Understanding τ decay

constraining Higgs sector by leptonic τ decays

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(in collaboration with David Temes – hep-ph/0410248)

Early papers - Guth, Hoang, Kuhn '92; Hollik, Sack '92; Rosiek '90, Chankowski et al. '94, new - Morse '04, Is the Difference Between the Pion Form Factor Measured in e+e- Annihilations and - Decays Due to an H- Propagator?

Standard Models

SM = 1HDM ⇒ one Higgs SU(2) doublet

One scalar (spin zero) doublet ϕ

Basic parameter v - vacuum expecation value of scalar field

one Higgs boson

one unknown parameter describing whole sector:

mass or selfcoupling

interaction with gauge bosons: $M_V \sim gv$ ($v \sim$ 246 GeV),

Higgs coupling to V $\sim$ M_V

Yukawa interaction with fermions: $g_f \sim m_f$

Direct LEP searches: $M_{H_{SM}}$ larger than 114.4 GeV

2HDM $\Rightarrow$ two Higgs SU(2) doublets

Two scalar (spin zero) doublets ϕ_1 and ϕ_2 with vev v_1 and v_2

(with $v^2 = v_1^2 + v_2^2$, often we use $\tan\beta = v_2/v_1$)

Degrees of freedom: 8 fields - 3 (for long.components of W/Z) = 5 $\Rightarrow$
five physical Higgs bosons, spin=0, 3 - neutral, two charged !!

Other characteristics: quantum numbers - C,P...,

Number of parameters? Depends on the form of potential,
between 8 to 14 (minus 1 for v-constraint, minus 1 for overall rephasing)

- CP conservation: Higgs sector: h,H,A, $H^{\pm}$; $\tan\beta, \alpha$ (h,H)
h,H - CP-even, A - CP-odd

- CP violation: mixing between h_1, h_2, h_3, more mixing angles
and CP parity of Higgs bosons - not defined

more on 2HDM

Interaction with gauge bosons and fermions- Higgs bosons share obligations, eg

$$(g_W^h)^2 + (g_W^H)^2 + (g_W^A)^2 = (g_W^{H_{SM}})^2$$

Various models of Yukawa interaction with fermions:

Model II: where one scalar doublet couples to up-type quarks, other to down-type quarks and charged leptons

The potential problems related to ϕ_1, ϕ_2 mixing:

- Flavour Changing Neutral Current may be large (in nature FCNC small)
- CP-violation may be large

2HDM models without and with CP violation

2HDM Potential: quartic and quadratic terms separated:

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

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

No (ϕ_1, ϕ_2) mixing if Z_2 symmetry satisfied (NO FCNC & NO CPV):
$\phi_1 \to -\phi_1$, $\phi_2 \to \phi_2$ (or vice versa) $\Rightarrow \lambda_6 = \lambda_7 = m_{12}^2 = 0$

Hard violation of Z_2 symmetry: quartic terms with λ_6, λ_7

Soft violation of Z_2 symmetry: ($\lambda_6 = \lambda_7 = 0$) - governed by $\mu^2 \propto$ Re m_{12}^2

Lee, Diaz-Cruz, Mendez, Haber, Pomarol, Barroso, Santos, Hollik, Djouadi, Illana, Branco,Gunion, Akeroyd, Arhrib,...

CP conservation: Higgs masses and couplings

Physical content of potential:

- Higgs masses (quadratic couplings) - mass of H^+, A can be large if due large μ^2
- 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**:

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

The relative "basic couplings":

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

Existing constraints for 2HDM (II)

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

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

$\Rightarrow$ 7 parameters: $M_h, M_H, M_A, M_{H^\pm}$, α, β, and μ^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 $\tan\beta$ enhanced couplings to $d-$type fermions (charged leptons)!

DATA

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

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

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

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

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: ($H^\pm$) $b \to s\gamma$**,** $M_{H^\pm} >$ 490GeV **(Misiak,Gambino'01)**

leptonic tau decay (MK, Temes - hep-ph/0410248)

g-2 data (MK based on hep-ph/0410081)

Global fit •**(all Higgses)**

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

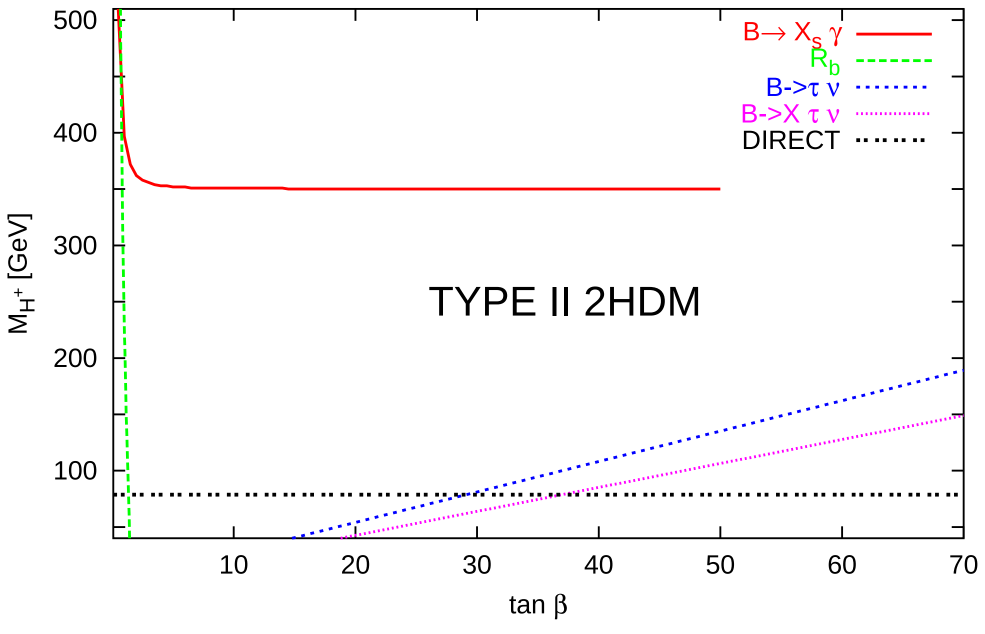
Cheung and Kong '03

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

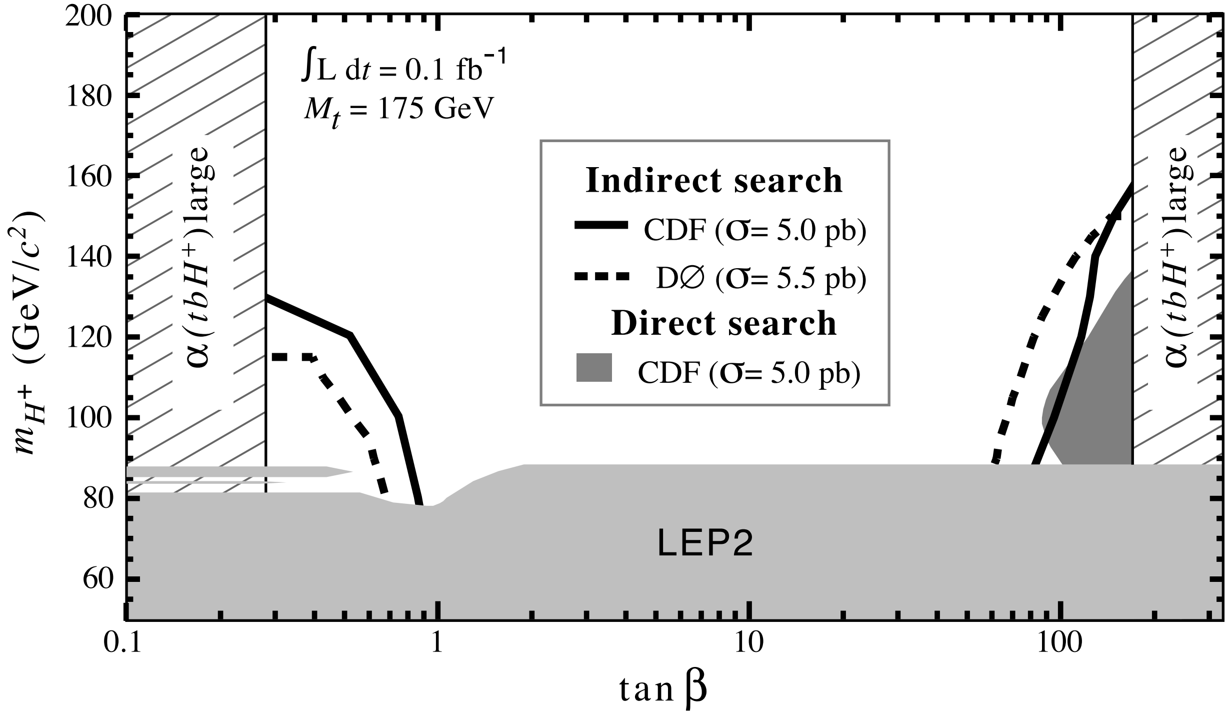
$$\text{BR}_\gamma^{\text{exp}} = (3.23 \pm 0.42) \times 10^{-4}$$

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



Here mass limit 350 GeV corresponds to 99 % CL !

Direct limits for charged Higgs boson - PDG2004

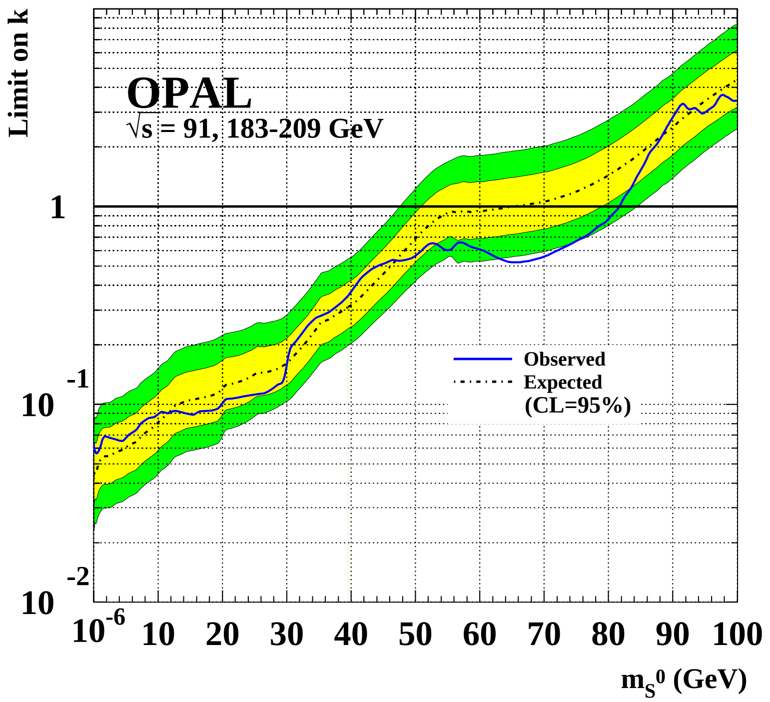


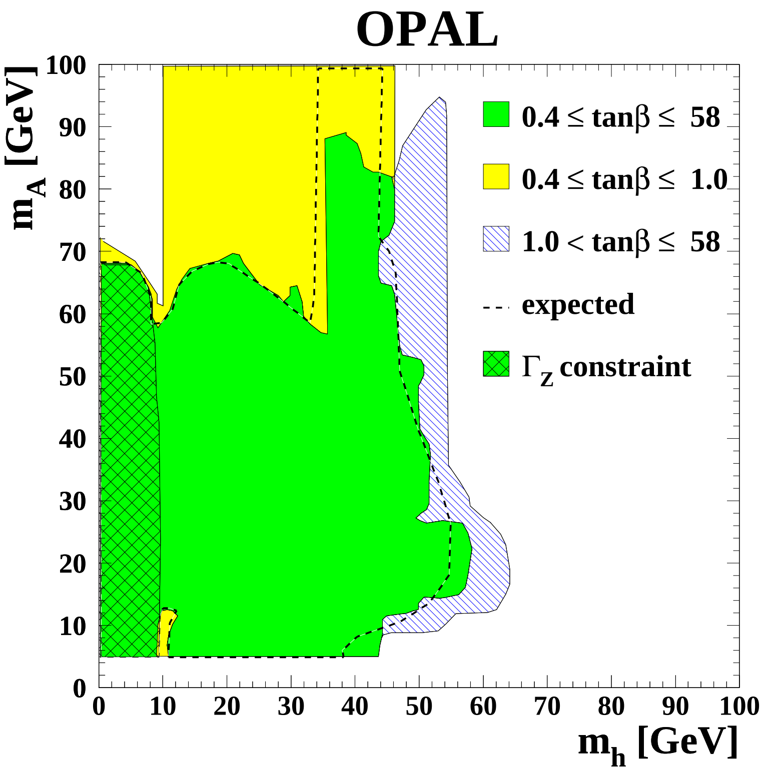
Tevatron and LEP limits (90 GeV)

Light h OR light A in agreement with current data

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

$k = sin^2(\beta-\alpha)$





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

$a_\mu^{exp} = 11659203(8) \cdot 10^{-10}$

E821, Phys. Rev. Lett. **89** (2002) 101804 [Erratum-ibid. **89** (2002) 129903] [arXiv:hep-ex/0208001]

$a_\mu^{SM} = a_{QED} + a_\mu^{EW} + a_\mu^{had}$

had=vac.pol.1+vac.pol.2+ lbl

→

A significant revision due to change in sign of the light by light hadronic contribution to a_μ light-by-light (lbl):
previous av: -8.5(2.5)10^{-10}
recent:
Knecht,Nyffeler +8.3(1.2)
Hayakawa,Kinoshita +8.9(1.5)
Bijnens,et al +8.3(3.2)
Blokland,et al. +5.6

$$\Delta a_\mu = a_\mu^{exp} - a_\mu^{SM}$$

SM and data

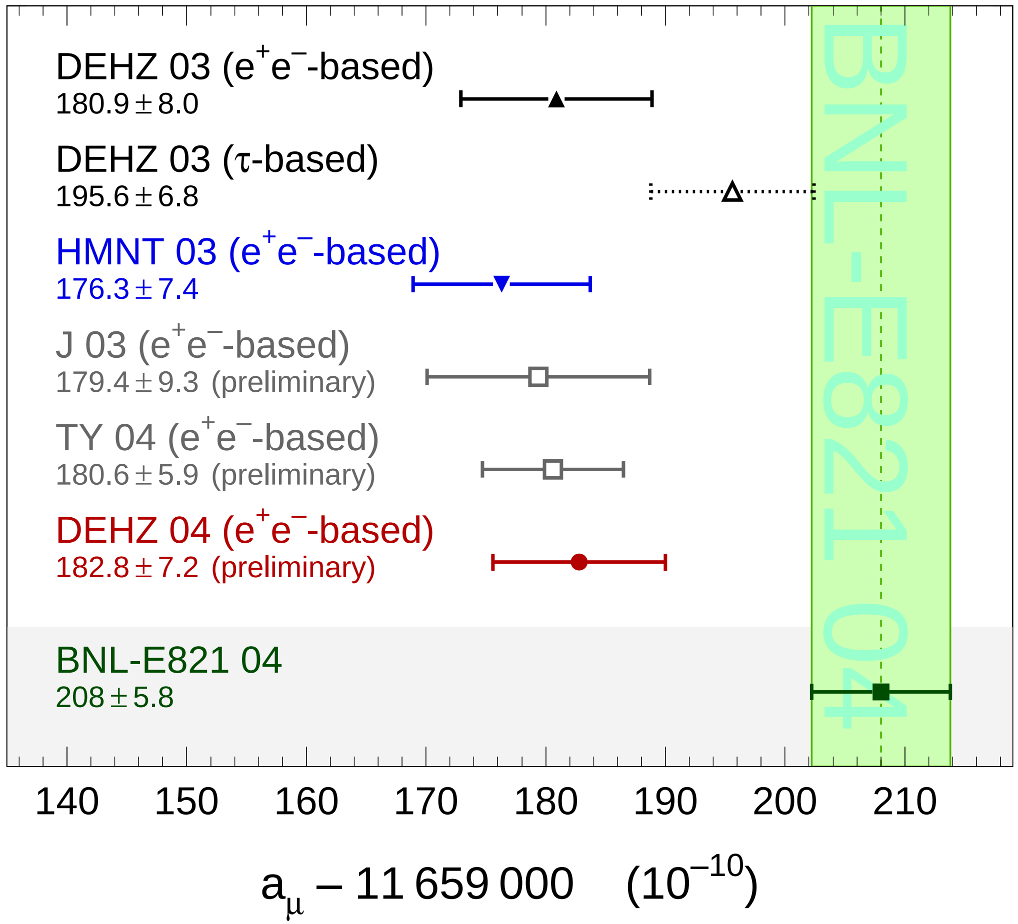
SM contribution		[in 10^{-11}]
QED	116 584 705.7	(2.9)
had[FJ02]	6 869.0	(70.7)
EW	152.0	(4.0)
tot	116 591 726.7	(70.9)
$\Delta a_\mu(\sigma)$		303.3 (106.9)
lim(95%)		$93.8 \leq \delta a_\mu \leq 512.8$

[HMNT (ex)]: $\Delta a_\mu(\sigma) = 297.0\,(107.2)$ $87.2 \leq \delta a_\mu \leq 507.4$,
[HMNT(in)] : $\Delta a_\mu(\sigma) = 357.2\,(106.4)$ $148.7 \leq \delta a_\mu \leq 565.7$
[DEHZ (e+e-)]: $\Delta a_\mu(\sigma) = 339.0\,(112)$

Jegerlehner, Talk at Marseille, March 2002
Hagiwara et al (hep-ph/0209187v2)
Davier et al (hep-ph/0208177)
19.09.03 $\Delta a_\mu(\sigma) = 234\,(119)$ $0.076 \leq \delta a_\mu \leq 467$
BNL 10.01.2004 $\Delta a_\mu(\sigma) = 301\,(104.1)$ $96.96 \leq \delta a_\mu \leq 505$
Hocker (10.2004) $\Delta a_\mu(\sigma) = 252(92)$

δa_μ (positive now!) can be used to constrain parameters of new models at 95% CL

Summer 2004 Summary



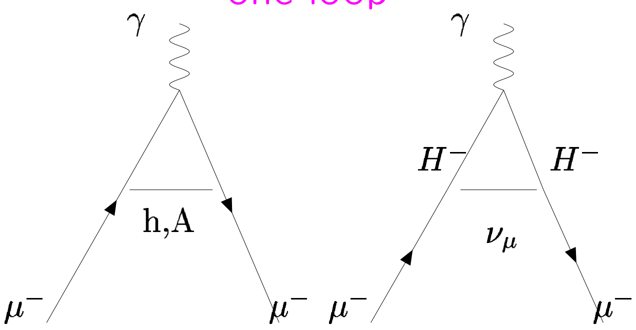
2HDM(II): Contribution to $g-2$ for muon

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

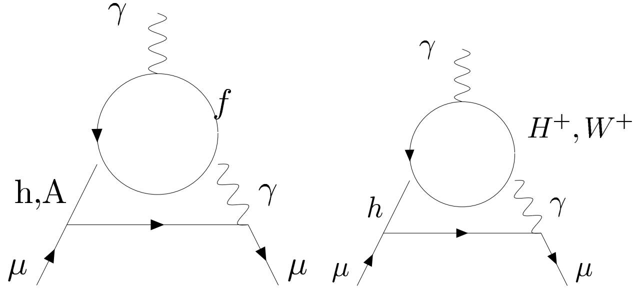
•light h scenario : $a_\mu^{\text{2HDM}} \approx a_\mu^h$

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

one loop



two loop



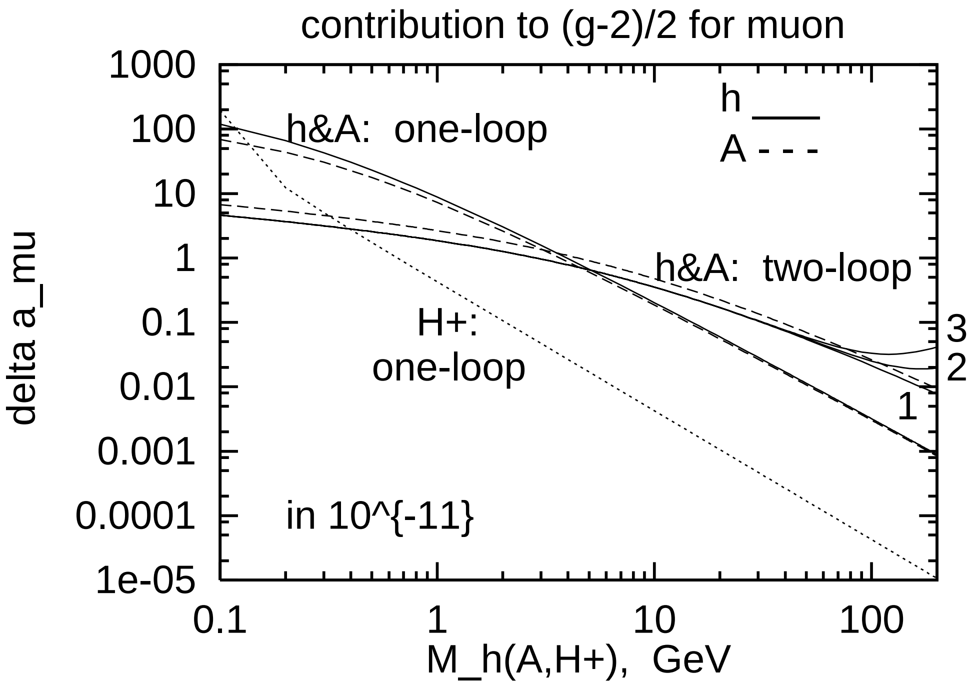
Zochowski,MK'96,MK'01;Dedes,Haber'01

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
MK, hep-ph/0112112 Snowmass proc
MK, Acta Phys. Pol. B 33 (2002) 2621
(hep-ph/020807)

Various 2HDM(II) contributions for couplings = 1



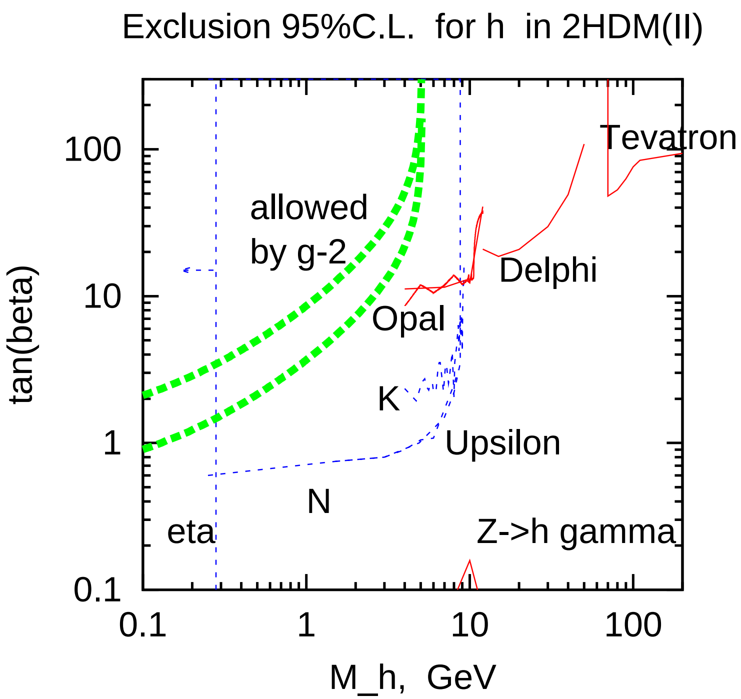
1–
no H^+
2–
$M_{H^\pm}$=800GeV
3–
$M_{H^\pm}$=400GeV

light A
contr. positive
for mass above 5 GeV

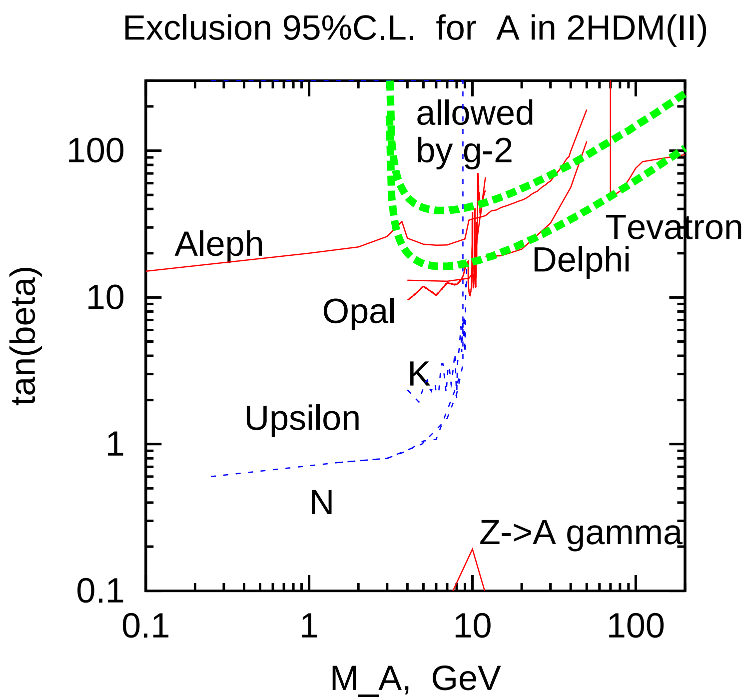
light h
contr. positive
for mass below 3 GeV
$\beta - \alpha = 0$, $\mu^2 = 0$

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

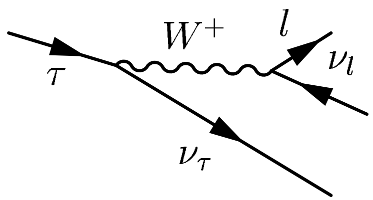
plus LEP data, etc

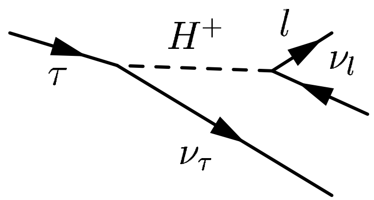
If all existing data are taken into account $\rightarrow$ allowed regions for A only

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

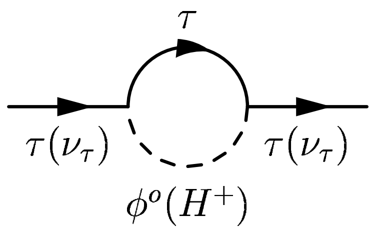
Leptonic tau decays

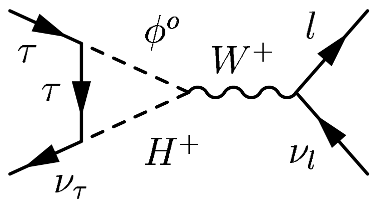
In SM - tree W exchange, tree level in 2HDM: charged Higgs bosons





Loop corrections involve also neutral Higgs bosons – dominant contributions at large $\tan\beta$





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 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 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 Δ^l, for the electron and muon decay mode:

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

The negative contributions are constrained more strongly..

Partial widths or leptonic τ decays: SM vs 2HDM

SM at tree-level = the $W^\pm$ exchange. In the Fermi approximation, with leading order corrections to the W propagator, and dominant QED one-loop contributions

$$\Gamma^l|_{SM} = \Gamma^{W^\pm}_{tree} = \Gamma^l_0 = \frac{G_F^2 m_\tau^5}{192\pi^3} f(\frac{m_l^2}{m_\tau^2}) \left(1 + \frac{3m_\tau^2}{5m_W^2} - 2\frac{m_l^2}{m_W^2}\right) \times \left(1 + \frac{\alpha(m_\tau)}{2\pi}(\frac{25}{4} - \pi^2)\right)$$

$$f(x) = 1 - 8x + 8x^3 - x^4 - 12x^2 \ln x.$$

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

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

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

The second term coming from the interference with the SM amplitude much more important

One loop contribution for large $\tan\beta$

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

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

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

$$F(R \ll 1) \sim -1 \ , \ F(R = 1) = -3 \ , \ F(R \gg 1) \sim -(1 + 2\ln R^2)$$

NOTE, Δ does not depend on m_τ! The exact and approximated expressions can not be distinguished

Loop corrections for some scenarios

Interesting scenarios:

• 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 therefore the Higgsstrahlung process at LEP is not sensitive to such Higgs boson, the leptonic tau decays have maximal sensitivity to h!

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

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

Large effects for large mass splitting - watch data for ρ !

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

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

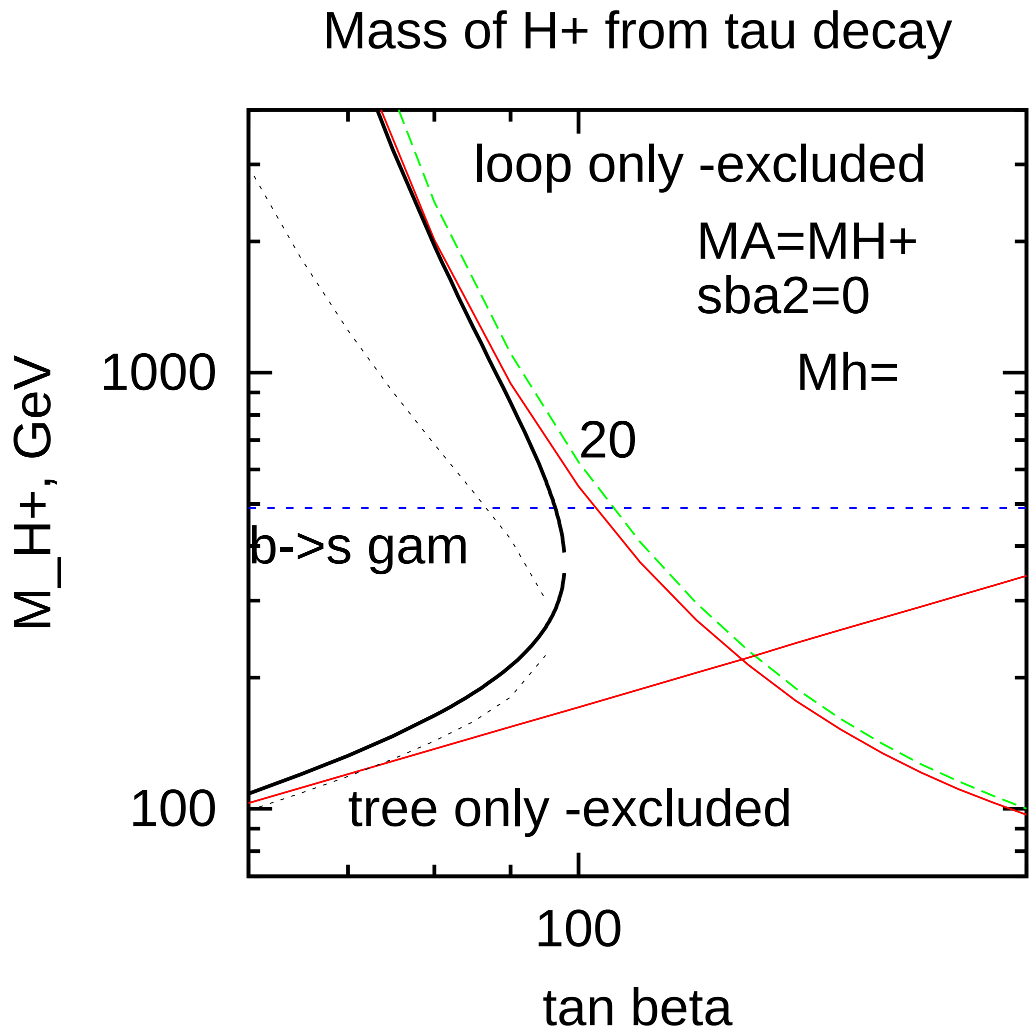
$$M_{H^\pm} \gtrsim 1.71 \tan\beta \text{ GeV}$$

coefficient to be compared to 1.86, 1.4 from Dova at al and Stahl

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

However loop effects large...

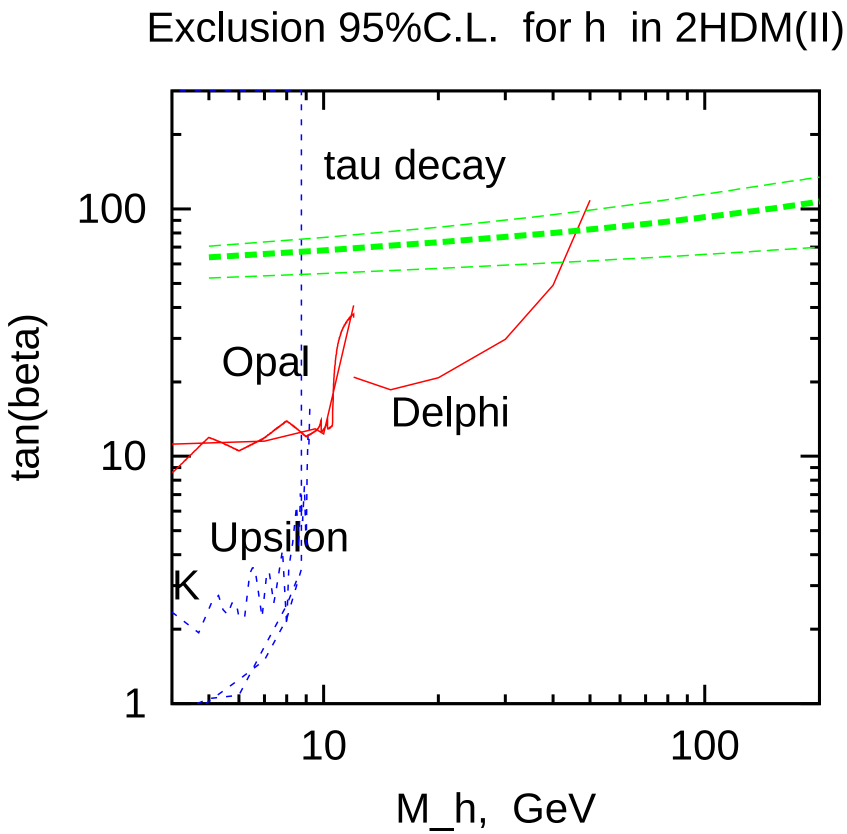
Limits for mass of H^+: One-loop and tree contr.



MK,D. Temes' 04

Constraints for h and A

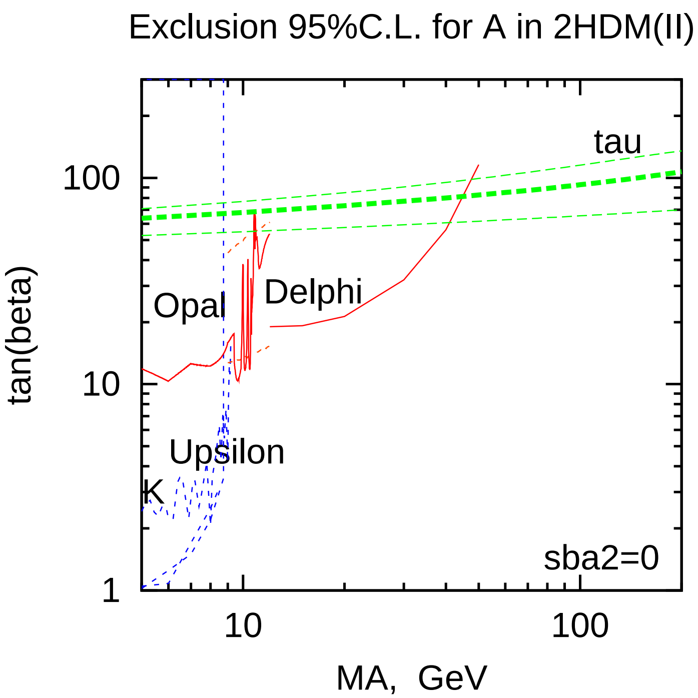
We also derive constraits for neutral Higgs bosons. For light h:

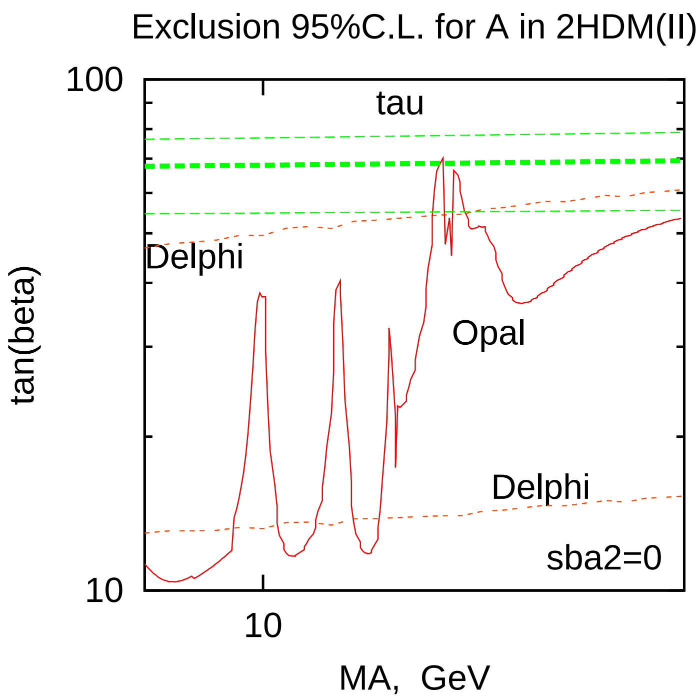


sin$(\beta - \alpha) = 0$, $M_A = 100$ GeV, $M_{H^\pm} = 500$ GeV and 4 TeV, upper and lower; degenerate A and H^+ (4 TeV) -thick line

For pseudoscalar A

For light A



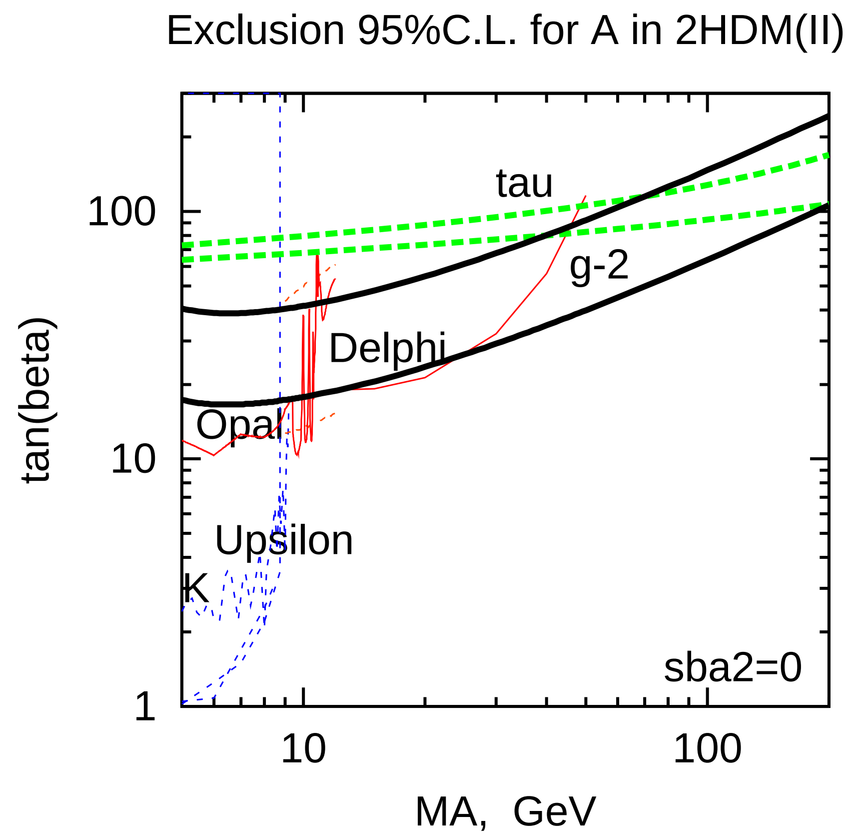


$M_h = 100$ GeV and $M_{H^\pm} = 500$ GeV and 4 TeV, upper and lower

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

Right: Mass range for A from 8 to 12 GeV.

Combining limits for A



Upper limits for $\tan\beta$ from the leptonic τ decay and the allowed region from the newest $g-2$ for muon data.
Degenerate masses of h, H, H^+ equal to 1 (upper) and 4 (lower) TeV

Conclusion

• The one-loop contributions to the branching ratios for leptonic τ decays are calculated in the CP conserving 2HDM(II) at large $\tan\beta$ - agreement with previous results by Guth & Kuhn, 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 τ 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 an upper limit on $M_{H^{\pm}}$.