Decays of MSSM Higgs in Flavour-Changing Quark Channels

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Work based on:

A. M. C., M. J. Herrero and D. Temes,
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A. M. C., M. J. Herrero, W. Hollik, F. Merz and S. Peñaranda,
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ElectroWeak Interactions and Unified Theories, 2004

Motivation

- 1^{st} step in Supersymmetry search $\rightarrow$ Direct search
- Indirect search $\rightarrow$ SUSY particle contributions via Radiative corrections
  - If SUSY particles are too heavy
  - Succesful method while searching for Top
- Flavour changing Higgs boson decays FCHD
  - Processes very supressed in the SM
  - New contributions at 1-loop $\longrightarrow$ Distinguish between the SM and possible new physics
- Study $\left\{ \begin{array}{l} Br(h_0, H_0, A_0 \rightarrow b\bar{s}, s\bar{b}) \\ Br(H_0, A_0 \rightarrow t\bar{c}, c\bar{t}) \end{array} \right.$ $\longrightarrow$ larger in the MSSM
- Full diagrammatic approach valid for:

  $\left\{ \begin{array}{l} \text{All SUSY-QCD and SUSY-EW loop contributions} \\ \text{All } \tan\beta \text{ values} \\ \text{All values of } \lambda \end{array} \right.$
- Appear Non decoupling effect of SUSY

MSSM spectrum

- The Minimal Supersymmetric Model (MSSM) spectrum

Particles extended SM	SUSY Particles
q, l Fermions	$\tilde{q}_L, \tilde{q}_R, \tilde{l}_L, \tilde{l}_R$ Sfermions
V Gauge Bosons	$\tilde{V}$ Gauginos
g Gluons	$\tilde{g}$ Gluinos
H_1, H_2 Higgs bosons	$\tilde{H}_1, \tilde{H}_2$ Higgsinos

- Higgs Sector

(a) Made from 2 doublets that generate 5 physical particles

- 2 neutral scalars h^o y H^o
- 1 neutral pseudoscalar A^o
- 2 charged scalars $H^\pm$

(b) New free parameters: M_A, $M_{H^\pm}$, α, v_1, v_2, $\tan\beta = v_2/v_1$, ... $\rightarrow$ only 2 independent: M_A and $\tan\beta$

(c) Due to supersymmetry

- $M_{h^o} < M_Z|\cos 2\beta|$ at tree - level
- $M_{h^o} \leq 135$ GeV with radiative corrections

Induced FCHD from two sources

1. CKM mixing⇒ Quark-Squark-Chargino.
2. Misalignment between quark and squark mass matrices ⇒ Quarks and squarks are not flavour diagonal at the same time

   ⇒FCHD mediated by loops with vertices

$$\text{Quark - Squark -} \begin{cases} \text{Gluino} \\ \text{Neutralino} \\ \text{Chargino} \end{cases}$$

- We rotate quarks and squarks to the physical basis

$$q_i = \Sigma V_{ij} q_j^{'}$$
$$\tilde{q}_i = \Sigma \tilde{U}_{ij} \tilde{q}_j^{'} \, , \, \tilde{U} \neq V$$

- Ex. Vertices Quark - Squark - Gluino change flavour

$$\mathcal{L} = g_s \tilde{g} \Sigma q_i^{'} \tilde{q}_i^{'*} + h.c$$
$$\sim g_s \tilde{g} \Sigma \left(\tilde{U} V^{\dagger} \right)_{lj} q_j \tilde{q}_l^{*} + h.c$$

- The most general scenario
- $q\tilde{q}\tilde{g}$ Are the most relevant $\rightarrow \alpha_S$

Non-diagonal flavour squark mixing

- After diagonalization of quark matrices, squark matrices still non-diagonal

$$\tilde{q}'_\alpha = \sum R^{(q)}_{\alpha\beta} \tilde{q}_\beta \,,$$

$$\tilde{u}'_\alpha = \begin{pmatrix} \tilde{c}_L \\ \tilde{c}_R \\ \tilde{t}_L \\ \tilde{t}_R \end{pmatrix} \,,\; \tilde{d}'_\alpha = \begin{pmatrix} \tilde{s}_L \\ \tilde{s}_R \\ \tilde{b}_L \\ \tilde{b}_R \end{pmatrix}, \tilde{u}_\alpha = \begin{pmatrix} \tilde{u}_1 \\ \tilde{u}_2 \\ \tilde{u}_3 \\ \tilde{u}_4 \end{pmatrix} \,,\; \tilde{d}_\alpha = \begin{pmatrix} \tilde{d}_1 \\ \tilde{d}_2 \\ \tilde{d}_3 \\ \tilde{d}_4 \end{pmatrix}$$

- Parametrization of non-diagonal squark mass matrices:

$$M^2_{\tilde{u}} = \begin{pmatrix} M^2_{L,c} & X_c & \Delta^u_{LL} & 0 \\ X_c & M^2_{R,c} & 0 & 0 \\ \Delta^u_{LL} & 0 & M^2_{L,t} & X_t \\ 0 & 0 & X_t & M^2_{R,t} \end{pmatrix}$$

$$M^2_{\tilde{d}} = \begin{pmatrix} M^2_{L,s} & X_s & \Delta^d_{LL} & 0 \\ X_s & M^2_{R,s} & 0 & 0 \\ \Delta^d_{LL} & 0 & M^2_{L,b} & X_b \\ 0 & 0 & X_b & M^2_{R,b} \end{pmatrix}$$

$$\begin{aligned} M^2_{L,q} &= M^2_{\tilde{Q},q} + m^2_q + \cos 2\beta (T^q_3 - Q_q s^2_W) m^2_Z \,, \\ M^2_{R,(c,t)} &= M^2_{\tilde{U},(c,t)} + m^2_{c,t} + \cos 2\beta Q_t s^2_W m^2_Z \,, \\ M^2_{R,(s,b)} &= M^2_{\tilde{D},(s,b)} + m^2_{s,b} + \cos 2\beta Q_b s^2_W m^2_Z \,, \\ X_{c,t} &= m_{c,t}(A_{c,t} - \mu \cot\beta) \,,\; X_{s,b} = m_{s,b}(A_{s,b} - \mu \tan\beta) \,, \end{aligned}$$

$$\Delta^u_{LL} = \lambda M_{L,c} M_{L,t} \,,\; \Delta^d_{LL} = \lambda M_{L,s} M_{L,b}$$

$$0 \le \lambda \le 1 \,,\; \Delta_{LL} >> \Delta_{LR} >> \Delta_{RR}$$

Constraints on the Flavour Mixing Parameters

$(\lambda_{23})_{LL}$ not very constrained by experiments

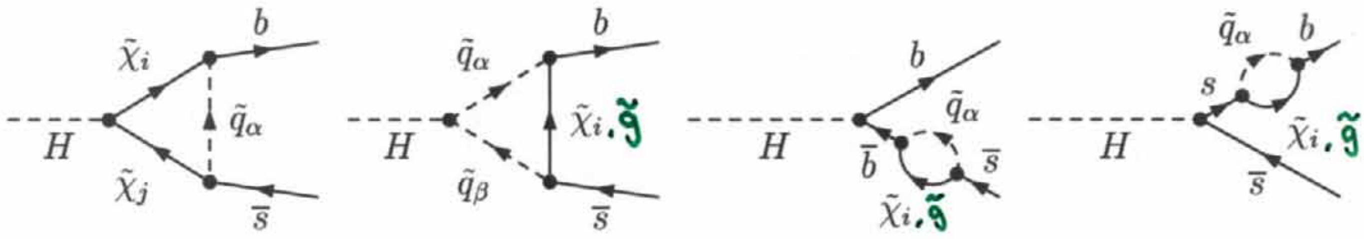
Experimental constraints:

Constraints	Processes
$(\lambda^d_{12})_{LL,RR} < \mathcal{O}(10^{-2})$	$K^o - \bar{K}^o,\ K_L \to \mu^+\mu^-$
$(\lambda^d_{12})_{LR,RL} < \mathcal{O}(10^{-3})$	$K^o - \bar{K}^o$
$(\lambda^d_{13})_{LL,RR} < \mathcal{O}(10^{-1})$	$B^o_d - \bar{B}^o_d,\ B_d \to \mu^+\mu^-$
$(\lambda^d_{13})_{LR,RL} < \mathcal{O}(10^{-2})$	$B^o_d - \bar{B}^o_d$
$(\lambda^d_{23})_{LL,RR} < \mathcal{O}(1)$	$b \to s\gamma,\ B^o_s - \bar{B}^o_s,\ B_s \to \mu^+\mu^-$
$(\lambda^d_{23})_{LR,RL} < \mathcal{O}(10^{-2})$	$b \to s\gamma,\ B^o_s - \bar{B}^o_s$
$(\lambda^u_{12})_{LL} < \mathcal{O}(10^{-1})$	$D^o - \bar{D}^o$

For review see ex.: F. Gabbiani, *et. al*, Nucl. Phys.B477, 321 (1996). G. Isidori and A. Retico, JHEP0209, 063 (2002).

SUSY contributions to FCHD

- Diagrams for $H \to b\bar{s}$



- All SUSY-QCD and SUSY-EW loops considered

$$iF = -ig\bar{u}_q(p_1)(F_L^{qq'}(H)P_L + F_R^{qq'}(H)P_R)v_{q'}(p_2)H(p_3)$$

- We compute all the form factors $F^{qq'}_{L,R}(H_a)$. We find:

$\Rightarrow$ Renormalization is not needed because the process doesn't exist at tree - level $\longrightarrow$ Final result is finite.

$\Rightarrow$ $\tan\beta$ explicit dependence in the squarks mixing $L-R$ that preserves flavour.

$\Rightarrow$ Effect on the SUSY-QCD width $\mathcal{O}(\alpha_S^2)$

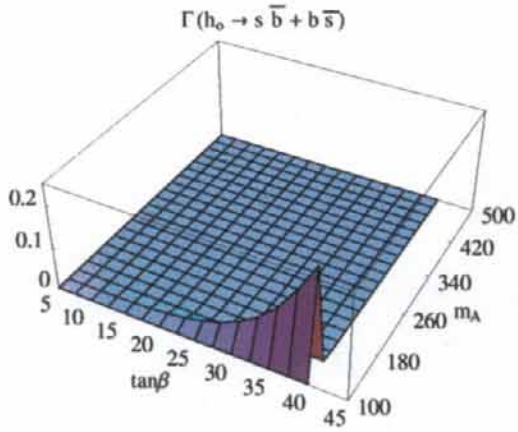
$\Rightarrow$ λ enters in rotation matrices and physical squark masses.

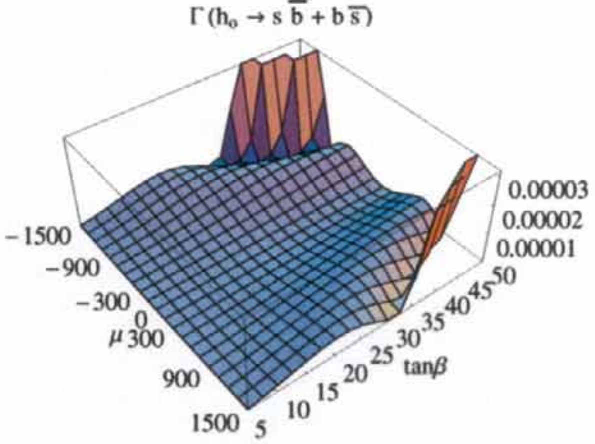
$\Rightarrow$ Phenomenological analysis on the MSSM parameter dependences needed

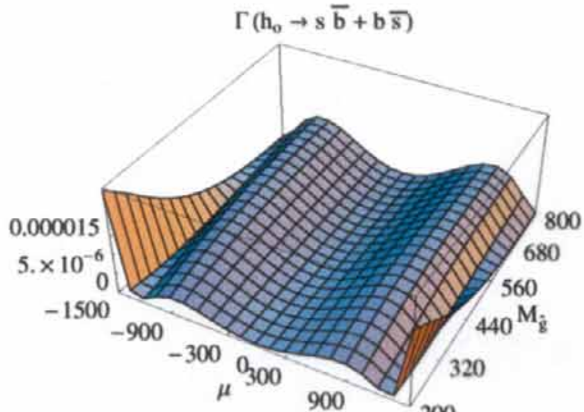
1. Study sizes numerically
2. Parameter region that maximizes the effect
3. Study full behaviour with λ and for all $\tan\beta$ values

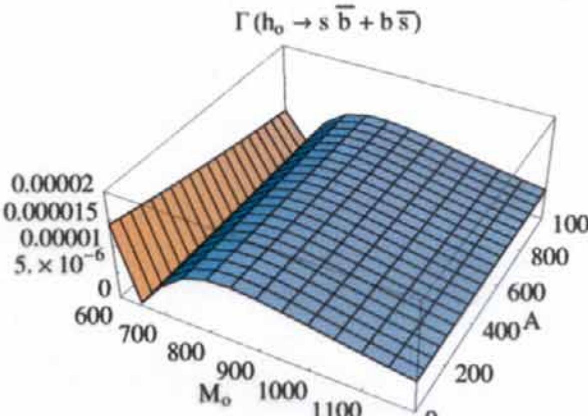
Numerical results for $h_o \to b\bar{s}, s\bar{b}$

SUSY-QCD contribution

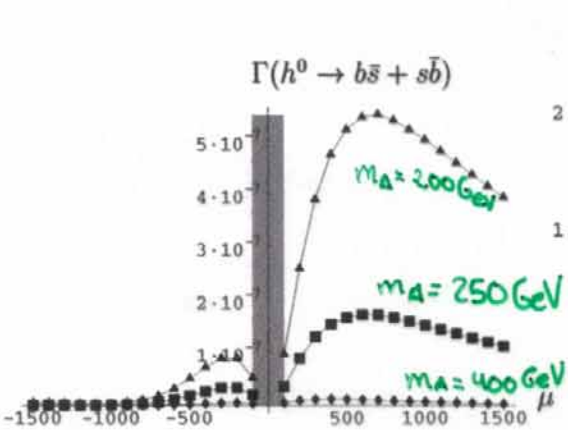


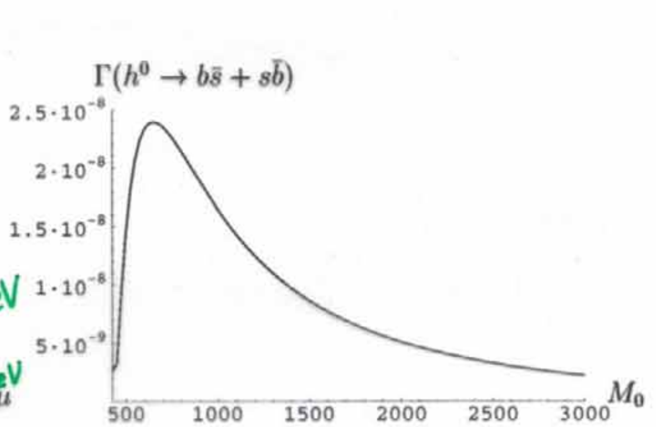






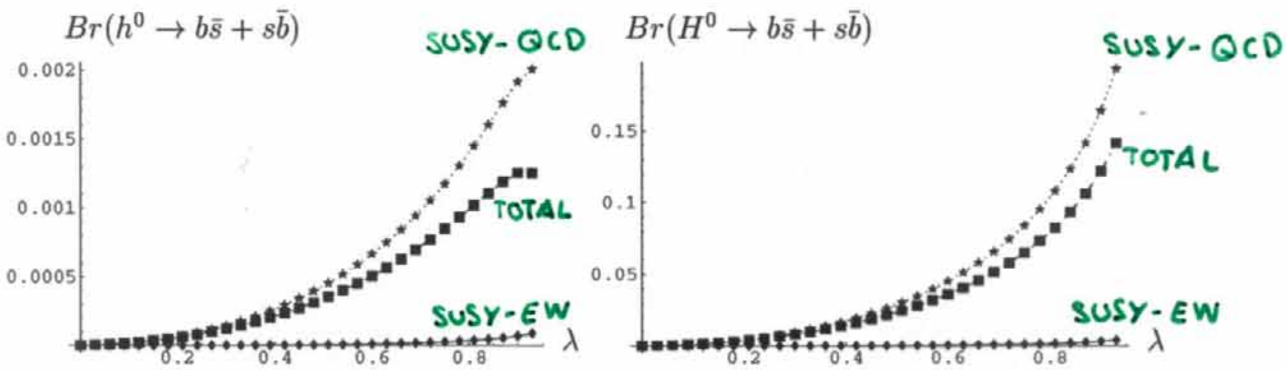
SUSY-EW contribution



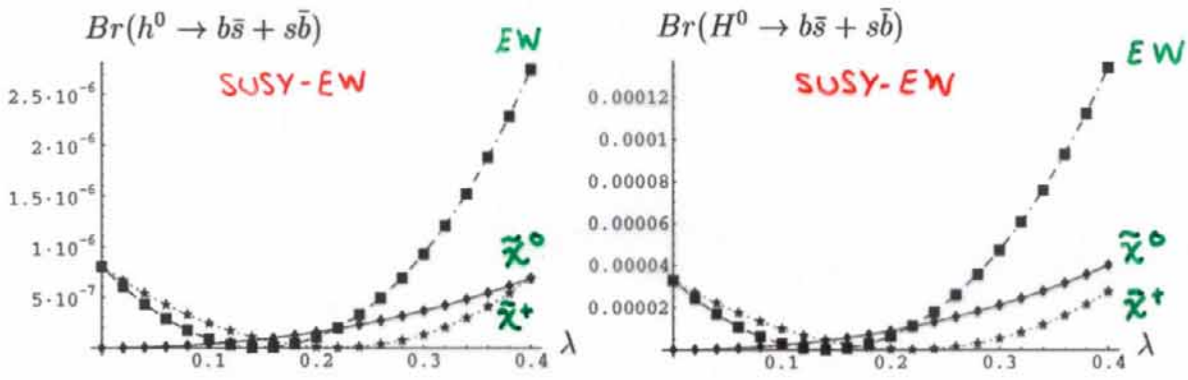


Analysis of $Br(H \to b\bar{s} + s\bar{b})$ vs. λ

1. Investigate contributions from: Gluinos, Charginos, Neutralinos
2. Sizable $Br >> Br_{SM} \approx \mathcal{O}(10^{-8})$
3. S-QCD dominant BUT S-EW interference effects



- 2 FC effects compete
- Neutralino contribution can be sizable
- SUSY-EW Br two orders larger that SM



(Choice of MSSM parameters: $\mu = 800GeV$, $M_o = 800GeV$, $A = 500GeV$, $m_A = 400GeV$, $M_2 = 300GeV$, $\tan\beta = 35$)

Non-Decoupling Behaviour of Heavy SUSY particles in FCHD

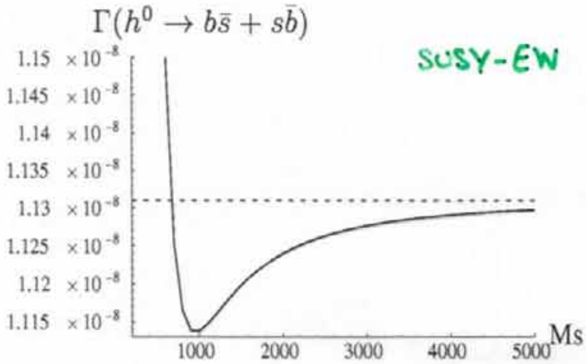
Pessimistic scenario $\rightarrow$ very heavy SUSY spectrum.
$\Rightarrow$Non-decoupling with M_{SUSY}

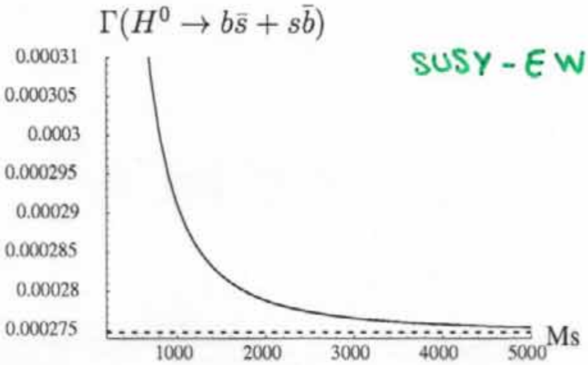
Ex. Dominant SUSY-QCD Form factor:

$$F_{L_{\tilde{g}}}^{(h_0)} = \frac{\alpha_s}{6\pi}\frac{m_b \sin\alpha}{2m_W \cos\beta}(\tan\beta + \cot\alpha)\frac{\mu M_{\tilde{g}}}{M_0^2}F(\lambda)$$

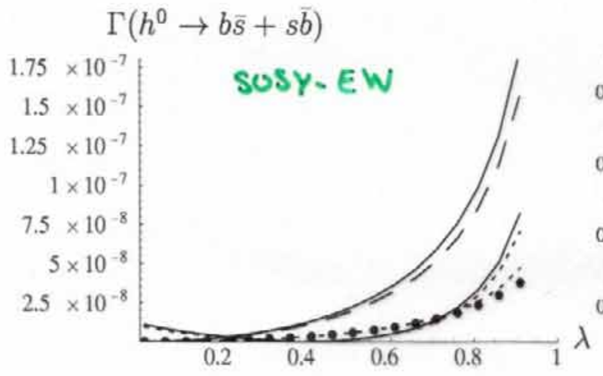
$$F(\lambda) = \frac{2}{\lambda^2}[(\lambda+1)\ln(\lambda+1) + (\lambda-1)\ln(1-\lambda) - 2\lambda];\ \lim_{\lambda\to 0} F(\lambda) \simeq 0$$

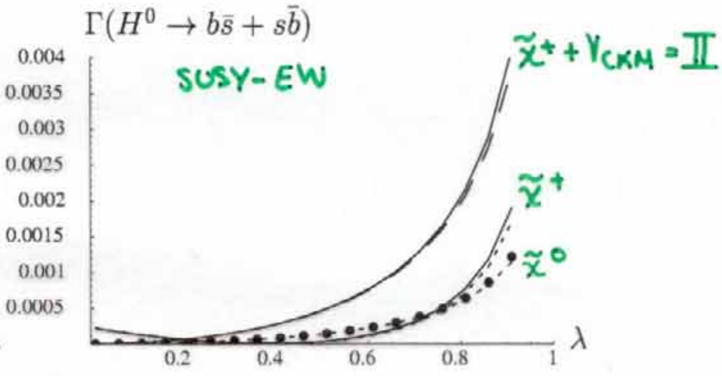
$\Rightarrow$ Expansions good aproximation





$\Rightarrow$ Well description of behaviour with λ in assymptotic formulas





- Decoupling only if $m_A \gg m_Z$
  $\cot\alpha \to -\tan\beta \Rightarrow F_{L,R}^{(h_o)} \to 0$: Recovering SM result

Conclusions

- FCHD as a possible indirect search of SUSY.
- Analyzed dependence with MSSM parameters and λ.
- Exact result valid for all $\tan\beta$ and λ
- SUSY-QCD at least one order of magnitud larger but important interference effects of SUSY-EW
- For $\lambda = 0.3$, $\mu = 800GeV$, $M_o = 800GeV$, $A = 500GeV$, $m_A = 400GeV$, $M_2 = 300GeV$, $\tan\beta = 35$, $Br(h_0 \to b\bar{s} + s\bar{b}) \approx \mathcal{O}(10^{-4})$ and $Br(H_0 \to b\bar{s} + s\bar{b}) \approx \mathcal{O}(10^{-2}) >> Br_{SM} \approx \mathcal{O}(10^{-8})$
- Interesting phenomenological SUSY signals at colliders.
- Non-Decoupling of heavy SUSY particles$\to$ Even in most pessimistic scenario of very heavy spectra, FC effect can be sizable.

FCHD constitute an interesting scenario for a possible indirect search of Supersymmetry, with important contributions in some regions of the MSSM parameter space, that remain even for a very heavy SUSY spectra.