Footprints of Supersymmetry on Higgs Decay

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based on work with M.Nojiri & T.Moroi

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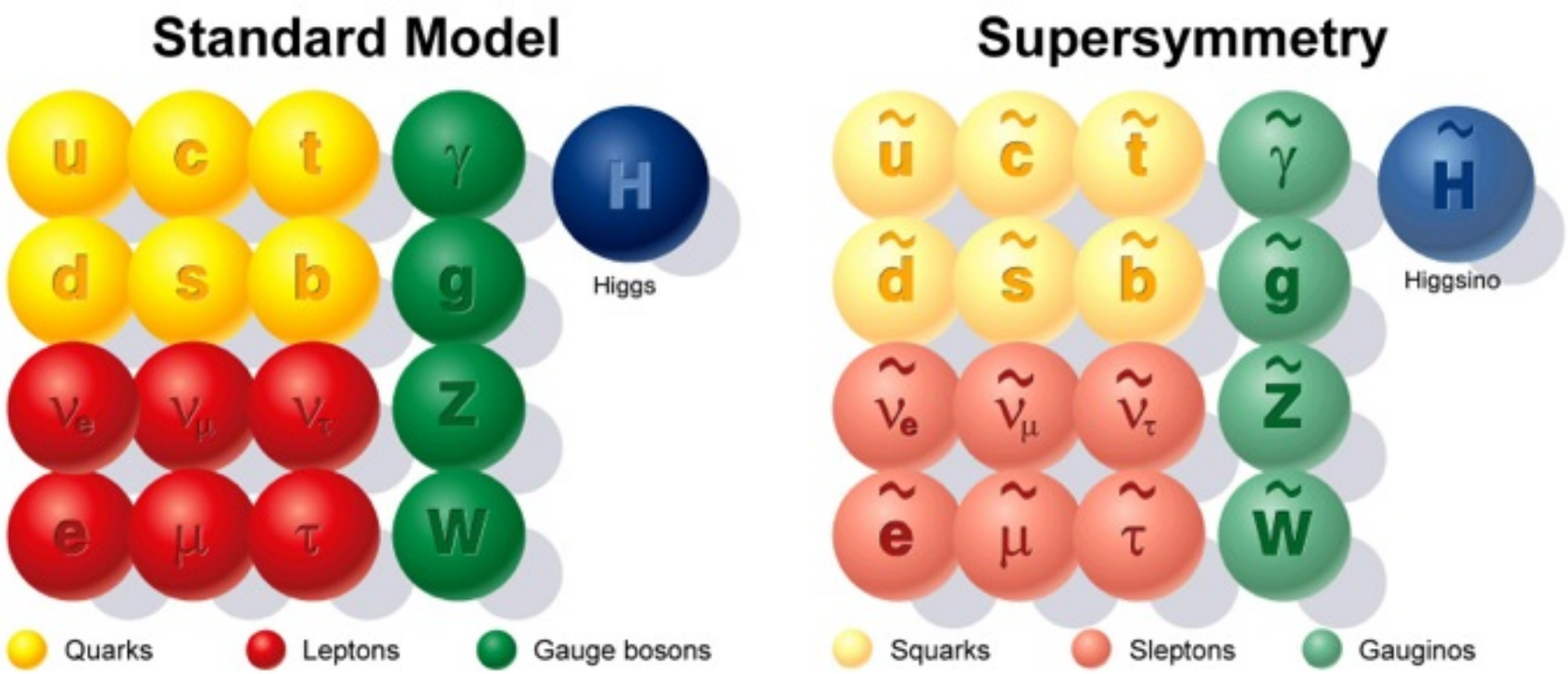
Supersymmetry



- HL-LHC: ~3TeV for gluino and ~1.4TeV for stop
- Nothing would be observed at LHC, if very heavy

Need lepton collider?

"Nightmare"

- too heavy to search at LHC
- indirect contributions are naively suppressed

Should we build e+e- colliders?

- measure Higgs partial widths at % levels
- "non-decoupling" corrections
- How large can the partial widths deviate from SM?

Higgs couplings

Type-II 2HDM (tree-level)

$$\tan\beta \equiv \langle H_u^0\rangle / \langle H_d^0\rangle$$

κ_V	κ_u	κ_d	κ_e
$\sin(\beta-\alpha)$	$\frac{\cos\alpha}{\sin\beta}$	$-\frac{\sin\alpha}{\cos\beta}$	$-\frac{\sin\alpha}{\cos\beta}$

+ corrections

hbb coupling: $-\mathcal{L}_{\rm eff} = y_b\,\bar{b}_R H_d Q_L + \Delta y_b\,\bar{b}_R Q_L H_u^* + \text{h.c.}$

$$\kappa_{\bar{b}b} = \left[-\frac{\sin\alpha}{\cos\beta}\right]\frac{1-\Delta_b\cot\alpha\cot\beta}{1+\Delta_b}$$

$$= \sin(\beta-\alpha) - \boxed{\frac{\tan\beta-\Delta_b\cot\beta}{1+\Delta_b}\cos(\beta-\alpha)} \qquad \left[\Delta_b = \frac{\Delta y_b}{y_b}\tan\beta\right]$$

≃1 (SM) deviation: α, Δ_b

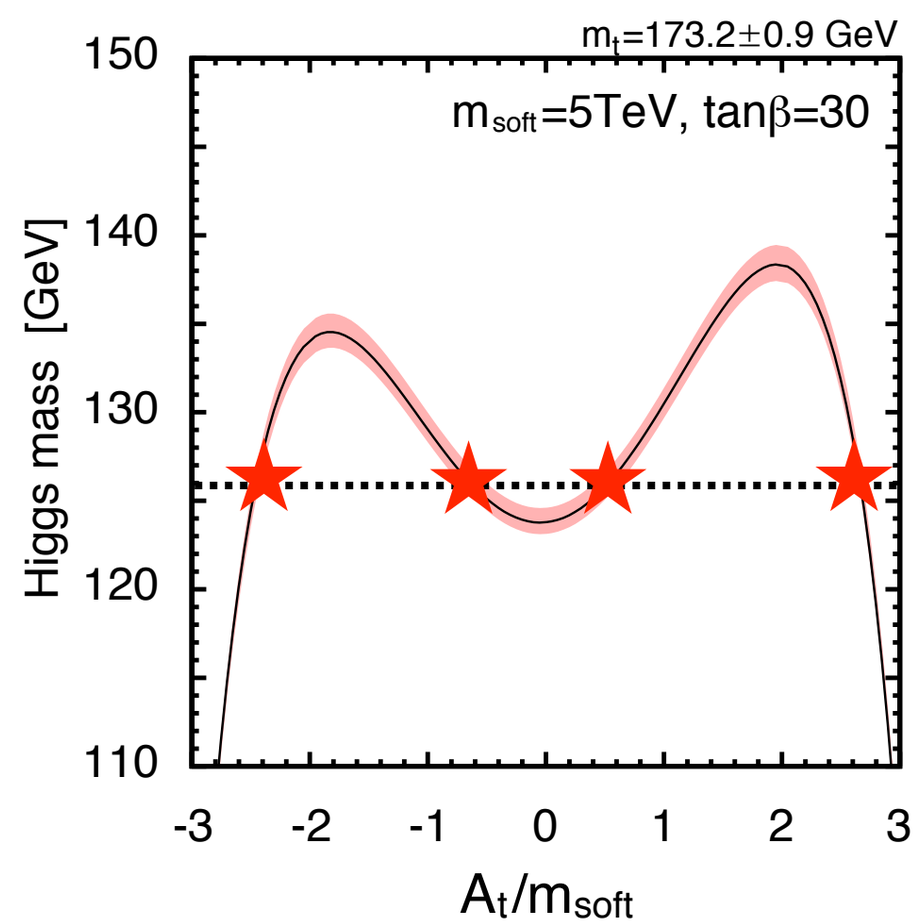
Higgs sector

Higgs sector receives sizable radiative corrections

$$m_h^2 \sim m_Z^2 \cos^2 2\beta + \frac{3m_t^4}{2\pi^2 v^2}\left[\log\frac{m_{\tilde{t}}^2}{m_t^2} + \frac{\tilde{A}_t^2}{m_{\tilde{t}}^2}\left(1 - \frac{\tilde{A}_t^2}{12m_{\tilde{t}}^2}\right)\right]$$

A_t has (up to) 4 solutions to achieve m_h=125GeV

positive/negative, large/small



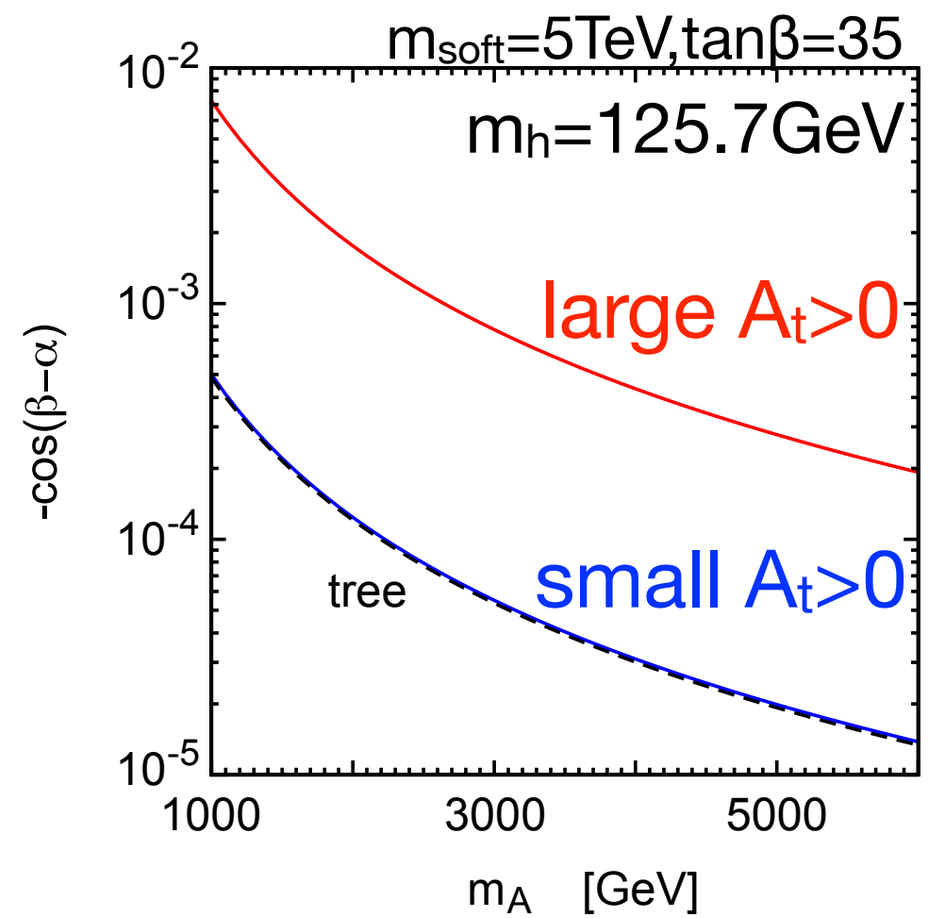
Higgs mixing angle

Higgs mixing angle receives similar corrections

$$\kappa_{\bar{b}b} = \sin(\beta - \alpha) - \frac{\tan\beta - \Delta_b \cot\beta}{1 + \Delta_b} \cos(\beta - \alpha)$$

"non-decoupling"

= not suppressed by large SUSY masses, but by large m_A



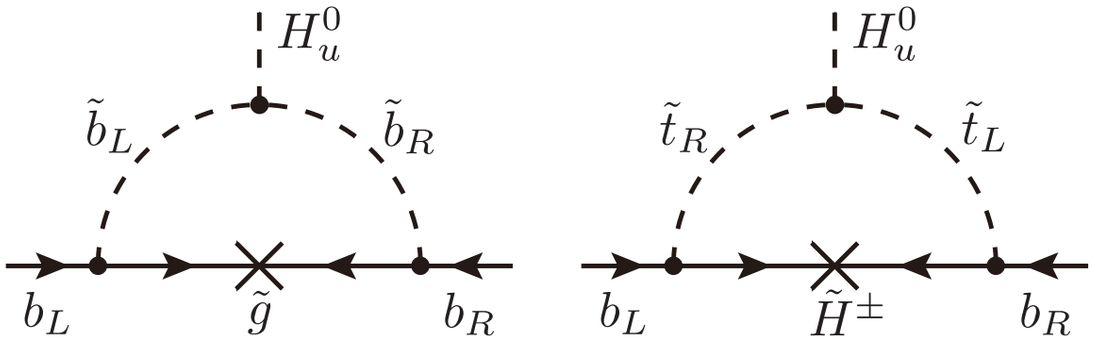
Yukawa corrections

- non-holomorphic corrections

$$-\mathcal{L}_{\rm eff} = y_b\, \bar{b}_R H_d Q_L + \boxed{\Delta y_b\, \bar{b}_R Q_L H_u^*} + \text{h.c.}$$

$$\Delta_b \simeq \left[\frac{2\alpha_s}{3\pi} M_3 \mu\, I(m^2_{\tilde{b}_1}, m^2_{\tilde{b}_2}, M_3^2) + \frac{y_t^2}{16\pi^2}\mu A_t\, I(m^2_{\tilde{t}_1}, m^2_{\tilde{t}_2}, \mu^2)\right] \tan\beta$$

- non-decoupling effects
- enhanced by μ, A_t, tanβ



Higgs decay in SUSY

- SUSY contributions to h→bb can be sizable

$$\kappa_{\bar{b}b} = \sin(\beta - \alpha) - \frac{\tan\beta - \Delta_b \cot\beta}{1 + \Delta_b} \cos(\beta - \alpha)$$

  - α, Δ_b : “non-decoupling” corrections
- similar contribution to hττ coupling, but $\Delta_\tau < \Delta_b$

→ constraints?

* SUSY contributions to other final states are much smaller

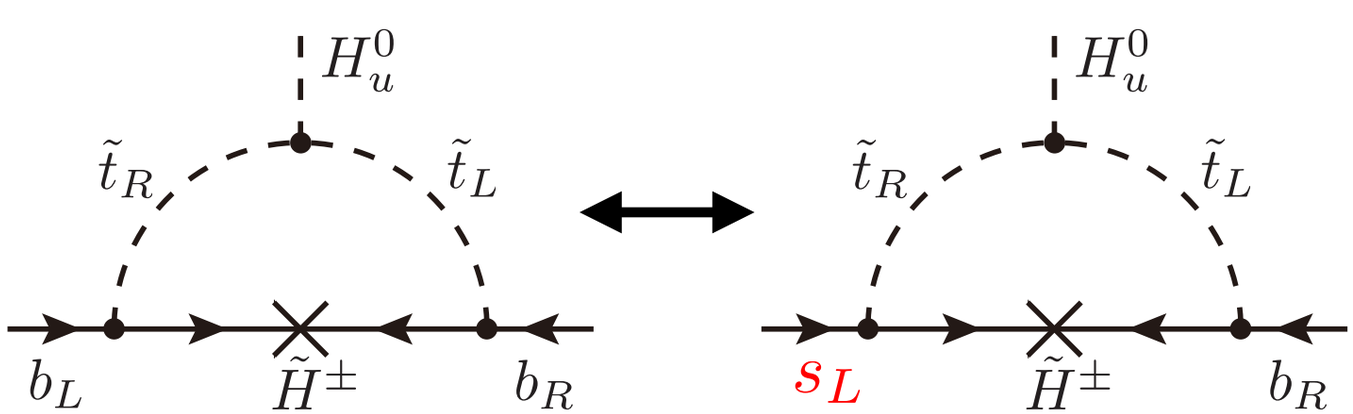
b-s transitions

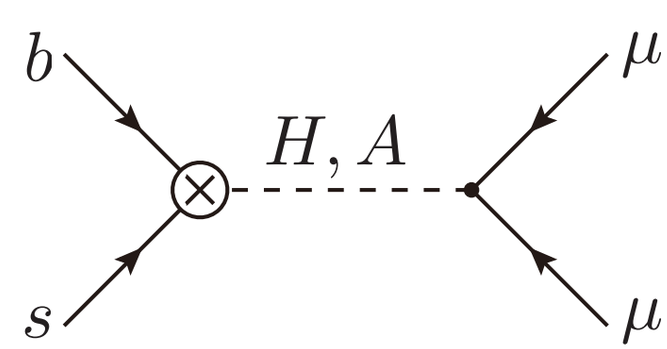
- non-holomorphic contributions

$$\mathcal{L}_{\rm eff} \simeq \frac{g m_b}{\sqrt{2} m_W \cos\beta} \frac{\Delta_{\rm FC}}{(1+\Delta_b)(1+\Delta_0)} V_{tb} V_{ts}^* \left(\bar{s}_L b_R\right)\left(H + iA\right)$$

$$\Delta_{\rm FC} = \frac{y_t^2}{16\pi^2} \mu A_t \tan\beta \, I(m_{\tilde{t}_1}^2, m_{\tilde{t}_2}^2, \mu^2)$$

- constraint by Br($B_s \to \mu^+\mu^-$)



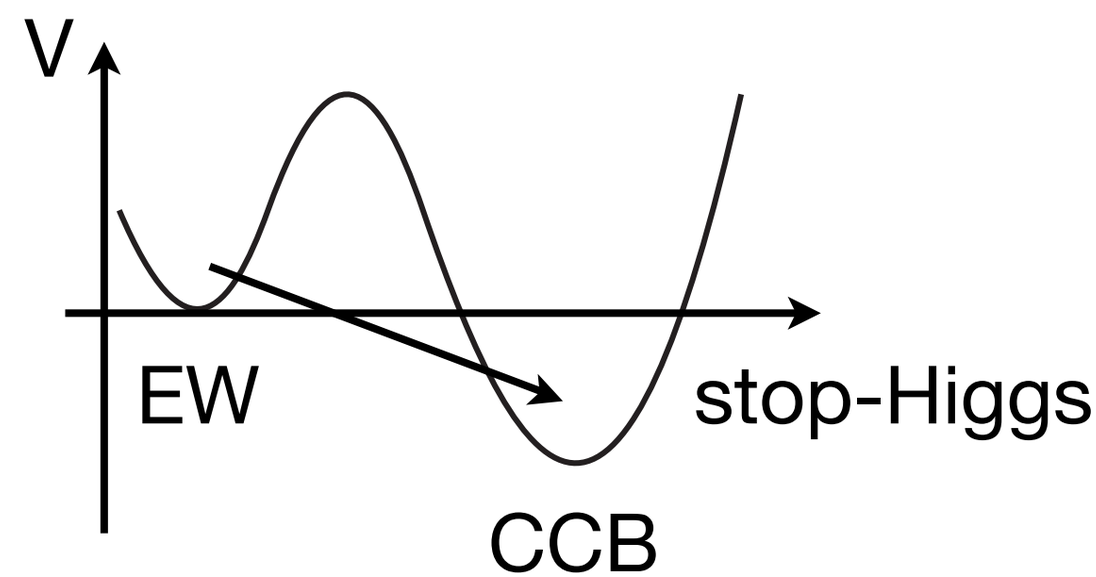


Vacuum instability

too large A_t, μ spoils stability of the EW vacuum

$$V = \frac{1}{\sqrt{2}} y_t (A_t h_u - \mu h_d) \tilde{t}_L \tilde{t}_R$$

calculate decay rate (T=0)
→ upper bound on μ, At



Yukawa perturbativity

too large Δ_b spoils perturbativity of Yukawa coupling

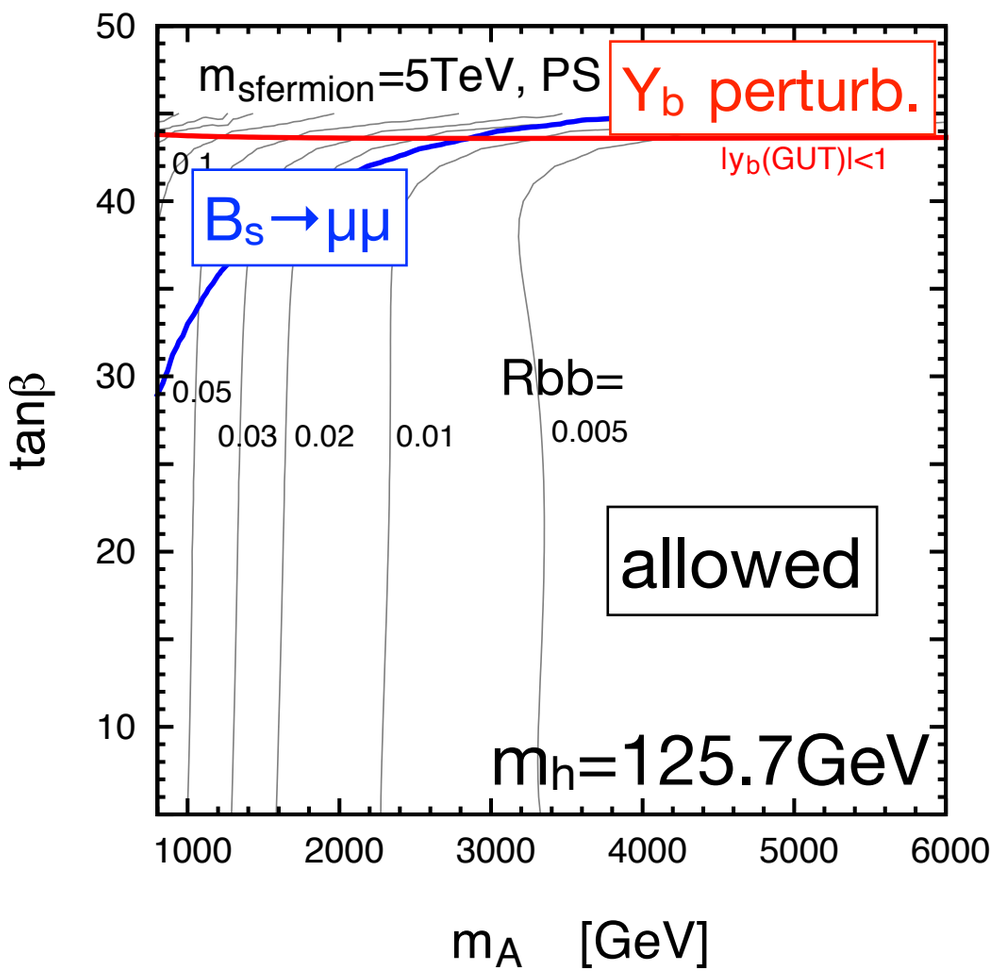
$$y_b \simeq \frac{\sqrt{2} m_b}{v \cos\beta (1 + \Delta_b)}$$

- y_b is enhanced when Δ_b is negative and large
- constraint: $|y_b| < 1$ up to GUT scale

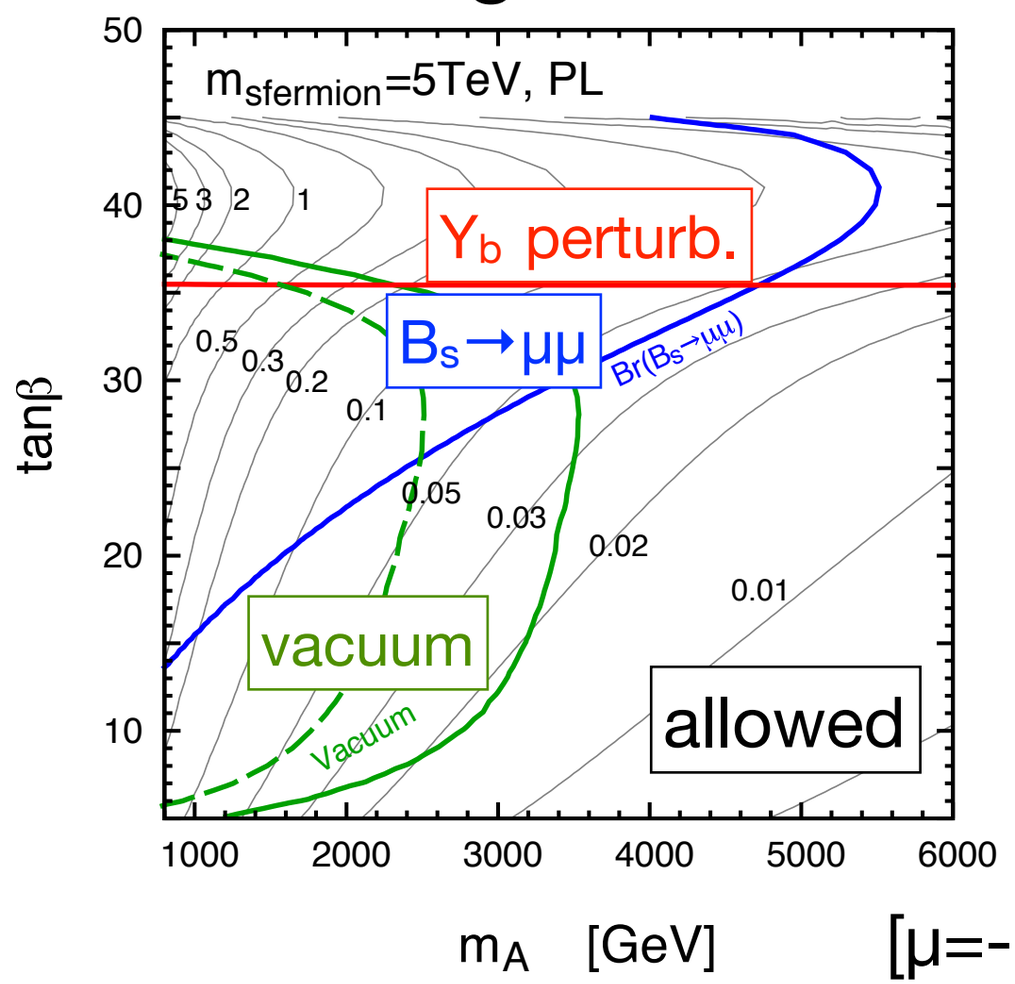
R_{bb} vs constraints

$R_{\bar{b}b} = \frac{\Gamma(h \to \bar{b}b)}{\Gamma_{(\mathrm{SM})}}$: enhanced by large A_t, but constrained

small A_t>0



large A_t>0

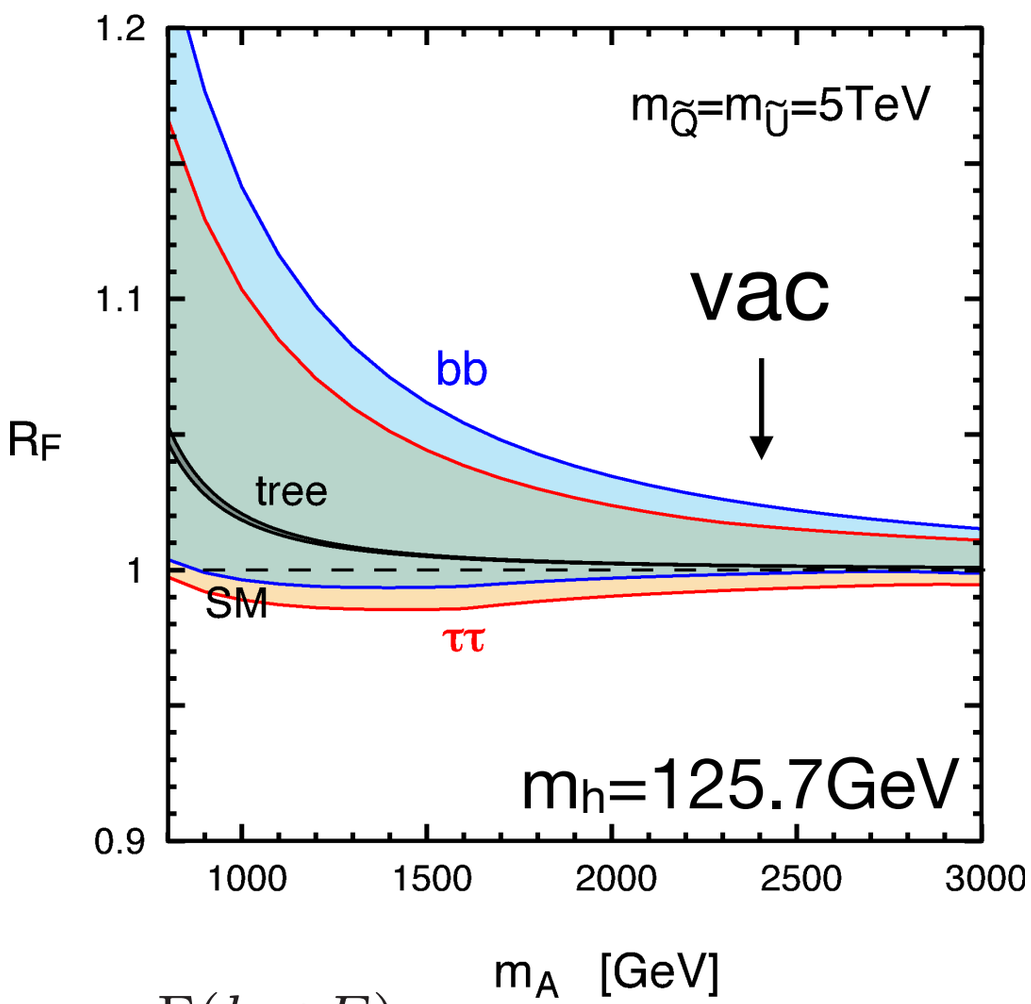


[μ=-$m_{sfermion}$]

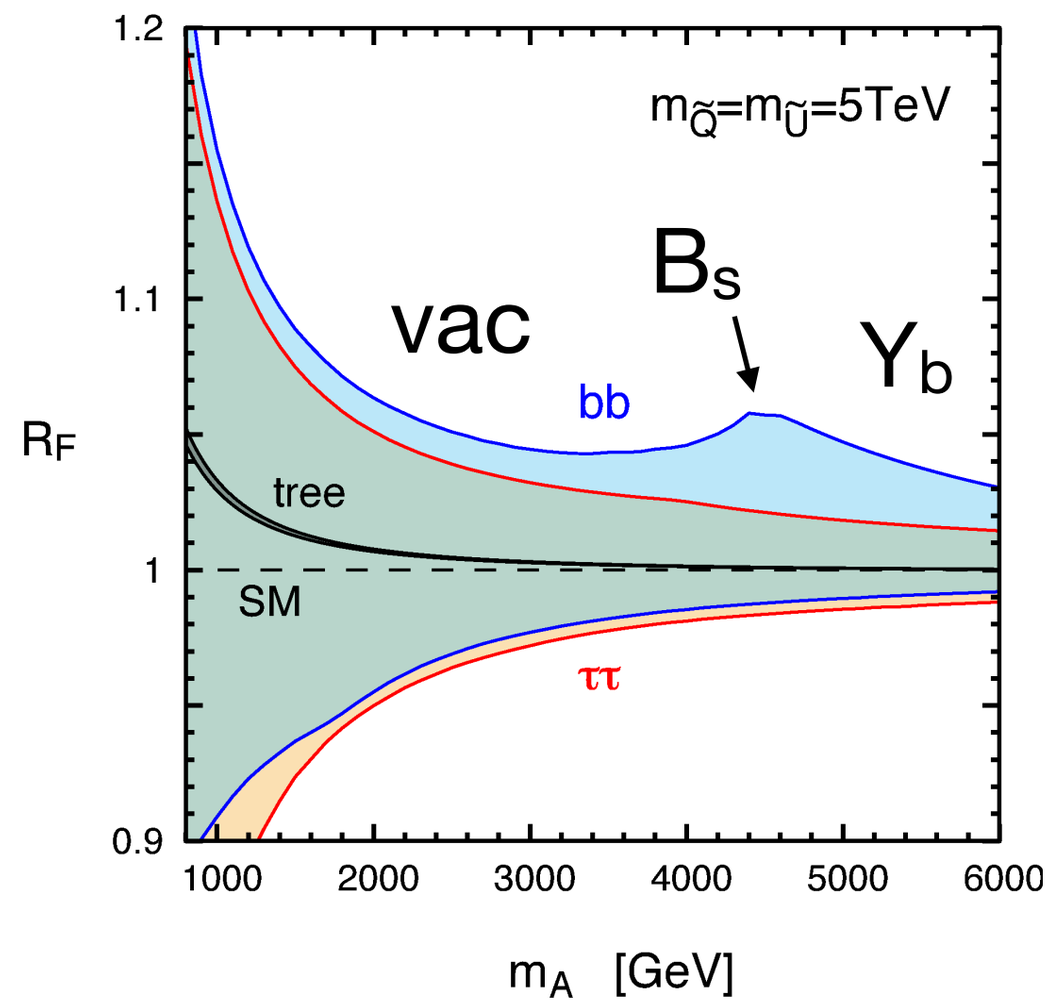
How large can deviation be?

scan performed in MSSM parameters [μ, tanβ]

small A_t solutions



all A_t solutions

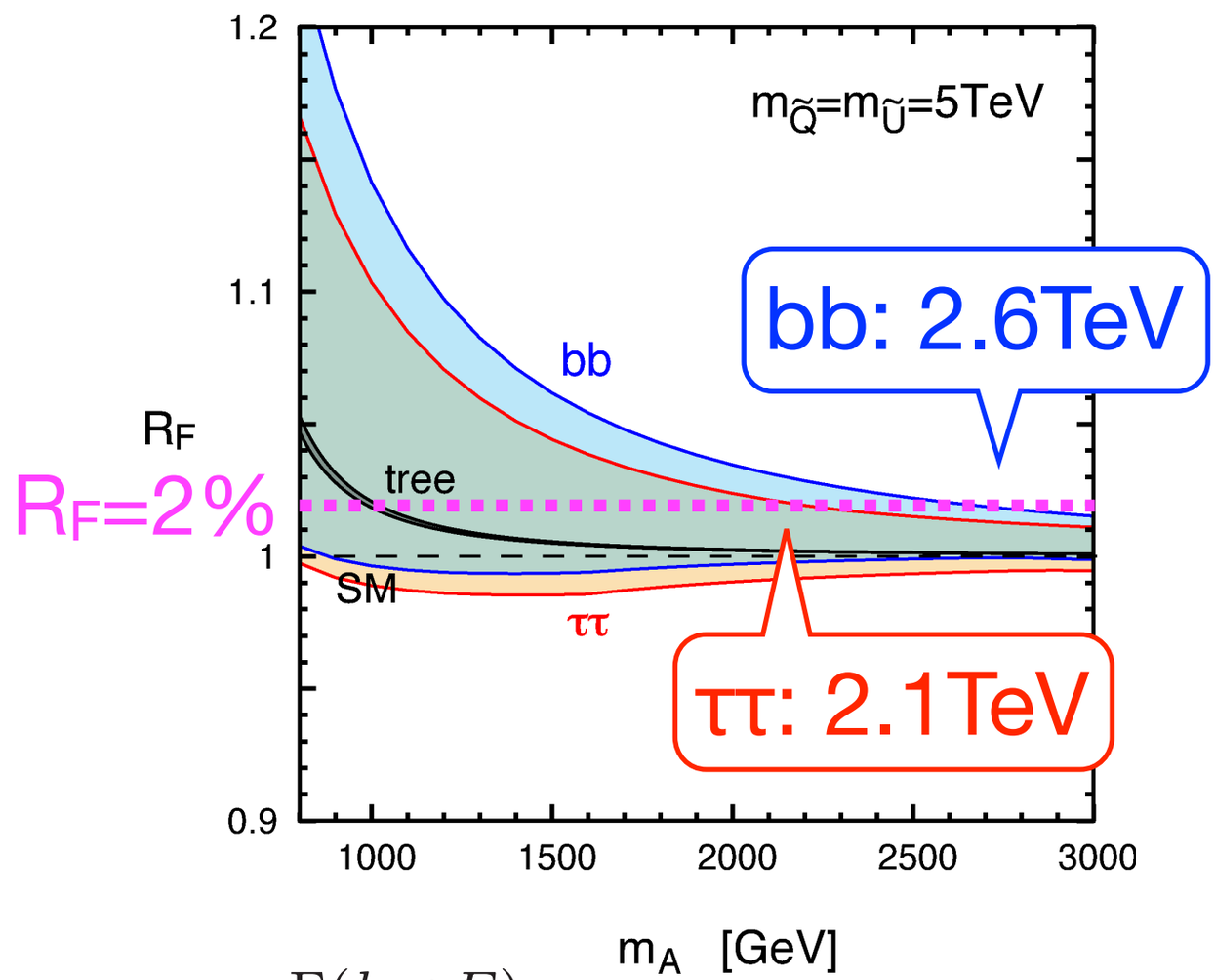


$$R_F = \frac{\Gamma(h \to F)}{\Gamma(h \to F)_{(\mathrm{SM})}}$$

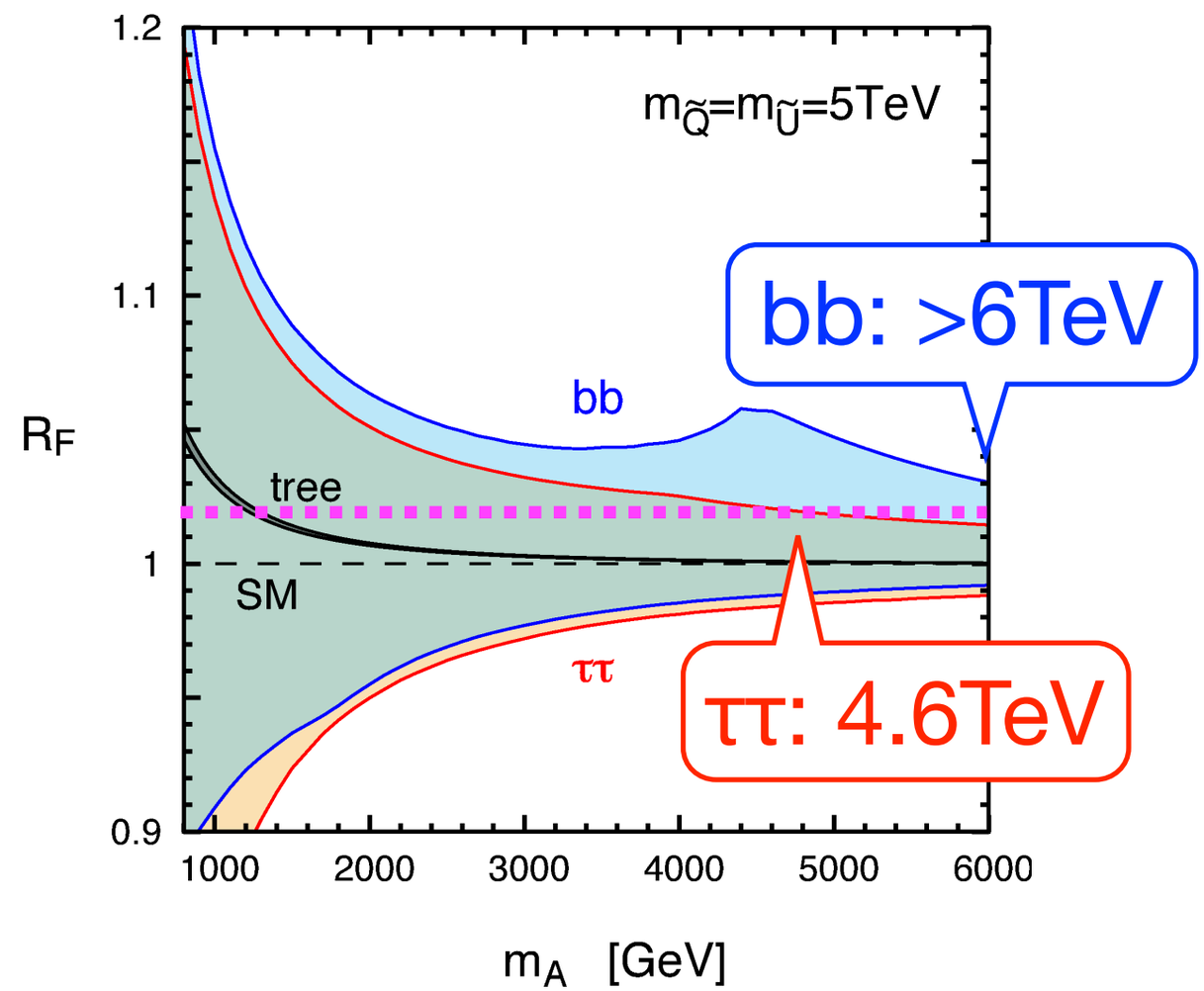
How large can deviation be?

lepton colliders have a chance to probe multi TeV scale

small A_t solutions



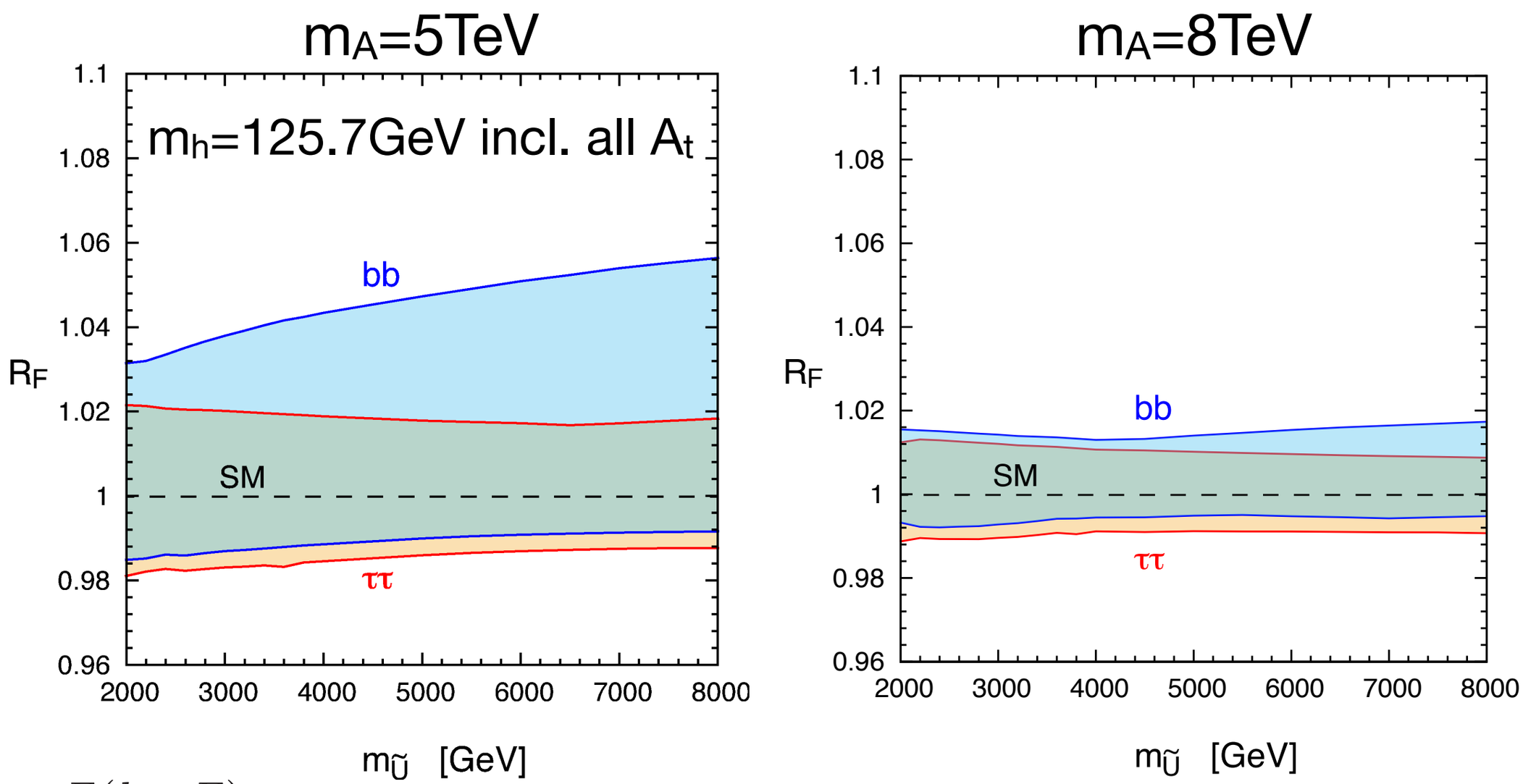
all A_t solutions



$$R_F = \frac{\Gamma(h \to F)}{\Gamma(h \to F)_{(\mathrm{SM})}}$$

SUSY mass dependence

Not decoupled by SUSY mass, but smaller by large m_A



$$R_F = \frac{\Gamma(h \to F)}{\Gamma(h \to F)_{(\mathrm{SM})}}$$

Summary

- We considered nightmare scenario in SUSY.
- Higgs partial widths can be measured at percent levels in lepton colliders.
- Widths receive “non-decoupling” contributions.
- Deviations can be O(1)% in $h \to bb$ and $h \to \tau\tau$, even if SUSY particles are out of reach of 14TeV LHC.

Higgs measurements

Partial decay widths can be measured at % levels

$$\delta\Gamma(h \to \bar{b}b) = 0.64\%,\ \delta\Gamma(h \to \bar{\tau}\tau) = 1.1\%,\ \delta\Gamma(h \to gg) = 1.2\%$$

Expected accuracies of Γ(h→F) in units of percents

	LHC [3]		ILC [54]				TLEP [3]	
$\sqrt{s}$ [GeV]	1400	1400	250	500	1000		240	350
$\int dt\,\mathcal{L}$ [fb^{-1}]	300	3000	250	500	1000	2500	10000	+2600
$\gamma\gamma$	10 – 14	4 – 10	38	17	5.8	3.8	3.4	3.0
gg	12 – 16	6 – 10	12	4.0	1.6	1.2	2.2	1.6
$\bar{b}b$	20 – 26	8 – 14	9.4	1.9	0.78	0.64	1.8	0.84
$\bar{\tau}\tau$	12 – 16	4 – 10	10	3.8	1.6	1.3	1.9	1.1

Calculation details

FeynHiggs 2.10.2

- Higgs mass, mixing angle, partial widths
- include QCD, resummation of leading logarithms
- bug fixes in $h \to VV$ partial widths ($\to$ 2.10.3)
- α_{eff} approximation: wave function renormalization at $p^2=0$ for $h \to VV$ widths ($\to$ 2.10.3)

SuperIso 3.4

- B transition rates, $Br(B_s \to \mu^+\mu^-)$
- squark universality

CosmoTransitions 2.0a1

- vacuum transition rate at tree-level and T=0

Parameter scan

For given $m_{\tilde{U}}$

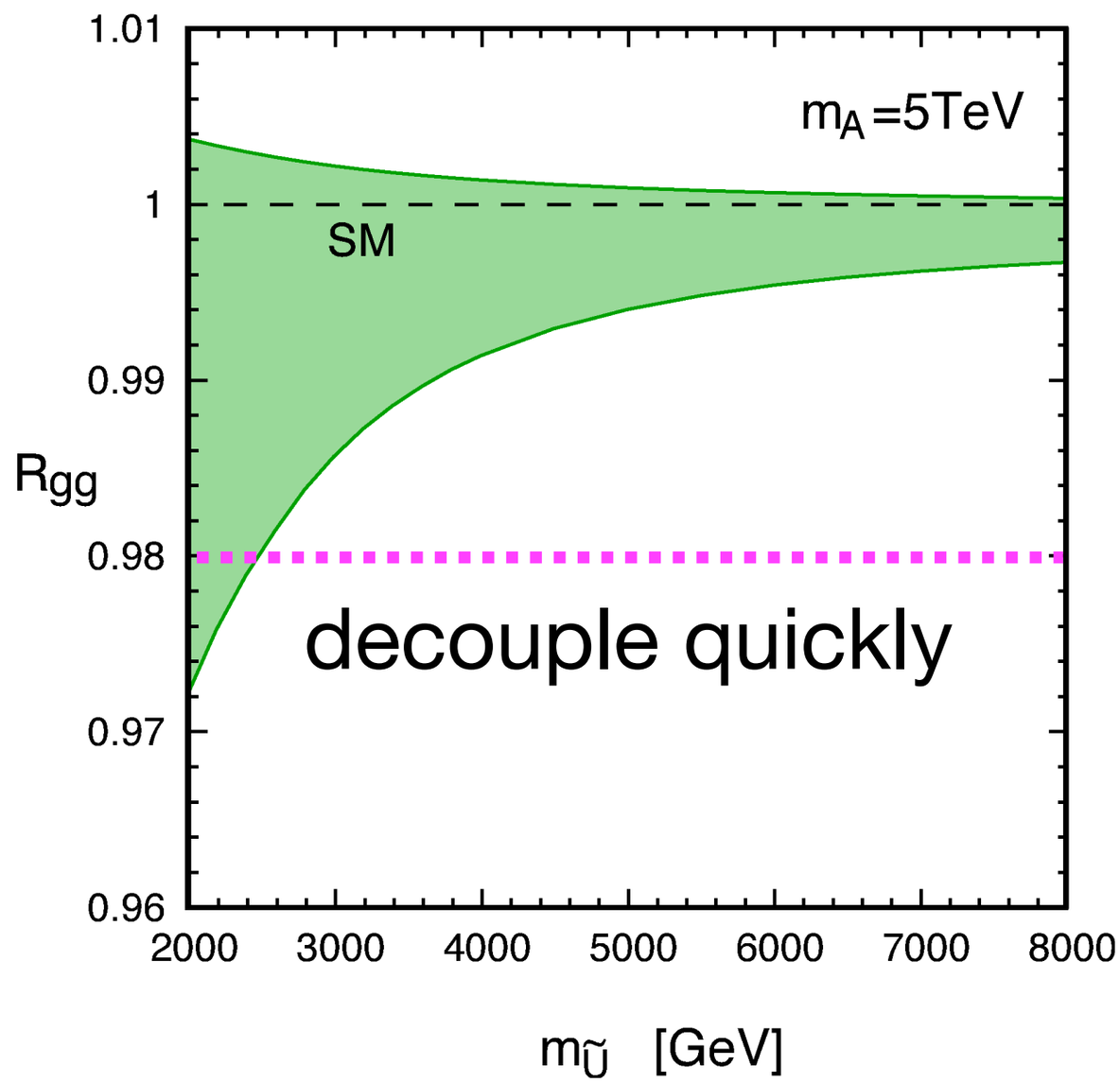
- $A_t = A_t^{(\mathrm{NS})}, A_t^{(\mathrm{NL})}, A_t^{(\mathrm{PS})}, A_t^{(\mathrm{PL})}$ [4 solutions of m_h=125.7GeV]
- $5 \leq \tan\beta \leq 50$
- $0.8\,\mathrm{TeV} \leq m_A \leq 6\,\mathrm{TeV}$
- $-5 \leq \mu/m_{\tilde{U}} \leq -0.5$, or $0.5 \leq \mu/m_{\tilde{U}} \leq 5$
- $m_{\tilde{D}} = m_{\tilde{L}} = m_{\tilde{E}} = \max(m_{\tilde{U}}, |\mu|)$

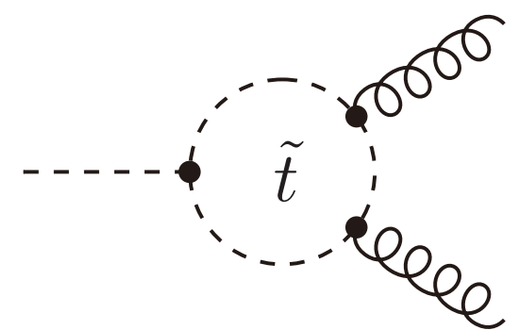
gaugino mass: GUT relation w/ $M_3 = m_{\tilde{U}}$

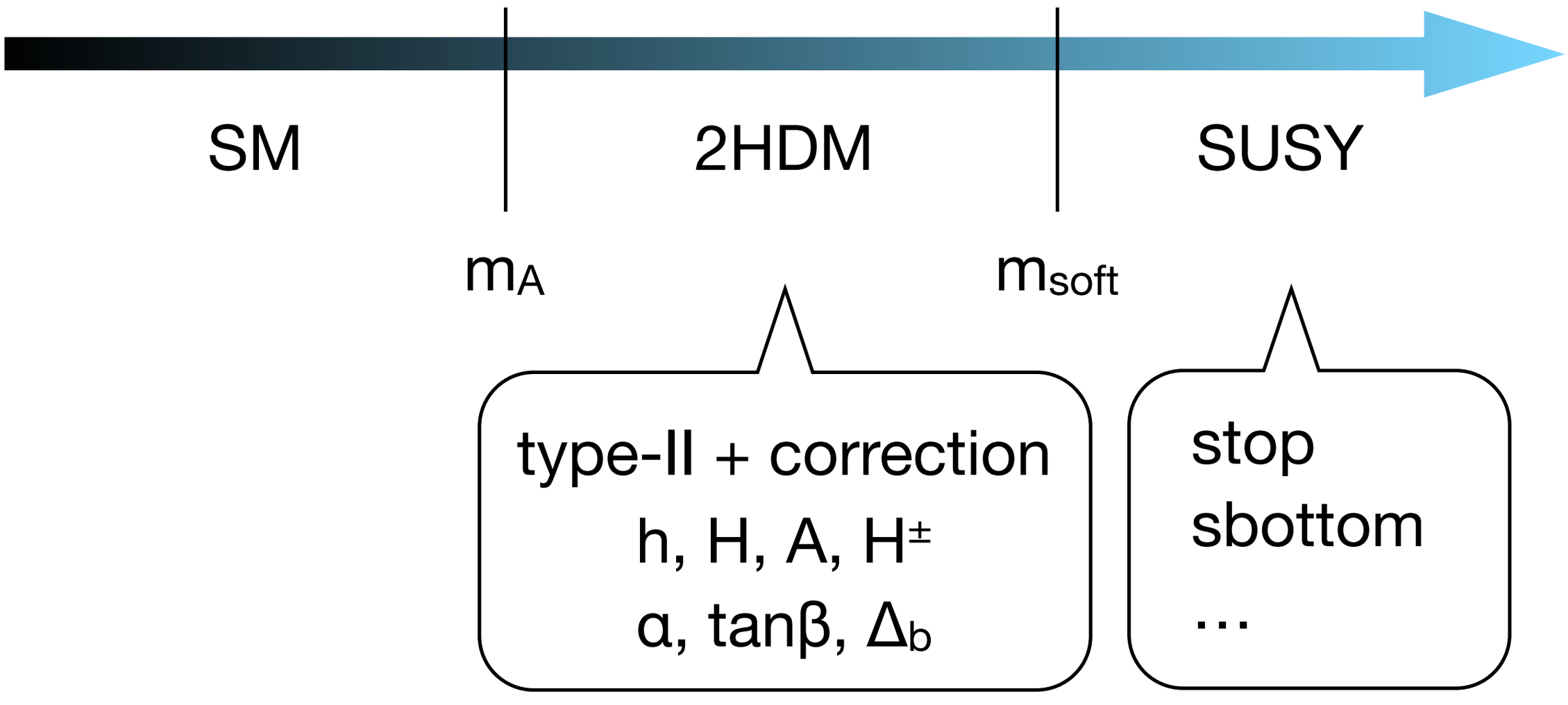
Other modes

h→gg can have a sizable deviation by stop loops

$$R_F = \frac{\Gamma(h \to F)}{\Gamma(h \to F)_{(\mathrm{SM})}}$$





R_F=2%

Effective theory