Probing Supersymmetry through Higgs, Flavor Violation and Dark Matter Searches

Marcela Carena
Theoretical Physics Department, Fermilab

Joint Experimental-Theoretical Seminar
Fermilab, May 19, 2006

Based on works done in collaboration with:

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A.Menon, R. Noriega, A Szynkman and C. Wagner, hep-ph/0603106
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A. Finch, A Freitas, C. Milstene, H. Novak and A. Sopczak, Phys. Rev. D72, 2005
D. Hooper and P. Skands, hep-ph/0603180

Outline

- Introduction ==> Higgs and Flavor in the Standard Model
- The Flavor Issue in Supersymmetry ==> Minimal Flavor Violation (MFV)

-- $\tan\beta$ enhanced loop corrections to neutral Higgs-fermion couplings

==> Flavor conserving processes :

Non-Standard MSSM Higgs production at the Tevatron and LHC

==> Flavor Changing Neutral Currents (FCNC)

B_S Mixing and the rare decay rate $B_S \to \mu^+\mu^-$

-- Loop FC effects in the Charged Higgs-fermion couplings

==> $\mathrm{BR}(b \to s\gamma)$ and $\mathrm{BR}(B_u \to \tau\nu)$

==> Probing SUSY parameters through B and Higgs Physics at the Tevatron and LHC

- Other Examples ==> MFV from GUT's and General Flavor SUSY Models
- Direct SUSY Dark Matter detection <==> Higgs searches at the Tevatron
- Conclusions

- Standard Model ⟶ works well !

Successfully describes processes up to energies ≈a few hundred GeV

- What is Beyond the SM ⟶ is certainly very exciting!

Some of the key open questions:

⋆The origin of Electroweak Symmetry breaking: The Higgs Mechanism?

How to stabilize the Higgs quantum corrections: Why $v << M_{Pl}$?

⋆The nature of Dark Matter

⋆The explanation for the observed matter-antimatter asymmetry

⋆The connection of electroweak and strong interactions with gravity

Are there New Symmetries in Nature, such as SUPERSYMMETRY, which can provide the answers?

Collider Experiments ⟶ **Tevatron, LHC, ILC**

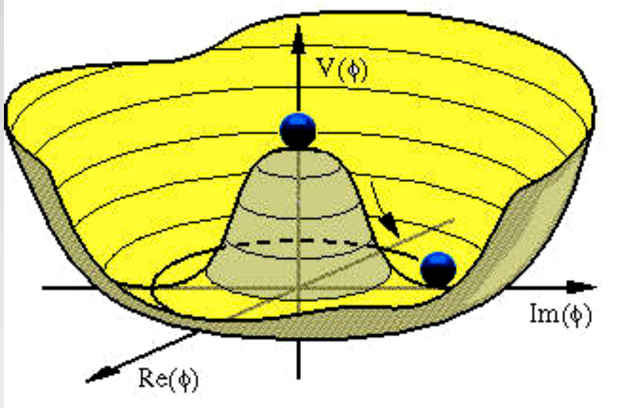
+

Dark Matter Detection Experiments ⟶ **CDMS**

==> our most promising avenues to discover the new physics that will answer these questions

<u>In the Standard Model</u>: The Higgs Mechanism

a self interacting complex scalar doublet with no trivial quantum numbers under $SU(2)_L \times U(1)_Y$



The Higgs field acquires a non-zero value to minimize its energy:

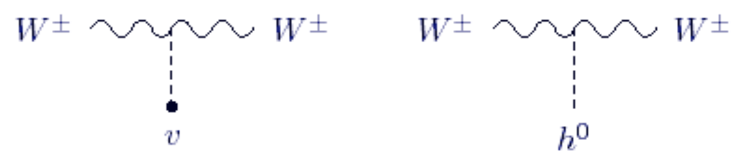
$$V(\phi) = -m^2\phi^2 + \frac{\lambda}{2}\phi^4$$

Higgs vacuum condensate $v \Longrightarrow$ scale of EWSB

- Spontaneous breakdown of the symmetry generates 3 massless Goldstone bosons which are absorbed to give mass to $V = W, Z$

  ⋆ interaction with gauge fields

  $m_V^2 = g_{\phi\ VV}\ v/2 \quad \longrightarrow v = 174$ GeV

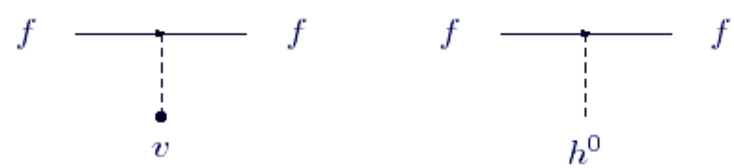


Higgs neutral under strong and electromagnetic interactions $\Longrightarrow \quad m_\gamma = 0 \quad m_g = 0$

exact symmetry $SU(3)_C \times SU(2)_L \times U(1)_Y \quad \Longrightarrow \quad SU(3)_C \times U(1)_{em}$

⋆ mass to fermions via Yukawa interactions

$m_f = g_{\phi\ f\bar{f}}\ v$



- One state left in the spectrum: <u>HIGGS Boson</u> with mass $m_\phi^2 = 2\lambda v^2$

The Flavor Structure in the SM

- **The fermion part of the SM Lagrangian**

$$\mathcal{L} = \sum_i \bar{\Psi}^i_{L,R} \mathcal{D}^\mu \gamma_\mu \Psi^i_{L,R} + \sum_{i,j} \left(\bar{\Psi}^i_L h^d_{ij} H d^j_R + \bar{\Psi}^i_L h^u_{ij} (i\sigma_2 H^*) u^j_R + h.c. \right)$$

In the mass eigenstate basis, the interactions of the Higgs field are also flavor diagonal $\bar{d}_i(\hat{m}_i + \hat{h}_i H) d_i, \quad \text{with} \quad \hat{m}_i = \hat{h}_i v$

Flavor Changing effects arise from charged currents, which mix left-handed up and down quarks:

$\bar{u}_{L,i} V^{ij}_{CKM} \gamma_\mu d_{L,j} W^+_\mu + h.c.$ where $V_{CKM} = U^\dagger_L D_L$

- The CKM matrix is almost the identity ==> transitions between different flavors are suppressed in the SM

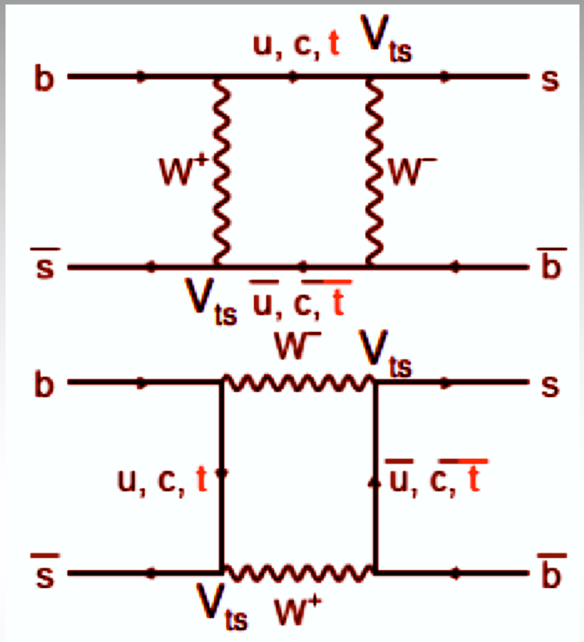
- The Higgs sector and the neutral gauge interactions do not lead to FCNC

FC effects in B observables in the SM

A) Bs mixing

$$B_s^0 = (\bar{b} s) \qquad \bar{B}_s^0 = (b \bar{s})$$

Flavor eigenstates mix via weak interactions



Mass eigenstates:

$$B_H = pB_s^0 + q\bar{B}_s^0 \qquad B_L = pB_s^0 - q\bar{B}_s^0$$

B_H and B_L differ from CP eigenstates:

$$q/p = e^{-i2\beta_S} \text{ with } \beta_S = O(10^{-2})$$

The B meson mass matrix
$$M = \begin{bmatrix} M - i\Gamma/2 & M_{12} - i\Gamma_{12}/2 \\ M_{12}^* - i\Gamma_{12}^*/2 & M - i\Gamma/2 \end{bmatrix} \qquad \Gamma_{12} << M_{12}$$

$$\Delta M_s = M_{B_H} - M_{B_L} = 2\,|M_{12}| = \frac{G_F^2}{6\pi^2}\eta_B m_{B_S} \underbrace{\hat{B}_{B_S} f_{B_S}^2}_{\text{lattice}} M_W^2 S_0(m_t)\,|V_{ts}|^2$$

Short distance QCD corrections

Box-diagram

ΔM_S Direct Measurement and Global CKM Fit

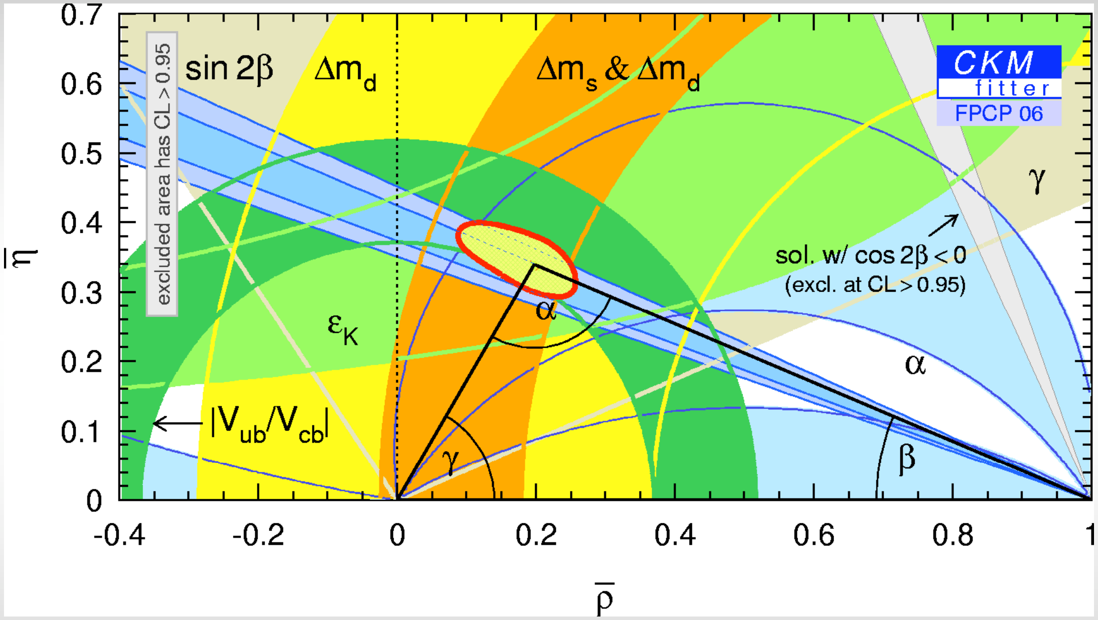
$$\Delta M_S^{\text{CDF.}} = 17.33^{+0.42}_{-0.21} \pm 0.07\,ps^{-1} \qquad 17\,ps^{-1} < \Delta M_S^{\text{D0@90\%C.L.}} < 21\,ps^{-1}$$

Using ratio

↓

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{Bs}}{m_{Bd}} \frac{f_{Bs}^2 B_{Bs}}{f_{Bd}^2 B_{Bd}} \frac{|V_{ts}|^2}{|V_{td}|^2}$$

Minimize QCD lattice uncertainty providing a measurement of $|V_{ts}|/|V_{td}|$

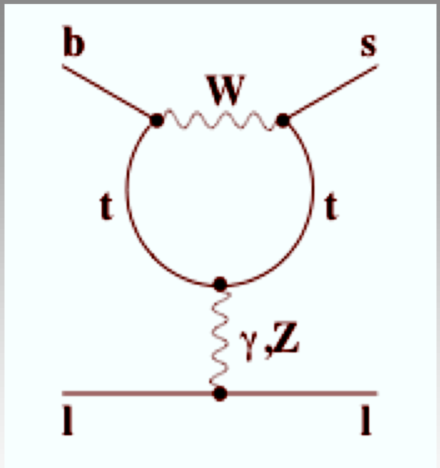


- SM fit:

$$\text{CMK fit} \Rightarrow \Delta M_S = 21.7^{+5.9(+9.7)}_{-4.2(-6.8)}\,ps^{-1} \text{ at } 1(2)\ \sigma \text{ C.L.} \qquad \Rightarrow -14.1 < \Delta M_{B_s}^{NP}[ps^{-1}] < 2.4$$

$$\text{UT fit} \Rightarrow \Delta M_S = 21.5 \pm 2.6\,ps^{-1} \text{ at } 1\ \sigma \text{ C.L.} \qquad \Rightarrow -9.4 < \Delta M_{B_s}^{NP}[ps^{-1}] < 1 \text{ at } 2\sigma$$

B) Rare decay rate $B_S \to \mu^+\mu^-$

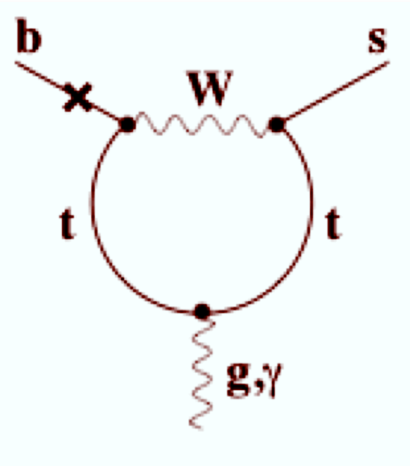


$$\text{SM amplitude} \propto V_{ts} \frac{m_\mu}{M_W}$$

$$BR(B_s \to \mu^+\mu^-)_{SM} \approx (3.8 \pm 1.0) \times 10^{-9}$$

- Present CDF limit: $BR(B_s \to \mu^+\mu^-) < 1.\ 10^{-7}$

C) Rare decay rate $B \to X_S\gamma$

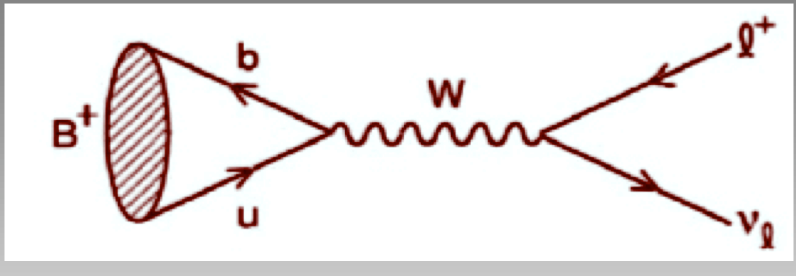


$$BR(B \to X_S\gamma)^{SM}_{E_\gamma > 1.8\,\mathrm{GeV}} = (3.38 \ {}^{+0.31}_{-0.42} \ {}^{+0.32}_{-0.30}) \times 10^{-4}$$

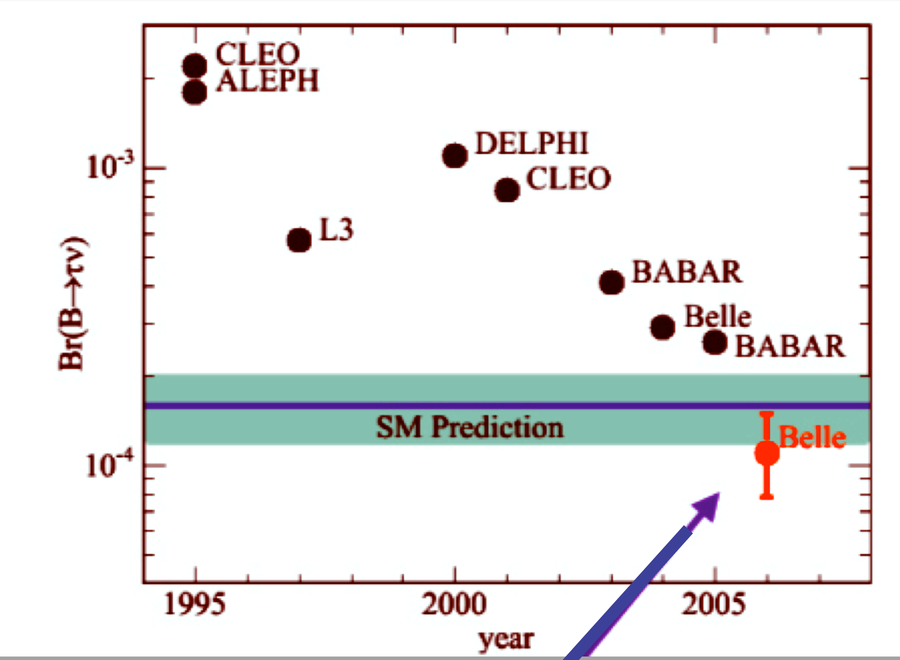
Estimated bound on New Physics
using Belle results ==> Neubert 05

$$|BR(B \to X_S\gamma)^{\exp} - BR(B \to X_S\gamma)^{SM}| < 1.3 \times 10^{-4}$$

D) $B_u \to \tau\nu$ transition



$$BR(B_u \to \tau\nu)^{SM} = \frac{G_F^2 m_B m_\tau^2}{8\pi}\left(1 - \frac{m_\tau^2}{m_B^2}\right) f_B^2 |V_{ub}|^2 \tau_B = (1.59 \pm 0.40) \times 10^{-4}$$



In agreement with SM within errors

$$BR(B_u \to \tau\nu)^{exp} = (1.06\ {}^{+0.34}_{-0.28}\ {}^{+0.18}_{-0.16})\ 10^{-4}$$

Flavor Beyond the Standard Model

- **Two Higgs doublet Models:**

  Yukawa interactions ==> $\bar{d}_{R,i}(h^{ij}_{d,1}\,\phi_1 + h^{ij}_{d,2}\,\phi_2)\,d_{L,j}$

The Higgs doublets acquire different v.e.v.'s and the mass matrix reads

==> $m^{ij}_d = h^{ij}_{d,1}\mathrm{v}_1 + h^{ij}_{d,2}\mathrm{v}_2$

Diagonalization of the mass matrix will not give diagonal Yukawa couplings
==> will induce large, usually unacceptable FCNC in the Higgs sector

Easiest solution: One Higgs doublet couples only to down quarks and the other couples to up quarks only

Supersymmetry, at tree level

$$-L = \overline{\psi}^i_L\left(h^{ij}_d\phi_1 d^J_R + h^{ij}_u\phi_2 u^j_R\right) + h.c.$$

Since the up and down sectors are diagonalized independently, the Higgs Interactions remain flavor diagonal at tree level.

The flavor problem in SUSY Theories

SUSY breaking mechanisms ==> also can give rise to large FCNC effects

- Novel sfermion-gaugino-fermion interactions, e.g. for the down sector

$$\bar{d}^i_{L,R}\ \tilde{\lambda}\ \tilde{d}^j_{L,R} \rightarrow \bar{d}_{L,R} D^+_{L,R} \tilde{D}_{L,R} \tilde{\lambda}\ \tilde{d}_{L,R}$$

recall $V_{CKM} = U^+_L D_L$

where $\tilde{D}_{L,R}$ come from the block diagonalization of the squark mass matrix

$$\begin{pmatrix} \tilde{d}^{i\,*}_L & \tilde{d}^{i\,*}_R \end{pmatrix} \begin{pmatrix} M^2_Q + \mathrm{v}_1^2 h^+_d h_d + D_{\tilde{d}_L} & \mathrm{v}_1\left(A_d - \mu^* \tan\beta\right) h_d \\ \mathrm{v}_1\left(A^*_d - \mu \tan\beta\right) h^+_d & M^2_D + \mathrm{v}_1^2 h^+_d h_d + D_{\tilde{d}_R} \end{pmatrix} \begin{pmatrix} \tilde{d}^i_L \\ \tilde{d}^i_R \end{pmatrix}$$

- The diagonal entries are 3x3 matrices with M^2_Q, M^2_D the soft SUSY breaking mass matrices and the rest proportional to the Yukawa or I
- The off-diagonal matrices are proportional to the Yukawa and to the soft SUSY breaking matrices A_d coming from the trilinear interactions of the Higgs doublets with the sfermions

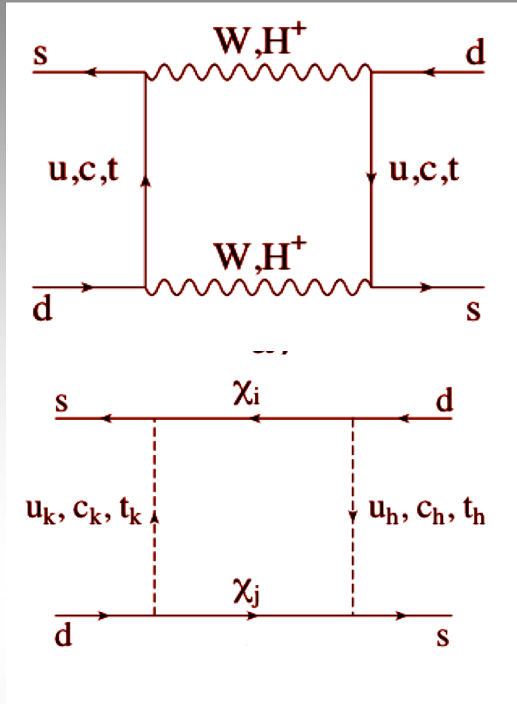
$$\tilde{u}^*_L h_u\left(A_u \phi_2 - \mu^* \phi_1\right)\tilde{u}_R + \tilde{d}^*_L h_d\left(A_d \phi_1 - \mu^* \phi_2\right)\tilde{d}_R + h.c.$$

Minimal Flavor Violation (MFV)

- 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 the SM .



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

  1) Both Higgs doublets couple to the up and down sectors
  ==> important effects in the B system at large tan beta

  2) Soft SUSY breaking parameters obey Renormalization Group 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 $h_u h_u^+$

In both cases the effective coupling governing FCNC processes

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

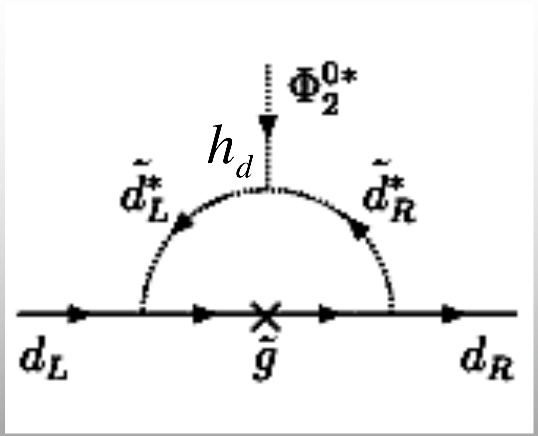
$\tan\beta$ enhanced loop corrections to neutral Higgs-fermion couplings

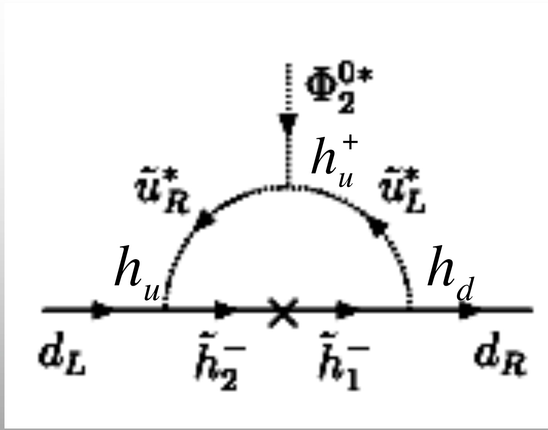
$$-L_{eff.} = \overline{d}_R^0 \hat{h}_d \left[\phi_1^{0^*} + \phi_2^{0^*} \left(\hat{\varepsilon}_0 + \hat{\varepsilon}_Y \hat{h}_u^+ \hat{h}_u \right) \right] d_L^o + \phi_2^0 \overline{u}_R^0 \hat{h}_u u_L^0 + h.c.$$

The ε factors correspond to the diagrams:

$\hat{h}_d \hat{\varepsilon}_0$

$\hat{h}_d \hat{\varepsilon}_Y \hat{h}_u^+ \hat{h}_u$





The ε loop factors are intimately connected to the assumed structure of the squark mass matrices

In terms of the quark mass eigenstates:

$$-L_{eff} = \frac{1}{v_2}\left(\tan\beta\,\Phi_1^{0^*} - \Phi_2^{0^*}\right)\bar{d}_R M_d\left[V^{+}R^{-1}V\right]d_L + \frac{1}{v_2}\Phi_2^{0^*}\bar{d}_R M_d d_L + \Phi_2^0\bar{u}_R h_u u_L + h.c.$$

where M_u, M_d are the physical quark mass matrices, $h_u = M_u / v_2$

V is the physical CKM matrix and the matrix R:

$$R = 1 + \varepsilon_0 \tan\beta + \varepsilon_Y \tan\beta |h_u|^2$$

- Considering the squark masses flavour diagonal ➔ R diagonal

Dependence on the SUSY parameters

$$\varepsilon_0^i \approx \frac{2\alpha_s}{3\pi}\frac{\mu M_{\tilde{g}}}{\max\left[m^2_{\tilde{d}_1^i}, m^2_{\tilde{d}_2^i}, M^2_{\tilde{g}}\right]} \rightarrow \text{gluino contribution}$$

$$\varepsilon_Y \approx \frac{\mu A_t}{16\pi^2 \max\left[m^2_{\tilde{t}_1^i}, m^2_{\tilde{t}_2^i}, \mu^2\right]} \rightarrow \text{higgsino contribution}$$

Neglecting h_u and h_c compared with h_t one can define $\rightarrow \varepsilon_J = \varepsilon_0^j + \varepsilon_Y h_t^2 \delta^{j3}$

Flavor Conserving Higgs-fermion couplings

Looking at $V_{CKM} \cong I$

$$-L_{eff} = \frac{1}{v_2}\left(\tan\beta\,\Phi_1^{0^*} - \Phi_2^{0^*}\right)\bar{d}_R M_d \frac{1}{R^{33}} d_L + \frac{1}{v_2}\Phi_2^{0^*}\bar{d}_R M_d d_L + h.c.$$

$$R^{33} = 1 + \varepsilon_3 \tan\beta \equiv 1 + \Delta_b$$

2 Higgs SU(2) doublets ϕ_1 and ϕ_2 : after Higgs Mechanism

==> 5 physical states: 2 CP-even h, H with mixing angle α

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

such that :

$$\phi_1^0 = -\sin\alpha\, h + \cos\alpha\, H + i\sin\beta\ A$$
$$\phi_2^0 = \cos\alpha\, h + \sin\alpha\, H\ -\ i\cos\beta\ A$$

and at large $\tan\beta$, $m_A > m_h^{\max}$:

$\cos\alpha \approx \sin\beta;\ \ \sin\alpha \approx -\cos\beta$

Hence:

$$H + iA \cong \sin\beta\ \phi_1^0 - \cos\beta\ \phi_2^0$$

$$-L_{eff} = \frac{m_b \tan\beta}{(1+\Delta_b)v}\phi_1^{0^*}\bar{d}_R d_L + h.c.$$

$$\longrightarrow \quad g_{Abb} \cong g_{Hbb} \cong \frac{m_b \tan\beta}{(1+\Delta_b)v}$$

destroy basic relation

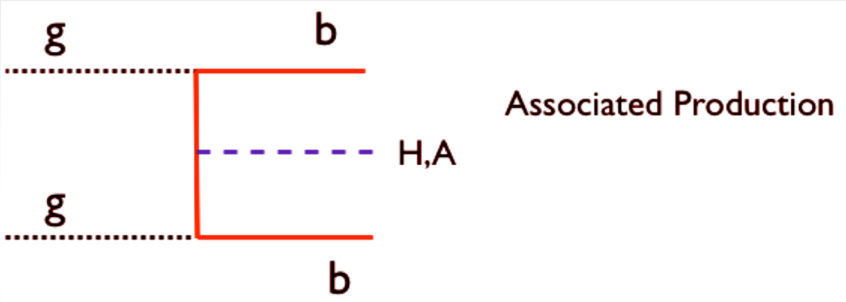
$$|\Delta_\tau| << |\Delta_b| \Rightarrow \quad g_{A\tau\tau} \cong g_{H\tau\tau} \cong m_\tau \tan\beta / v$$

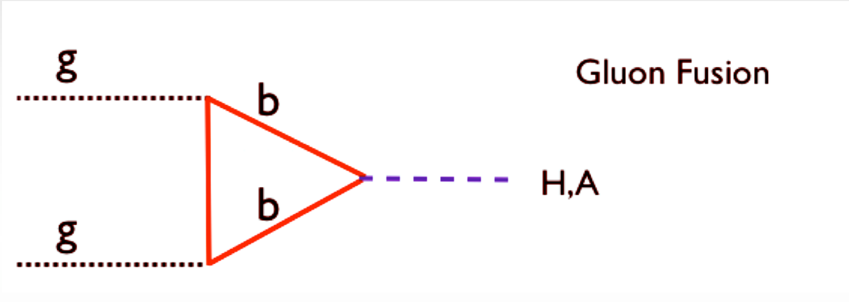
$$g_{A/H\,bb} / g_{A/H\,\tau\tau} \neq m_b / m_\tau$$

Non-Standard Higgs Production at the Tevatron and LHC

- Enhanced couplings to b quarks and tau-leptons
- Considering value of running bottom mass and 3 quark colors

$$BR(A \to b\bar{b}) \cong \frac{9}{9 + (1+\Delta_b)^2} \qquad BR(A \to \tau^+\tau^-) \cong \frac{(1+\Delta_b)^2}{9 + (1+\Delta_b)^2}$$





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

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

There may be a strong dependence on the SUSY parameters in the bb search channel. This dependence is much weaker in the tau-tau channel

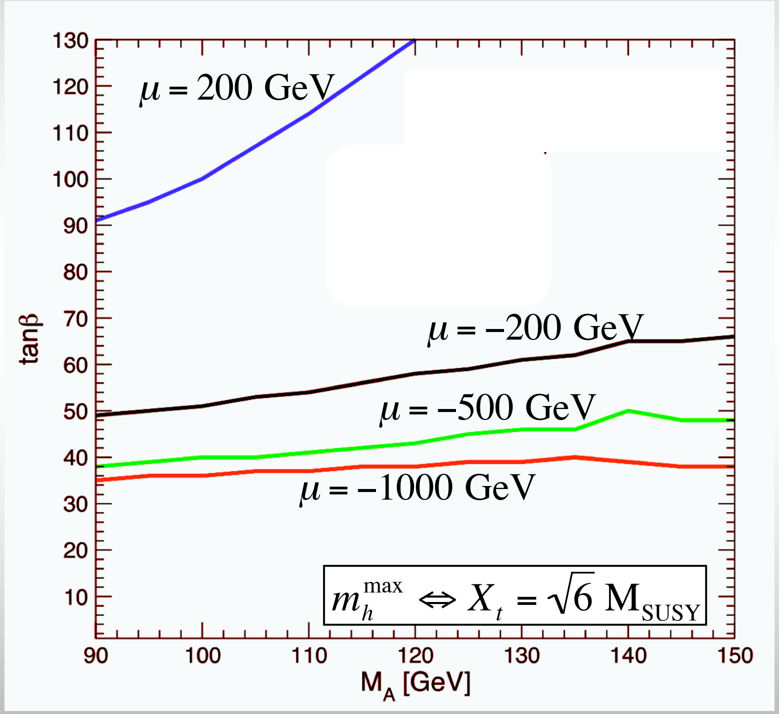
Searches for Non-Standard Higgs bosons at the Tevatron

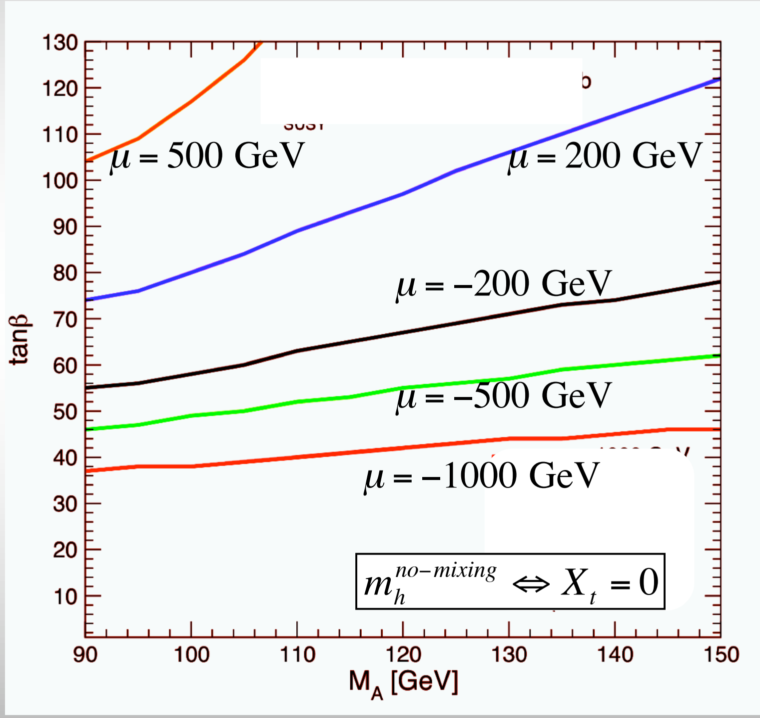
A) In the bb mode ==> probe large region of $\tan\beta - m_A$ plane

Stop mixing param.: $X_t = A_t - \mu/\tan\beta$

$$p\bar{p} \to b\bar{b}\phi, \quad \phi \to b\bar{b}$$

$\Rightarrow$ based on D0 $\to$ 200pb^{-1}





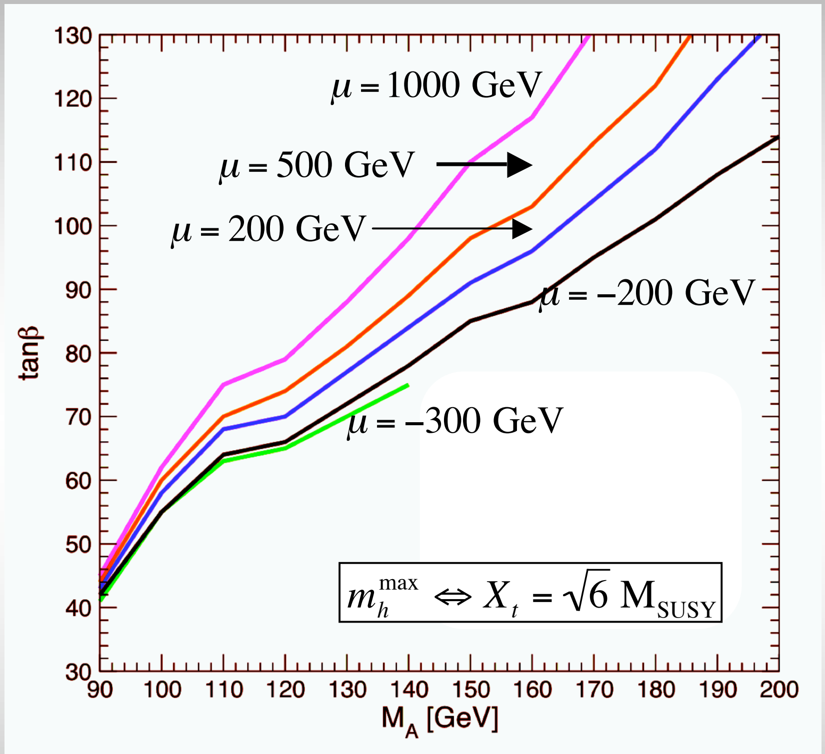
- Enhanced reach for negative values of μ
- Strong dependence on SUSY parameters

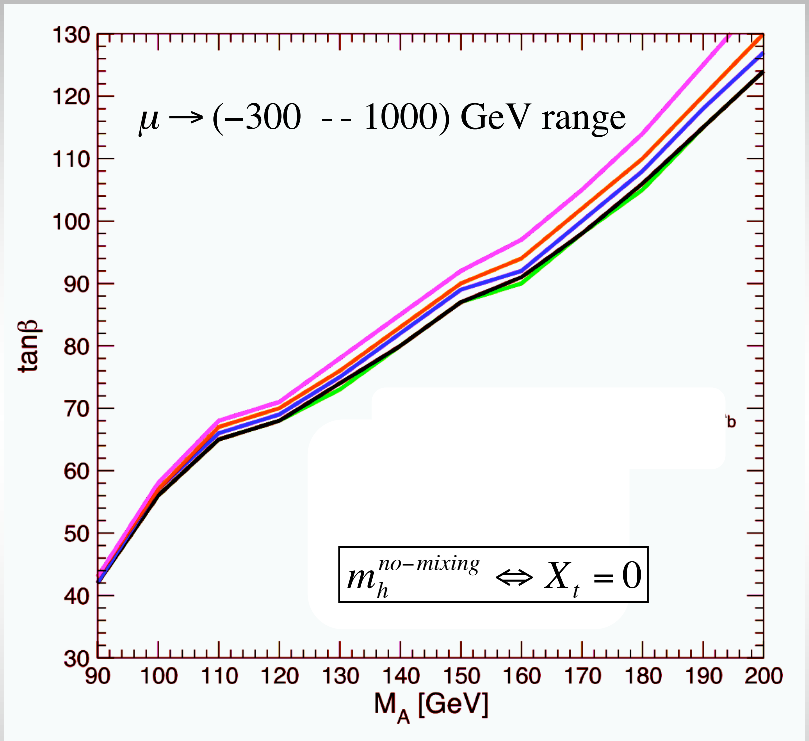
M. C. et al. hep-ph/0511023

$$\sigma(b\bar{b}\phi)BR(\phi \to b\bar{b}) \propto 1/(1+\Delta_b)^2 \Rightarrow \text{enhanced for } \Delta_b < 0 \Leftrightarrow \mu < 0 \ \ (\text{if } A_t \text{ and } M_{\tilde{g}} > 0)$$

B) In the tau tau inclusive mode

$$p\bar{p} \to X\phi, \;\; \phi \to \tau^+\tau^- \quad \Rightarrow \text{ based on CDF: } 200\text{pb}^{-1}$$





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- Important reach for large tanb, small m_A
- Weaker dependence on SUSY parameters via radiative corrections

Loop-induced Higgs mediated FCNC in the down-quark sector

- **In the MFV scenario, the neutral Higgs flavor changing Lagrangian**

$$-L_{FCNC} = \bar{d}_R^j \left(X_{RL}^S\right)^{ji} d_L^i \; \phi_S + h.c. \qquad \text{with } i \neq j \quad \phi_S = h, H, A$$

$$\text{and} \quad \left(X_{RL}^S\right)^{ji} = \frac{\overline{m}_{dJ}\, h_t^2 \, \varepsilon_Y \left(x_2^S - x_1^S \tan\beta\right)\tan\beta}{v\left(1+\varepsilon_0^j \tan\beta\right)\left(1+\Delta_b\right)} V_{CKM}^{3j\,*} V_{CKM}^{3i}$$

Example: case of universal soft SUSY squark mass parameters

x_1^S, x_2^S are the components of the h, H and A in ϕ_1^0, ϕ_2^0

==> $\tan\beta^2$ enhanced coupling for H/A or h/A, depending on value of m_A

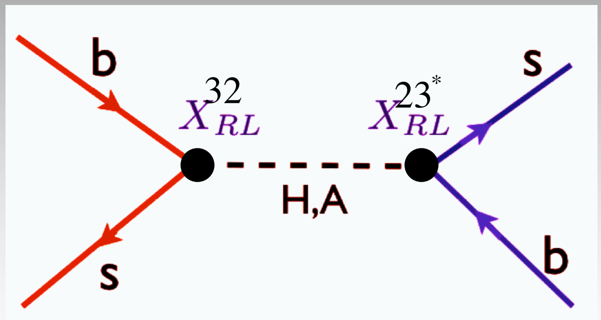
- Effects of RG evolution proportional to $h_u h_u^+$ in $M_Q \Rightarrow \left(X_{RL}^S\right)^{ji} \propto \Delta_b - \varepsilon_0^{1,2}$

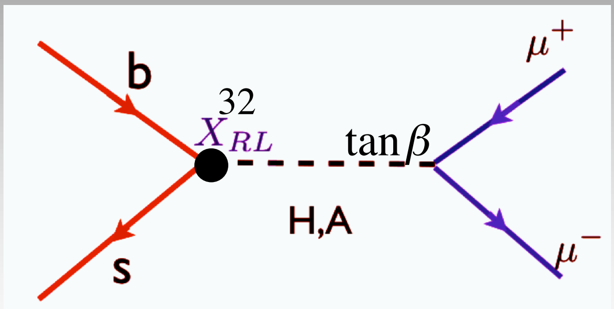
L-H. squarks are not diagonalized by the same rotation as L-H. quarks

==> induces FC in the left-handed quark-squark-gluino vertex prop V_{CKM}

Correlation between Bs mixing and $\mathrm{BR}(B_S \to \mu^+\mu^-)$

due to $\tan\beta$ enhanced Higgs mediated flavor violating effects





$$\left(\Delta M_{B_S}\right)^{SUSY} \propto \ominus \frac{X_{RL}^{32} X_{LR}^{32}}{m_A^2}$$

Negative sign with respect to SM

$$BR(B_S \to \mu^+\mu^-)^{SUSY} \propto \frac{\left|X_{RL}^{32}\right|^2 \tan\beta^2}{m_A^4}$$

- SUSY contributions strongly correlated, and for universal squark masses

$$\frac{\Delta M_{B_S}}{BR(B_S \to \mu^+\mu^-)} \propto \frac{m_A^2}{\tan\beta^2}$$

to maximize $\Delta \mathrm{M}_{\mathrm{B_S}}$ for a given value of $\mathrm{BR}(\mathrm{B_S} \to \mu^+\mu^-)$ $\Leftrightarrow$ minimize $\tan\beta$ (for fixed $\mathrm{m_A}$)

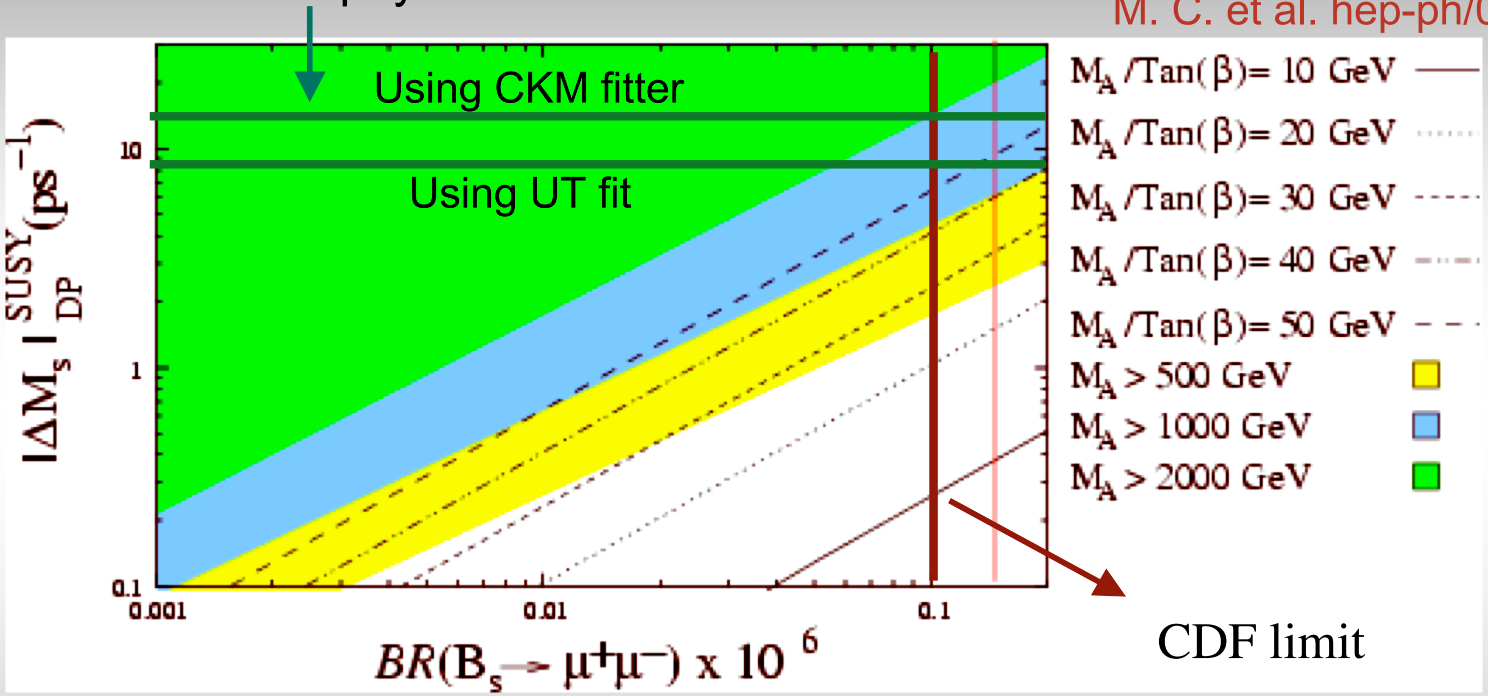
$\Rightarrow$ choose large, negative values of ε_0 and ε_Y (large implies $\mu \approx M_{\tilde{g}} \approx 2M_{\tilde{q}} \approx \frac{2}{3}A_t$)

• What can we learn from Bs-mixing?

How strong is the bound on $BR(B_s \to \mu^+\mu^-)$?

Upper bound on new physics from CDF measurement

M. C. et al. hep-ph/0603106



large ε factors implies heavy squark mass and trilinear terms

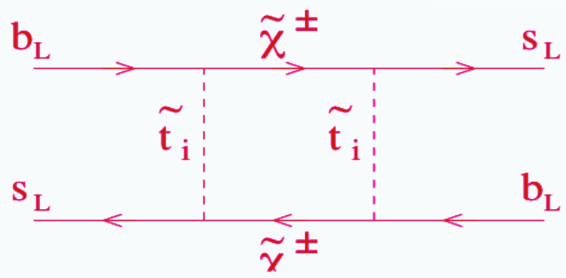
• For natural values of m_A< 1000 GeV ==> largest contributions at most a few ps-1

$$\left|\Delta M_{B_S}\right|^{SUSY}_{DP} \approx 3\,ps^{-1} \Rightarrow \text{resolve the "discrepancy" between the SM and experiment}$$

$$\Rightarrow \text{imply that } BR(B_S \to \mu^+\mu^-) \text{ should be at the Tevatron reach}$$

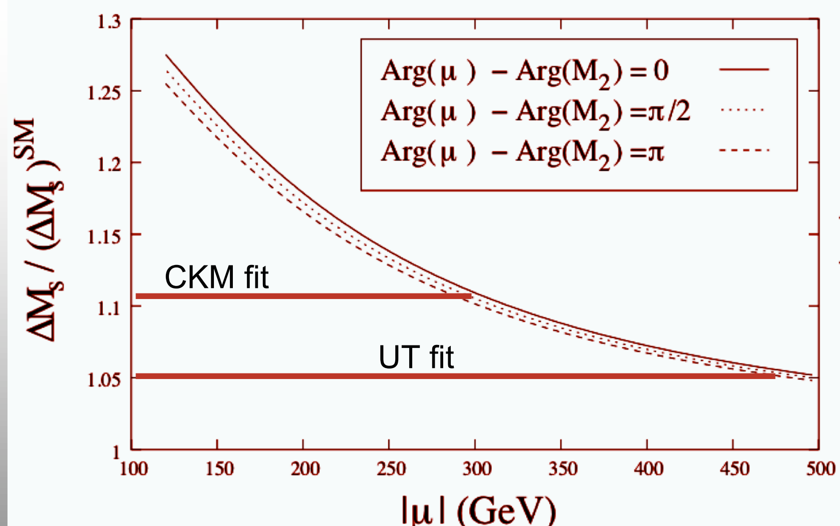
Stop-Chargino Contributions to ΔM_s in MFV

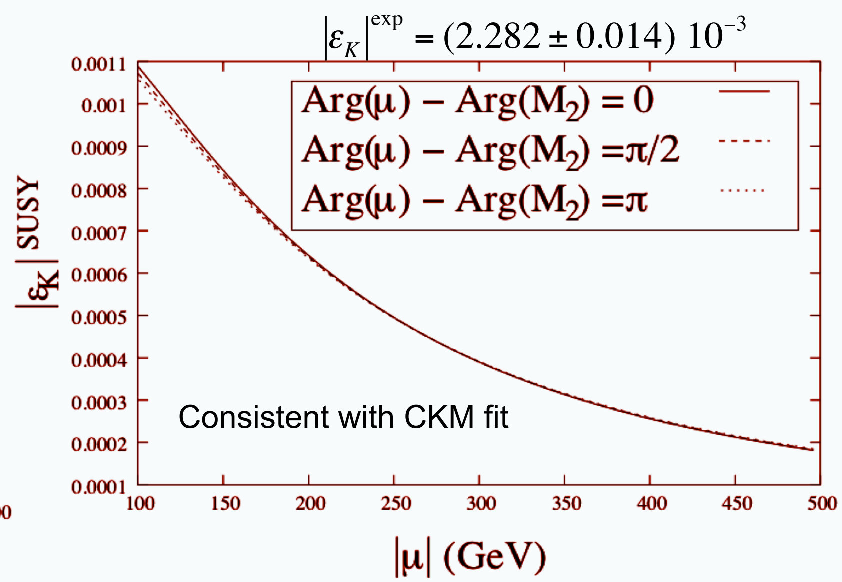
- Light stops and charginos can give substantial contributions to ΔM_s even for low values of $\tan\beta$.



Light stop scenario ==> compatible with Electroweak Baryogenesis

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



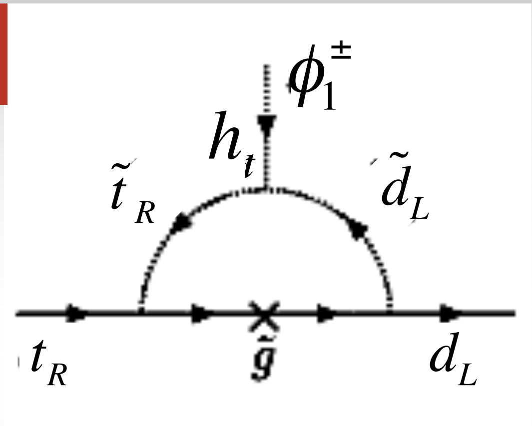


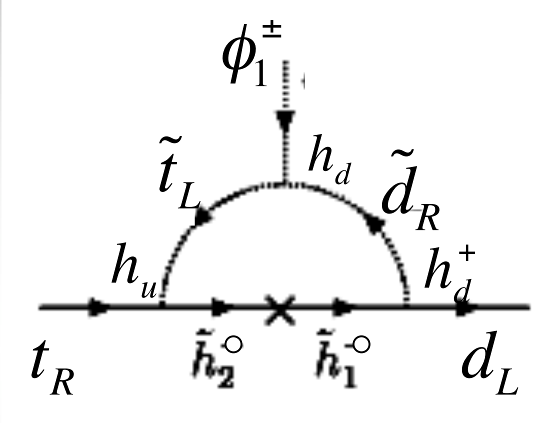
Within this scenario, small values of mu (< 250 GeV) are strongly disfavor by bounds from Bs-mixing

Flavor Changing in the charged Higgs coupling

- Similar to the neutral Higgs case, we have $\tan\beta$ enhanced loop corrections which depend on SUSY parameters

$\hat{h}_u \ \varepsilon_0^{'}$





$\hat{h}_u \ \varepsilon_Y^{'} \hat{h}_d^{+} \hat{h}_d$

$$-L_{eff}^{H^{\pm}} = \overline{u}_R^j \, P_{RL}^{ji} \, d_L^i \, H^+ + \overline{u}_L^j \, P_{LR}^{ji} \, d_R^i \, H^+ + h.c.$$

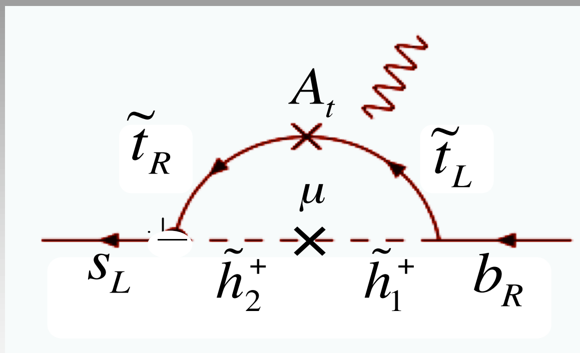
$$P_{RL}^{3i} \approx \frac{\sqrt{2}}{\mathrm{v}} \overline{m}_t \cot\beta \, V_{CKM}^{3i} \left(1 - \tan\beta\left(\varepsilon_0^{'} - \varepsilon_Y^{'} h_b^2\right)\right)$$

$$P_{LR}^{j3} = \frac{\sqrt{2}}{\mathrm{v}} \frac{\overline{m}_b \tan\beta}{\left(1 + \varepsilon_0^{3^*} \tan\beta\right)} V_{CKM}^{j3}$$

$$P_{LR}^{33} = P_{LR}^{j3}(J \rightarrow 3, \ \varepsilon_0^{3^*} \rightarrow \Delta_b^*)$$

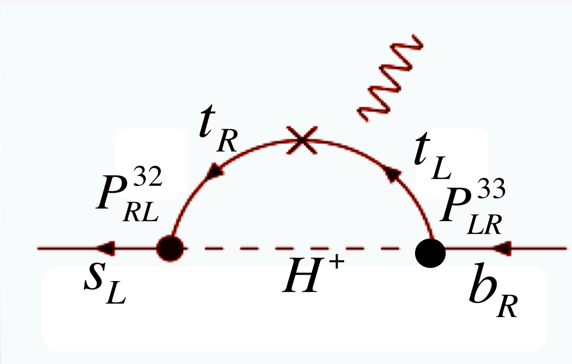
This type of corrections are most important in constraining new physics from $B \rightarrow X_S \gamma$ and $B_u \rightarrow \tau\nu$

Important SUSY contributions to $BR(B \to X_s \gamma)$



- Chargino-Stop amplitude

$$A(b \to s\gamma)_{\chi^+} \propto \frac{\mu A_t \tan\beta\, m_b}{(1+\Delta_b)}\, \mathrm{h}_t^2 f[m_{\tilde{t}_1}, m_{\tilde{t}_2}, \mu]\, V_{ts}$$



- Charged Higgs amplitude

in the large tanb limit

$$A(b \to s\gamma)_{H^+} \propto \frac{(h_t - \delta h_t \tan\beta)\, m_b}{(1+\Delta_b)}\, g[m_t, m_{H^+}]\, V_{ts}$$

$$\text{with } \delta h_t = h_t\left(\varepsilon_0' - \varepsilon_Y' h_b^2\right) \propto h_t \frac{2\alpha_S}{3\pi} \mu M_{\tilde{g}}$$

If: At ~0 (==> small stop mixing ==> light SM-like Higgs at Tevatron reach!)

==>small contributions to $b \to s\gamma$ from chargino-stops

+ large $\mu M_{\tilde{g}} > 0$ ==> cancellation of charged Higgs contribution

NO constraint on tanb-ma plane from $b \to s\gamma$

B and Higgs Physics at the Tevatron

explore complementary regions of SUSY parameter space

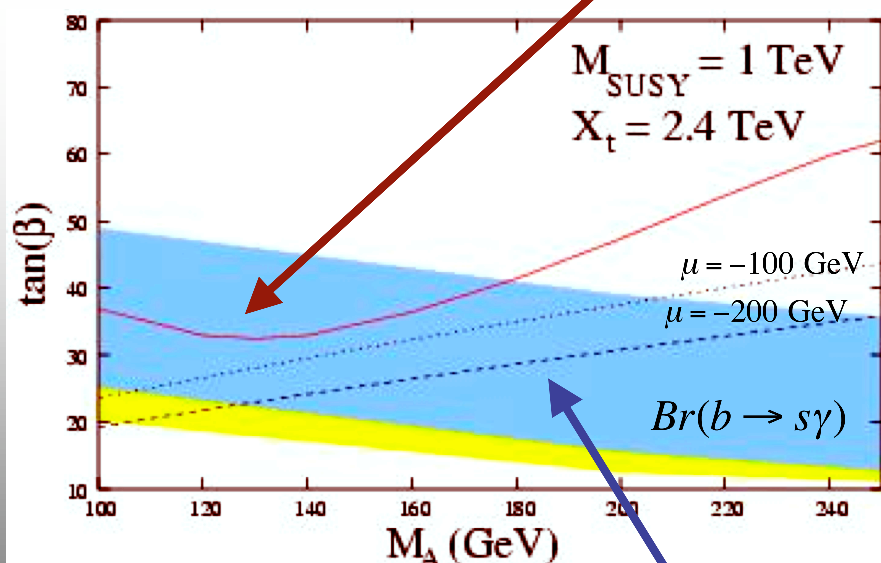
Large to moderate values of X_t ==> SM like Higgs heavier than 120 GeV

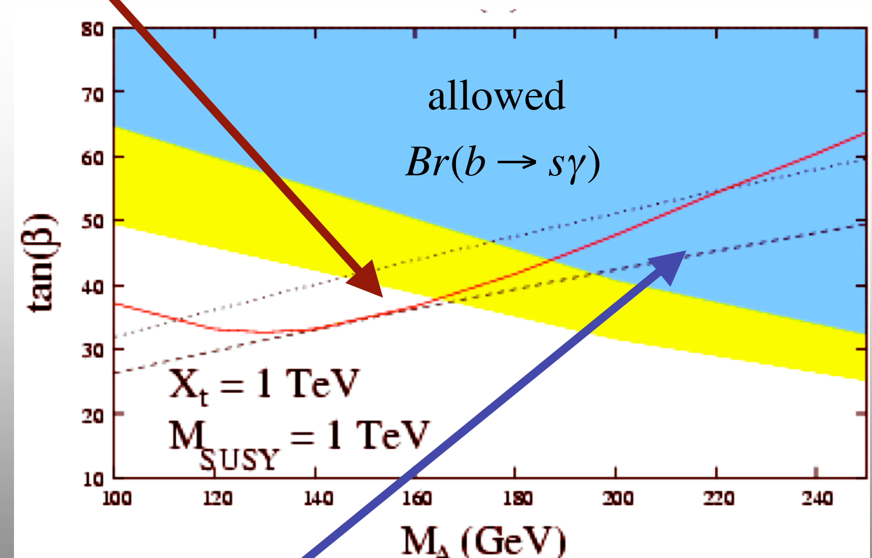
$BR(B_S \to \mu^+\mu^-) \propto |\mu A_t|^2 \Rightarrow$ Experimental bound ==> small μ and $X_t \leq 500$ GeV

Small $\mu < 0$ ==> $\cong$ constant H^+ and enhanced negative $\chi^+ - \tilde{t}$ contributions to $BR(b \to s\gamma)$

$p\bar{p} \to H/A \to \tau^+\tau^- \Rightarrow$ Tevatron Higgs reach with 1fb^{-1}

M. C. et al. hep-ph/0603106





CDF limit : $BR(B_S \to \mu^+\mu^-) < 1 \times 10^{-7}$

Tevatron Non-Standard Higgs searches at small X_t

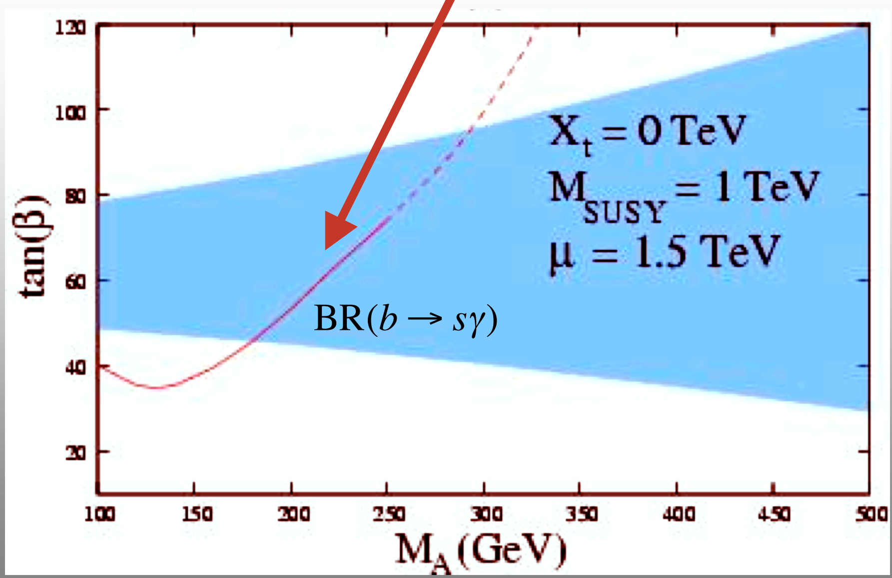
- Interesting region since light SM-like Higgs lighter than 125 GeV
- No constraints from $\mathrm{BR}(B_s \to \mu^+\mu^-)$
- Mild constraints from $\mathrm{BR}(b \to s\gamma)$ if large $\mu\, M_{\tilde{g}} > 0$

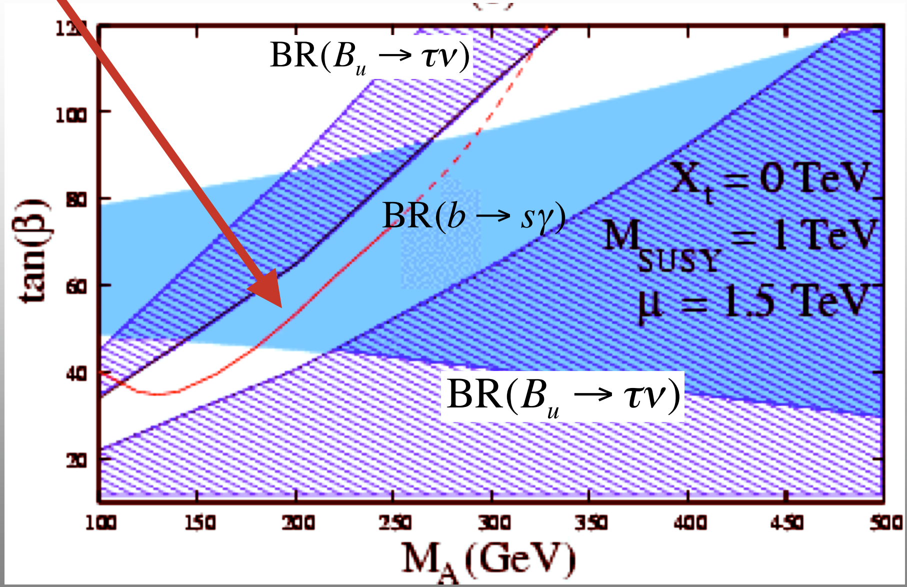
BUT, important constraint from recent measurement of $\mathrm{BR}(B_u \to \tau\nu)$

$$\frac{\mathrm{BR}(B_u \to \tau\nu)^{SUSY}}{\mathrm{BR}(B_u \to \tau\nu)^{SM}} = \left[1 - \left(\frac{m_B^2}{m_{H^\pm}^2}\right)\frac{\tan\beta^2}{(1+\Delta_b)}\right] \Leftrightarrow \frac{\mathrm{BR}(B_u \to \tau\nu)^{\exp}}{\mathrm{BR}(B_u \to \tau\nu)^{SM}} = 0.67^{+0.30}_{-0.27}$$

$p\bar{p} \to H/A \to \tau^+\tau^- \Rightarrow$ Tevatron Higgs reach with 1fb^{-1}

M. C. et al. hep-ph/0603106

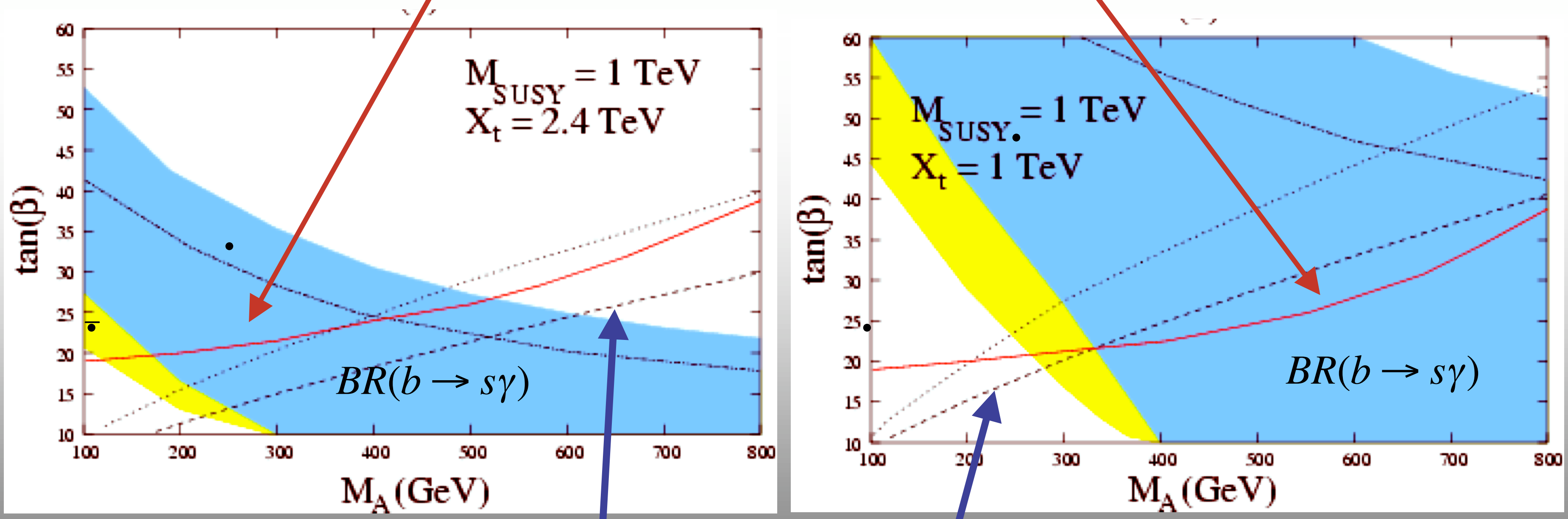




LHC Non-Standard Higgs searches in the large to moderate X_t region

- A relatively large region of SUSY parameter space can be probed at the LHC for these "low" luminosities
  - For small stop mixing parameter X_t and sizeable mu, H/A Higgs searches can make discoveries in a very large region of parameter space

$pp \to H/A \to \tau^+\tau^-$ with 30 fb^{-1} at the LHC



$BR(B_s \to \mu^-\mu^+) < 5.5\ 10^{-9}$ with 10 fb^{-1} at LHC

MFV Models with Grand Unification

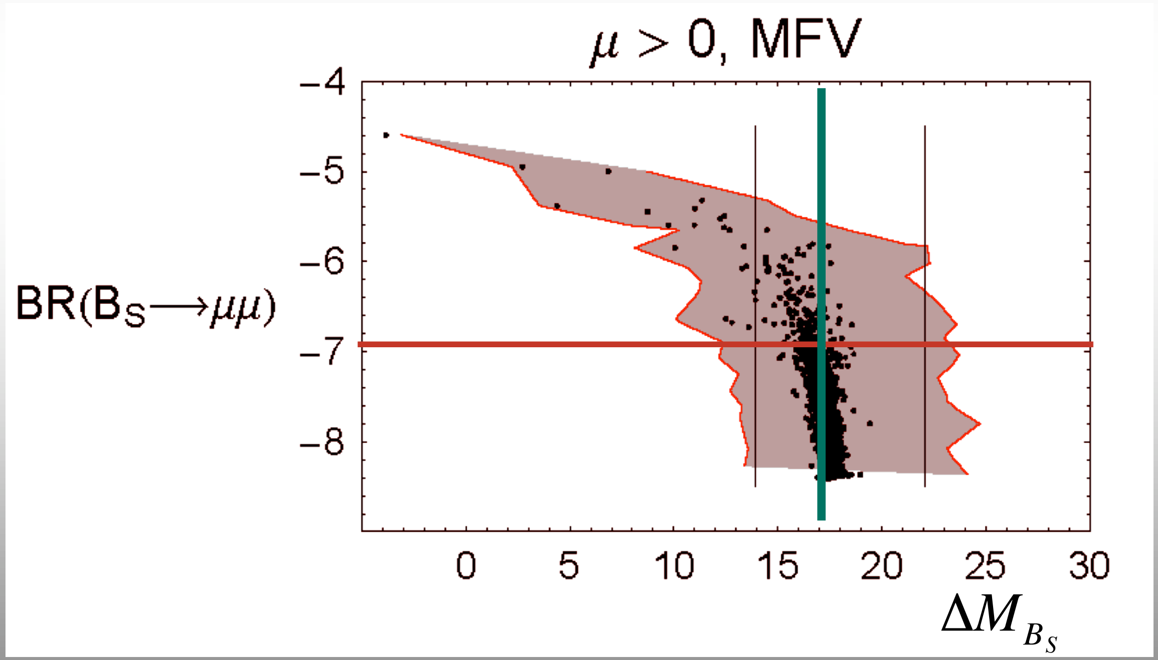
- Consider effects of renormalization group evolution of SUSY parameters defined at the GUT scale

-- gauge coupling and gaugino mass unification

-- Non-universal squark and trilinear mass parameters

Includes contraints from $b \to s\gamma, (g-2)_\mu,\ \Omega_{DM}$
and direct searches from colliders

Lunghi, Vives, Porod, hep-ph/0605177

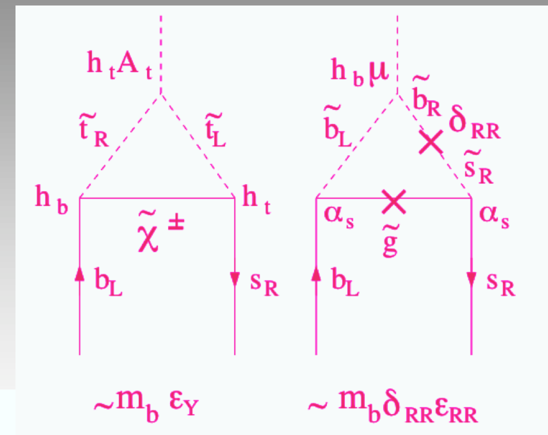


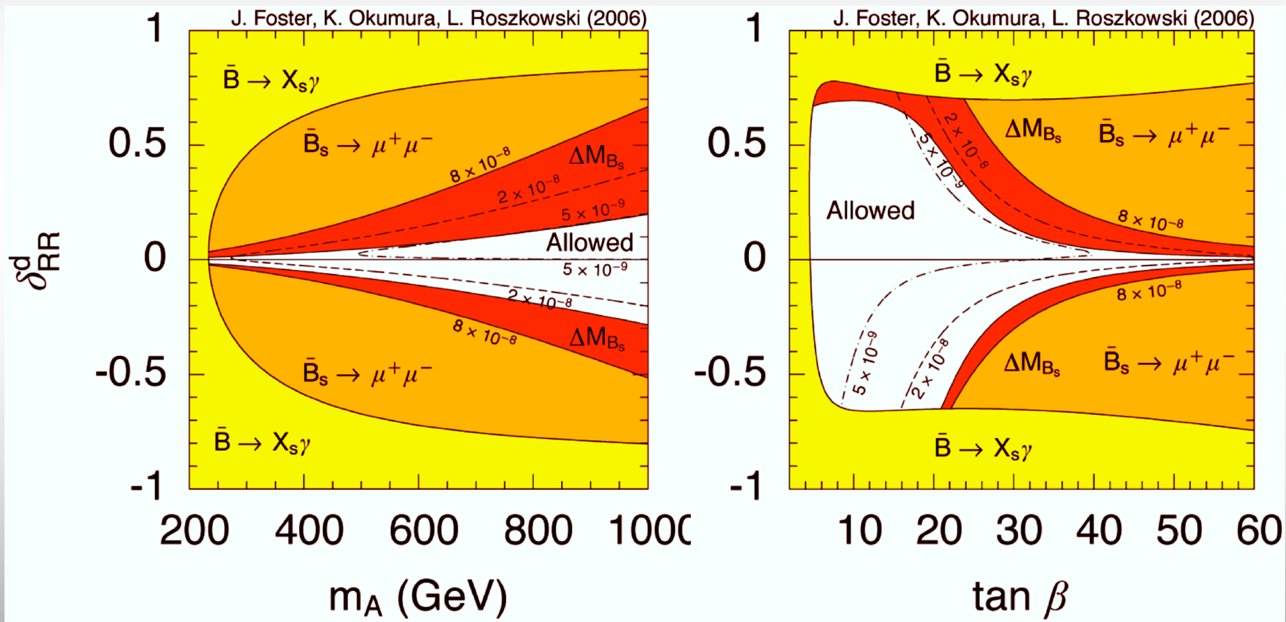
Large contributions to Bs-mixing strongly constrained by $BR(B_s \to \mu^+\mu^-)$

General Flavor Violation Models in SUSY (GFVM)

In GFVM ==> flavor violating entries of the squarks and trilinear mass parameters treated as being arbitrary

$$\left(\delta^d_{RR}\right)^{ij} = (m^2_{d,RR})^{ij} \Big/ \sqrt{(m^2_{d,RR})^{ii}(m^2_{d,RR})^{jj}} \Rightarrow$$





Tevatron measurement of $BR(B_s \to \mu^+\mu^-)$ ==> RR insertions are forbidden or, A_t and/or tanb must be very small

- Strict new constraints on general models of SUSY flavor violation arise form recent data on ΔM_{B_s} and $\mathrm{BR}(\mathrm{B_s} \to \mu^+\mu^-)$

Dark Matter: one of the fundamental open questions

==> it demands new physics and it may be intimately related to EWSB

- **Most suitable candidates beyond the Standard Model**:

==> Weakly interacting particles (WIMPS) with masses and interaction cross sections of order of the electroweak scale

SUSY with R-parity discrete symmetry conserved $R_P = (-1)^{3B+L+2S}$

==> naturally provides a neutral stable DM candidate: LSP ==> $\tilde{\chi}^0$

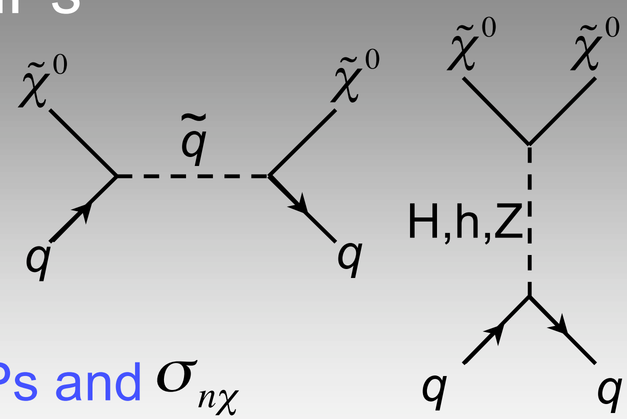
- **Collider experiments will find evidence of DM through $\not{E}_T$ signature**

and knowledge of new physics particle masses and couplings will allow to compute DM-annihilation cross sections and elastic scattering WIMP -proton cross sections

But only Direct Detection Experiments will confirm the existence of Dark Matter particles

Direct Detection of WIMPs

- WIMPs elastically scatter off nuclei in targets, producing nuclear recoils with $\sigma_{n\chi} \Rightarrow$



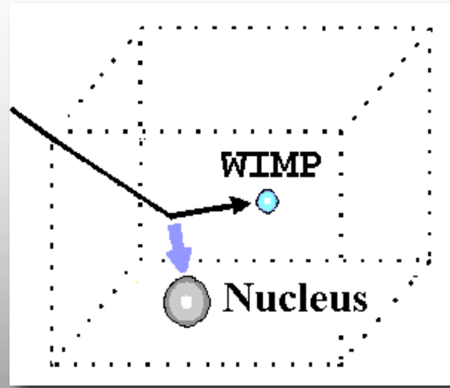
Main Ingredients to calculate signal:
Local density & velocity distribution of WIMPs and $\sigma_{n\chi}$
==> rate per unit time, per unit detector material mass

$$R = \sum_i N_i \, \eta_\chi \langle \sigma_{i\chi} \rangle$$

$\langle \sigma_{i\chi} \rangle$ → Scattering Cross section off nuclei averaged over relative wimp velocity

N_i → Number of target nuclei in the detector prop.to Detector mass/Atomic mass

η_χ → local WIMP density



<u>Direct detection has two big uncertainties</u>:

- The local halo density, inferred by fitting to models of galactic halo: assumed ==> $\eta_\chi \approx 0.3$ GeV / cm^3
- The galactic rotation velocity ≈ (230 +- 20) km/sec

Neutralino Elastic Scattering Cross Section -- CDMS Reach

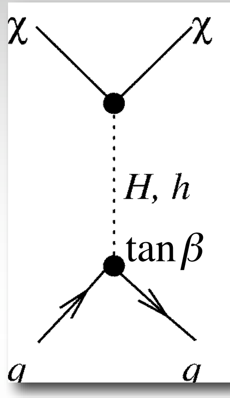
Current and near future experiments sensitive only to spin-independent scattering

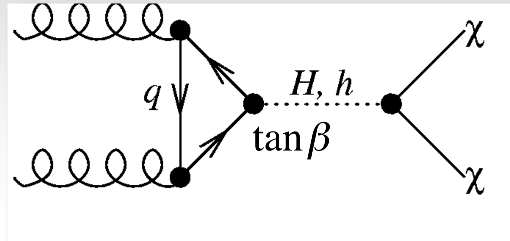
→ $\sigma_{SI} \leq 10^{-8}\, pb$

==> dominated by t-channel exchange of H and h, coupling to strange quarks and to gluons via bottom loops

↓

$\tan\beta$ enhanced couplings





Bino-like Neutralino example:

$$\sigma_{SI} \approx 4 \times 10^{-7} \left(\frac{N_{11}^2}{0.9}\right)\left(\frac{N_{13}^2}{0.1}\right)\left(\frac{300\text{GeV}}{m_A}\right)^4\left(\frac{\tan\beta}{50}\right)^2$$

If m_A and $\tan\beta$ are within Tevatron reach, a substantial elastic cross section, at the reach of CDMS, is expected

CDMS DM searches Vs the Tevatron H/A searches

•If the lightest neutralino makes up the DM of the universe

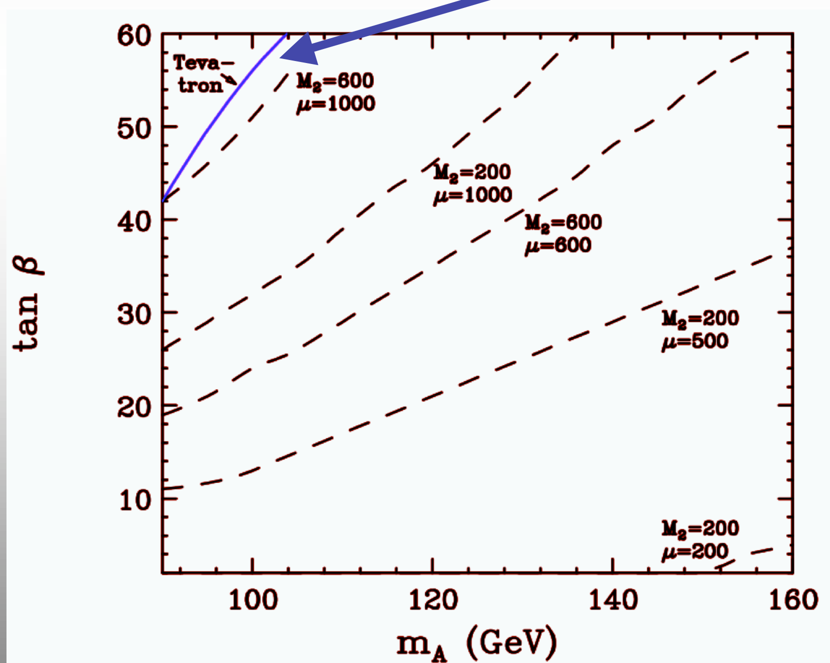
==> CDMS current limits disfavor discovery of H/A at the Tevatron, unless the neutralino has a large higgsino component $\Rightarrow \mu >> M_2$

==> a positive signal at CDMS will be very encouraging for Higgs searches

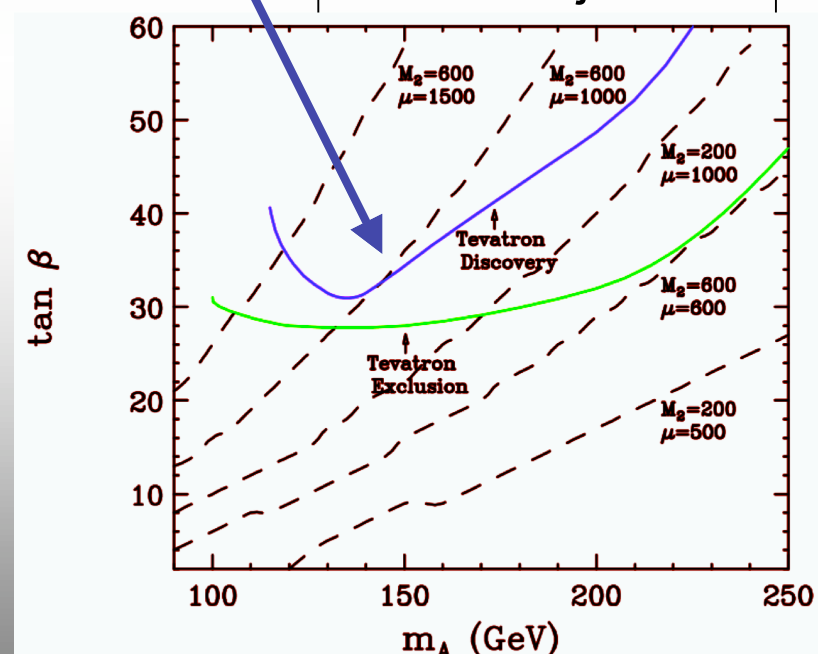
==>Evidence for H/A at the Tevatron without a CDMS signal would suggest a large value of μ

Tevatron reach in $p\bar{p} \to A/H \to \tau^+\tau^-$

2007 Projection



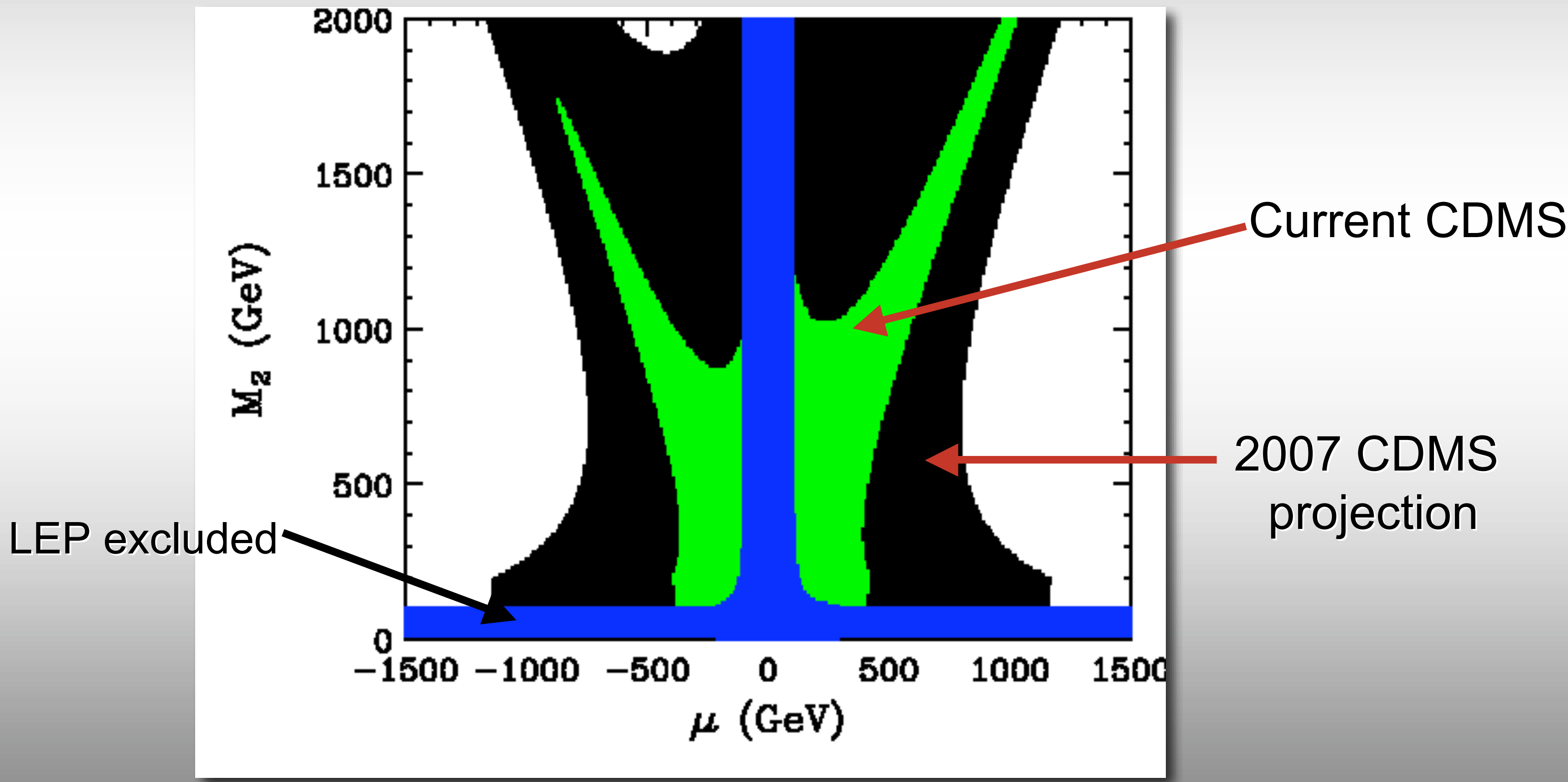
Current exclusion Comparison



M.C, Hooper, Skands, hep-ph/0603180

Direct Detection and Collider Searches

Constrained H/A discovery potential at the Tevatron (4 fb^{-1})

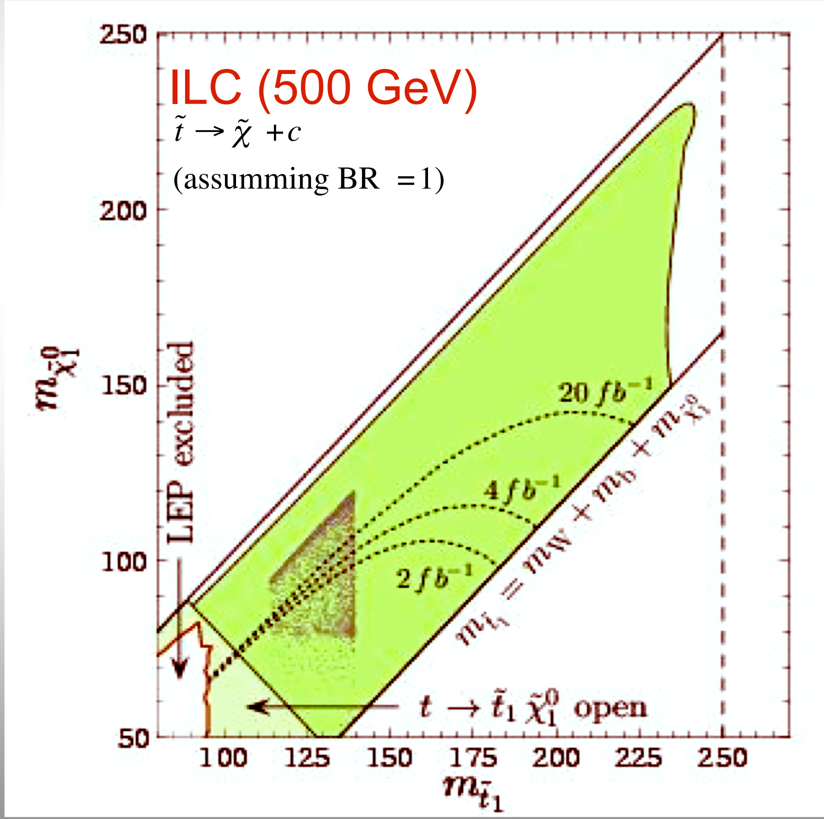


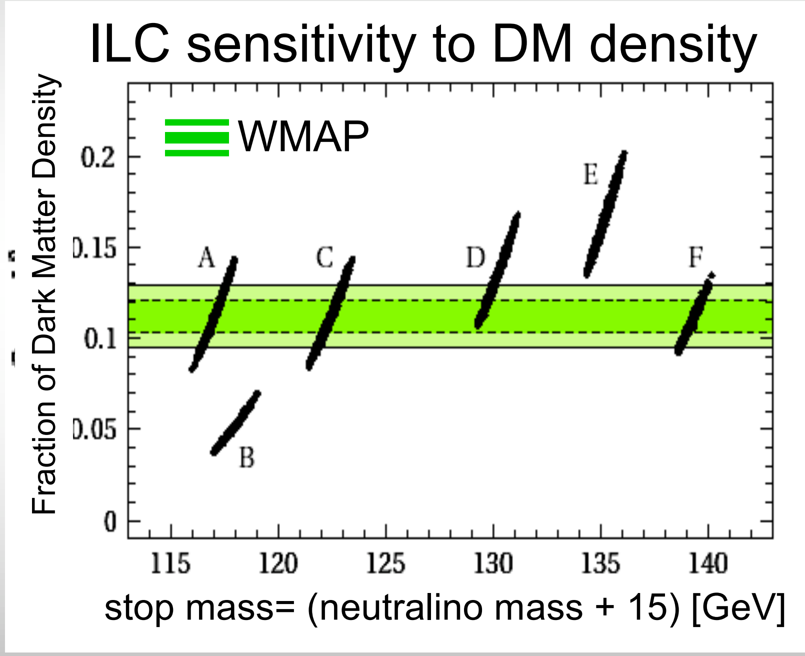
M.C, Hooper, Skands, hep-ph/0603180

Dark Matter at Colliders

The LHC will probably find evidence of DM particles through missing momentum and missing energy analyses

The ILC will determine its properties extremely accurately, allowing to compute which fraction of the total DM density of the universe it makes





SUSY models which explain DM and Matter-Antimatter Asymmetry

M. C. et al. hep-ph/0508152

A particle physics understanding of cosmological questions!

Conclusions

• Bs-mixing measurement ==> consistent with the SM, within errors.
==> in MFV SUSY models, with large tanb, consistent with $BR(B_s \to \mu^+\mu^-)$ bound.
However, it imposes strict constraints on General Flavor Violation SUSY Models.

• The ΔM_{B_S} and $\mathrm{BR}(\mathrm{B_u} \to \tau\nu)$ $\approx 2\sigma$ “discrepancy” between theory and experiment can be accomodated in MFV via large tanb effects, and can be probed by improving the reach on $BR(B_s \to \mu^+\mu^-)$

• Non-Standard MSSM Higgs searches at the Tevatron are highly constrained ---
-- for large stop mixing ==> from B physics measurements
-- for small higgsino mass parameter ==> from Direct DM detection searches

• Small stop mixing (Xt≈0) and large Higgsino mass parameter μ are promising for the Tevatron ==> has sensitivity to discover all 3 MSSM neutral Higgs bosons

• Discovery of H/A at the Tevatron together with discovery at CDMS will shed light to the composition of SUSY DM.

• Discovery of H/A at the Tevatron, without positive results from leptonic rare Bs decay and from CDMS
==> small X_t an large μ or Deviations from MFV together with
a different Nature of DM than usually assumed