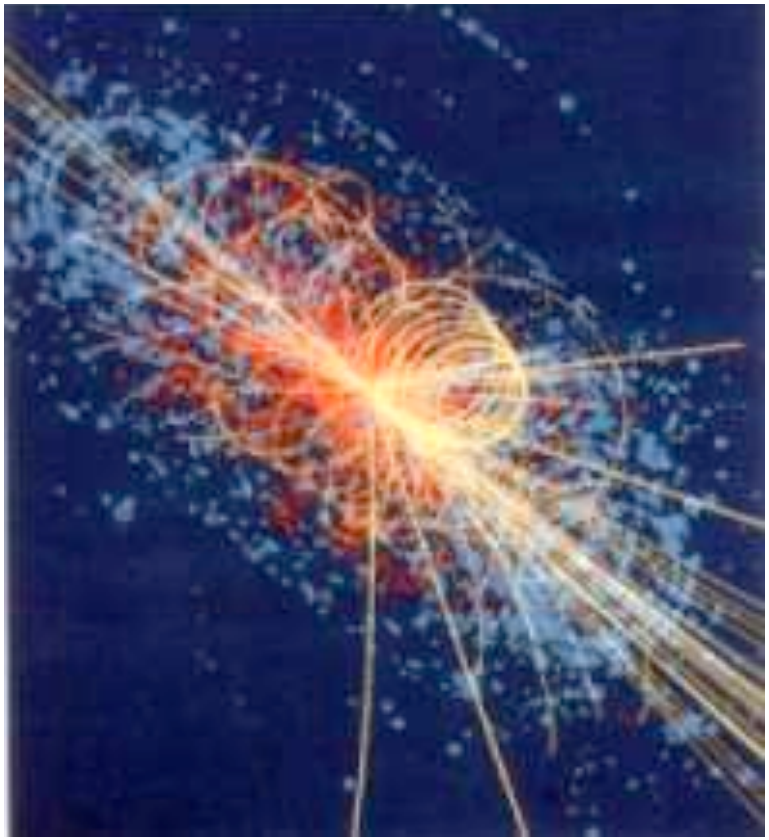
# B Physics, Direct Dark Matter detection and Supersymmetric Higgs Searches at Colliders



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Fermilab
May 18, 2007

# Based on:

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# Outline

- Introduction ==> **The connection between Higgs and Flavor Physics**
  -- The Flavour issue in Supersymmetry ==> Minimal Flavor Violation (MFV)

- The MSSM Higgs Bosons
  -- the impact of radiative corrections on Higgs-fermion couplings:
  **Flavour conserving and FCNC effects**

- SM-like Higgs and the $A/H \to \tau\tau$ channels at the TeVatron and the LHC

- **B and Higgs Physics at the Tevatron and LHC**
  -- correlation between Bs mixing and $BR(B_s \to \mu^+\mu^-)$
  -- the impact of rare decays: $BR(B_s \to \mu^+\mu^-)$, $BR(b \to s\gamma)$ and $BR(B_u \to \tau\nu)$
  on direct MSSM Higgs searches

- **The interplay between Collider Higgs Searches and Direct Dark Matter Searches**

# The Connection between Higgs and Flavour Physics

## The Flavor Structure in the SM

- In the mass eigenstate basis, the Higgs field interactions are also flavor diagonal

$$\bar{d}_i(\hat{m}_i + h_i H)d_i, \qquad \text{with} \quad \hat{m}_i = h_i v$$

Flavor Changing effects arise from charged currents, which mix left-handed up and down quarks: $\bar{u}_{L,i} V_{CKM}^{ij} \gamma_\mu d_{L,j} W_\mu^+ + h.c.$ where $V_{CKM} = U_L^\dagger D_L$

- The CKM matrix is almost the identity ==> Flavor changing transitions suppressed
- The Higgs sector and the neutral gauge interactions do not lead to FCNC

## Flavor Beyond the Standard Model

**Two Higgs doublet Models:** Yukawa interactions ==> $\bar{d}_{R,i}(\hat{h}_{d,1}^{ij}\ \phi_1 + \hat{h}_{d,2}^{ij}\ \phi_2)\ d_{L,j}$

Different v.e.v.'s ==> $\hat{m}_d^{ij} = \hat{h}_{d,1}^{ij} \mathrm{v}_1 + \hat{h}_{d,2}^{ij} \mathrm{v}_2$

Diagonalization of the mass matrix will not give diagonal Yukawa couplings

==> will induce large, usually unacceptable FCNC in the Higgs sector

**Solution:** Each Higgs doublet couples only to one type of quarks ==> SUSY at tree level

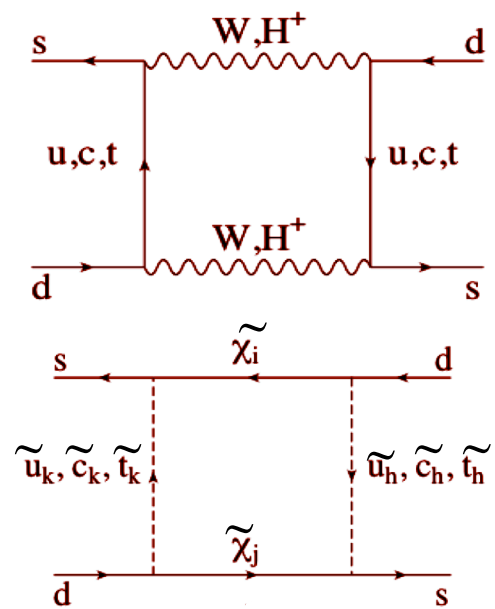
# The Flavor Problem in SUSY Theories

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

## Minimal Flavor Violation

- 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 SM.




Isidori, Retico: Buras et al.

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

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

  2) Soft SUSY 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 $h_u h_u^+$, and h.c.

In both cases the effective coupling governing FCNC processes

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

D'Ambrosio, Giudice, Isidori, Strumia

SUSY theories ==> extended Higgs sector with lightest Higgs having (usually) SM-like properties and $m_h < 200$ GeV

## The Higgs Sector in Minimal Supersymmetric Standard Model (MSSM)

- 2 Higgs SU(2) doublets $\phi_1$ and $\phi_2$: after Higgs Mechanism

  → 2 CP-even h, H with mixing angle $\alpha$
  1 CP-odd A and a charged pair $H^{\pm}$

All Higgs masses and couplings given in terms of 2 parameters $m_A$ and $\tan\beta = v_2/v_1$

$$\Rightarrow v^2 = v_1^2 + v_2^2 = 246 \text{ GeV}$$

At tree level, one Higgs doublet couples only to down quarks and the other couples to up quarks only

$$-L = \bar{\psi}_L^i \left( \hat{h}_d^{ij+} \phi_1 d_R^j + \hat{h}_u^{ij+} \phi_2 u_R^j \right) + h.c.$$

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

# The MSSM HIGGS sector

Couplings to gauge bosons and fermions
( normalized to SM values)

$$\mathrm{hZZ,\ hWW,\ ZHA,\ WH^{\pm}H} \longrightarrow \sin(\beta-\alpha)$$
$$\mathrm{HZZ,\ HWW,\ ZhA,\ WH^{\pm}h} \longrightarrow \cos(\beta-\alpha)$$

$$(\mathrm{h,H,A})\ u\bar{u} \longrightarrow \cos\alpha/\sin\beta,\ \ \sin\alpha/\sin\beta,\ \ 1/\tan\beta$$
$$(\mathrm{h,H,A})\ d\bar{d}/l^+l^- \longrightarrow -\sin\alpha/\cos\beta,\ \ \cos\alpha/\cos\beta,\ \ \tan\beta \longrightarrow \text{(enhanced)}$$

- Quantum corrections affect the couplings relevantly, especially for the heavy Higgs bosons

In most of the parameter space: $m_A >> m_Z$ (decoupling limit)

==> lightest Higgs: $m_h \leq m_Z$ and behaves like SM Higgs ==> similar searches at colliders

others heavy and roughly degenerate $m_A \approx m_H \approx m_{H^{\pm}}$

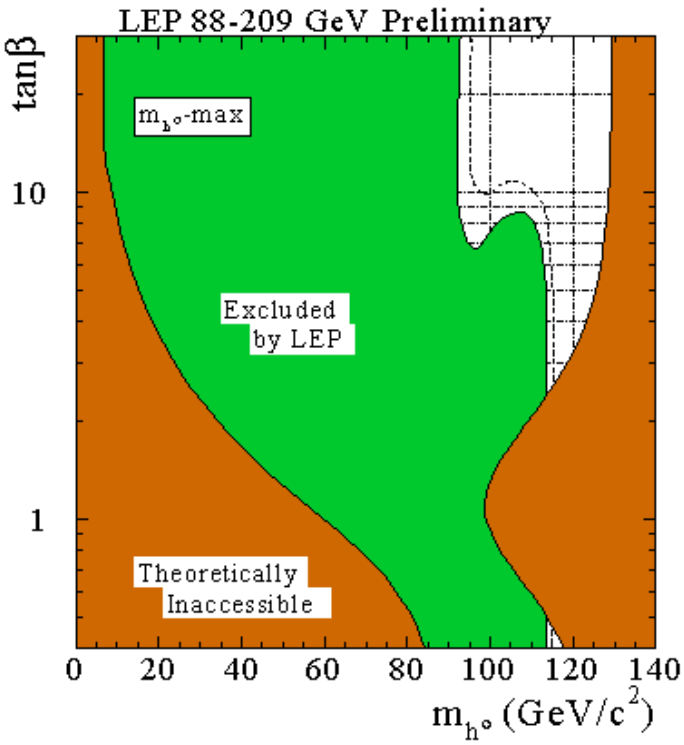
**LEP MSSM HIGGS limits:** $\longrightarrow$ $m_{H^{\pm}} > 78.6\mathrm{GeV}$

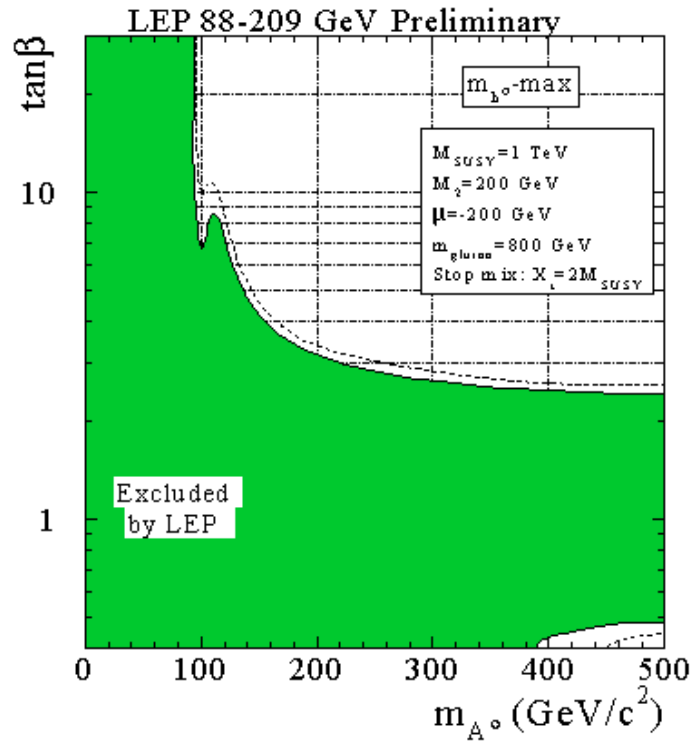
$m_h > 91.0$ GeV; $m_{A,H} > 91.9$ GeV; $m_h^{\mathrm{SM-like}} > 114.6\mathrm{GeV}$

# Present Status of MSSM Higgs searches

95%C.L. limits

$e^+e^- \xrightarrow{Z^*} hZ, HZ, Ah, AH$ main decay mode $h \to b\bar{b}$




MSSM Higgs $m_h > 91.0 GeV; \quad m_A > 91.9 GeV$

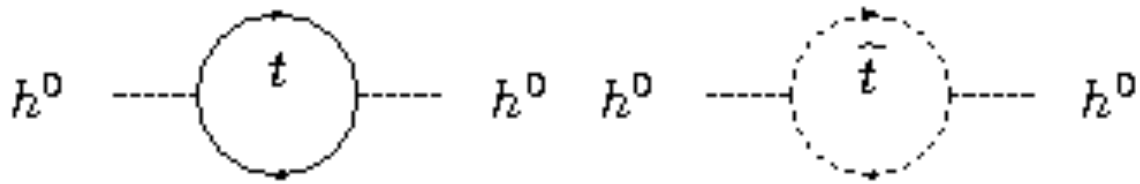
Charged Higgs $m_{H^\pm} > 78.6 GeV$

SM-like Higgs $m_h > 114.6 GeV$

# Radiative Corrections to Higgs Boson Masses

Important quantum corrections due to incomplete cancellation of particles and superparticles in the loops

Main effects: stops;
and sbottoms at large tan beta




$$m_h^2 = M_Z^2 \cos^2 2\beta + \frac{2\, g_2^2\, m_t^4}{8\pi^2\, M_W^2} \left[ \ln(M_S^2/m_t^2) + \frac{X_t^2}{M_S^2} \left( 1 - \frac{X_t^2}{12\, M_S^2} \right) \right] + \text{h.o.}$$

$$M_S^2 = \tfrac{1}{2}(m_{\tilde{t}_1}^2 + m_{\tilde{t}_2}^2) \text{ and } X_t = A_t - \mu/\tan\beta \longrightarrow \text{stop mixing}$$

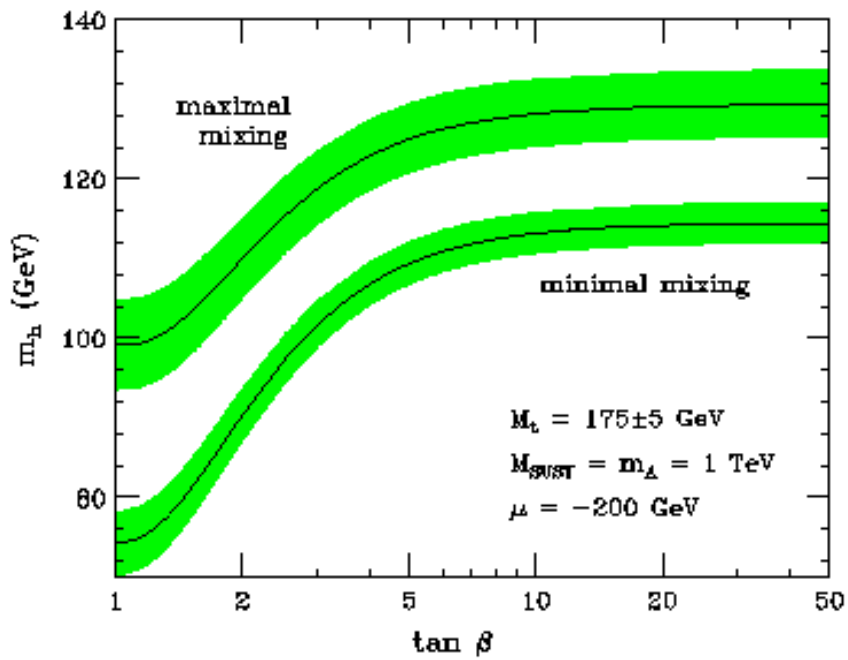
- $m_t^4$ **enhancement**
- **log sensitivity to stop masses** $M_S$
- **depend. on stop mass mixing** $X_t$

**After 2 -loop corrections**

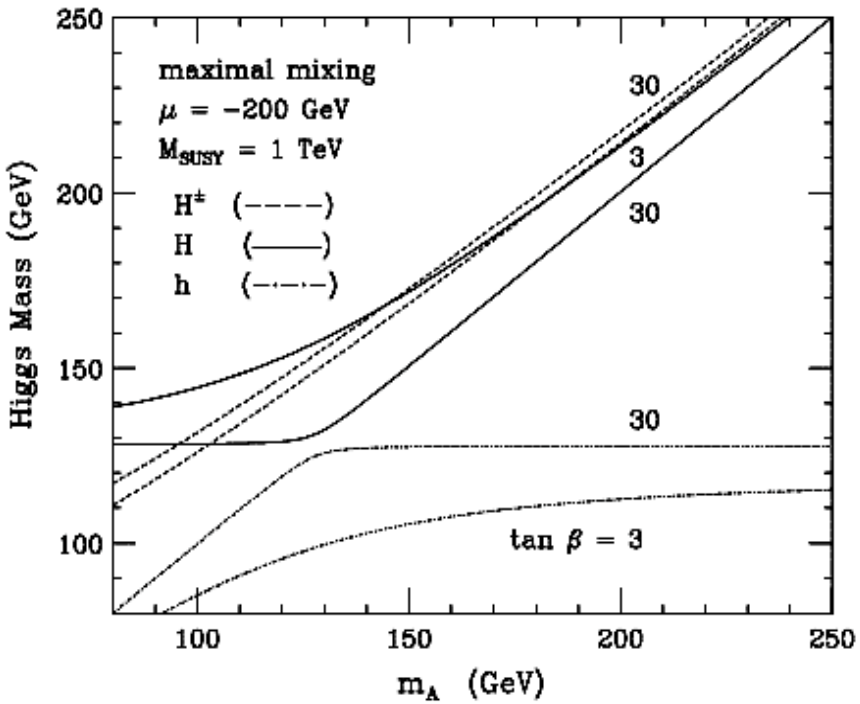
$$m_h \leq 135 \text{ GeV}$$

**stringent test of the MSSM**

$$M_S = 1 \rightarrow 2 \text{ TeV} \Longrightarrow \Delta m_h \simeq 2 - 5 \text{ GeV}$$
$$\Delta m_t = 1 \text{ GeV} \Longrightarrow \Delta m_h \sim 1 \text{ GeV}$$



# MSSM Higgs Masses as a function of $M_A$




$$m_H^2 \cos^2(\beta-\alpha) + m_h^2 \sin^2(\beta-\alpha) = [m_h^{max}(\tan\beta)]^2$$

- $\cos^2(\beta-\alpha) \to 1$ for large $\tan\beta$, low $m_A$
  $\Longrightarrow$ H has SM-like couplings to W,Z
- $\sin^2(\beta-\alpha) \to 1$ for large $m_A$
  $\Longrightarrow$ h has SM-like couplings to W,Z

for large $\tan\beta$:
always one CP-even Higgs with SM-like couplings to W,Z
and mass below $m_h^{max} \leq 135$ GeV

$\Downarrow$

if $m_A > m_h^{max}$ $\rightarrow$ $m_h \simeq m_h^{max}$ and $m_H \simeq m_A$

if $m_A < m_h^{max}$ $\rightarrow$ $m_h \simeq m_A$ and $m_H \simeq m_h^{max}$

$m_A$ nearly degenerate with $m_h$ or $m_H$

- **Mild variation of the charged Higgs mass with SUSY spectrum**

$$m_{H^\mp}^2 = m_A^2 + (\lambda_4 - \lambda_5)v^2$$

If sizeable $\mu$ and sizeable $A_t \times A_b < 0 \Rightarrow \lambda_4 - \lambda_5 < 0$ (smaller $m_{H^\mp}$)

# Radiative Corrections to the Higgs Couplings

**1) Through radiative corrections to the CP-even Higgs mass matrix** $\delta M_{ij}^2$ ,
which defines the mixing angle $\alpha$

$$\sin\alpha\cos\alpha = M_{12}^2 / \sqrt{\left(\mathrm{Tr}\, M^2\right)^2 - 4\det M^2}$$

The off diagonal elements are prop. to

M.C. Mrenna, Wagner

$$M_{12}^2 \propto -\left(m_A^2 + m_Z^2\right)\cos\beta\sin\beta + \frac{m_t^4}{16\pi^2 \mathrm{v}^2}\frac{\mu X_t}{M_S^2}\left(\frac{X_t^2}{M_S^2} - 6\right)$$

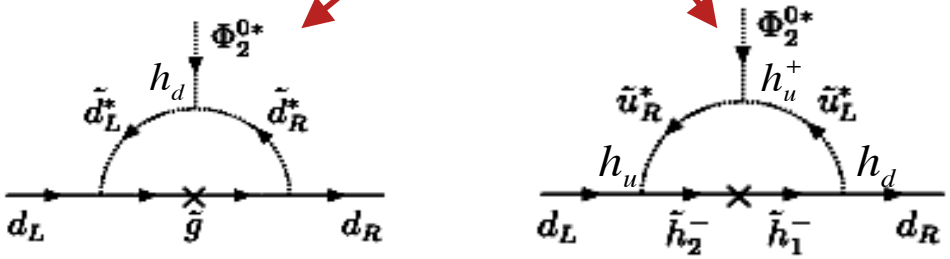
Important effects of rad. correc. on $\sin\alpha$ or $\cos\alpha$ depending on the sign of $\mu X_t$ and the magnitude of $X_t / M_S$

===> govern couplings of Higgs to fermions
===> via rad. correc. to $\cos(\beta-\alpha)$ and $\sin(\beta-\alpha)$ governs couplings to vector bosons

• If off-diagonal elements vanish (small $m_A$ & large tan beta) ===> $\sin\alpha$ or $\cos\alpha$ vanish
===> strong suppression of SM-like Higgs boson coupling to b-quarks and tau-leptons

## 2) Vertex corrections to neutral Higgs-fermion couplings ( $\tan\beta$ enhanced)

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




$\varepsilon$ loop factors intimately connected to the structure of the squark mass matrices.

- **<u>In terms of the quark mass eigenstates</u>** Dedes , Pilaftsis

$h_u = M_u / v_2$

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

and $R = 1 + \varepsilon_0 \tan\beta + \varepsilon_Y \tan\beta |h_u|^2$ ➔ R diagonal with $R^{33} \equiv 1 + \Delta_b$

Dependence on SUSY parameters ➔

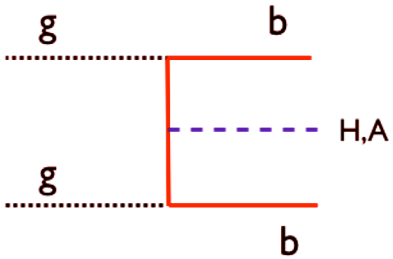
$$\varepsilon_0^i \approx \frac{2\alpha_s}{3\pi} \frac{\mu^* M_{\tilde{g}}^*}{\max\left[ m_{\tilde{d}_1^i}^2, m_{\tilde{d}_2^i}^2, M_{\tilde{g}}^2 \right]} \qquad \varepsilon_Y \approx \frac{\mu^* A_t^*}{16\pi^2 \max\left[ m_{\tilde{t}_1}^2, m_{\tilde{t}_2}^2, \mu^2 \right]}$$

# Non-Standard Higgs Production at the Tevatron and LHC

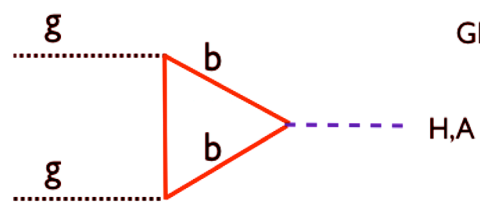
Looking at $V_{CKM} \cong I \Rightarrow$ Flavor Conserving Higgs-fermion couplings

- Important effects on couplings to b quarks and tau-leptons

destroy basic relation
$g_{\mathrm{h,H,Abb}} / g_{h,H,A\,\tau\tau} \propto m_b / m_\tau$




Associated Production




Gluon Fusion

$$\rightarrow g_{bbA/H} \approx \frac{m_b \tan\beta}{(1+\Delta_b)\mathrm{v}}$$

- Considering value of running bottom mass and 3 quark colors

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

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

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

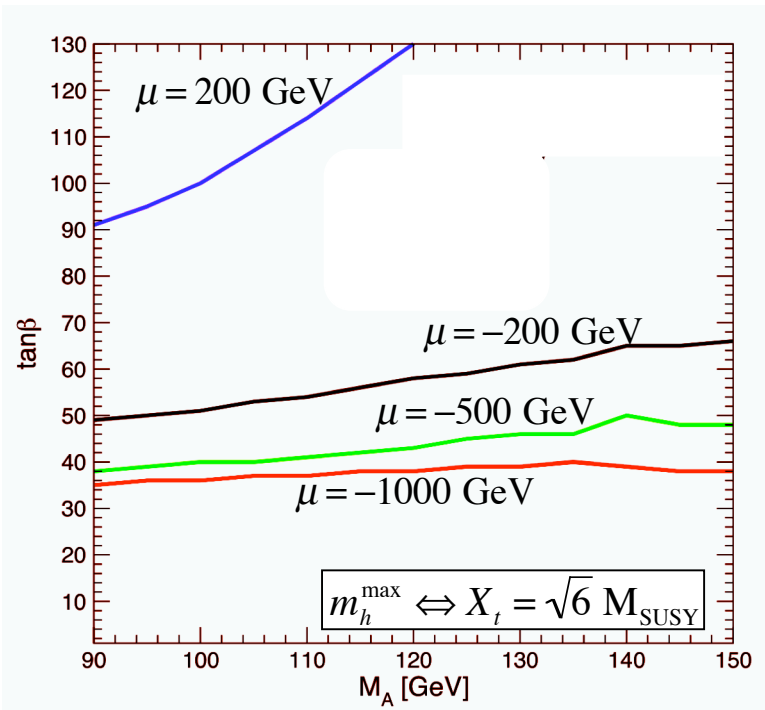
# Searches for Non-Standard Higgs bosons at the Tevatron

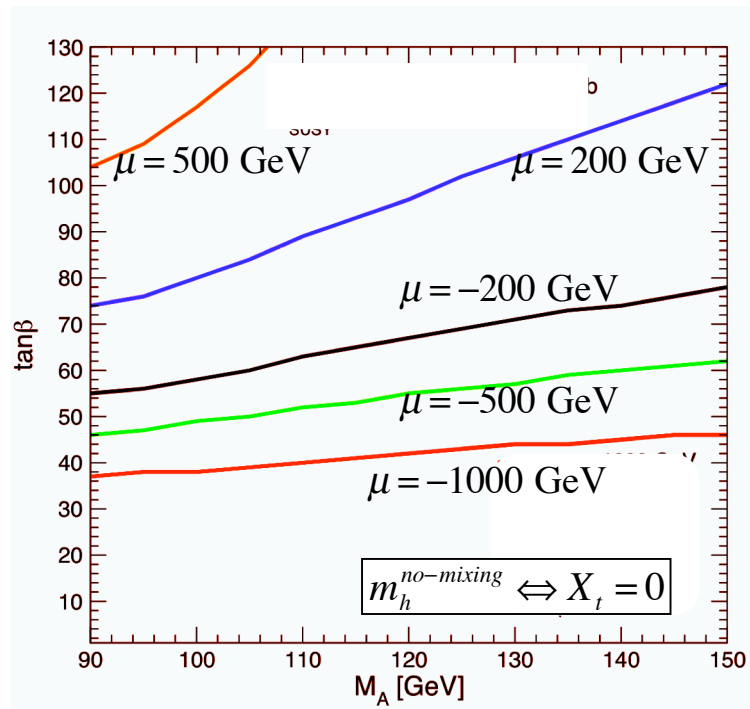
## A) In the bb mode ==> probe large region of $\tan\beta - m_A$ plane

$\boxed{\text{Stop mixing param.}: X_t = A_t - \mu/\tan\beta}$

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

$\boxed{\Rightarrow \text{ based on D0 } \to 260\text{pb}^{-1}}$



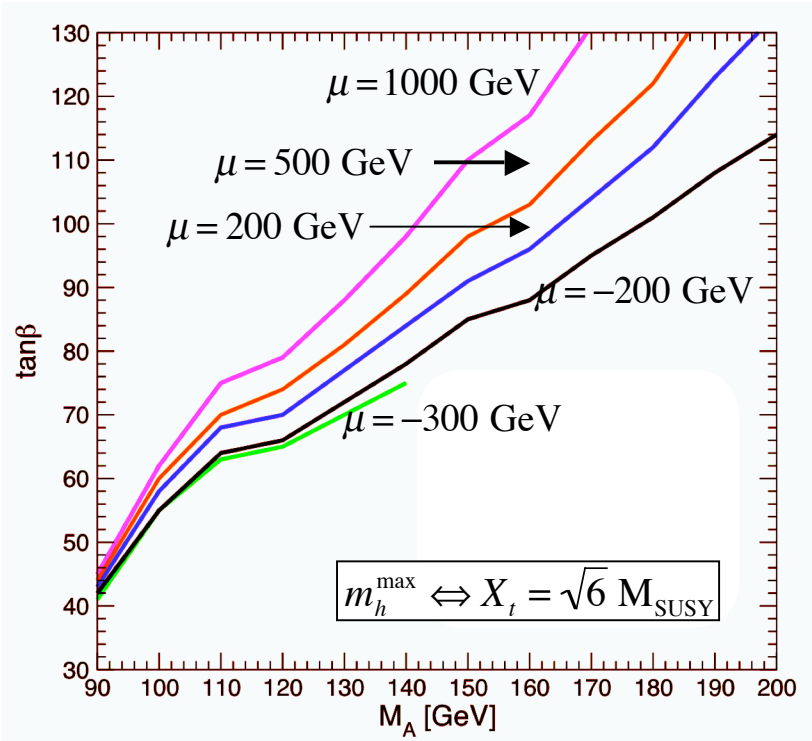

- Enhanced reach for negative values of $\mu$
- Strong dependence on SUSY parameters

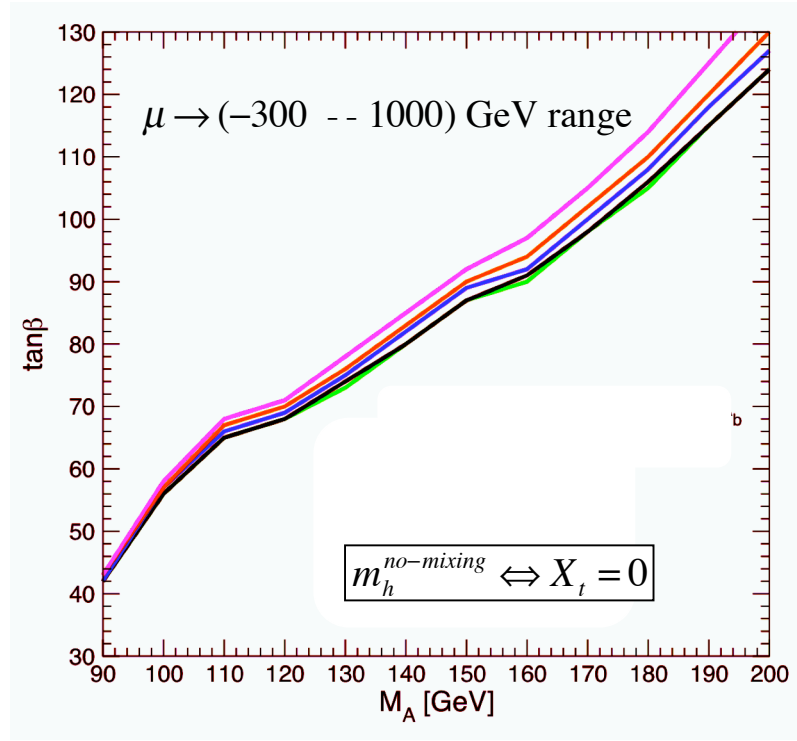
M. C. et al. hep-ph/0511023

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

## B) In the tau tau inclusive mode

$$p\bar{p} \to X\phi, \quad \phi \to \tau^+\tau^- \quad \Rightarrow \text{ based on CDF: } 310\text{pb}^{-1}$$



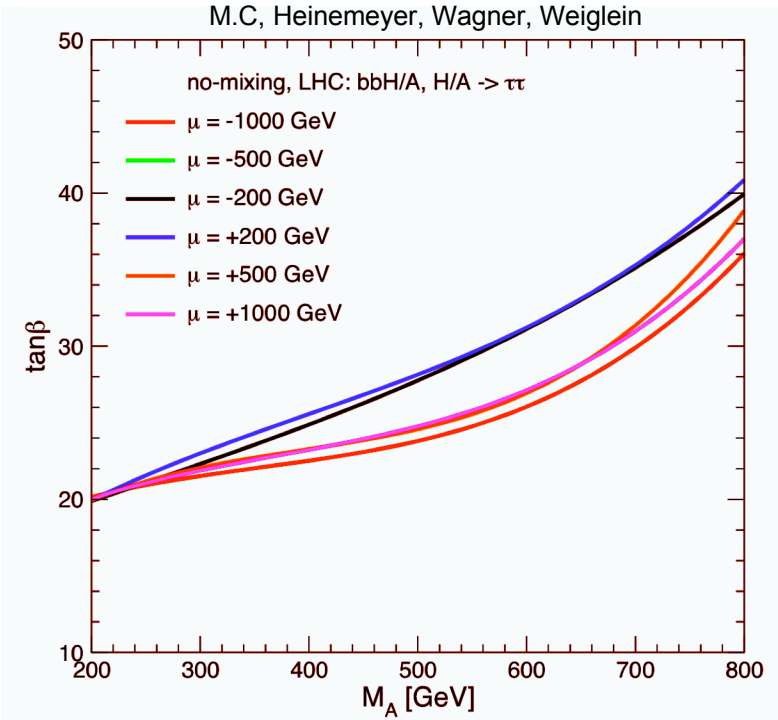




M. C. et al. hep-ph/0511023

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

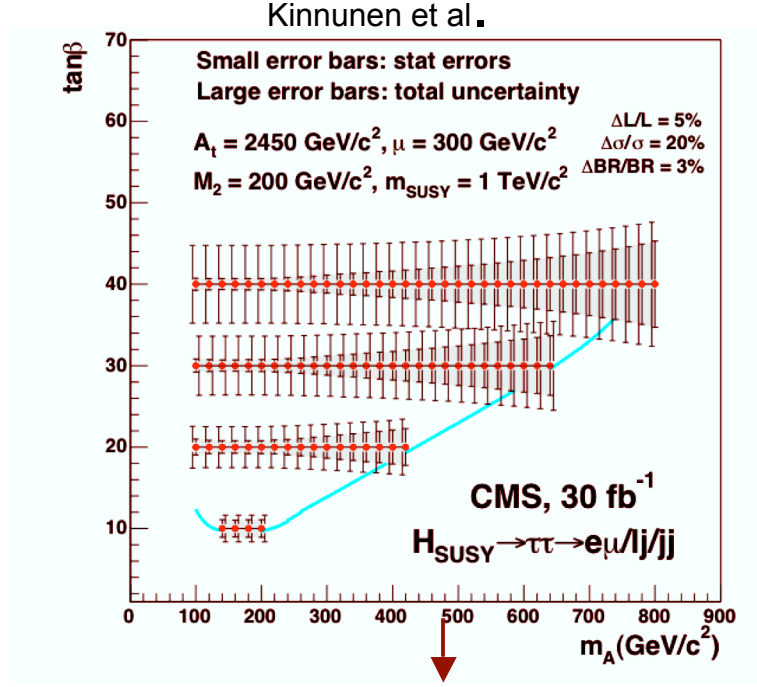
# Searches for Non-Standard Neutral Higgs bosons at the LHC

$pp \to A/H\,X,\;\; A/H \to \tau^+\tau^-,$ rescaling CMS prospects for 30 fb$^{-1}$ (similar for ATLAS)




- Enhancement of Hbb and Abb couplings by factor $\tan\beta$ compared with SM Higgs.
  ==> large production cross section
  ==> decay dominated by $A/H \to \tau^+\tau^-$
  (with different decay modes of tau leptons)

Kinnunen et al.




Cancellation of $\Delta_b$ effects ==> projections stable under variations of SUSY space ==> $\boxed{\Delta\tan\beta \approx 8}$

main variation ==> $A/H \to \tilde{\chi}_i^0\tilde{\chi}_j^0,\;\; \tilde{\chi}_k^{\pm}\tilde{\chi}_l^{\mp}$

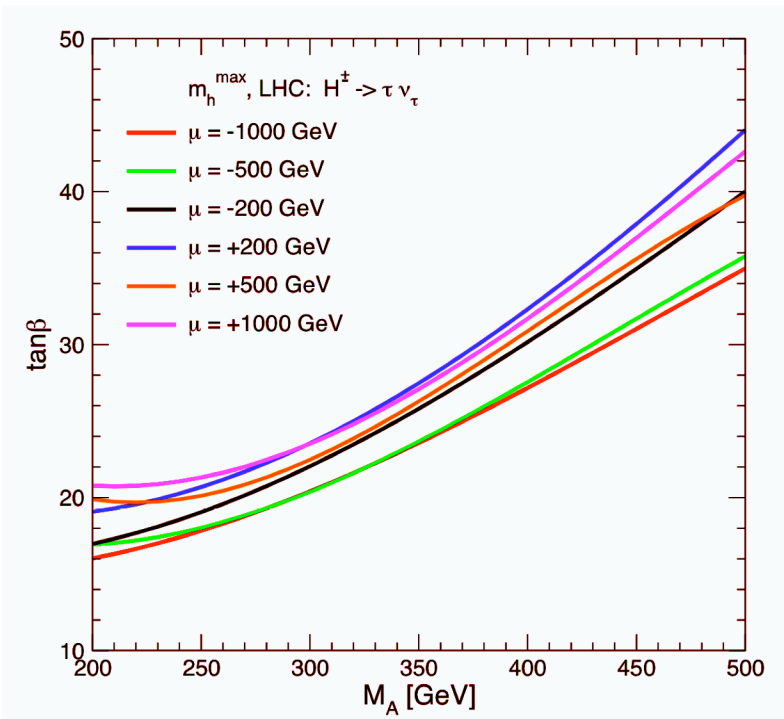
Robustness of results under variations of SUSY space ==>handle on tan beta

# Charged Higgs searches at the LHC

- Similarly to the neutral Higgs case, there are tan beta enhanced loop corrections which depend on SUSY parameters

For $m_{H^\pm} > m_t + m_b$ expect $H^\pm \to tb$ decay, however

$$\sigma(gb \to H^\pm t) \times BR(H^\pm \to \tau\nu) \propto \frac{\tan\beta^2}{(1+\Delta_b)^2} \frac{(1+\Delta_b)^2}{(1+\Delta_b)^2 + 9\left(1 - m_t^2/m_{H^\pm}^2\right)^2}$$




Much more robust under radiative corrections

$$\Delta \tan\beta \leq 10$$

Including variation due to charged Higgs decay into SUSY particles for small mu

M.C., Heinemeyer, Wagner, Weiglein

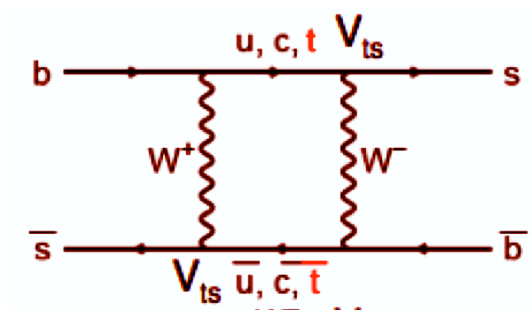
# Indirect searches for MSSM Higgs bosons in B meson observables

**B-observables:** rare B-meson transitions mediated by charged currents involving FC effects

## A) Bs mixing

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

Flavor eigenstates mix via weak interactions →




**Mass eigenstates:**

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

The B meson mass matrix:

$$M = \begin{bmatrix} M - i\Gamma/2 & M_{12} - i\Gamma_{12}/2 \\ M_{12}^* - i\Gamma_{12}^*/2 & M - i\Gamma/2 \end{bmatrix}$$

$$\Gamma_{12} << M_{12}$$

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

Short distance QCD corrections

Box-diagram

# $\Delta M_S$ Direct Measurement and Global CKM Fit

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

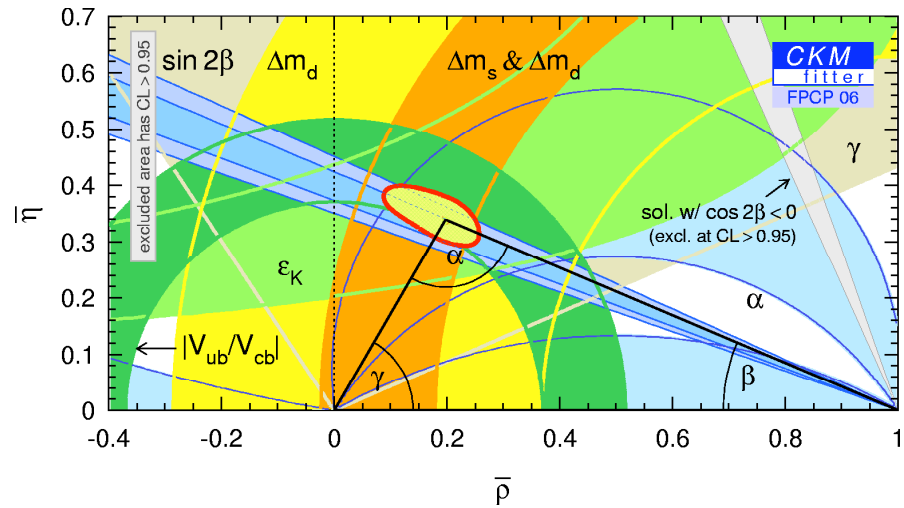
Minimize QCD lattice uncertainty providing a measurement of $|V_{ts}|/|V_{td}|$

CDF: $\Delta M_S = 17.7 \pm 0.10 \pm 0.07\, ps^{-1}$

SM fit :

$$\Delta M_S^{CKM} = 18.9^{+12.2}_{-5.5}\, ps^{-1}$$

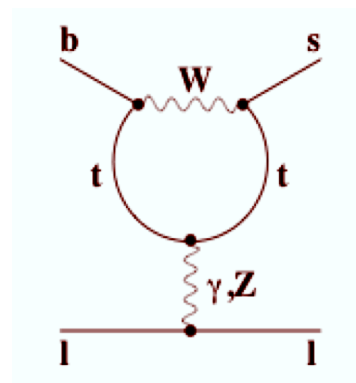
$$\Delta M_S^{UT} = 20.9 \pm 5.2\, ps^{-1}$$




## 2) Rare decay rate: $B_S \to \mu^+\mu^-$

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

Initial state $B_S = (\bar{b}s)$



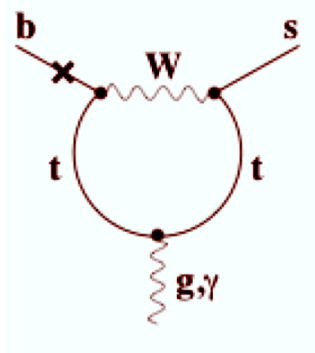

Final state

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

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

**A/H Higgs can affect these observables in a relevant way**

## 3) Rare decay rate $B \to X_S \gamma$




$$\mathrm{BR}(B \to X_S \gamma)^{\mathrm{SM}} = (2.98 \pm 0.26) \times 10^{-4}$$

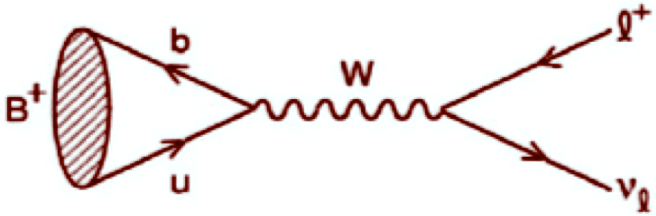
Considering world average measurement,

$$\mathrm{BR}(B \to X_S \gamma)^{\mathrm{exp}} = (3.55 \pm 0.24^{+0.09}_{-0.10}) \times 10^{-4}$$

and large theoretical uncertainty

2 $\sigma$ allowed range for new physics ==> $\boxed{0.92 \le \frac{\mathrm{BR}(B \to X_S \gamma)^{\mathrm{exp}}}{\mathrm{BR}(B \to X_S \gamma)^{SM}} \le 1.46}$

## 4) $B_u \to \tau \nu$ transition




$$BR(B_u \to \tau\nu)^{SM} = \frac{G_F^2 m_B m_\tau^2}{8\pi}\left(1 - \frac{m_\tau^2}{m_B^2}\right) f_B^2 |V_{ub}|^2 \tau_B = (0.85 \pm 0.13) \times 10^{-4}$$

Latest result from Belle & Babar ==> $BR(B_u \to \tau\nu)^{\mathrm{exp}} = (1.31 \pm 0.48)\ 10^{-4}$

**SUSY charged Higgs can contribute to flavor changing effects and affect in a relevant way the results for these B-meson observables**

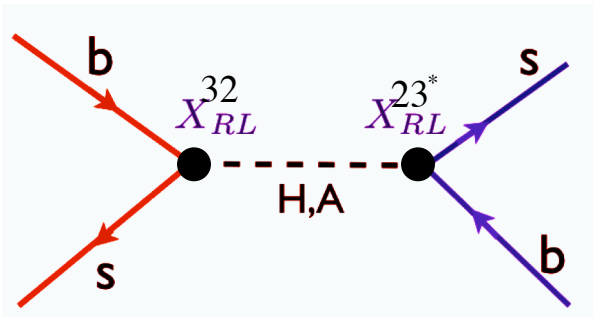
# B and Higgs Physics at the Tevatron and the LHC

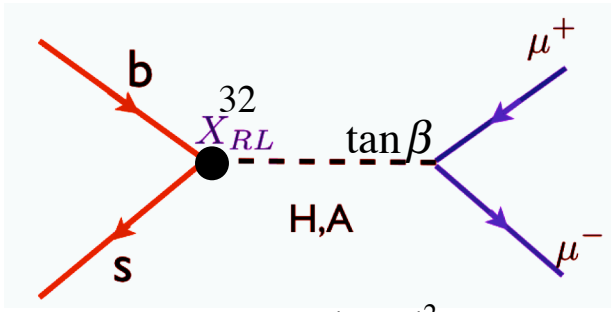
explore complementary regions of SUSY parameter space

**Important Flavor Changing effects:** 1) tree level ==> charged Higgs induced via $V_{CKM}$
2) tan beta enhanced loop corrections both in the neutral and charged Higgs sectors

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

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




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

Negative sign with respect to SM

$$BR(B_S \to \mu^+\mu^-)^{SUSY} \propto \frac{\left|X_{RL}^{32}\right|^2 \tan\beta^2}{m_A^4} \propto \frac{\left|\mu A_t\right|^2 \tan\beta^6}{m_A^4}$$

with $$\left(X_{RL}^{H/A}\right)^{ji} \approx -\frac{\bar{m}_{d_j}\, h_t^2\, \varepsilon_Y\, x_{\phi_1}^{H/A} \tan\beta^2}{v\left(1+\varepsilon_0^j \tan\beta\right)\left(1+\Delta_b\right)} V_{CKM}^{3j*} V_{CKM}^{3i} \implies \frac{\Delta M_{B_S}}{BR(B_S \to \mu^+\mu^-)} \propto \frac{m_A^2}{\tan\beta^2}$$

SUSY contributions strongly correlated

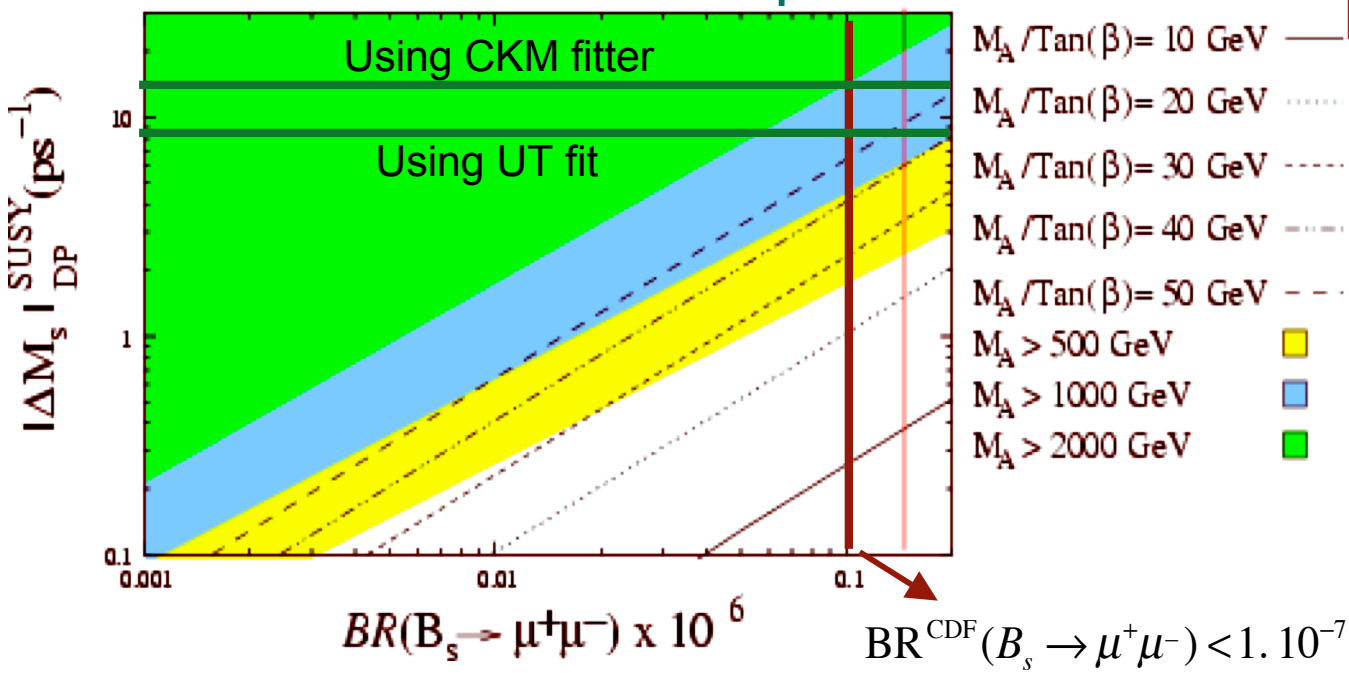
## •What can we learn from Bs-mixing?

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

Upper bound on NP from CDF ==> $\Delta M_S = 17.7 \pm 0.10 \pm 0.07\, ps^{-1}$

$\Delta M_S^{CKM} = 18.9^{+12.2}_{-5.5}\, ps^{-1}$

$\Delta M_S^{UT} = 20.9 \pm 5.2\, ps^{-1}$




$\mathrm{BR}^{CDF}(B_s \to \mu^+\mu^-) < 1.\, 10^{-7}$

$\mathrm{BR}(B_s \to \mu^+\mu-)_{SM}$ of order $10^{-9}$

↓

at the reach of LHC with about $10 fb^{-1}$

↓

SUSY corrections can enhance it by 2 orders of magnitude.

M. C., Menon, Papaqui, Zsynkman, Wagner 06

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

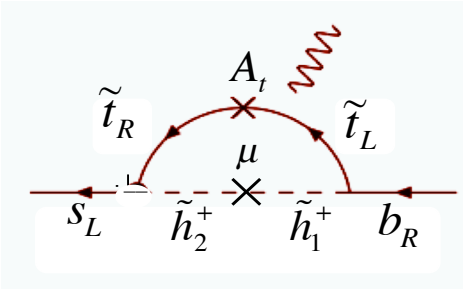
↕

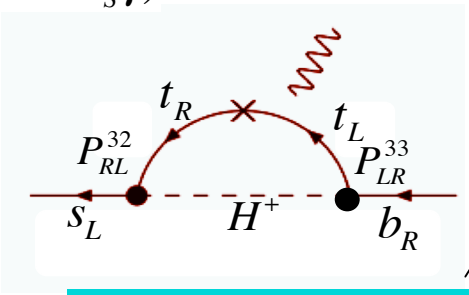
A/H at the reach of the Tevatron or the LHC <==> strong constraints on $|\Delta M_S|^{SUSY}_{DP}$

## Flavor Changing in the charged Higgs coupling:

Similar to the neutral Higgs case ==> tanb enhanced SUSY loop corrections

- **Important SUSY contributions to** $BR(B \to X_S \gamma)$




$$\delta h_t \propto h_t \frac{2\alpha_S}{3\pi} \mu^* M_{\tilde{g}}$$

$$A_{\chi^+} \propto \frac{\mu A_t \tan\beta \, m_b}{(1+\Delta_b)} \, h_t^2 f[m_{\tilde{t}_1}, m_{\tilde{t}_2}, \mu] \, V_{ts}$$

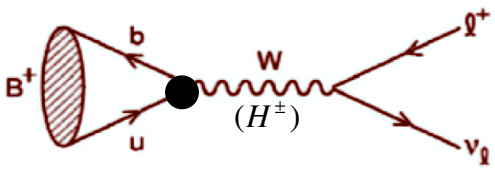
$$A_{H^+} \propto \frac{(h_t - \delta h_t \tan\beta) \, m_b}{(1+\Delta_b)} \, g[m_t, m_{H^+}] \, V_{ts}$$

If At ~0 + large $\mu M_{\tilde{g}} > 0$ ==> NO constraint on tanb-ma plane from $b \to s\gamma$

$$0.92 \leq \mathrm{BR}(B \to X_S\gamma)^{MSSM} / \mathrm{BR}(B \to X_S\gamma)^{SM} \leq 1.46 \quad 2\sigma \text{ range}$$

Becher and Neubert '06

- $B_u \to \tau\nu$ **transition**




In the MSSM ==> charged Higgs contribution interferes destructively with SM one.

$$R_{B_u \to \tau\nu} = \frac{\mathrm{BR}(B_u \to \tau\nu)^{MSSM}}{\mathrm{BR}(B_u \to \tau\nu)^{SM}} = \left[ 1 - \left( \frac{m_B^2}{m_{H^\pm}^2} \right) \frac{\tan\beta^2}{(1+\Delta_b)} \right]^2$$

Belle + Babar averaged:

$$BR(B_u \to \tau\nu)^{\exp} = (1.31 \pm 0.48) \; 10^{-4}$$

$$\Rightarrow 0.32 \leq R_{B_u \to \tau\nu} \leq 2.77 \quad \text{at } 2\,\sigma$$

# Interplay between Higgs and B physics searches in different SUSY scenarios

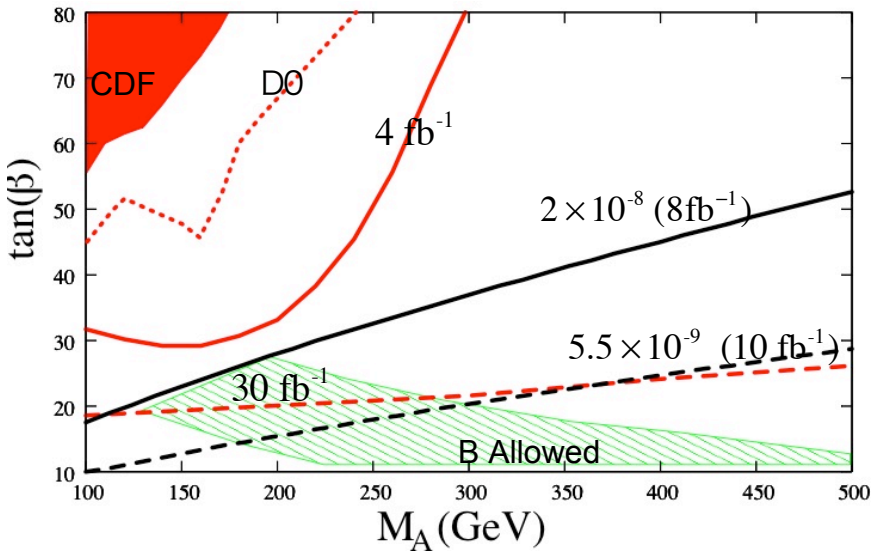
## 1) Non-SM-like Higgs and B-meson Searches

**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 $\mu$

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

M. C. et al. hep-ph/0603106 and hep-ph/0704.1143




Red $p\bar{p}, pp \to H/A \to \tau^+\tau^-$
-- 1 fb$^{-1}$ (CDF and D0 excluded)
-- projected 4 fb$^{-1}$ at the Tevatron
-- projected 30 fb$^{-1}$ at the LHC

black lines: $BR(B_s \to \mu^-\mu^+)$ reach:

Tevatron: $2\times10^{-8}$ (8fb$^{-1}$)

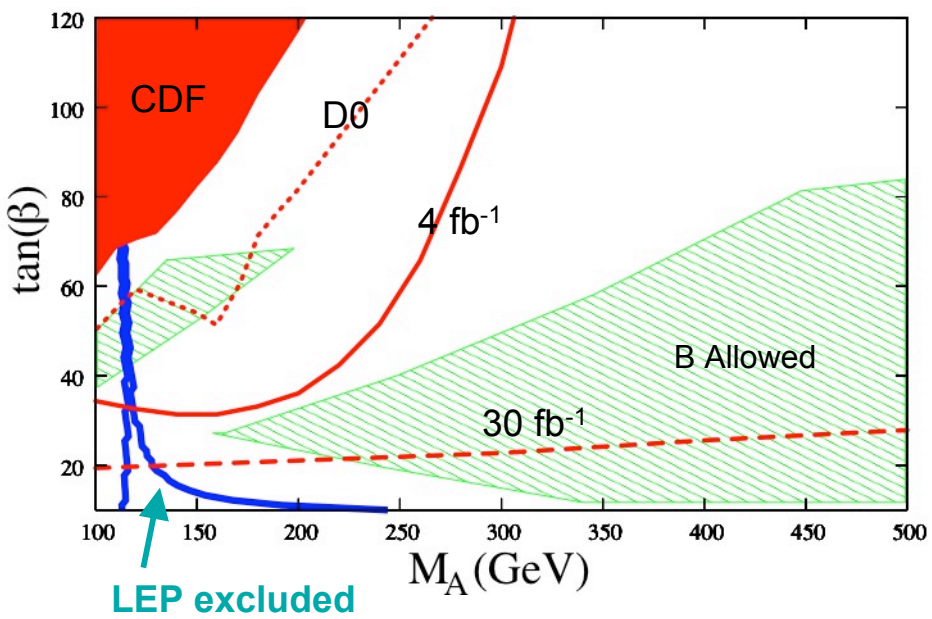
LHC: $5.5\times10^{-9}$ (10 fb$^{-1}$)

Hatched Area: Allowed regions by $BR(B_u \to \tau\nu)$, $BR(b \to s\gamma)$ and $BR(B_S \to \mu^+\mu^-)$

- Sizeable LR stop mixing <==> small/moderate mu
  ==> **B searches more powerful than Non-SM like Higgs searches**

- **Small $X_t$, sizeable $\mu$ ==> No mixing scenario**
  - Interesting region since light SM-like Higgs lighter than 125 GeV
  - **No constraints from** $\mathrm{BR}(B_s \to \mu^+\mu^-)$
  - Mild constraints from $\mathrm{BR}(\mathrm{b} \to \mathrm{s}\gamma)$ if large $\mu$ $\mathrm{M}_{\tilde{g}} > 0$
  - Important constraint from recent measurement of $\mathrm{BR}(B_u \to \tau\nu)$

M.C., Menon, Wagner




Red: $p\bar{p}, pp \to H/A \to \tau^+\tau^-$
-- 1 fb$^{-1}$ (CDF and D0 excluded)
-- projected 4 fb$^{-1}$ at the Tevatron
-- projected 30 fb$^{-1}$ at the LHC

Green: Allowed by B physics constraints

Blue: LEP Excluded from Higgs searches

Strong bounds on SM-like Higgs from LEP

**==> Non-SM like neutral Higgs searches can cover areas compatible with B physics constraints**

# Discovery reach for a SM-like MSSM Higgs at the Tevatron

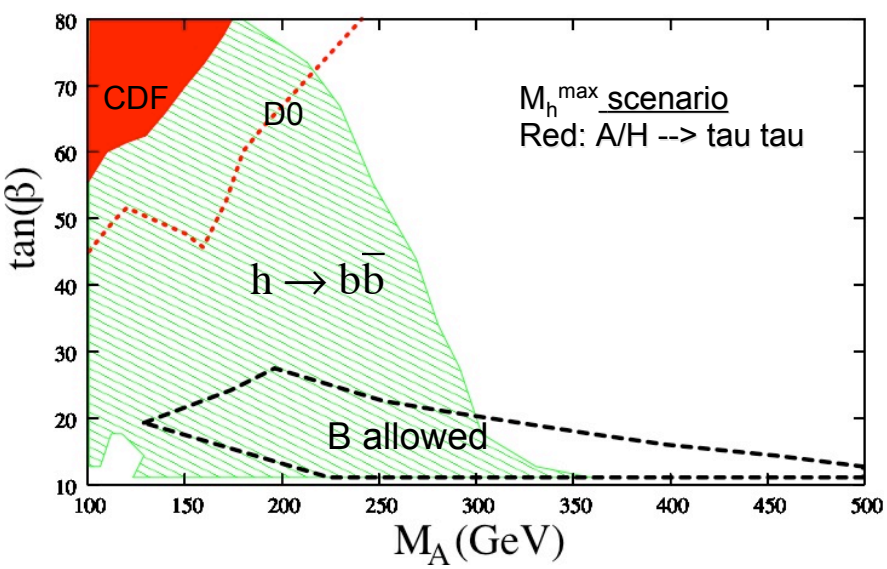
$p\bar{p} \rightarrow W/Z\ h$ with $h \rightarrow b\bar{b}$ with 4 $fb^{-1}$

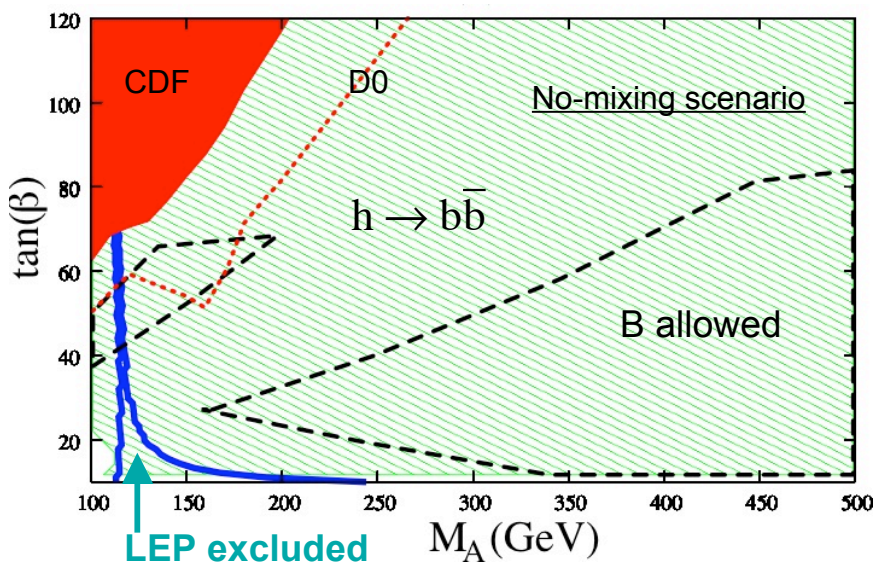
•The $m_h^{max}$ scenario: $M_S = 1$ TeV ; $X_t = 2.4\ M_S$ ; $m_{\tilde{g}} = -0.8\ M_S$ ; $M_2 = -\mu = 200$GeV; $A_t = A_b$

-- Maximizes $m_h$ and allows conservative tan beta bounds

-- $g_{hbb}, g_{h\tau\tau}$ enhanced due to $\sin\alpha_{eff}/\cos\beta$ factor for low $m_A$ and intermediate and large tan beta (analogous for H if $m_A < m_h^{max}$)

==> strong suppression of $h \rightarrow \gamma\gamma$




•The No-Mixing scenario: $X_t$=0, $M_S$= 2 TeV ==> lightest Higgs mass < 125 GeV

==> similar behavior for Higgs couplings to tau leptons, bottom quarks and photons.

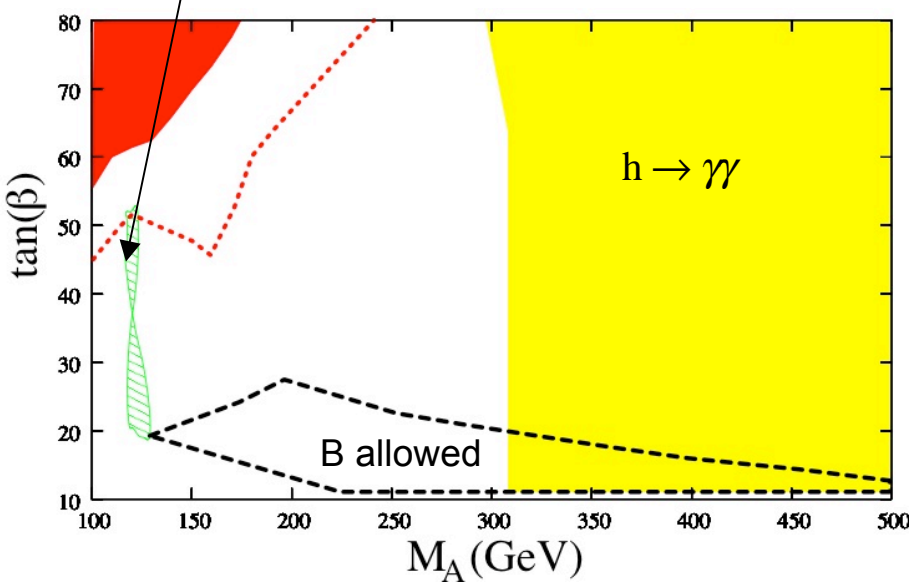
Tevatron may have sensitivity to discover all 3 MSSM neutral Higgs bosons

# Discovery reach for SM-like MSSM Higgs at the LHC with 30 fb-1

- The $m_h^{max}$ scenario: $M_S = 1\ \mathrm{TeV}$ ; $X_t = 2.4\ M_S$ ; $m_{\tilde{g}} = 0.8\ M_S$ ; $M_2 = -\mu = 200\mathrm{GeV}$; $A_t = A_b$

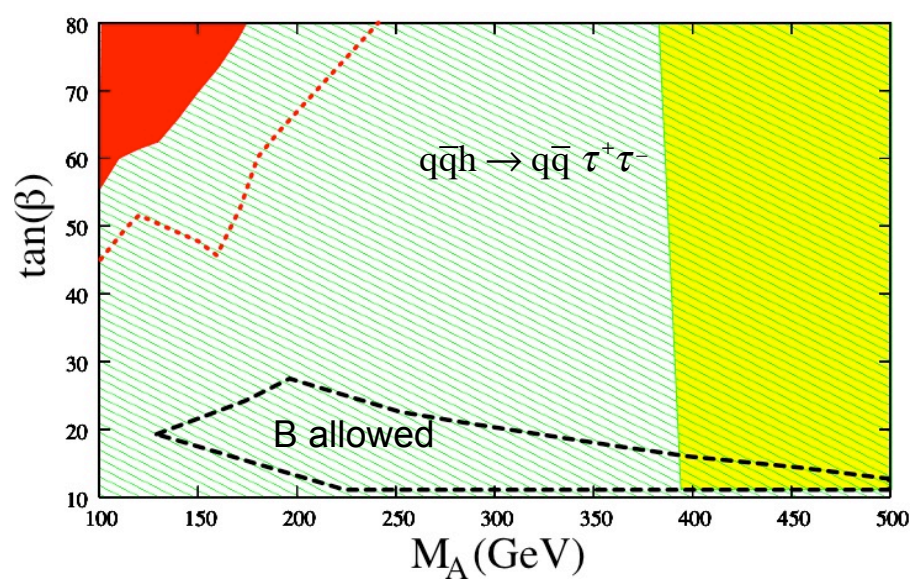
Production and decay channels: $q\bar{q}h \to q\bar{q}\ \tau^+\tau^-$ and $h \to \gamma\gamma$ inclusive

$q\bar{q}h \to q\bar{q}\ \tau^+\tau^-$ CMS Projections




ATLAS Projections

re-evaluating Higgs studies at present




First, full simulation analysis of qqH, H->ττ->l+jet,
Optimized $h \to \gamma\gamma$ Nikitenko, ICHEP 06

CMS can cover small part of B allowed region, with $h \to \gamma\gamma$ and $h \to \tau\tau$ ;

ATLAS tau tau channel seems to have full coverage with $h \to \tau\tau$

# Discovery reach for SM-like MSSM Higgs at the LHC

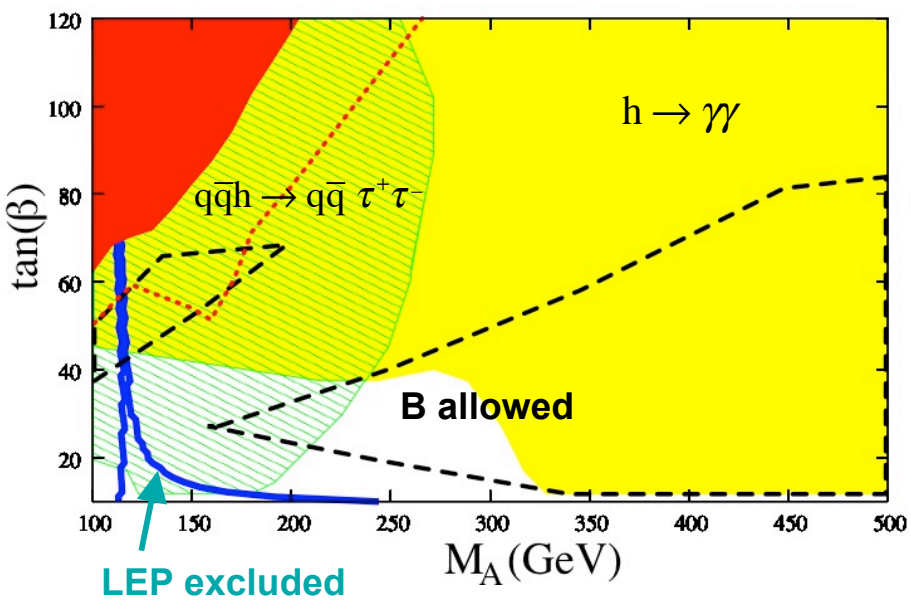
with 30 $fb^{-1}$

•The No mixing scenario:

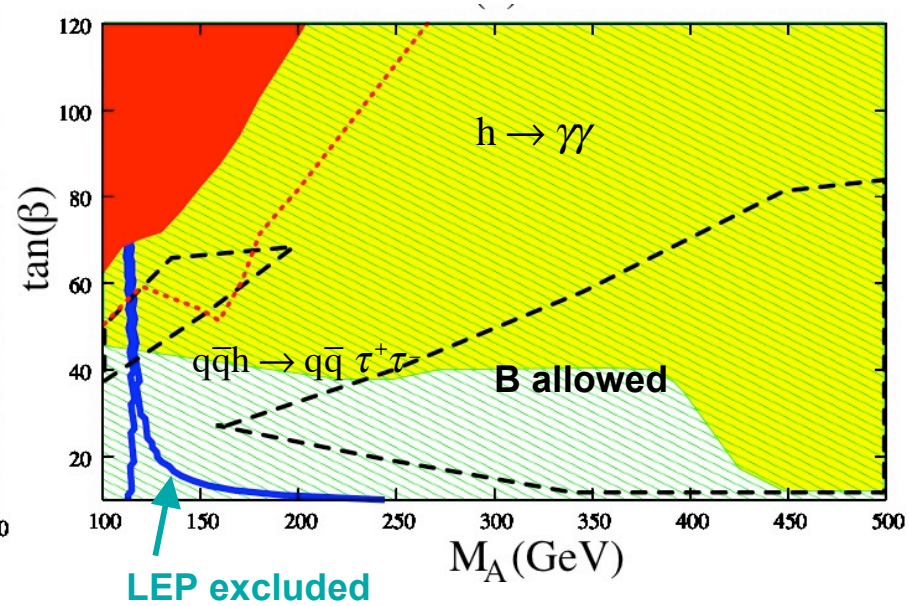
$$M_S = 2\ \text{TeV}\ ;\quad X_t = 0\ ;\ m_{\tilde{g}} = 0.8\ M_S\ ;\ M_2 = 200\text{GeV};\ A_t = A_b;\ \mu = 1.5\ \text{TeV}$$

Production and decay channels: $q\bar{q}h \to q\bar{q}\ \tau^+\tau^-$ and $h \to \gamma\gamma$ inclusive

CMS Projections




ATLAS Projections




SM-like Higgs needs di-tau and di-photon channels to secure discovery with 30 $fb^{-1}$
some B allowed regions remain uncovered

# Prospects for SM–like Higgs searches at Tevatron and LHC for:

- The small $\sin\alpha_{eff}$.(rad.correc.$\alpha$ ) scenario:

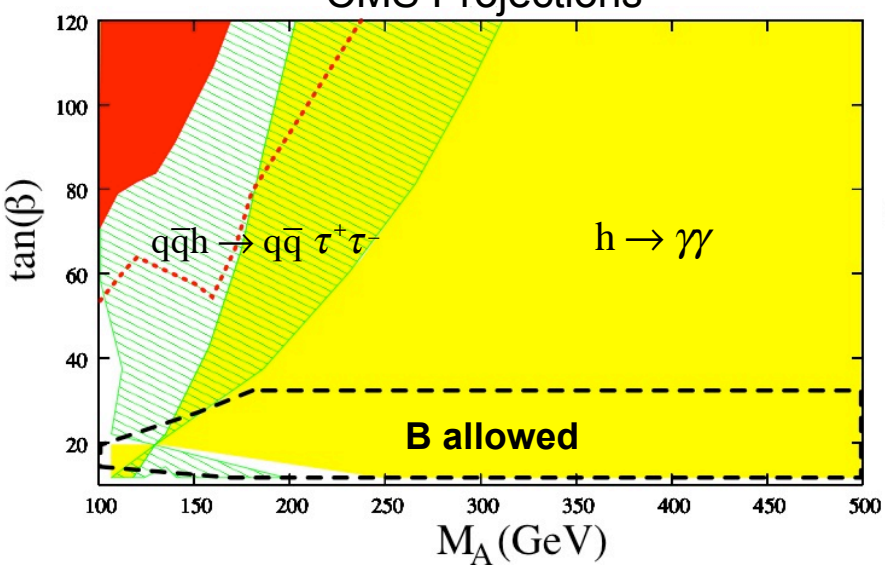
$$M_S = 800\ \text{GeV}\ ;\quad X_t = -\ 1.2\ \text{TeV}\ ;\ \mu = 2.5\ M_s\ ;\ m_{\tilde{g}} = M_2 = 500\text{GeV};\ \ A_t = A_b$$

==> $g_{hbb}$, $g_{h\tau\tau}$ importantly suppressed for large tan beta and small $m_A$, and in different ways due to $\Delta_b$ corrections

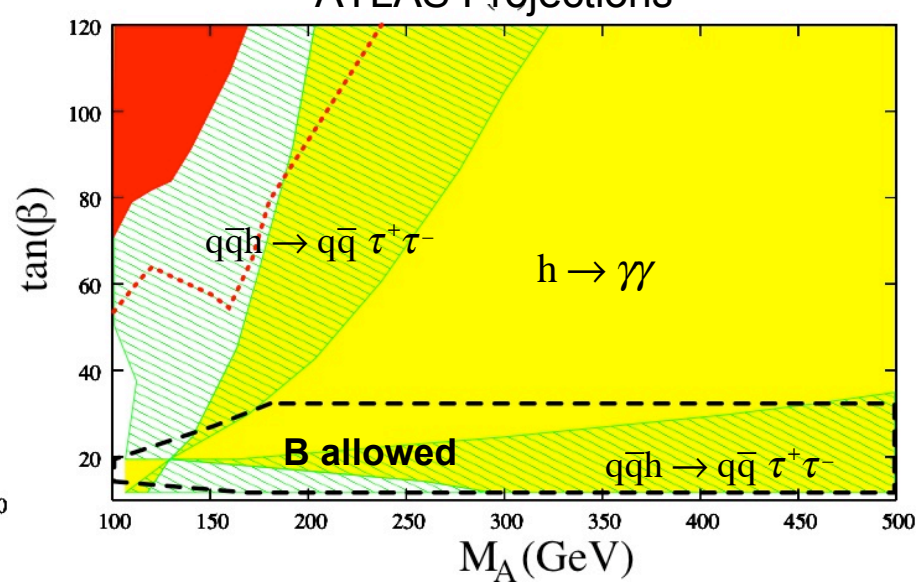
hence, $h \to \gamma\gamma$ channel enhanced with respect to SM

M.C., Menon. Wagner
Hep-ph/0704.1143

CMS Projections



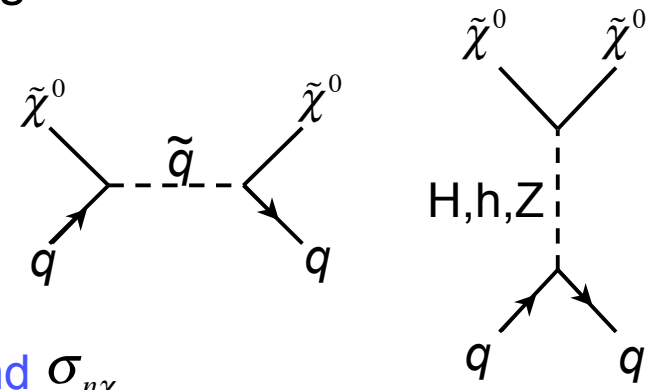

ATLAS Projections




-- The Tevatron has almost no chance due to the suppressed hbb coupling
-- LHC: Complementarity in coverage
-- One can see a SM-like Higgs in the $\gamma\gamma$ channel and not in the $\tau^+\tau^-$channel

# Direct Detection of WIMPs

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



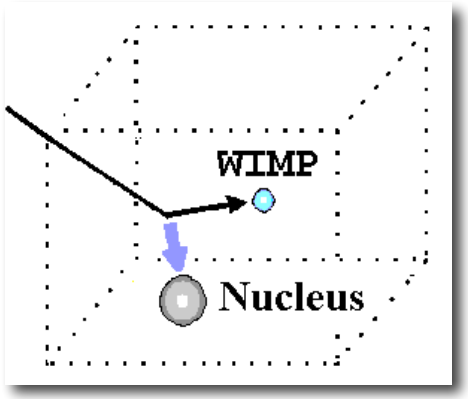

Main Ingredients to calculate signal:
Local density & velocity distribution of WIMPs and $\sigma_{n\chi}$
==> rate per unit time, per unit detector material mass

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

Scattering Cross section off nuclei averaged over relative wimp velocity

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

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

# Indirect searches for MSSM Higgs bosons via direct Dark Matter experiments

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

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

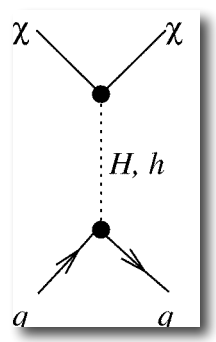
**But only Direct Detection Experiments will confirm the existence of Dark Matter particles**

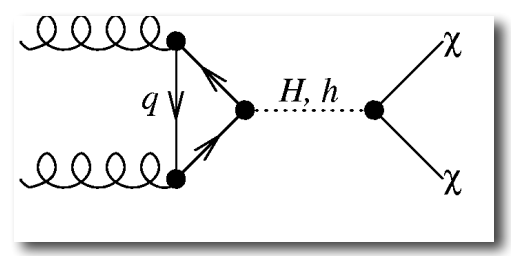
Direct DM experiments: CDMS, ZEPLIN, EDELWEISS, CRESST,WARP,…
sensitive mainly to spin-independent elastic scattering cross section $\longrightarrow \sigma_{SI} \leq 10^{-8}\, pb$

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

$\downarrow$

$\tan\beta$ enhanced couplings for H



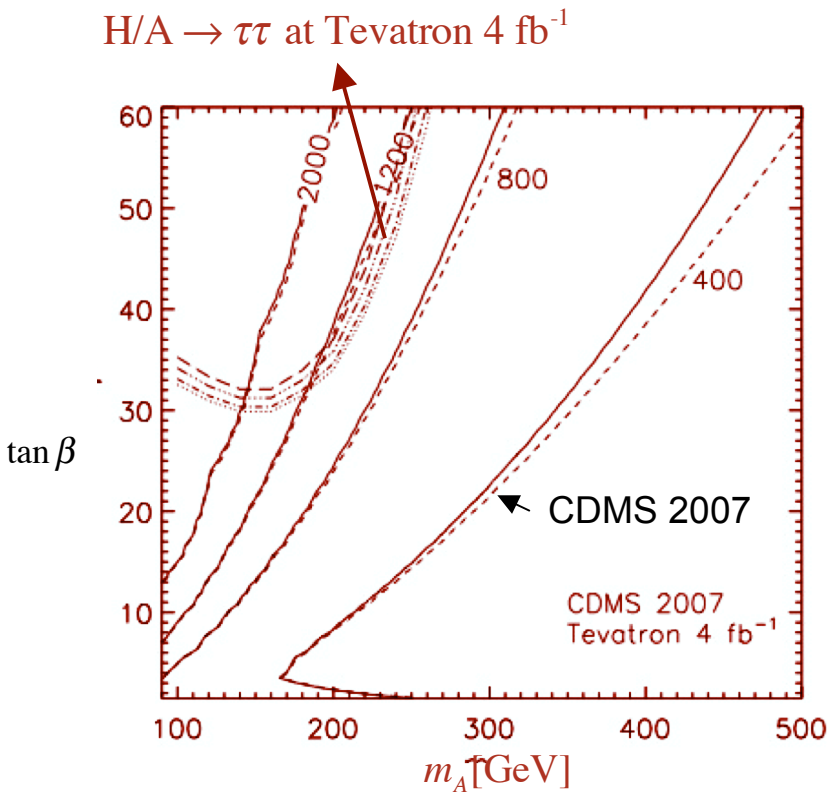



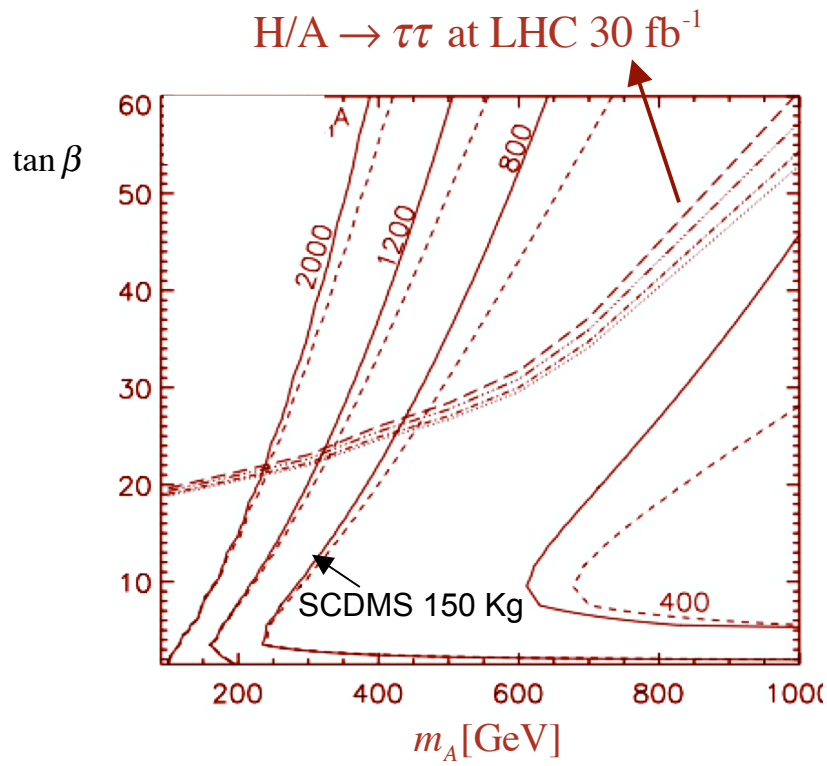
# Direct DM searches Vs the Tevatron and LHC H/A searches

Both MSSM Higgs searches and neutralino direct DM searches depend on $m_A$ and $\tan\beta$

For $\mu = 400, 800, 1200, 2000$ GeV

Smaller $\mu$ values imply larger Higgsino component of the LSP ==> larger $\sigma_{SI}$




**Direct detection of DM <==> detection of A/H at the Tevatron and LHC**

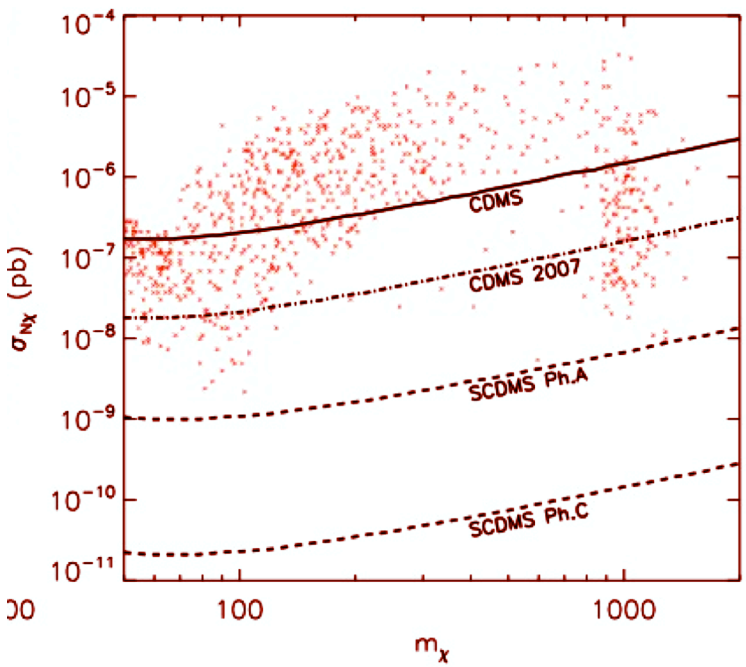
# CDMS DM searches Vs the Tevatron and LHC H/A searches

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

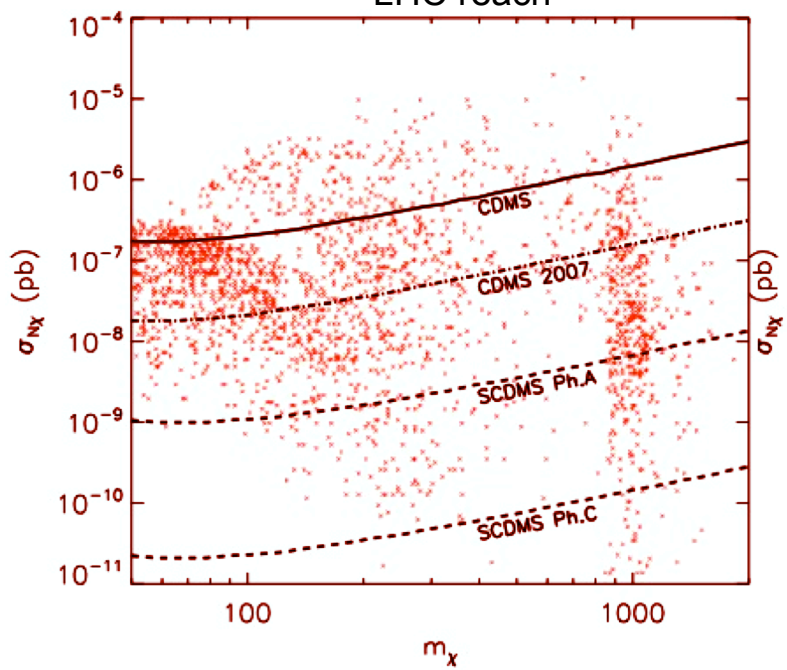
==> Evidence for H/A at the Tevatron (LHC) predict neutralino cross sections typically within the reach of present (future) direct DM detection experiments.

(strong $\mu$ dependence)

Tevatron reach




LHC reach



# Conclusions

- SUSY SM-like Higgs ==> strong variation in the discovery reach depending on SUSY parameter space via radiative corrections

  Complementarity of channels important for early Higgs discovery

- Other MSSM Higgs bosons ==> Need sizeable $\tan\beta$ enhancement for discovery

  $A/H \to \tau^+\tau^-$ and $H^\pm \to \tau\nu \to$ robust results under variation of SUSY space

  ↓

  moderate sensitivity to tan beta

- The Non-Standard MSSM Higgs searches at the LHC can be strongly constrained by B physics measurements depending on the SUSY parameter space.

- **Tevatron results will yield important information for the LHC**
  and may help to understand the type of Supersymmetry that may be realized in nature

**Supersymmetry is a leading candidate for a theory beyond the Standard Model**

**==>** it opens the possibility of a more complex Higgs structure
and connects Higgs physics with Flavor physics and Cosmology

# EXTRAS

# The flavor problem in SUSY Theories

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

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

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

$$\boxed{\text{recall } V_{CKM} = U_L^+ D_L}$$

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

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

- The diagonal entries are 3x3 matrices with $M_Q^2, M_D^2$ the soft SUSY breaking mass matrices and the rest proportional to the Yukawa or $\mathrm{I}$
- 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

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

# The Higgs Sector in Minimal Supersymmetric Standard Model

- 2 Higgs SU(2) doublets $\phi_1$ and $\phi_2$ :

  → 2 CP-even h, H with mixing angle $\alpha$ ,1 CP-odd A and a charged pair $H^{\pm}$

**At tree level**,

Masses and couplings given in terms of $m_A$ and $\tan\beta = v_2/v_1$

**Each Higgs doublet couples only to one type of quarks**

$$-L = \overline{\psi}_L^i \left( \hat{h}_d^{ij+} \phi_1 d_R^j + \hat{h}_u^{ij+} \phi_2 u_R^j \right) + h.c.$$

$$\overline{\psi}_L^i = \begin{pmatrix} \overline{u}_L \\ \overline{d}_L \end{pmatrix}^i$$

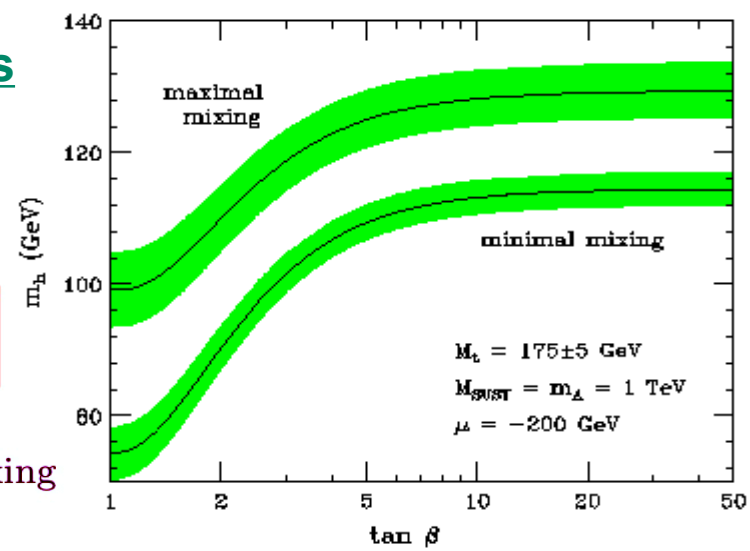
Up and down sectors diagonalized independently ==>Higgs interactions remain flavor diagonal.

## Radiative Corrections to Higgs Boson Masses

Important effects due to incomplete cancellation of particles and superparticles in the loops

$$m_h^2 = M_Z^2 \cos^2 2\beta + \frac{2\, g_2^2\, m_t^4}{8\pi^2\, M_W^2} \left[ \ln(M_S^2/m_t^2) + \frac{X_t^2}{M_S^2} \left( 1 - \frac{X_t^2}{12\, M_S^2} \right) \right]$$

$$M_S^2 = \tfrac{1}{2}(m_{\tilde{t}_1}^2 + m_{\tilde{t}_2}^2) \text{ and } X_t = A_t - \mu/\tan\beta \longrightarrow \text{stop mixing}$$




**After 2 -loop corrections** $m_h \leq 135\text{GeV}$ **==> stringent test of the MSSM**

Looking at $V_{CKM} \cong I \Rightarrow$ <u>Flavor Conserving Higgs-fermion couplings</u>

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

$$R^{33} = 1 + \left(\varepsilon_0^3 + \varepsilon_Y h_t^2\right)\tan\beta \equiv 1 + \Delta_b$$

In terms of h,H and A:

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

Hence:

$$g_{hbb} \approx \frac{-m_b \sin\alpha}{(1+\Delta_b)\, v \cos\beta}\left(1 - \Delta_b / \tan\alpha \tan\beta\right)$$

$$g_{Hbb} \approx \frac{m_b \cos\alpha}{(1+\Delta_b)\, v \cos\beta}\left(1 - \Delta_b \tan\alpha / \tan\beta\right)$$

$$g_{Abb} \approx \frac{m_b \tan\beta}{(1+\Delta_b) v}$$

M.C. Mrenna, Wagner

destroy basic relation

$$g_{h,H,Abb} / g_{h,H,A\,\tau\tau} \propto m_b / m_\tau$$

At large $\tan\beta \Rightarrow g_{Hbb} \approx g_{Abb}$

- <u>strong suppression</u> of coupling of $h$ $(H)$ to bottoms if

$\tan\alpha \simeq \Delta_b / \tan\beta \longrightarrow g_{h\,b\bar{b}} \simeq 0$ ; $g_{h\,\tau\tau} \simeq -\frac{m_\tau}{v}\Delta_b$ (similar for H)

$\Longrightarrow$ main decay modes of SM-like MSSM Higgs: $b\bar{b} \sim 80\%$ $\tau^+\tau^- \sim 7-8\%$

*drastically changed* $\Longrightarrow$ other decay modes enhanced

# B and Higgs Physics at the Tevatron and the LHC

explore complementary regions of SUSY parameter space

**Important Flavor Changing effects:** 1) tree level ==> charged Higgs induced via
2) tan beta enhanced loop corrections both in the neutral and charged Higgs sectors
==> model dependent ==> assume Minimal Flavor Violation

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

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

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

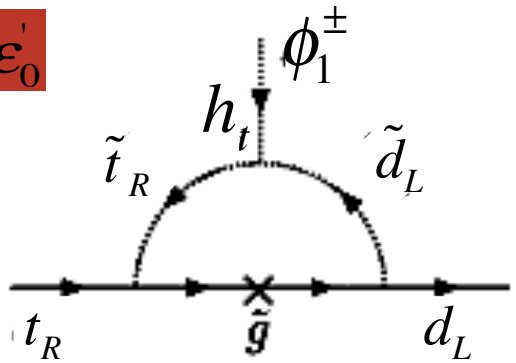
Example: case of universal soft SUSY squark mass parameters

$x_1^S, x_2^S$ are the components of the h, H and A in $\phi_1^0, \phi_2^0$
==> $\tan\beta^2$ enhanced coupling for H/A or h/A, depending on value of $m_A$

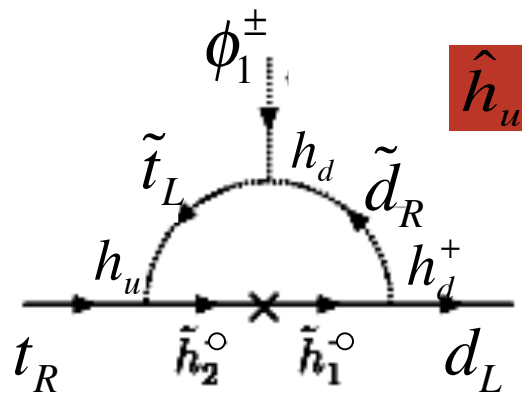
# Flavor Changing in the charged Higgs coupling

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

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




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




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

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

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

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

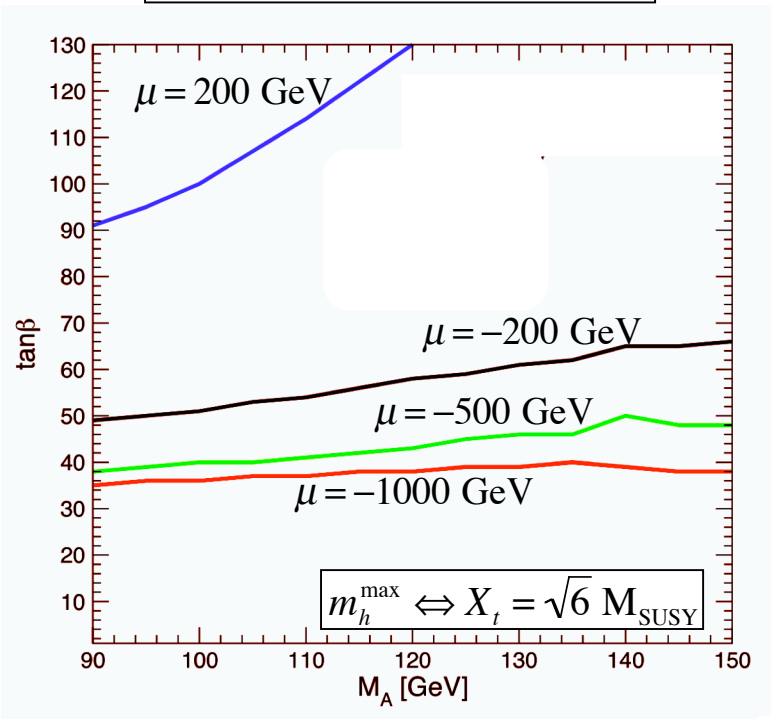
This type of corrections are most important in constraining new physics from $B \to X_S\gamma$ and $B_u \to \tau\nu$

# Searches for Non-Standard Higgs bosons at the Tevatron

A) In the bb mode $p\bar{p} \to b\bar{b}\phi, \quad \phi \to b\bar{b}$

==> probe large region of $\tan\beta - m_A$ plane

$\Rightarrow$ based on D0 $\to 260\text{pb}^{-1}$




- Enhanced reach for negative values of $\mu$
- Strong dependence on SUSY parameters

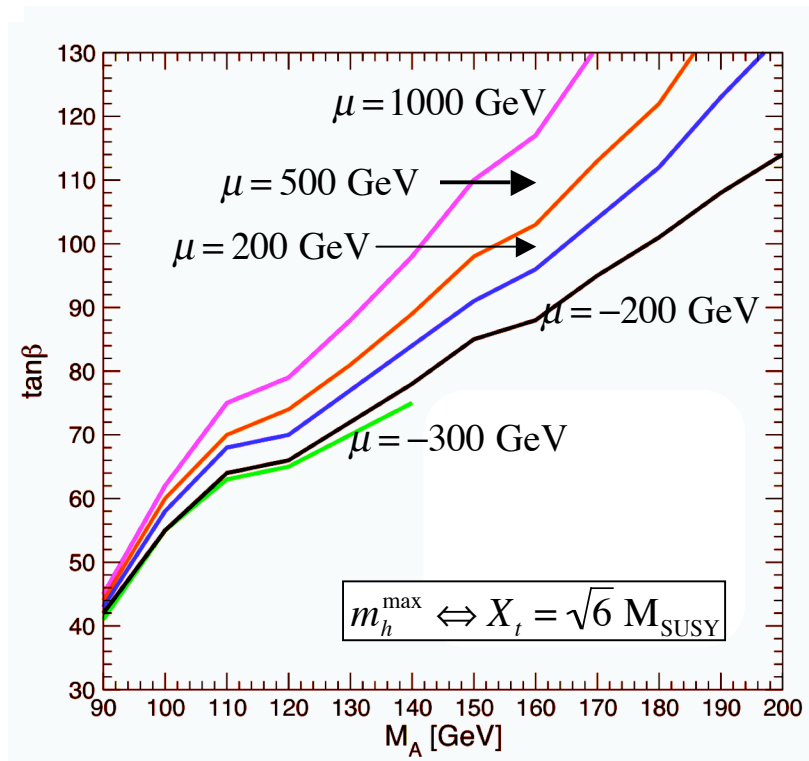
$$\sigma(b\bar{b}\phi)BR\left(\phi \to b\bar{b}\right) \propto 1/\left(1+\Delta_b\right)^2$$

$$\Rightarrow \text{enhanced for } \Delta_b < 0 \;\Leftrightarrow\; \mu < 0 \;\; (\text{if } A_t \text{ and } M_{\tilde{g}} > 0)$$

B) In the tau tau inclusive mode

$$p\bar{p} \to X\phi, \quad \phi \to \tau^+\tau^-$$

$\Rightarrow$ based on CDF : $310\text{pb}^{-1}$

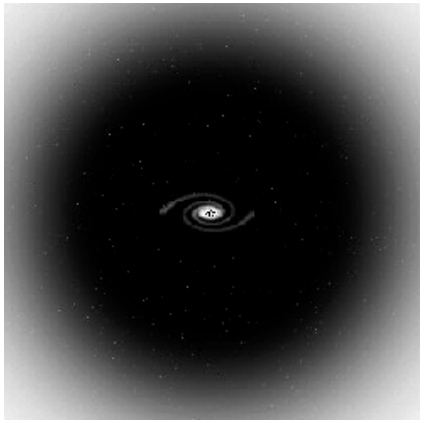



- Important reach for large tanb, small $m_A$
- Weaker dependence on SUSY parameters via radiative corrections

M. C., Heinemeyer, Wagner,Weiglein '05

# Indirect searches for MSSM Higgs bosons via direct Dark Matter experiments

Dark Matter: one of the fundamental open questions
==> demands new physics



- **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 ==> $\tilde{\chi}^0$

$$\Omega_{CDM} \sim 1 \,/\, \int_0^{x_F} \langle \sigma_A \, v \rangle \, dx \qquad x \equiv \frac{M}{T}$$

$0.089 < \Omega_{CDM} h^2 < 0.131$ WMAP at 3 $\sigma$

Many processes contribute to the $\tilde{\chi}_1^0 \, \tilde{\chi}_1^0$ annihilation cross section: $\langle \sigma_A \, v \rangle$

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

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**

# Conclusions (continued)

- **The Non-Standard MSSM Higgs searches at the Tevatron and the LHC can be strongly constrained by B physics measurements depending on the SUSY parameter space.**

-- sizeable LR stop mixing <==> small/moderate mu ==> B searches more powerful

-- small stop mixing (Xt≈0) and large Higgsino mass parameter $\mu$
==> good for the Tevatron ==> has sensitivity to discover all 3 MSSM neutral Higgs bosons

-- increasing the stop mixing for sizeable mu
==> Tevatron A/H searches become marginal, but excellent window of opportunity for LHC

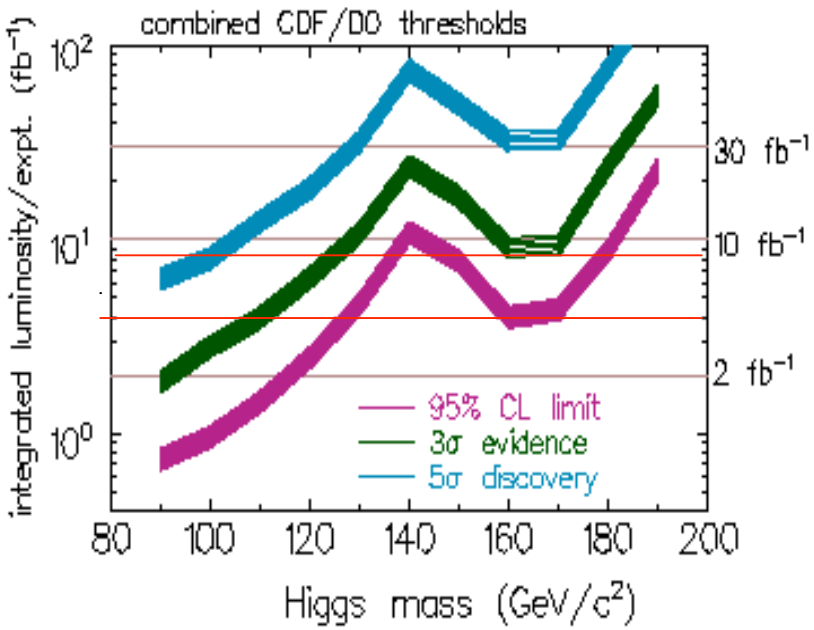
- **Tevatron results will yield important information for the LHC**

-- Non-observation of $B_s \to \mu^+\mu^-$ at the Tevatron ==> reduced parameter space for non-Standard MSSM Higgs searches at the LHC, specially for large $X_t$ and $\mu < 0$

-- Discovery of H/A at the Tevatron, without positive results from leptonic rare Bs decay ==> small $X_t$ an large $\mu$ or Deviations from MFV

•**Tevatron can search for a Higgs in parts of the mass range preferred by precision data**

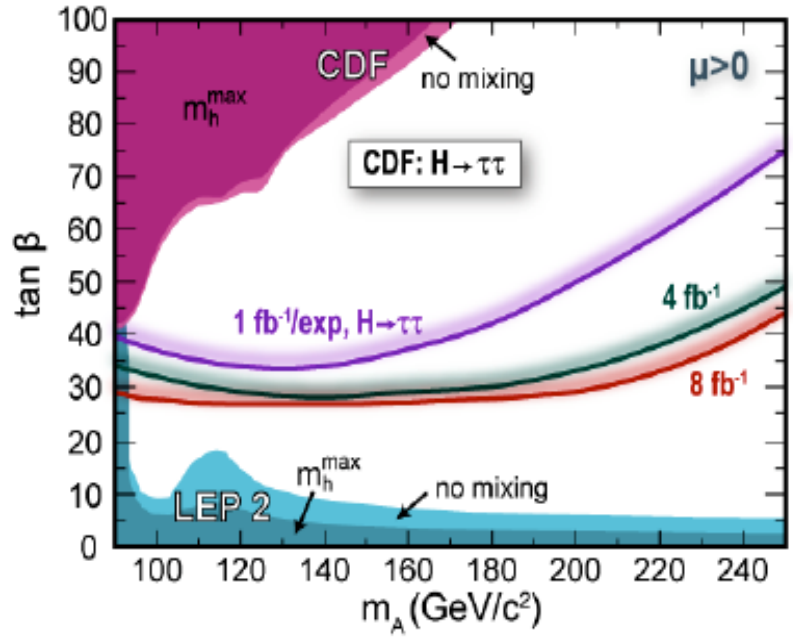
$$p\bar{p} \to V\,H \to Vb\bar{b} \quad \text{with } V = W, Z$$



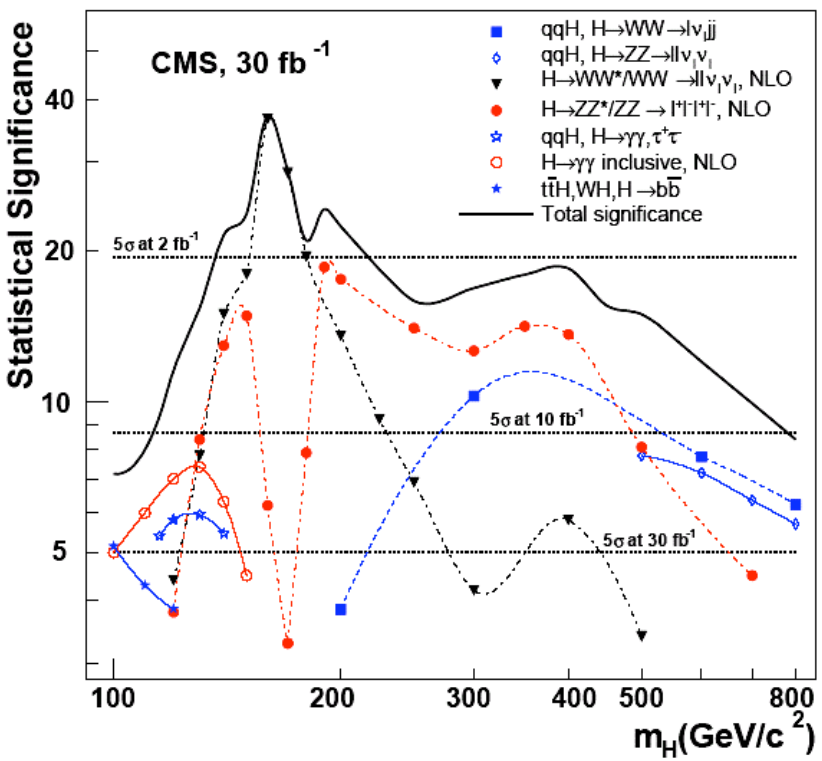

Quite challenging! Evidence of a signal will mean that the Higgs has strong (SM-like) couplings to W and Z

Heavy neutral MSSM Higgs searches

- **pp → Ab+X → bbb+X**
- **pp → A+X → ττ +X**

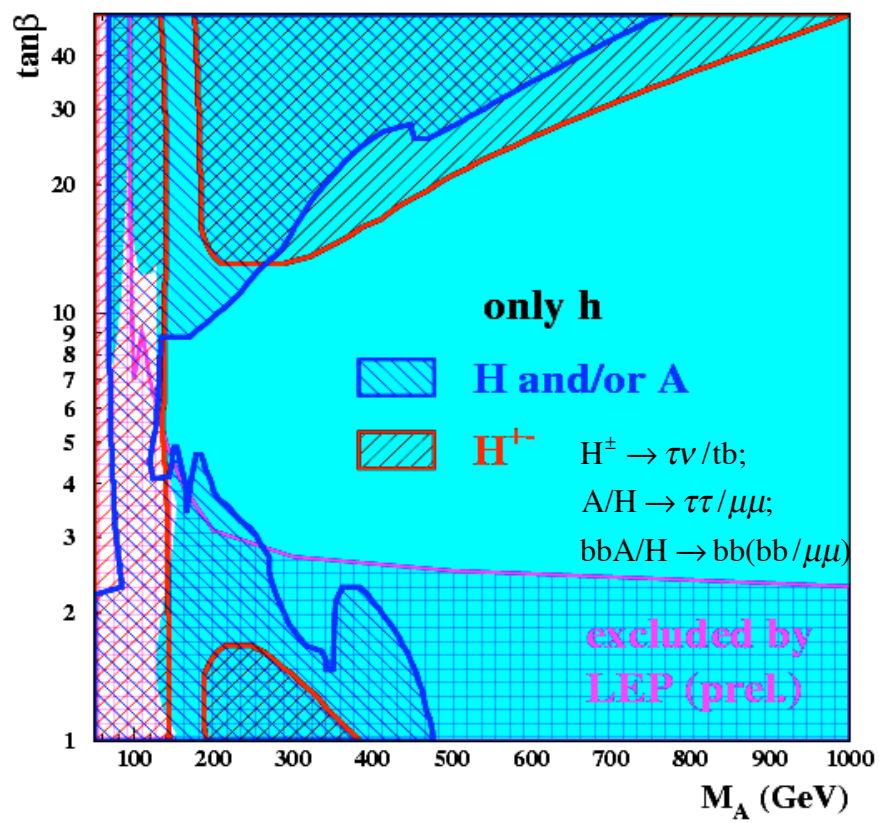


- LHC can search for a Higgs via many channels, already in the first few years

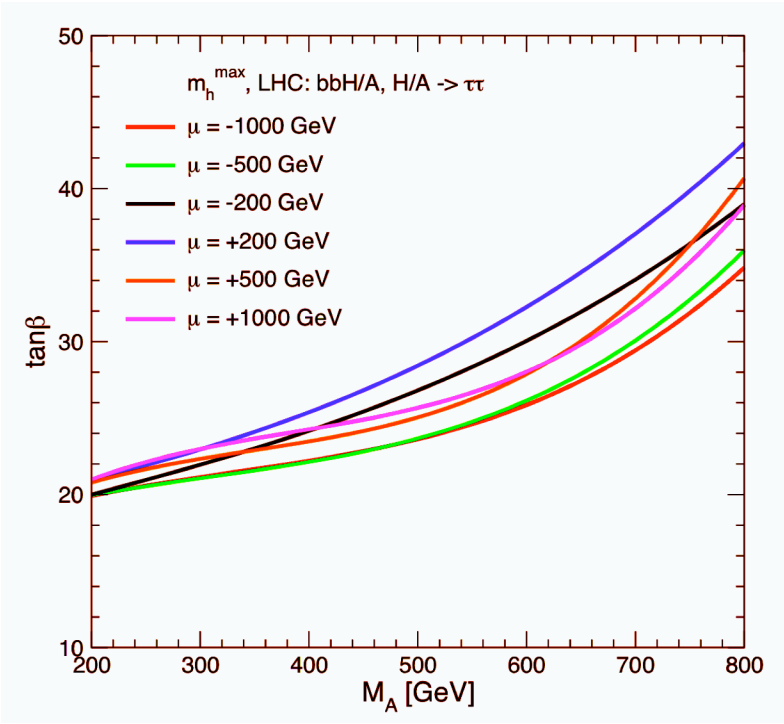


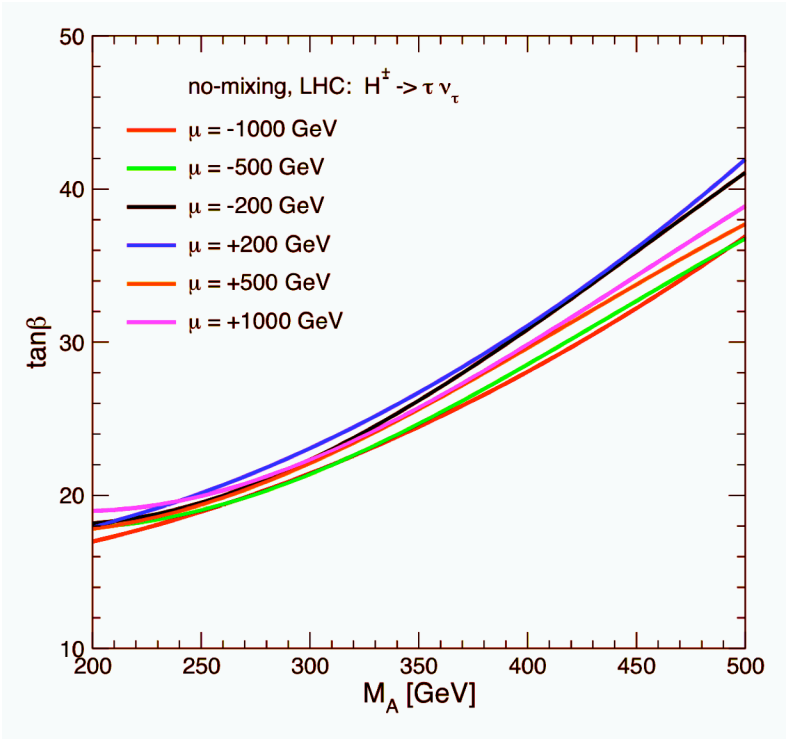

- Many SUSY Higgs production and decay processes accessible with full LHC potential

ATLAS and CMS with 300fb$^{-1}$

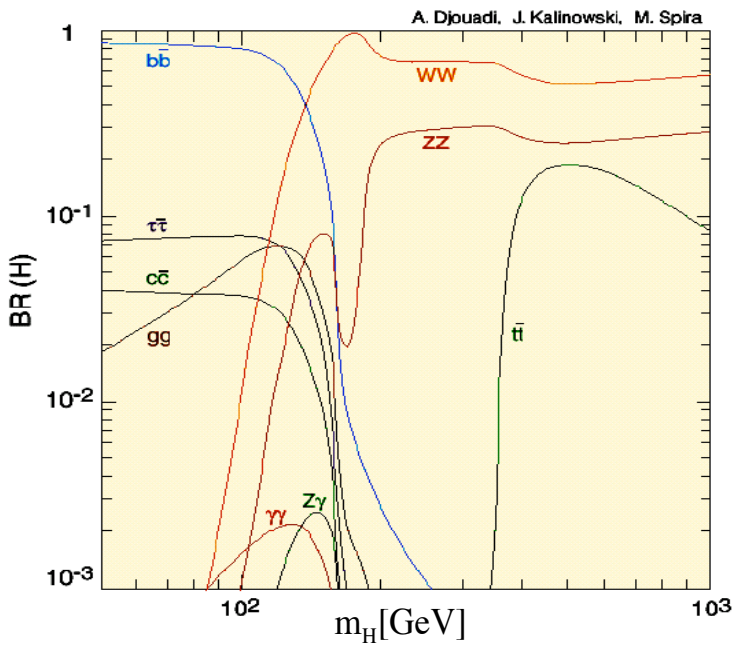



Still regions where only a SM-like Higgs is visible

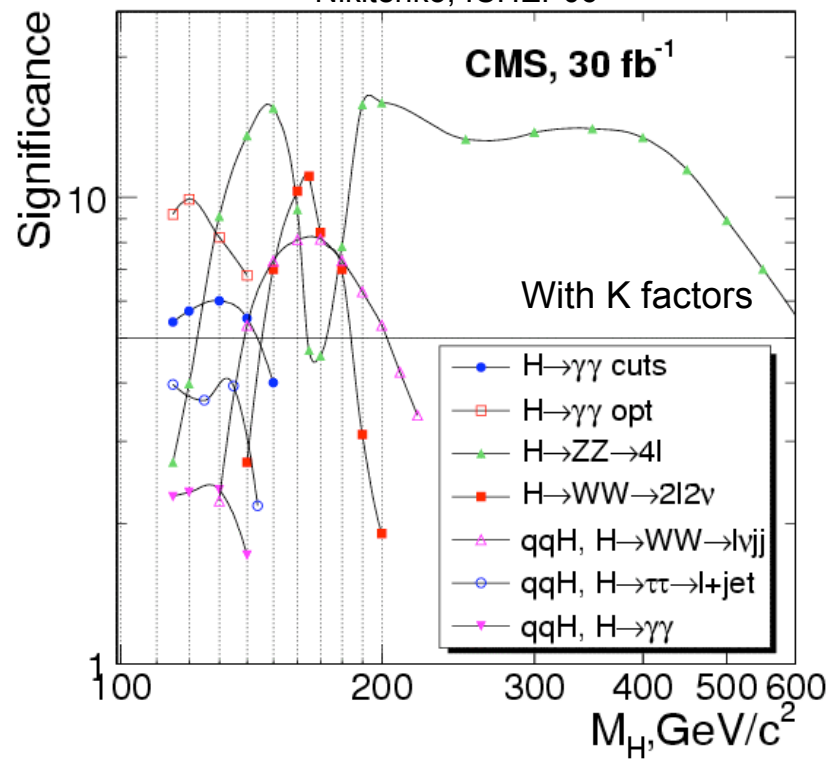

$m_h^{max}$, LHC: bbH/A, H/A -> ττ
μ = -1000 GeV
μ = -500 GeV
μ = -200 GeV
μ = +200 GeV
μ = +500 GeV
μ = +1000 GeV
tanβ
$M_A$ [GeV]
50
40
30
20
10
200
300
400
500
600
700
800


no-mixing, LHC: $H^{\pm}$ -> τ $\nu_\tau$
μ = -1000 GeV
μ = -500 GeV
μ = -200 GeV
μ = +200 GeV
μ = +500 GeV
μ = +1000 GeV
tanβ
$M_A$ [GeV]
50
40
30
20
10
200
250
300
350
400
450
500

# Search Channels for the SM Higgs at the LHC




Nikitenko, ICHEP06

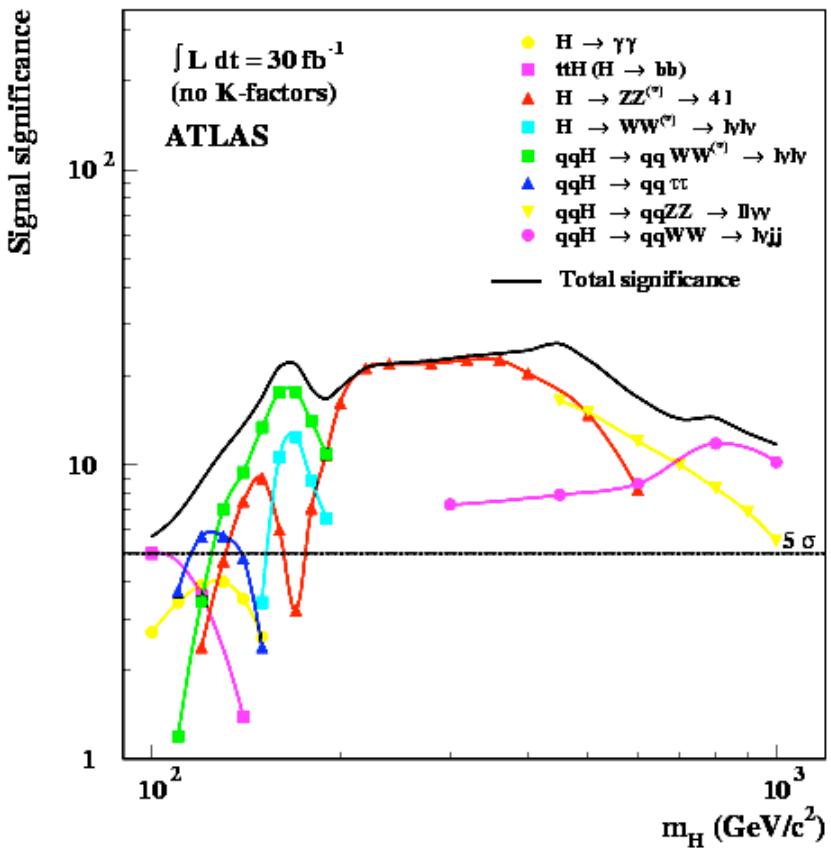


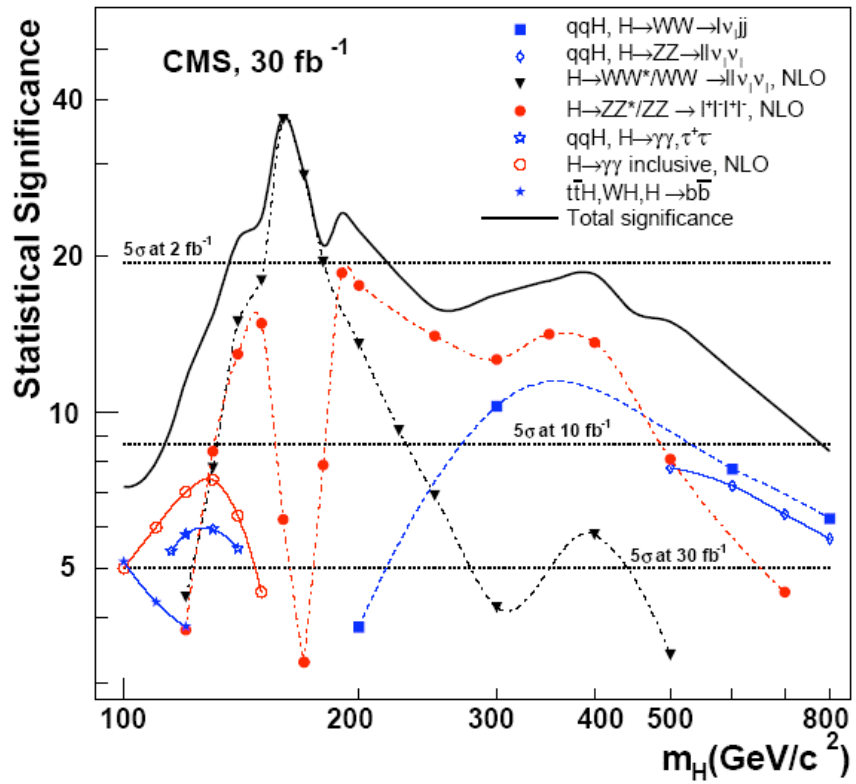

- **Low mass range** $m_H$ < 200 GeV

| Production<br>DECAY | Inclusive | VBF | WH/ZH | ttH |
|---|---|---|---|---|
| $H \rightarrow \gamma\gamma$ | YES | YES | YES | YES |
| $H \rightarrow bb$ | | | YES | YES |
| $H \rightarrow \tau\tau$ | | YES | | |
| $H \rightarrow WW^*$ | YES | YES | YES | |
| $H \rightarrow ZZ^*, Z \rightarrow l^+l^-$ | YES | | | |

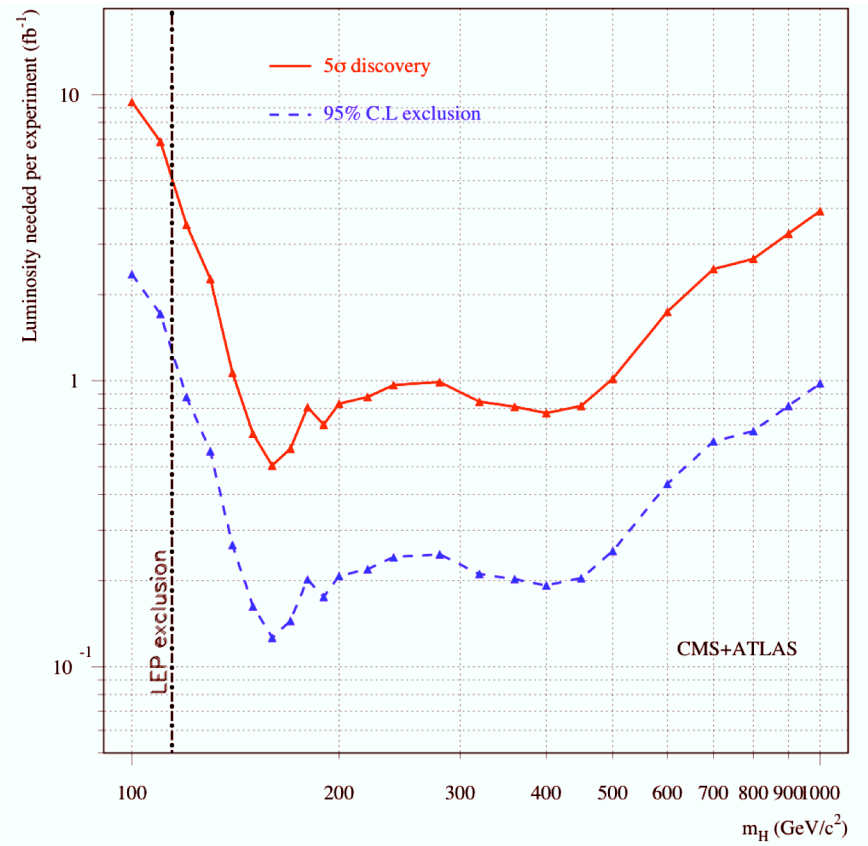
- **Intermediate mass range**
  200 GeV < $m_H$< 700 GeV
  Inclusive H ==>ZZ-->4l

- **Large mass range**: $m_H$> 700 GeV
  VBF with H ==>WW==>lν jj
  ZZ ==>ll νν


Signal significance
∫L dt = 30 fb-1
(no K-factors)
ATLAS
H → γγ
ttH (H → bb)
H → ZZ(*) → 4 l
H → WW(*) → lνlν
qqH → qq WW(*) → lνlν
qqH → qq ττ
qqH → qqZZ → llνν
qqH → qqWW → lνjj
Total significance
5 σ
10 2
10
1
10 2
10 3
m_H (GeV/c2)


Statistical Significance
CMS, 30 fb -1
qqH, H→WW→lνjjj
qqH, H→ZZ→llνlνl
H→WW*/WW →llνlνl, NLO
H→ZZ*/ZZ → l+l-l+l-, NLO
qqH, H→γγ,τ+τ-
H→γγ inclusive, NLO
tt̄H,WH,H →bb̄
Total significance
5σ at 2 fb-1
5σ at 10 fb-1
5σ at 30 fb-1
40
20
10
5
100
200
300
400
500
800
mH(GeV/c 2)

# The LHC potential




Total sensitivity combining all channels plus two experiments

5 $\sigma$ discovery possible over the entire SM Higgs mass range of interest with 5 fb-1 (?)

==> For $m_H$~120 GeV combination of many different channels necessary, hence, requires a good understanding of the detectors.

==> The Tevatron may explore such region

**Higgs mass resolution**: 0.1 to 1%, combining most channels for 300 fb-1 and both experiments, using H-->ZZ--> 4l or H-->gamma gamma

**Total Width resolution**: 5-8 % for $m_H$ > 300 GeV, ATLAS 300 fb-1, H-->ZZ--> 4l