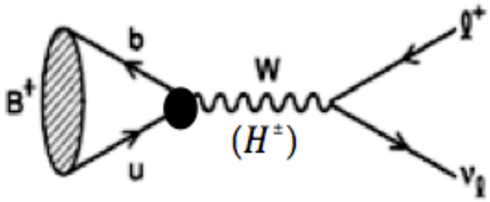
In the SM:
$a=b=c=d_3=d_4=1$
all h.d.o.
coefficients are 0



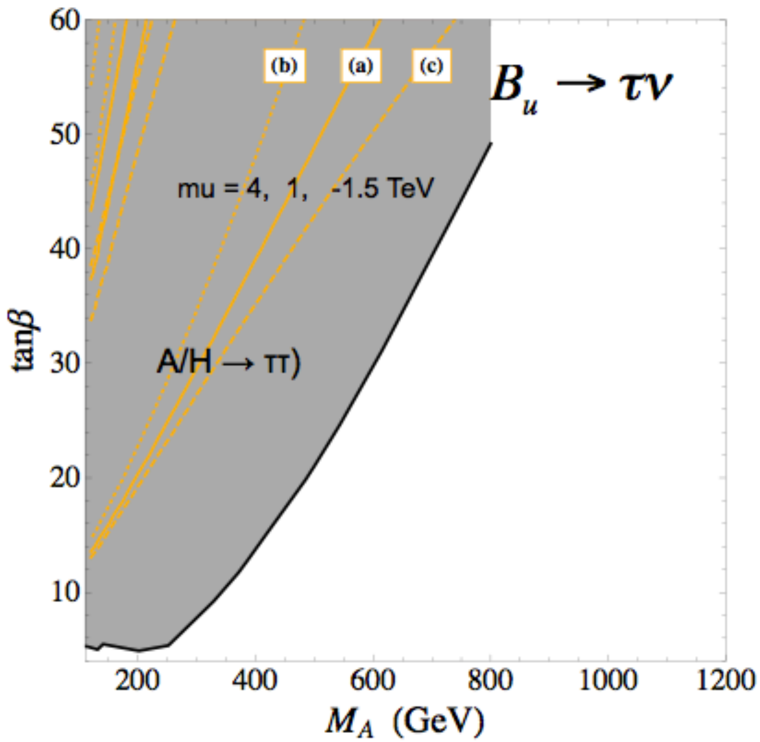
The Higgs discovery and the Higgs-flavor connection in the MFV MSSM

M_h ~ 125 GeV and flavor in the MSSM

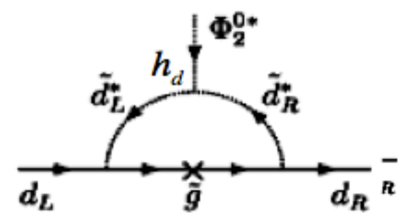
- **$B_u \to \tau\nu$ transition** MSSM charged Higgs & SM contributions interfere destructively



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



$$\varepsilon_0^i \approx \frac{2\alpha_s}{3\pi}\frac{\mu^* M_{\tilde g}^*}{\max\left[m_{\tilde d_1^i}^2, m_{\tilde d_2^i}^2, M_{\tilde g}^2\right]}$$



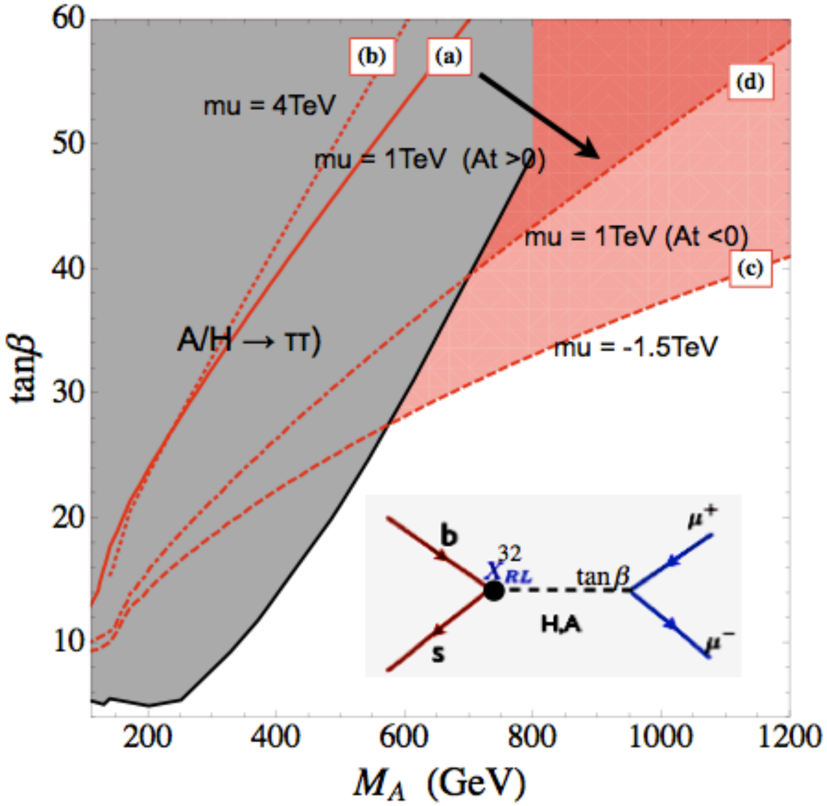
Independent on stop mixing
Almost independent of
SUSY breaking scale
it became less powerful than direct
Heavy Higgs searches for large tanβ

Altmannshofer, MC, Shah,Yu '12.

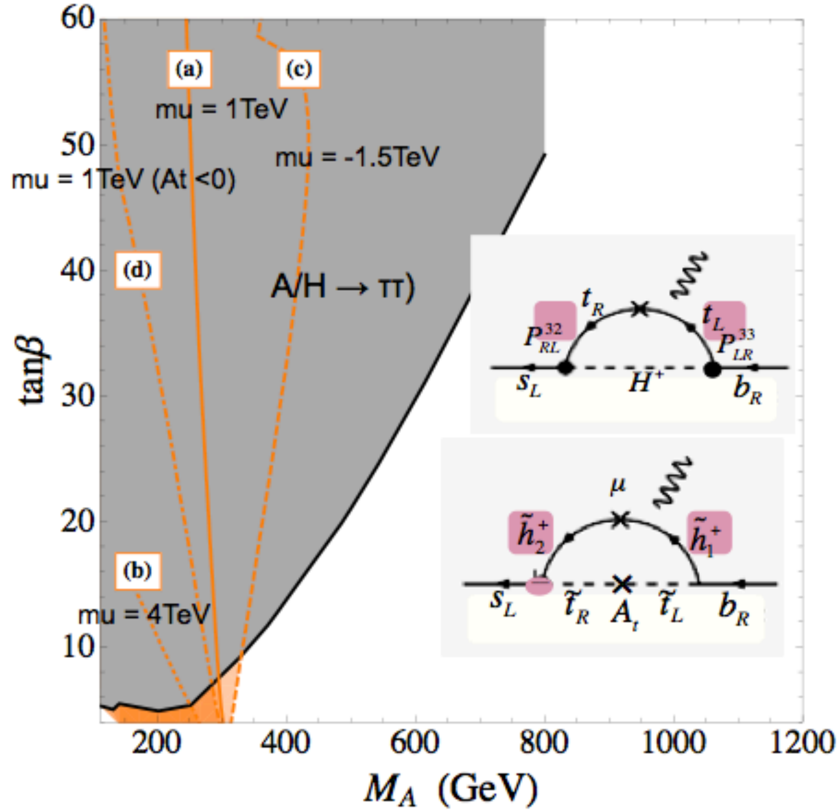
M_h ~125 GeV and Higgs-flavor connection in the MFV MSSM

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

Outlook

The Higgs Discovery is of paramount importance

We need more precise measurements of Higgs Properties
to further advance in our understanding of EWSB

This is one of the most exciting moments in our field in decades

We expect physics beyond the SM
Where to find it? How to interpret it?

NP can be new particles, new interactions or something else

- **What does the Higgs tells us about Naturalness?**
- **Is there a Higgs Portal to Dark Matter?**
- **How does the Higgs interact with neutrinos?**
- **Is the Higgs triggering baryogenesis?**