Top Quark and charged Higgs boson: Decay and associated production in the MSSM and THDM

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<u>References</u>:

S. Béjar, J. Guasch, J.S., Nucl. Phys. **B**600 (2001)

A. Belyaev, J. Guasch, J.S. Phys. Rev. **D**65 (2002) 031701 (R); *ibid.* hep-ph/0203031 (sub. to JHEP)

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GUIDELINES

- Introduction and Motivation.
- Top quark decays in the SM and beyond.
- $t \to H^+ b$ in the MSSM and 2HDM.
- Conventional FCNC top quark decays.
- FCNC interactions in the 2HDM and MSSM.
- Promising FCNC top quark decays:
  - $t \to h\, c$ and $t \to g\, c$ in the the MSSM.
    ($h \equiv h^0, H^0, A^0$)
  - $t \to h\, c$ and $t \to g\, c$ in a general 2HDM.
- FCNC top quark decays at Tev33, LHC and at the LC: could they be visible?.
- $\boxed{p\bar{p}(pp) \to tbH^{\pm} + X}$ at the Tevatron and the LHC
- Conclusions.

Introduction and Motivation

- Experimental accuracy reached for the EW precision observables allows to test the SM and its extensions at the Quantum Level.

- When extending the Higgs Sector, we mainly focus on 2HDM's (Type I and Type II) and most particularly on the MSSM.

- The MSSM, being a <u>full</u> Quantum Field Theory, is the most attractive framework for extending the theory of strong and EW interactions.

- Moreover, the MSSM offers a starting point for a successful GUT where a radiatively stable Higgs Sector can survive.

- Although precision observables at LEP have played an important role to test the SM and extensions thereof, future experiments at the Tevatron, LHC and LC will be necessary to find out the nature of the SSB.

- The fact that Higgs bosons couple most likely to heavy quarks suggests that the physics of the top quark and of the bottom quark is the natural arena where to try to get a hint of the existence of Higgs particles.

- FCNC decays of the top quark are extremely suppressed in the SM, and there is no hope whatsoever to see them in any foreseeable high luminosity top quark factory in the future.

$\Downarrow \quad \Downarrow$

FCNC top quark decays into non-SM Higgs bosons could be the clue to the discovery of New Physics.

Similarly, finding a charged Higgs boson would be indisputable evidence of New Physics.

$\Downarrow \qquad \Downarrow$

A most preferred production process in hadron colliders like the Tevatron, and specially the LHC, would be

$$p\bar{p}(pp) \to tbH^{\pm} + X \quad \text{(Tevatron)(LHC)}\,,$$

Top quark decays in the SM and beyond

- Of course the leading decay is the SM one:

$$t \to W^{+} b$$

- BUT –perhaps– the non-SM decay

$$t \to H^{\pm} + b$$

is ALSO possible.

◇ The latter is the closest to the SM decay mode. However, it does not mean that $H^{\pm}$ is SUSY!.

◇ Tree-level effects cannot distinguish whether $H^{\pm}$ is SUSY or not. Quantum effects– in principle– CAN!!.

(J. A. Coarasa, D. Garcia, J. Guasch, R.A. Jiménez, J.S., *Eur. Phys. J.* **C 2** (1998) 373)

SUSY top quark decays

- Two-body decays

$$\begin{aligned} t &\rightarrow \tilde{t}\,\tilde{g} \\ &\rightarrow \tilde{b}\,\chi^{+} \\ &\rightarrow \tilde{t}\,\chi^{0} \end{aligned}$$

- Three-body decays

$$\begin{aligned} t &\rightarrow \tilde{b}\,\tilde{g}\,W^{+} \\ &\rightarrow b\,\chi^{+}\,\chi^{0} \\ &\rightarrow \tilde{t}\,\tilde{b}\,\bar{b} \\ &\rightarrow \tilde{b}\,c\,\tilde{s} \\ &\rightarrow \tilde{b}\,\tau\,\tilde{\nu} \\ &\rightarrow b\,\tilde{g}\,\chi^{+} \\ &\rightarrow b\,\tilde{t}\,\bar{\tilde{b}} \\ &\rightarrow b\,\tau\,\nu_{\tau} \\ &\rightarrow b\,\tilde{\tau}\,\tilde{\nu} \\ &\rightarrow h^{0}\,b\,W^{+} \\ &\quad \ldots \end{aligned}$$

(J. Guasch, J.S., *Z. Phys.* **C74** (1997) 337.)

$\boxed{\text{Renormalization framework}}$

On-shell schemes:

- α-scheme

$$(\alpha_{\text{em}}, M_W, M_Z, M_H, m_f, M_{SUSY} \ldots)$$

- G_F-scheme

$$(G_F, M_W, M_Z, M_H, m_f, M_{SUSY} \ldots)$$

Connection:

$$\frac{G_F}{\sqrt{2}} = \frac{\pi\, \alpha}{2\, M_W^2\, s_W^2}(1 + \Delta r)$$

Related corrections in the two schemes:

$$\delta(G_F) = \delta(\alpha_{\text{em}}) - \Delta r$$

$\boxed{\text{Conventional } t \to \text{FCNC}}$

• At tree-level there are no FCNC processes in the SM, and at one-loop they are induced by charged current (W) interactions, which are GIM-suppressed.

• Common examples at low-energy:
$K^0 - \bar{K}^0$ $(d \leftrightarrow s)$, $B - \bar{B}$ mixing $(d \leftrightarrow b)$, radiative B-decays: $\boxed{B(b \to s\gamma) \sim 10^{-4}}$.

• FCNC decays of the top quark are very much suppressed in the SM. The rates into electroweak gauge bosons are* $(m_t \simeq 175\, GeV)$:

$$\boxed{B(t \to \gamma\, c) \simeq 5 \times 10^{-13}\,, \quad B(t \to Z\, c) \simeq 1 \times 10^{-13}}$$

• Reason for extreme suppression: SM loop amplitudes controled by down-quarks, with m_b^2 setting the scale $\Rightarrow$

$$\Gamma(t \to FCNC) \sim |V_{tb}^* V_{bc}|^2 \alpha\, G_F^2\, m_t\, m_b^4 \sim |V_{bc}|^2 \alpha^3\, m_t \left(\frac{m_b}{M_W}\right)^4$$

* G.Eilam et.al.,*PR* **D44** (1991) 1473

• Largest SM rate is top decaying into glue*:

$$\boxed{B(t \to g\, c) \simeq 4 \times 10^{-11}.}$$

Too small! Expected visible level: $\sim 10^{-5}$ ($\to$ see later).

• The situation is even worse with the FCNC decay into the SM Higgs boson**:

$$\boxed{B(t \to H\, c) \simeq 10^{-13} - 10^{-15}\, (M_Z \leq M_H \leq 2\, M_W)}$$

• $t \to V + c\; (V = \gamma, Z)$ have also been studied* both in the MSSM ($< 10^{-6}$) and 2HDM ($< 10^{-7}$) $\Rightarrow$ (still too small!);
$t \to c\, g$ could be barely visible in the MSSM

• We will concentrate on

$$t \to h + c \quad (h \equiv h^0, H^0, A^0)$$

and shall re-compute and numerically analize $t \to c\, g$ in parallel as a referential.

* G.Eilam et.al.,*PR* **D44** (1991) 1473; J. Lopez et.al.,*PR* **D56** (1997) 3100; G.de Divitiis et al.*NP* **B504** (1997) 45.

** B. Mele et.al.,*PL* **B435** (1998) 401

$\boxed{\text{Higgs bosons in 2HDM and MSSM}}$

S. Béjar, J. Guasch, J.S., Nucl. Phys. **B**600 (2001) 21

J. Guasch, J.S., Nucl. Phys. **B**562 (1999) 3

- An extended Higgs sector can be a large source of new quantum effects e.g. FCNC or larger Higgs production cross-sections

- Case of 2HDM:

$$H_1 = \begin{pmatrix} H_1^0 \\ H_1^- \end{pmatrix} \ , \ H_2 = \begin{pmatrix} H_2^+ \\ H_2^0 \end{pmatrix}$$

- Possible cures (arrangements of Y.C.):
  - $\boxed{\text{2HDM I}}$: Only one doublet couples to fermions (due to a discrete symmetry);
  - $\boxed{\text{2HDM II}}$: H_1 couples to down-quarks and H_2 to up-quarks.
  - $H^\pm$ can still mediate loop induced FCNC: $B(b \to s\gamma) \sim (2-4) \times 10^{-4}$ (CLEO) $\Rightarrow$

$$m_{H^\pm} > 160\, GeV!!$$

Physical fields and Goldstone bosons:

$$\begin{pmatrix} G^+ \\ H^+ \end{pmatrix} = \begin{pmatrix} \cos\beta & \sin\beta \\ -\sin\beta & \cos\beta \end{pmatrix} \begin{pmatrix} -H_1^+ \\ H_2^+ \end{pmatrix}$$

$$\begin{pmatrix} G^0 \\ A^0 \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} \cos\beta & \sin\beta \\ -\sin\beta & \cos\beta \end{pmatrix} \begin{pmatrix} -\mathrm{Im}(H_1^0) \\ \mathrm{Im}(H_2^0) \end{pmatrix}$$

$$\begin{pmatrix} H^0 \\ h^0 \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} \mathrm{Re}(H_1^0) - v_1 \\ \mathrm{Re}(H_2^0) - v_2 \end{pmatrix}$$

$$\boxed{\tan\beta = \frac{v_2}{v_1}} \qquad M_W^2 = \frac{g^2}{2}(v_1^2 + v_2^2)$$

Neutral Higgs Couplings:

$$\alpha \to \beta \Rightarrow \begin{cases} (H^0, G^0, G^+) \text{ SM-like} \\ (h^0, A^0, H^+) \text{ enhanced couplings} \end{cases}$$

$$\alpha \to \beta - \frac{\pi}{2} \Rightarrow \begin{cases} (h^0, G^0, G^+) \text{ SM-like} \\ (H^0, A^0, H^+) \text{ enhanced couplings} \end{cases}$$

	$H^0 uu$	$H^0 dd$	$h^0 uu$	$h^0 dd$	$A^0 uu$	$A^0 dd$
Model I	$\frac{\sin\alpha}{\sin\beta}$		$\frac{\cos\alpha}{\sin\beta}$		$\frac{1}{\tan\beta}$	
Model II	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\cos\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\sin\alpha}{\cos\beta}$	$\frac{1}{\tan\beta}$	$\tan\beta$

- Charged Higgs Couplings:

$$\mathcal{L}^{(j)}_{Htb} = \frac{g\,V_{tb}}{\sqrt{2}\,M_W}\,H^-\bar{b}\,[m_t \cot\beta\,P_R + m_b\,a_j\,P_L]\,t + h.c.$$

$a_I = -\cot\beta$ and $a_{II} = +\tan\beta$.

- SUSY interactions in the MSSM can also trigger FCNC processes:

  – MSSM Higgs sector is of Type II

  – Loop induced FCNC processes from SUSY-EW and SUSY-QCD effects

- SUSY-EW computed in the Super-CKM basis $\Rightarrow$ FCNC processes appear at one loop through normal MSSM contributions from the charged sector (charged Higgs and charginos).

- SUSY-QCD interactions may induce tree-level gluino-mediated FCNC!!

- This is because of (tree-level or radiatively induced) misalignment of quark/squark mass matrices. It could be the dominant source of top quark FCNC decays in the MSSM!!.

- In 6-dimensional (flavour)$\times$(chiral) space reads (in the mass-eigenstate basis):

$$
\begin{aligned}
\mathcal{L}_{\mathrm{SQCD}} = & -\frac{g_s}{\sqrt{2}}\,\bar{\psi}_c^{\tilde{g}}\,[R^*_{5\alpha}\,P_L - R^*_{6\alpha}\,P_R]\,\tilde{q}^*_{\alpha,i}\,\lambda^c_{ij}\,t_j \\
& -\frac{g_s}{\sqrt{2}}\,\bar{\psi}_c^{\tilde{g}}\,[R^*_{3\alpha}\,P_L - R^*_{4\alpha}\,P_R]\,\tilde{q}^*_{\alpha,i}\,\lambda^c_{ij}\,c_j \\
& -\frac{g_s}{\sqrt{2}}\,\bar{\psi}_c^{\tilde{g}}\,[R^*_{1\alpha}\,P_L - R^*_{2\alpha}\,P_R]\,\tilde{q}^*_{\alpha,i}\,\lambda^c_{ij}\,u_j\ .
\end{aligned}
$$

where the R are rotation matrices R which diagonalize the 6×6 squark mass-matrix $\mathcal{M}^2_{(\tilde{u},\tilde{d})}$:

$$
\begin{aligned}
\tilde{q}'_\alpha &= \sum_\beta R^{(q)}_{\alpha\beta}\tilde{q}_\beta \\
R^{(q)\dagger}\mathcal{M}^2_{\tilde{q}}R &= \mathcal{M}^2_{\tilde{q}D} = \mathrm{diag}\{m^2_{\tilde{q}_1},\ldots,m^2_{\tilde{q}_6}\}\ ,\ q\equiv u,\,d
\end{aligned}
$$

with indices $\alpha = 1,2,3,\ldots,6 \equiv \tilde{u}_L,\tilde{u}_R,\tilde{c}_L,\ldots,\tilde{t}_R$ for up-type squarks, and a similar assignment for down-type squarks.

$\diamond$ The gluino interactions above lead to FCNC because the 6×6 squark mass-matrix contains intergenerational coefficients, which we restrict within the LL block:

$$(M^2_{LL})_{ij} = m^2_{ij} \equiv \delta_{ij}\, m_i\, m_j \ ,$$

with m_i the mass of the left-handed ith-squark.
$\diamond$ The δ_{ij} are restricted by low-energy data on FCNC processes involving the d-quark sector (e.g. from $b \to s\,\gamma$ etc.)*.

$\diamond$ $SU(2)$ gauge invariance $(M^2_{\tilde{U}})_{LL} = K\ (M^2_{\tilde{D}})_{LL}\ K^\dagger$ is used to transfer these bounds to the up-quark sector:

$$\begin{aligned} |\delta_{12}| &< .1\,\sqrt{m_{\tilde{u}}\, m_{\tilde{c}}}/500\ \text{GeV} \\ |\delta_{13}| &< .098\,\sqrt{m_{\tilde{u}}\, m_{\tilde{t}}}/500\ \text{GeV} \\ |\delta_{23}| &< 8.2\, m_{\tilde{c}}\, m_{\tilde{t}}/(500\ \text{GeV})^2 \ . \end{aligned}$$

where K is the CKM matrix $\Rightarrow$ if $M^2_{\tilde{D}}$ is parametrized with the δ_{ij} $\Rightarrow$ $(M^2_{\tilde{U}})_{LL}$ inherits a similar form with a new set of δ_{ij} which differ from the previous ones by factors of $\mathcal{O}(1)$.

$*$ F.Gabbiani et.al., *NP* **B477** (1996) 321)

Numerical Analysis

- It is conventional to define the fiducial ratio

$$B(t \to h\,c) \equiv \frac{\Gamma(t \to h\,c)}{\Gamma(t \to W^+\,b) + \Gamma(t \to H^\pm\,b)}$$

which will be the main object of our numerical study. It is <u>not</u> the total branching fraction $BR(t \to h\,c)$.

- The following restrictions must be respected:

  - $\delta\rho^{2HDM} \leq 0.001$

  - CLEO bound (for non-SUSY Type II): $m_{H^\pm} > 160\,GeV$ ($\tan\beta \gtrsim 1$)

  - Unitarity bound for trilinear couplings: $|\lambda_{HHH}| \leq \left|\lambda^{(SM)}_{HHH}(m_H = 1\,TeV)\right| = 3g(1\,TeV)^2/2M_W$

  - Mass bounds for m_h (but very light $h's$ not too relevant for $t \to FCNC$).

$t \to FCNC$: can they be visible?

• The sensitivities to FCNC top quark decays for 100 fb^{-1} of integrated luminosity for the relevant colliders are estimated to be*:

$$\begin{array}{rcll} \textbf{LHC} : B(t \to c\,X) & \gtrsim & 5 \times 10^{-5} & (\uparrow) \\ \textbf{LC} : B(t \to c\,X) & \gtrsim & 5 \times 10^{-4} & (\uparrow) \\ \textbf{TEV33} : B(t \to c\,X) & \gtrsim & 5 \times 10^{-3} & (\downarrow)\ . \end{array}$$

• LHC and LC could both be sensitive to $t \to FCNC$ and be complementary. TEV33 is essentially blind.

•Signatures? $\tan\beta \geq 30$: $t \to h\ c \to c\, b\bar{b}$
$\Rightarrow$ high p_T c-quark jets and a recoiling $b\bar{b}$ pair with large invariant mass.

• See at least two Higgs modes! in LHC (LC) (... and LEP 200?...) Check MSSM Higgs mass relations and MSSM fits $\Rightarrow$ SUSY or non-SUSY Higgses.

($*$) Even in the low $\mathcal{L}$ phase, LHC $\to 10^7$ $t\,\bar{t}$ pairs/year!!

CONCLUSIONS

- In SUSY-QCD and 2HDM II the maximum contributions to $t \to FCNC$ satisfy

  $$B(t \to g + c) < 10^{-5}(10^{-6}) < B(t \to h + c) \sim \boxed{10^{-4}}$$

- In both cases the Higgs modes are at least 7 orders of magnitude larger than the largest FCNC top rate in the SM ($t \to g + c$), and 10 orders above $t \to H_{SM} + c$.

- Comparison of maximum EW-FCNC rates in SUSY-EW and 2HDM II :

  $$\begin{aligned} B^{SUSY}(t \to h\, c) &\simeq 1 \times 10^{-6} \\ B^{2HDM}(t \to h\, c) &\simeq 1 \times 10^{-4}. \end{aligned}$$

- Should be possible to discriminate between SUSY and non-SUSY $t \to h + c$.

$$\Downarrow$$

LHC and LC could make it!

$$\boxed{p\bar{p}(pp) \to tbH^{\pm} + X}$$

A. Belyaev, J. Guasch, J.S. Phys. Rev. **D**65 (2002) 031701;

ibid. hep-ph/0203031 (sub. to JHEP)

◇ At large $\tan\beta$ this is the leading process for Higgs boson production.

◇ At the parton level it proceeds through:

$$q\bar{q} \to H^+\,\bar{t}\,b, \qquad gg \to H^+\,\bar{t}\,b,$$

and

$$\bar{b}g \to H^+\bar{t}$$

◇ Appropriate subtraction of the gluon splitting term required:

$$\begin{aligned}\sigma(g\bar{b} + gg \to H^+\bar{t} + X)_{real} \\ = \sigma(g\bar{b} \to H^+\bar{t}) + \sigma(gg \to H^+\bar{t}b) \\ -\sigma(g \to b\bar{b} \otimes g\bar{b} \to H^+\bar{t}).\end{aligned}$$

◇ Examples of background processes:

Tevatron

$\sigma(qq \to t\bar{t}b\bar{b})$	=	6.62 fb
$\sigma(gg \to t\bar{t}b\bar{b})$	=	0.676 fb
$\sigma(gb \to t\bar{t}b)$	=	1.22 fb
Subtr. term	:	0.72 fb
Total	:	7.80 fb

LHC

$\sigma(qq \to t\bar{t}b\bar{b})$	=	0.266 pb
$\sigma(gg \to t\bar{t}b\bar{b})$	=	6.00 pb
$\sigma(gb \to t\bar{t}b)$	=	4.33 pb
Subtr. term	:	2.1 pb
Total	:	8.50 pb

◇ Crucial statistical parameter is the significance of the signal:

$$\boxed{S/\sqrt{B}}$$

◇ Standard discovery limit is

$S/\sqrt{B} = 5$ (99.999957% $C.L.$).

Exclusion limit is defined as:

$S/\sqrt{B} = 2$ ($\sim$ 95% $C.L.$).

$\boxed{\text{Subtraction Term}}$

• Overlap arises because the b-density in the $\bar{b}g$ amplitude receives contributions from gluon splitting already counted in the gg amplitude, so we have to avoid double counting by subtracting the gluon splitting term.

$$\begin{aligned}\sigma(\bar{b}g + gg \to H^+\bar{t} + X)_{net} = \quad & \sigma(g\bar{b} \to H^+\bar{t}) + \sigma(gg \to H^+\bar{t}b) \\ & -\sigma(g \to b\bar{b} \otimes g\bar{b} \to H^+\bar{t}).\end{aligned}$$

$$\frac{df_{b/h}(x,Q^2)}{d\ln Q^2} = \frac{\alpha_S(Q^2)}{2\pi}\int_x^1 \frac{dz}{z}\left\{P_{b\leftarrow b}(z)\, f_{b/h}(\frac{x}{z},Q^2) + P_{b\leftarrow g}(z)\, f_{g/h}(\frac{x}{z},Q^2)\right\}$$

• The subtraction term can be approximated by integrating the gluon-splitting part $g \to b$ of this equation at the leading order in $\alpha_S(Q^2) \Rightarrow$ the modified b-density is:

$$\tilde{f}_{b/h}(x,Q^2) = \frac{\alpha_S(Q^2)}{2\,\pi}\ln\left(\frac{Q^2}{m_b^2}\right)\int_x^1 \frac{dz}{z}\left[\frac{z^2+(1-z)^2}{2}\right] f_{g/h}\left(\frac{x}{z},Q^2\right) ,$$

where $P_{b\leftarrow g}(z) = (1/2)\left[z^2 + (1-z)^2\right]$ is the gluon splitting function.

• Thus the modified b-density contains the collinear log and splitting function $P_{b\leftarrow g}$ convoluted with the g-density $\Rightarrow$ the expression for the subtraction term is:

$$\boxed{\text{Subt.term}(AB \to H^+\bar{t}b)} \quad =$$

$$\int dx_1 dx_2 \left\{\begin{array}{c} \tilde{f}_{b/A}(x_1,Q^2) f_{g/B}(x_2,Q^2)\sigma(\bar{b}g \to \bar{t}H^+) \\ +f_{g/A}(x_1,Q^2)\tilde{f}_{b/B}(x_2,Q^2)\sigma(g\bar{b} \to \bar{t}H^+) \end{array}\right\}$$

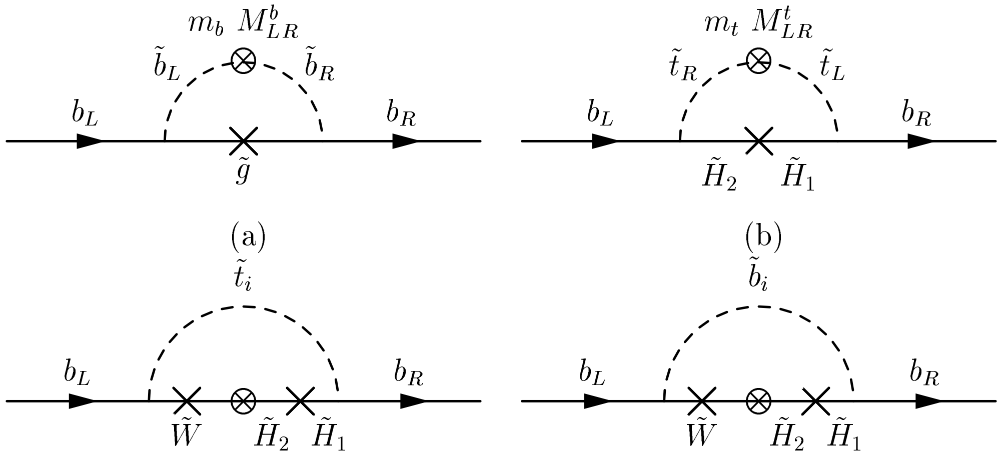
Leading SUSYcorrections

$$
\begin{aligned}
(\Delta m_b)_{\mathrm{SUSY-QCD}} &= -\,C_F \frac{\alpha_S(M_{\mathrm{SUSY}})}{2\pi}\, m_{\tilde g}\, M^b_{LR}\, I(m_{\tilde b_1}, m_{\tilde b_2}, m_{\tilde g}) \\
&\to +\frac{2\alpha_S(M_{\mathrm{SUSY}})}{3\pi}\, m_{\tilde g}\, \mu \tan\beta\, I(m_{\tilde b_1}, m_{\tilde b_2}, m_{\tilde g})
\end{aligned}
$$

where $C_F = (N_c^2-1)/2N_c = 4/3$ is a color factor (with $N_c = 3$). Moreover we have $\alpha_S(M_{\mathrm{SUSY}}) \simeq 0.09$, $M^b_{LR} = A_b - \mu \tan\beta$ and the last expression holds only for sufficiently large $\mu \tan\beta \gg A_b$. Here μ is the higgsino mass parameter in the superpotential and A_b is the bottom quark trilinear coupling in the soft-SUSY-breaking part of the superpotential. As for the electroweak effects on Δm_b they stem from similar loops involving mixed LH and RH-stops and mixed charged higgsinos $\tilde H_1 - \tilde H_2$ and read

$$
\begin{aligned}
(\Delta m_b)_{\mathrm{SUSY-Yukawa}} &= +\frac{h_t h_b}{16\pi^2}\, \frac{\mu}{m_b}\, m_t\, M^t_{LR} I(m_{\tilde t_1}, m_{\tilde t_2}, \mu) \\
&\to +\frac{Y_t}{4\pi}\, A_t\, \mu \tan\beta\; I(m_{\tilde t_1}, m_{\tilde t_2}, \mu)
\end{aligned}
$$

Here A_t is the top quark trilinear coupling; $Y_t \equiv h_t^2/4\pi \simeq 1/4\pi$ and $M^t_{LR} = A_t - \mu \cot\beta$.



(c)

SUSY K-factor

- Useful to define an "effective K-factor" in the MSSM context:

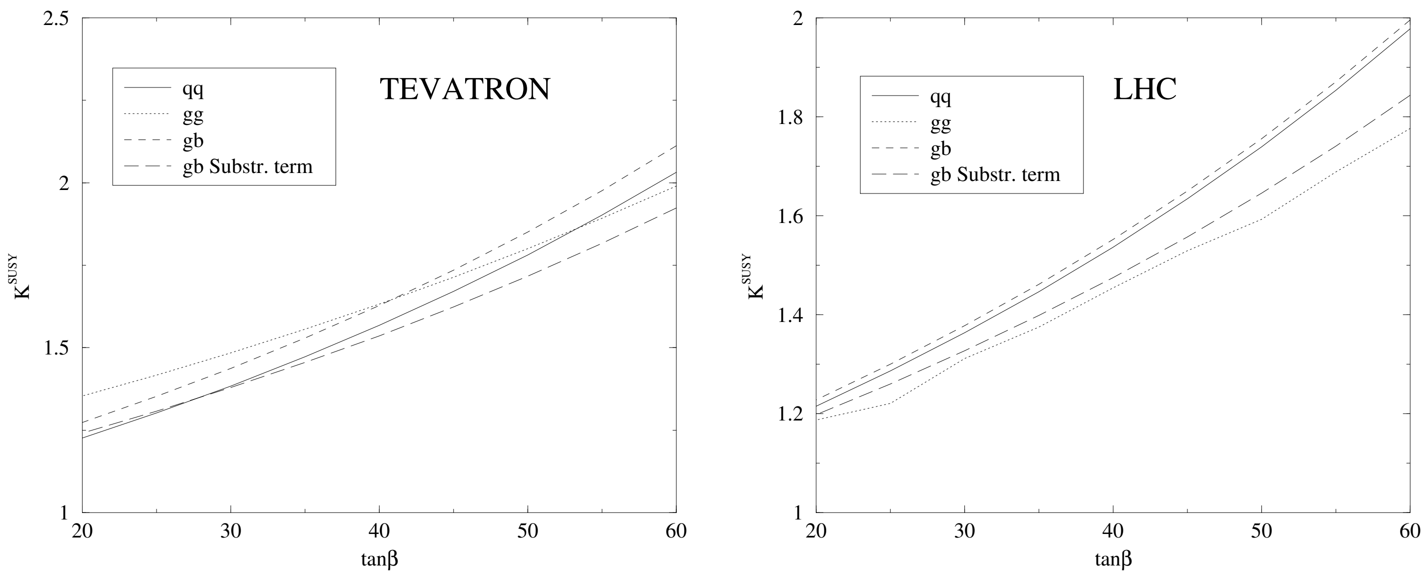
$$\boxed{K^{\text{MSSM}} = K^{\text{QCD}}\, K^{\text{SUSY}}}$$

where K^{SUSY} stands for the genuine R-odd effects.

- We have

$$K^{\text{SUSY}} = \frac{\sigma^{\text{MSSM}}}{\sigma^{\text{QCD}-\text{corrected}}} = \frac{\sigma^{\text{SUSY}-\text{corrected}}}{\sigma^{\text{Tree}-\text{level}}}$$

- For instance, for $K^{\text{MSSM}} \gtrsim 2$ (e.g. through $K^{\text{QCD}} = 1.4$ and $K^{\text{SUSY}} = 1.5$) the opportunity to chase a MSSM Higgs boson already at the Tevatron would be open!!



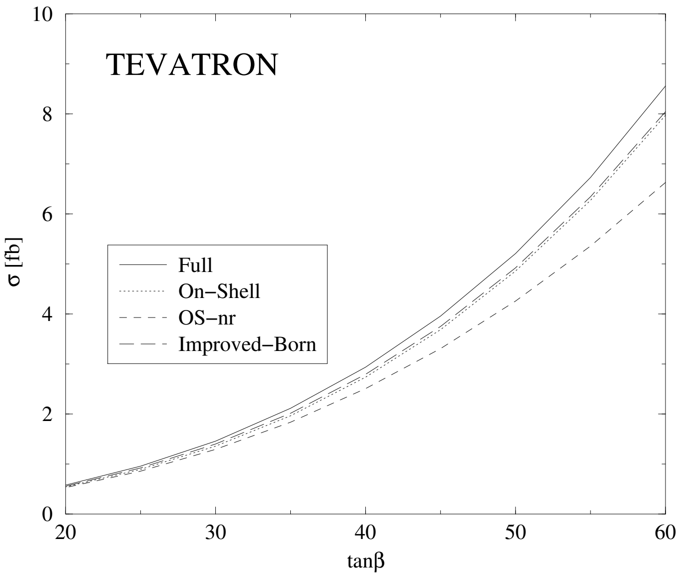
Cross-section in various approximations

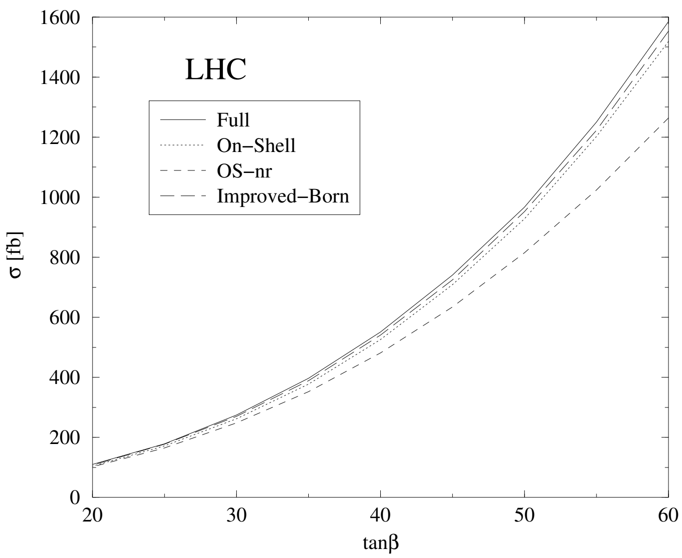
Let us compare the following set of corrections:

- the full set of SUSY corrections, including resummation and the off-shell two- and three-point functions (labeled Full);
- the corrections including resummation, but using on-shell values for the irreducible three-point functions (On-Shell);
- the one-loop (without resummation) corrections, using also on-shell values for the irreducible three-point functions (OS-nr);
- the tree-level result with the pole quark masses replaced by the effective Yukawa couplings (Improved-Born).

The following hierarchy of quantum effects is observed:

$$\boxed{\sigma(\mathrm{Full}) \gtrsim \sigma(\mathrm{Improved-Born}) > \sigma(\mathrm{On-shell}) > \sigma(\mathrm{OS-nr})}$$





Related processes

• The charged Higgs production calculation has been first considered at a preliminary level in:

J.F. Gunion, *Phys. Lett.* B 322 (1994)125; V. Barger, R.J. Phillips, D.P. Roy, *Phys. Lett.* B 324 (1994)236.

• More recently:

J.A. Coarasa, J. Guasch, J. Solà, hep-ph/9909397. Contributed to Physics at Run II: Workshop on Supersymmetry/Higgs: Summary Meeting, Batavia, Ill, 19–21 Nov. 1998 (including preliminary SUSY effects)

A. Belyaev, D. Garcia, J. Guasch, J. Solà, *Phys. Rev.* D 65 (2002)031701(R) (first results with leading SUSY effects); comprehensive study in: *ibid.* hep-ph/0203031 (sub. JHEP)

F. Borzumati, J. Kneur, N. Polonsky, *Phys. Rev.* D 60 (1999)115011 (without SUSY effects)

• To identify the SUSY nature of the Higgs bosons, useful to correlate the charged Higgs production process with the neutral ones

$$p\bar{p}(pp) \to h\, b\bar{b} + X$$

where $h = h^0, H^0, A^0$.

• This correlation was first discussed (I believe) in J.A. Coarasa, R.A. Jiménez, J. Solà, *Phys. Lett.* B 389 (1996)312, hep-ph/9511402, and also in the network meeting in Barcelona (UB) (in 1996?)

• Recent detailed analyses in:

M. Carena, S. Mrenna, C.E.M. Wagner, *Phys. Rev.* D 60 (1999)075010, hep-ph/9808312

J. Ellis, S. Heinemeyer, K.A. Olive, G. Weiglein, *Phys. Lett.* B 515 (2001)348, hep-ph/0105061.

• In the SM case ($h^0 \equiv H$) with full NLO-QCD effects:

L. Reina, S. Dawson, *Phys. Rev. Lett.* 87 (2001)201804

W. Beenakker, S. Dittmaier, M. Krämer, B. Plümper, M. Spira, P.M. Zerwas, *Phys. Rev. Lett.* 87 (2001) 201805.

CONCLUSIONS

- At high $\tan\beta$ the MSSM quantum effects are dominated by exceptionally important effects that can be absorbed into an effective $tbH^{\pm}$ vertex, and therefore in practice they can be treated as an "improved Born approximation"
- From a detailed signal versus background study we have shown that the prospects for the signal discovery are viable for the **Tevatron** if

$$M_{H^{\pm}} \lesssim 250\, GeV$$

  and promising for the **LHC** if

$$M_{H^{\pm}} \lesssim 1.5\, TeV$$

- In deriving these limits we have demonstrated that the quantum machinery from the MSSM can play a crucial role to increase the signal. In large portions of the parameter space the genuine SUSY corrections could show up as a *smoking gun* over the tree-level cross-section (after subtracting the conventional QCD effects) with a contribution of the order or larger than the QCD effects themselves.
- A close comparison with the corresponding neutral Higgs boson production processes should be, if available, very useful to confirm or dismiss the MSSM nature of the charged and neutral Higgs bosons.

$$\Downarrow$$

$\boxed{\text{Tevatron and LHC could make it!}}$