Mass of the charged Higgs boson in 2HDM: decoupling and CP violation

Maria Krawczyk, Warsaw U.

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In this talk:

- Basics of the Two-Higgs-Doublet Model (2HDM)
- Explicite CP conserving 2HDM
- Spontaneous CP violation for exact and softly broken Z_2 symmetry
- Mass of the charged Higgs boson
- Model II and the constraints on M_{H^+} from low energy experiments

Symmetries of the 2HDM model

I. Ginzburg, MK, P. Osland hep-ph/0101208,0101229,0211371;IG&MK PRD'05;
H. Haber, MK in hep-ph/0608079 - CERN Report 2006

$$V_{2HDM} = \frac{1}{2}\lambda_1(\phi_1^\dagger\phi_1)^2 + \frac{1}{2}\lambda_2(\phi_2^\dagger\phi_2)^2 + \lambda_3(\phi_1^\dagger\phi_1)(\phi_2^\dagger\phi_2) + \lambda_4(\phi_1^\dagger\phi_2)(\phi_2^\dagger\phi_1)$$
$$+\frac{1}{2}\left[\lambda_5(\phi_1^\dagger\phi_2)^2 + \text{h.c.}\right] + \left[(\lambda_6(\phi_1^\dagger\phi_1) + \lambda_7(\phi_2^\dagger\phi_2))(\phi_1^\dagger\phi_2) + \text{h.c.}\right]$$
$$-\frac{1}{2}\left\{m_{11}^2(\phi_1^\dagger\phi_1) + \left[m_{12}^2(\phi_1^\dagger\phi_2) + \text{h.c.}\right] + m_{22}^2(\phi_2^\dagger\phi_2)\right\}$$

In general 14 parameters: $\lambda_1, \lambda_2, \lambda_3, \lambda_4$, $\lambda_5, \lambda_6, \lambda_7$, m_{11}^2, m_{22}^2, m_{12}^2
however only $\boxed{\mathbf{11}}$ independent physical parameters

Z_2 transf. $\phi_1 \to -\phi_1$, $\phi_2 \to \phi_2$ $(1 \leftrightarrow 2)$; mixed terms $(\phi_1^\dagger\phi_2)$ in V

Z_2-symmetry if $\lambda_6 = \lambda_7 = m_{12}^2 = 0$

Soft Z_2 breaking is governed by a single parameter $\mathrm{Re}\, m_{12}^2 \sim \mu^2 = \nu\, v^2$

Lee, Veltman,Weinberg, Glashow, Diaz-Cruz, Mendez, Haber, Pomarol, Barroso, Santos, Hollik, Pokorski, Rosiek, Djouadi, Illiana, Branco, Rebelo, Zerwas, Gunion, Grzadkowski, Kalinowski, Akeroyd, Arhrib, Dubnin, Froggatt, Sher, Pilaftsis, Kanemura, Okada, Carena, Davidson, Ivanov, Nachtmann...

Symmetries of Two Higgs Doublet Model

I. F. Ginzburg, M. K., hep-ph/0408011 (PRD'05); I. F. Ginzburg at PLC2005

• 2HDM allows for CP violation Lee' 73; Glashow and Weinberg'77- CP violation and the tree level flavour changing neutral currents (FCNC) can be naturally suppressed by imposing in Lagrangian (V and Yukawa interaction) a Z_2 symmetry, that is the invariance of L under

$$(\phi_1 \leftrightarrow \phi_1, \phi_2 \leftrightarrow -\phi_2) \quad \text{or} \quad (\phi_1 \leftrightarrow -\phi_1, \phi_2 \leftrightarrow \phi_2).$$

Note, that hard Z_2 violation eg.term $\lambda_7(\phi_2^\dagger\phi_2)(\phi_2^\dagger\phi_1)$ leads to FCNC in contrast to the soft Z_2 violation

• 2HDM contains two fields, ϕ_1 and ϕ_2, with identical quantum numbers: $T = 1/2$ and $Y = +1$, so global transformations which mix these fields and change the relative phases are allowed without changing physical picture (apparent hard Z_2 violation, $\tan\beta$ may change, apparent CP violation ..)

Transformation of fields

Two fields (doublets) with identical quantum numbers: a global unitary transf. which mix these fields and change the phases, $\hat{\mathcal{F}} = \hat{\mathcal{F}}(\rho_0; \rho, \tau, \theta)$:

$$\begin{pmatrix} \phi_1' \\ \phi_2' \end{pmatrix} = \hat{\mathcal{F}} \begin{pmatrix} \phi_1 \\ \phi_2 \end{pmatrix}, \quad \hat{\mathcal{F}} = e^{-i\rho_0} \begin{pmatrix} \cos\theta\, e^{i\rho/2} & \sin\theta\, e^{i(\tau-\rho)/2} \\ -\sin\theta\, e^{-i(\tau-\rho)/2} & \cos\theta\, e^{-i\rho/2} \end{pmatrix}$$

ρ_0 - an overall phase; relevant other 3 parameters

$\rightarrow$ PHASE ROTATION AND MIXING OF FIELDS (changing field basis)

The particular case $\theta = 0$ - no mixing, independent phase rotations:

$$\phi_{1,2} \rightarrow e^{-i\rho_{1,2}} \phi_{1,2}; \quad \rho_1 = \rho_0 - \rho/2, \;\; \rho_2 = \rho_0 + \rho/2, \;\; \rho = \rho_2 - \rho_1 \,.$$

$\rightarrow$ PHASE ROTATION FOR FIELDS (rephasing fields)

Transformation of fields leads to the induced
REPARAMETRIZATION TRANSFORMATION OF LAGRANGIAN

Reparametrization group

•Reparametrization transf. - the 3–parametrical (ρ, τ, θ) *reparametrization group, operating in the space of Lagrangians* with coordinates given by λ_i, m^2_{ij} $\rightarrow$ A reparametrization invariance

•A set of the physically equivalent Lagrangians - *the reparametrization equivalent space* (a subspace of the entire space of L).

•"Family of Lagrangians" with explicit property - eg.with a soft Z_2 viol.

Rephasing group

A particular reparametrization wit $\theta = 0$ is equivalent to a change of phase of the *complex* parameters of Lagrangian :

$$\lambda_5 \rightarrow \lambda_5\, e^{-2i\rho}\,, \quad \lambda_{6,7} \rightarrow \lambda_{6,7}\, e^{-i\rho}\,, m^2_{12} \rightarrow m^2_{12} e^{-i\rho}.$$

$\rightarrow$ A rephasing invariance.

•Rephasing transformations - the 1–parametrical rephasing group with *the rephasing parameter* ρ $\rightarrow$ subgroup of the reparametrization group

•*Rephasing equivalent space of Lagrangians*

Explicite and spontaneus CP violation in 2HDM

The complex values of some of parameters in V provide *a necessary condition* for the CP violation in the Higgs potential. If V can be reparametrized so that all parameters became real - no explicite CP violation is present.

Below I will assume this case (all parameters in V real) and will look at the possible spontaneous CP breaking. To simplified analysis only the exact and softly broken Z_2 case will be considered (ie. $\lambda_6 = \lambda_7 = 0$) - (work with D. Sokołowska)

Diaz-Cruz..,Lin..,Branco..,Barroso..,Haber..,Gunion...

The most general VEV

The most general VEV can be reduced to the form

$$\langle\phi_1\rangle = \begin{pmatrix} 0 \\ \frac{1}{\sqrt{2}}v_1 \end{pmatrix}, \quad \langle\phi_2\rangle = \begin{pmatrix} u \\ \frac{1}{\sqrt{2}}v_2' e^{i\xi} \end{pmatrix}.$$

with v_1, v_2', u, ξ real ($v^2 = v_1^2 + v_2'^2 = (246\text{GeV})^2$).
$u \neq 0$ corresponds to *a charged vacuum*, with a heavy photon, charge nonconservation, etc

Diaz-Cruz, Mendez'1992, Barroso, Ferreira, Santos..'94,'04,'05, Ginzburg'05

Veltman' 97 - ..introducing more than one scalar doublet has the obvious disadvantage that in general no zero mass vector boson survives. In other words, the observed zero photon mass is then 'accident'. New results by Barosso et al - seems it is no accident

Extremum conditions

$$\left.\frac{\partial V}{\partial \phi_1}\right|_{\substack{\phi_1=\langle\phi_1\rangle,\\ \phi_2=\langle\phi_2\rangle}} = 0, \qquad \left.\frac{\partial V}{\partial \phi_2}\right|_{\substack{\phi_1=\langle\phi_1\rangle,\\ \phi_2=\langle\phi_2\rangle}} = 0.$$

lead to following set of conditions:

- $[(\lambda_4 + \lambda_5)v_1 v_2' cos\xi - m_{12}]u = 0$
- $[(\lambda_5 - \lambda_4)v_1 v_2' sin\xi]u = 0$
- $[2\lambda_5 v_1 v_2' cos\xi - m_{12}]v_2' sin\xi = 0$

etc.

To fulfil - [..]=0, and/or $u = 0$, and sin$\xi = 0$

To get minimum eigenvalues of the squared mass matrix should be positive.

Masses for $u = 0, sin\xi = 0$ (CP consv)

•For $m_{12} = 0 \rightarrow Z_2$ symmetry:

$$M_{H+}^2 = -\frac{v^2}{2}(\lambda_5 + \lambda_4)$$

and

$$M_A^2 = -\lambda_5 v^2$$

In order to get positive mass squared: $\lambda_5 < 0$, while $|\lambda_5| > \lambda_4$.

•For $m_{12} \neq 0 \rightarrow$ softZ_2 breakingin both masses there is extra term $m_{12}^2 v^2/2v_1v_2 = \nu v^2$, which is positive for $m_{12}^2 > 0$.

Positive squared masses for $\nu - \lambda_5 > 0$ and $2\nu - (\lambda_5 + \lambda_4) > 0$

Note that large masses can be obtained by large $\nu \rightarrow$ *decoupling*

Masses for $u = 0, sin\xi \neq 0$ (CP violation)

- For $m_{12} = 0 \rightarrow Z_2$ symmetry there is no CP violation.
- For $m_{12} \neq 0 \rightarrow$ soft Z_2 breaking - CP violation possible

Here $cos\xi = \nu/\lambda_5$, and therefore $|\nu/\lambda_5| < 1$

$$M^2_{H^+} = \frac{v^2}{2}(\lambda_5 - \lambda_4) \text{ and } M^2_A = v^2(\lambda_5^2 - \nu^2)/\lambda_5$$

with λ_5 positive, larger than ν, and $\lambda_5 > \lambda_4$

Note, that there is no ν dependence in mass of H^+, also possible large mass of A can no be governed by ν

So, there is no-decoupling expected here, and masses of H^+ and A can not be too large (unitarity constraints)

Constraints on model

The parameters of Higgs potential are constrained by conditions:

- positivity (vacuum stability) constraints
- minimum constraints
- tree-level unitarity and perturbativity constraints,

The positivity and unitarity constraints for the case of a soft Z_2 violation (Ma 1978, Ginzburg 2003, Kastening1992, Kanemura 1999, Gunion 2002) The unitarity constraints in the CP conserving case (Huffel 1980, Akeroyd 2000), for soft and hard Z_2 symmetry violation and CP violation (Ginzburg, Ivanov 2003 and 2005)

- To have a *stable vacuum*, the potential must be positive at large quasi–classical values of fields $|\phi_k|$ (*positivity constraints*) for an arbitrary direction in the (ϕ_1, ϕ_2) plane. It is enough to consider only quartic terms of the potential.
- To have a minimum not eg. saddle point This condition is realized if the physical mass squared, are positive: $M^2_{h_{1-3}}$, $M^2_{H^\pm} > 0$.
- The (λ_i) are transformed to the quartic self–couplings of the physical Higgs bosons. They lead, in the tree approximation, to the s–wave

Higgs-Higgs and $W_L W_L$ and $W_L H$, etc. scattering amplitudes for different elastic channels. These amplitudes should not overcome unitary limit for this partial wave – that is *the tree-level unitarity constraint*.

•The *perturbativity condition (constraint)* for a validity of a tree approximation in the description of some particular phenomena (e.g. interactions of the lightest Higgs boson h_1) may be less restrictive.

Heavy Higgs bosons and non-decoupling

Decoupling property and masses of heavy Higgs bosons depend on ν^2 ($\nu = m_{12}^2/2v_1v_2$) for CP conserving case, since

- $M_{H^\pm}^2 = v^2[\nu - \frac{1}{2}(\lambda_4 + \lambda_5)]$, $M_A^2 = v^2[\nu - \lambda_5]$

- small $\nu \to$ non-decoupling observed
eg. h SM-like (tree) with deviation from SM for loop couplings due to heavy Higgs particles; unitarity constraints (for λ_i) crucial if heavy Higgs bosons exist and ν is small

- large $\nu \to$ decoupling, h SM-like (tree and loop couplings)

- hH^+H^- coupling sensitive to ν (important for $\gamma\gamma h$):
$\gamma\gamma h$ has 10 % deviation due to H^+, 2 % accuracy at $\gamma\gamma$ collider

Existing constraints for 2HDM (II) with CP conservation

CP conserv. 2HDM(II) with soft violation of Z_2 symmetry (ν^2 term):

$\Rightarrow$ five Higgs bosons: h,H,A,$H^{\pm}$

$\Rightarrow$ 7 parameters: $M_h, M_H, M_A, M_{H^{\pm}}$, α, $\tan\beta$, and ν^2

MODEL II (as in MSSM)

Couplings (relative to SM):	h	A
to W/Z:	$\chi_V = \sin(\beta-\alpha)$	0
to down quarks/leptons:	$\chi_d = \chi_V - \sqrt{1-\chi_V^2}\tan\beta$	$-i\gamma_5\tan\beta$
to up quarks:	$\chi_u = \chi_V + \sqrt{1-\chi_V^2}/\tan\beta$	$-i\gamma_5/\tan\beta$

- For H couplings like for h with:

$\sin(\beta-\alpha) \leftrightarrow \cos(\beta-\alpha)$ and $\tan\beta \rightarrow -\tan\beta$.

- For large $\tan\beta \rightarrow$ enhanced couplings to $d-$type fermions (and τ, μ, e)!

- $\chi^h_{VH^+} = \cos(\beta-\alpha)$ - complementarity to hVV!

DATA

LEP • **direct:**(h) **Bjorken process** $Z \to Zh$, $\to \sin(\beta - \alpha)$

(hA) **pair prod.** $e^+e^- \to hA$, $\to \cos(\beta - \alpha)$

(h/A) **Yukawa process** $e^+e^- \to bbh/A$, $\tau\tau h/A$, $\to \tan\beta$

($H^\pm$) $e^+e^- \to H^+H^-$

via loop:(h/A, **and** $H^\pm$) $Z \to h/A\gamma$ $\to$ **large and small** $\tan\beta$

Others exp.• **via loop:**(h/A) $\Upsilon \to h/A\gamma$ $\to$ **upper limits for** χ_d

loop: ($H^\pm$) $b \to s\gamma$, $\to$ **lower limit for** $M_{H^\pm}$

leptonic tau decay $\to$ $\to$ **lower & upper limit for** $M_{H^\pm}$

g-2 data , $\to$ **allowed bound for** χ_d

Global fit (2HDM) • **(all Higgses)**

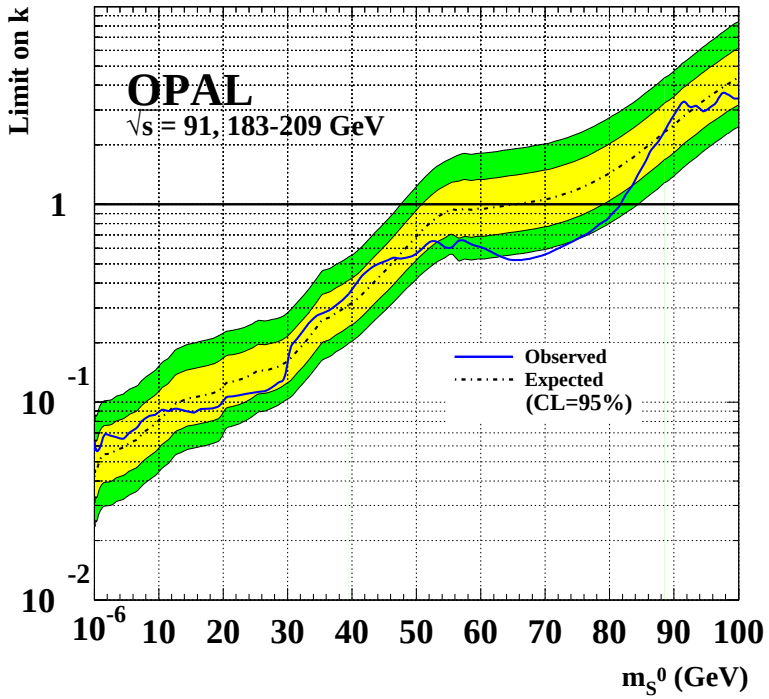
Chankowski at al.,'99 (EPJC 11,661;PL B496,195)

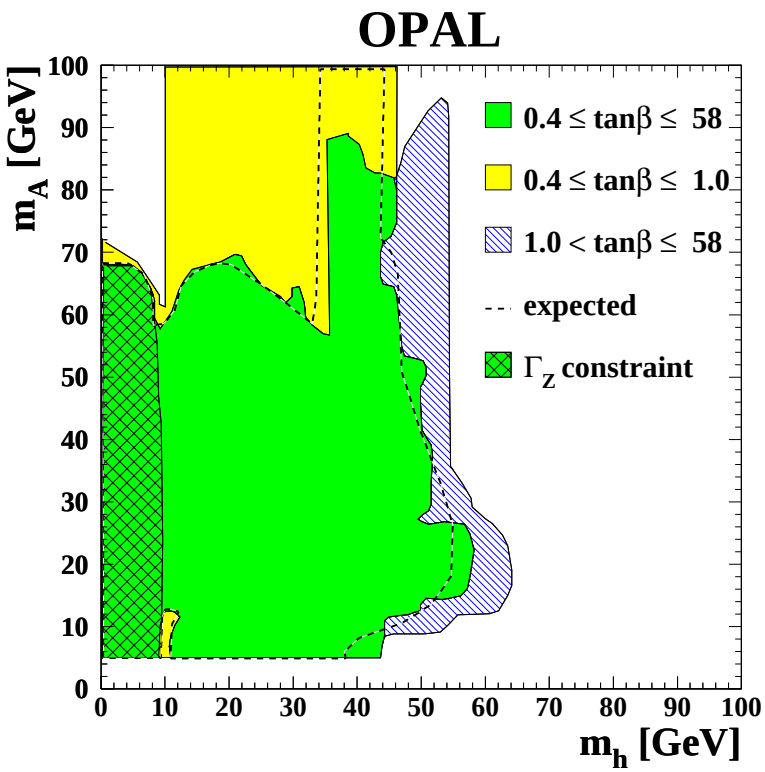
Cheung and Kong '03 **Akesson et al...**

Neutral Higgs bosons - couplings to gauge boson, and mass exclusion

Light h OR light A in agreement with current data

hZZ: $sin(\beta - \alpha)$ and hAZ: $cos(\beta - \alpha)$





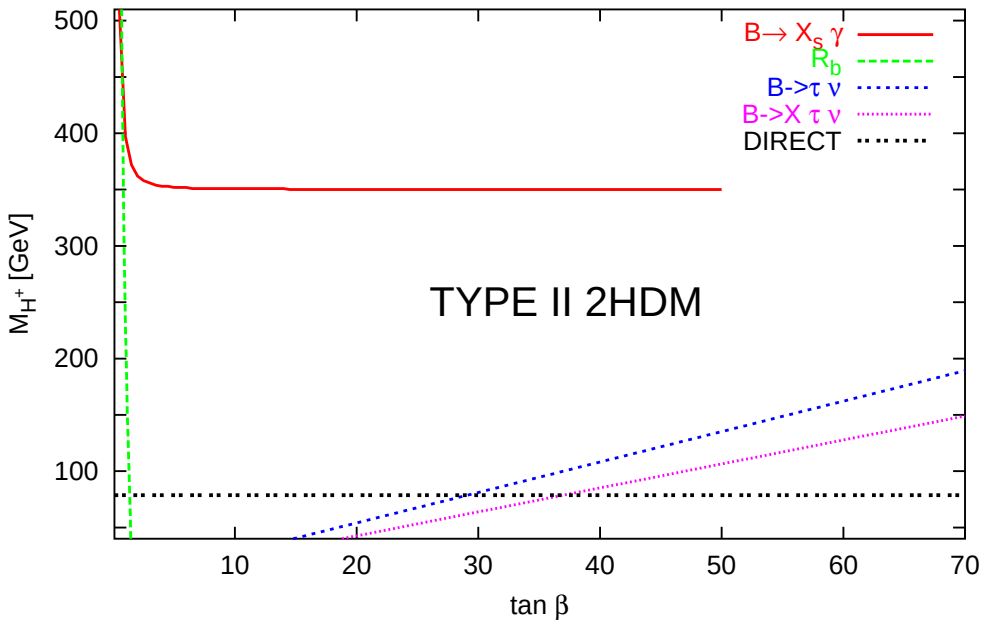
Light scalar $h \rightarrow$ small $k = sin^2(\beta - \alpha)$!

Constraints from $b \to s\gamma$ - Gambino, Misiak'01

Strong constraints on new physics from $\bar{B} \to X_s\gamma$
The weighted average for $\mathrm{BR}_\gamma \equiv \mathrm{BR}[\bar{B} \to X_s\gamma]$

$$\mathrm{BR}_\gamma^{\mathrm{exp}} = (3.23 \pm 0.42) \times 10^{-4}$$

NLO prediction (Misiak, Gambino'01): M_{H+} above 490 GeV (95%)



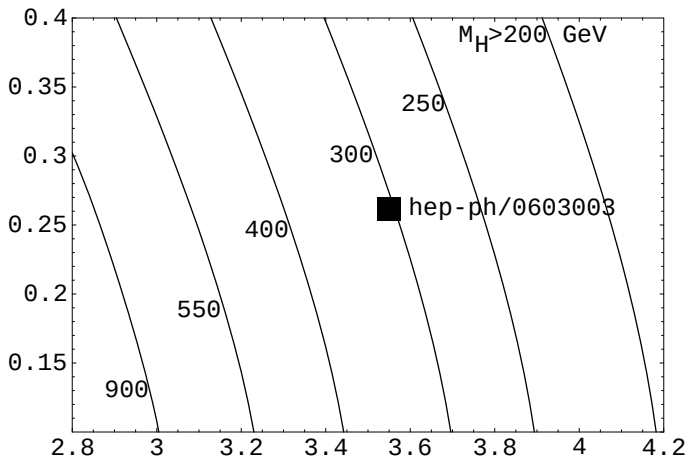
Here lower mass limit 350 GeV corresponds to 99 % CL !

New analysis - A. D. 2006

NNLO QCD calculations by Greub, Czakon, Steinhauser, Haisch, Gambino, Gorbahn, Ewert, Asatrian, Hovhannisyan, Poghosyan, Hurth, Blokland, Slusarczyk, Tkachov, Czarnecki, Misiak (Misiak talk at EURIDICE Meeting in August 2006, Kazimierz)

$$Br(B \to X_s\gamma)^{NNLO}_{E_\gamma} \geq 1.6GeV = (3.17 \pm 9.25) \times 10^{-4}$$

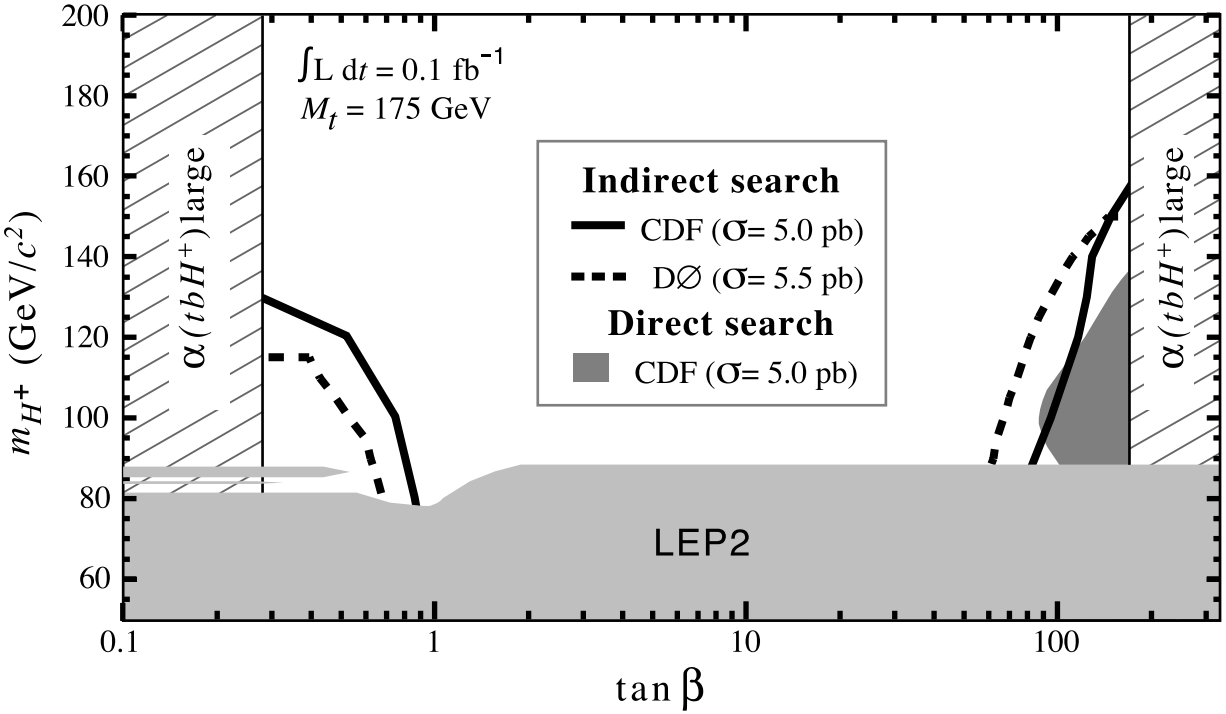
Using the latest HFAG average for BR^{exp} 3.55 $\pm 0.24^{+0.09}_{-0.10} \pm 0.03) \times 10^{-4}$ (hep-ex/0603003, not yet the new BaBar results from hep-ex/0607071)



So, the lower limit on mass of the charged Higgs is 300 GeV (95% CL)

(axis: y- error on exp. Br and x- exp. Br times 10^4)

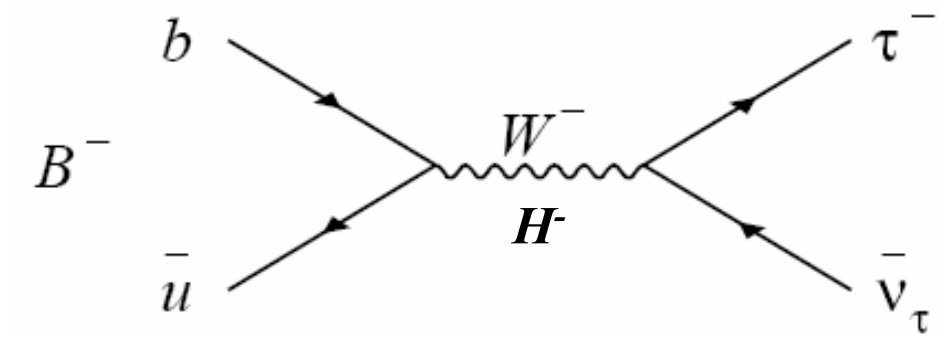
Direct and undirect limits for charged Higgs boson - PDG2004



Tevatron and LEP limits (90 GeV)

$B^+ \to \tau^+\nu$

Simple decay through weak annihilation



Sensitive to B decay constant f_B or to charged Higgs boson

$$\mathcal{B}(B_u \to \tau\nu)^{\rm SM} = \frac{G_F^2 m_B m_\tau^2}{8\pi}\left(1-\frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B = (1.59 \pm 0.40)\times 10^{-4}$$

$\tan^4\beta$ modifications in 2HDM II model:

$$R_{B\tau\nu} = \frac{\mathcal{B}(B_u \to \tau\nu)}{\mathcal{B}(B_u \to \tau\nu)^{\rm SM}} = r_H = \left[1 - \tan^2\beta\,\frac{m_B^2}{m_{H^\pm}^2}\right]^2$$

f_B dependence can be removed via ratio with Δm_d, error shrinks 25% → <13% (Isidori & Paradisi)

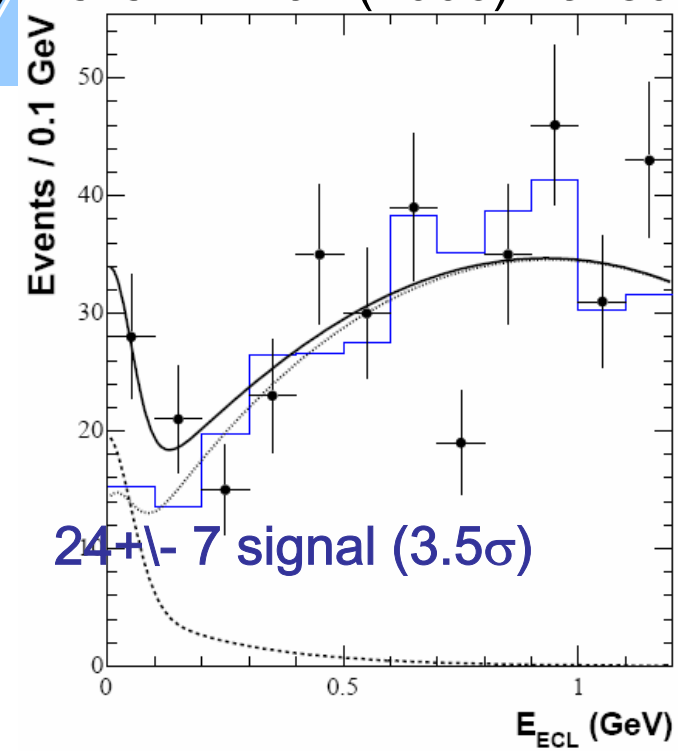
$$\left.\frac{\mathcal{B}(B_u \to \tau\nu)}{\tau_B \Delta M_{B_d}}\right|^{\rm SM} = 1.77\times 10^{-4}\left(\frac{|V_{ub}/V_{td}|}{0.464}\right)^2\left(\frac{0.836}{\hat{B}_{B_d}}\right)$$

$B^+ \to \tau^+\nu$

Belle PRL 97 (2006) 251802

Tag side reco of:
hadronic B decay (Belle, ε = 0.15%)
or D^0 l X ν decay (BaBar, ε = 0.6%)

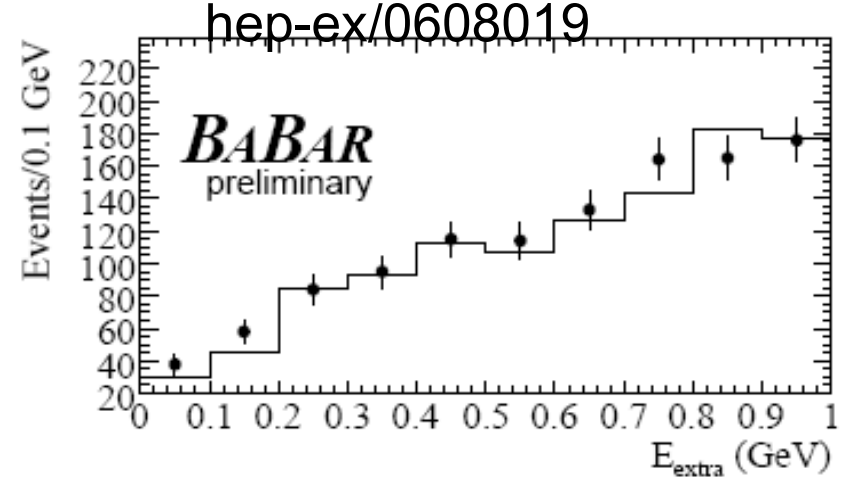
& signal side τ
(Belle: leptonic or 1- or 3-prong, ε = 16%)
(BaBar: leptonic or 1-prong, ε = 13%)
& no other tracks & small extra ECAL energy



hep-ex/0608019

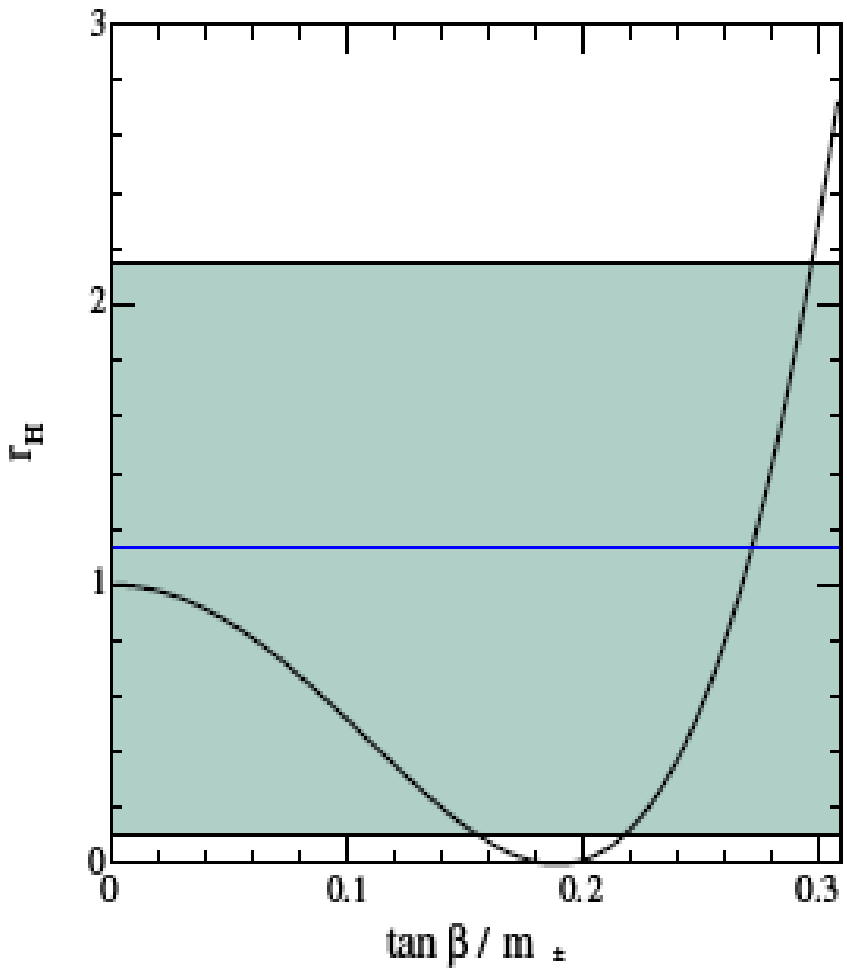
HFAG BF($B \to \tau\nu$) = 1.34 ± 0.48 10^{-4}

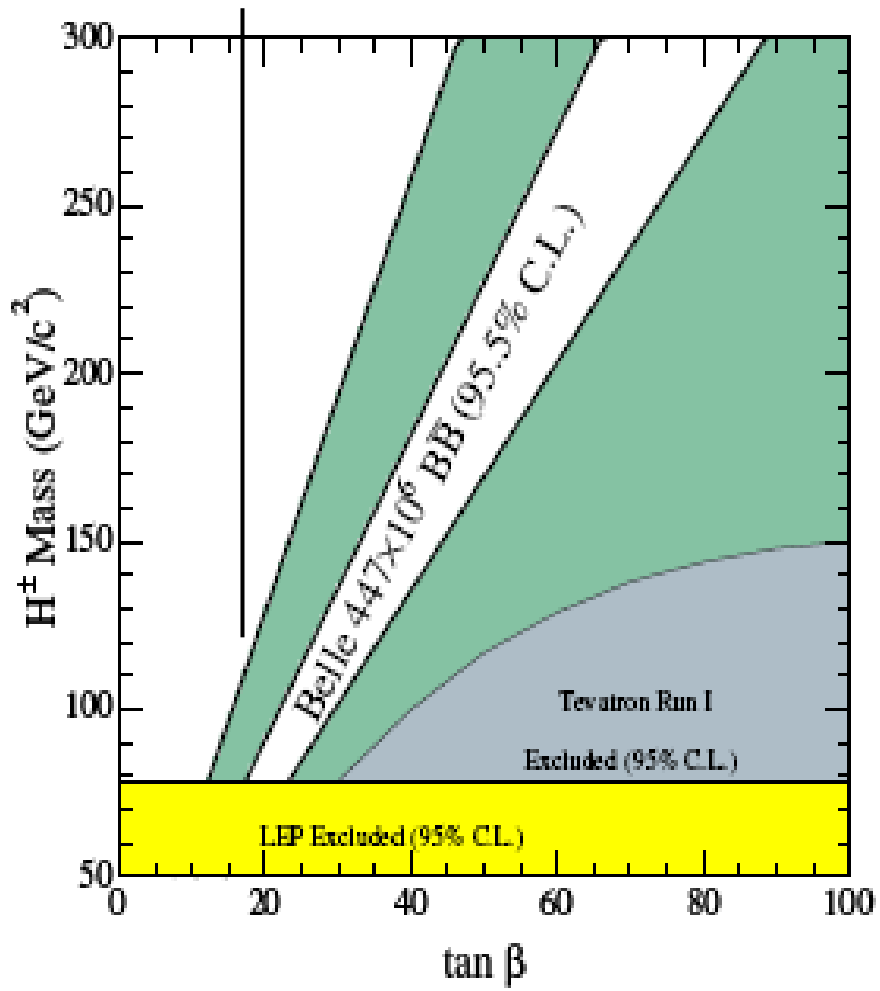
Consistent with SM.



$B^+ \rightarrow \tau^+\nu$

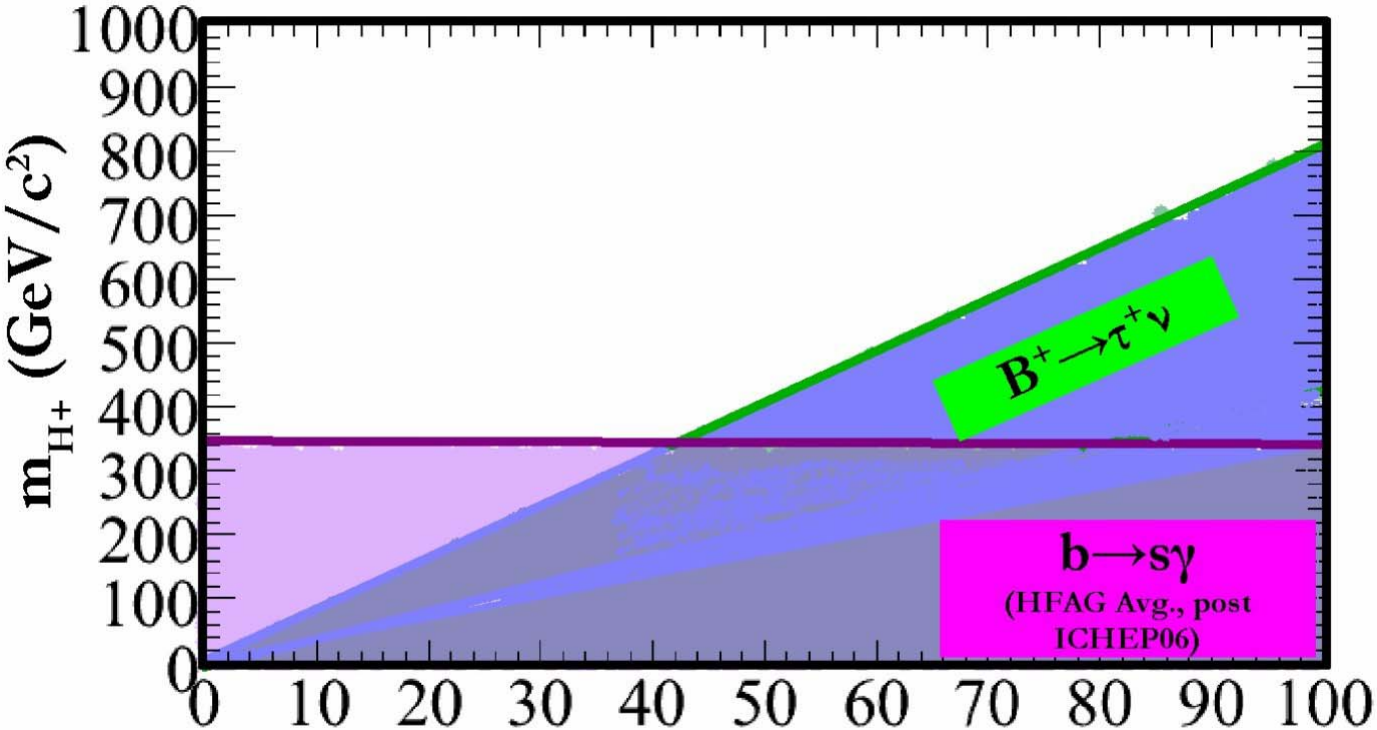
Belle result excludes (at tan β = 30) M(H+) < 100, 130 < M(H+) < 190 GeV





MK'07

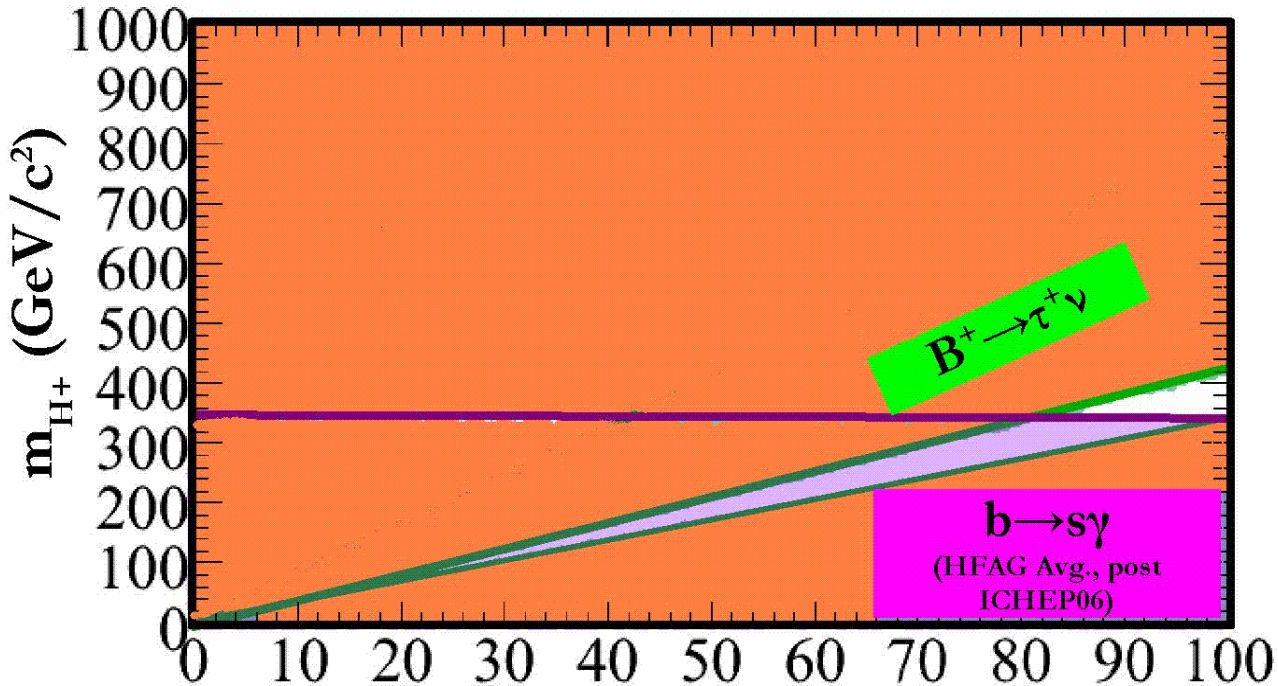
Current Constraints on 2HDM



Shaded regions are excluded at 90% CL

MK'07

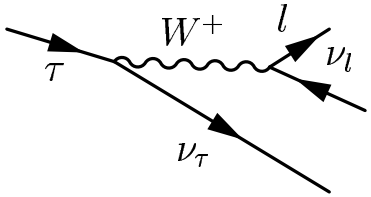
Current Constraints on 2HDM

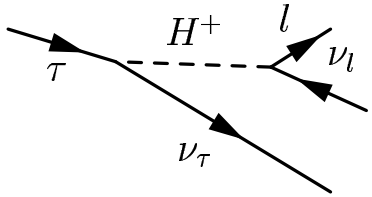


Shaded regions are excluded at 90% CL

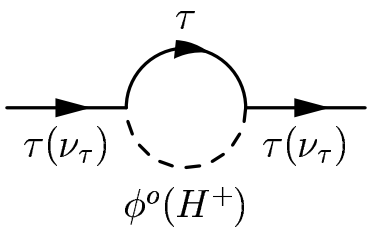
Leptonic tau decays

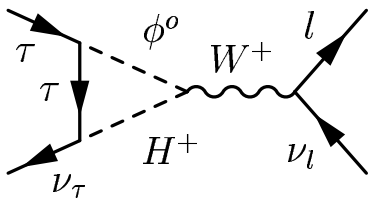
In SM - tree-level W exchange, in 2HDM: tree-level charged Higgs





In 2HDM loop corrections involve also neutral Higgs bosons $\rightarrow$ dominant contributions at large $\tan\beta$ ($\phi^0 = h, H, A$)





- with D. Temes, EPJC 44, 435 (2005)

The branching ratios for leptonic decays

- We consider $\tau \to e\bar{\nu}_e\nu_\tau$ and $\tau \to \mu\bar{\nu}_\mu\nu_\tau$.
- The '04 world av. data for the leptonic τ decays and τ lifetime:

$$Br^e|_{exp} = (17.84 \pm 0.06)\%, \quad Br^\mu|_{exp} = (17.37 \pm 0.06)\%$$

$$\tau_\tau = (290.6 \pm 1.1) \times 10^{-15} s.$$

- The SM prediction and a possible beyond the SM contribution $\to \Delta^l$

$$Br^l|_{SM} = \frac{\Gamma^l|_{SM}}{\Gamma^{tot}_{exp}} = \Gamma^l|_{SM}\tau_\tau \quad Br^l = Br^l|_{SM}(1 + \Delta^l)$$

$$Br^e|_{SM} = (17.80 \pm 0.07)\%, \; Br^\mu|_{SM} = (17.32 \pm 0.07)\%.$$

$$\Delta^e = (0.20 \pm 0.51)\%, \quad \Delta^\mu = (0.26 \pm 0.52)\%.$$

- 95% C.L. bounds on Δ^l, for the electron and muon decay mode:

$$(-0.80 \leq \Delta^e \leq 1.21)\%, \quad (-0.76 \leq \Delta^\mu \leq 1.27)\%.$$

Partial widths or leptonic τ decays: SM vs 2HDM

SM at tree-level = the $W^{\pm}$ exchange (with leading order corrections to the W propagator, and dominant QED one-loop contributions)

2HDM extra tree contribution due to the exchange of H^{+}

$$\Gamma_{tree}^{H^{\pm}} = \Gamma_0 \left[\frac{m_\tau^2 m_l^2 \tan^4\beta}{4M_{H^{\pm}}^4} - 2\frac{m_l m_\tau \tan^2\beta}{M_{H^{\pm}}^2}\frac{m_l}{m_\tau}\kappa\left(\frac{m_l^2}{m_\tau^2}\right)\right],$$

where $\kappa(x) = \frac{g(x)}{f(x)}$, $g(x) = 1 + 9x - 9x^2 - x^3 + 6x(1+x)\ln(x)$.

The second term - from the interference with the SM - much more important. It gives negative contribution to Br:

$$-m_l^2/M_{H^{\pm}}^2 \tan\beta^2$$

One loop contribution for large $\tan\beta$

$$\Delta_{oneloop} \approx \frac{G_F m_\tau^2}{8\sqrt{2}\pi^2} \tan^2\beta\, \tilde{\Delta}$$

$$\tilde{\Delta} = \left[-\left(\ln\left(\frac{M_{H^+}^2}{m_\tau^2}\right) + F(R_{H^\pm}) \right) + \frac{1}{2}\left(\ln\left(\frac{M_A^2}{m_\tau^2}\right) + F(R_A) \right) + \frac{1}{2}\cos^2(\beta-\alpha)\left(\ln\left(\frac{M_h^2}{m_\tau^2}\right) + F(R_h) \right) + \frac{1}{2}\sin^2(\beta-\alpha)\left(\ln\left(\frac{M_H^2}{m_\tau^2}\right) + F(R_H) \right) \right], \quad (1)$$

where $R_\phi \equiv M_\phi / M_{H^\pm}$ and $F(R) = -1 + 2\,R^2 \ln R^2/(1-R^2)$

NOTE, $\tilde{\Delta}$ does not depend on m_τ!

Loop corrections are the same for e and μ channels

The exact and approximated expressions can not be distinguished

Loop corrections for some scenarios

Interesting scenarios: $\sin^2(\beta-\alpha)=0$, any, 1

•light h and $\sin^2(\beta-\alpha)=0$, $\rightarrow \tilde{\Delta}$ does not depend on M_H:

$$M_A = M_{H^\pm} \rightarrow \tilde{\Delta} = \ln\frac{M_h}{M_{H^\pm}}+1 \text{ or } M_A \ll M_{H^\pm} \rightarrow \tilde{\Delta} = \ln\frac{M_h}{M_{H^\pm}}+\ln\frac{M_A}{M_{H^\pm}}+2.$$

h does not couple to gauge bosons and the Higgsstrahlung process at LEP is not sensitive to such Higgs boson. The leptonic tau decays have maximal sensitivity to h!

•For arbitrary $\sin^2(\beta-\alpha)$ and degenerate $H, A, H^\pm$ (with mass M):

$$\tilde{\Delta} = \cos^2(\beta-\alpha)\ [\ln\frac{M_h}{M}+1].$$

•SM-like scenario, with light h, $\sin^2(\beta-\alpha)=1$ and very heavy degenerate additional Higgs bosons: $\tilde{\Delta}\rightarrow 0$ (decoupling)

Mass charged Higgs boson

If the tree level H^+ exchange only (as in PDG04, Dova98, Stahl'97..): we obtain the 95% CL deviation from the SM prediction

$$M_{H^\pm} \gtrsim 1.71 \tan\beta \text{ GeV}$$

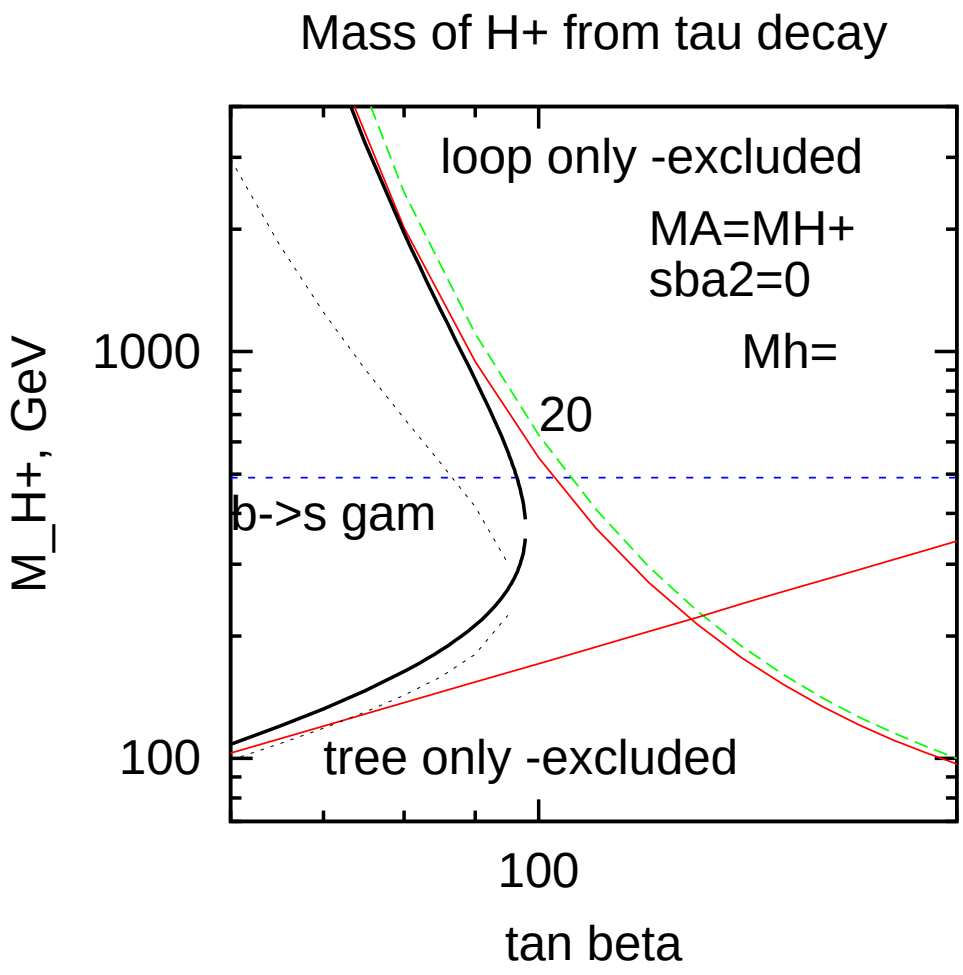
coefficient to be compared to 1.86 (1.4) from Dova at al (Stahl)

(the Michel parameter η in the 2HDM (II))

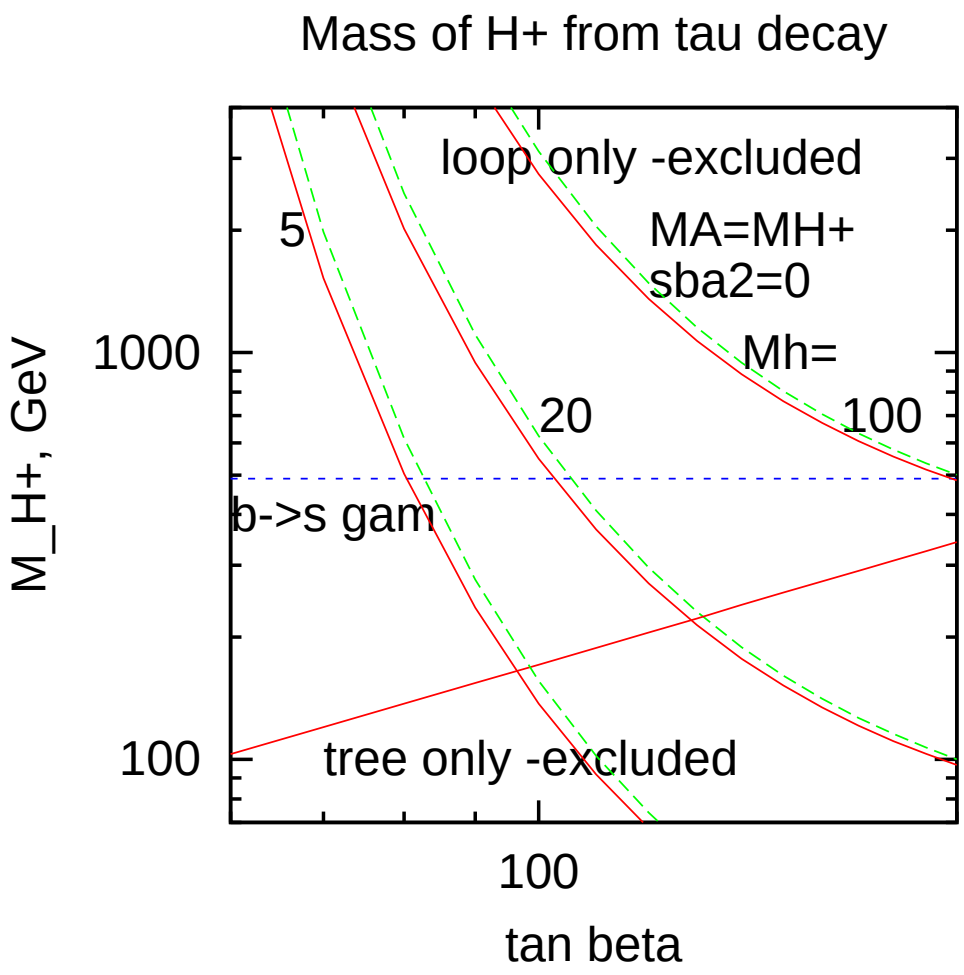
New results (2006) from $B \to \tau\nu_\tau$ give coefficient 8-10 !

However loop effects large...

Limits for mass of H^+: One-loop and tree contr.



dotted: $M_A = 100$ GeV; μ (red), e (green) (old $b \to s\gamma$)



The upper limits:

for $M_h = 5, 20, 100$ GeV and $\sin^2(\beta - \alpha) = 0$, assuming $M_A = M_{H+}$

2HDM - an ideal laboratory for BSM

Large activity during last years with focus on

- Non-decoupling
- Reparametrization invariance
- Vacuum structure
- Constraints on potential
- Phenomenology of the 2HDM (mainly CP conserv. Model II for Yukawa interaction - where ϕ_2 couples to up-type quarks, ϕ_1 to down-type quraks and charged leptons)

- More results is coming