Constraints on B and Higgs Physics in MSSM

A. Menon

Argonne National Laboratory and

the University of Chicago

May 16th, 2006

Based on:

M. Carena, A.M., R. Noriega-Papaqui, A. Szynkman and

C. Wagner,[arXiv:hep-ph/0603106];

MSSM Higgs and Sfermion sector review

• The Higgs neutral components acquire VEV's v_1 and v_2 and their ratio is $\tan\beta = v_2/v_1$.

• Neglecting CP violation in the Higgs sector, electroweak breaking leaves one CP odd Higgs of mass M_A and two CP even Higges with tree-level masses

$$M^2_{h,H} = \frac{1}{2}\left(M_A^2 + M_Z^2 \mp \sqrt{(M_A^2 + M_Z^2)^2 - 4M_Z^2 M_A^2 \cos^2 2\beta}\right),$$

and one charged Higgs of mass

$$M^2_{H^+} = M_A^2 + M_W^2$$

.

• Assuming a uniform trilinear for the different generations of squarks (and neglecting D-term contributions) the generic structure of the squark mass matrices is

$$M_U^2 = \begin{pmatrix} \hat{\mathbf{M}}^2_{\tilde{\mathbf{u}}_\mathbf{L}} & \left(A_u - \frac{\mu}{\tan\beta}\right)\frac{v_2}{\sqrt{2}}\hat{\mathbf{Y}}_\mathbf{u} \\ \left(A_u^* - \frac{\mu^*}{\tan\beta}\right)\frac{v_2}{\sqrt{2}}\hat{\mathbf{Y}}^\dagger_\mathbf{u} & \mathbf{M}^2_{\tilde{\mathbf{u}}_\mathbf{R}} \end{pmatrix}$$

$$M_D^2 = \begin{pmatrix} \hat{\mathbf{M}}^2_{\tilde{\mathbf{d}}_\mathbf{L}} & (A_d - \mu\tan\beta)\frac{v_1}{\sqrt{2}}\hat{\mathbf{Y}}_\mathbf{d} \\ (A_d^* - \mu^*\tan\beta)\frac{v_1}{\sqrt{2}}\hat{\mathbf{Y}}^\dagger_\mathbf{d} & \mathbf{M}^2_{\tilde{\mathbf{d}}_\mathbf{R}} \end{pmatrix}.$$

The Effective Resummed MSSM Lagrangian

- Resumming the SUSY loop corrections to the quark masses leads to an effective mass Lagrangian for the down quarks.

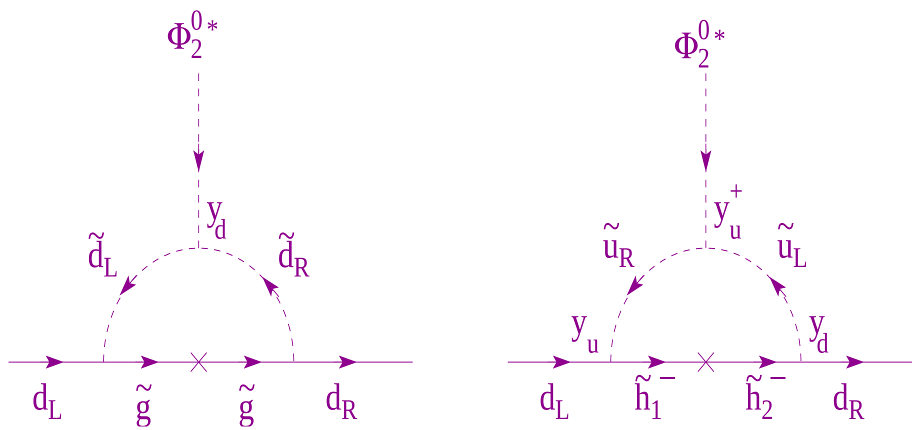
$$-\mathcal{L}_m = \bar{d}_R \mathbf{m_d} [1 + \tan\beta \left(\epsilon_0 + \mathbf{V_0^\dagger} \epsilon_{\mathbf{Y}} |\mathbf{Y_u}|^2 \mathbf{V_0}\right)] d_L + h.c.$$

where V_0 is the tree-level CKM matrix and for uniform squark masses

$$|\epsilon_0| \approx \frac{2\alpha_s}{3\pi} |M_3||\mu| C_0(m^2_{\tilde{b}_1}, m^2_{\tilde{b}_2}, |M_3|^2)$$

$$|\epsilon_Y| \approx \frac{1}{16\pi^2} |A_t||\mu| C_0(m^2_{\tilde{t}_1}, m^2_{\tilde{t}_2}, |\mu|^2)$$

.



- The quark mass matrices need to be rediagonalized. Thereby inducing Flavor Changing Neutral Currents (FCNC) $\propto V^{3J*} V^{3I}$.

Constraints on B Physics in the MSSM

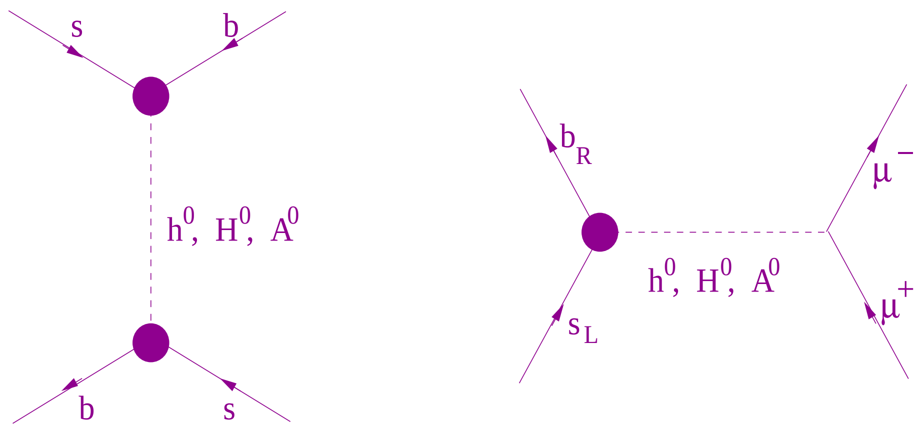
Contributions to ΔM_s and $B_s \to \mu^+\mu^-$ in MSSM

- At large $\tan\beta$ the double penguin contribution to ΔM_s is dominant and $\propto |\epsilon_Y|^2 \tan^4\beta/(|1+\epsilon_3\tan\beta|^2 M_A^2)$, which interferes destructively with the SM.

- Similarly for large $\tan\beta$ the dominant contribution to $B_s \to \mu^+\mu^- \propto |\epsilon_Y|^2 \tan^6\beta/M_A^4$

- Therefore values of $B_s \to \mu^+\mu^-$ and ΔM_s at large $\tan\beta$ are correlated. So for uniform squark masses the only SUSY dependence in their ratio is

$$\frac{\Delta M_s}{\mathcal{BR}(B_s \to \mu^+\mu^-)} \propto \frac{M_A^2}{\tan^2\beta}$$



- For moderate or low $\tan\beta$ the large contributions to ΔM_s are possible for light squarks, charginos or gluinos.

Experimental constraints and Standard Model values of ΔM_s and $B_s \to \mu^+\mu^-$

• The SM contribution to ΔM_s is dominanted by W-Top box diagram and allows ranges

CKMfitter: $\Delta M_s = 21.7^{+5.9}_{-4.2}\text{ps}^{-1}$

J. Charles *et al.* [CKMfitter Group], Eur. Phys. J. C **41**, 1 (2005) [arXiv:hep-ph/0406184];

UTfit: $\Delta M_s = (21.5 \pm 2.6)\text{ps}^{-1}$ http://www.utfit.org

• The experimental values of ΔM_s are:

D0: $\Delta M_s = (19 \pm 2)\text{ps}^{-1}$.

V. Abazov *et al.* [D0 Collaboration], [arXiv:hep-ex/0603029];

CDF $\Delta M_s = (17.33^{+0.42}_{-0.21} \pm 0.07(\text{syst}))(\text{ps})^{-1}$.

http://www-cdf.fnal.gov/physics/new/bottom/060406.blessed-Bsmix/

• The Z-penguins mediate the $B_s \to \mu^+\mu^-$ process in the SM and predicts a value

$$\mathcal{BR}(B_s \to \mu^+\mu^-)_{SM} = (3.8 \pm 1) \times 10^{-9}$$

• The CDF experimental bound on $\mathcal{BR}(B_s \to \mu^+\mu^-) \leq 1.5 \times 10^{-7}$.

R. Bernhard *et al.* [CDF Collaboration], [arXiv:hep-ex/0508058];

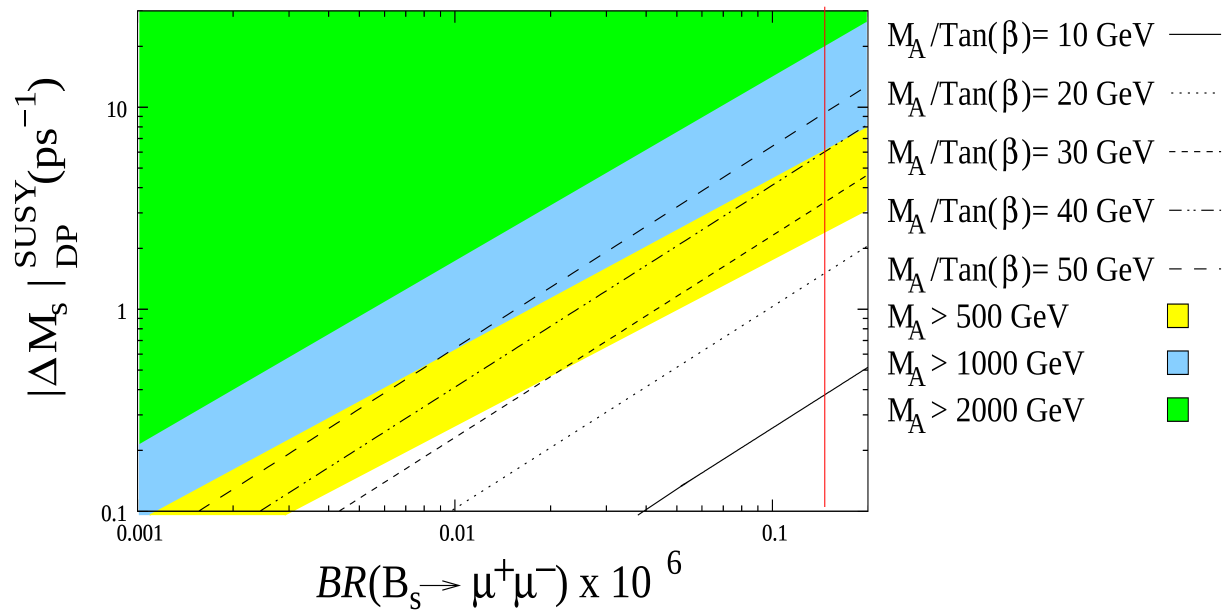
How large can the Double Penguin SUSY contributions to ΔM_s be?

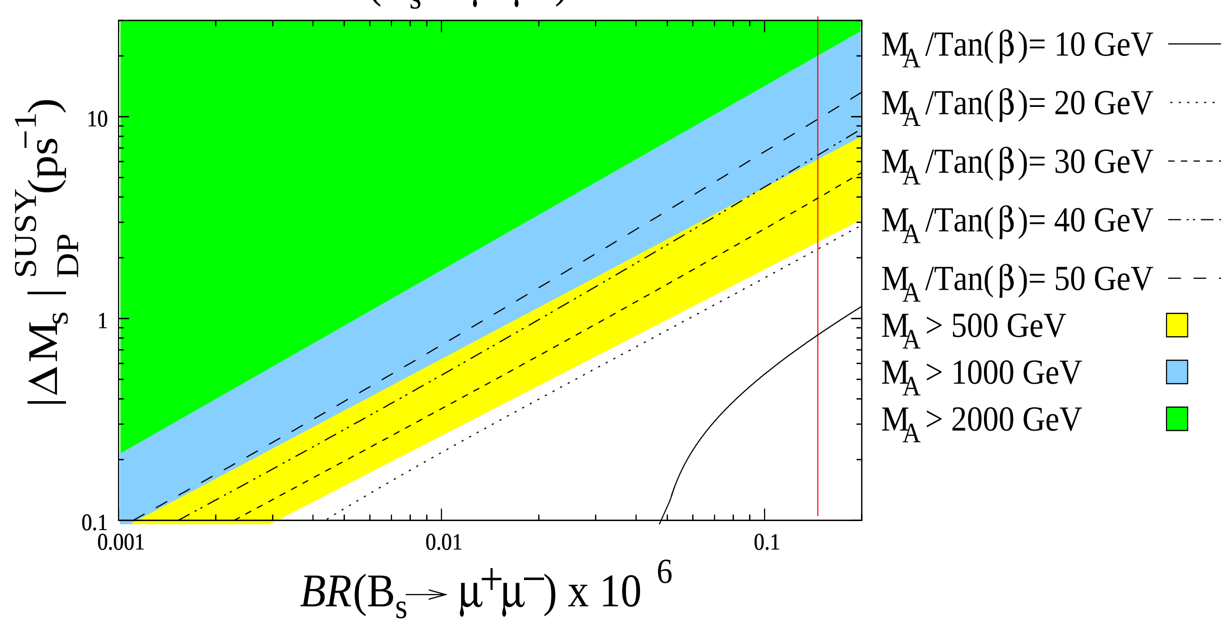
- Large SUSY contributions to ΔM_s within the experimental bound on $\mathcal{BR}(B_s \to \mu^+\mu^-)$ requires $\mu \sim 2M_{\tilde{q}} \sim M_3$.

- For natural values of $M_A \leq 1000$ GeV the largest double penguin contributions can be atmost a few ps^{-1}.

- For MFV, splitting the squark masses so that $M_{\tilde{q}_1} = M_{\tilde{q}_2} = 10 M_{\tilde{q}_3}$ still means a ΔM_s of a few ps^{-1}.

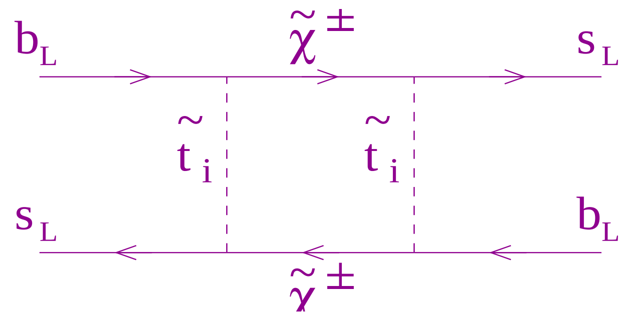
- Can resolve 2σ discrepency between SM and experiment G. Isidori and P. Paradisi, [arXiv:hep-ph/0605012]; $\Rightarrow$ a lower bound $\mathcal{BR}(B_s \to \mu^+\mu^-) \geq 3 \times 10^{-8}$





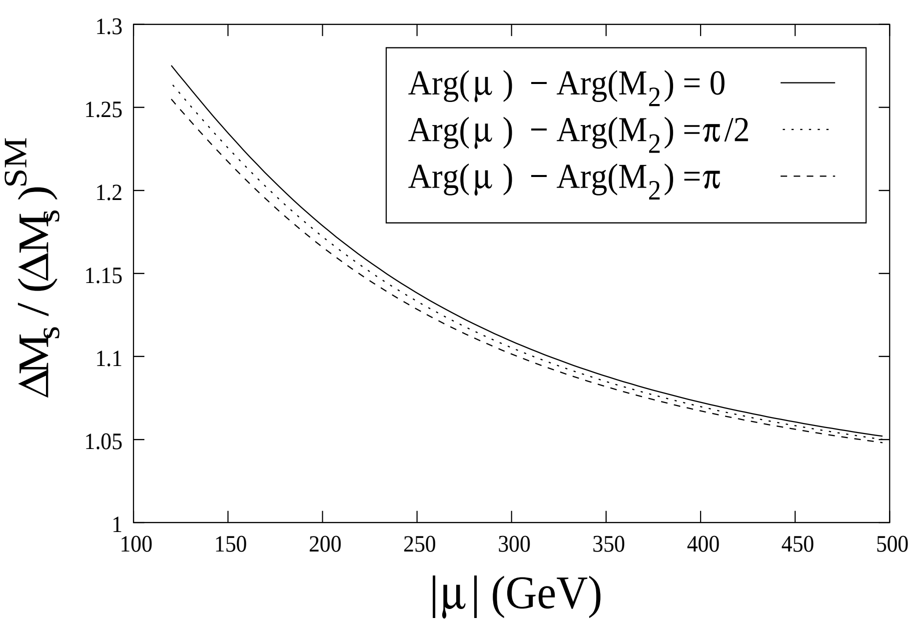
Stop-Chargino Contributions to ΔM_s in MFV

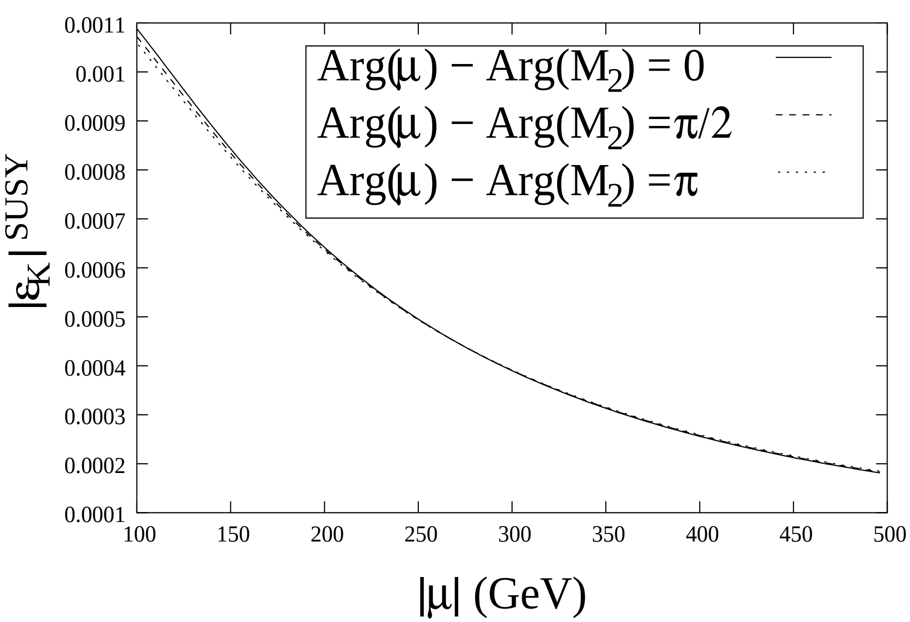
- Light stops and charginos can give substantial contributions to ΔM_s even for low values of $\tan\beta$.



- However these kinds of SUSY particle spectra can also induce large contributions to ϵ_K if SM CP phase is order $\pi/3$.

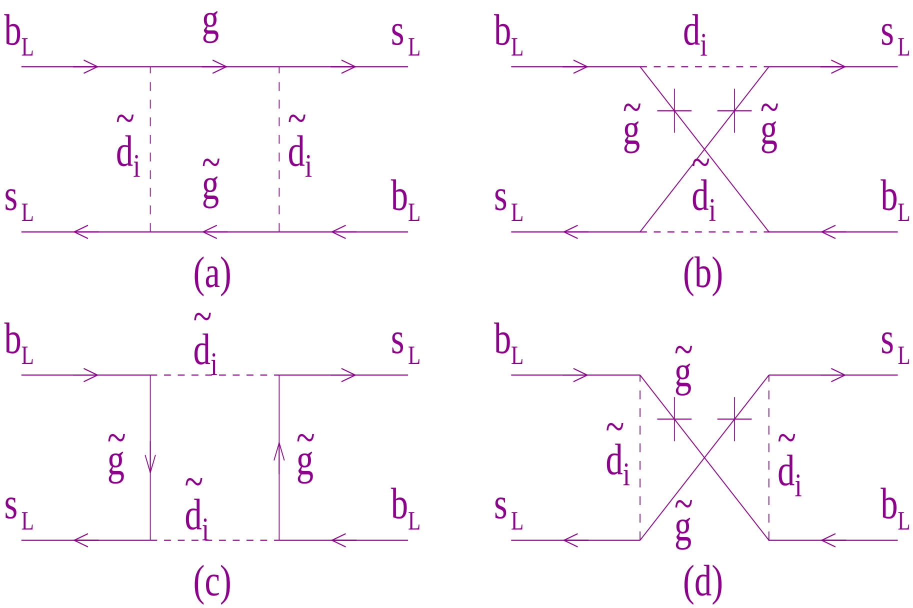
- The experimentally measured value of $\epsilon_K = (2.282 \pm 0.014) \times 10^{-3}$



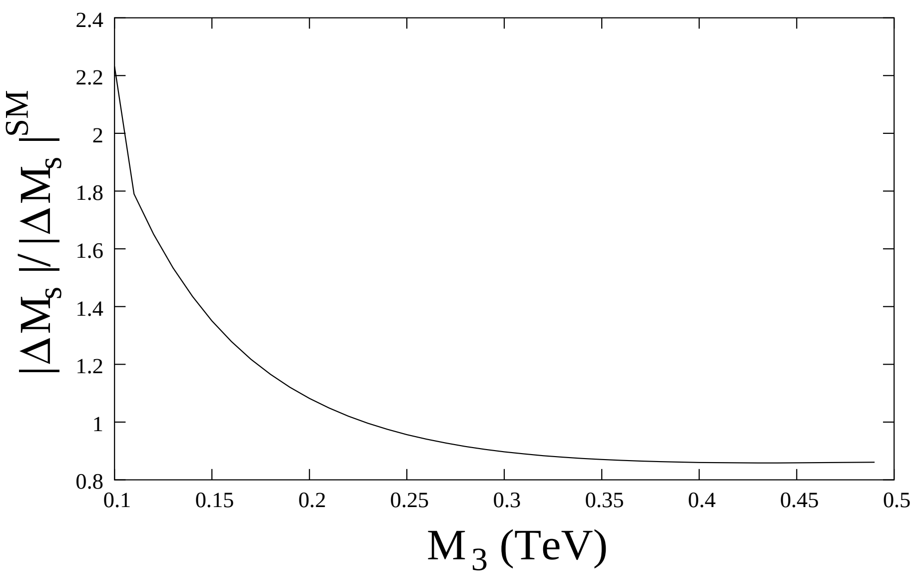


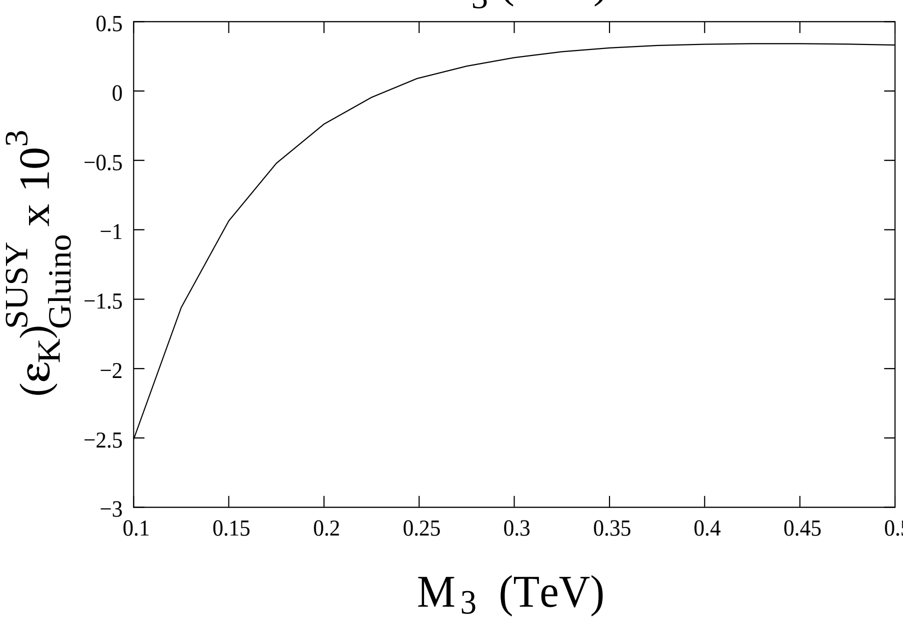
Gluino Contributions to ΔM_s for the Non Miminal Flavor Violation

- In Non Minimal Flavor Violation the gluino-quark-squark vertex is not diagonal and so box diagrams with light gluinos and sbottoms can give substantial contributions to ΔM_s



- Generating these large contributions needs extremely constrained SUSY parameter region.





Constraints on Higgs Searches at the Tevatron

$b \to s\gamma$ in the MSSM

- The experimental bound on $\mathcal{BR}(b \to s\gamma) = 3.38^{+0.3}_{-0.28} \times 10^{-4}$.

- The theoretical error on the SM value: $\mathcal{BR}(b \to s\gamma)^{Exp} - \mathcal{BR}(b \to s\gamma)^{SM} \leq 1 \times 10^{-4}$.
M. Neubert, Eur. Phys. J. C **40**, 165 (2005), [arXiv:hep-ph/0408179]

- The Charged Higgs amplitude in the large $\tan\beta$ limit is

$$\mathcal{BR}(b \to s\gamma)_{H^+} \propto \frac{h_t \cos\beta - \delta h_t \sin\beta}{\cos\beta(1 + \epsilon_3 \tan\beta)}$$

where

$$\delta h_t \propto h_t \frac{\alpha_s}{3\pi} \mu M_3$$

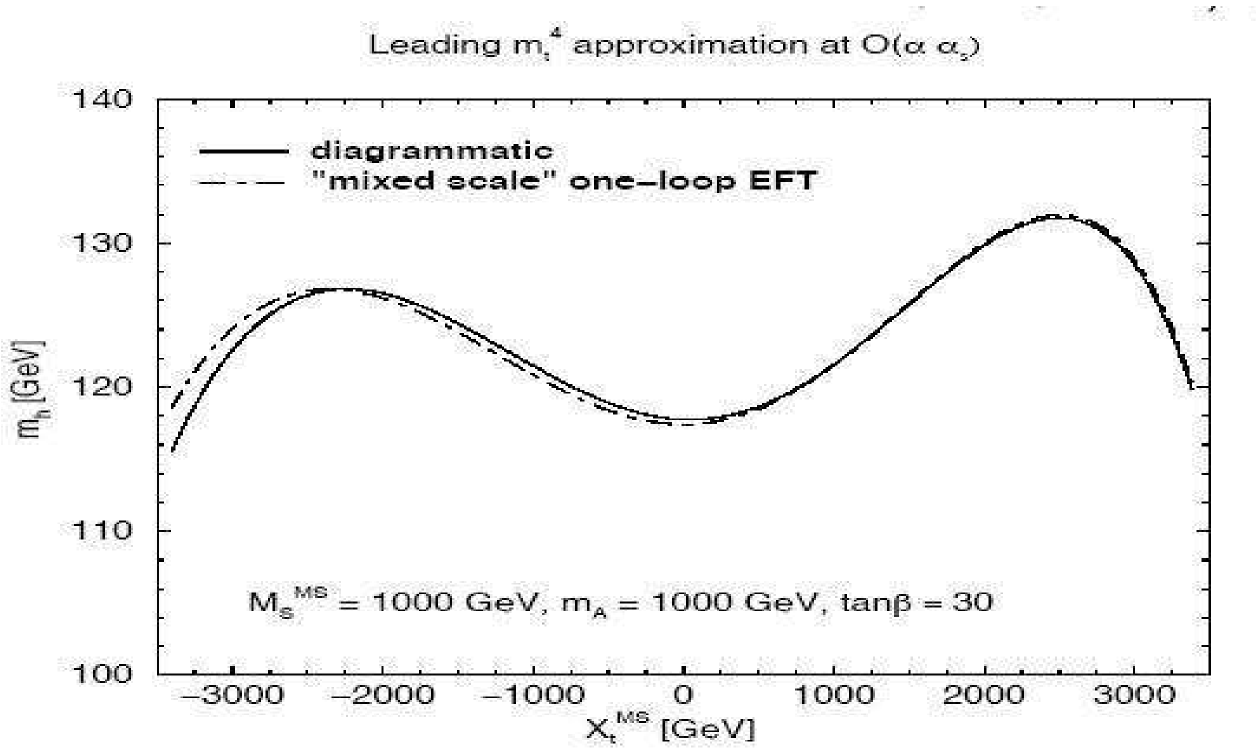
- While the Chargino-Stop amplitude is

$$\mathcal{BR}(b \to s\gamma)_{\chi^+} \propto \frac{\mu A_t \tan\beta}{1 + \epsilon_3 \tan\beta}$$

for large $\tan\beta$

M. Carena, et. al., Phys. Lett. B **499** (2001) [arXiv:hep-ph/001003]
G. Degrassi, et.al., JHEP **0012**, 009 (2000) [arXiv:hep-ph/0009337].

The Higgs Bench Mark Scenarios in the MSSM



M. Carena et.al. Nucl. Phys. B **580**, 29 (2000) [arXiv:hep-ph/0001002].

- For large CP odd Higgs mass M_A and uniform squark mass M_S the SM like Higgs has

$$M_h^2 \approx M_Z^2 \cos^2 2\beta + \frac{3m_t^4}{4\pi^2 v^2}\left(\log\frac{M_S^2}{m_t^2} + \frac{X_t}{M_S^2}\left(1 - \frac{X_t^2}{12M_S^2}\right)\right)$$

where $X_t = A_t - \frac{\mu}{\tan\beta}$

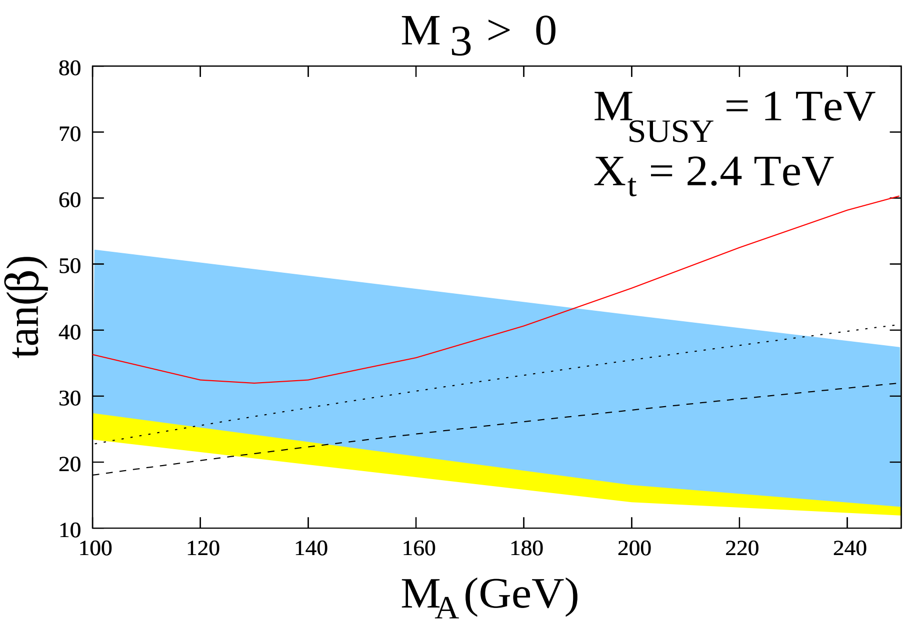
- Maximal Mixing $\Rightarrow X_t = \sqrt{6}M_{SUSY}$, while Minimal Mixing $\Rightarrow X_t = 0$.

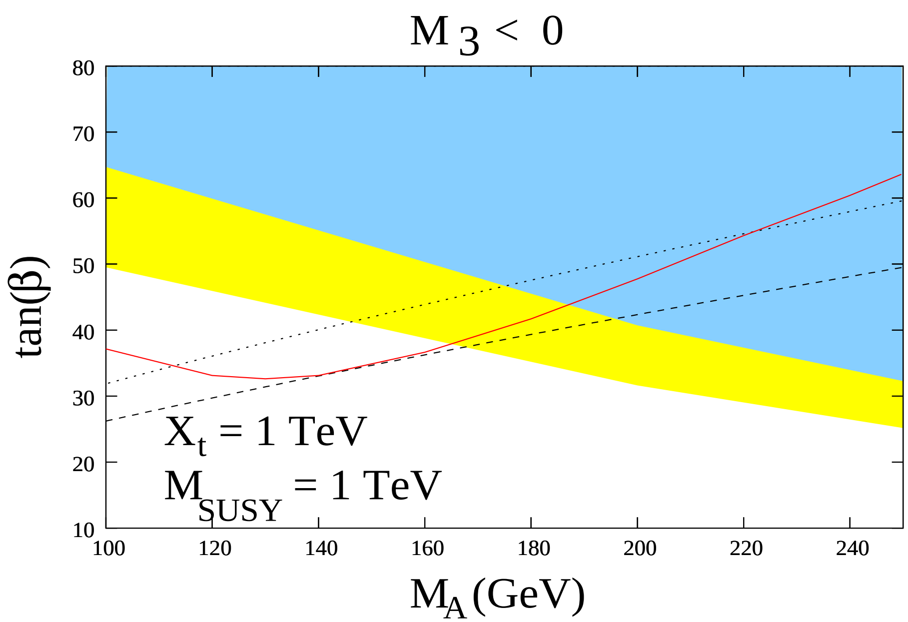
- Tevatron has greater sensitivity to for a low mass of M_h.

Tevatron Higgs searches with moderate to large X_t

- $\mathcal{BR}(B_s \to \mu^+\mu^-) \propto \epsilon_Y \propto \mu A_t$. So experimental bound $\Rightarrow$ small μ for $X_t \geq 500$ GeV.

- For small negative μ $\Rightarrow$ approximately constant Charged Higgs contribution and growing negative Chargino Stop contribution to $b \to s\gamma$.



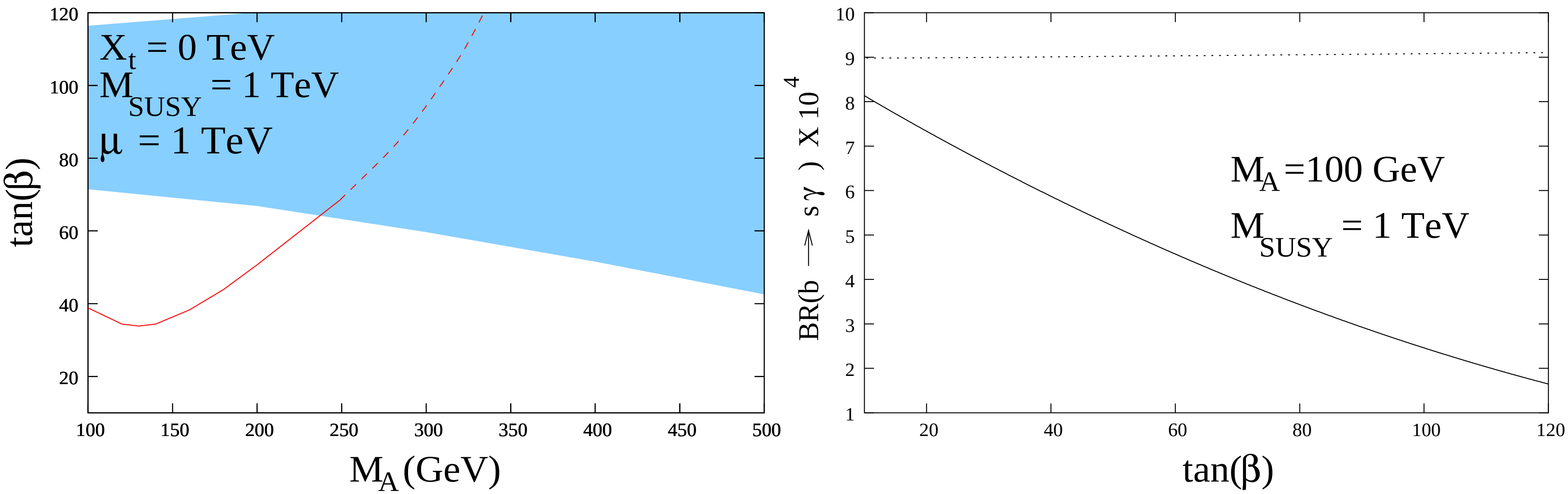


Tevatron Higgs searches with small X_t

- $X_t \sim 0 \Rightarrow A_t$ small. $\Rightarrow$ a small contribution to $b \rightarrow s\gamma$ from the Charginos and Stops.

- But also a large Charged Higgs contribution to $b \rightarrow s\gamma$, unless μ is large so that $\delta h_t \sim h_t$. In which case $b \rightarrow s\gamma$ puts not constraint on M_A.

- $\mathcal{BR}(B_s \rightarrow \mu^+\mu^-)$ puts no constraint on the $M_A - \tan\beta$ plane as A_t is small.



Conclusions

• Within the MSSM the measurements of ΔM_s at D0 and CDF are consistent with the bound on $B_s \to \mu^+\mu^-$.

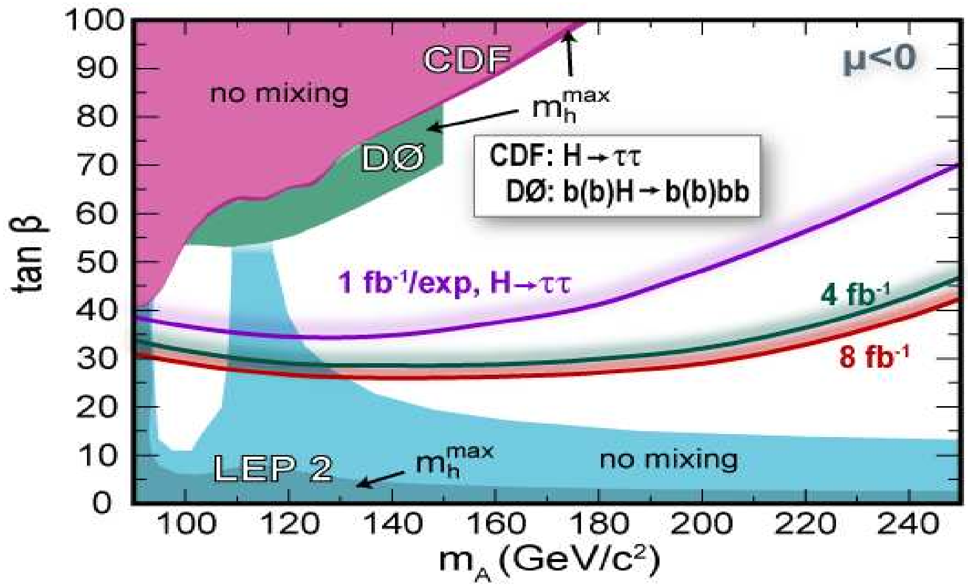
• The assumption that 2σ difference between the SM and the experiment is due to large $\tan\beta$ SUSY effects can be tested by improving the bound on $B_s \to \mu^+\mu^-$.

• Searches for Non Standard Model Higgses at the Tevatron are highly constrained for large X_t. The Tevatron can only probe regions of low to moderate X_t.

• In addition the small X_t scenario looks much more promising for the Tevatron as it is more sensitive for lower values of M_h.

• Observation of a Non Standard Model Higgs at the Tevatron would imply either moderate X_t small μ or large μ small X_t or a deviation from Minimal Flavor Violation.

Estimating the Tevatron Reach for Higgs Searches



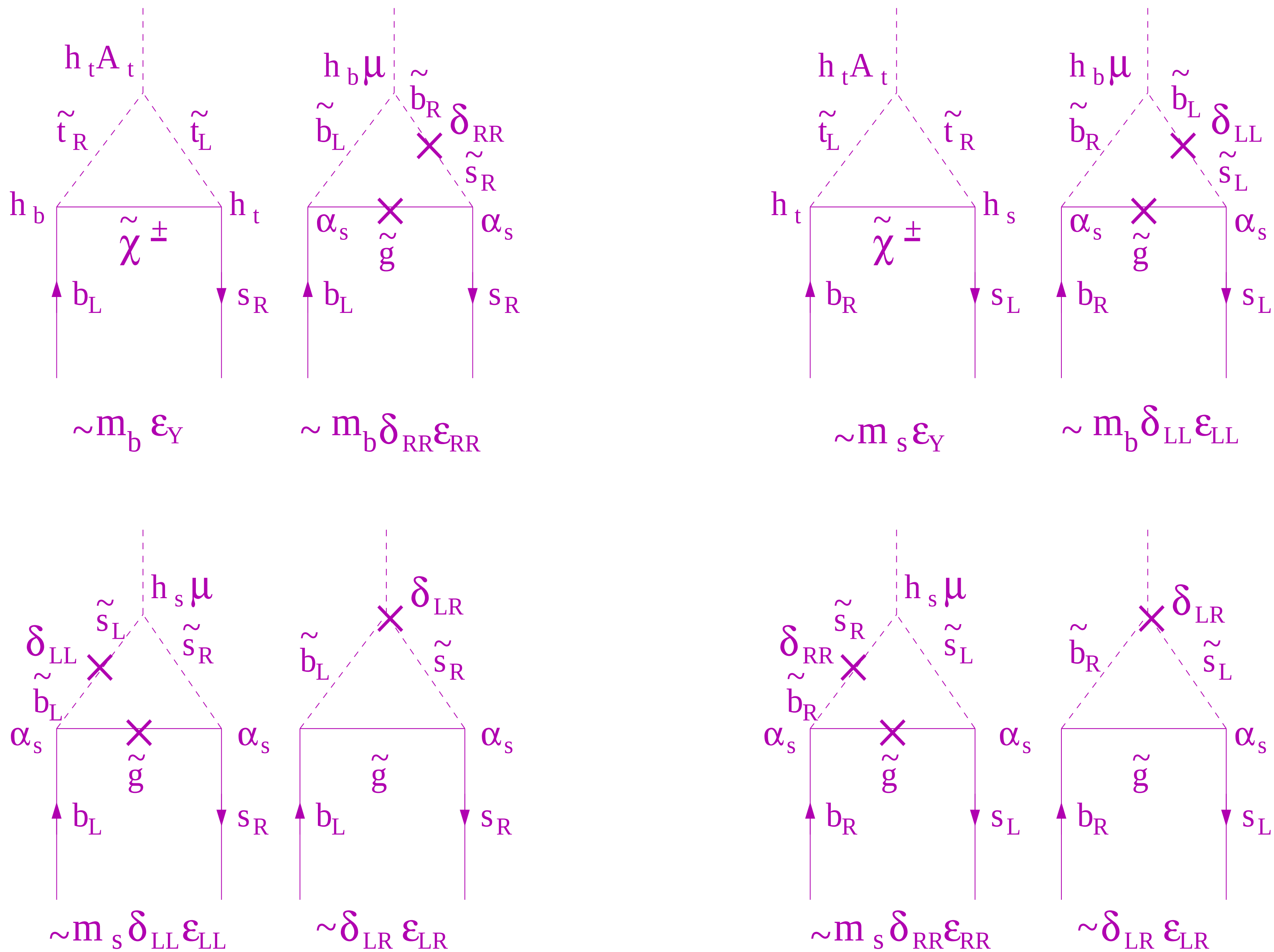
http://www-cdf.fnal.gov/physics/exotic/r2a/20050519.mssm_htt/index.htm

• The approximate relation between the Standard Model production cross-section of τ pairs and that in the MSSM at large $\tan\beta$ allows us to estimate the Tevatron reach.

$$\sigma(gg, b\bar{b} \to A) \times \mathcal{BR}(A \to \tau^+\tau^-) \sim \sigma(gg, b\bar{b} \to A)_{SM} \frac{\tan^2\beta}{(1+\epsilon_3 \tan\beta)^2 + 9}$$

M. Carena *et al.*, [arXiv:hep-ph/0511023]

• For the Tevatron we have used the $1\ \text{fb}^{-1}$ luminosity curve for $H \to \tau\tau$.



h t A t
t̃ R
t̃ L
h b
h t
χ̃ ±
b L
s R
~m b ε Y
h b μ
b̃ R
δ RR
b̃ L
s̃ R
α s
α s
g̃
b L
s R
~ m b δ RR ε RR
h t A t
t̃ L
t̃ R
h t
h s
χ̃ ±
b R
s L
~m s ε Y
h b μ
b̃ L
δ LL
b̃ R
s̃ L
α s
α s
g̃
b R
s L
~ m b δ LL ε LL
h s μ
s̃ L
δ LL
s̃ R
b̃ L
α s
α s
g̃
b L
s R
~m s δ LL ε LL
δ LR
b̃ L
s̃ R
α s
g̃
b L
s R
~δ LR ε LR
h s μ
s̃ R
δ RR
s̃ L
b̃ R
α s
α s
g̃
b R
s L
~m s δ RR ε RR
δ LR
b̃ R
s̃ L
α s
g̃
b R
s L
~δ LR ε LR