Φυσική Χιγκς ως Διερευνητης της Νέας Φυσικής

1st International Conference on New Frontiers in Physics

Κολυμπαρι, Κρήτη, Ιούνιος 2012

Marcela Carena
Fermilab and EFI/KICP, U. of Chicago

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Higgs Physics as a Probe of New Physics

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The Tevatron and LHC experiments

are extensively testing the SM-like Higgs above the LEP limit

Talks by Prokofiev, Choudhury and Safonov

The SM works beautifully, explaining all experimental phenomena to date with great precision ➔ no compelling hints for deviations

But many questions remain unanswered:

Higgs hierarchy problem, Dark Matter, Matter-antimatter asymmetry

…

Hence, the "prejudice" that there must be "New Physics"

the "hope" that it is around the corner

Beyond the SM scenarios of EWSB:

- **Weakly interacting, self-coupled, elementary scalar (Higgs) dynamics**

Standard Model, Supersymmetry

Antoniadis' & Zoupanos' talks

- **New strong dynamics at the TeV scale** among new fermions, perhaps mediated by gauge interactions, in possible connection with warped extra dimensions

QCD-like technicolor, Higgsless 5D models, top-condensation/top-color,
Little Higgs, Gauge Higgs unification, …

- ○ **No Higgs Boson**
- ○ **Composite Higgs Bosons:** attractive four-Fermi interactions form a quark condensate
- ○ **Pseudo Nambu-Goldstone Higgs Boson:** (also a composite Higgs)
  associated to a global symmetry partly broken by gauge/Yukawa interactions

These mechanisms generate new particles with experimental signatures and
strong impact on Higgs production and decay rates

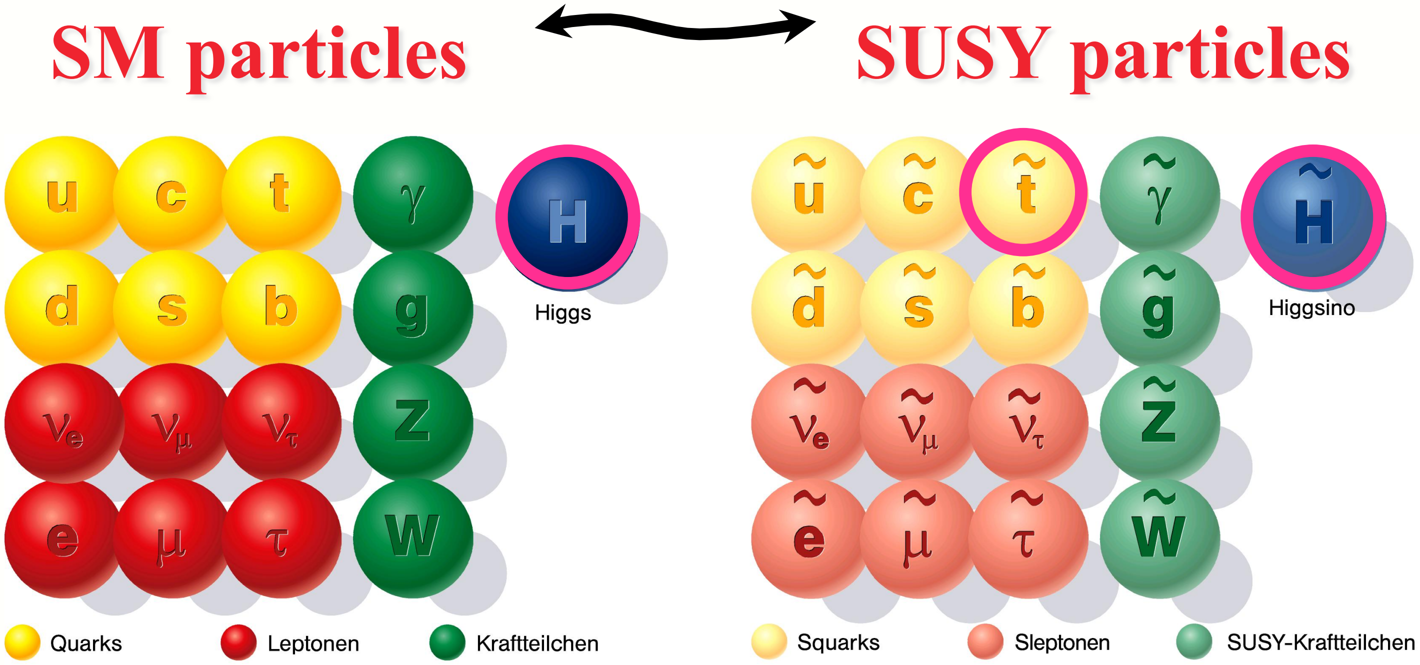
What does a 125 GeV Higgs mean for the different BSM framework?

- For No Higgs models these are bad news.
- For Composite Higgs/Pseudo-Goldstone Higgs models it depends on the scenario
- What about SUSY?

New Fermion-Boson Symmetry: **SUPERSYMMETRY** (SUSY)

==> For every fermion there is a boson with equal mass and couplings

Just as for every particle there exists an antiparticle



- **Helps stabilize the weak-scale—Planck scale hierarchy**
- **Provides good Dark Matter candidate (the Lightest SUSY Particle)**
- **Allows for Gauge coupling Unification**
- **Induces electroweak symmetry breaking radiatively**

A good BSM

What does SUSY imply for the Higgs Sector?

- Minimal Higgs Sector: Two Higgs doublets

  2 CP-even h (SM-like), H with mixing angle α

  + 1 CP-odd A + 1 charged pair $H^{\pm}$

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

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

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

  ➔ **Higgs interactions flavor diagonal if SUSY preserved**

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

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

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

- Important quantum corrections to the lightest Higgs 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 Higgs mass strongly depends on:

* CP-odd Higgs mass m_A * tan beta *the top quark mass

*the stop masses and mixing $$M^2_{\tilde{t}} = \begin{pmatrix} m^2_Q + m^2_t + D_L & m_t X_t \\ m_t X_t & m^2_U + m^2_t + D_R \end{pmatrix}$$

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 sbottom/stau sectors for large tan beta]

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

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

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

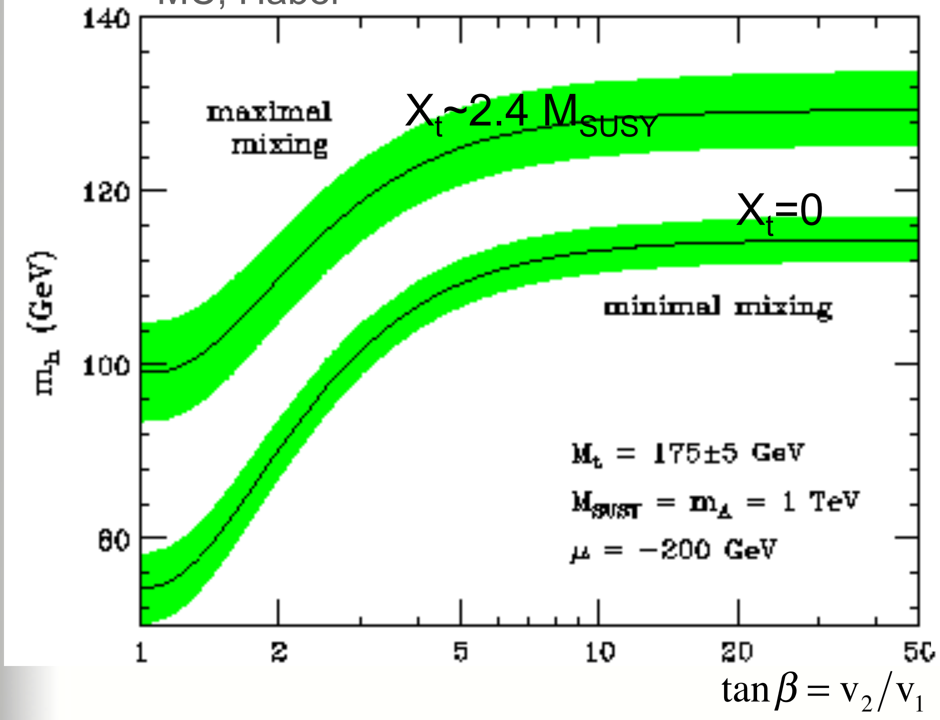
$\underline{X_t = A_t - \mu/\tan\beta}$ → LR stop mixing

M.C, Espinosa, Quiros, Wagner'95
MC, Quiros, Wagner '95

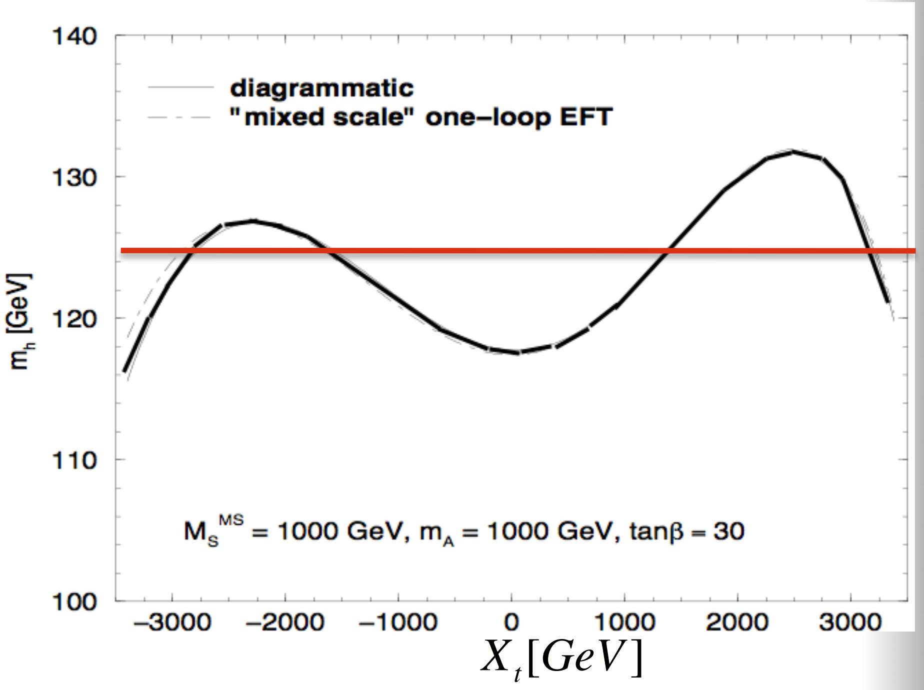
Analytic expression valid for $M_{SUSY} \sim m_Q \sim m_U$

SM-like MSSM Higgs Mass:

MC, Haber



M.C, Haber, Heinemeyer, Hollik, Weiglein, Wagner



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

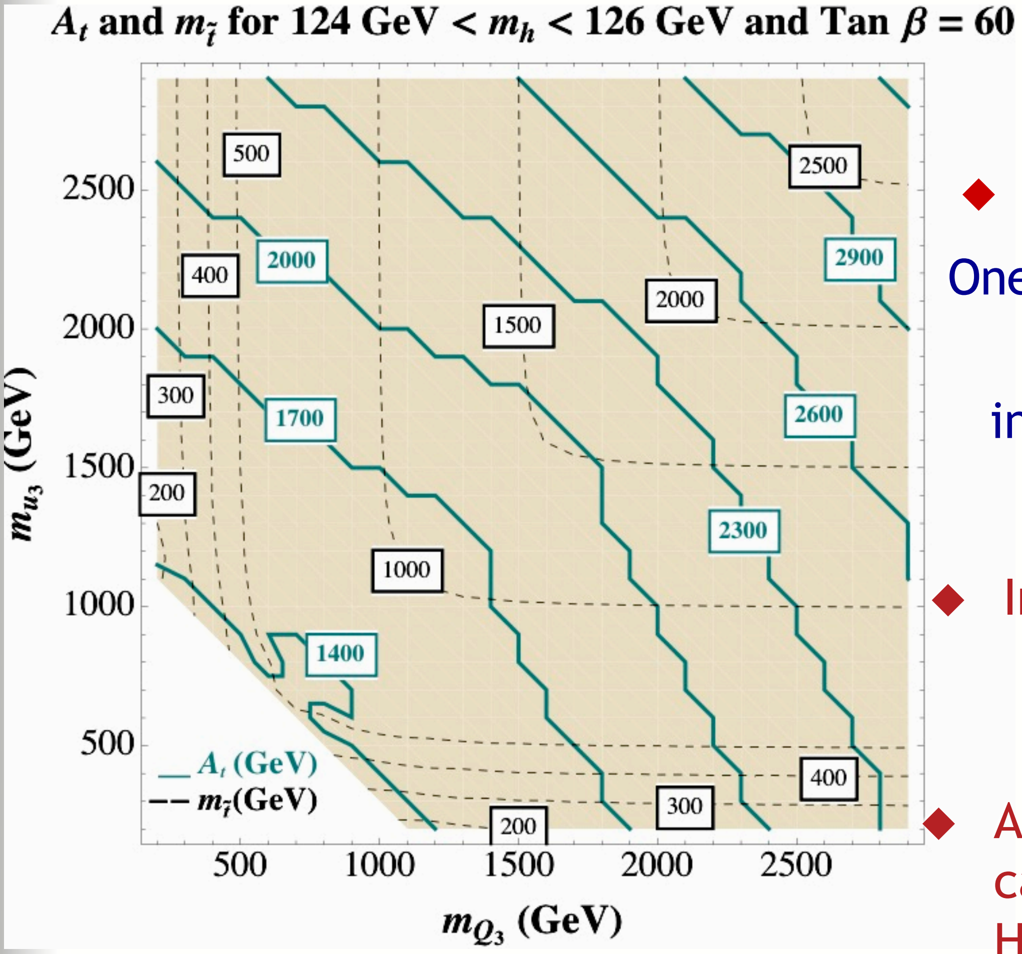
(for sparticles of ~ 1 TeV)

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, …

What does a 125 GeV SM-like Higgs imply for SUSY?

- **Low energy MSSM** (no constraints on high energy parameters of the theory)



A_t and $m_{\tilde{t}}$ for 124 GeV < m_h < 126 GeV and Tan β = 60

M.C, Gori, Shah, Wagner'11

◆ 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 stop can be below 1TeV

◆ Intermediate values of tan beta lead to the largest values of m_h for the same values of stop mass parameters

◆ At large tan beta, light staus/sbottoms can decrease mh by several GeV's via Higgs mixing effects and compensate tan beta enhancement

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

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 new physics.
- If one partial width is modified, then the total width is modified as well, producing modifications of all BR's.

Wagner's talk

Main production channel: Gluon Fusion

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

How much can we perturbe the gluon production mode?

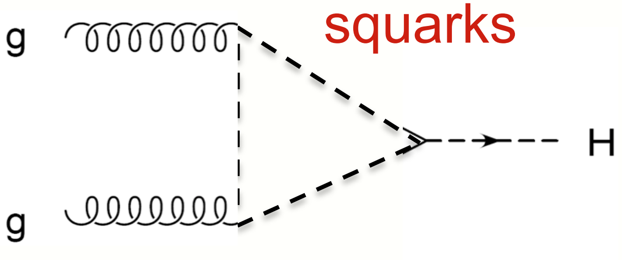
Is it possible to change WW and ZZ decay rates independently?

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

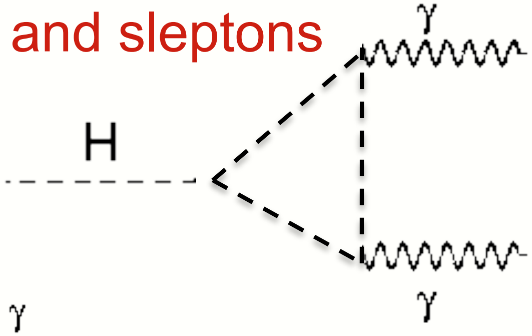
What about the decay rate into b-pairs at the Tevatron? (Figure)

Departures in the production and decay rates at the LHC:

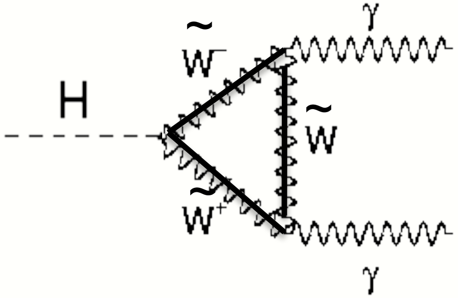
- Through SUSY particle effects in loop induced processes



squarks



squarks and sleptons



charginos

- Through enhancement/suppression of the Higgs-bb and Higgs-di-tau coupling strength via mixing in the Higgs sector :

This affects in similar manner BR's into all other particles

Gluon Fusion in the MSSM

- Receives contributions from top, **stops and sbottoms** (via mixing for large tan beta) **[if masses above 1 TeV➔ very mild modifications]**
- Light 3rd gen. squarks can increase the gluon fusion rate, but A_t as required for m_h values of interest, tends to lead to its suppression

. Dermisek,Low

$$\sigma(gg \to h)/\sigma(gg \to h)_{SM}$$

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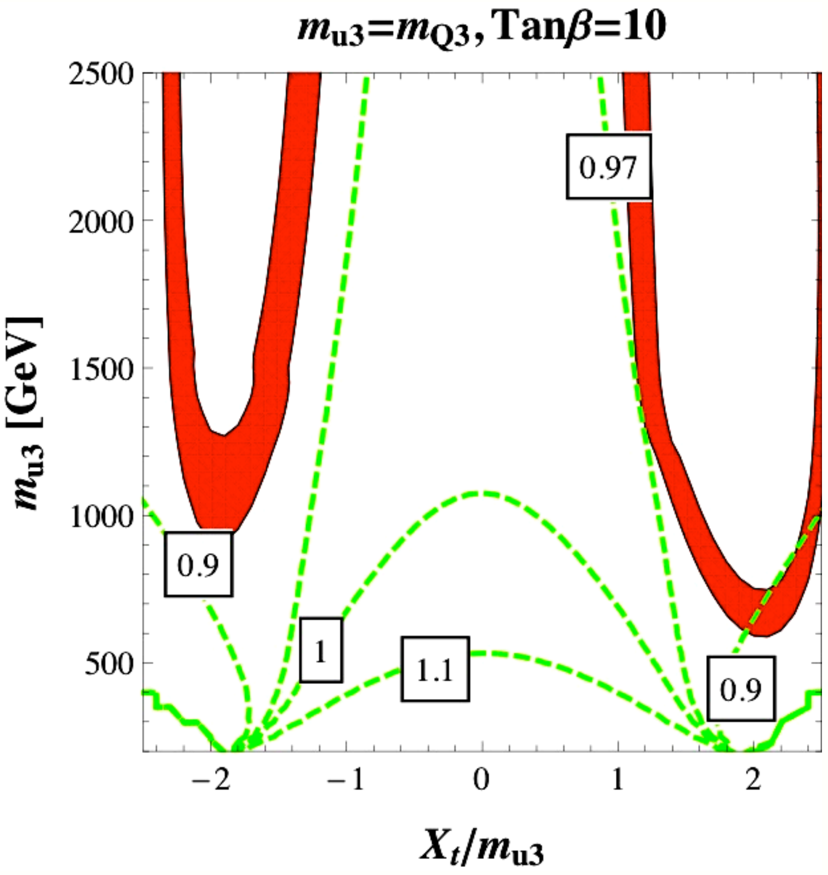
mh ~ 124-126 GeV range

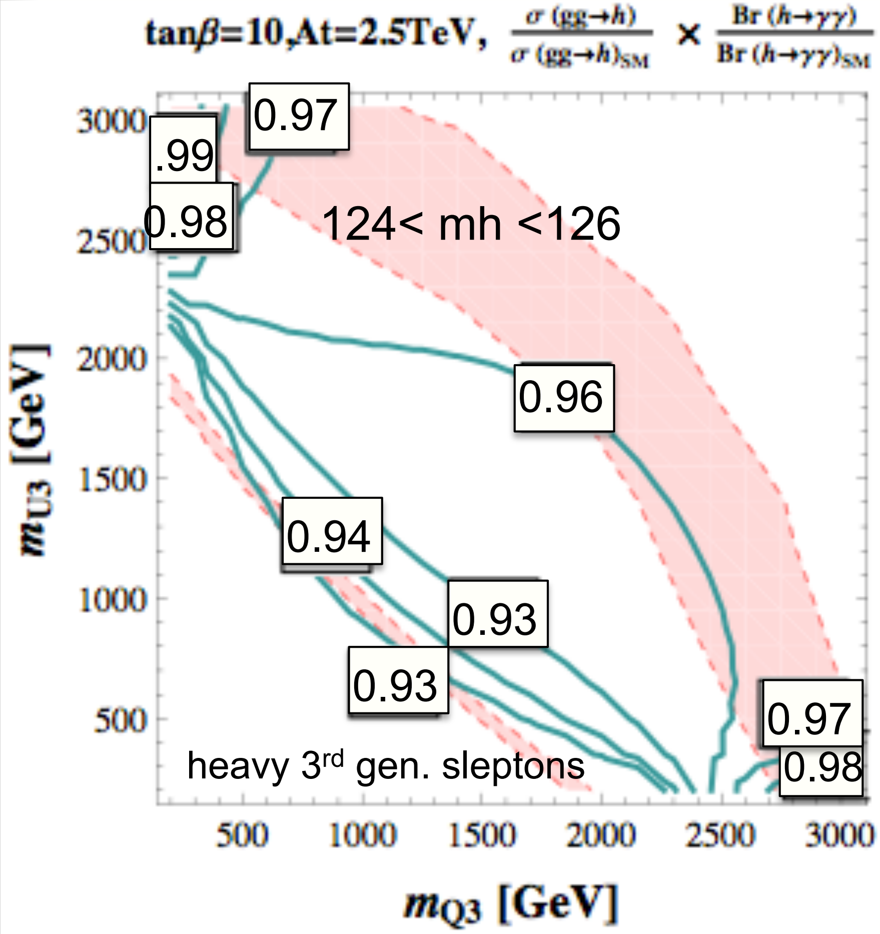
Present LHC limits on stop masses are model dependent



Squark effects in gluon fusion and di-photon decay in the MSSM

For $M_h \sim 125$ GeV in the MSSM ➔ sizeable stop mixing parameter

- **Gluon fusion: suppression**
- **Di-photon decay rate:** enhancement



. M.C, Gori, Shah, Wagner'11

Effect of SUSY particles in di-photon rate:

In SM: W loop partially suppressed by the top loop.

In SUSY: light stops give suppression or, **if mixing is large**, produce enhancement

See also Wagner's talk

For heavy third gen. sleptons, and third gen. squark masses consistent with a 125 GeV Higgs, overall effects tends to lead to **suppression in**

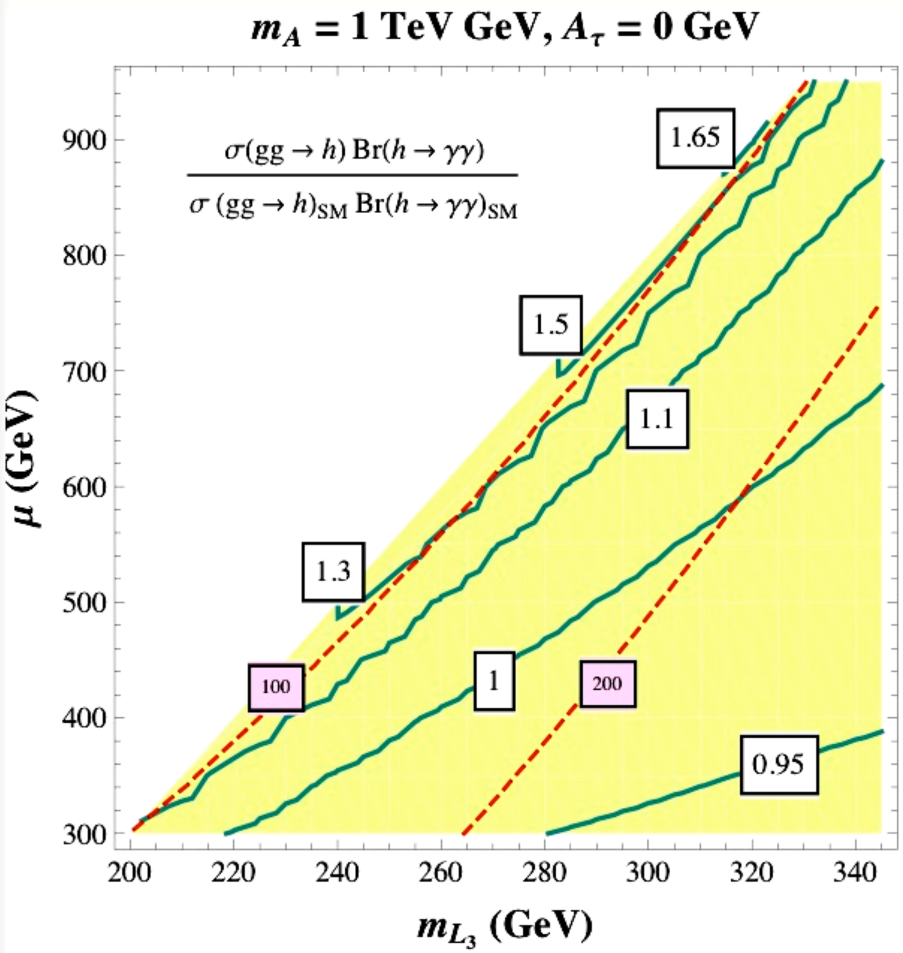
Gluon fusion x di-photon decay

$$\sigma(gg\to h)BR(h\to\gamma\gamma) \le \sigma(gg\to h)_{SM}\, BR(h\to\gamma\gamma)_{SM}$$

In the MSSM for light Staus with large mixing [sizeable mu and tan beta]

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

Higgs into di-photon rate can be enhanced



. M.C, Gori, Shah, Wagner

$$\Delta A_{\gamma\gamma} \propto \frac{Q_{\tilde{S}}^2}{3} \frac{\partial \log\left[\det M_{\tilde{S}}^2(v)\right]}{\partial \log(v)}$$

$$\Delta A_{\gamma\gamma} \propto -\frac{(\mu \tan\beta)^2 m_\tau^2}{m_{L3}^2 m_{e3}^2 - m_\tau^2 (\mu \tan\beta)^2}$$

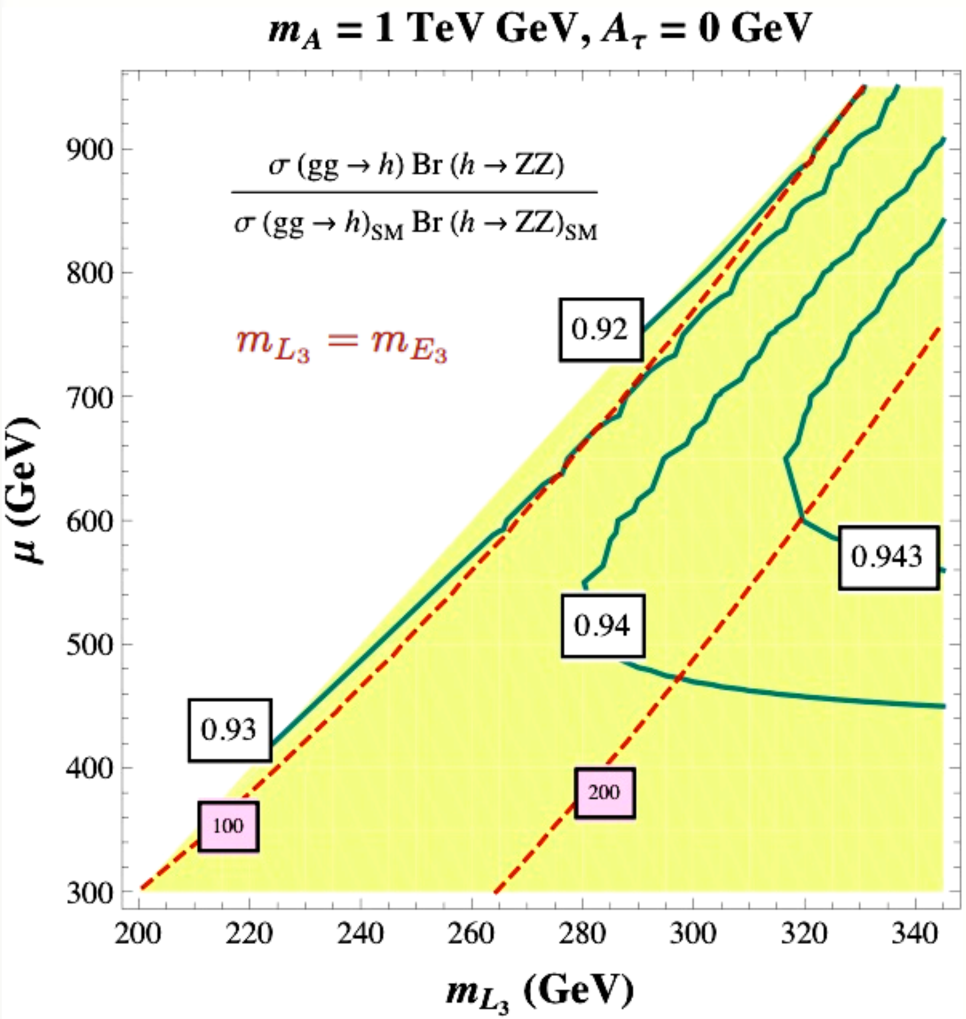
Contours of constant

$$\frac{\sigma(gg \to h) Br(h \to \gamma\gamma)}{\sigma(gg \to h)_{SM} Br(h \to \gamma\gamma)_{SM}}$$

for $M_h \sim 125$ GeV

In the MSSM for light Staus with large mixing [sizeable mu and tan beta]

Higgs into di-photon rate can be enhanced without changing the Higgs into WW/ZZ rates



Contours of constant

$$\frac{\sigma(gg \to h)Br(h \to ZZ)}{\sigma(gg \to h)_{SM}\,Br(h \to ZZ)_{SM}}$$

for M_h ~ 125 GeV

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

. [M.C, Gori, Shah, Wagner]

Mixing Effects in the CP- even Higgs Sector

- Mixing can have relevant effects in the production and decay rates

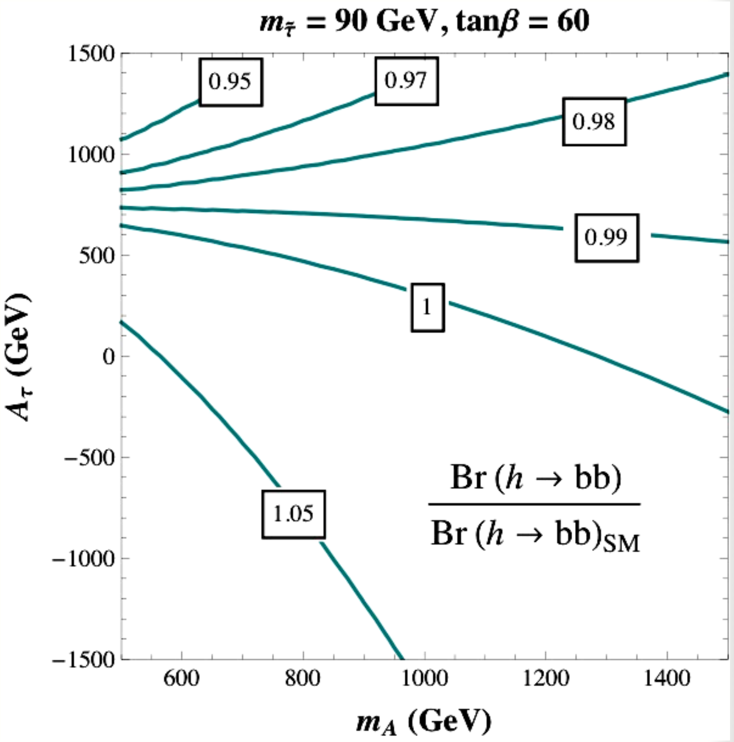
$$\mathcal{M}_H^2 = \begin{bmatrix} m_A^2 \sin^2\beta + M_Z^2 \cos^2\beta & \boxed{-(m_A^2 + M_Z^2)\sin\beta\cos\beta + \mathrm{Loop}_{12}} \\ -(m_A^2 + M_Z^2)\sin\beta\cos\beta + \mathrm{Loop}_{12} & m_A^2 \cos^2\beta + M_Z^2 \sin^2\beta + \mathrm{Loop}_{22} \end{bmatrix}$$

$$\mathrm{Loop}_{12} \sim + \frac{h_\tau^4 v^2}{48\pi^2} \sin^2\beta \frac{\mu^3 A_\tau}{M_{\tilde{\tau}}^4}$$

Important effects through radiative corrections
to the CP-even mass matrix
which defines the mixing angle alpha

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

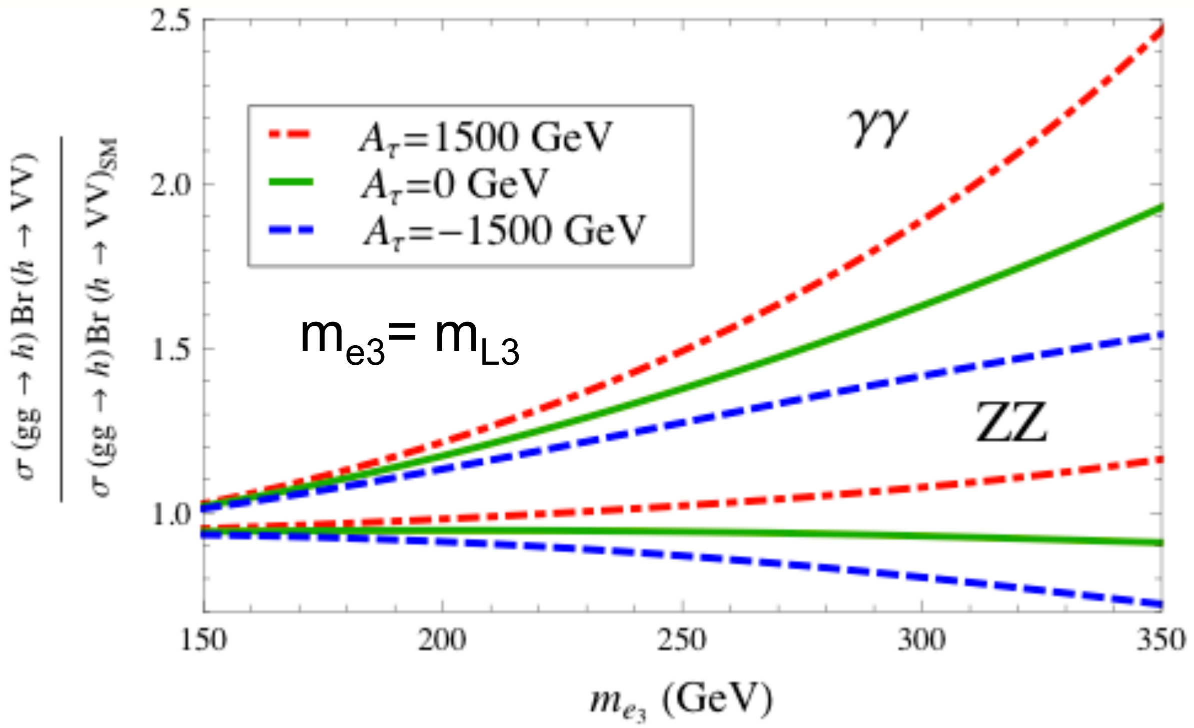
$$hb\bar{b} : \quad -\frac{\boxed{\sin\alpha}}{\cos\beta}$$



Small Variations in the Br(H→bb) can induce significant variations in the other Higgs Br's

Further modifications of the Higgs rates into gauge bosons via A_{tau} mixing effects in the Higgs sector

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



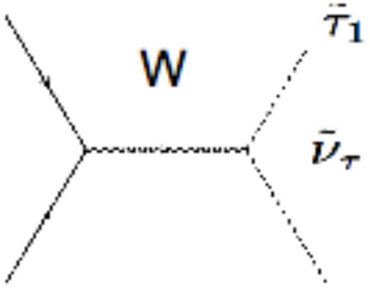
Light stau ~ 90 GeV $\qquad$ M_h ~ 125 GeV

In good agreement with precision EW measurements

Correct DM relic density through stau co-annihilation

Stau Searches at the LHC

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



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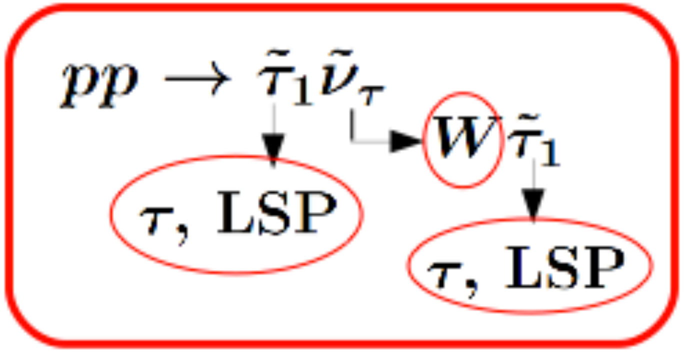


signature:
Lepton, 2 taus, missing energy

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

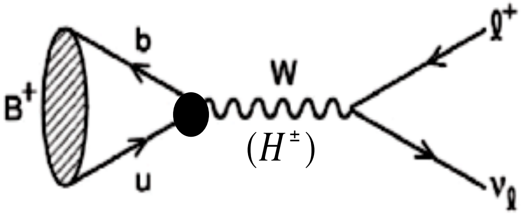
Estimation at the parton level shows promising results at 8 TeV LHC

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

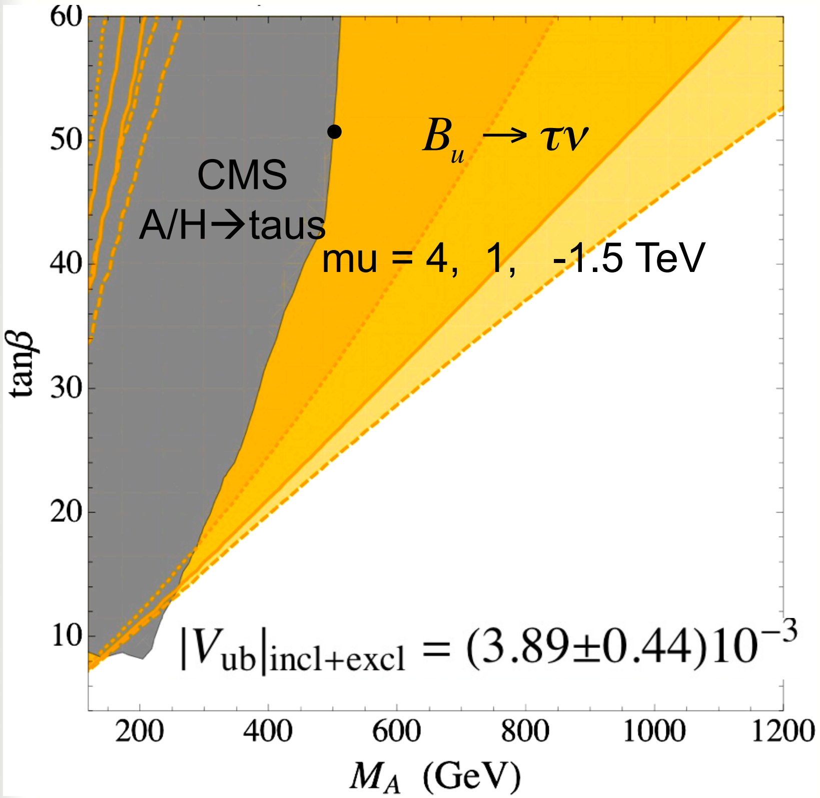
The Higgs-Flavor connection

M_h ~ 125 GeV and Minimal Flavor Violation in the MSSM

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



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

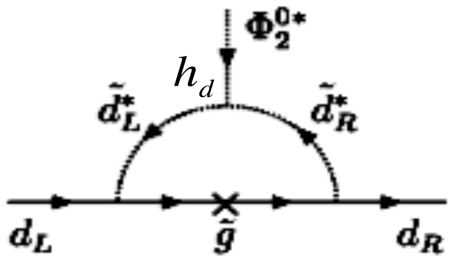


Altmannshofer, MC, Shah,Yu

Radiative corrections:

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

ε loop factors intimately connected to the structure of the squark mass matrices.



•Independent on stop mixing

•Almost independent of RG evolution

more powerful than Higgs searches

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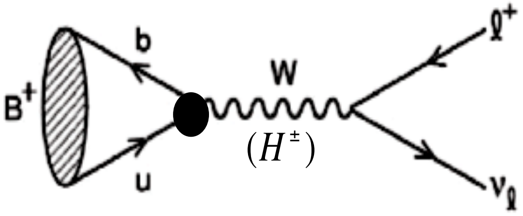

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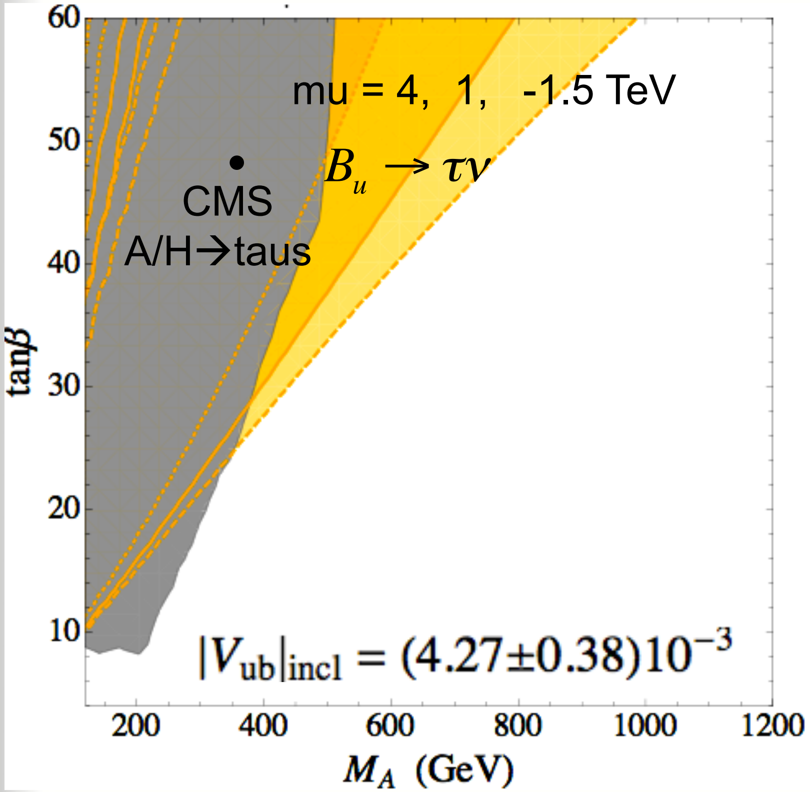

Altmannshofer, MC, Shah,Yu

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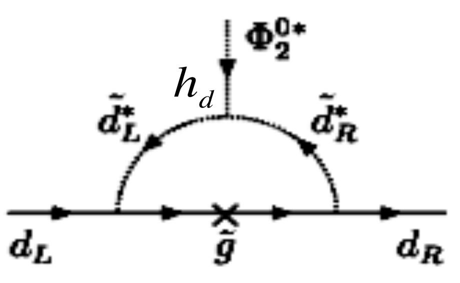

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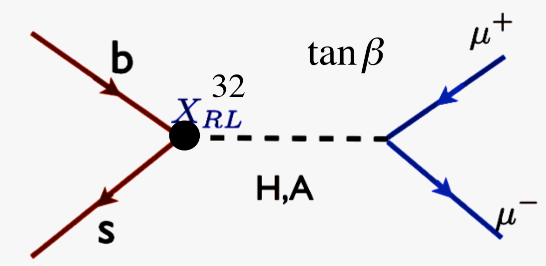
M_h ~ 125 GeV and Minimal Flavor Violation in the MSSM

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

$$A_{SUSY}/A_{SM} \propto \frac{X_{RL}^{bs}\tan\beta}{m_A^2} \propto -\frac{\mu^* A_t^* \tan\beta^3}{m_A^2}$$

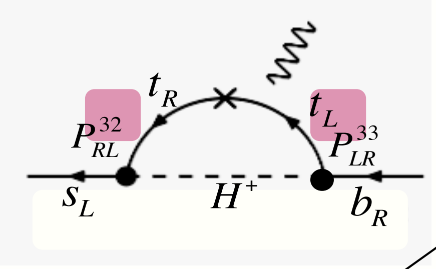


$$\text{with } \left(\mathrm{X}_{\mathrm{RL}}^{\mathrm{H/A}}\right)^{bs} \approx -\frac{\mathrm{m_b}}{\mathrm{v}}\frac{h_t^2\ \varepsilon_Y\ \tan\beta^2}{\left(1+\varepsilon_0^3\tan\beta\right)\left(1+\Delta_b\right)}\mathrm{V}_{\mathrm{CKM}}^{tb^*}\mathrm{V}_{\mathrm{CKM}}^{\mathrm{ts}}$$

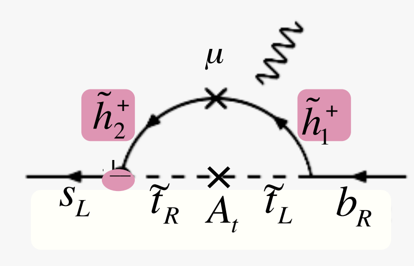
$$\varepsilon_Y \approx \frac{\mu^* A_t^*}{16\pi^2 \max\left[m_{\tilde t_1}^2, m_{\tilde t_2}^2, \mu^2\right]}$$

$$R^{33} = 1+\left(\varepsilon_0^3+\varepsilon_Y h_t^2\right)\tan\beta \equiv 1+\Delta_b$$

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



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

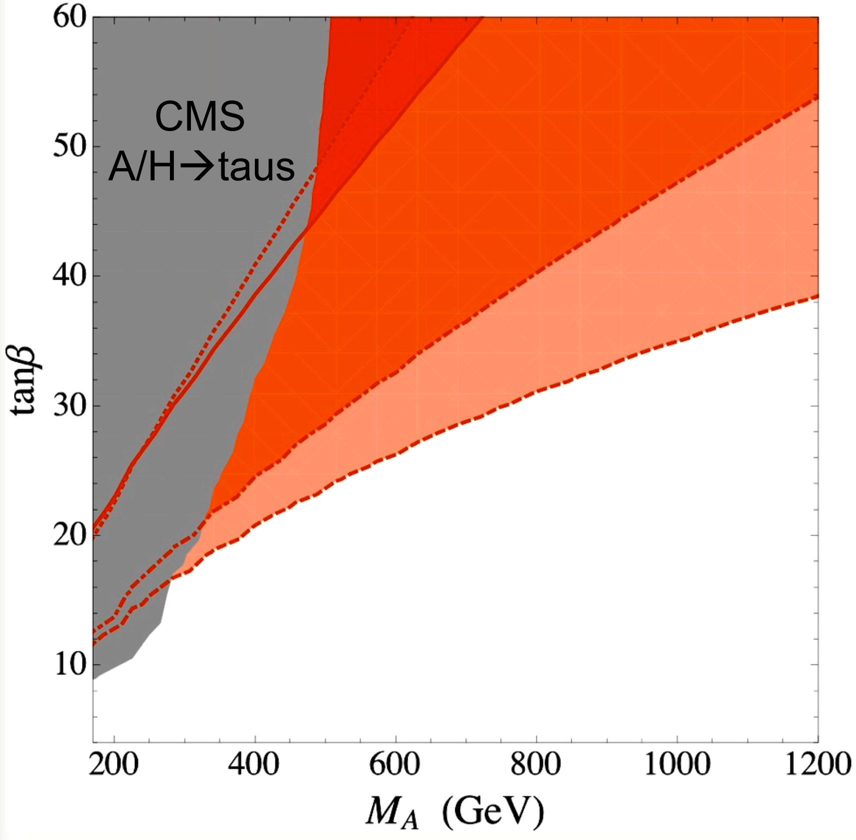


$$A_{H^+} \propto \frac{(h_t - \delta h_t\tan\beta)\,m_b}{\left(1+\Delta_b\right)} g[m_t, m_{H^+}]\ V_{ts}$$

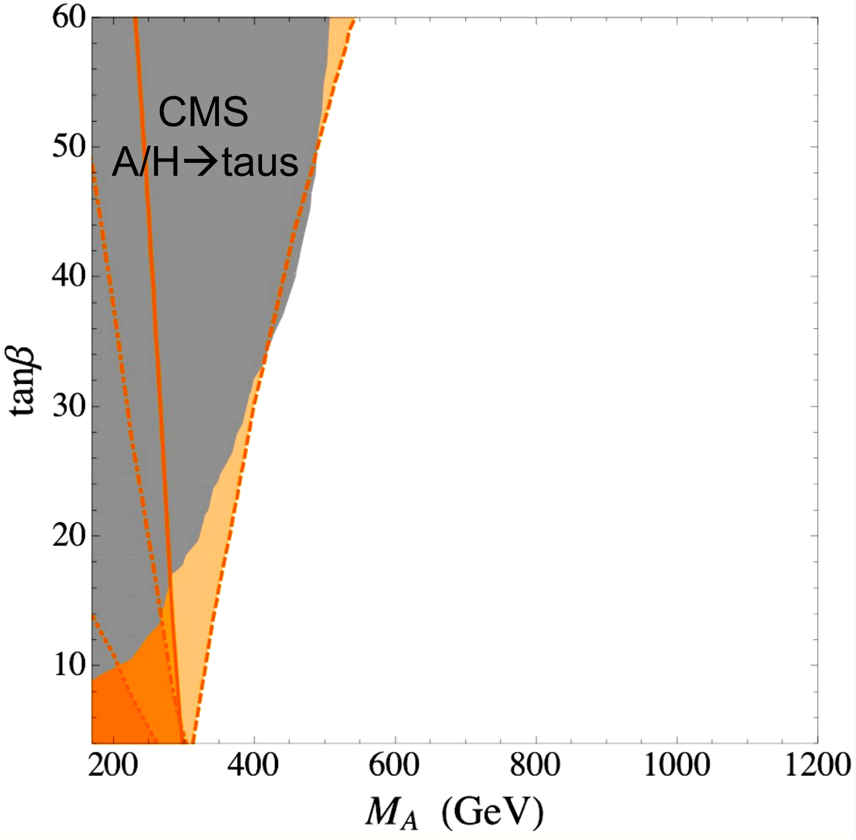
$$A_{\chi^+} \propto \frac{\mu A_t\tan\beta\ m_b}{\left(1+\Delta_b\right)} \mathrm{h}_t^2 f[m_{\tilde t_1}, m_{\tilde t_2}, \mu]\ V_{ts}$$

M_h ~ 125 GeV and flavor in the MSSM

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



Bounds from B $\rightarrow X_s$ gamma



Altmannshofer, MC, Shah,Yu

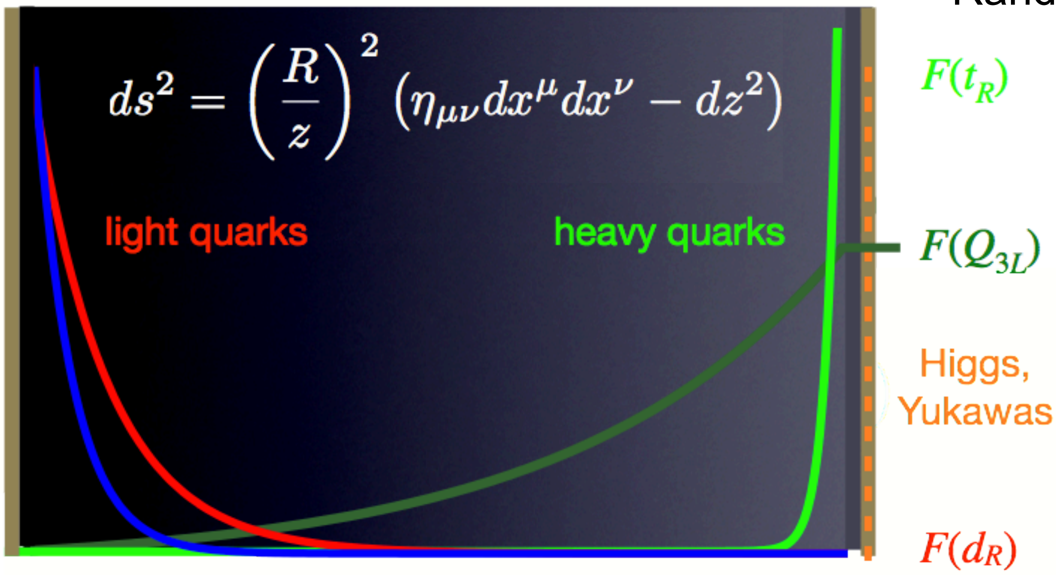
- Solid, dotted and dashed lines for for mu = 1, 4 and -1.5 TeV, respectively
  M_{gluino} = 1.5 TeV; M_{squark} = 2 TeV, A_t >0 and to give m_h=125 GeV
- Dot-dashed same as solid but for negative At

Embedding the SM in a Warped Extra Dimension

Randall, Sundrum

UV brane

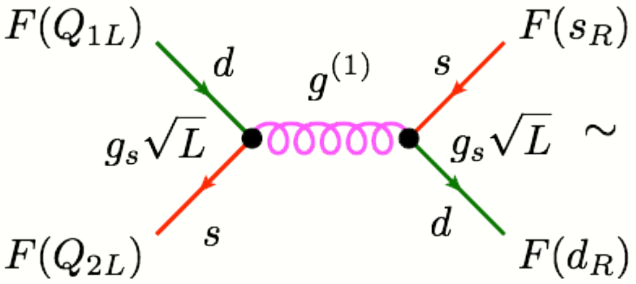
IR brane



Grossman, Neubert;
Ghergetta, Pomarol

Fermion localization depends exponentially on O(1) parameters related to 5D **bulk masses. Overlap integrals with IR-localized Higgs give fermion mass hierarchies**

RS-GIM protection of FCNCs



$$\sim \frac{g_s^2}{M_{\rm KK}^2} L\, F(Q_{1L}) F(d_R)\, F(Q_{2L}) F(s_R)$$

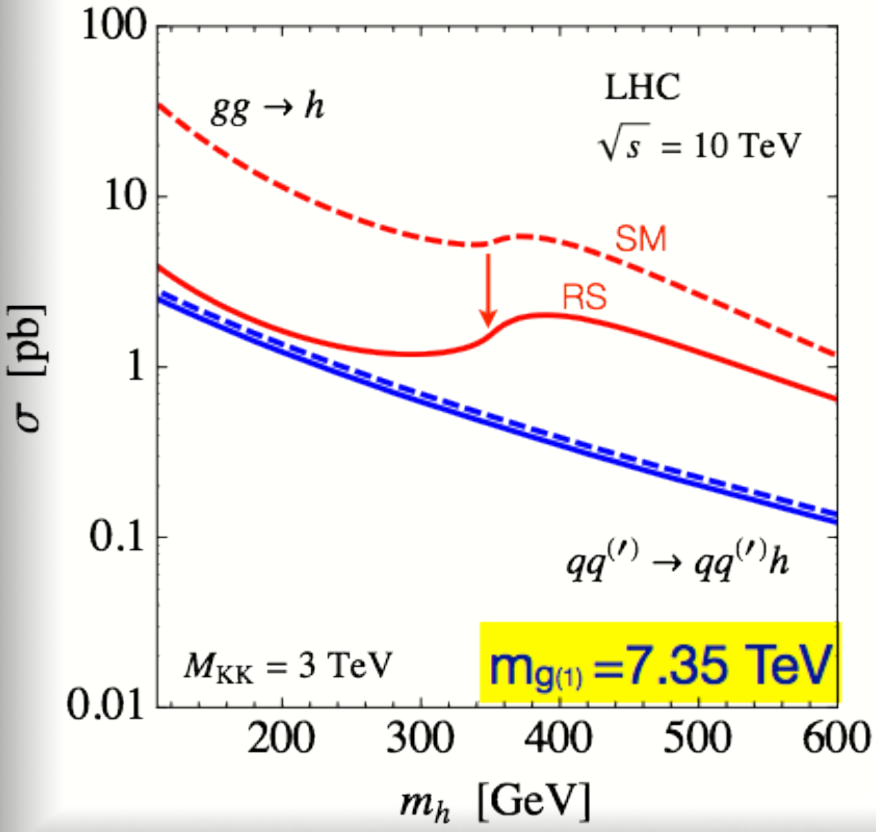
Still new symmetries needed to suppress dangerous FCNC's and to fit EWPT with KK modes in the few TeV mass range

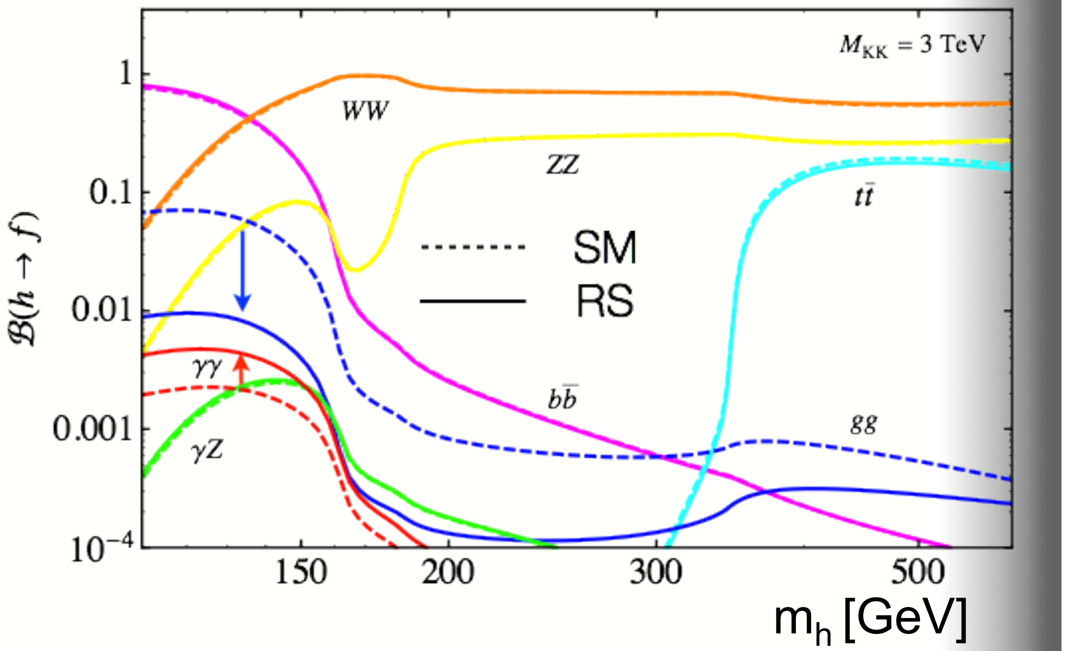
Higgs production cross sections and BR's in WED

- **Large number of bulk fermionic fields in the 5D theory induce large loop effects, changing the effective hγγ & hgg couplings significantly**

Spectacular effects on Higgs production via gluon fusion, even for KK masses out of production reach at LHC

Correspondingly, find **significant enhancement (suppression) of the h→γγ *(h→gg) branching ratios:***





Casagrande, Goertz, Haisch, Neubert, Pfoh

M.C, Casagrande, Goertz, Haisch, Neubert

Conclusions:

An MSSM SM-like 125 GeV Higgs implies

- Large mixing effects in the stop sector
- SM like Gluon-fusion production
- Possible enhanced di-photon rates if light staus with sizeable mixing *
- Possible modified di-photon/WW/ZZ rates if light staus + sizeable A_{tau}*

*large tan beta required

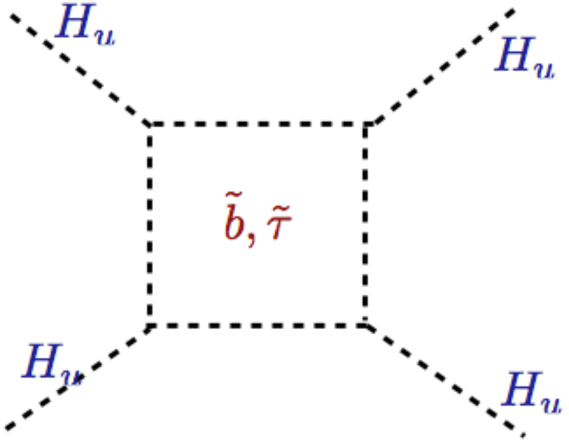
- Direct A/H searches and B-observable constraints restrict large regions of the tan beta-mA plane
- MFV (including RG effects) ➔ positive mu and A_t preferred

SUSY models with extra singlets, triplets, W', Z's can accommodate a 125 GeV SM-Higgs with modified production/decay rates

Models of Warped Extra dimensions have towers of new vector-like fermions than can importantly modify loop induced Higgs processes

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

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

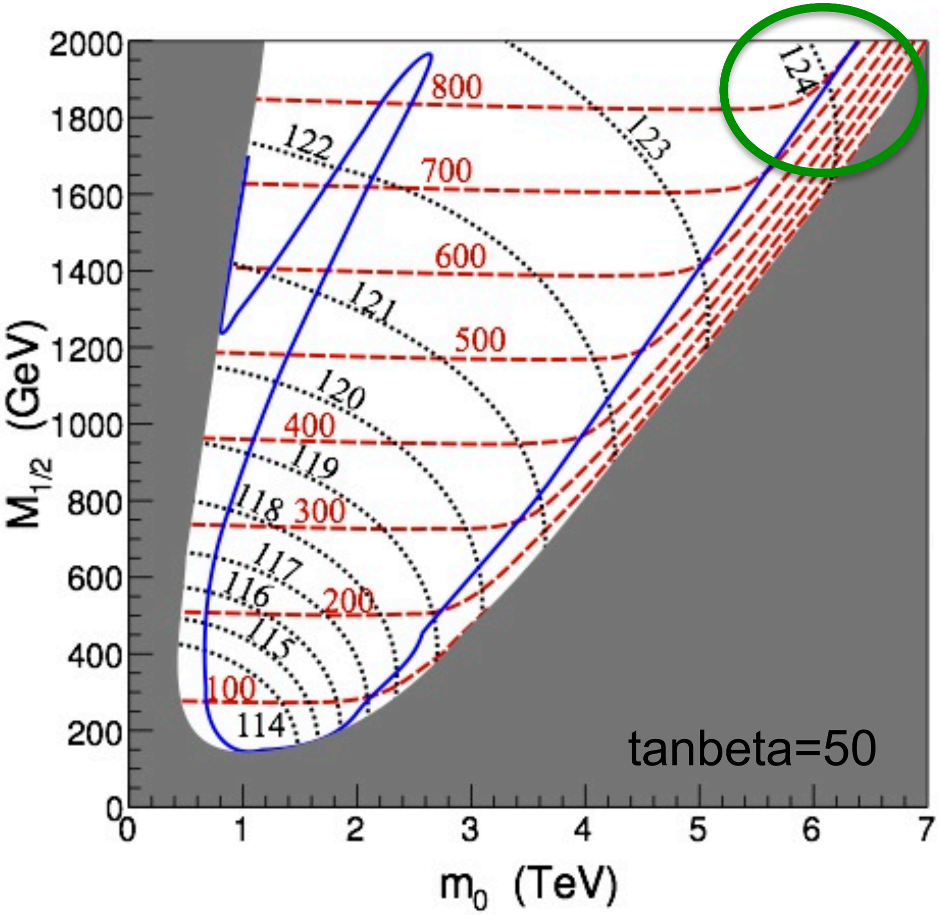
Both corrections give negative contributions to the Higgs mass hence smaller values of μ and positive values of μM_2 and $\mu M_{\tilde{g}}$ enhance the value of the Higgs mass

Maximal effect: lower m_h by several GeV

What does a 125 GeV SM-like Higgs imply for SUSY?

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

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



→Heavy scalars

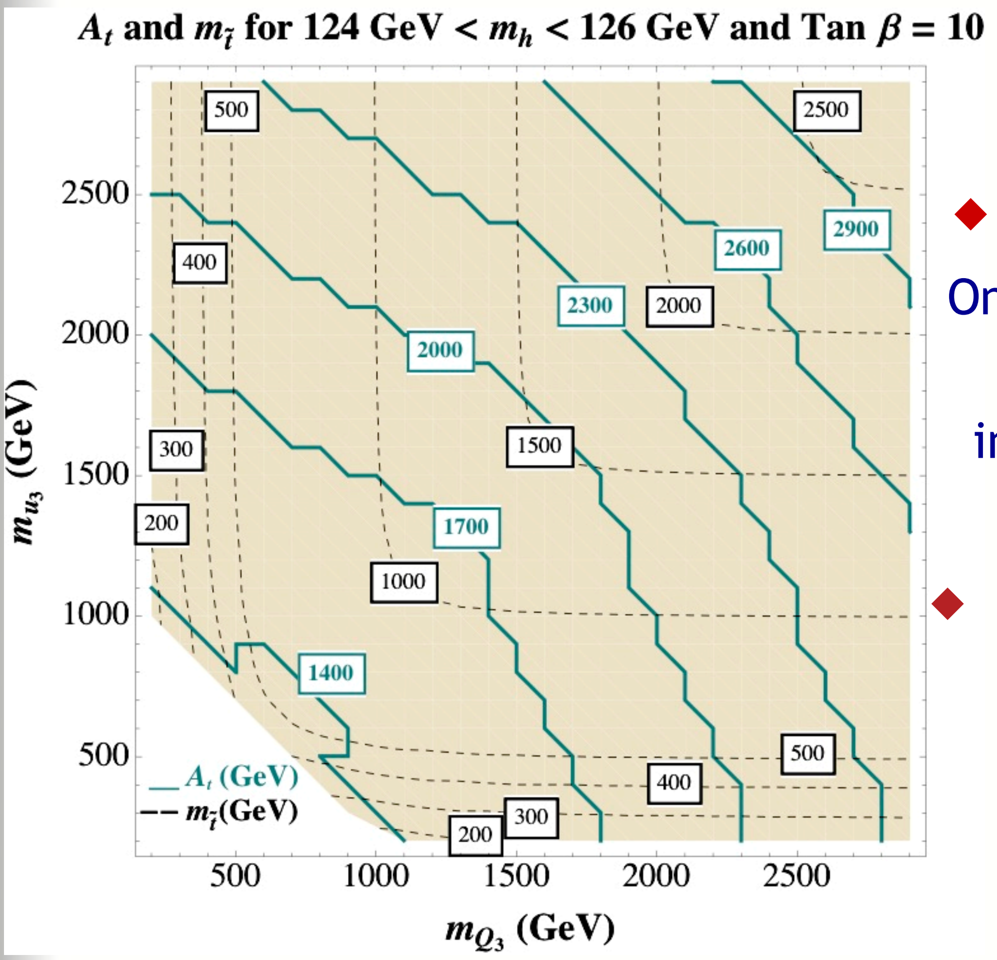
Good agreement with null results for SUSY searches :(

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

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

What does a 125 GeV SM-like Higgs imply for SUSY?

- **Low energy MSSM** (no constraints on high energy parameters of the theory)



A_t and $m_{\tilde{t}}$ for 124 GeV < m_h < 126 GeV and Tan $\beta = 10$

M.C, Gori, Shah, Wagner'11

◆ **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.

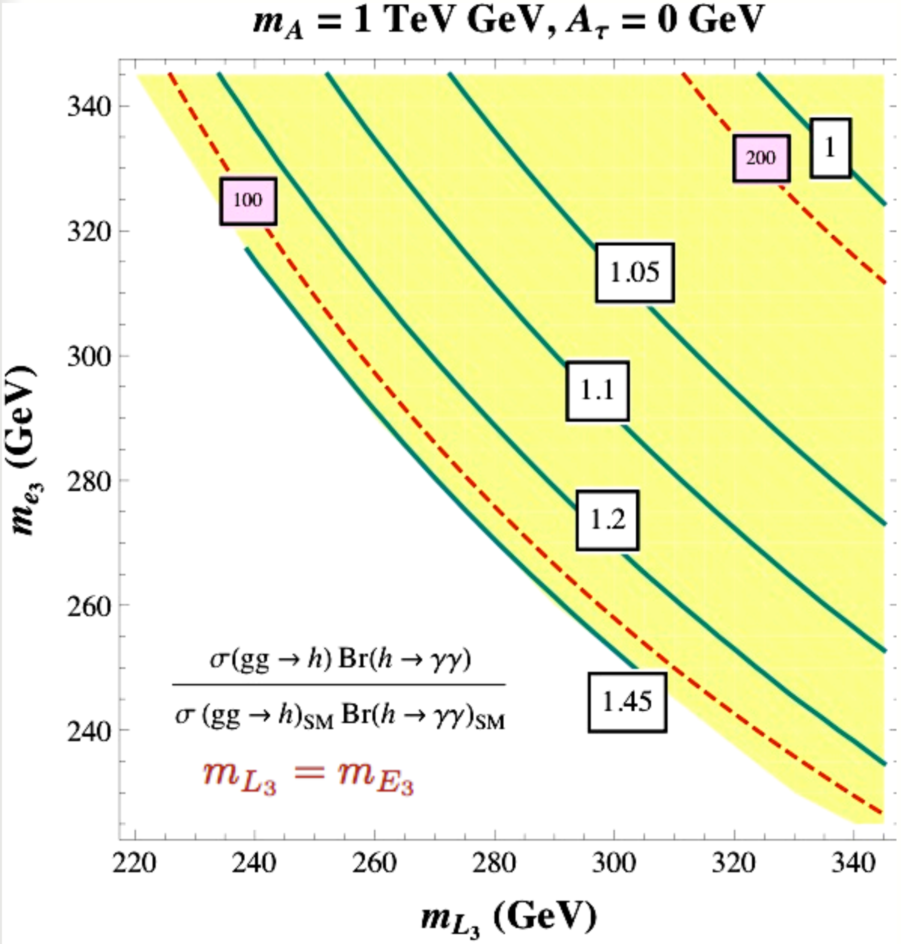
both stops can be below 1TeV

◆ Intermediate values of tan beta lead to the largest values of m_h for the same values of stop mass parameters

In the MSSM for light Staus with large mixing [sizeable mu and tan beta]

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

Higgs into di-photon rate can be enhanced



$$\Delta A_{\gamma\gamma} \propto \frac{Q_{\tilde{S}}^2}{3} \frac{\partial \log[\det M_{\tilde{S}}^2(v)]}{\partial \log(v)}$$

$$\Delta A_{\gamma\gamma} \propto -\frac{(\mu \tan\beta)^2 m_\tau^2}{m_{L3}^2 m_{e3}^2 - m_\tau^2 (\mu \tan\beta)^2}$$

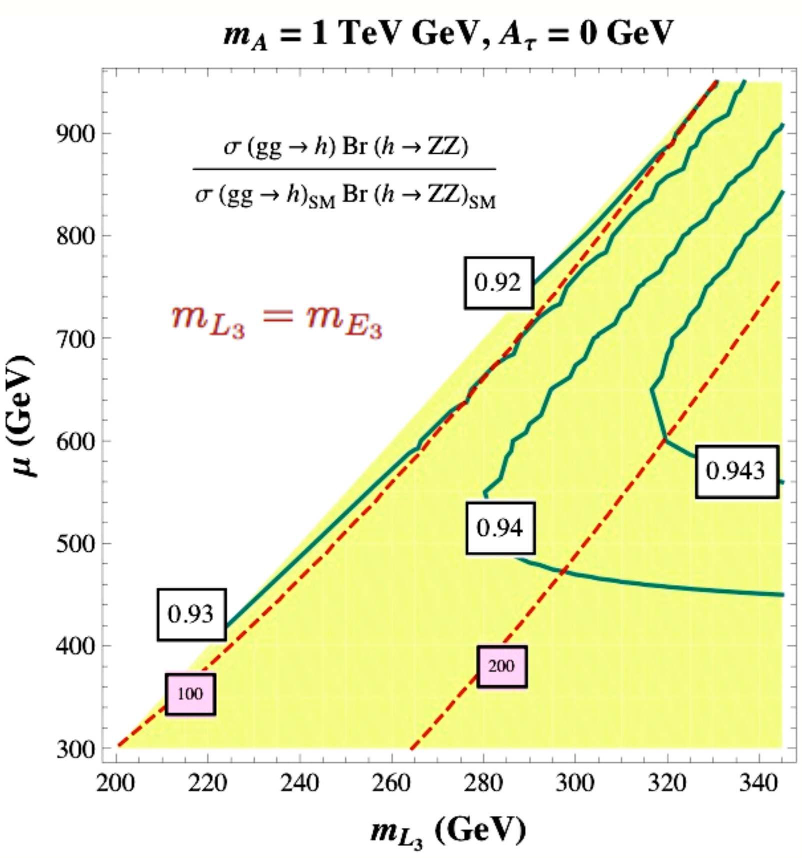
Contours of constant

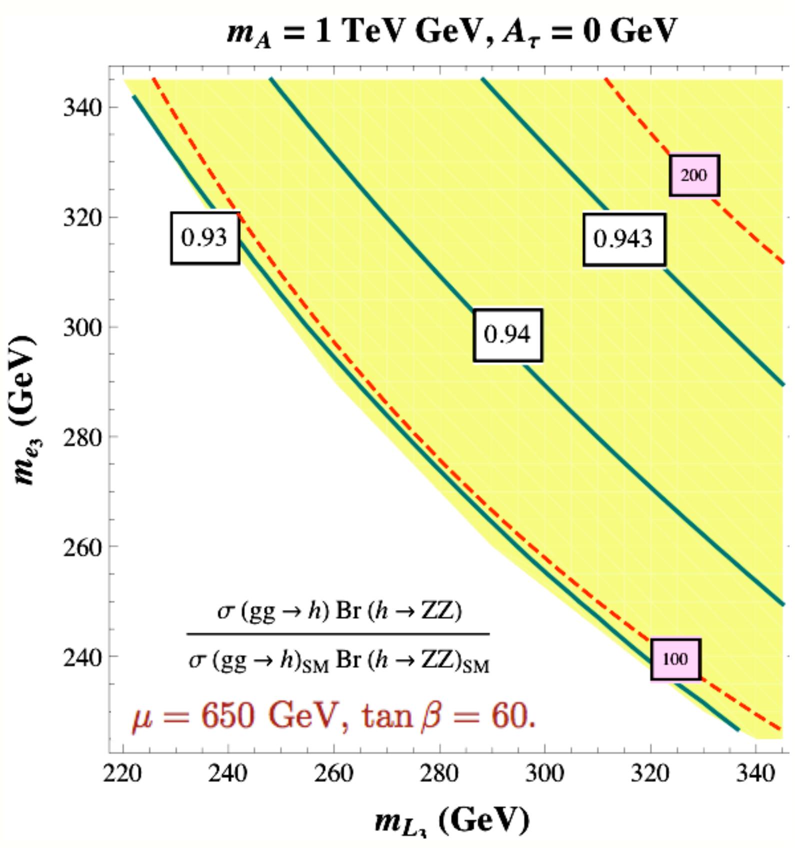
$$\frac{\sigma(gg \to h) Br(h \to \gamma\gamma)}{\sigma(gg \to h)_{SM} Br(h \to \gamma\gamma)_{SM}}$$

for M_h ~ 125 GeV

. M.C, Gori, Shah, Wagner

In the MSSM for light Staus with large mixing [sizeable mu and tan beta]
Higgs into di-photon rate can be enhanced without changing the Higgs into WW/ZZ rates



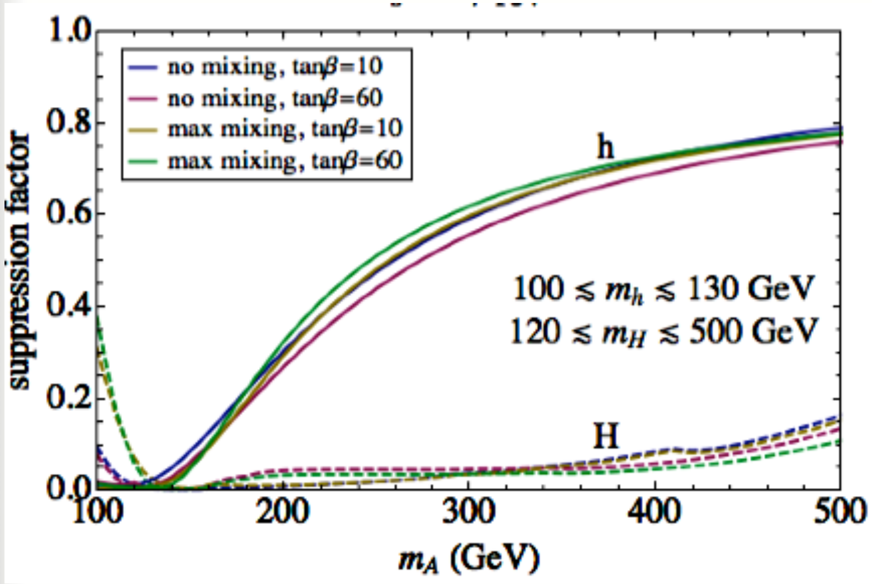


Contours of constant $\frac{\sigma(gg\to h)Br(h\to ZZ)}{\sigma(gg\to h)_{SM}\,Br(h\to ZZ)_{SM}}$ for M_h ~ 125 GeV

. [M.C, Gori, Shah, Wagner]

A) For large region of parameter space : The dominant width of Higgs decay to bottom quarks is enhanced due to mixing with non-standard Higgs bosons

➔ suppression of the $\gamma\gamma$ mode at the LHC



$$\frac{\sigma(gg \to h) Br(h \to \gamma\gamma)}{\sigma(gg \to h)_{SM} Br(h \to \gamma\gamma)_{SM}}$$ ➔ suppression

still sizable for m_A as large as 500 GeV

Similar Suppression for WW/ZZ modes

. M.C, Draper, Liu, Wagner'11

B) When off-diagonal elements vanish, either $\sin\alpha$ or $\cos\alpha$ vanish

=> strong suppression of the SM-like Higgs boson coupling to b-quarks and taus

Enhancement of BR (h/H --> WW/ZZ/$\gamma\gamma$) for $m_{h/H} < 135$ GeV

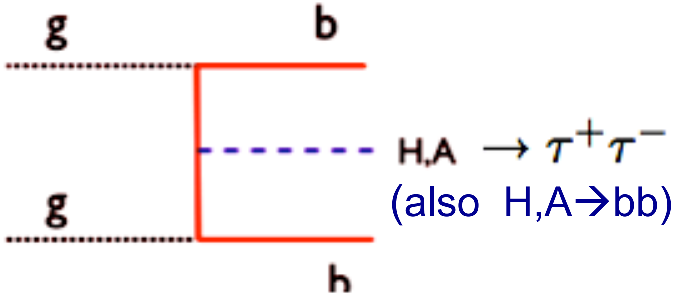
1) possible for positive, large values of mu A_t and light stops

[mh ~ 125 GeV demands low m_A & large tan beta, in conflict with A/H di-tau searches]

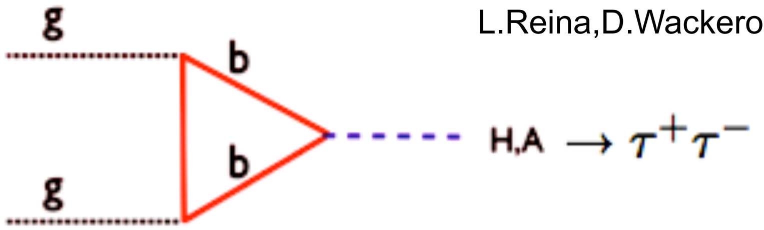
2)possible for positive, sizeable A_{tau} and light staus [allow larger m_A and tan beta]

Non-Standard MSSM Higgs searches in inclusive $\tau^+\tau^-$decays

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



(also H,A→bb)



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

M. C., Heinemeyer, Wagner,Weiglein '05

Important reach for large tanb, small m_A

- Weaker dependence on SUSY parameters via radiative corrections

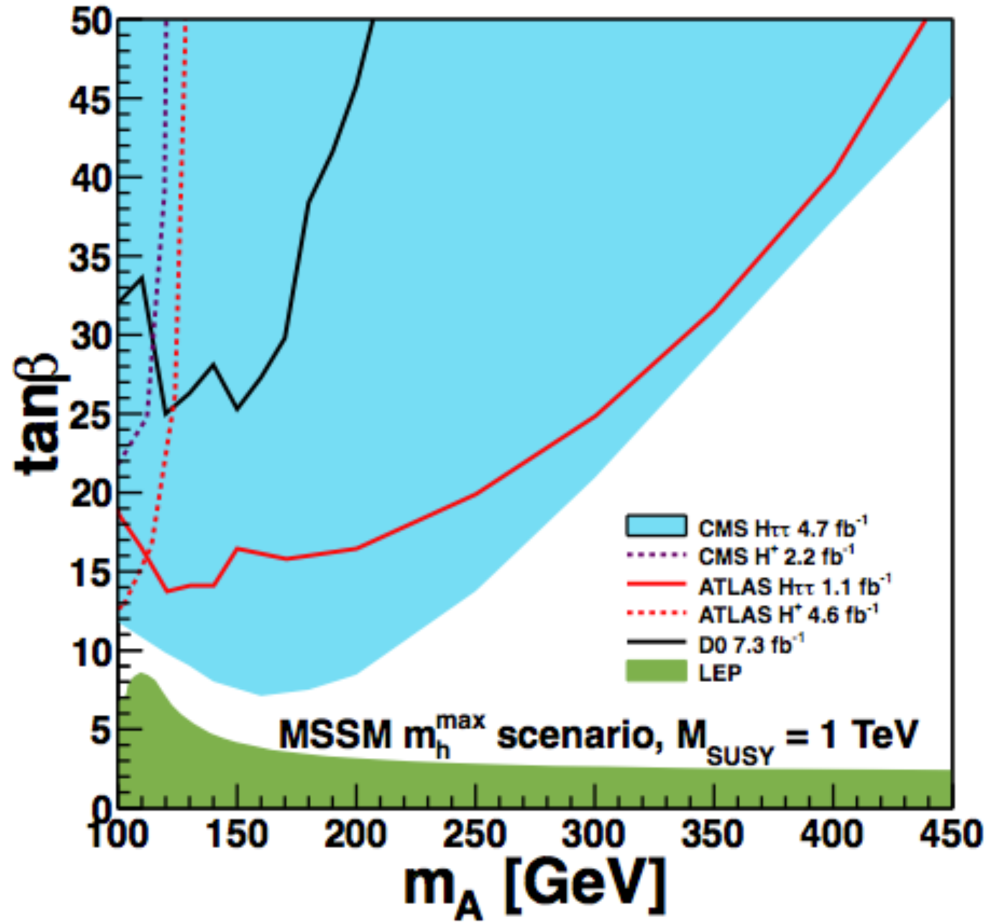
tan beta enhanced vertex corrections to A/Hbb coupling from SUSY loops

- Also possible to look for bbA/H with A/H decays to bb ==> 3 b's final state BUT, strong dependence on SUSY spectrum via radiative corrections

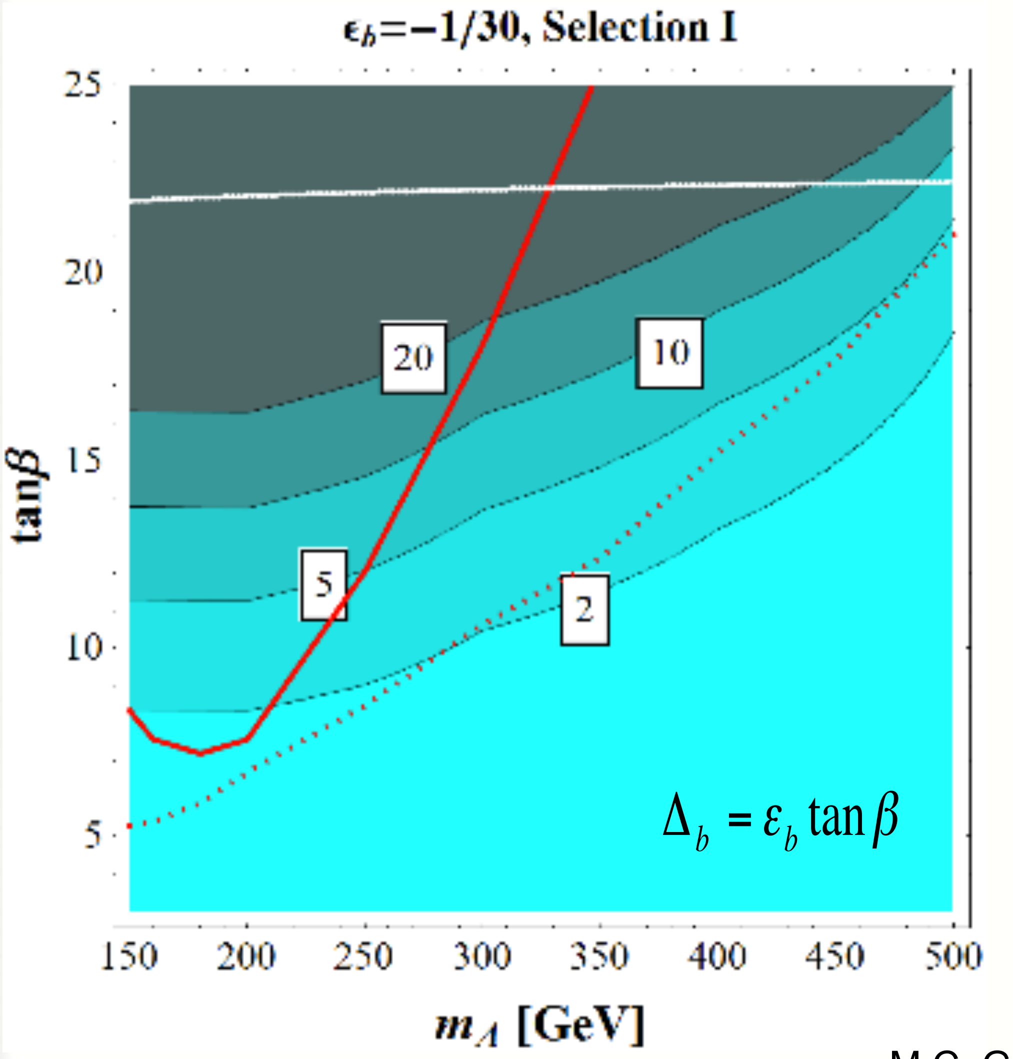
$$\boxed{\sigma(b\bar{b}A) \times BR(A \to b\bar{b}) \simeq \sigma(b\bar{b}A)_{\rm SM} \frac{\tan^2\beta}{(1+\Delta_b)^2} \times \frac{9}{(1+\Delta_b)^2+9}}$$

Results confirmed by NLO computation by D. North and M. Spira '08
Further work: Muhlleitner, Rzehak and Spira'08, Dawson et al '10, Djouadi et al'11

MSSM non-standard Higgs searches
The state of the art



MSSM non-standard Higgs searches in 3b's decays



Statistical significance at the 7 TeV LHC for an integrated luminosity of 30 fb-1

The red solid (dashed) : present (projected at 30 fb-1) bound on inclusive A/H → di-taus.

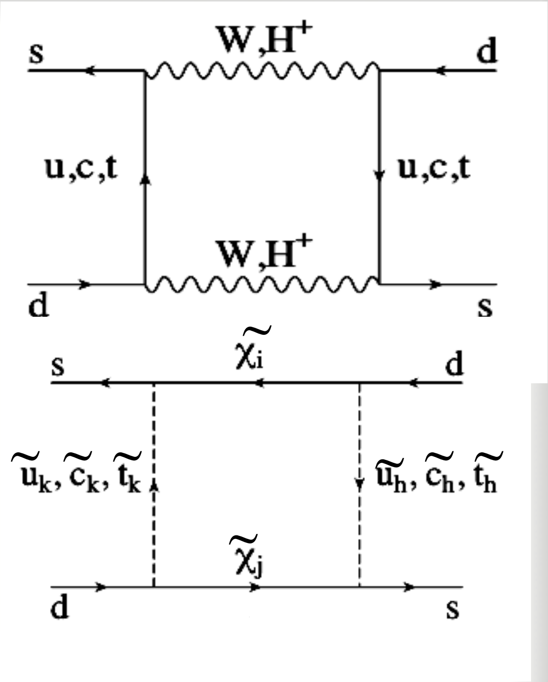
M.C, Gori,Juste,Menon,Wagner,Wang '12

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.

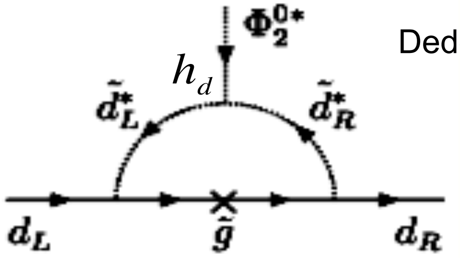
Isidori, Retico: Buras et al.



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

1) Both Higgs doublets couple to up and down sectors

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



Dedes, Pilaftsis

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

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

D'Ambrosio, Giudice, Isidori, Strumia

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: $B_s \to \mu^+\mu^-$

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

$\varepsilon_0^3-\varepsilon_0^{1,2}>0$ 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 $b \to s\gamma$

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

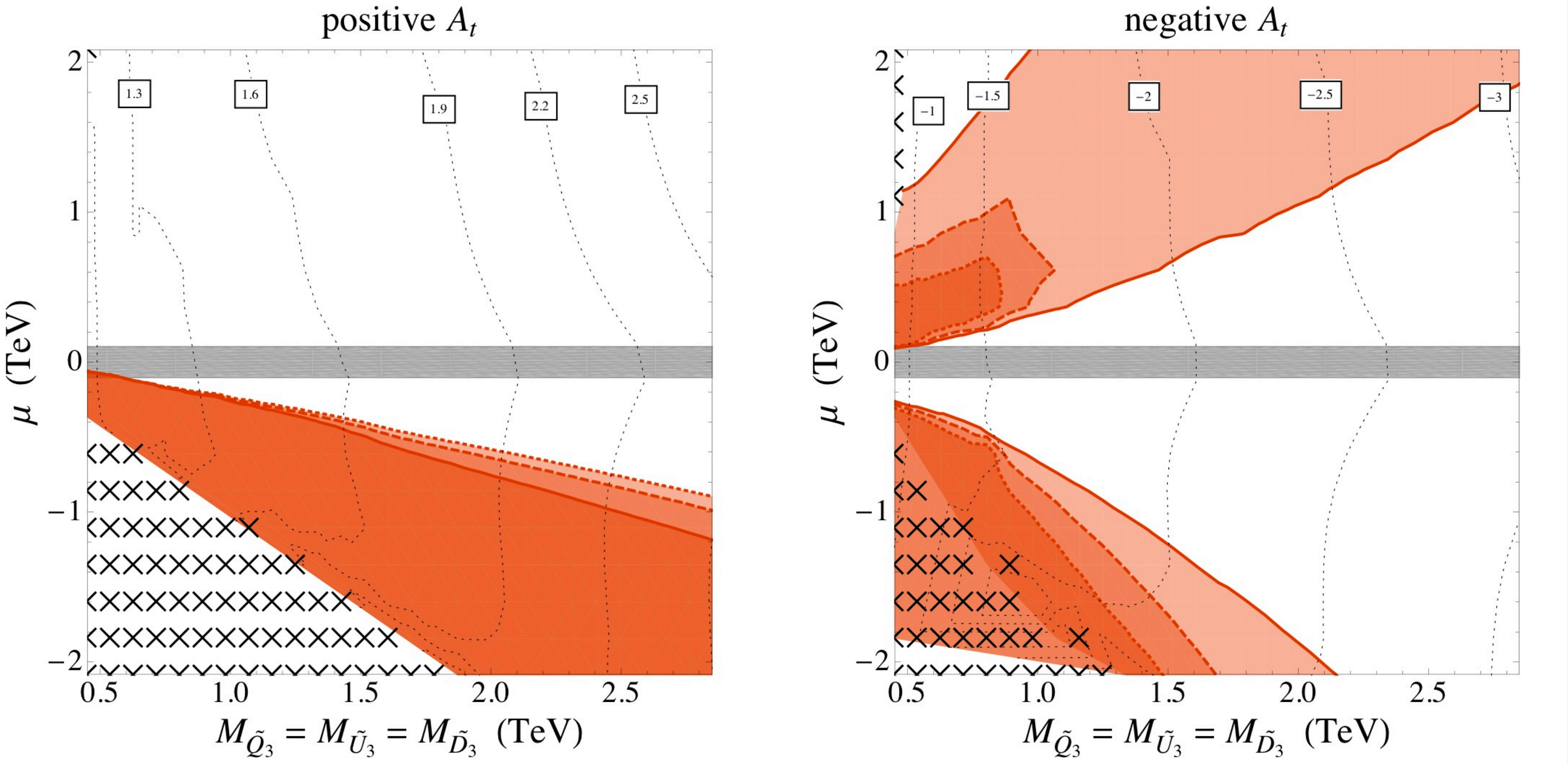
Borzumati, Bertolini,
Masiero,Ridolfi

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

Low Energy vs High Energy SUSY breaking effects $B_s \rightarrow$ mu$^+$mu-

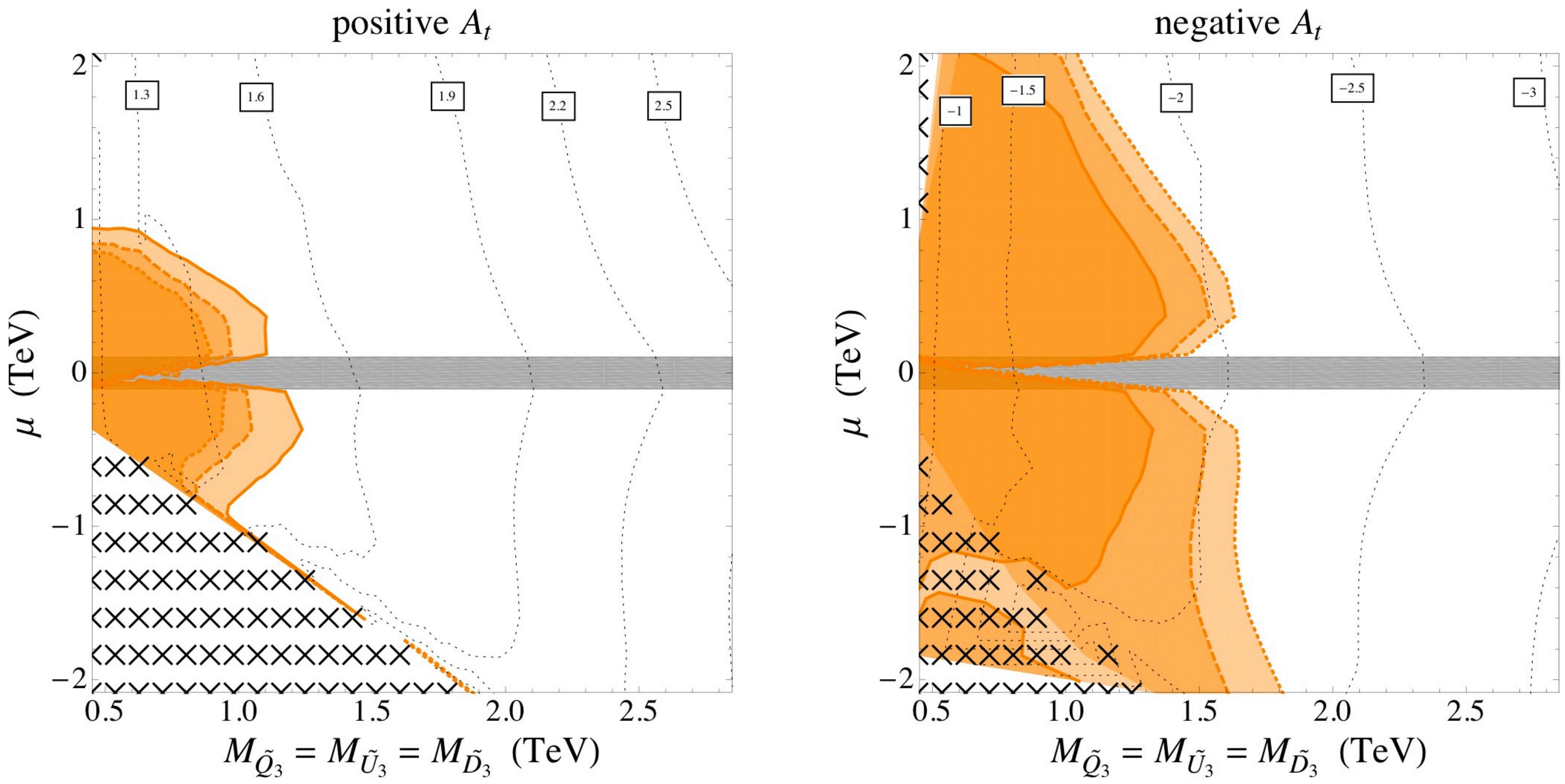


tan beta=40 M_A=800 GeV   Altmannshofer, MC, Shah,Yu

- Red solid line: $B_s \rightarrow$ mu$^+$mu$^-$ with low energy SUSY breaking effects
- Red dashed (dotted) line has 25% (50%) splitting from RG

M_h ~ 125 GeV and flavor in the MSSM

Low Energy vs High Energy SUSY breaking effects on B →X_s gamma



tan beta=40 M_A=800 GeV

Altmannshofer, MC, Shah,Yu

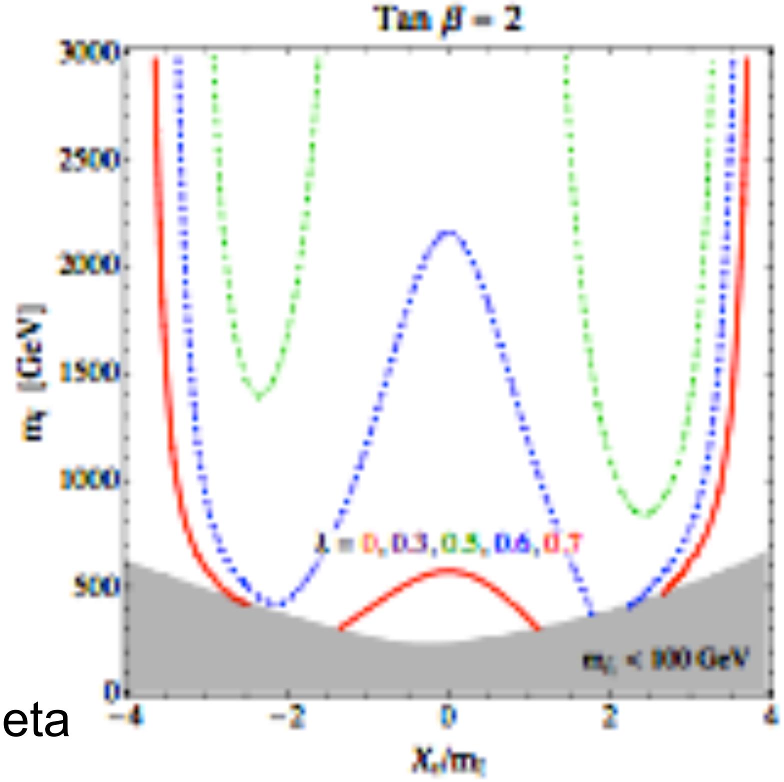
- Orange solid line from B →X_s gamma with low energy SUSY breaking effects
- Orange dashed (dotted) line has 25% (50%) splitting from RG

If a SM-like Higgs particle exists, the LHC will measure its mass and production rates

Many minimal SUSY models can produce m_h=125 GEV

NMSSM: extra singlet S
with extra parameter

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



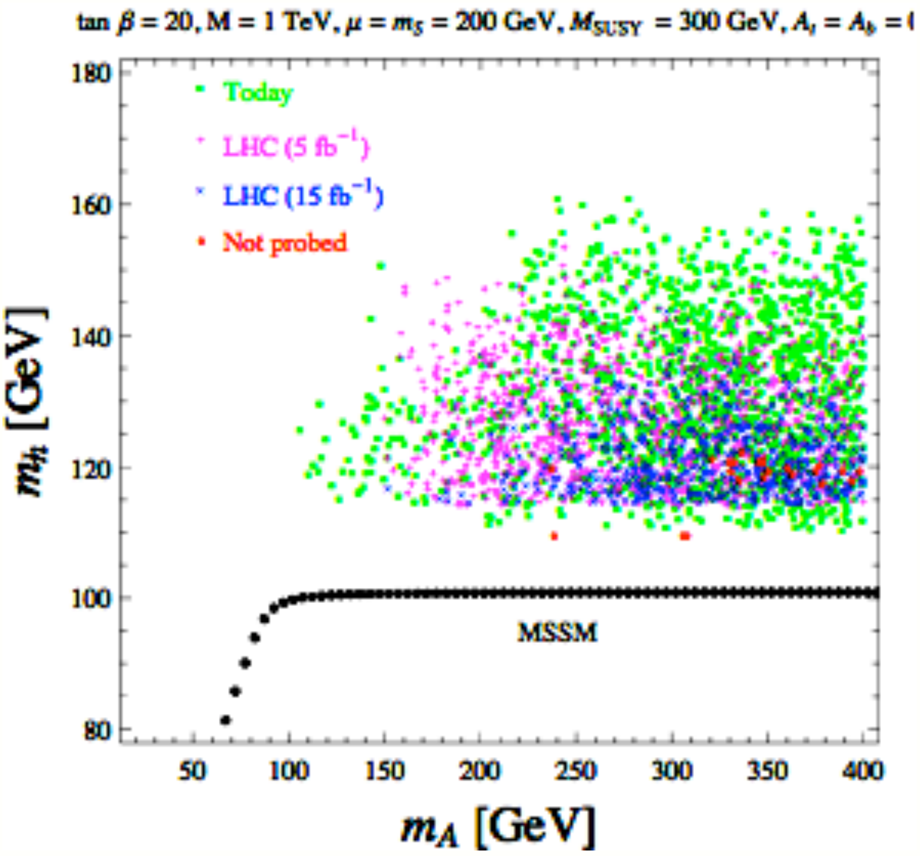
Hall, Pinner, Ruderman

- Large effect on the mass only for low tan beta
- More freedom in gluon fusion production
- Higgs mixing effects can be also triggered by extra new parameter
- Light staus would not enhance di-photon rate since at low tan beta there is negligible mixing in the stau sector.

More general MSSM Higgs extensions: EFT approach

$$W = \mu H_u H_d + \frac{\omega_1}{2M}(H_u H_d)^2 \; W_X \quad \supset \quad \frac{\omega_1}{2M} X (H_u H_d)^2$$

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



Scan over parameters including all possible dimension 5 and 6, SUSY Higgs operators

Higgs mass = 125 GeV easy to achieve for light stops, small mixing

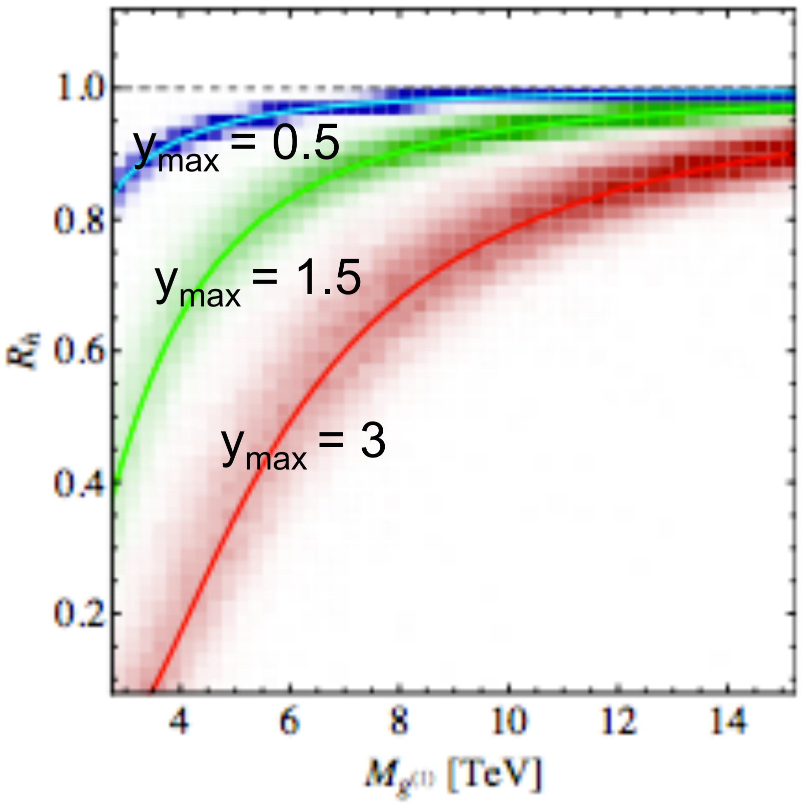
Enhancement of h→di-photons due to bb suppression or light staus

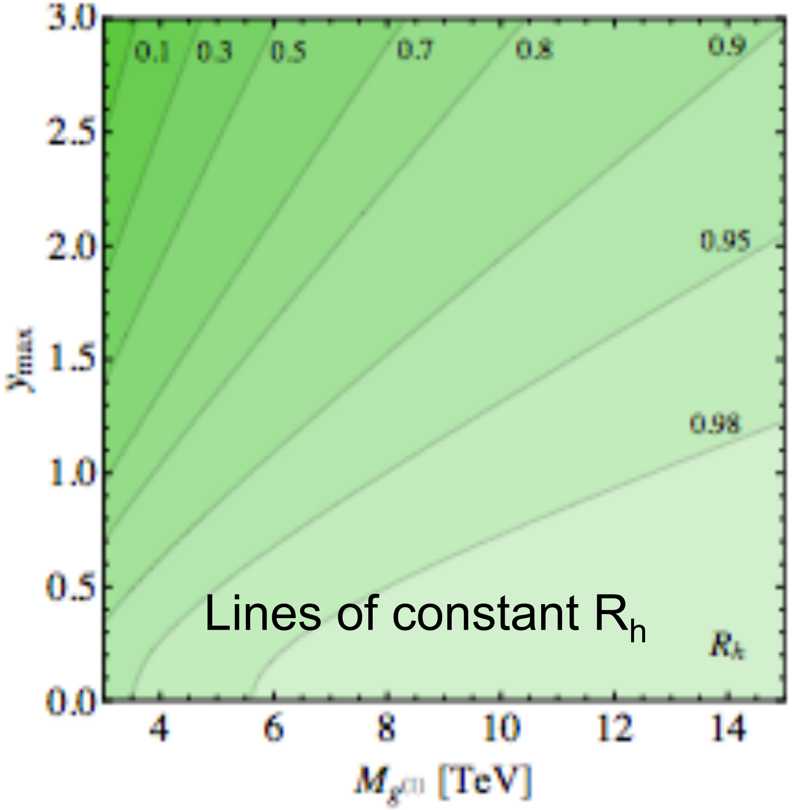
Higgs cascade decays → from large splitting in masses : h/H→ AA

If the new physics is seen only indirectly it will be hard to disentangle among new singlets, triplets, extra Z', W', a given mixture of the above

Higgs Phenomenology in Minimal RS model: Production

$R_h = \frac{\sigma(gg \to h)_{\rm RS}}{\sigma(gg \to h)_{\rm SM}}$ ➔ Suppression



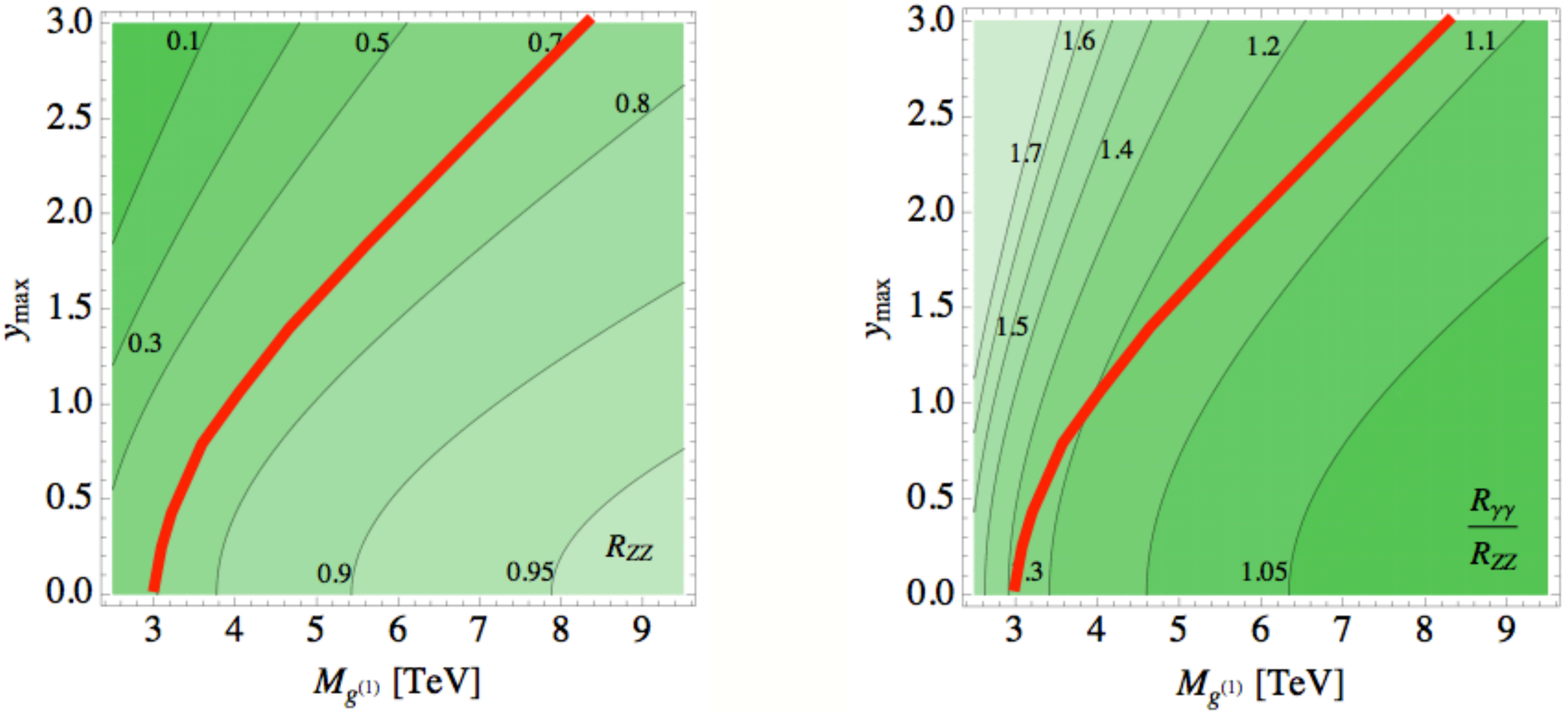


Lines of constant R_h

◆ Strong suppression could be interpreted as a **hint for existence of WEDs and translated into parameter space of such models**

◆**σ(gg→h) close to SM prediction would imply tight bounds on model parameters, perhaps moving KK masses out LHC reach for direct production**

Higgs Phenomenology in Minimal RS model: Decay



Higgs to diphotons can be larger than H→ZZ but below SM value

A measurement **R_{ZZ} ≈ 0.7 along with a slight enhancement of the di-photon over the ZZ channel would then imply (for y_{max} =3) KK masses ≈ 8 TeV, far outside reach for direct production at the LHC (a lower bound R_{ZZ} > 0.7 would imply very strong bounds)**