Updated Constraints from B Physics on the MSSM and the NMSSM.[1]

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[1] F. Domingo and U. Ellwanger, arXiv:0710.3714 [hep-ph].

Recent Experimental and SM Achievements on B Physics Observables

$BR(B \to X_s\gamma)$

- Status until 2005:

$$BR(B \to X_s\gamma)|^{exp.}_{E_\gamma > 1.6\,GeV} = (3.23 \pm 0.42)\,.10^{-4} \quad \text{Exp. World Average, 2001}$$
$$BR(B \to X_s\gamma)|^{NLO}_{E_\gamma > 1.6\,GeV} = (3.61 \pm 0.5)\,.10^{-4} \quad \text{SM NLO prediction, [\textit{Hurth et al.}, 2005]}$$

- Present situation:

$$BR(B \to X_s\gamma)|^{exp.}_{E_\gamma > 1.6\,GeV} = \left(3.55 \pm 0.24^{+0.09}_{-0.10} \pm 0.03\right).10^{-4} \quad \text{Exp. World Average, 2005}$$
$$BR(B \to X_s\gamma)|^{NNLO}_{E_\gamma > 1.6\,GeV} = (3.15 \pm 0.23)\,.10^{-4} \quad \text{SM NNLO, [\textit{Misiak et al.}, 2006]}$$
$$BR(B \to X_s\gamma)|^{NNLO}_{E_\gamma > 1.6\,GeV} = (2.98 \pm 0.26)\,.10^{-4} \quad \text{SM NNLO, [\textit{Becher, Neubert}, 2006]}$$

(using an improved treatment of the photon energy cutoff)

$\Delta M_d = M_{B_d} - M_{\bar{B}_d}$, $\Delta M_s = M_{B_s} - M_{\bar{B}_s}$

- ΔM_d:

$$\Delta M_d^{exp} = (0.507 \pm 0.004)\,.ps^{-1} \quad \text{HFAG, 2005}$$
$$\Delta M_d^{SM} = (0.59 \pm 0.19)\,.ps^{-1} \quad \text{SM prediction}$$

- ΔM_s:

$$\Delta M_s^{exp} = (17.77 \pm 0.12)\,.ps^{-1} \quad \text{CDF, 2006}$$
$$\Delta M_s^{SM} = (20.5 \pm 3.1)\,.ps^{-1} \quad \text{SM prediction}$$

$BR(\bar{B}_s \to \mu^+\mu^-)$

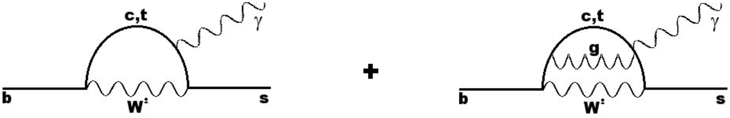
$$BR(\bar{B}_s \to \mu^+\mu^-)\big|_{exp} < 5.8 \times 10^{-8} \;\; (95\% C.L.) \qquad \text{CDF, 2007}$$
$$BR(\bar{B}_s \to \mu^+\mu^-)\big|_{SM} = (3.8 \pm 0.1) \times 10^{-9} \qquad [\textit{Dedes et al.}, 2002]$$

$BR(\bar{B}^+ \to \tau^+\nu_\tau)$

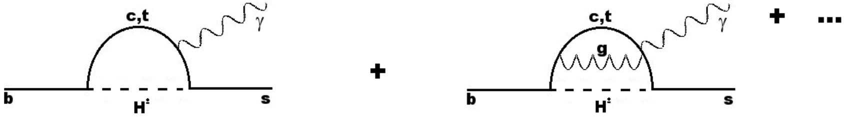
$$BR(\bar{B}^+ \to \tau^+\nu_\tau)\big|_{exp.} = (1.32 \pm 0.49)\,.10^{-4} \quad \text{HFAG, 2005}$$
$$BR(\bar{B}^+ \to \tau^+\nu_\tau)\big|_{SM} \;\text{from}\; (0.85 \pm 0.13)\,.10^{-4} \;\; [\textit{Carena et al.}, 2007] \quad |V_{ub}|_{excl.} \sim 3.7 \times 10^{-3}$$
$$\text{to}\; (1.59 \pm 0.40)\,.10^{-4} \;\; [\textit{Isidori, Paradisi}, 2006] \quad |V_{ub}|_{incl.} \sim 4.4 \times 10^{-3}$$

Contributions to $BR(b \to s\gamma)$

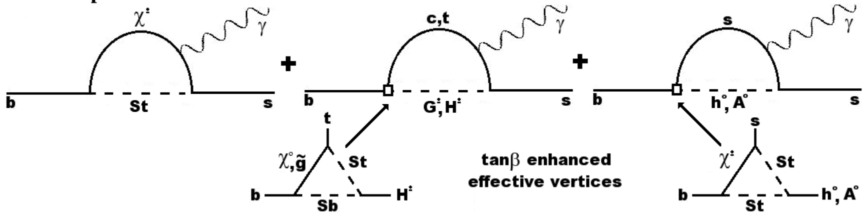
- SM:



- Charged Higgs:



- SUSY particles:



$BR(\bar{B} \to X_s\gamma)$: Formalism [*Gambino, Misiak*, 2001]; [*Hurth, Lunghi, Porod*, 2005]

Formula derived in a low-energy Effective Theory (matching scale $\mu_o \equiv m_t$):

$$BR(\bar{B} \to X_s\gamma)\Big|_{E_\gamma > E_o} = \frac{6\alpha_{em}}{\pi C}\left|\frac{V_{ts}^* V_{tb}}{V_{cb}}\right|^2 BR(\bar{B} \to X_c e\bar{\nu}) \times \left[\left|K_c + \frac{m_b(m_t)}{m_b^{1S}}(K_t + K_{BSM}) + \epsilon_{ew}\right|^2 + B(E_o) + N\right]$$

Quantities Involved:

- $K_c + \frac{m_b(m_t)}{m_b^{1S}}(K_t + K_{BSM})$: NLO QCD partonic amplitude for $b \to s\gamma$. Ambiguous dependence at NLO on $\frac{m_c}{m_b} = 0.23\,^{+0.08}_{-0.05}$: SM NNLO results reproduced for $\frac{m_c}{m_b} \simeq 0.307$;
- $BR(\bar{B} \to X_c e\bar{\nu})$: measured experimentally, $\simeq 0.1061$;
- $C = \left|\frac{V_{ub}}{V_{cb}}\right|^2 \frac{\Gamma(\bar{B} \to X_c e\bar{\nu})}{\Gamma(\bar{B} \to X_u e\bar{\nu})}$, calculable $\simeq 0.580$;
- N: Non-Perturbartive corrections (Heavy Quark Effective Theory) $\sim \frac{\Lambda_{QCD}^2}{m_c^2}$ (+ higher orders);
- $B(E_o)$: (gluon) Bremsstrahlung corrections, depends on the lower limit E_o on the photonic energy E_γ. Here: $E_o = 1.6\,GeV$;
- ϵ_{ew}: electroweak radiative corrections;

Calculation of ΔM_q, $q = d, s$

Formula for the Mass difference, [*Buras et al.*, 2003]

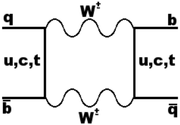
$$\Delta M_q = \frac{G_F^2 M_W^2}{6\pi^2} M_{B_q} \eta_B f_{B_q}^2 \hat{B}_{B_q} \left|V_{tq}^* V_{tb}\right|^2 \left|F_{tt}^q\right|$$

with: $$F_{tt}^q = S_0(x_t) + \frac{1}{4r} C_{new}^{VLL} + \bar{P}_1^{SLL}\left(C_1^{SLL} + C_1^{SRR}\right) + \bar{P}_2^{LR} C_2^{LR} + \ldots$$

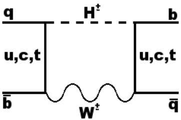
Parameters

- Hadronic parameters (lattice QCD):
  $f_{B_s}\sqrt{\hat{B}_{B_s}} = (0.281 \pm 0.021)\,\mathrm{GeV}$ [*Dalgic et al.*, 2007]
  $f_{B_s}\sqrt{\hat{B}_{B_s}}/f_{B_d}\sqrt{\hat{B}_{B_d}} = 1.216 \pm 0.041$ [*Okamoto*, 2006]
- CKM, from Tree Level measurements [*Ball,Fleisher*, 2006]:
  $|V_{td}^* V_{tb}| = (8.6 \pm 1.4).10^{-3}$
  $|V_{ts}^* V_{tb}| = (41.3 \pm 0.7).10^{-3}$

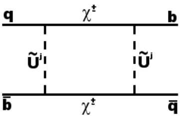
- SM



- Charged Higgs

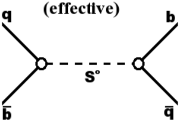


- SUSY



-Neutral Higgs

(effective)



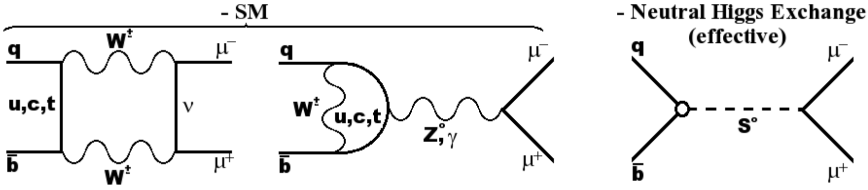
Branching Ratio $\bar{B}_s \to \mu^+\mu^-$

Formula [*Bobeth et al.*, 2002]

$$BR(\bar{B}_s \to \mu^+\mu^-) = \frac{G_F^2\alpha^2 M_{B_s}^5 f_{B_s}^2 \tau_{B_s}}{64\pi^3 \sin^4\theta_W}\left|V_{tb}V_{ts}^*\right|^2 \sqrt{1-4\frac{m_\mu^2}{m_{B_s}^2}}\left[\frac{1-4\frac{m_\mu^2}{M_{B_s}^2}}{\left(1+\frac{m_s}{m_b}\right)^2}|c_S|^2 + \left|\frac{c_P}{1+\frac{m_s}{m_b}} + \frac{2m_\mu}{M_{B_s}^2}c_A\right|^2\right]$$

Effective coefficients

- SM contribution in c_A: 1 order of magnitude below the sensitivity of experiments;
- Effective Neutral Higgs contributions in c_S, c_P: enhanced for light scalars/large $\tan\beta$.



Branching ratio $\bar{B}^+ \to \tau^+\nu_\tau$

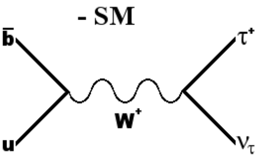
Formula [*Akeroyd, Recksiegel*, 2003]

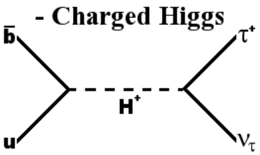
$$BR(\bar{B}^+ \to \tau^+\nu_\tau) = \frac{G_F^2 M_B m_\tau^2}{8\pi}\left(1 - \frac{m_\tau^2}{M_B^2}\right)^2 f_B^2\,|V_{ub}|^2\,\tau_B\,r_H$$

$$r_H = \left[1 - \left(\frac{M_B}{m_{H^\pm}}\right)^2 \frac{\tan^2\beta}{1+\tilde{\varepsilon}_0\tan\beta}\right]^2$$

Parameters

- Hadronic parameter: $f_B = (0.216 \pm 0.022)$ GeV, HPQCD, 2005;
- CKM: large uncertainty; we take $|V_{ub}| = (4.0 \pm 0.35).10^{-3}$.





NMSSM specific effects relative to B constraints with respect to the MSSM…

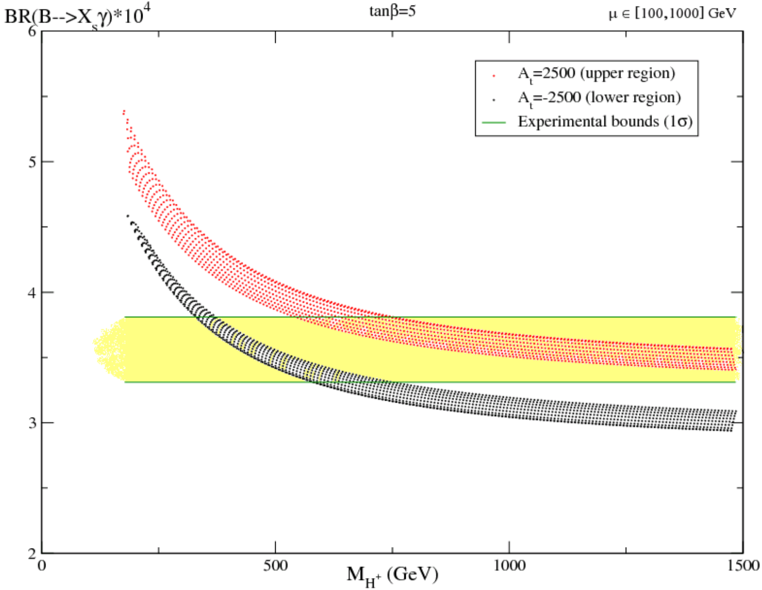
Differences of the Model

- Superfield content: H_d, H_u, Q_L, U^c_R, D^c_R, L_L, E^c_R + 1 singlet S;
- Superpotential: $W = \lambda\, S H_u.H_d + \frac{\kappa}{3} S^3 + Y_u\, Q_L.H_u U^c_R - Y_d\, Q_L.H_d D^c_R - Y_e\, L_L.H_d E^c_R$;
- MSSM "μ" term generated when $< S > \neq 0$; possible solution of the "μ-problem".

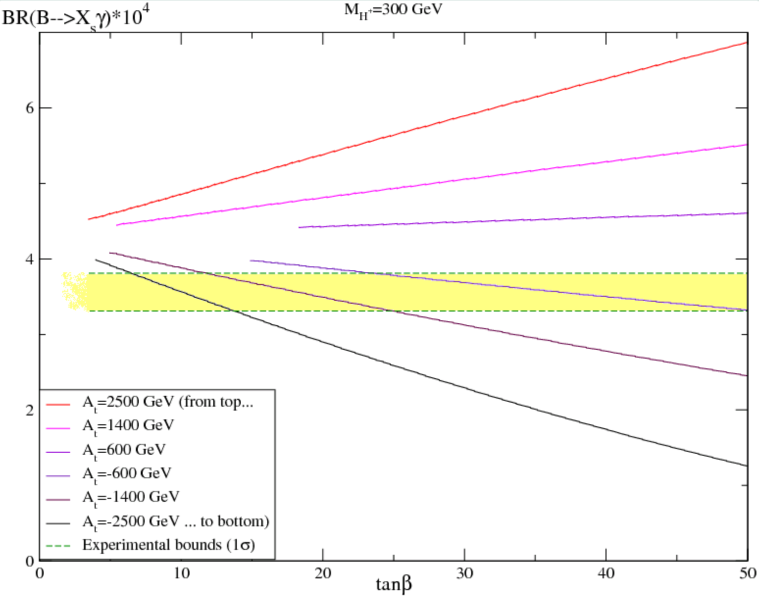
Peculiarities concerning B processes

- Extended Unconstrained Parameter Space: in the NMSSM, low values of $\tan\beta$ (~ 1.5) are not excluded by LEP;
- Charged Higgs Mass: the NMSSM parameter λ gives a negative contribution to $M_{H^\pm}$, which allows for slight modulations on $\bar{B} \to X_s\gamma$;
- The effect of the extended neutralino sector is negligibly small;
- Light pseudoscalars (below 10 GeV) escape LEP constraints, but they are significantly constrained by ΔM_q and $BR(\bar{B}_s \to \mu^+\mu^-)$.

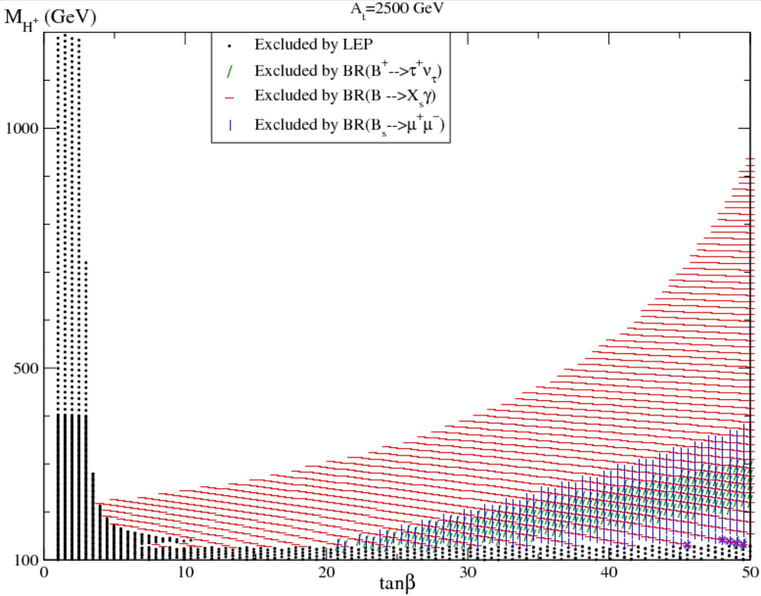
$BR(\bar{B} \to X_s \gamma)$ as a function of $M_{H^\pm}$



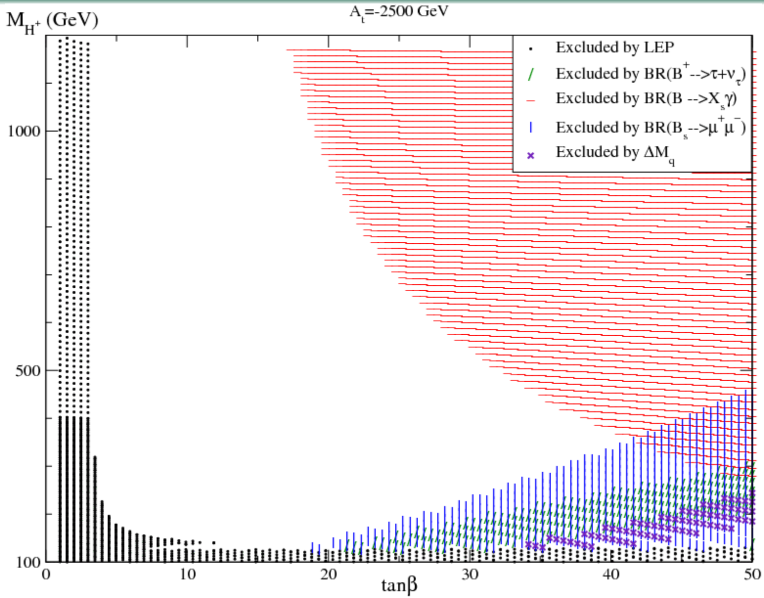
$BR(\bar{B} \to X_s\gamma)$ as a function of $\tan\beta$



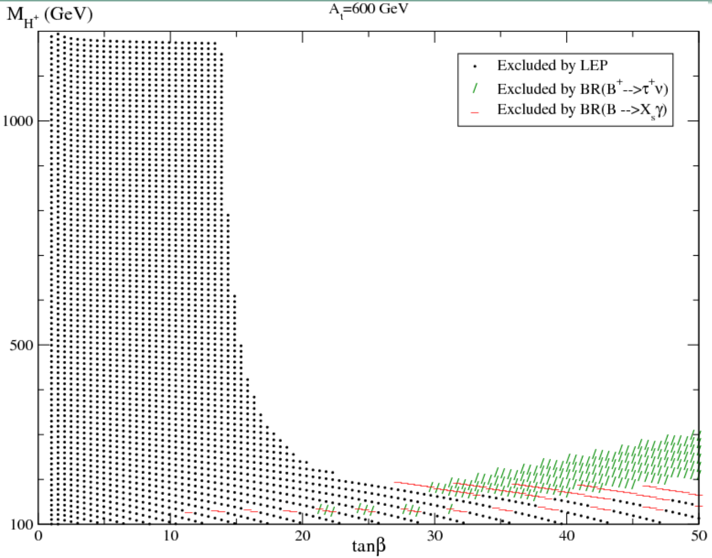
B constraints on the $(M_{H^+}, \tan\beta)$ plane



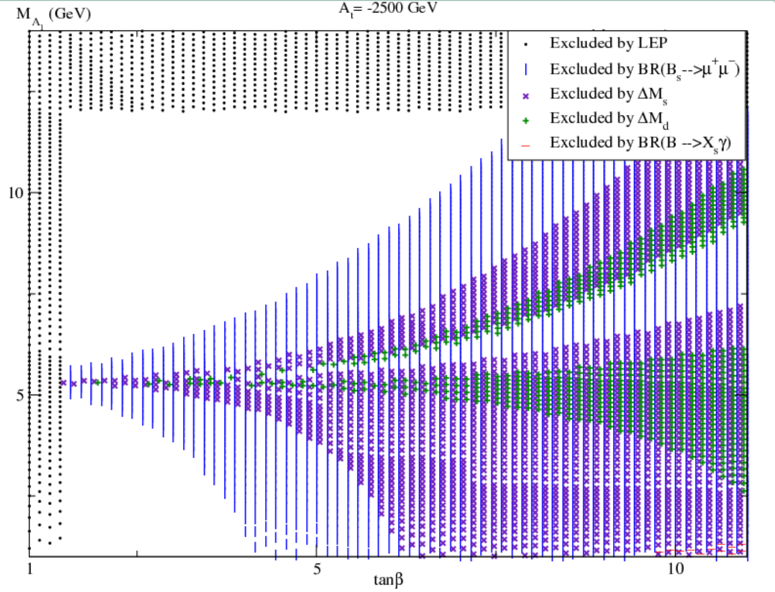
Playing SUSY against Charged Higgs Contribution



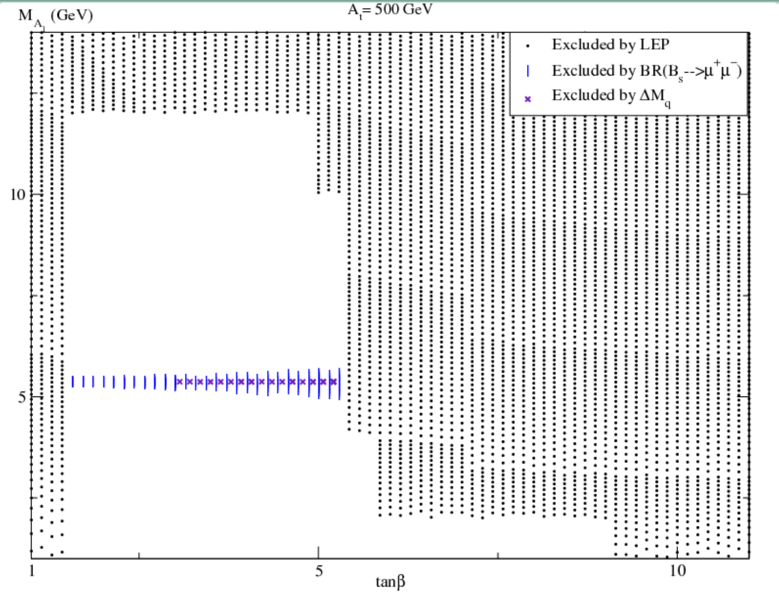
Low values of A_t: weaker B constraints vs enhanced LEP bounds



NMSSM Light Pseudoscalars



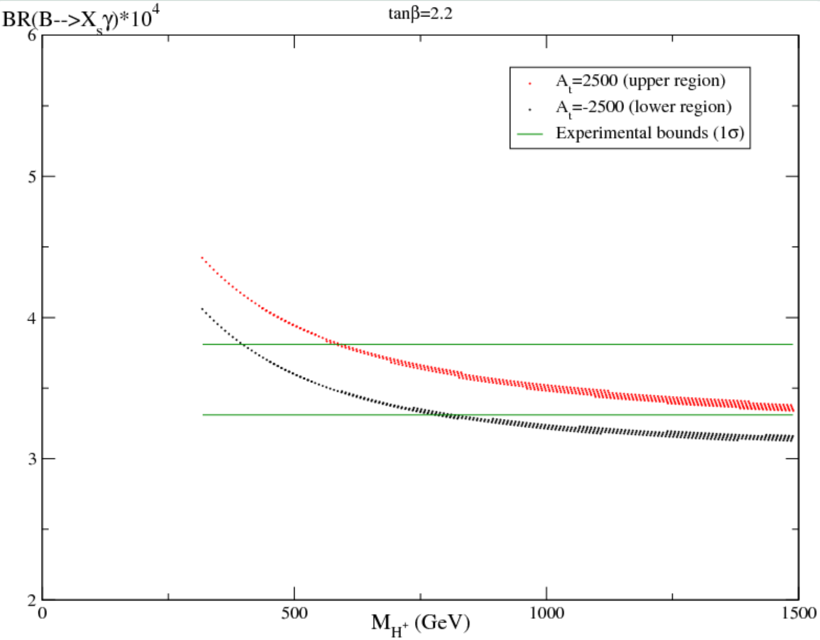
Low A_t

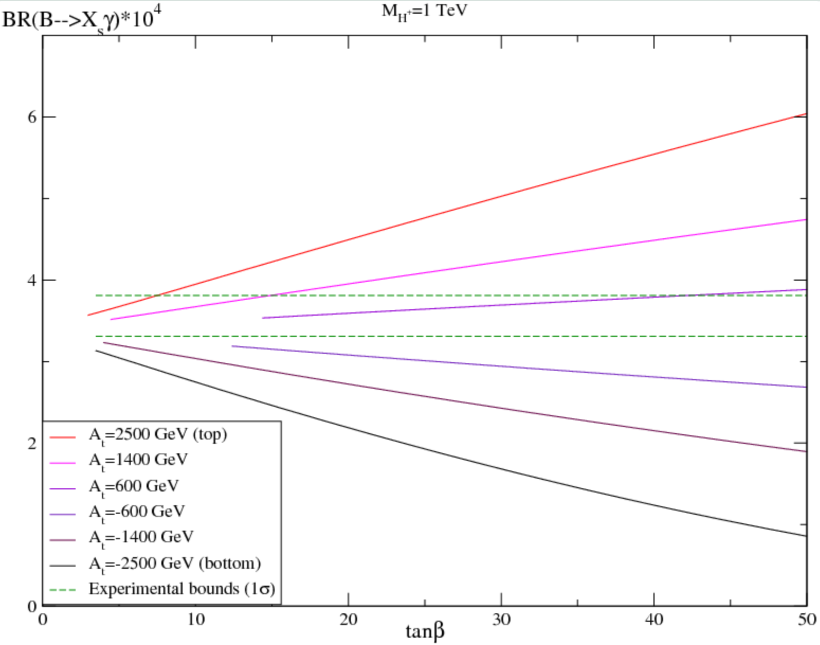


A_t= 500 GeV
M_A1 (GeV)
10
5
1
5
10
tanβ
Excluded by LEP
Excluded by BR(B_s-->μ+μ-)
Excluded by ΔM_q

Conclusions

- Constraints from $\bar{B} \to X_s\gamma$ are weaker than they used to be thanks to the recent improvements on the experimental side and the SM analysis.
- Still, very light ($\leq 200\,GeV$) charged Higgs lead to difficulties for low $\tan\beta$. Domains with both large A_t and large $\tan\beta$ are also strongly constrained.
- $BR(\bar{B}_s \to \mu^+\mu^-)$ is the most sensitive observable depending on neutral scalar exchanges, provides us with significant constraints especially for light scalars.
- The Fortran code will be added to the NMSSMTools package (and could also be used for the MSSM...). Such codes for the MSSM: FeynHiggs, Suspect, MicrOmegas, Spheno.


BR(B-->X_sγ)*10^4
tanβ=2.2
A_t=2500 (upper region)
A_t=-2500 (lower region)
Experimental bounds (1σ)
2
3
4
5
6
0
500
1000
1500
M_H+ (GeV)



BR(B-->X_sγ)*10^4
M_H+=1 TeV
0
2
4
6
0
10
20
30
40
50
tanβ
A_t=2500 GeV (top)
A_t=1400 GeV
A_t=600 GeV
A_t=-600 GeV
A_t=-1400 GeV
A_t=-2500 GeV (bottom)
Experimental bounds (1σ)