Charged Higgs in CP-conserving 2HDM

cHarged 2010

September 29

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Goals

- Start with CP-conserving 2HDM (4 versions)
- Identify regions of the 2HDM where a charged Higgs can be found
- Different signatures (in the 4 versions)?
- Perform (use) parton level analysis for the best scenarios
- Other models: CP-violating 2HDM

and Outline

- The models
- Defining the benchmarks
- The production processes
- The signatures
- Conclusion and outlook

The 2HDM potential

$$V(\Phi_1,\Phi_2) = m_1^2\Phi_1^\dagger\Phi_1 + m_2^2\Phi_2^\dagger\Phi_2 - (m_{12}^2\Phi_1^\dagger\Phi_2 + \text{h.c}) + \frac{1}{2}\lambda_1(\Phi_1^\dagger\Phi_1)^2 + \frac{1}{2}\lambda_2(\Phi_2^\dagger\Phi_2)^2$$
$$+ \lambda_3(\Phi_1^\dagger\Phi_1)(\Phi_2^\dagger\Phi_2) + \lambda_4(\Phi_1^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1) + \frac{1}{2}\lambda_5[(\Phi_1^\dagger\Phi_2)^2 + \text{h.c.}]$$

$m_h,\ m_H,\ m_A,\ m_{H^\pm},\ \tan\beta,\ \sin(\beta-\alpha)$ $\qquad M^2 = \dfrac{m_{12}^2}{\sin\beta\cos\beta}$

- couplings that involve gauge bosons

$$\sin(\beta-\alpha)$$

- couplings that involve fermions

$$\tan\beta$$

4 independent ways to couple the Higgs to the fermions **no FCNC**

III ≡ I' ≡ Y

IV ≡ II' ≡ X ≡ Leptonic

	I	II	III	IV
up	Φ_2	Φ_2	Φ_2	Φ_2
down	Φ_2	Φ_1	Φ_1	Φ_2
lepton	Φ_2	Φ_1	Φ_2	Φ_1

Choosing the benchmarks

- All models - LEP bound for a charged Higgs

$$BR(\to \tau\nu) + BR(\to cs) = 1 \qquad m_{H^\pm} > 79.3\, GeV$$

- Models II and Y

$$B \longrightarrow X_s\gamma \qquad m_{H^\pm} \gtrsim 300\ GeV$$

Benchmark for Models I and X $\quad m_{H^\pm} = 100\, GeV$

Benchmark Models II and Y $\quad m_{H^\pm} = 300\, GeV$

- All models

$$Z \longrightarrow b\bar{b} \qquad B_q\bar{B}_q \qquad \tan\beta > 1$$

- Model Y

$$\tan\beta > 40 \qquad m_{H^\pm} = 100\, GeV$$

CDF and D0

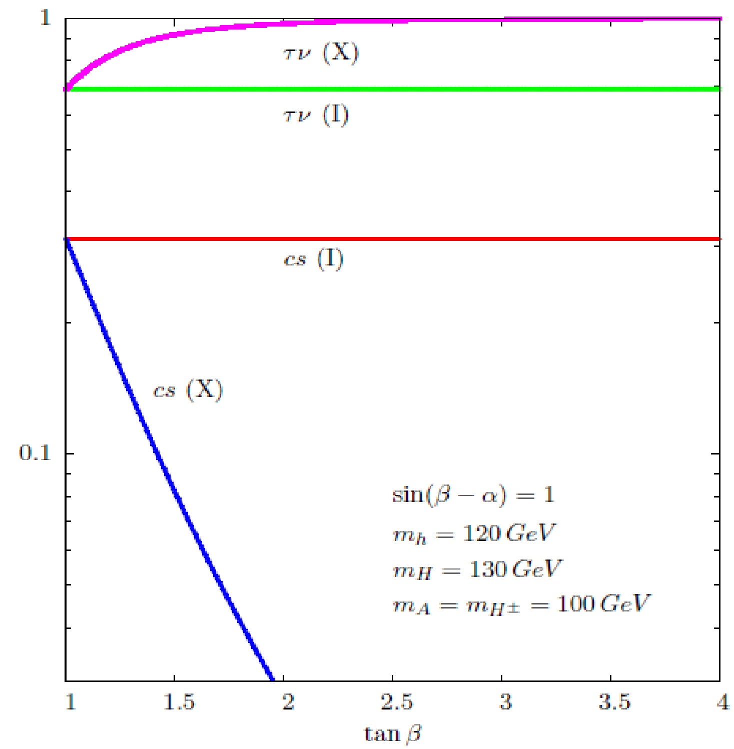
Choosing the benchmarks

Benchmark for all Models

$$\tan\beta = 1,\ 3,\ \sqrt{m_t / m_b},\ 30$$

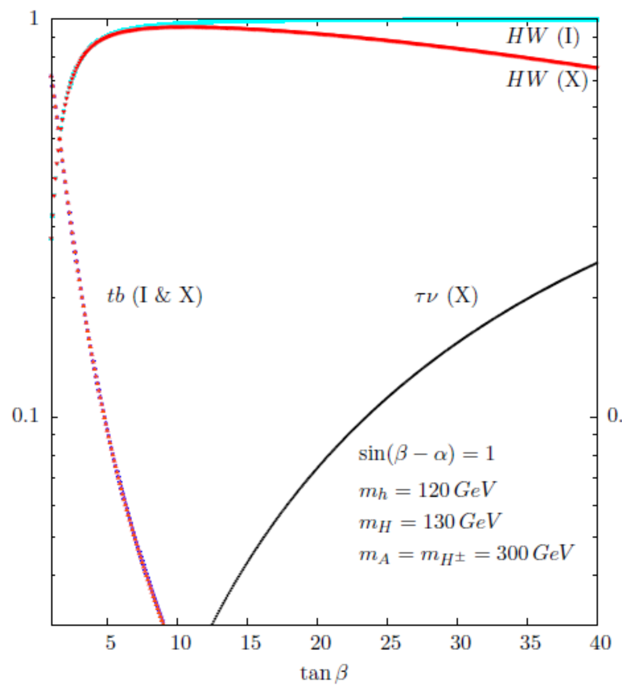
Branching ratios

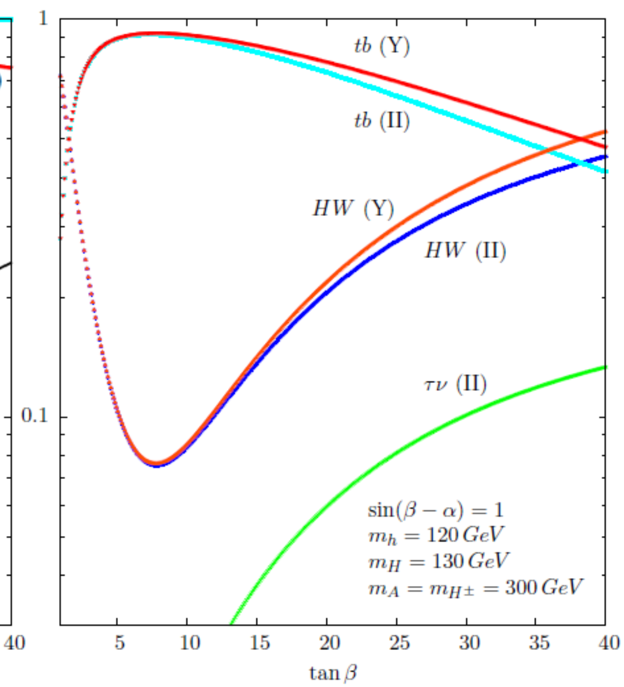
Cross sections



- $|\delta\rho| \lesssim 10^{-3}$

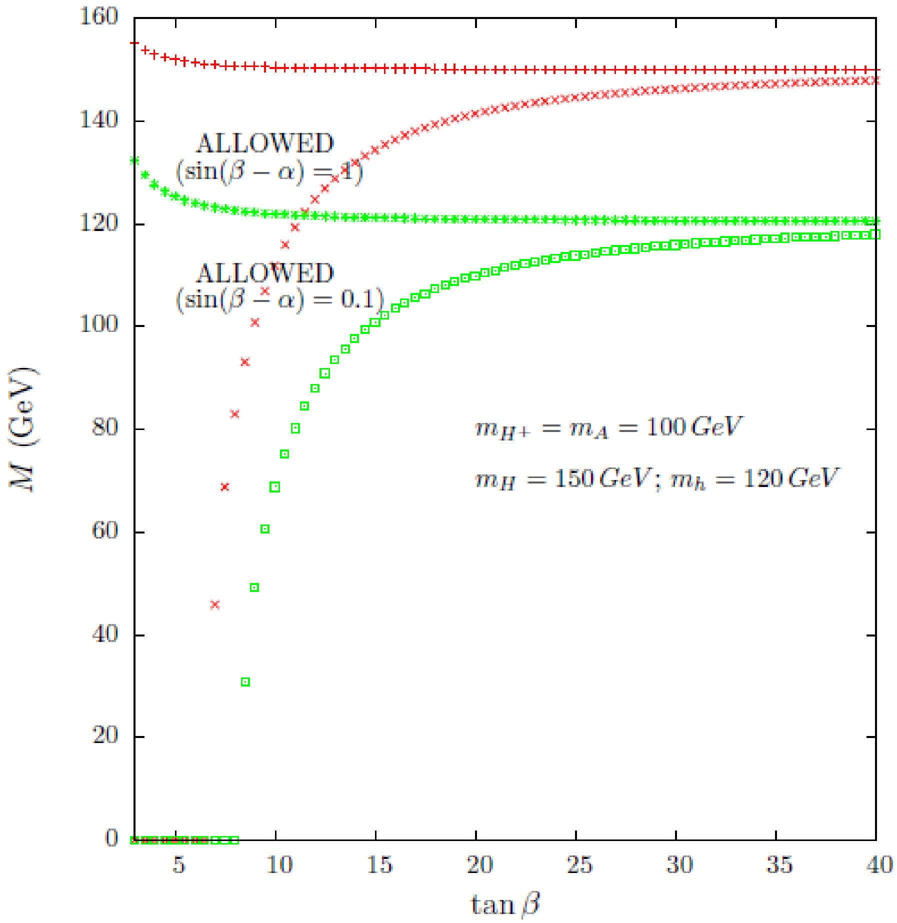
$$\begin{cases} m_A = m_{H^\pm} \\ \sin(\beta-\alpha)=1 \Rightarrow m_{H^\pm} = m_H \\ \sin(\beta-\alpha)=0 \Rightarrow m_{H^\pm} = m_h \end{cases}$$

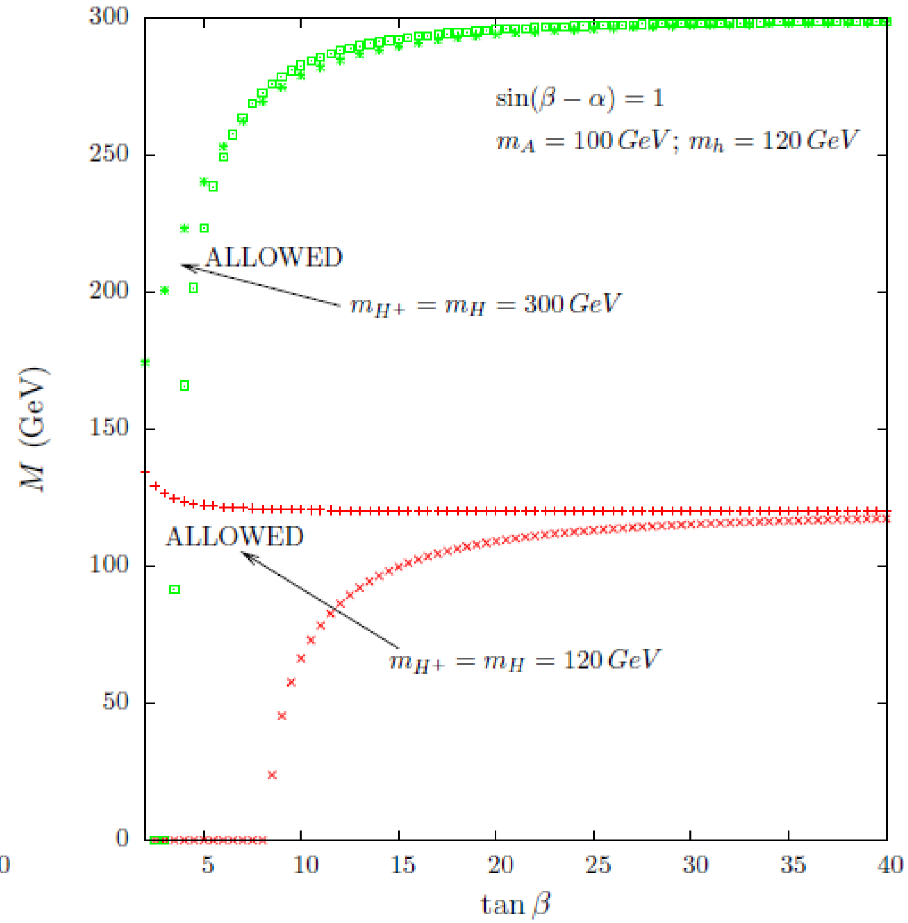




Choosing the benchmarks

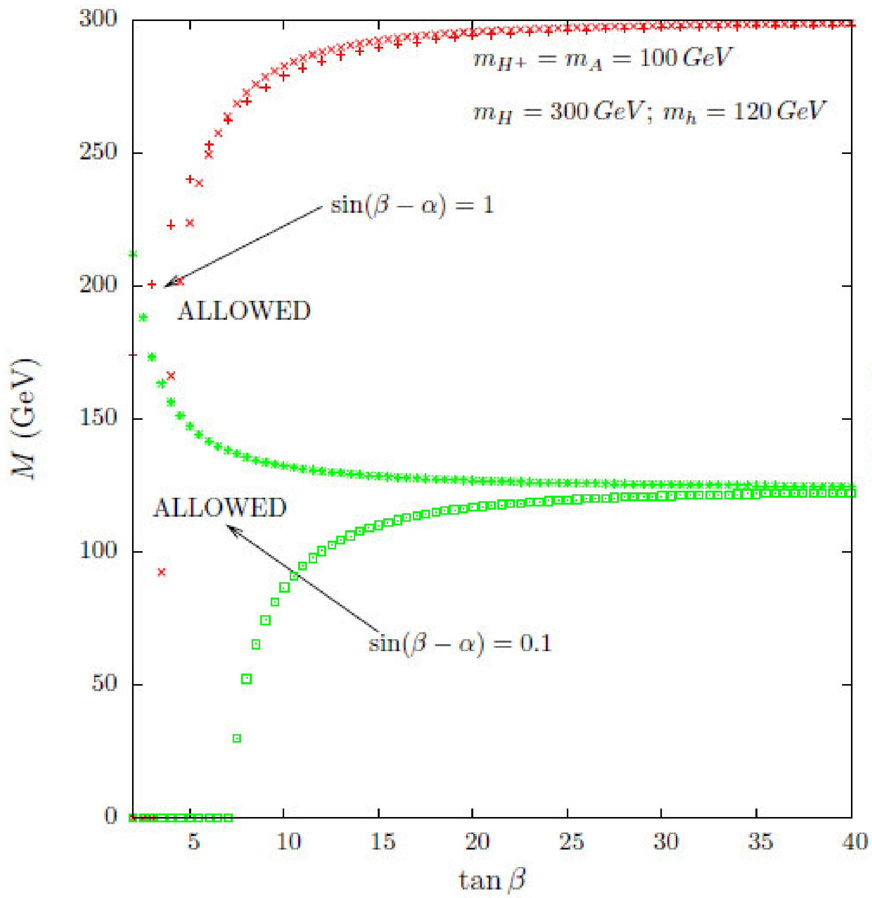
- **Remaining parameters are fixed by the theoretical constraints - tree-level vacuum stability and perturbative unitarity.**

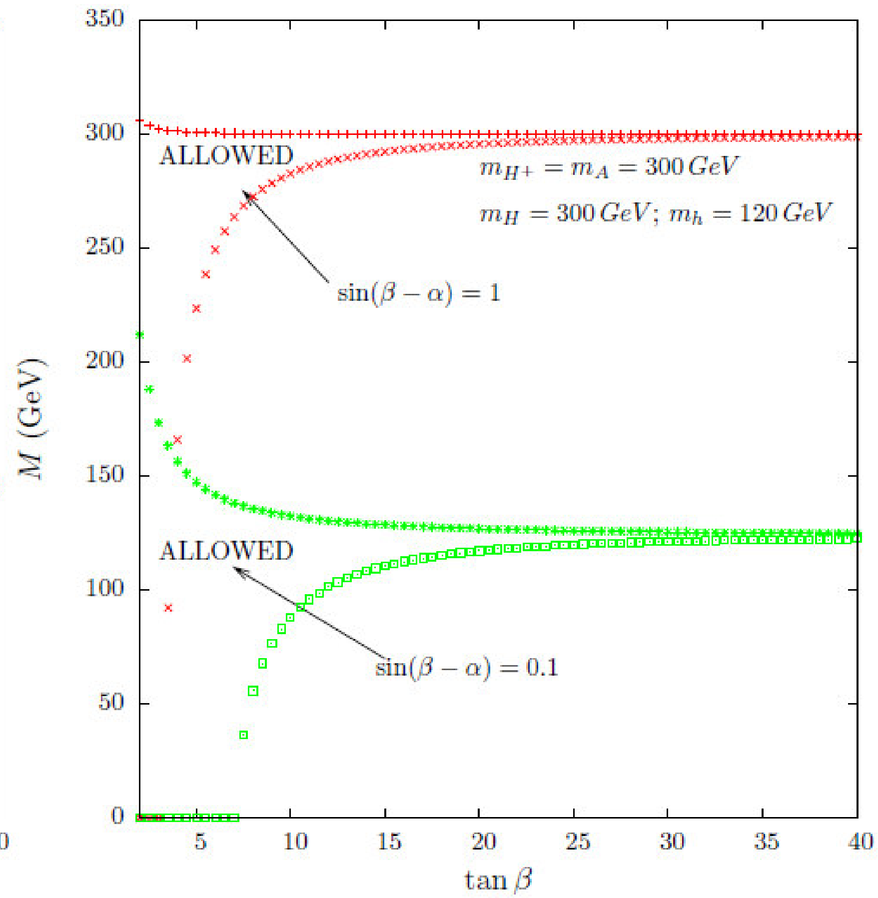




Choosing the benchmarks

- **More of the same**





List of production processes

- $gg + q\bar{q} \longrightarrow b\bar{t}H^+$
- $bQ \longrightarrow bQ'H^+$
- $gg, b\bar{b} \longrightarrow W^-H^+$
- $q\bar{q} \longrightarrow H^+H^-$
- $gg, b\bar{b} \longrightarrow H^+H^-$
- $qQ \longrightarrow q'Q'H^+H^-$
- $gg \longrightarrow b\bar{b}H^+H^-$
- $qQ \longrightarrow H^+h(H, A)$

Feynman diagrams

First set of benchmarks – the SM-like limit

$\sin(\beta - \alpha) = 1$ $\qquad m_h = 120\ GeV$

$$(g_{hVV})^{SM} \approx (g_{hVV})^{2HDM};\ (g_{hff})^{SM} \approx (g_{hff})^{2HDM};\ (g_{hhh})^{SM} \approx (g_{hhh})^{2HDM}$$

- B1a: $m_{H^\pm} = m_A = 100\,GeV$; $m_H = M = 130\,GeV$ and $\tan\beta = 1, 3, \sqrt{m_t/m_b}, 30$
- B1b: $m_{H^\pm} = m_A = 100\,GeV$; $m_H = 300\,GeV$; $M = 100\,GeV$ and $\tan\beta = 1, 3$
- B1c: $m_{H^\pm} = m_H = 130\,GeV$; $m_A = 300\,GeV$; $M = 100\,GeV$ and $\tan\beta = 1, 3$
- B2: $m_{H^\pm} = m_A = m_H = M = 300\,GeV$ and $\tan\beta = 1, 3, \sqrt{m_t/m_b}, 30$
- B3: $m_{H^\pm} = m_A = 300\,GeV$; $m_H = M = 130\,GeV$ and $\tan\beta = 1, 3, \sqrt{m_t/m_b}, 30$
- B4: $m_{H^\pm} = m_H = 300\,GeV$; $m_A = 100\,GeV$ and the pair of values $(M, \tan\beta) = (100, 1)$ and $(M, \tan\beta) = (200, 3)$

Single Higgs production

$$gg + q\bar{q} \rightarrow b\bar{t}H^+$$

Alwall and Rathsman 2004; Kidonakis 2005; Dittmaier et al 2009

Depends only on tanβ and on the charged Higgs mass

$m_{H^\pm} = 100$ GeV

Independent of $\sin(\beta - \alpha)$ and all other Higgs masses

tanβ	σ (pb)	I (cs)	I($\tau\nu$)	IV(cs)	IV($\tau\nu$)
1	522	162	360	162	360
3	82	26	56	0	82
7	15.6	4.9	10.7	0	15.6
30	0.86	0.27	0.59	0	0.86

Single Higgs production

$m_{H^\pm} = 300$ GeV

B2

tanβ	$\sigma_{I,X}$ (fb)	$\sigma_{II,Y}$ (fb)	I	II	X	Y
1	2189	2178	2189 (tb)	2178 (tb)	2189 (tb)	2178 (tb)
3	244	247	244 (tb)	247 (tb)	244 (tb)	247 (tb)
7	44	72	44 (tb)	64 (tb)	39 (tb)	72 (tb)
30	2.4	562	2.4 (tb)	433 (tb)	2.4 ($\tau\nu$)	562 (tb)

B3

tanβ	$\sigma_{I,X}$ (fb)	$\sigma_{II,Y}$ (fb)	I	II	X	Y
1	2189	2178	1576 (tb)	1568 (tb)	1576 (tb)	1568 (tb)
3	244	247	190 (hW)	190 (hW)	190 (hW)	190 (hW)
7	44	72	42 (hW)	66 (hW)	41 (hW)	66 (hW)
30	2.4	562	2.4 (hW)	309 (hW)	2.0 (hW)	348 (hW)

Difference between models II and Y does not increase much as tanβ grows

$m_{H^\pm} = 300$ GeV

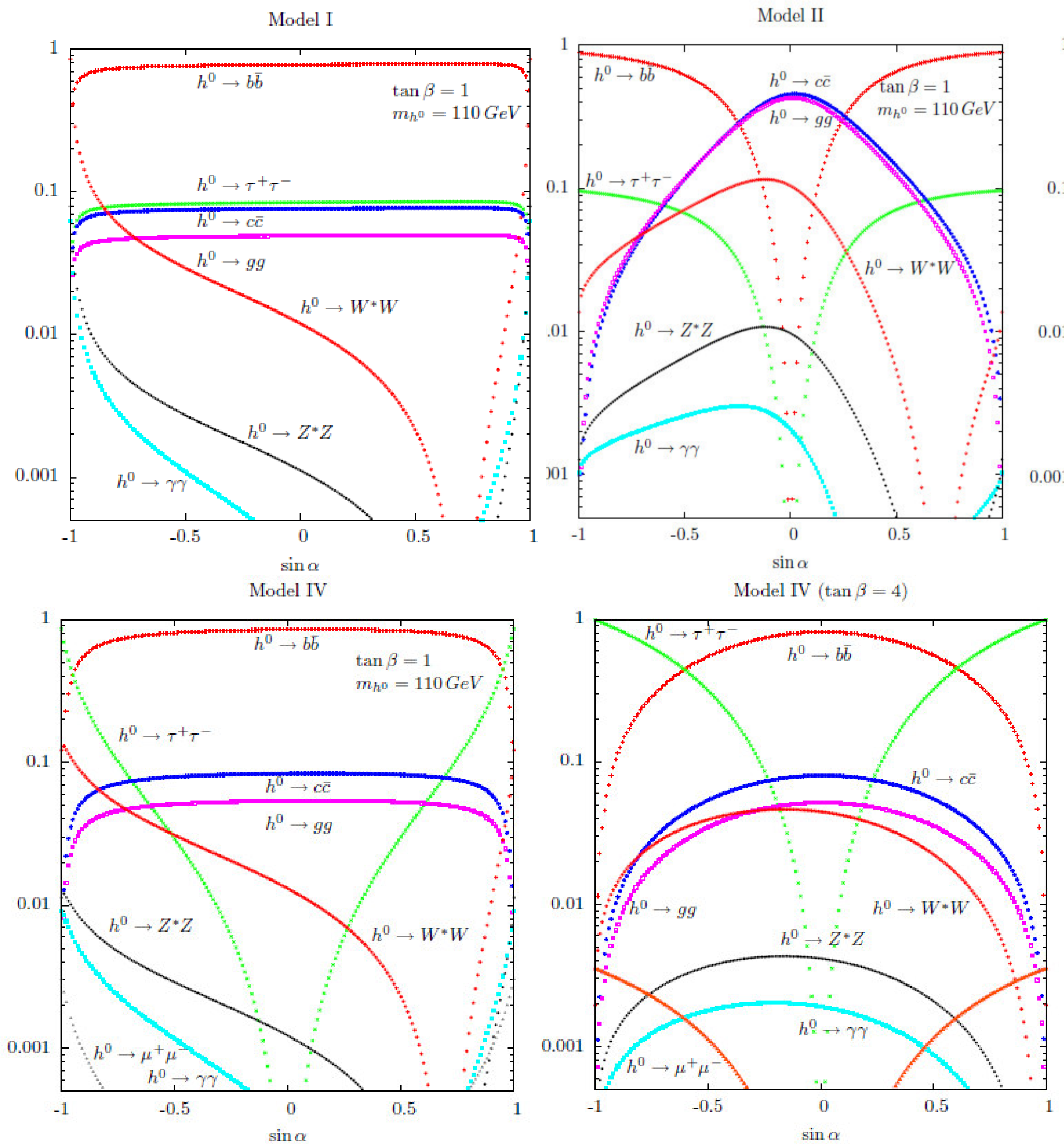
Single Higgs production

B4

tanβ	$\sigma_{I,X}$ (fb)	$\sigma_{II,Y}$ (fb)	I	II	X	Y
1	2189	2178	1394 (tb)	1387 (tb)	1394 (tb)	1387 (tb)
3	244	247	204 (AW)	206 (AW)	204 (AW)	206 (AW)
7	44	72	42 (AW)	68 (AW)	42 (AW)	66 (AW)
30	2.4	562	2.4 (AW)	363 (AW)	2.1 (AW)	393 (AW)

$\sin(\beta - \alpha) = 0$ **B4 → 100 % hW+AW for all tanβ except tanβ =1**

- **For the other benchmarks hW+AW is always dominant (except tanβ =1)**
- $b\bar{b} \longrightarrow b\bar{t}H^+$ → **Always at the percent level – no information on the potential**



There are still some chances of distinguishing between models for hW final states

Single Higgs production

- $bQ \to bQ' H^+$

Diagrams that could tell us something about the potential are always negligible. No triple scalar vertices present.

Diagrams related to single top production give the largest contribution of the order of 10 % of tbH production for 100 GeV charged Higgs.

tanβ	σ (pb)	I (cs)	I($\tau\nu$)	IV(cs)	IV($\tau\nu$)
1	67	21	46	21	46
3	7.4	2.3	5.1	0	7.4

Negligible for 300 GeV

- $gg + b\bar{b} \to W^- H^+$ — Asakawa, Brein and Kanemura 2005

Cross sections can reach the pbarn level for all models and even for a charged Higgs mass of 300 GeV (except large tanβ and heavy charged Higgs in models I and X)

As compared to the MSSM we can have a reduction of the strong negative interference and resonant propagator contributions.

Higgs pair (+ 2 jets (VBF))

- $q\bar{q} \rightarrow H^+H^-$

Best scenario: ≈ 200 fb in models I and X for the light charged Higgs with 100 % decay to τν.

- $qQ \rightarrow q'Q'H^+H^-$ S. Moretti 2004

$$\lambda^{SM-like}_{H^\pm H^\pm h} = \frac{2}{v}\left[-\frac{m_h^2}{2} + M^2 - m_{H^\pm}^2\right]$$

$$\lambda^{SM-like}_{W^+W^-h} = \lambda^{SM}_{W^+W^-h}$$

$$\lambda^{SM-like}_{W^+W^-H} = 0$$

no tanβ dependence

How large lambda has to be to get a measurable cross section?

$M = 130$ GeV $\Rightarrow$ $\sigma \sim$ fb

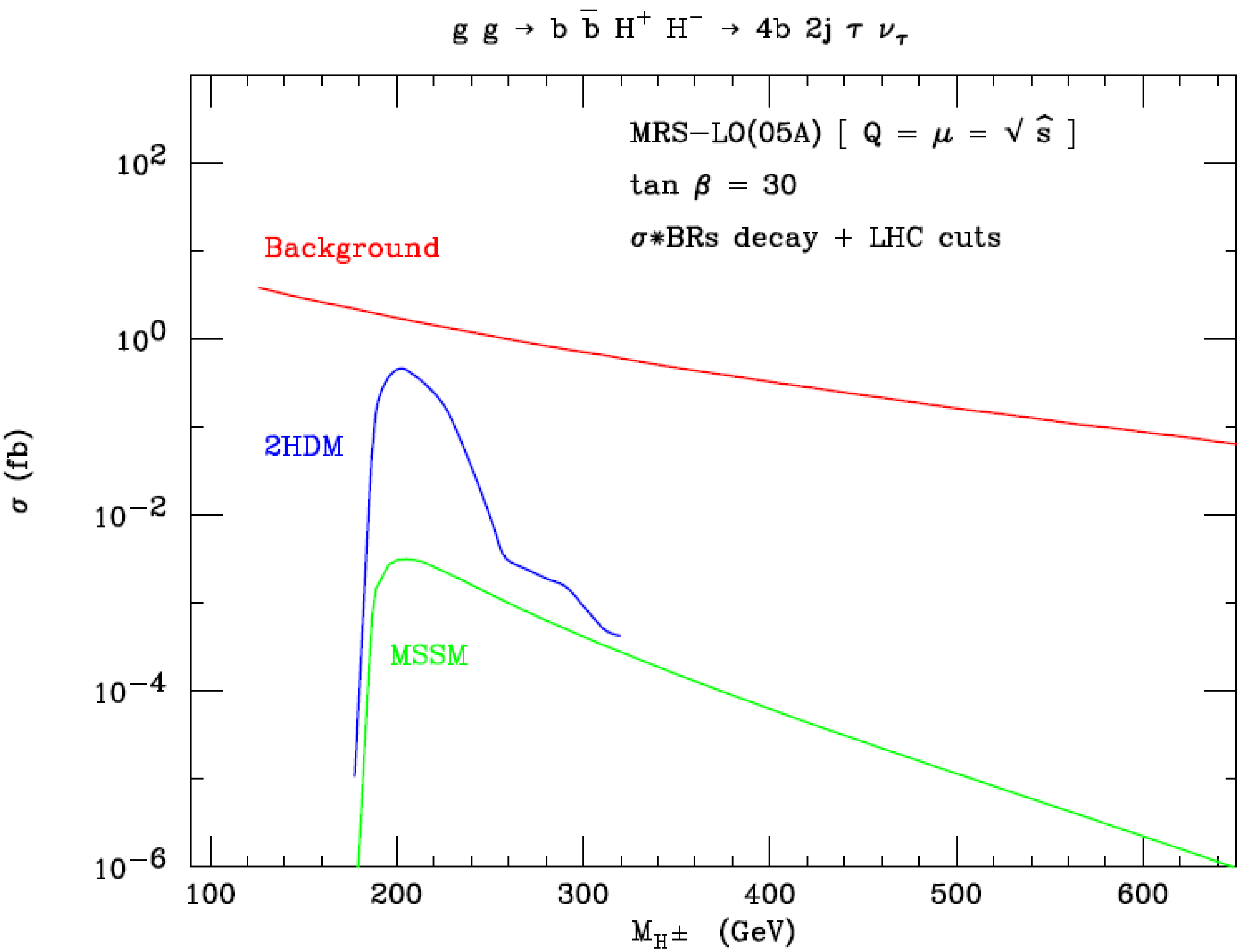
$M^2 = -(500)^2$ GeV $\Rightarrow$ $\sigma \sim 150$ fb

Stills needs a lot of luminosity

Higgs pair + 2 b-jets

$$gg \to b\bar{b}H^+H^-$$

Moretti, Rathsman 2004



Resonant production + larger couplings

Conclusions and Outlook

• Production processes that depend only on $\tan\beta$ are MSSM-like. However signatures can be different.

• The Yukawa versions have significantly different cross sections only for large $\tan\beta$.

• If the final states involve neutral Higgs, signatures can differ from model to model.

• In loop processes cancelations between diagrams can be reduced leading to an increase in the cross sections.

• Resonant production can take place – Higgs masses are not as constrained as in the MSSM.

• List of processes to be added include resonant production via cb fusion, W+Higgs production and pair production (gg+bb).

the end

Higgs pair production

$$\left\{ \begin{array}{l} q\bar{q} \longrightarrow H^+H^- \\ b\bar{b} \longrightarrow H^+H^- \\ gg \longrightarrow H^+H^- \end{array} \right.$$

All tanβ

$$\sigma^{I}_{q\bar{q}\to H^+H^-} > \sigma^{I}_{gg\to H^+H^-} > \sigma^{I}_{b\bar{b}\to H^+H^-}$$

$$\sigma^{II}_{q\bar{q}\to H^+H^-} > \sigma^{II}_{gg\to H^+H^-} > \sigma^{II}_{b\bar{b}\to H^+H^-}$$

low tanβ

high tanβ

$$\sigma^{II}_{gg\to H^+H^-} > \sigma^{II}_{q\bar{q}\to H^+H^-} > \sigma^{II}_{b\bar{b}\to H^+H^-}$$

Alves and Plehn 2005

Except for resonant production and/or large self-couplings and/or large Yukawa couplings.

$$\lambda^{SM-like}_{H^\pm H^\pm h} = \frac{2}{v}\left[-\frac{m_h^2}{2} + M^2 - m^2_{H^\pm}\right]$$

$$\lambda^{SM-like}_{\bar{b}bh} = \lambda^{SM}_{\bar{b}bh}$$

$$\lambda^{I,SM-like}_{\bar{b}bH} = -\frac{1}{\tan\beta}\lambda^{SM}_{\bar{b}bh}$$

$$\lambda^{SM-like}_{H^\pm H^\pm H} = -\frac{1-\tan^2\beta}{v\tan\beta}\left[-m_H^2 + M^2\right]$$

$$\lambda^{II,SM-like}_{\bar{b}bH} = \tan\beta\,\lambda^{SM}_{\bar{b}bh}$$

In models I and X the best one can have is ≈ 200 fb with 100 % decay to τν.

Single Higgs production

$$qQ \rightarrow qQ'H^{+}$$

Exists only when q=b. The diagrams that could tell us something about the potential are always negligible. There are no triple scalar vertices present.

Diagrams related to single top production give the largest contribution of the order of 10 % of tbH production for 100 GeV charged Higgs.

tanβ	σ (pb)	I (cs)	I($\tau\nu$)	IV(cs)	IV($\tau\nu$)
1	67	21	46	21	46
3	7.4	2.3	5.1	0	7.4

For models II and Y and a charged Higgs mass of 300 GeV the contribution is negligible.

Single Higgs production

$$gg + b\bar{b} \rightarrow W^- H^+$$

Asakawa, Brein and Kanemura 2005

Cross sections can reach the pbarn level for small tanβ < 3 for models I and X for light charged Higgs.

In models II and Y cross sections can reach the pbarn level for all tanβ and for a charged Higgs of 300 GeV.

As compared to the MSSM we can have a reduction of the strong negative interference and resonant propagator contributions.