DECOUPLING PROPERTIES OF MSSM PARTICLES IN HIGGS AND TOP DECAYS

María J. Herrero

Universidad Autónoma de Madrid

In collaboration with:

H.Haber, H.Logan, S.Peñaranda, S.Rigolin and D.Temes

RADCOR/2000

Carmel, California, September 11-15, 2000

MOTIVATIONS/GOALS

- We want to distinguish MSSM from SM even if SUSY spectra and extra Higgses are heavy $\leftrightarrow$ $M_{SUSY}, M_A \gg M_Z$

- Use radiative corrections from SUSY particles and extra Higgses in observables with external SM particles as indirect signals of new physics from MSSM

  (Same spirit of EW precision fits: indirect top signals, indirect SM Higgs searches....)

- We want to know if Higgs decays, top decays....are significantly affected by radiative corrections from heavy SUSY particles and/or heavy Higgses

  -Is there decoupling of heavy MSSM particles beyond tree level?. Do the various sectors decouple separately?
  - In case there is decoupling, how is it? (fast,slow,..?)
  - Are there special choices of the MSSM parameters, where radiative corrections are significant even for a heavy MSSM spectrum?: Delayed decoupling? (large $tan\beta$, size and sign of μ,...?)

- In this talk I will concentrate on the SUSY-QCD corrections to the main $h^0, H^\pm, t$ decays

DECOUPLING LIMIT IN THE HIGGS SECTOR

(Haber & Nir 1990)

$\rightarrow$Tree level,

$M_A \gg M_Z$

$$M_{H^o} \simeq M_{H^\pm} \simeq M_A \gg M_Z$$
$$M_{h^o} \simeq M_Z |cos2\beta|$$

Higgs couplings in the MSSM normalized to SM couplings

ϕ		$g_{\phi\bar{t}t}$	$g_{\phi\bar{b}b}$	$g_{\phi VV}$
SM	H	1	1	1
MSSM	h^o	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$\sin(\beta-\alpha)$
	H^o	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$	$\cos(\beta-\alpha)$
	A^o	$1/\tan\beta$	$\tan\beta$	0

$$\frac{\cos\alpha}{\sin\beta} \simeq 1 + \mathcal{O}(M_Z^2/M_A^2)\,, \quad -\frac{\sin\alpha}{\cos\beta} \simeq 1 + \mathcal{O}(M_Z^2/M_A^2)$$
$$\sin(\beta-\alpha) \simeq 1 + \mathcal{O}(M_Z^4/M_A^4)$$

$\rightarrow$Beyond tree level,

$M_A \gg M_Z$

$$M_{H^o} \simeq M_{H^\pm} \simeq M_A \gg M_Z$$
$$M_{h^o} \leq 130 - 135\, GeV$$

Interested in the decoupling behaviour of heavy SUSY particles and heavy Higgses, at one loop, in h^0 couplings/production/decays

DECOUPLING LIMIT IN THE SUSY-QCD SECTOR

-sbottoms:

$$\hat{M}^2_{\tilde{b}} = \begin{pmatrix} M^2_{\tilde{Q}} + m_b^2 - M_Z^2(\frac{1}{2} + Q_b s_W^2)\cos 2\beta & m_b(A_b - \mu \tan\beta) \\ m_b(A_b - \mu \tan\beta) & M^2_{\tilde{D}} + m_b^2 + M_Z^2 Q_b s_W^2 \cos 2\beta \end{pmatrix}$$

-stops:

$$\hat{M}^2_{\tilde{t}} = \begin{pmatrix} M^2_{\tilde{Q}} + m_t^2 + M_Z^2(\frac{1}{2} - Q_t s_W^2)\cos 2\beta & m_t(A_t - \mu \cot\beta) \\ m_t(A_t - \mu \cot\beta) & M^2_{\tilde{U}} + m_t^2 + M_Z^2 Q_t s_W^2 \cos 2\beta \end{pmatrix}$$

We consider the limit:

$$M_{SUSY} \sim M_{\tilde{Q}} \sim M_{\tilde{D}} \sim M_{\tilde{U}} \sim M_{\tilde{g}} \sim \mu \sim A_b \sim A_t \gg M_Z$$

$\Longleftrightarrow$ heavy squarks and heavy gluino

and study two extreme cases for:

$$\hat{M}^2 \equiv \begin{pmatrix} M_L^2 & m_q X_q \\ m_q X_q & M_R^2 \end{pmatrix}$$

-Close to maximal mixing: $\theta_{\tilde{q}} \sim 45^\circ$

$$|M_L^2 - M_R^2| \ll m_q X_q \Rightarrow |M^2_{\tilde{q}_1} - M^2_{\tilde{q}_2}| \ll |M^2_{\tilde{q}_1} + M^2_{\tilde{q}_2}|$$

-Close to minimal mixing: $\theta_{\tilde{q}} \sim 0^\circ$

$$|M_L^2 - M_R^2| \gg m_q X_q \Rightarrow |M^2_{\tilde{q}_1} - M^2_{\tilde{q}_2}| \sim \mathcal{O}|M^2_{\tilde{q}_1} + M^2_{\tilde{q}_2}|$$

Decoupling in low-energy electroweak gauge boson physics

It has been shown that all one-loop corrections to low-energy electroweak gauge boson physics involving SUSY particles and extra Higgses decouple in the limit of large sparticle masses and large M_A

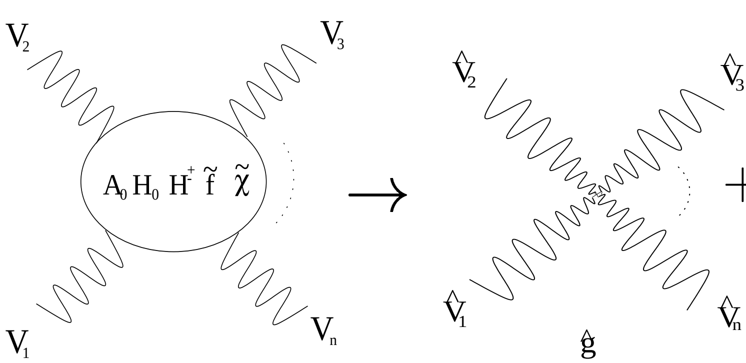
(A.Dobado, M.H & S.Peñaranda 1999, 2000)

- Computation of $\Gamma_{eff}[A, Z, W^{\pm}]$ by integrating out $\tilde{q}, \tilde{l}, \tilde{\chi}_i^{\pm}, \tilde{\chi}_j^{o}, H^{\pm}, H^0, A^0$ to one loop.

$$\mathrm{e}^{i\Gamma_{eff}[V]} = \int [\mathrm{d}\tilde{f}]\, [\mathrm{d}\tilde{f}^*]\, [\mathrm{d}\tilde{\chi}^+]\, [\mathrm{d}\bar{\tilde{\chi}}^+]\, [\mathrm{d}\tilde{\chi}^0]\, [\mathrm{d}H]\, \mathrm{e}^{i\Gamma_{\mathrm{MSSM}}[V,\tilde{f},\tilde{\chi}^+,\tilde{\chi}^0,H]}$$

- Large sparticle masses and large M_A expansion of $\Gamma_{eff}[A, Z, W^{\pm}]$.

$$m_{\tilde{q}},\, m_{\tilde{l}},\, m_{\tilde{\chi}_i^{\pm}},\, m_{\tilde{\chi}_j^{o}},\, M_A \gg \text{ EW scale}$$
$$|\tilde{m}_i^2 - \tilde{m}_j^2| \ll |\tilde{m}_i^2 + \tilde{m}_j^2| \; \forall i,j$$

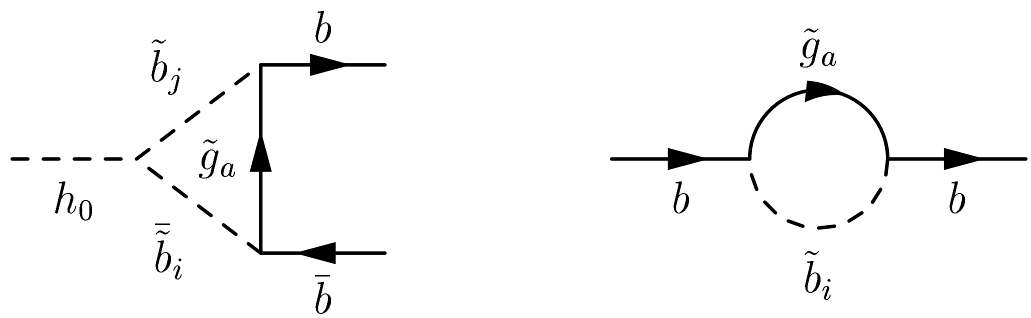


$$+\, \mathcal{O}\left(\left(\frac{p}{M_{SUSY}}\right)^m, \left(\frac{M_{EW}}{M_{SUSY}}\right)^r, \left(\frac{\Delta M_{SUSY}}{M_{SUSY}}\right)^t\right)$$

Decoupling *a la* Appelquist Carazzone

SUSY-QCD corrections to $h^o \to \bar{b}b$

$\Gamma(h^o \to b\bar{b})$ to one loop and $O(\alpha_S)$:



$$\Gamma_1(h^o \to b\bar{b}) \equiv \Gamma_0(h^o \to b\bar{b})(1 + 2\Delta_{QCD} + 2\Delta_{SQCD}),$$

- Δ_{QCD} , QCD correction gives a $\sim$ 50% reduction in $\Gamma(h^o \to b\bar{b})$ decay rate for M_{h^0} in its MSSM range.
  QCD correction has the same form in MSSM as in SM.
  (Braaten & Leveille 1980, Sakai 1980, Inami & Kubota 1981)

- Δ_{SQCD} , SUSY-QCD correction is comparable to QCD correction for a wide window of the parameter space.
  (Dabeltein '95, Corasa,Jimenez& Sola '96),
  (Carena et al. '99, Eberl et al. '00), (Heinemeyer et al. '00)

We are interested in Δ_{SQCD} in the decoupling limit

Previous numerical computations seem to reveal decoupling of SUSY-QCD corrections in the heavy sparticles limit (Corasa,Jimenez& Sola 1996)

We want to explore decoupling behaviour both numerically and analitically

Δ_{SQCD} in the Decoupling Limit

(H.Haber,M.H,H.Logan,S.Peñaranda,S.Rigolin & D.Temes, 2000)

We consider the limit:

$$M_{SUSY} \sim M_{\tilde{Q}} \sim M_{\tilde{D}} \sim M_{\tilde{g}} \sim \mu \sim A_b \gg M_Z$$

$\Rightarrow$ heavy sbottoms and heavy gluino

and expand C_0, B_0, $\sin\theta_{\tilde{b}}$...in inverse powers of M_{SUSY}

defining:

$$\tilde{M}_S^2 \equiv \frac{1}{2}(M_{\tilde{b}_1}^2 + M_{\tilde{b}_2}^2) \ , \ R \equiv \frac{M_{\tilde{g}}}{\tilde{M}_S} \ , \ f_i(1) = 1$$
$$X_b \equiv A_b - \mu \tan\beta \ , \ Y_b \equiv A_b + \mu \cot\alpha$$

We get, for $\theta_{\tilde{b}} \sim \pm 45°$, and up to $\mathcal{O}(M_{Z,h^o}^2/M_{SUSY}^2)$:

$$\Delta_{SQCD} = \frac{\alpha_s}{3\pi}\left\{\frac{-\mu M_{\tilde{g}}}{\tilde{M}_S^2}(\tan\beta + \cot\alpha)\, f_1(R) - \frac{Y_b M_{\tilde{g}} m_h^2}{12\tilde{M}_S^4} f_4(R) + \frac{2}{3}\frac{M_Z^2}{\tilde{M}_S^2}\frac{\cos\beta\sin(\alpha+\beta)}{\sin\alpha} I_3^b \left(f_5(R) + \frac{M_{\tilde{g}} X_b}{\tilde{M}_S^2} f_2(R)\right) + \mathcal{O}\left(\frac{m_b^2}{\tilde{M}_S^2}\right)\right\}$$

First term agrees with effective coupling result in the zero ext. mom. approx. (Carena,Mrenna & Wagner 1999)

No Decoupling with M_{SUSY} if fixed M_A

Recovering decoupling if all MSSM spectra heavy

If, in addition, to heavy sbottoms and gluino, we have also heavy extra Higgses, $M_A \gg M_Z$, , then:

$$\cot\alpha = -\tan\beta - 2\frac{M_Z^2}{M_A^2}\tan\beta\cos 2\beta + \mathcal{O}\left(\frac{M_Z^4}{M_A^4}\right)$$

and, therefore:

$$\Delta_{SQCD} = \frac{\alpha_s}{3\pi}\left\{\frac{2\mu M_{\tilde{g}}}{\tilde{M}_S^2}f_1(R)\tan\beta\cos 2\beta\frac{M_Z^2}{M_A^2} - (A_b - \mu\tan\beta)\frac{M_{\tilde{g}}m_{h^o}^2}{12\tilde{M}_S^4}f_4(R)\right.$$
$$\left. + \frac{2}{3}\frac{M_Z^2}{\tilde{M}_S^2}\frac{\cos\beta\sin(\alpha+\beta)}{\sin\alpha}I_3^b\left(f_5(R) + \frac{M_{\tilde{g}}X_b}{\tilde{M}_S^2}f_2(R)\right) + \mathcal{O}\left(\frac{m_b^2}{\tilde{M}_S^2}\right)\right\}$$

Decoupling if and only if
M_{SUSY} and $M_A \to \infty$

Comments:

- Dominant terms go as $\Delta_{SQCD} \sim C_1\frac{M_Z^2}{M_A^2} + C_2\frac{M_{Z,h^0}^2}{M_{SUSY}^2}$
- In the limit $\tan\beta \gg 1$:

  $|\Delta_{SQCD}|$ grows with $\tan\beta$: delayed decoupling

  Both C_1 and C_2 enhanced by $\tan\beta$

  sign of Δ_{SQCD} governed by sign of μ and $M_{\tilde{g}}$
- Similar results for $\theta_{\tilde{b}} \sim 0^\circ$

A simple example with $\theta_{\tilde{b}} \sim 45^\circ$

Take just one scale M_S:

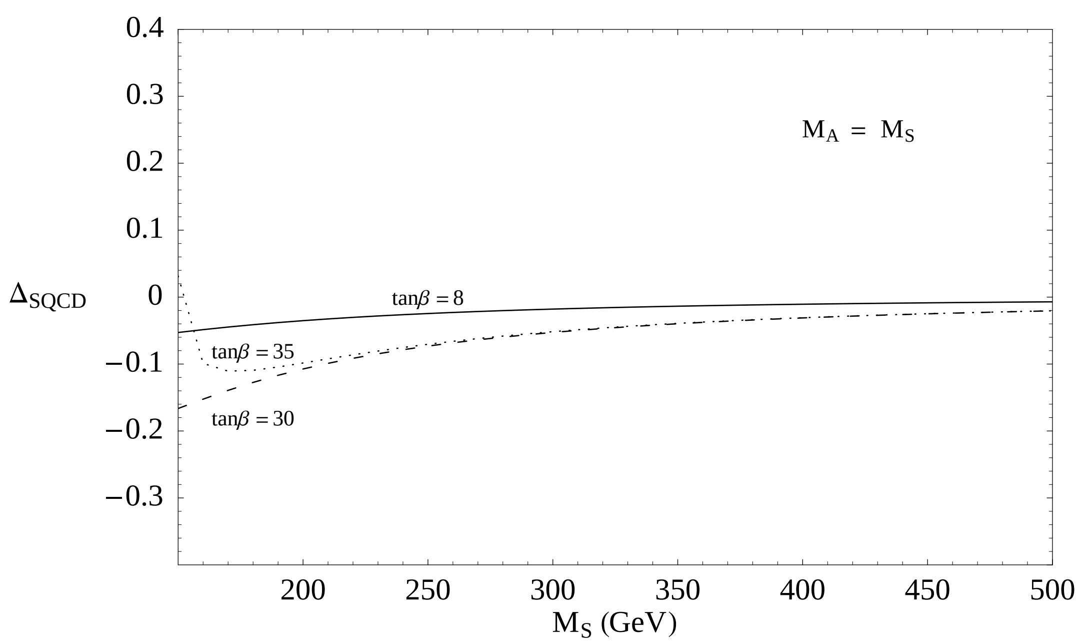
$A_b = \mu = M_{\tilde{Q}} = M_{\tilde{D}} = M_{\tilde{g}} = M_S$

$M_A = M_S$

In the limit $M_S \gg M_Z$ we get:

$$\Delta_{\rm SQCD} = \frac{\alpha_s}{3\pi}\frac{1}{M_S^2}\Big\{2\tan\beta\cos 2\beta M_Z^2 + \frac{2}{3}M_Z^2\cos 2\beta I_3^b(2-\tan\beta) - \frac{M_{h^o}^2}{12}(1-\tan\beta) + \cdots\Big\}$$

In agreement with numerical behaviour of exact result:



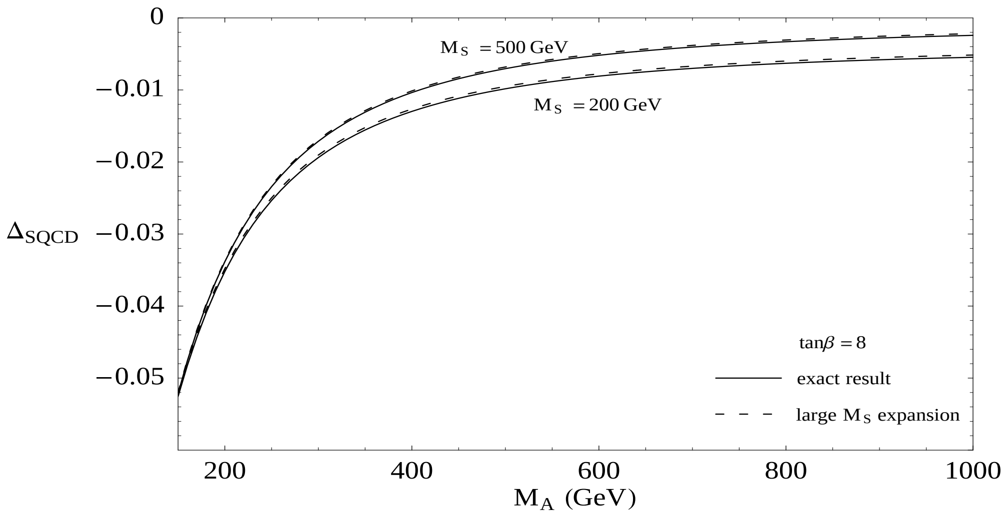
Decoupling with M_S

Typical size for $M_S \geq 250\, GeV$: $\Delta_{SQCD} \leq -10\%$

Two different scales $M_A \neq M_S$

1) For fixed M_S and large M_A

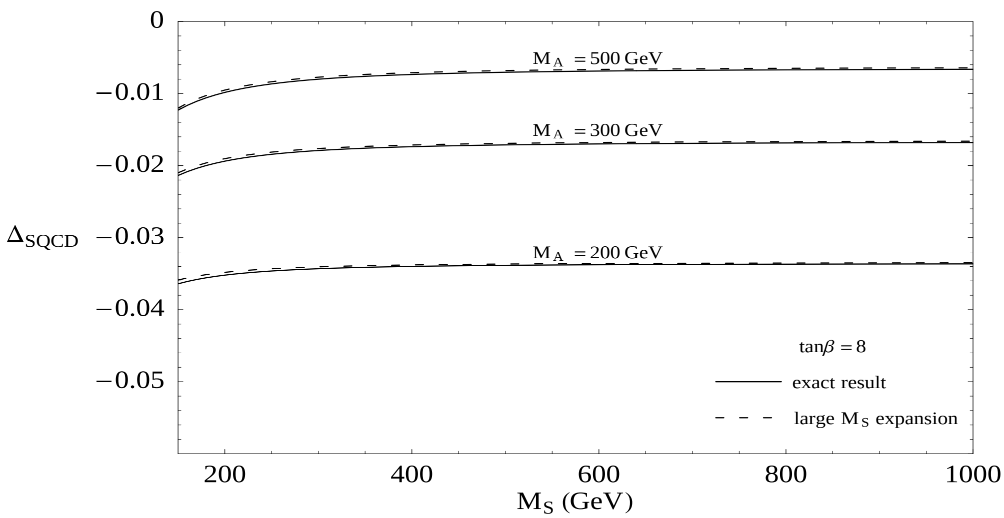
Δ_{SQCD} tends to a non vanishing constant:



No independent decoupling with M_A

2) For fixed M_A and large M_S

Δ_{SQCD} tends to a non vanishing constant:



No independent decoupling with M_S

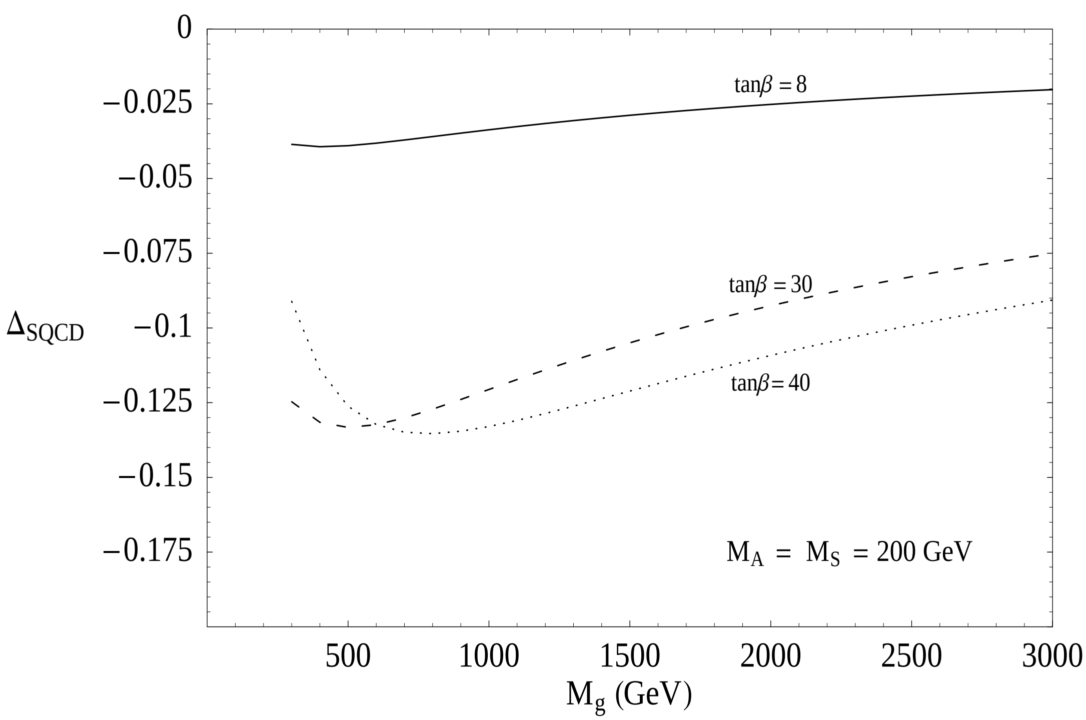
Independent decoupling of gluino

We expand the correction in the heavy gluino limit
$M_{\tilde{g}} \gg \tilde{M}_S \sim \mu \sim A_b \gg M_Z$:

$$\Delta_{SQCD} = \frac{\alpha_s}{3\pi}\Big\{\frac{2\mu}{M_{\tilde{g}}}(\tan\beta + \cot\alpha)\left(1 - \log\left(\frac{M_{\tilde{g}}^2}{\tilde{M}_S^2}\right)\right) + \frac{2X_b}{M_{\tilde{g}}}\frac{M_Z^2}{\tilde{M}_S^2}\frac{\cos\beta\sin(\alpha+\beta)}{\sin\alpha}I_3^b - \frac{Y_b}{3M_{\tilde{g}}}\frac{m_h^2}{\tilde{M}_S^2} + \mathcal{O}\left(\frac{M^2}{M_{\tilde{g}}^2}\right)\Big\}.$$

In agreement with exact numerical result:

(Corasa, Jimenez & Sola 1996)



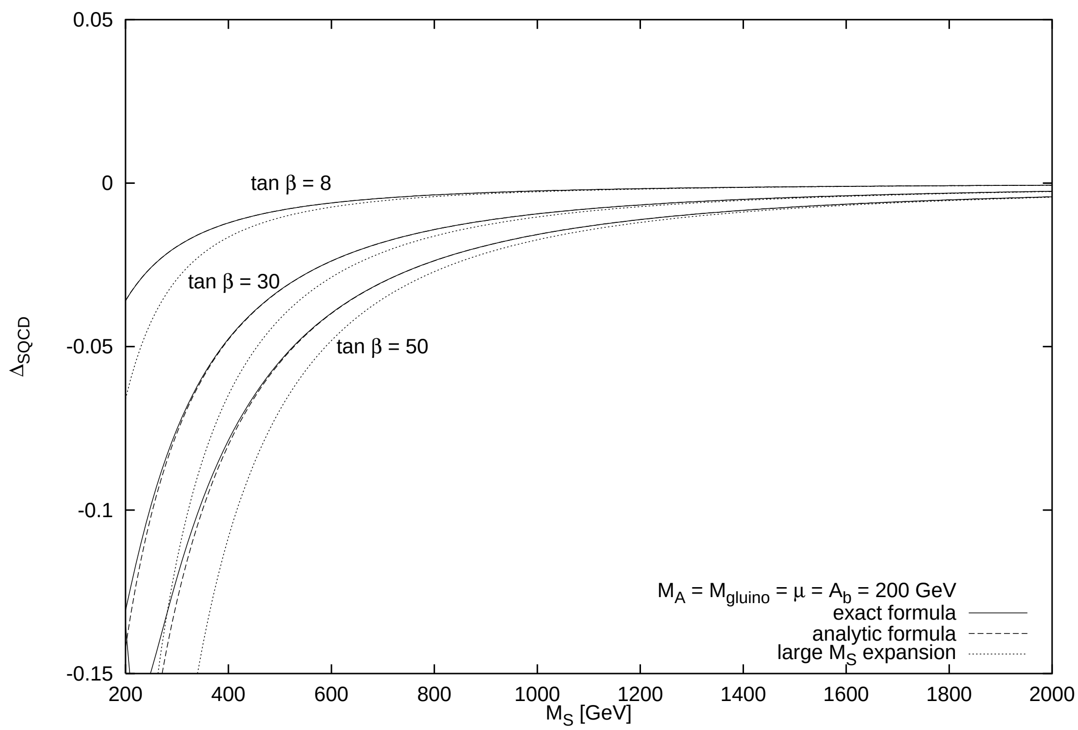
Very slow decoupling with $M_{\tilde{g}}$

Sizeable correction even for large $M_{\tilde{g}}$:
For $\tan\beta = 30$ and $M_{\tilde{g}} = 1TeV$, $\Delta_{SQCD} = -12\%$

Independent decoupling of sbottoms

We expand the correction in the heavy sbottoms limit $\tilde{M}_S \gg M_{\tilde{g}} \sim \mu \sim A_b \gg M_Z$:

$$\Delta_{SQCD} = \frac{\alpha_s}{3\pi} \left\{ \frac{-2\mu M_{\tilde{g}}}{\tilde{M}_S^2} (\tan\beta + \cot\alpha) + \frac{M_Z^2}{\tilde{M}_S^2} \frac{\cos\beta \sin(\alpha+\beta)}{\sin\alpha} I_3^b + \mathcal{O}\left(\frac{m_b^2}{\tilde{M}_S^2}\right) \right\}$$

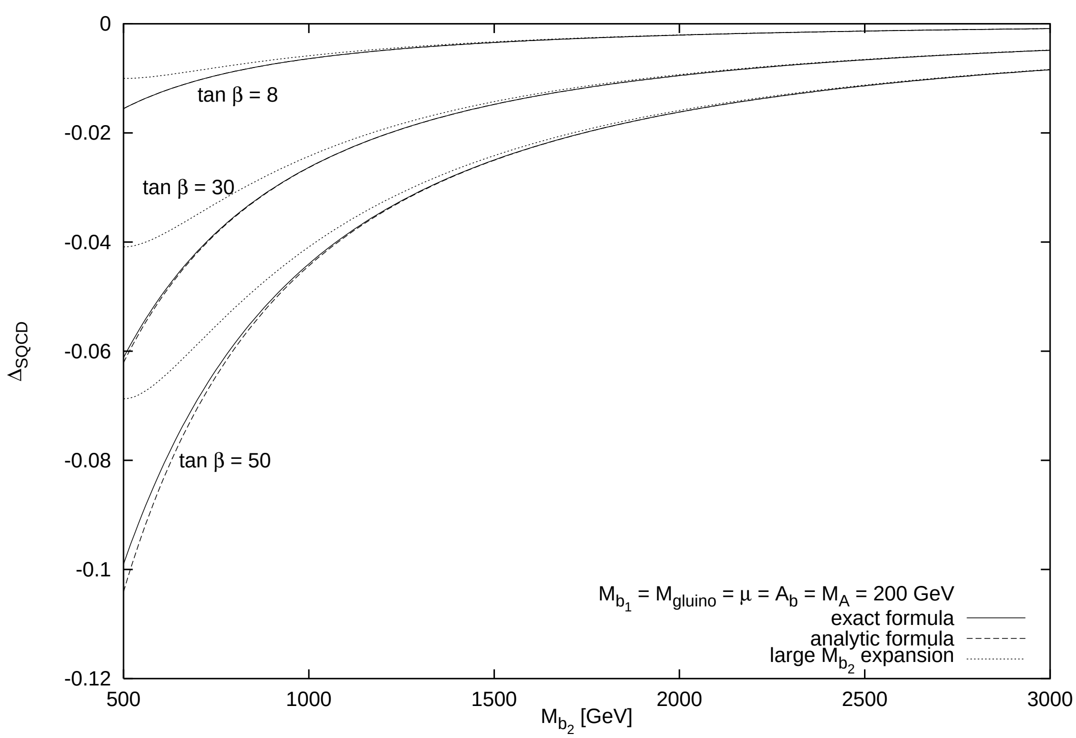


Fast decoupling with $\tilde{M}_S$

No decoupling of heaviest sbottom

Expand the correction in the heavy sbottoms limit $M_{\tilde{D}} \gg M_{\tilde{Q}} \sim M_{\tilde{g}} \sim \mu \sim A_b \gg M_Z$, so that $M_{\tilde{b}_2} \gg M_{\tilde{b}_1}$:

$$\Delta_{SQCD} = \frac{\alpha_s}{3\pi} \left\{ \frac{2}{3} \frac{M_Z^2}{M_{\tilde{b}_1}^2} \frac{\cos\beta \sin(\alpha+\beta)}{\sin\alpha} (I_3^b - Q_b s_W^2) f_5(R_1) \right.$$
$$+ \frac{2\mu M_{\tilde{g}}}{M_{\tilde{b}_2}^2} (\tan\beta + \cot\alpha) \left[h_1(R_1) + \log\left(\frac{M_{\tilde{g}}^2}{M_{\tilde{b}_2}^2}\right) \right]$$
$$+ \frac{M_Z^2}{M_{\tilde{b}_2}^2} \frac{\cos\beta \sin(\alpha+\beta)}{\sin\alpha} \left[(I_3^b - Q_b s_W^2) \frac{2 M_{\tilde{g}} X_b}{M_{\tilde{b}_1}^2} f_1(R_1) + Q_b s_W^2 \right]$$
$$\left. + \mathcal{O}\left(\frac{m_b^2}{M_{SUSY}^2}\right) \right\}.$$

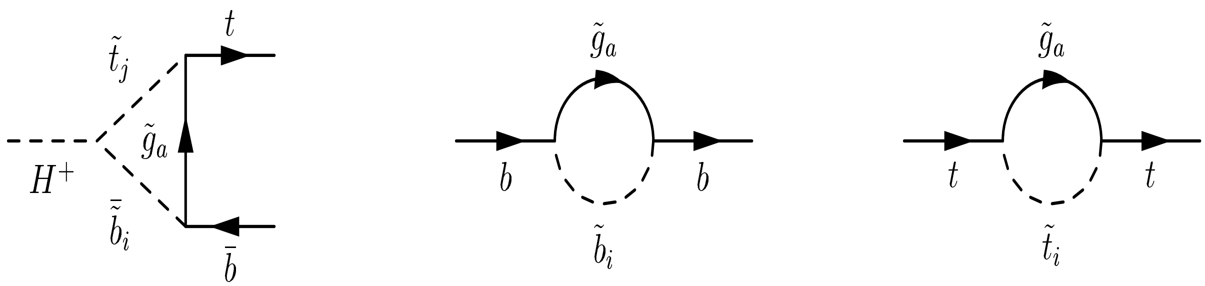


No decoupling with $M_{\tilde{b}_2}$

SUSY-QCD corrections to $H^+ \to t\bar{b}$

$\Gamma(H^+ \to t\bar{b})$ to one loop and $\mathrm{O}(\alpha_S)$:

(R. Jimenez and J. Sola, A. Bartl et al., 1996)



Results in the decoupling limit

(M.H., S.Peñaranda and D.Temes in progress)

$$\Gamma_1(H^+ \to t\bar{b}) \equiv \Gamma_0(H^+ \to t\bar{b})(1 + 2\Delta_{QCD} + 2\Delta_{SQCD}),$$

We have obtained analytical expansions for Δ_{SQCD} including $\mathcal{O}(M_{EW}^2/M_{SUSY}^2)$ corrections, for max/min $\theta_{\tilde{b},\tilde{t}}$

For $\theta_{\tilde{b},\tilde{t}} \sim 45^o$ and $\tilde{M}_S^2 \equiv \frac{1}{2}(M_{\tilde{b}_1}^2 + M_{\tilde{b}_2}^2) \equiv \frac{1}{2}(M_{\tilde{t}_1}^2 + M_{\tilde{t}_2}^2)$ we get:

$$\Delta_{SQCD} = \frac{\alpha_s}{3\pi}\left\{\frac{-\mu M_{\tilde{g}}}{\tilde{M}_S^2}(\tan\beta + \cot\beta)\, f_1(R) + \mathcal{O}\left(\frac{M_{EW}^2}{\tilde{M}_S^2}\right)\right\}$$

The leading term agrees with result from effective lagrangian approach: (Eberl et al. '00, Carena et al. '00)

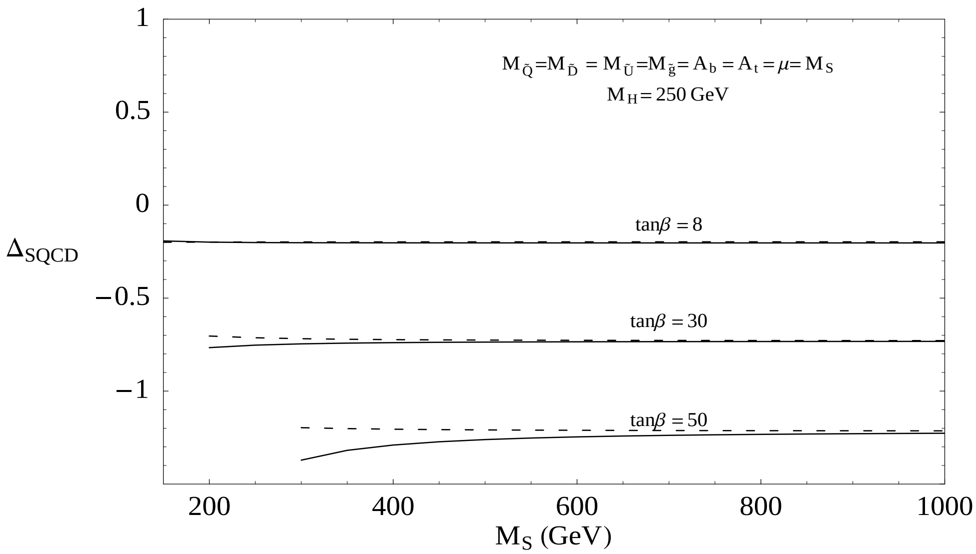
No Decoupling with M_{SUSY}

- Enhanced by $\tan\beta$
- Proportional to $M_{\tilde{g}}\mu$
- Similar results for $\theta_{\tilde{b},\tilde{t}} \sim 0^o$

$H^+ \to t\bar{b}$ in the decoupling limit

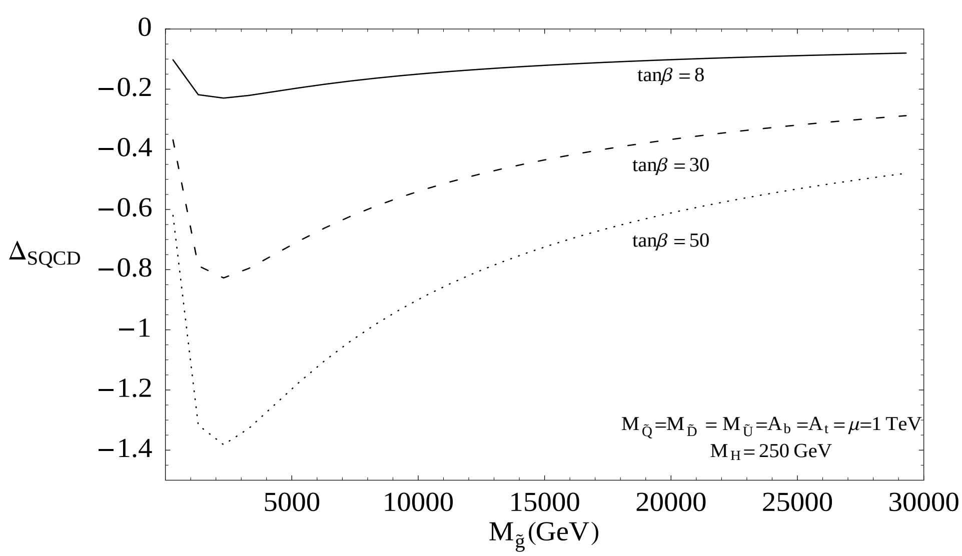
(M.H., S.Peñaranda and D.Temes in progress)

1) One scale $M_S = M_{\tilde{Q}} = M_{\tilde{U}} = M_{\tilde{D}} = M_{\tilde{g}} = A_b = A_t = \mu$



No decoupling with M_{SUSY}

2) Independent decoupling of gluino



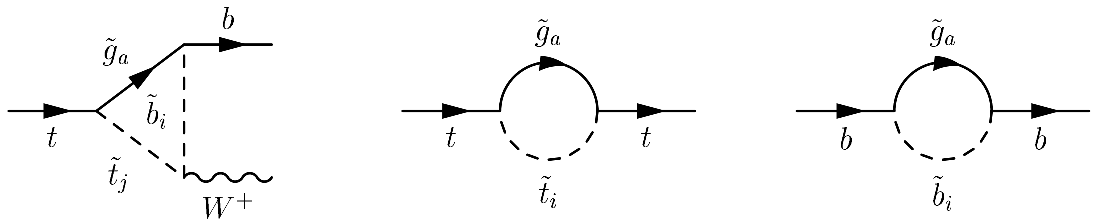
Very slow decoupling with $M_{\tilde{g}}$

Large correction even for large $M_{\tilde{g}}$:

For $\tan\beta = 30$ and $M_{\tilde{g}} = 1$ TeV, $\Delta_{SQCD} = -75\%$

SUSY-QCD corrections to $t \to W^+ b$

(Dabelstein et al 1995, Guasch et al 1995)



$\Delta_{SQCD} \sim -5\%$ to -10% quite insensitive to $\tan\beta$

to be compared with SUSY-EW corrections (Garcia et al 1994):

$\Delta_{SEW} \sim -1\%$ to -10% growing with $\tan\beta$

SUSY-QCD corrections in the decoupling limit

(M.H,D.Temes, in progress)

Simplest choice:

$$M_{\tilde{Q}} = M_{\tilde{U}} = M_{\tilde{D}} = A_t = A_b = \mu = M_{\tilde{g}} = M_S \gg m_{EW}$$

Expanding Δ_{SQCD} in inverse powers of M_S we get:

$$\Delta_{SQCD} = -\frac{2\alpha_s}{3\pi}\frac{m_t^2}{M_S^2}\left(\frac{1}{6} + \frac{1}{24}(1-\cot\beta)^2 + \frac{1}{6}(1-\cot\beta)\right) + ...$$

Fast decoupling with M_S ; Not enhanced by $\tan\beta$

CONCLUSIONS

The one-loop SUSY-QCD corrections to

$\Gamma(h^o \to \bar{b}b)$:

- Do not decouple if internal $\tilde{g}$ and $\tilde{b}$ are very heavy!!
- Decouple if and only if both M_{SUSY} and M_A are very large
- Sizeable for large $\tan\beta \Rightarrow$ Delayed decoupling
- Decouple independently and very slowly with $M_{\tilde{g}}$
- Decouple independently and fast with $M_{\tilde{b}}$

$\Gamma(H^+ \to t\bar{b})$:

- Do not decouple if internal $\tilde{g}$ and $\tilde{b}$, $\tilde{t}$ are very heavy!!
- Sizeable for large $\tan\beta \Rightarrow$ Delayed decoupling
- Decouple independently and very slowly with $M_{\tilde{g}}$

$\Gamma(t \to W^+ b)$:

- Decouple fast with M_{SUSY}

Indirect SUSY breaking signals at low energy Higgs physics?
Sizeable corrections that can be negative $\Rightarrow$ Interesting enhacements in
$BR(h^0 \to \tau^+\tau^-)$ and $BR(H^+ \to \tau^+\nu_\tau)$