# Leptonic $\tau$ decays in 2HDM

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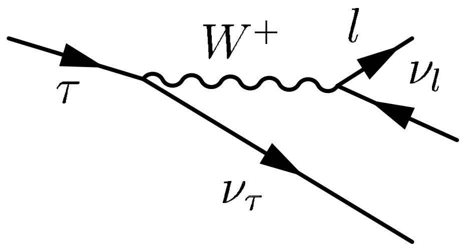
with David Temes – hep-ph/0410248 [EPJC 44(2005)435]

Outlook

- The leptonic tau decays
- Two Higgs Doublet Model (CP conservation)
- Large loop corrections for leptonic tau decays
- Constraints on masses and couplings for neutral and charged Higgs bosons

# The $\tau$ lepton

A unique laboratory to test the Standard Model and beyond




The coupling of the $\tau$ lepton to the $W$: $g_\tau$ = coupling $(\tau \nu_\tau W)$

In Standard Model → lepton universality: $g_e = g_\mu = g_\tau$

- Radiative corrections in 2HDM –Rosiek '90
- A $\tau$ puzzle '92: Data on leptonic branching ratio too low by $2.5\sigma$ than expected in SM

→ "Tau decay in the two Higgs doublet model": Guth, Hoang, Kuhn '92
→ "Can a second Higgs doublet diminish the leptonic tau decay width?" Hollik, Sack '92,

- Precise data in agreement with SM - can be used to constrain 2HDM

# 2HDM models without and with CP violation

2HDM Potential with quartic and quadratic terms separated:

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

In general 14 parameters: $\lambda_1, \lambda_2, \lambda_3, \lambda_4$, $\lambda_5, \lambda_6, \lambda_7$, $m_{11}^2$, $m_{22}^2$, $m_{12}^2$

The $(\phi_1, \phi_2)$ mixing $\leftrightarrow Z_2$ symmetry: $\phi_1 \to -\phi_1$, $\phi_2 \to \phi_2$ (or $1 \leftrightarrow 2$)

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

soft violation of $Z_2$ symmetry governed by $\mu^2 \sim \text{Re}\, m_{12}$

Lee, Diaz-Cruz, Mendez, Haber, Pomarol, Barroso, Santos, Hollik, Djouadi, Illana, Branco,Gunion, Grzadkowski,Akeroyd, Arhrib, Dubnin, Froggatt, Sher, Pilaftsis, Carena.. Kalinowski, Zerwas, Choi, Kanemura, Okada,.

# Symmetries of Two Higgs Doublet Model

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

• 2HDM contains two fields, $\phi_1$ and $\phi_2$, with identical quantum numbers: weak isodoublets ($T = 1/2$) with hypercharges $Y = +1$

•Global transformations which mix these fields and change the relative phases are allowed without changing physical picture

• One of the reason for introducing 2HDM was to describe phenomenon of CP violation Lee' 73; Glashow and Weinberg'77-
CP violation and the flavour changing neutral currents (FCNC) can be naturally suppressed by imposing in Lagrangian a $Z_2$ symmetry, that is the invariance of the Lagrangian under the interchange

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

This symmetry forbids the $\phi_1 \leftrightarrow \phi_2$ transition.

Branco, Rebelo' 85

# Symmetries of 2HDM

Weinberg, Glashow, '77; Branco, Rebelo '85 - '05; Botella, Silva '94, Botella, Nebot, Vives, Lavoura 95,04..Ginzburg, MK '04, Ivanov'05, Haber, Gunion'05

Two fields with identical quantum numbers $\rightarrow$ mixing

A global unitary transformation U(1)x SU(2):

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

This transformation induces changes in parameters of L:

$$\lambda_i \rightarrow \lambda_i' \text{ and } m_{ij}^2 \rightarrow (m')_{ij}^2$$

A space of Lagrangians with coordinates given by parameters of L...

• A reparametrization transformation (RPaT) $\lambda_i \rightarrow \lambda_i'$ and $m_{ij}^2 \rightarrow (m')_{ij}^2$ - 3 parametrical group with parameters: $\rho$, $\theta$, $\tau$

•A reparametrization invariance $\rightarrow$ a reparametrization equivalent space of L (3-dim subspace in 14-dim space)

*Physical observables invariant of the RPaT like masses. But not* $\tan\beta$*!*

•The rephasing transformation group - one parameter only $\rho$.

## Reparametrization: Lagrangian and $Z_2$ symmetry

The violation of the $Z_2$ symmetry allows for the $\phi_1 \leftrightarrow \phi_2$ transitions.

•Exact $\boldsymbol{Z_2}$ symmetry. $\lambda_6 = \lambda_7 = m_{12}^2 = 0$. Only $\lambda_5$ can be complex, by rephasing $\rightarrow \lambda_5$ real.

•A soft violation of $\boldsymbol{Z_2}$ symmetry. Adding to the $Z_2$ symmetric Lagrangian the term $m_{12}^2(\phi_1^\dagger \phi_2) + h.c.$, with a generally complex $m_{12}^2$; as before $\lambda_5$ can be made real by rephasing.

•A hard violation of $Z_2$ symmetry. (Operator dimension 4) with generally complex parameters $\lambda_6$, $\lambda_7$ are added to V with a softly broken $Z_2$ symmetry. The *true* hard violation of $Z_2$ - if $V$ cannot be transformed to the case of $Z_2$ conservation, nor its weak violation.

## Remarks on CP

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

# Vacuum

The extremes of the potential define the vacuum expectation values (v.e.v.'s) of the fields $\phi_{1,2}$

$$\left.\frac{\partial V}{\partial \phi_1}\right|_{\substack{\phi_1=\langle\phi_1\rangle,\\ \phi_2=\langle\phi_2\rangle}} = 0, \qquad \left.\frac{\partial V}{\partial \phi_2}\right|_{\substack{\phi_1=\langle\phi_1\rangle,\\ \phi_2=\langle\phi_2\rangle}} = 0. \tag{1}$$

The $\mathrm{U}(1)_{QED}$ symmetric one corresponds to the lower energy than the charged one (Diaz-Cruz, Mendez; Santos, Barroso, Velhinho, GK)

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

- The rephasing of fields shifts the phase difference $\xi$ as

$$\xi \to \xi - \rho\,. \tag{3}$$

so, the phase difference $\xi$ has no physical sense (Branco).

- The ratio $\tan\beta = \frac{v_2}{v_1}$ depends on reparametrization!

## CP conservation: Higgs masses and couplings

Physical content of the Higgs potential: $h, H, A, H^{\pm}$

- Higgs masses -
  Two cases: masses of $H^+, A, H$ can be large due
  large $\mu^2$ (decoupling) or large $\lambda' s$ (nondecoupling)
- Higgs trilinear couplings
- Higgs quartic couplings

Independent of the form of Higgs potential are:

- couplings to gauge bosons: $hWW$, $HWW$, while $AWW = AZZ = 0$
- couplings to fermions (Yukawa) e.g. Model **II**:

$\phi_1 \rightarrow u$-type fermions $\phi_2 \rightarrow d$-type fermions

The relative "basic couplings":

$$\chi_j^i = \frac{g_j^i}{g_j^{\text{SM}}} \qquad i = h, H, A; \; j = V, u, d$$

Relations between relative couplings: eg. $\Sigma_i (\chi_j^i)^2 = 1$, for $j = V, u, d$

# Existing constraints for 2HDM (II)

CP conserv. 2HDM(II) with soft violation of $Z_2$ symmetry ($\mu^2$ term):
$\Rightarrow$ five Higgs bosons: $h$,$H$,$A$,$H^{\pm}$
$\Rightarrow$ 7 parameters: $M_h, M_H, M_A, M_{H^{\pm}}$, $\alpha, \beta$, and $\mu^2$

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 $\tan\beta \to -\tan\beta$.

For large $\tan\beta \to$ enhanced couplings to $d-$type fermions (and $\tau, \mu, e$)!

$\chi^h_{VH+} = \cos(\beta-\alpha)$ - 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 $H^\pm$)** $Z \to h/A\gamma$

**Others exp.** • **via loop:($h/A$) Wilczek process** $\Upsilon \to h/A\gamma$

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

**leptonic tau decay** $\to$

**g-2 data ,** $\to$ **upper limit for** $\chi_d$

**Global fit** • **(all Higgses)**

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

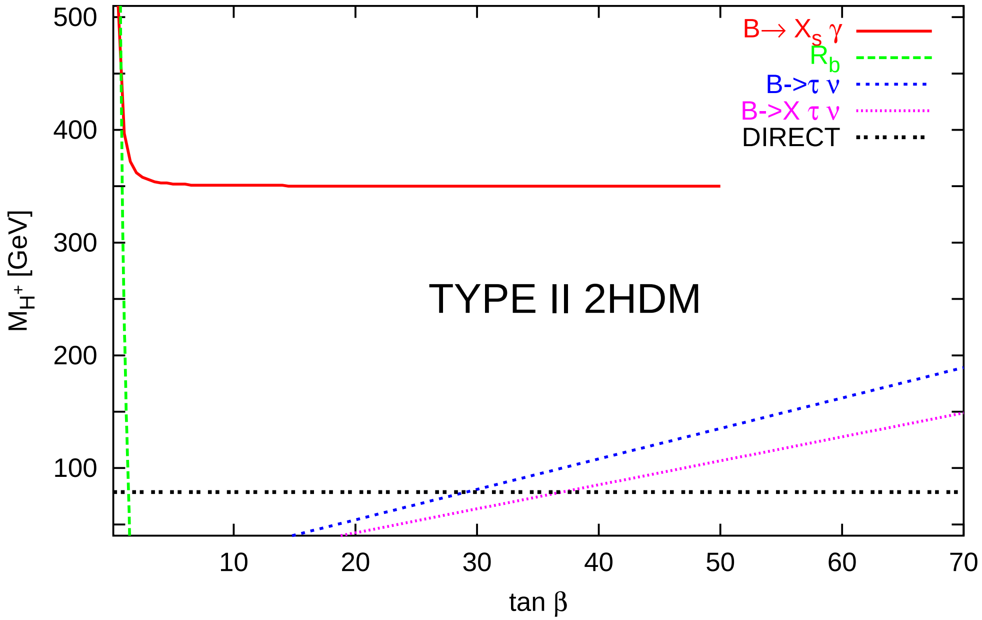
**Cheung and Kong '03**

# 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 $\mathrm{BR}_\gamma \equiv \mathrm{BR}[\bar{B} \to X_s\gamma]$

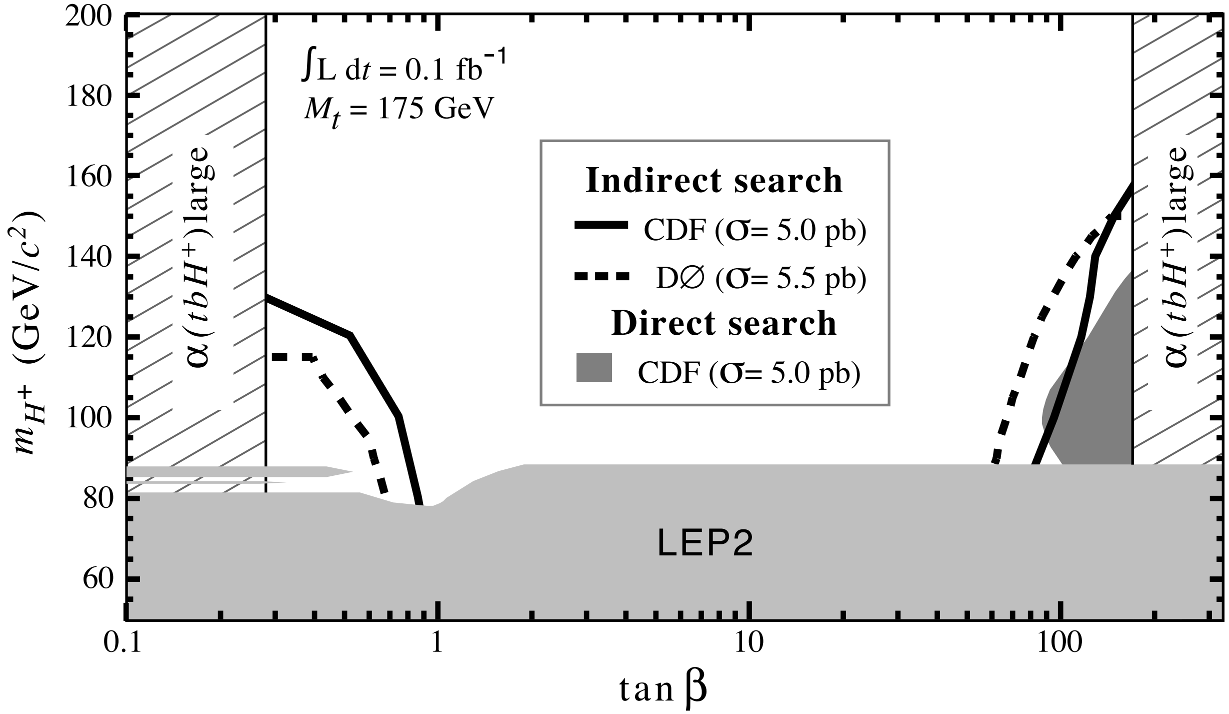
$$\mathrm{BR}_\gamma^{\mathrm{exp}} = (3.23 \pm 0.42) \times 10^{-4}$$

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




Here mass limit 350 GeV corresponds to 99 % CL !

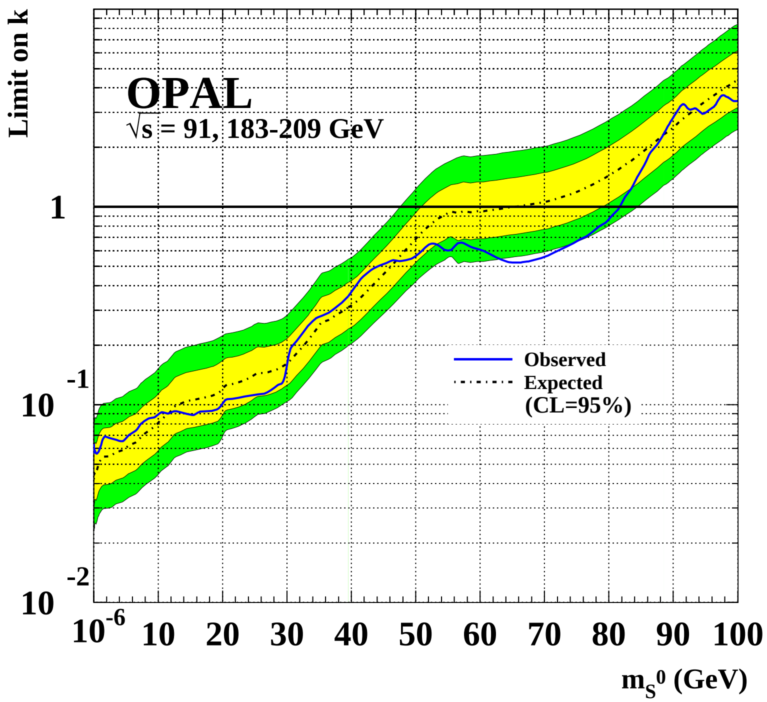
# Direct and undirect limits for charged Higgs boson - PDG2004

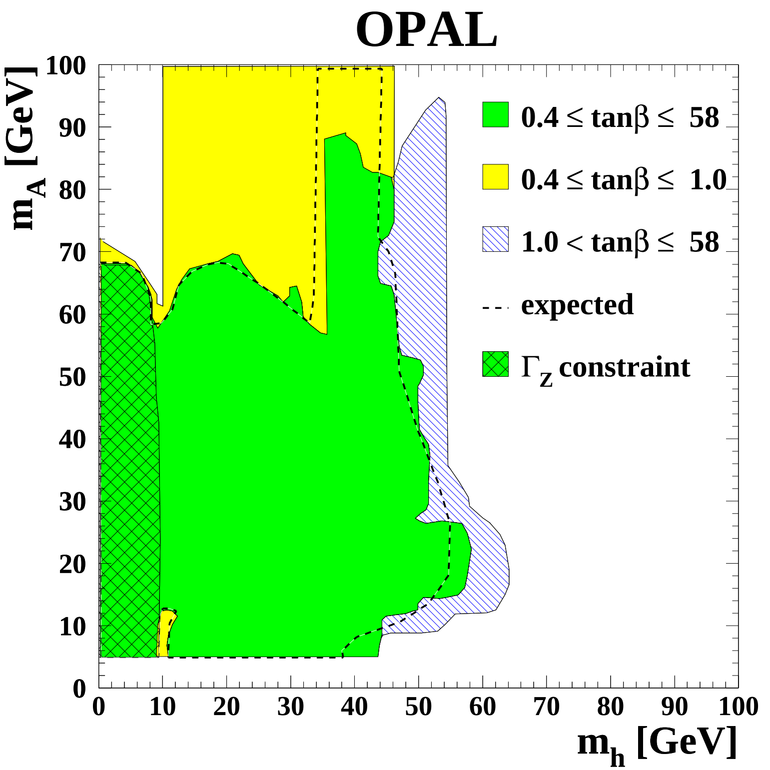



Tevatron and LEP limits (90 GeV)

## Light h OR light A in agreement with current data

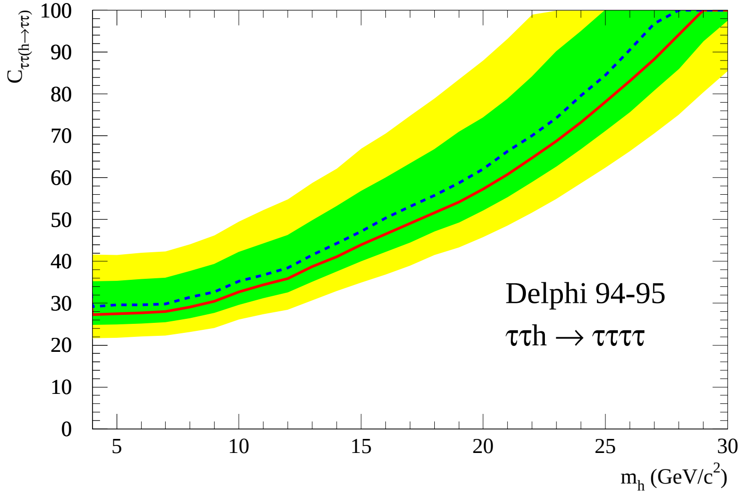
hZZ: $sin(\beta - \alpha)$ and hAZ: $cos(\beta - \alpha)$

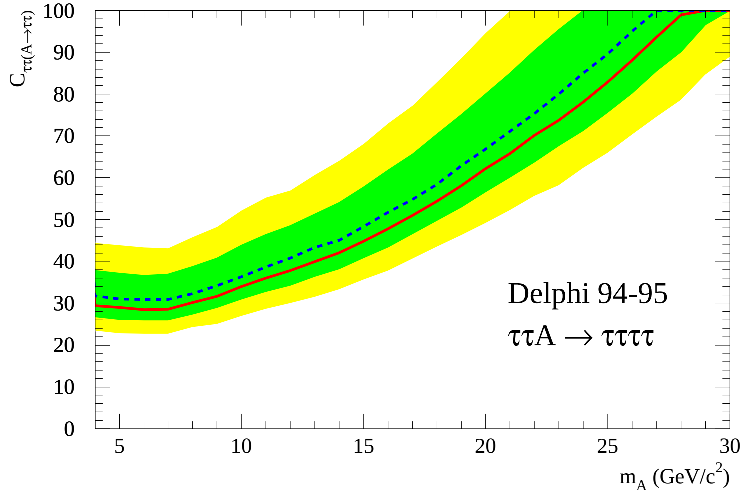


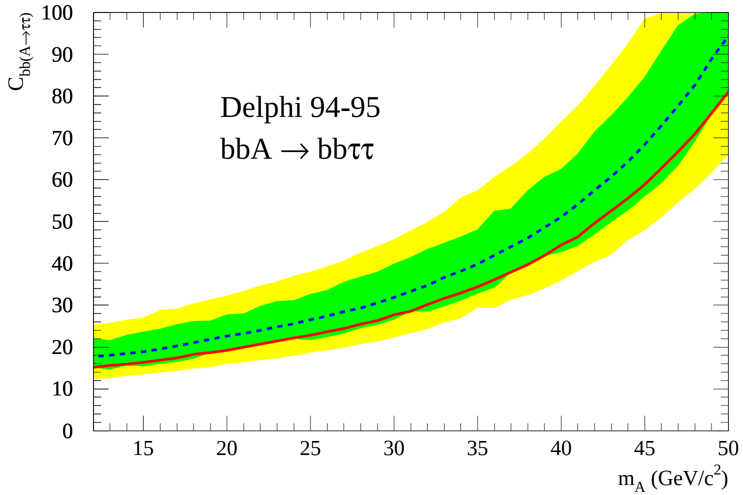

Light scalar $h \rightarrow$ small $k = sin^2(\beta - \alpha)$ !

# Upper (95%) limits for Yukawa couplings $\chi_d$ ($\tan\beta$) in 2HDM (II)



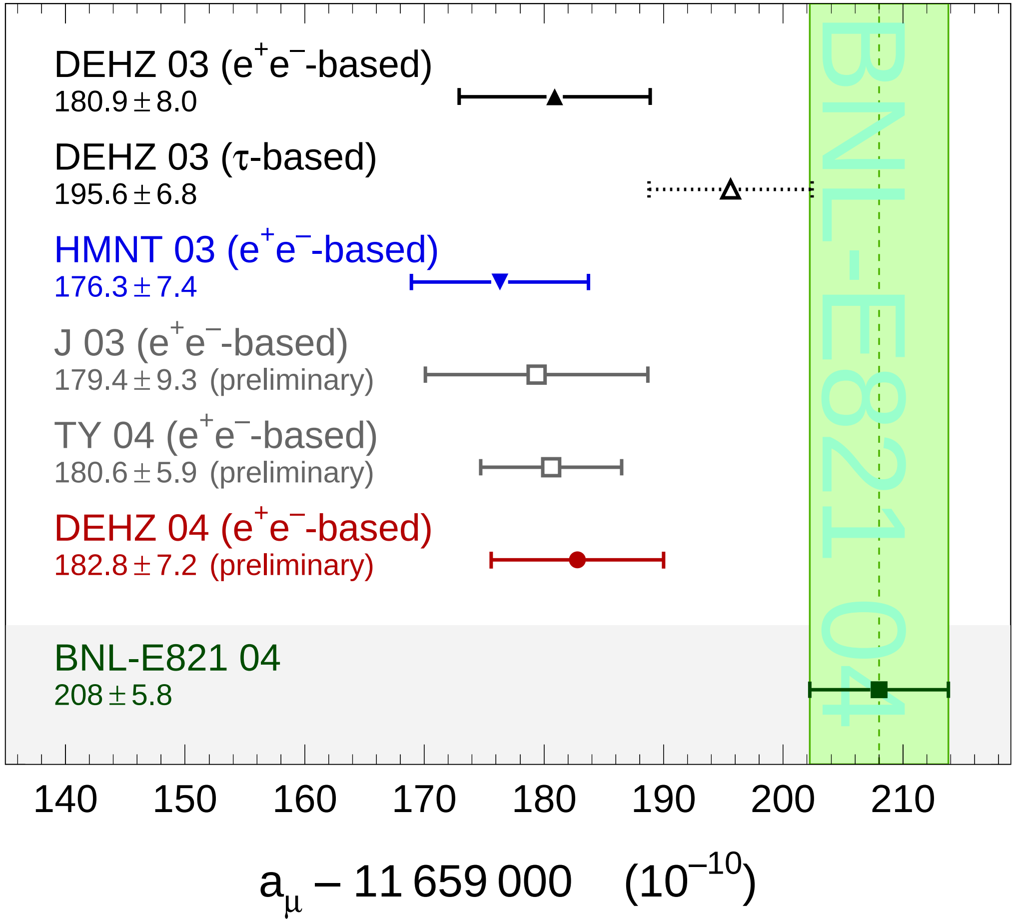




Yukawa coupling ($\tan\beta$) up to 20 allowed mass larger than 35 GeV!



# DATA and SM prediction for $g-2$ for muon $a_\mu \equiv \frac{(g-2)_\mu}{2}$

Summer 2004 Summary




Average: $a_\mu(\text{exp}) = 11\,659\,208(6) \times 10^{-10} (0.5\,ppm)$

# SM and data

| SM contribution | [in $10^{-11}$] | |
|---|---|---|
| QED | 116 584 705.7 | (2.9) |
| had[FJ02] | 6 869.0 | (70.7) |
| EW | 152.0 | (4.0) |
| tot | 116 591 726.7 | (70.9) |
| $\Delta a_\mu(\sigma)$ | 303.3 (106.9) | |
| lim(95%) | $93.8 \leq \delta a_\mu \leq 512.8$ | |

In hadronic part data for $e^+e^-$ are used

- using hadronic tau decay problematic...

Jegerlehner, Talk at Marseille, March 2002
Hagiwara et al (hep-ph/0209187v2)
Davier et al (hep-ph/0208177)
Hocker ($e^+e^-$ Oct. 2004)

$\Delta a_\mu(\sigma) = 252(92) \rightarrow 96.96 \leq \delta a_\mu \leq 505$

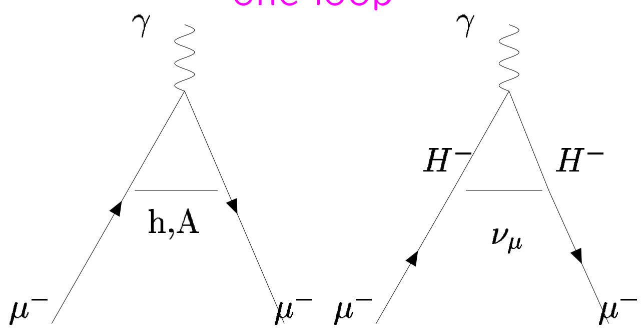
**$\delta a_\mu$ (positive only) can be used to constrain parameters of models at 95% CL**

$$\textbf{2HDM contribution to } a_\mu\textbf{:}\ a_\mu^{\text{2HDM}} = a_\mu^h + a_\mu^A + a_\mu^H + a_\mu^{H^\pm}$$

$$\bullet\textbf{light } h \textbf{ scenario : } a_\mu^{\text{2HDM}} \approx a_\mu^h$$

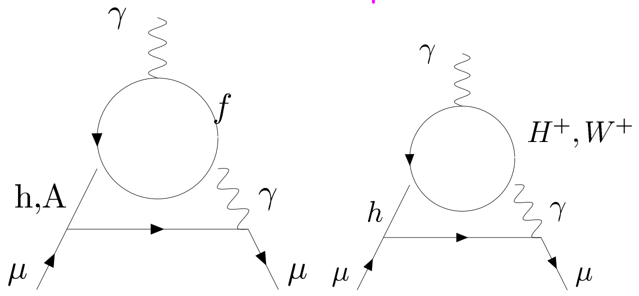
$$\bullet\textbf{light } A \textbf{ scenario : } a_\mu^{\text{2HDM}} \approx a_\mu^A$$

one loop




Zochowski,MK'96,MK'01;Dedes,Haber'01

two loop

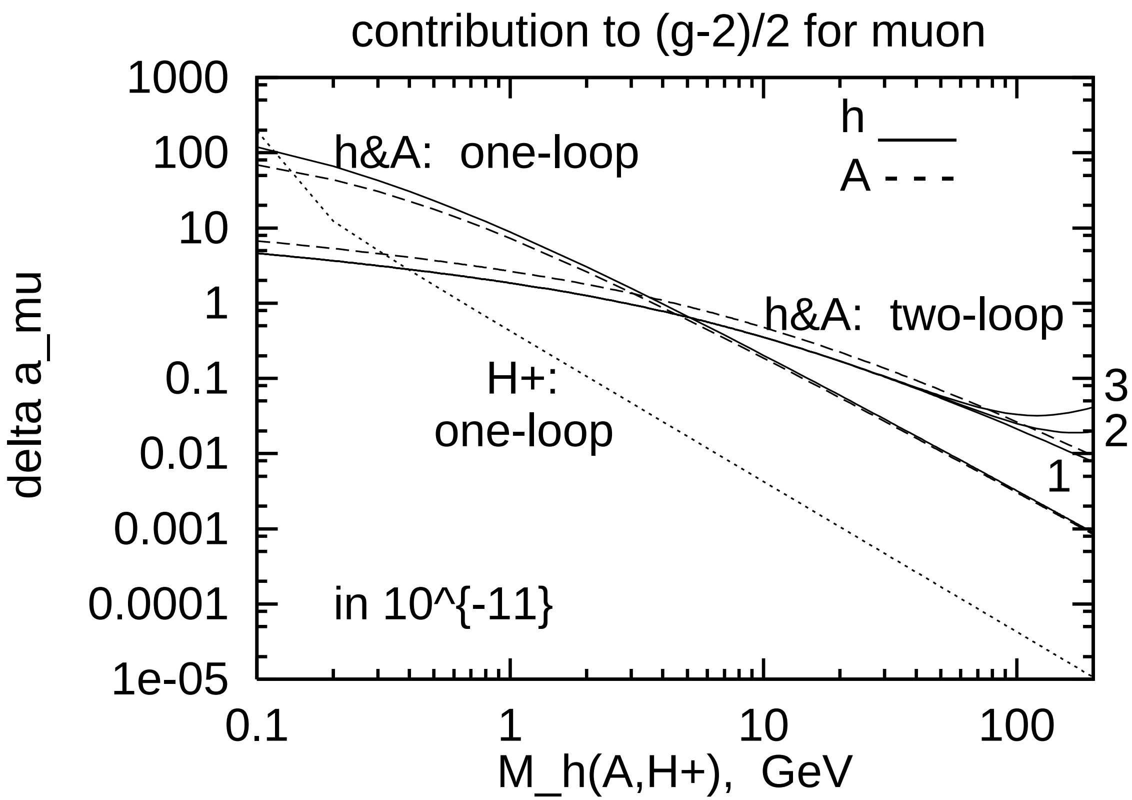



Chang at al.,Cheung at al, Wu,Zhou, MK'01,'02..

Two loop contributions larger than one-loop for mass $\sim$ few GeV!

MK, hep-ph/0103223v3, Acta Phys. Pol. B 33 (2002) 2621 (hep-ph/020807)

# Various 2HDM(II) contributions for couplings = 1




1– no $H^+$

2– $M_{H^\pm}$=800GeV

3– $M_{H^\pm}$=400GeV

light h

contr. positive

for mass below 3 GeV

light A

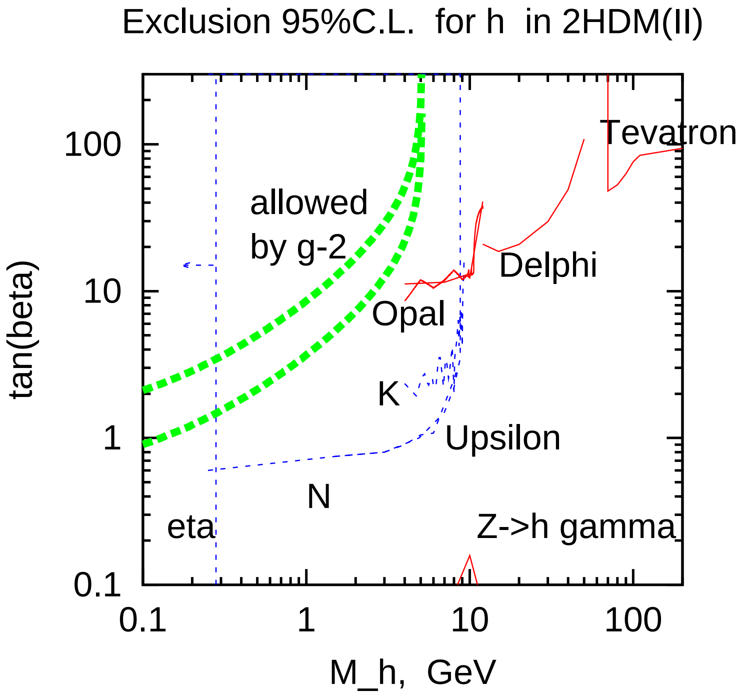
contr. positive

for mass above 5 GeV

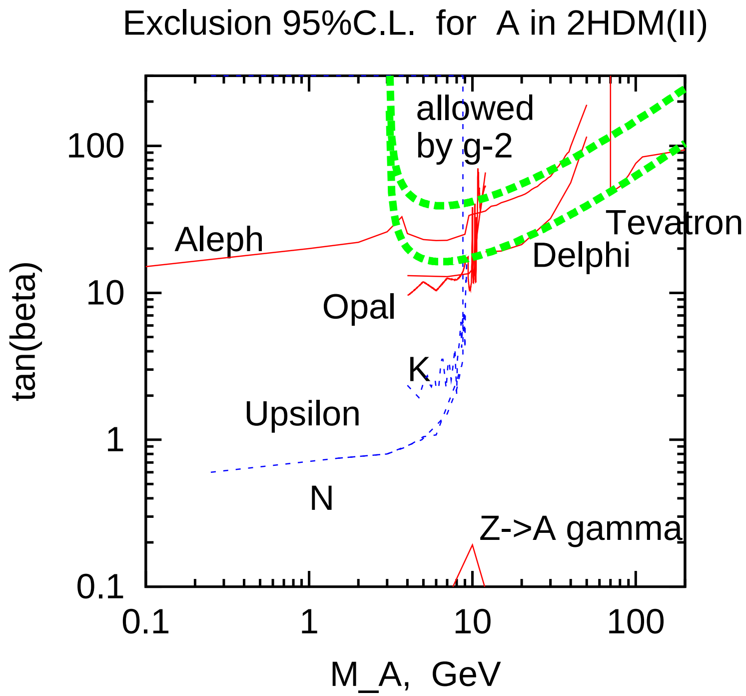
$\beta - \alpha = 0,\ \mu^2 = 0$

# Combined 95% CL constraints for $h$ and $A$ in 2HDM(II) '2004

scalar h for $\beta - \alpha = 0$, $\mu^2 = 0$




pseudoscalar A




thick lines : upper & lower limits from g-2

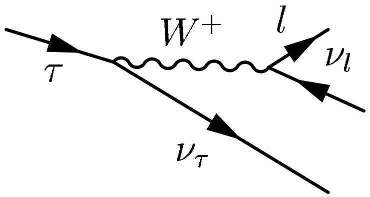
plus LEP data, etc

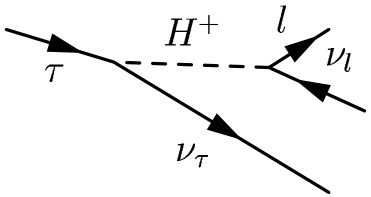
If all existing data are taken into account → allowed regions for $A$ only

$A$ with mass 25-70 GeV and $25 < \tan\beta < 115$ in agreement with data

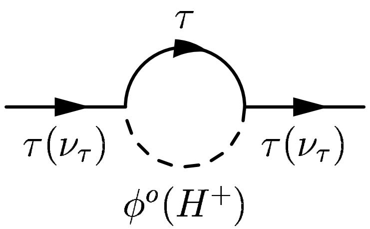
# Leptonic tau decays

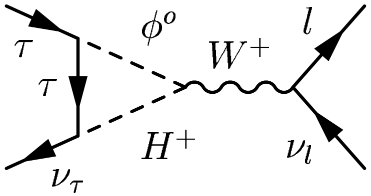
In SM - tree-level W exchange,   in 2HDM: tree-level charged Higgs




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



# The branching ratios for leptonic decays

- We consider

$$\tau \to e\bar{\nu}_e\nu_\tau \text{ and } \tau \to \mu\bar{\nu}_\mu\nu_\tau.$$

- The '04 world av. data for the leptonic $\tau$ decays and $\tau$ 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 defined as

$$Br^l|_{SM} = \frac{\Gamma^l|_{SM}}{\Gamma^{tot}_{exp}} = \Gamma^l|_{SM}\tau_\tau$$

- A possible beyond the SM contribution $\to \Delta^l$

$$Br^l = Br^l|_{SM}(1 + \Delta^l)$$

## 95% CL extra contributions

The lowest order of SM

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

Together with the experimental data we get

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

95% C.L. bounds on $\Delta^l$, for the electron and muon decay mode:

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

The negative contributions are constrained more strongly..

## Partial widths or leptonic $\tau$ 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:

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

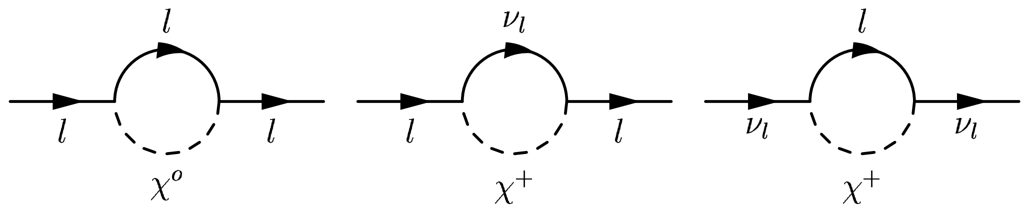
# Calculation of one-loop 2HDM(II) corrections

•Evaluation in the 't Hooft-Feynman's gauge using definitions and conventions for one-loop integrals of Hollik.

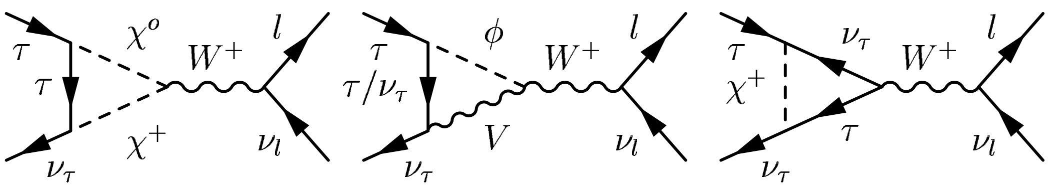
•$H^{\pm}$ and $W^{\pm}$ masses are very large compared to the leptonic masses and external momenta so $\Delta^{\mu}_{oneloop} = \Delta^{e}_{oneloop} = \Delta_{oneloop}$.

•large $\tan\beta$ enhanced contributions

•Self-energies: Two-point diagrams ($\chi^o = h, H, A, G^o$ and $\chi^+ = H^+, G^+$).




•Three-point contribution ( $(V, \phi) = (G^+, Z), (W^+, h), (W^+, h)/(Z, G^+)$)




$W^{\pm}\tau\nu_{\tau}$ vertex corrections, similar diagrams for the $W^{\pm}l\nu_l$ vertex

- Charged lepton self-energies. Contributions involving the exchange of a charged boson proportional to $m_l^2/M_W^2$ and $m_l^2/M_{H^\pm}^2$ (for $\chi^+ = G^+$and $H^+$, respectively) - negligible. Neutral Higgs and Goldstone bosons contr only for $\tau$ self-energy.

- Neutrino self-energies for tau neutrino only

$$
\begin{aligned}
\delta Z_{L\,\nu_e} &= \delta Z_{L\,\nu_\mu} = 0 \\
\delta Z_{L\,\nu_\tau} &= \Delta_{\nu_\tau}^{H^+} + \Delta_{\nu_\tau}^{G^+} \\
\Delta_{\nu}^{H^+} &= -\frac{G_F m_\tau^2}{4\sqrt{2}\pi^2} \tan^2\beta [B_0 + B_1](0; M_{H^\pm}^2, m_\tau^2). \\
\Delta_{\nu}^{G^+} &= \frac{G_F m_\tau^2}{4\sqrt{2}\pi^2} [B_0 + B_1](0; M_W^2, m_\tau^2) \simeq 0.
\end{aligned}
\tag{4}
$$

- One-loop three-point contribution

Only the radiative contributions to the $W^\pm \tau \nu_\tau$ vertex important.

• $\chi^+ - \chi^0 - \tau$ Loops.

$$\Delta^{H^+h}_{loops} = \frac{G_F m_\tau^2}{2\sqrt{2}\pi^2} \tan\beta \frac{\sin\alpha}{\cos\beta} \cos(\alpha-\beta) C_{20}(m_\tau^2, m_{\nu_\tau}^2; M_h^2, m_\tau^2, M_{H^\pm}^2) + \dots$$
$$\Delta^{H^+A}_{loops} = \frac{G_F m_\tau^2}{2\sqrt{2}\pi^2} \tan^2\beta C_{20}(m_\tau^2, m_{\nu_\tau}^2; M_A^2, m_\tau^2, M_{H^\pm}^2) + \dots$$
$$\Delta^{H^+H}_{loops} = -\frac{G_F m_\tau^2}{2\sqrt{2}\pi^2} \tan\beta \frac{\cos\alpha}{\cos\beta} \sin(\alpha-\beta) C_{20}(m_\tau^2, m_{\nu_\tau}^2; M_H^2, m_\tau^2, M_{H^\pm}^2) + \dots$$
$$\Delta^{G^+h}_{loops} = -\frac{G_F m_\tau^2}{2\sqrt{2}\pi^2} \frac{\sin\alpha}{\cos\beta} \sin(\alpha-\beta) C_{20}(m_\tau^2, m_{\nu_\tau}^2; M_h^2, m_\tau^2, M_W^2) + \dots \simeq 0$$
$$\Delta^{G^+H}_{loops} = -\frac{G_F m_\tau^2}{2\sqrt{2}\pi^2} \frac{\cos\alpha}{\cos\beta} \cos(\alpha-\beta) C_{20}(m_\tau^2, m_{\nu_\tau}^2; M_H^2, m_\tau^2, M_W^2) + \dots \simeq 0$$
$$\Delta^{G^+G^o}_{loops} = -\frac{G_F m_\tau^2}{2\sqrt{2}\pi^2} C_{20}(m_\tau^2, m_{\nu_\tau}^2; M_Z^2, m_\tau^2, M_W^2) + \dots \simeq 0 \qquad (5)$$

$\boldsymbol{V - \phi - l}$ **Loops -neglected**

$\boldsymbol{\tau - \nu_\tau} - \chi^+$ **Loops** -neglected

One-loop box diagrams can be neglected

# One loop contribution for large $\tan\beta$

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

$$\begin{aligned}\tilde{\Delta} = \quad & \left[ - \left( \ln\left(\frac{M_{H+}^2}{m_\tau^2}\right) + F(R_{H^\pm}) \right) \right. \\ & + \frac{1}{2}\left( \ln\left(\frac{M_A^2}{m_\tau^2}\right) + F(R_A) \right) \\ & + \frac{1}{2}\cos^2(\beta-\alpha) \left( \ln\left(\frac{M_h^2}{m_\tau^2}\right) + F(R_h) \right) \\ & \left. + \frac{1}{2}\sin^2(\beta-\alpha) \left( \ln\left(\frac{M_H^2}{m_\tau^2}\right) + F(R_H) \right) \right], \qquad (6)\end{aligned}$$

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 $m_\tau$!

Loop corrections are the same for $e$ and $\mu$ 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

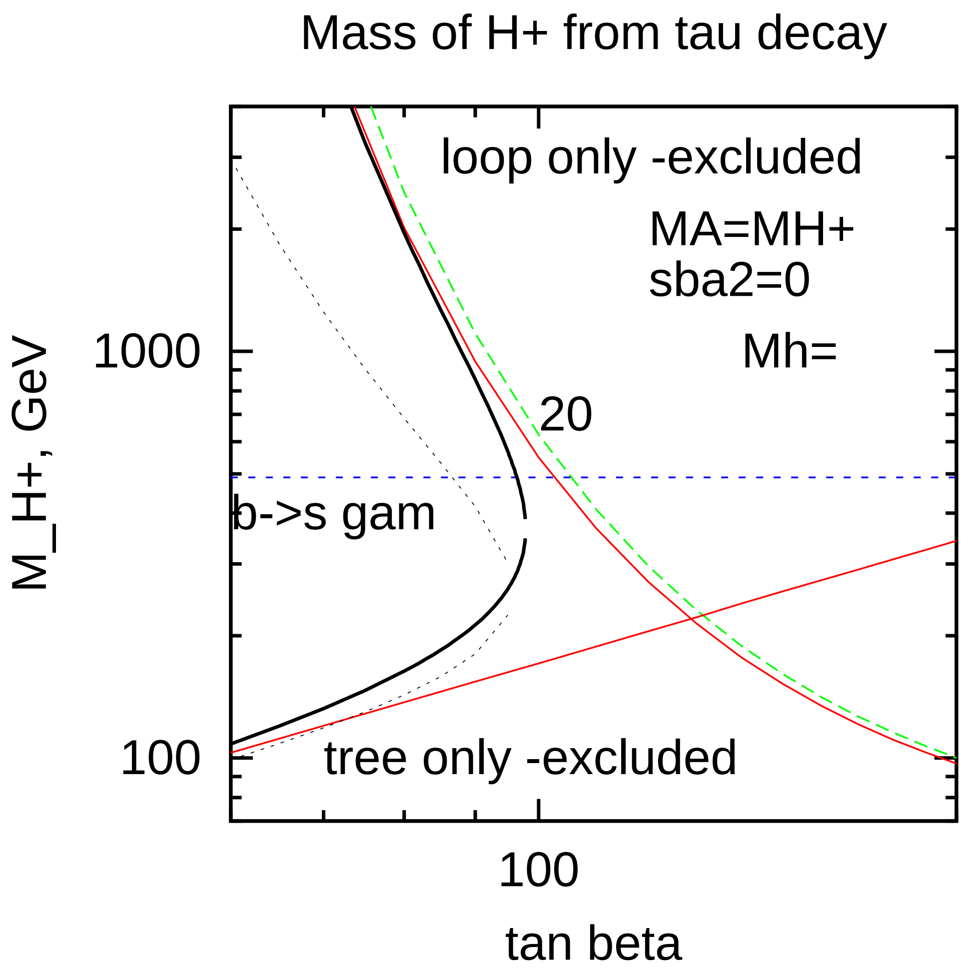
$$M_{H^\pm} \gtrsim 1.71 \tan\beta \ \text{GeV}$$

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

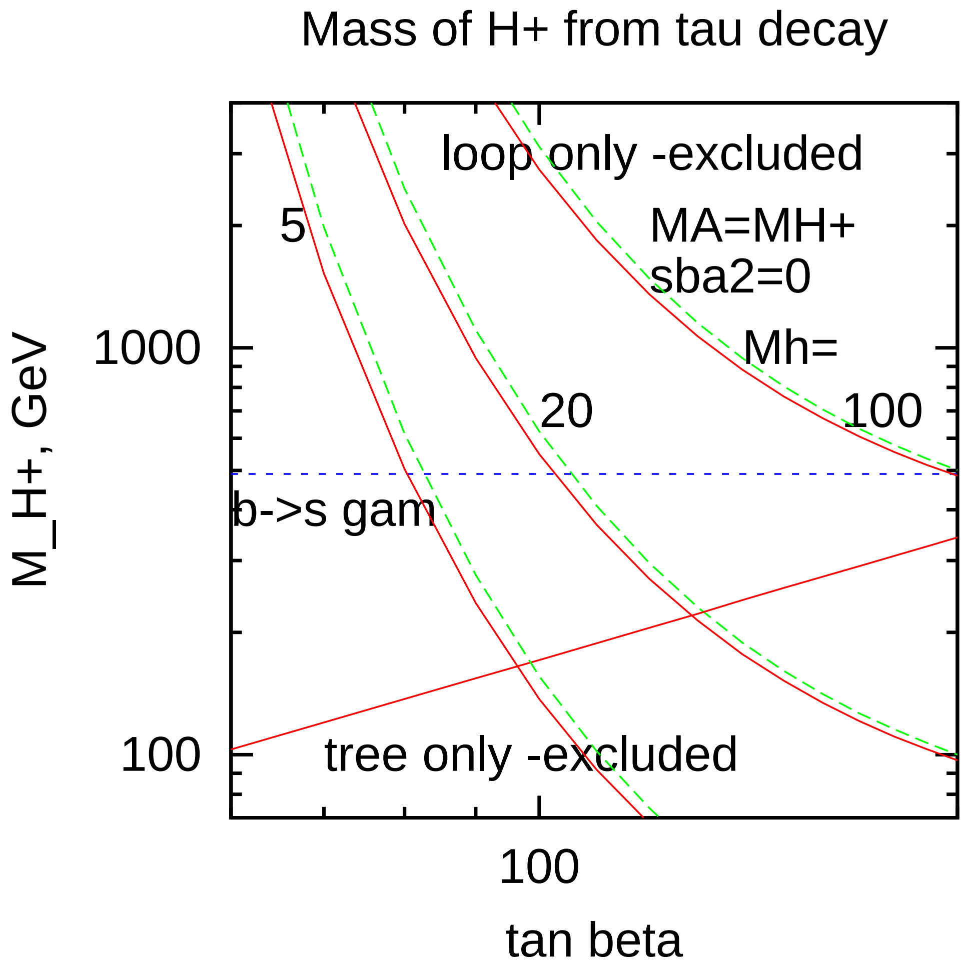
(the Michel parameter $\eta$ in the 2HDM (II))

However loop effects large...

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




dotted: $M_A = 100$ GeV; $\mu$ (red), $e$ (green)

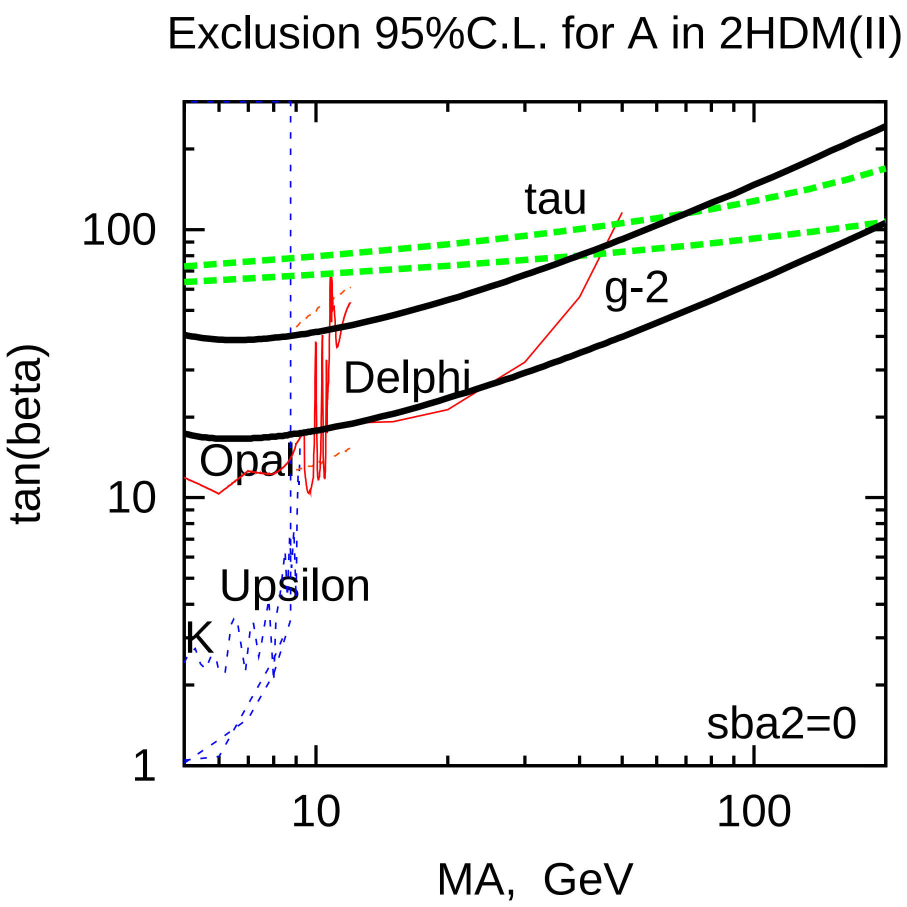



The upper limits:

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

# Combining limits for $A$

Upper limits for $\tan\beta$ from the leptonic $\tau$ decay (degenerate masses of $h, H, H^+$) and the allowed region from the newest $g-2$ for muon data




1/4 TeV (upper/lower green line)

# Conclusion

•The one-loop contributions to the branching ratios for leptonic $\tau$ decays are calculated in the CP conserving 2HDM(II) at large $\tan\beta$ - agreement with previous results by Guth & Kuhn, Rosiek, Chankowski et al, extension of Hollik & Sack.

•One-loop contributions, involving both neutral and charged Higgs bosons, dominate over the tree-level $H^{\pm}$ exchange
(the latter one being totally negligible for $e$).

•We show that the leptonic branching ratios of $\tau$ are complementary to the Higgsstrahlung processes for $h(H)$

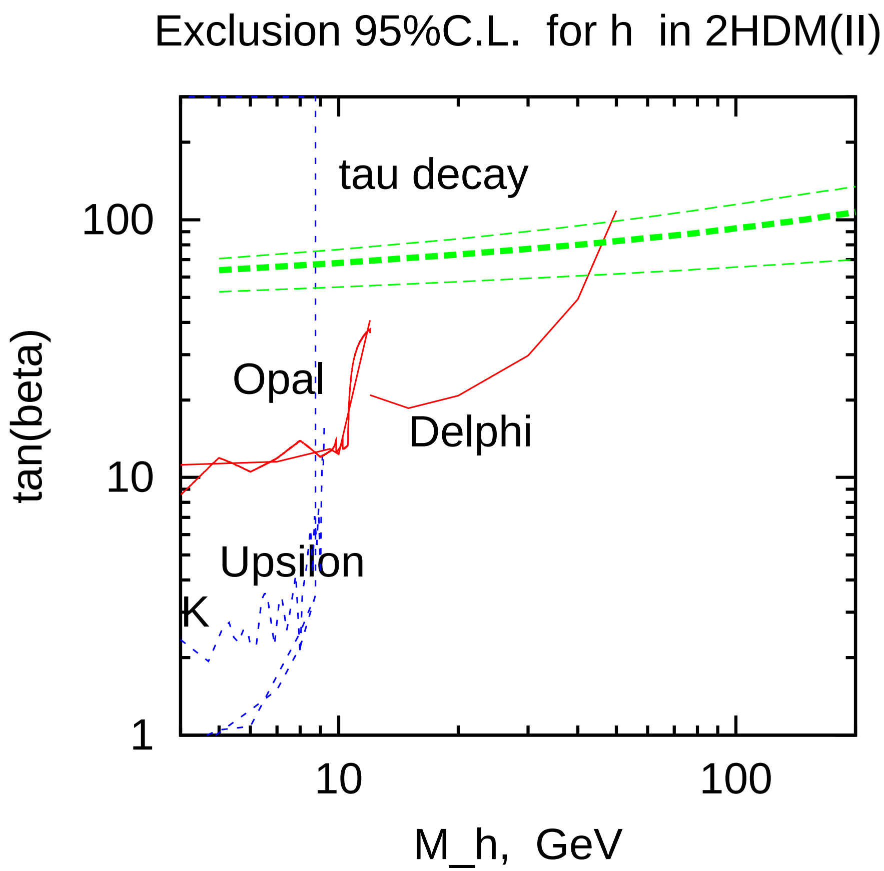
•We got upper limits on Yukawa couplings for both light $h$ and light $A$ scenarios

•New lower limit on mass of $M_{H^{\pm}}$ as a function of $\tan\beta$, which differs significantly from what was considered as standard constraint (based on the tree-level $H^{\pm}$ exchange only)

•We obtain also a upper limit on $M_{H^{\pm}}$ !

# Constraints for $h$ and $A$

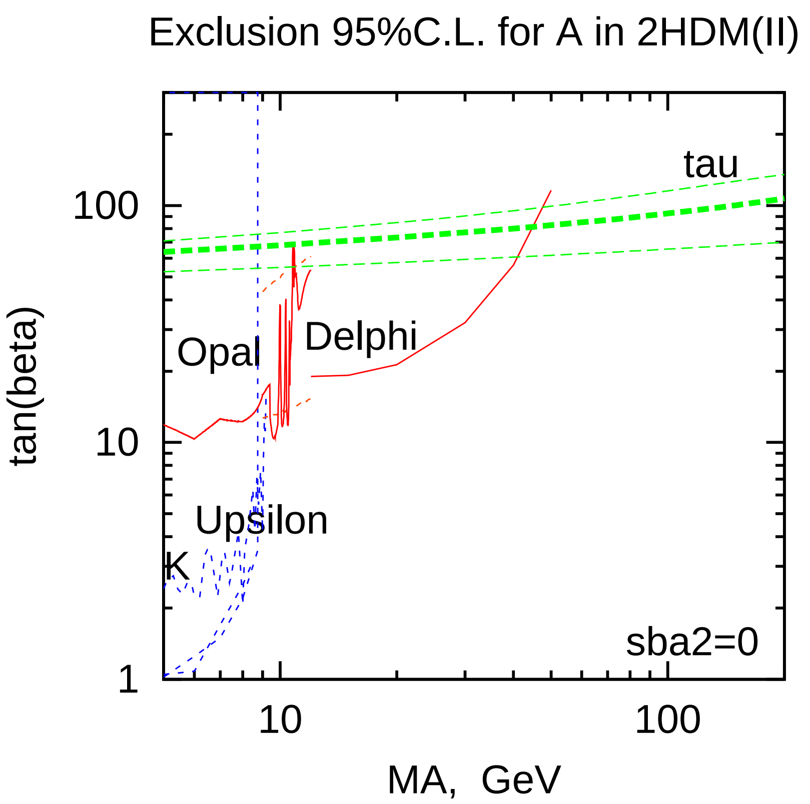
We also derive constraits for neutral Higgs bosons. For light $h$:




$\sin(\beta - \alpha) = 0$, $M_A = 100$ GeV, $M_{H^\pm} = 500$ GeV and 4 TeV, upper and lower green lines; degenerate $A$ and $H^+$ (mass 4 TeV) -thick green line

# Constraints for pseudoscalar $A$

Upper limits for Yukawa coupling ($\tan\beta$) for light $A$




Limits from tau decay:

$M_h = 100$ GeV, $M_{H^\pm} = 500$ GeV and 4 TeV, upper and lower green line

The degenerate $h$ and $H^\pm$ with mass 4 TeV - thick green line