Higgs boson FCNC decays into top quark in the 2HDM models

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Flavour in the era of the LHC

S. B., J. Guasch, and J. Solà. *Nucl. Phys.* **B675** (2003), 270-288. hep-ph/0307144.

Outline

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Motivation

- The Standard Model (SM) tested with high precision
- Not the definitive model
- Two Higgs doublet models (2HDM) are one of the simplest extensions of the SM.
- Higgs boson FCNC decays extremely suppressed in the SM
- Couplings quarks–Higgs bosons $\propto$ fermion masses
- In this work we present the Higgs (h^0, H^0) production times the branching ratio in the 2HDM II

Rare FCNC decays

	SM	2HDM	MSSM
$B(t \to c\gamma)$	$\sim 5 \times 10^{-13}$	$\lesssim 1 \times 10^{-7}$	$< 1 \times 10^{-6}$
$B(t \to cZ)$	$\gtrsim 1 \times 10^{-13}$	$< 10^{-6}$	$< 10^{-7}$
$B(t \to cg)$	$\sim 4 \times 10^{-11}$	$\lesssim 10^{-5}$	$\lesssim 10^{-5}$
$B(t \to cH)$	$\sim 10^{-13} - 10^{-15}$	$\lesssim 10^{-4}$	$\lesssim 10^{-4}$
$B(H \to t\bar{c})$	$\sim 10^{-13}(m_H < 2m_W)$	$\lesssim 10^{-4}$	$\lesssim 10^{-4}$
	$\lesssim 10^{-15}(m_H > 2m_W)$		
$B(H \to b\bar{s})$	$\lesssim 10^{-7}(m_H < 2M_W)$	$\lesssim 10^{-5}$	$\lesssim 10^{-4}$
	$\lesssim 10^{-10}(m_H > mt)$		

Conventional FCNC

FCNC in the SM

- One-loop
- Charged currents
- GIM mechanism

$\Rightarrow$ small rates

Common examples at low energy

- $K^0 - \bar{K}^0$ $(d \leftrightarrow s)$
- $B - \bar{B}$ mixing $(d \leftrightarrow b)$
- Radiative B-decays: $B(b \to s\gamma) \sim 10^{-4}$

FCNC beyond SM

- New physics at the same order than SM physics
- Ideal laboratory to search for new physics

Two Higgs doublet models

- SM + an extra Higgs boson doublet
- In general with tree-level FCNC

- Induced FCNC at one-loop by the charged Higgs boson

Two Higgs doublet models

- SM + an extra Higgs boson doublet
- In general with tree-level FCNC

Solution: Glashow and Weinberg theorem

All fermions of a given electric charge couple to no more than one Higgs doublet

- Type I: ϕ_2 couples to all the quarks.
- Type II: $\phi_1(\phi_2)$ couples to the down(up) quarks

- Induced FCNC at one-loop by the charged Higgs boson

Higgs sector

Potential

$$\begin{aligned}\mathcal{V}(\phi_1,\phi_2) = \quad & \lambda_1(\phi_1^\dagger\phi_1 - v_1^2)^2 + \lambda_2(\phi_2^\dagger\phi_2 - v_2^2)^2 + \\ & + \lambda_3\left[(\phi_1^\dagger\phi_1 - v_1^2) + (\phi_2^\dagger\phi_2 - v_2^2)\right]^2 + \\ & + \lambda_4\left[(\phi_1^\dagger\phi_1)(\phi_2^\dagger\phi_2) - (\phi_1^\dagger\phi_2)(\phi_2^\dagger\phi_1)\right] + \\ & + \lambda_5[\phi_1^\dagger\phi_2 - v_1 v_2]^2\end{aligned}$$

Parameters

$$(\lambda_1, ..., \lambda_5, v_1, v_2) \Rightarrow (m_{h^0}, m_{H^0}, m_{A^0}, m_{H^\pm}, \alpha, \beta, M_W)$$

Physical Higgs bosons

- neutral CP-even: h^0 and H^0 $(m_{h^0} < m_{H^0})$
- neutral CP-odd: A^0
- charged: $H^{\pm}$

Couplings

- $h_i - h_j - h_k \propto m^2_{h_i} - m^2_{h_j}$
- $h_i - h_j - h_k \propto 1/\sin(2\beta) \rightarrow \tan\beta$ $(\tan\beta \gg 1)$
- $h - f - f$
  - Type I: $\sim \{\sin, \cos\}\{\alpha, \beta\}/\sin\beta$
  - Type II: up $\sim 1/\sin\beta$
    down $\sim 1/\cos\beta \rightarrow \tan\beta$ $(\tan\beta \gg 1)$

Physical Higgs bosons

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

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

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

$$\tan\beta = \frac{v_2}{v_1} \qquad 0.1 < \tan\beta \lesssim 60 \qquad M_W^2 = \frac{g^2}{2}(v_1^2 + v_2^2)$$

Physical Higgs bosons

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

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

	H^0uu	H^0dd	h^0uu	h^0dd	A^0uu	A^0dd
2HDM I	$\frac{\sin\alpha}{\sin\beta}$		$\frac{\cos\alpha}{\sin\beta}$		$\frac{1}{\tan\beta}$	
2HDM II	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\cos\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\sin\alpha}{\cos\beta}$	$\frac{1}{\tan\beta}$	$\tan\beta$

Restrictions

$$
\begin{aligned}
\text{Perturbativity} \Rightarrow \quad & 0.1 && < \tan\beta \lesssim 60 \\
\text{Custodial symmetry} \Rightarrow \quad & |\delta\rho^{\text{2HDM}}| && \leqslant 0.001 \\
bs\gamma \Rightarrow \quad & m_{H^\pm} && > 350\,\text{GeV} \\
\text{Unitarity} \Rightarrow \quad & |\lambda_{HHH}| && \leqslant \left|\lambda^{(SM)}_{HHH}(m_H = 1\ TeV)\right| \\
& && = \frac{3\,g\,(1\ TeV)^2}{2\,M_W}
\end{aligned}
$$

$pp \to h \to tc$ in the 2HDM

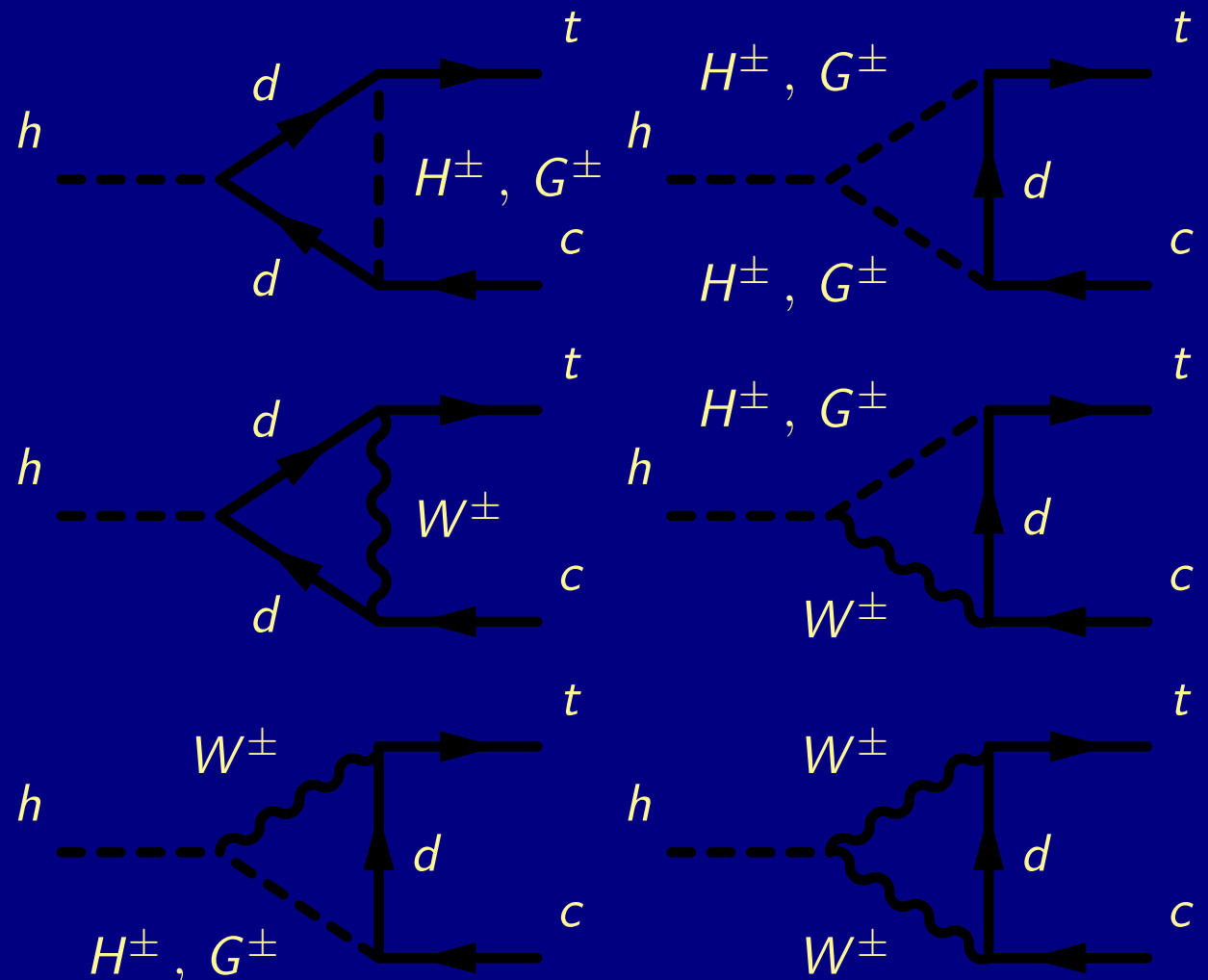
$$\sigma(pp \to h \to tc) \equiv \sigma(pp \to hX) \times B(h \to tc)$$

$$B(h \to tc) = \frac{\Gamma(h \to t\,\bar{c} + \bar{t}\,c)}{\Gamma(h \to b\,\bar{b}) + \Gamma(h \to t\,\bar{t}) + \Gamma(h \to V\,V) + \Gamma(h \to H\,H)}$$

Parameter scan

$$(m_{h^0}, m_{H^0}, m_{A^0}, m_{H^\pm}, \tan\alpha)$$

Diagrams


h
d
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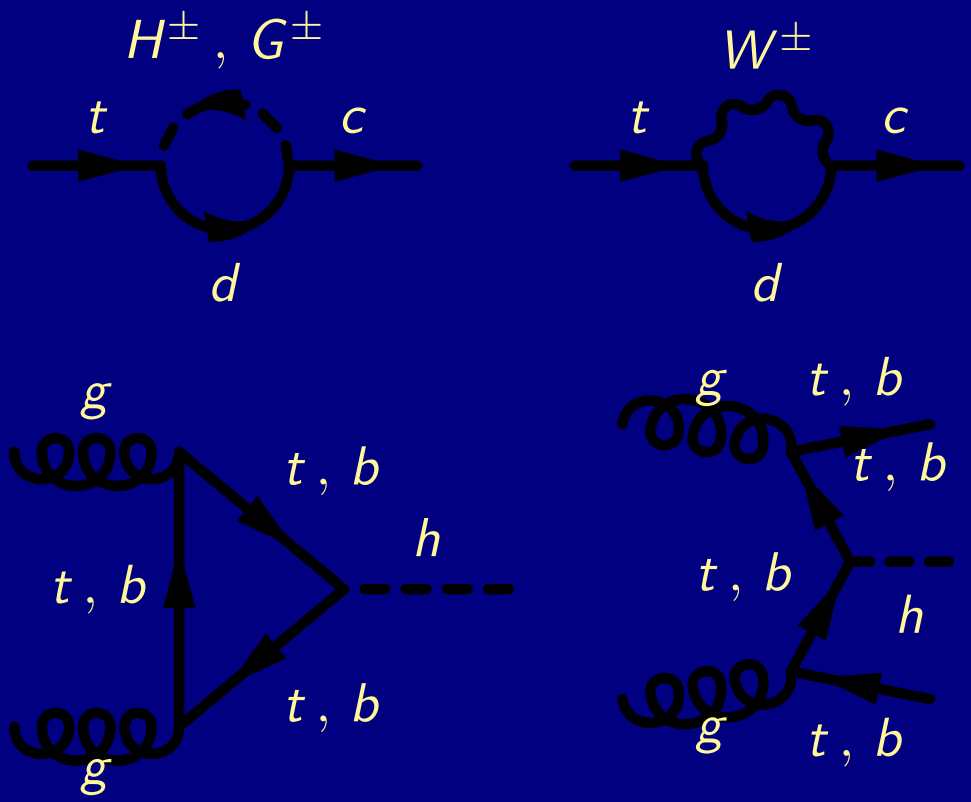
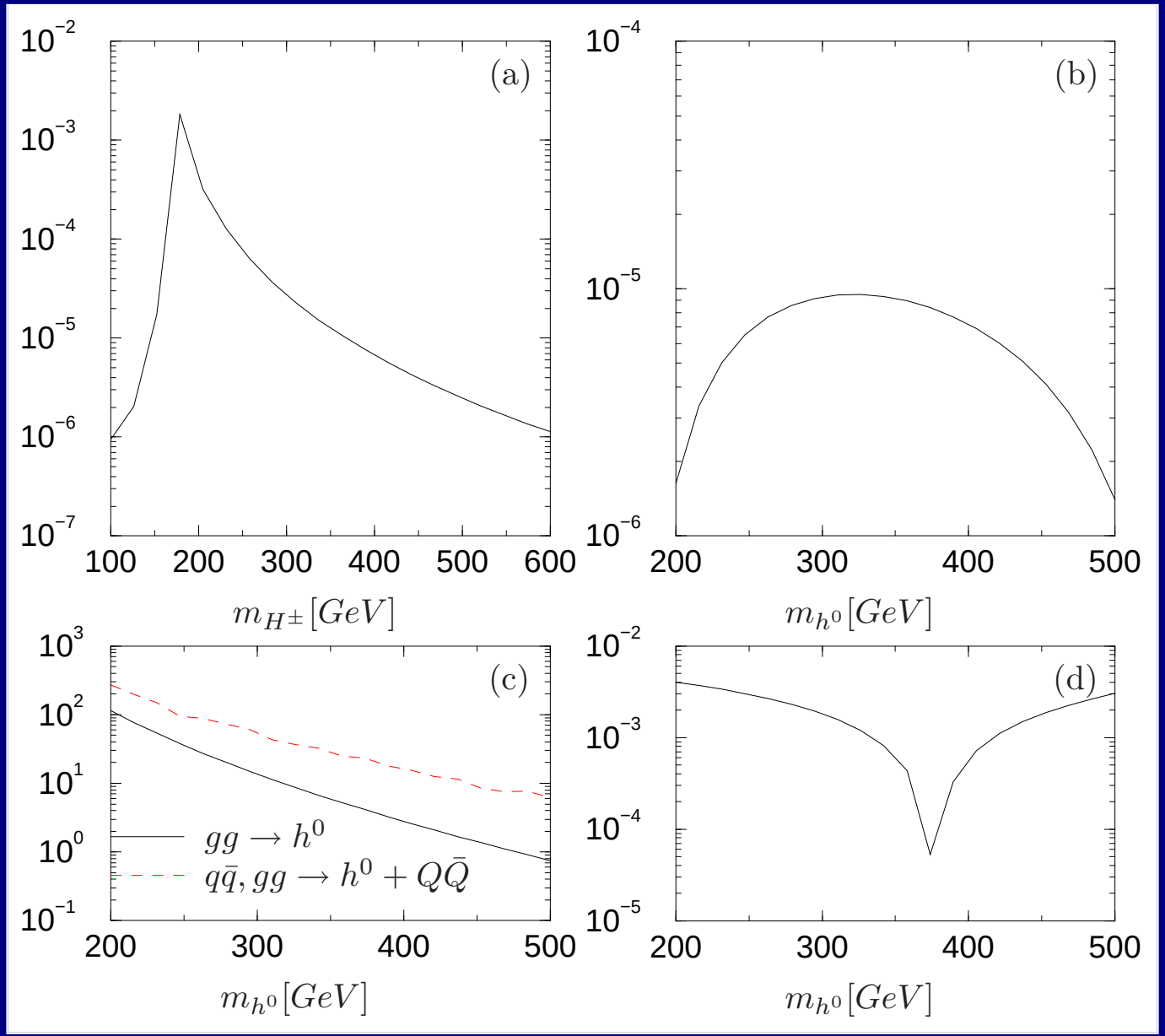
Diagrams



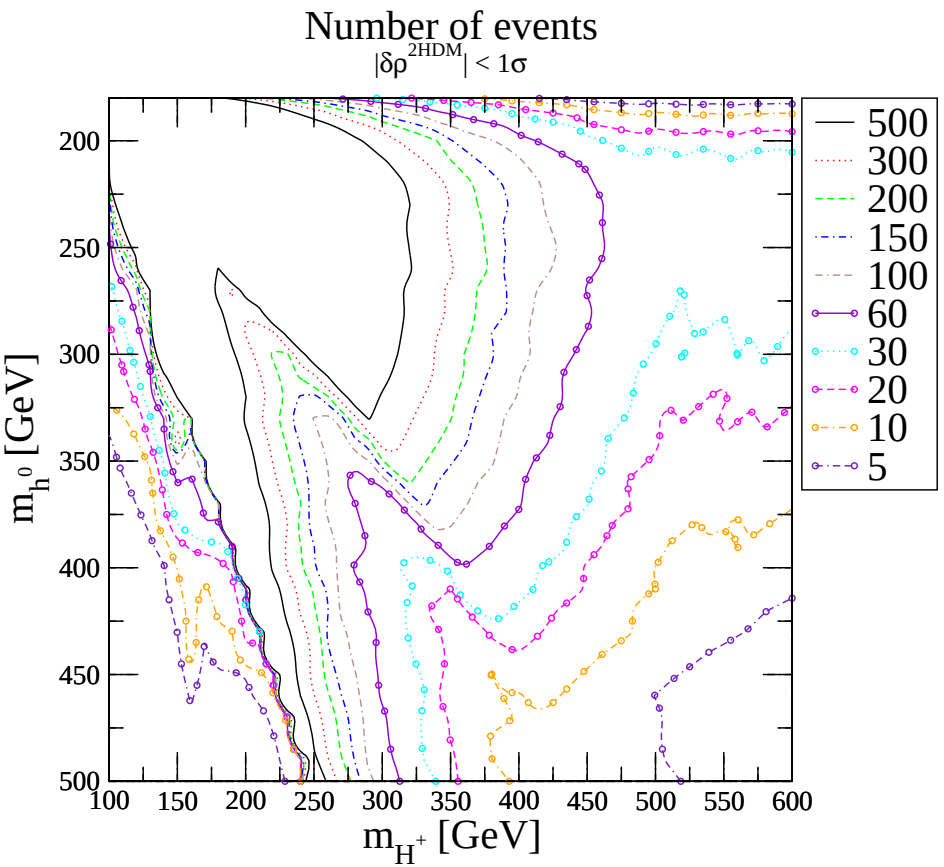
$B(h \to tc)$



$\sigma(pp \to h^0)$ $|\delta\rho^{\text{2HDM}}|$

$(m_{h^0}, m_{A^0}, m_{H^\pm}) = (350, 550, 375)\,\text{GeV}$ $\tan\alpha = 30$ $\tan\beta = 60$

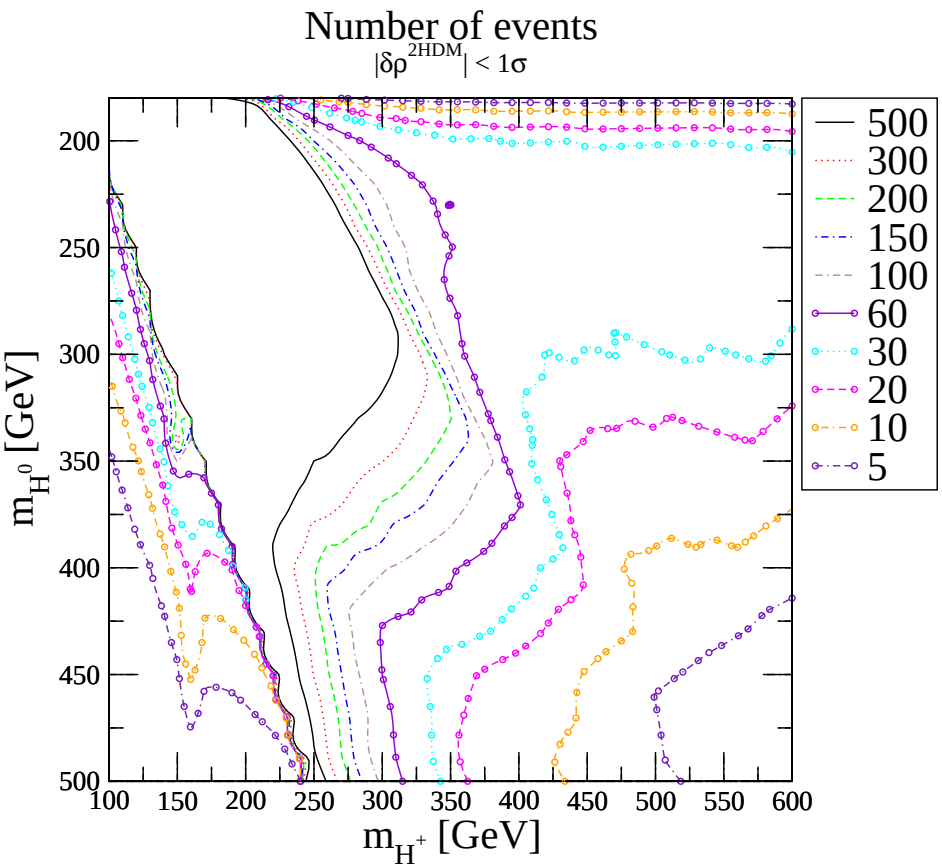
$pp \longrightarrow h^0 \longrightarrow tc$: Number of events/100 fb^{-1} at LHC



$m_{A^0} \approx 600\,\text{GeV}$ $\alpha \approx \dfrac{\pi}{2}$

$\tan\beta = 60$

$pp \longrightarrow H^0 \longrightarrow tc$: Number of events $/100\,\mathrm{fb}^{-1}$ at LHC



$m_{A^0} \approx 600\,\mathrm{GeV} \qquad \alpha \approx 0$

$\tan\beta = 60$

Conclusions

$pp \longrightarrow h \longrightarrow tc$ in 2HDM II

- Branching ratios up to ten billion times the SM
- Up to few hundred events for h^0 or H^0 at LHC
- Hopeless for A^0
- h^0/H^0: large $\tan\beta$ and $m_h \ll m_{A^0}$
- h^0: large $\tan\alpha$
- H^0: small $\tan\alpha$