Constraing Higgs sector by low energy experiments

Maria Krawczyk

Focus: CP conserving Higgs sector (2HDM)

- Direct searches

- Precision measurements or indirect searches

- High energy colliders: LEP, TEVATRON, HERA, ...LHC, LC, PLC

- Low energy experiments: $b \to s\gamma$, $g-2$ for muon, leptonic $\tau decay$

Standard Models

SM = 1HDM $\Rightarrow$ 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),

coupling $\sim M_V$

Yukawa interaction with fermions: $m_f \sim g_f$

Direct 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 charecteristics: 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 rephasing)

CP or not CP concervation in Higgs sector

- 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 (in nature - small effects)

2HDM models without and with CP violation

2HDM Potential: quartic and quadratic terms separated:

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

soft violation of Z_2 symmetry

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) $\Rightarrow \lambda_6 = \lambda_7 = m_{12}^2 = 0$

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

Hard violation of Z_2 symmetry: quartic terms with λ_6, λ_7 (below =0)

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

Minimum (vacuum) at (here $\lambda_6 = \lambda_7 = 0$):

$$\phi_1 = \begin{bmatrix} 0 \\ \frac{1}{\sqrt{2}} v_1 \end{bmatrix} \phi_2 = \begin{bmatrix} 0 \\ \frac{1}{\sqrt{2}} v_2 \, e^{i\xi} \end{bmatrix}$$

Note, that

$$m_{12}^2 = [\mu^2/v^2 + i\delta] 2 v_1 v_2 e^{-i\xi},$$

so $\boxed{\mu = \text{Re}\,(m_{12}^2) v^2 / 2 v_1 v_2}$

$$\boxed{\text{Im}(m_{12}^2 e^{i\xi}) = \text{Im}(\lambda_5 e^{2i\xi}) v_1 v_2}$$

Naive conclusion: phase ξ violates CP ("complex" fermion masses)

However (eg. Branco), phase ξ can be removed by suitable redefinitions of phases of Higgs fields $\phi_{1,2}$, λ_5 and m_{12}^2:

$$\phi_{1,2} \to \phi_{1,2} \, e^{-i\rho_{1,2}}, \lambda_5 \to \lambda_5 \, e^{2i(\rho_2 - \rho_1)}, m_{12}^2 \to m_{12}^2 \, e^{i(\rho_2 - \rho_1)}$$

and the same for fermion fields. So, the ξ disappears, we can put 0 (rephasing invariance). CPV if $\text{Im}\,\lambda_5 \neq 0$.

Mass terms and decoupling (CP consv.)

Masses of pseudoscalar and charged Higgs bosons:

$$M_{A^0}^2 = \mu^2 - \lambda_5 v^2, \qquad M_{H^\pm}^2 = \mu^2 - \frac{1}{2}(\lambda_4 + \lambda_5) v^2$$

To get large masses we need:

large μ (leading to decoupling)

The lightest Higgs h has all properties as the SM Higgs boson all heavier Higgs bosons decouple...

OR

large $\lambda_{4,5}$ (small μ)

There are non-decoupling effects

Unitarity constraints- upper limits of heavy Higgs bosons 600 GeV

λ_i in terms of masses, μ^2 etc.

Solving:

$$\lambda_1 v^2 = \frac{1}{\cos^2\beta}\{M_H^2 \cos^2\alpha + M_h^2 \sin^2\alpha\} - \mu^2 \tan^2\beta$$
$$\lambda_2 v^2 = \frac{1}{\sin^2\beta}\{M_H^2 \sin^2\alpha + M_h^2 \cos^2\alpha\} - \mu^2 \cot^2\beta$$

Remaining λ_i:

$$\lambda_5 = \frac{1}{v^2}[-M_{A^0}^2 + \mu^2]$$
$$\lambda_4 = \frac{1}{v^2}[M_{A^0}^2 - 2M_{H^\pm}^2 + \mu^2]$$
$$\lambda_3 = \frac{1}{v^2}\left[2M_{H^\pm}^2 + \frac{\sin 2\alpha}{\sin 2\beta}(M_H^2 - M_h^2) - \mu^2\right]$$

CP conservation: Higgs masses and couplings

Physical content of potential

- Higgs masses (quadratic couplings)
- Higgs trilinear couplings
- Higgs quartic couplings

Note, if selfcouplings are expressed in terms of masses, also μ enters!

$$g_{hhh} = -3v\Big[-\cos\beta\sin^3\alpha\,\lambda_1 + \sin\beta\cos^3\alpha\,\lambda_2 - \tfrac{1}{2}\sin 2\alpha\cos(\beta+\alpha)\lambda_{345}\Big],$$
$$= \frac{-3g}{\sin 2\beta\, M_W}\Big[(\cos\beta\cos^3\alpha - \sin\beta\sin^3\alpha)M_h^2 - \cos^2(\beta-\alpha)\cos(\beta+\alpha)\mu^2\Big],$$

Basic couplings to gauge bosons $V = W/Z$ and fermions u, d-types

Independent of potential are:

- couplings to gauge bosons: hWW, HWW, while $AWW = AZZ = 0$
  for eg. Z: $g_h^2 + g_H^2 = g_{H_{SM}}^2$

- couplings to fermions (Yukawa)
  e.g. Model II:

It is useful to express all couplings in terms of the relative "basic couplings":

$$\chi_i^{\phi} = \frac{g_i^{\phi}}{g_i^{\text{SM}}}, \phi = h, H, A$$ with $i = V, u, d$

DIRECT COUPLINGS in 2HDM

$$\chi_V^h = \sin(\beta-\alpha)$$
$$\chi_u^h = \sin(\beta-\alpha) + \cot\beta\cos(\beta-\alpha)$$
$$\chi_d^h = \sin(\beta-\alpha) - \tan\beta\cos(\beta-\alpha)$$

$$\chi_V^H = \cos(\beta-\alpha)$$
$$\chi_u^H = \cos(\beta-\alpha) - \cot\beta\sin(\beta-\alpha)$$
$$\chi_d^H = \cos(\beta-\alpha) + \tan\beta\sin(\beta-\alpha)$$

$\tan\beta$ – the ratio of the vacuum expectation values of the two basic Higgs doublets [(0, $\pi/2$)]

α –parameterizes mixing among the two neutral CP-even Higgs fields [eq. ($-\pi$, 0)]

Pattern relation

We found that for both h and H:

$$(\chi_u - \chi_V)(\chi_V - \chi_d) + \chi_V^2 = 1$$

or

$$(\chi_u + \chi_d)\chi_V = 1 + \chi_u\chi_d.$$

Also,

$$\tan^2\beta = \frac{\chi_V - \chi_d}{\chi_u - \chi_V} = \frac{1-\chi_d^2}{\chi_u^2 - 1}$$

The pattern relation was obtained here in the tree approximation.
Radiative corrections will modify it at the level of *few percents*.

Selfcouplings in terms of observables

One can introduce a relative coupling for $\phi H^+ H^-$, $\phi = h, H$:

$$\chi_{H^\pm}^{\phi} \equiv -\frac{v g_{\phi H^+ H^-}}{2i M_{H^\pm}^2} = \left(1 - \frac{M_\phi^2}{2M_{H^\pm}^2}\right) \chi_V^{\phi} + \frac{M_\phi^2 - \mu^2}{2M_{H^\pm}^2} (\chi_u^{\phi} + \chi_d^{\phi})$$

“Finite” for “large” $M_{H^\pm}^2$ (non-decoupling for small μ)
important for $\gamma\gamma\phi$ loop-coupling.

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

Pattern relation holds: $(\chi_u + \chi_d)\chi_V = 1 + \chi_u\chi_d$

I. Ginzburg, MK, P. Osland, hep-ph/0101208

DATA

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

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

(h/A) Yukawa pro. $e^+e^- \to bbh/A$

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

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: ($H^\pm$) $b \to s\gamma$ $M_{H^\pm} >$ 500GeV (Misiak,Gambino 2001)

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

g-2 data (Hocker SM - hep-ph/0410081)

Global fit •(all Higgses)

Chankowski at al., EPJC 11,661;PL B496,195

Cheung and Kong - hep-ph/0302111

b to s gamma

Strong constraints on new physics from $\bar{B} \to X_s\gamma$ crucially depend on theoretical uncertainties in the Standard Model prediction for this decay

$$\mathrm{BR}[\bar{B} \to X_s\gamma] = \left[3.21 \pm 0.43_{\mathrm{stat}} \pm 0.27_{\mathrm{sys}} \; \binom{+0.18}{-0.10}_{\mathrm{theory}}\right] \times 10^{-4} \qquad (\mathrm{CLEO}\ ),$$

$$\mathrm{BR}[\bar{B} \to X_s\gamma] = \left[3.36 \pm 0.53_{\mathrm{stat}} \pm 0.42_{\mathrm{sys}} \pm 0.54_{\mathrm{theory}}\right] \times 10^{-4} \qquad (\mathrm{BELLE}\ ),$$

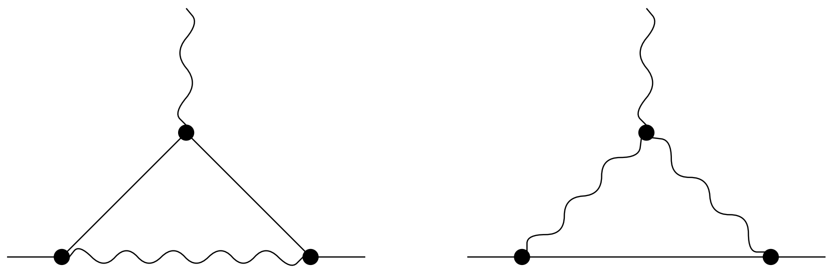
$$\mathrm{BR}[b \to s\gamma] = (3.11 \pm 0.80_{\mathrm{stat}} \pm 0.72_{\mathrm{sys}}) \times 10^{-4} \qquad (\mathrm{ALEPH}\ ).$$

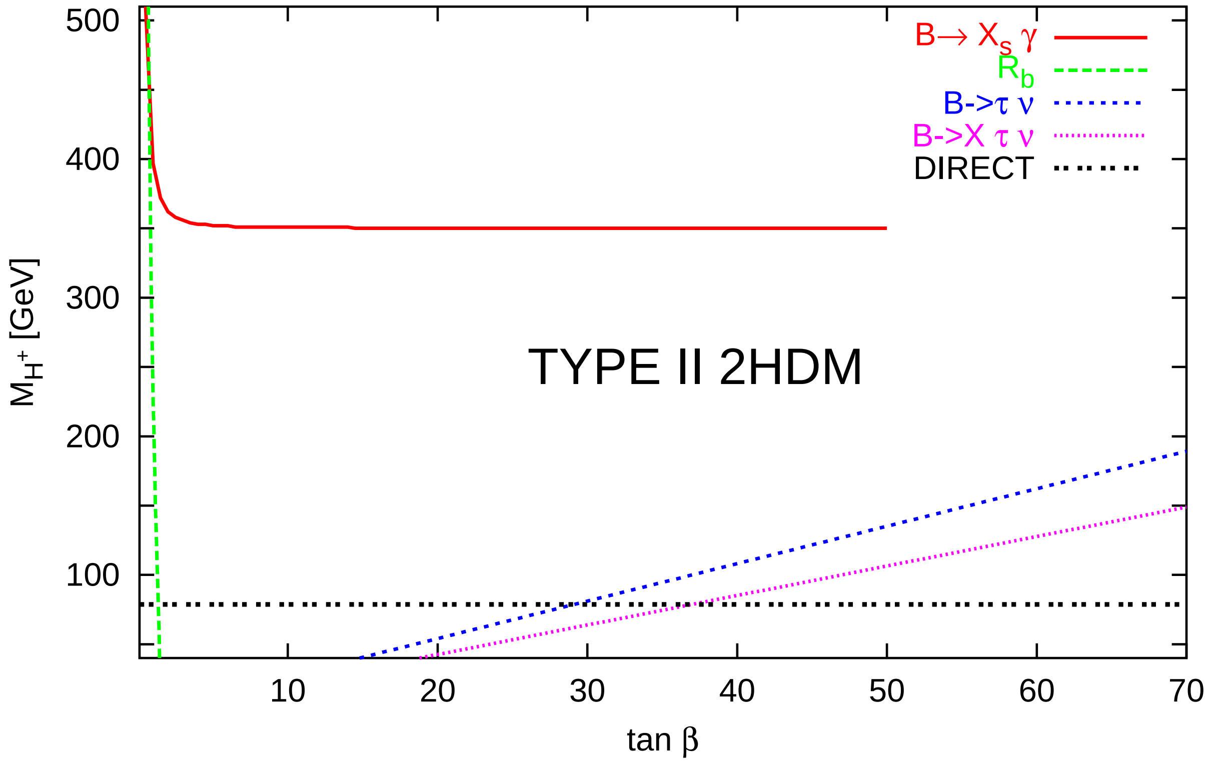
The weighted average for $\mathrm{BR}_\gamma \equiv \mathrm{BR}[\bar{B} \to X_s\gamma]$

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

with an error of around 13%. Improved experimental results coming- reduce the theor. uncertainty significantly below 10% needed

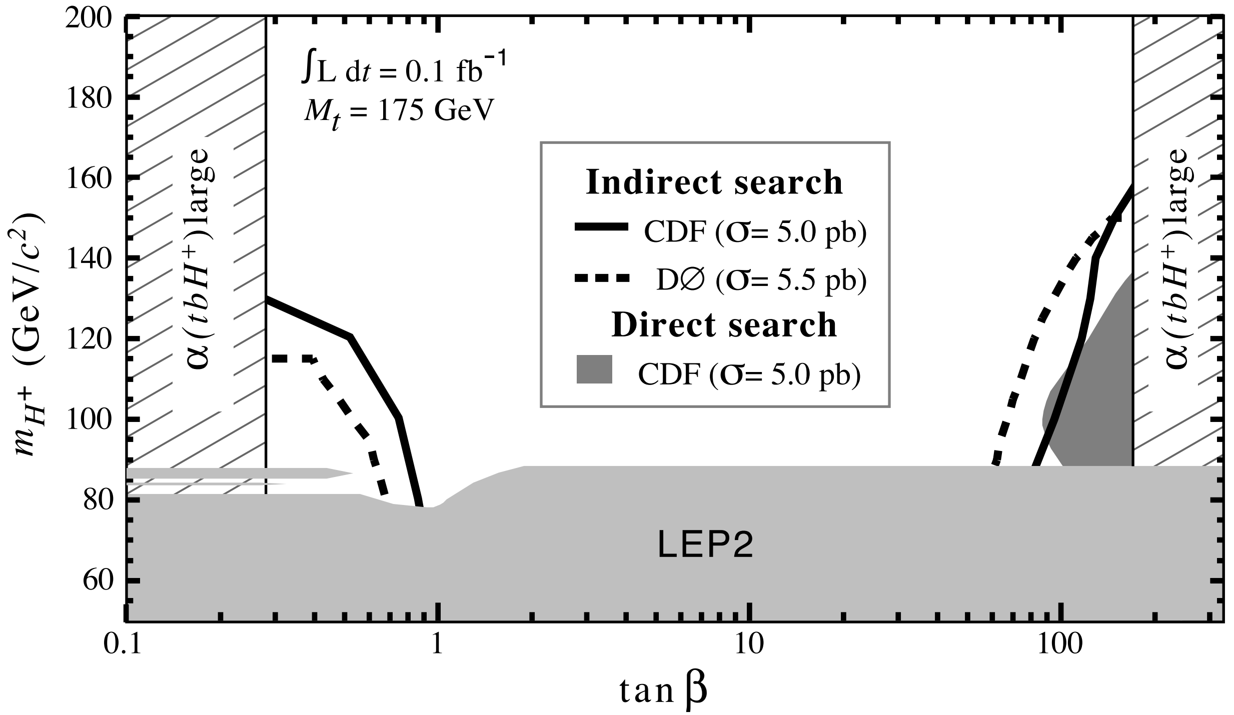
Sources of uncertainties in the theoretical prediction:
parametric, non-perturbative and perturbative
Limits: at 95 % CL - MH+ above 500 GeV





B→ X_s γ
R_b
B->τ ν
B->X τ ν
DIRECT
TYPE II 2HDM
M_H+ [GeV]
tan β
500
400
300
200
100
10
20
30
40
50
60
70

Limits for charged Higgs boson



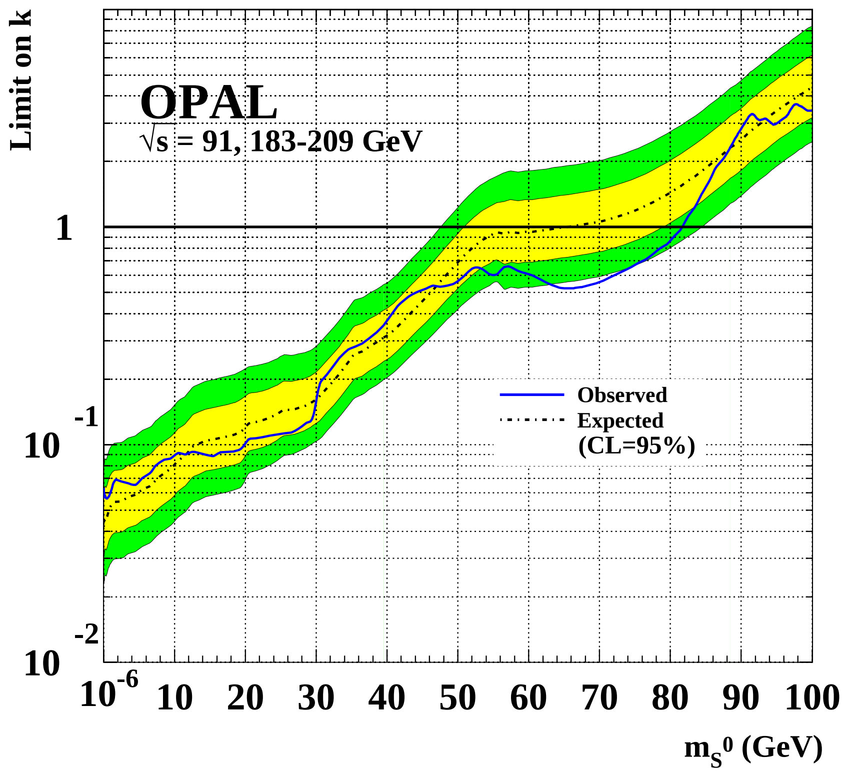
Tevatron, LEP data

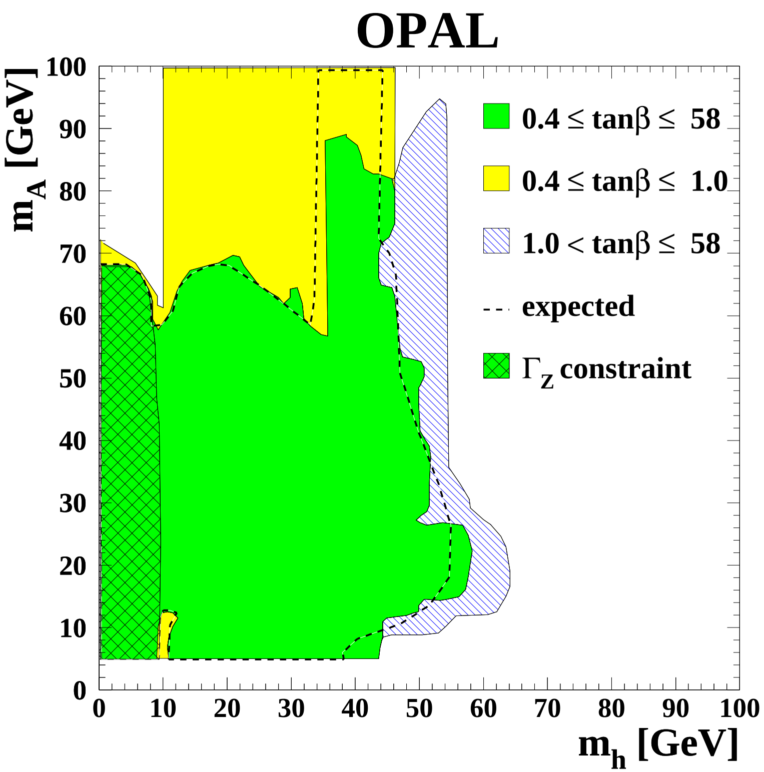
h,A - coupling to gauge boson, and mass plot

Light h OR light A in agreement with current data

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

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





Precision results for (g-2) for muon

and

the lightest Higgs boson in 2HDM(II)

hep-ph/0103223v3
hep-ph/0112112 Snowmass proc
Acta Phys. Pol. B 33 (2002) 2621
(hep-ph/020807)

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 contributions

Hadronic contribution	[in 10^{-11}]	
ho (Krause)	– 100	(6)
lbl (Nyffeler)	80	(40)
vp1 (Jeg02)	6889	(58)
had [FJ02]	6869	(71)

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%)		$93.8 \le \delta a_\mu \le 512.8$

[HMNT (ex)]: $\Delta a_\mu(\sigma) = 297.0\,(107.2)$ $87.2 \le \delta a_\mu \le 507.4$,

[HMNT(in)] : $\Delta a_\mu(\sigma) = 357.2\,(106.4)$ $148.7 \le \delta a_\mu \le 565.7$

[DEHZ (e+e-)]: $\Delta a_\mu(\sigma) = 339.0\,(112)$

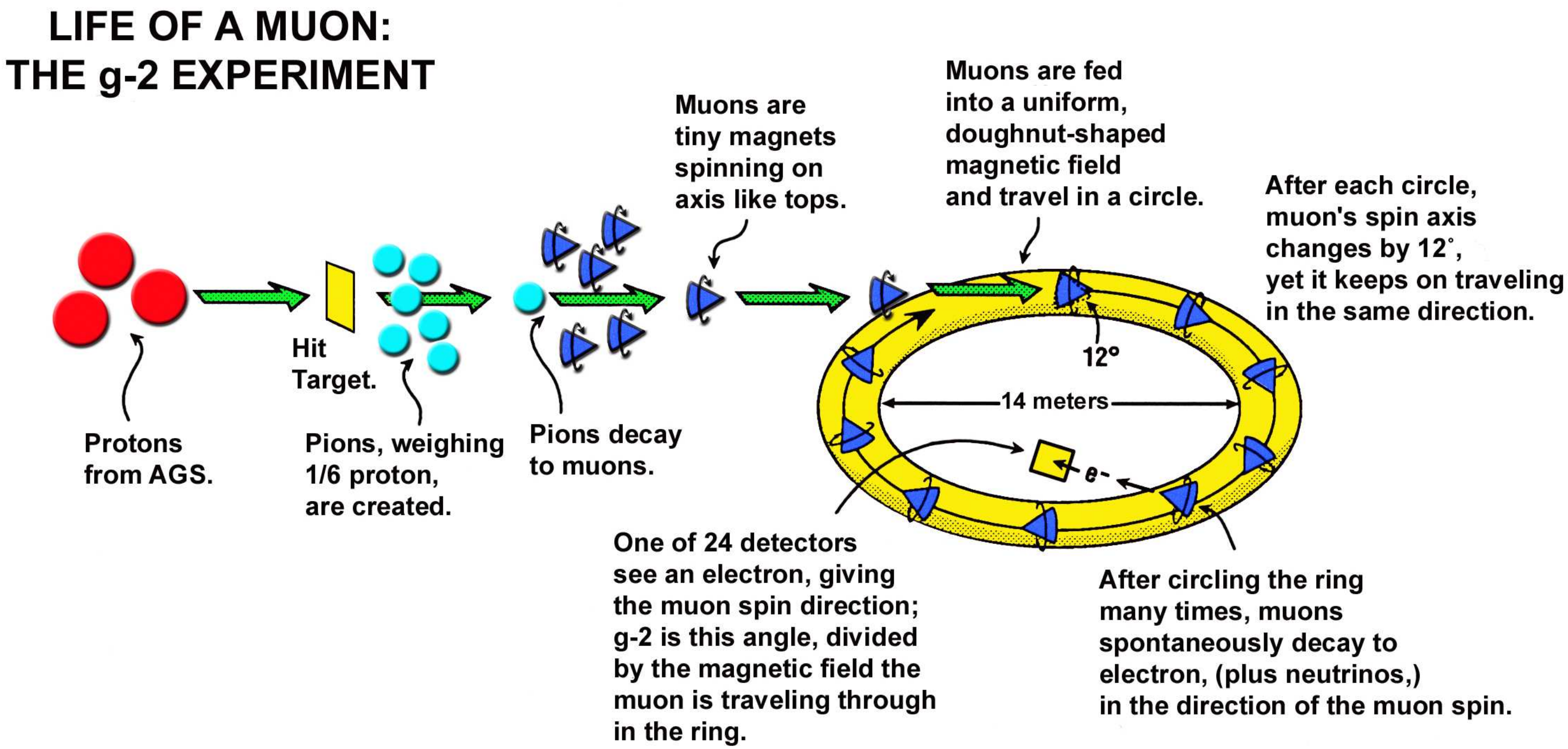
Jegerlehner, Talk at Marseille, March 2002
Hagiwara et al (hep-ph/0209187v2)
Davier et al (hep-ph/0208177)
19.09.03 $\Delta a_\mu(\sigma) = 234\,(119)$ $0.076 \le \delta a_\mu \le 467$
BNL 10.01.2004 $\Delta a_\mu(\sigma) = 301\,(104.1)$ $96.96 \le \delta a_\mu \le 505$
Hocker (10.2004) $\Delta a_\mu(\sigma)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

δa_μ region can be used to constrain parameters of new models

Hot News: BNL hep-ex/0401008

Measurement of the Negative Muon Anomalous Magnetic Moment to 0.7 ppm muon spin precession in a magnetic storage ring with electrostatic focusing. The same experimental technique as in a_{μ^+}, and a similar precision of 0.7 ppm was achieved.

Overview of the experiment



The anomalous magnetic moments of the muon and the electron $\Rightarrow$ an important role in the development of the SM. Compared to the electron, the muon anomaly has a relative sensitivity to heavier mass scales proportional to $(m_\mu/m_e)^2$.

The negative muon anomalous magnetic moment from data collected in early 2001.

$$a_{\mu^-} = 11\,659\,214(8)(3) \times 10^{-10}(0.7\,ppm)$$

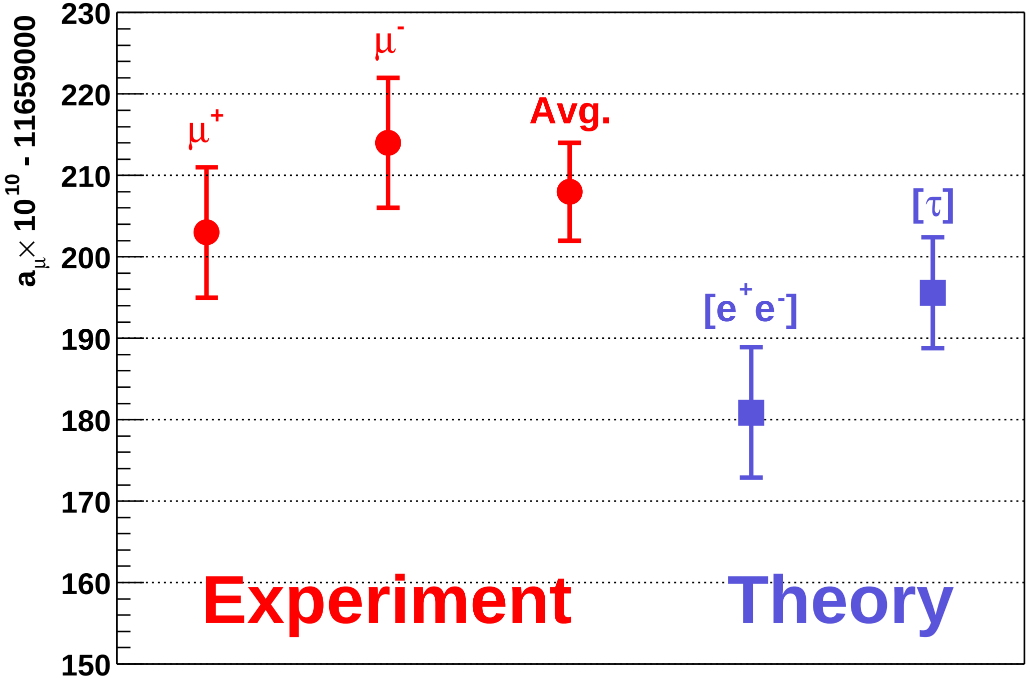
(statistical + systematic)

consistent with previous measurements of the anomaly for the positive and negative muon $a_\mu(\text{exp}) = 11\,659\,203(8) \times 10^{-10}$.

The average for the muon anomaly is

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

(correlated systematic errors between the data sets)



Two data sets do not give consistent results for the pion form factor.
e^+e^- annihilation gives $a_\mu(\mathrm{SM}) = 11\,659\,181(8) \times 10^{-10}$ (0.6 ppm)

τ decay gives result 15×10^{-10} larger.

So, The difference of a_μ^{exp} and the SM the e^+e^- or τ data for the calculation of the hadronic vacuum polarization is 2.7 σ and 1.4 σ

Hadronic contr. - this summer summary

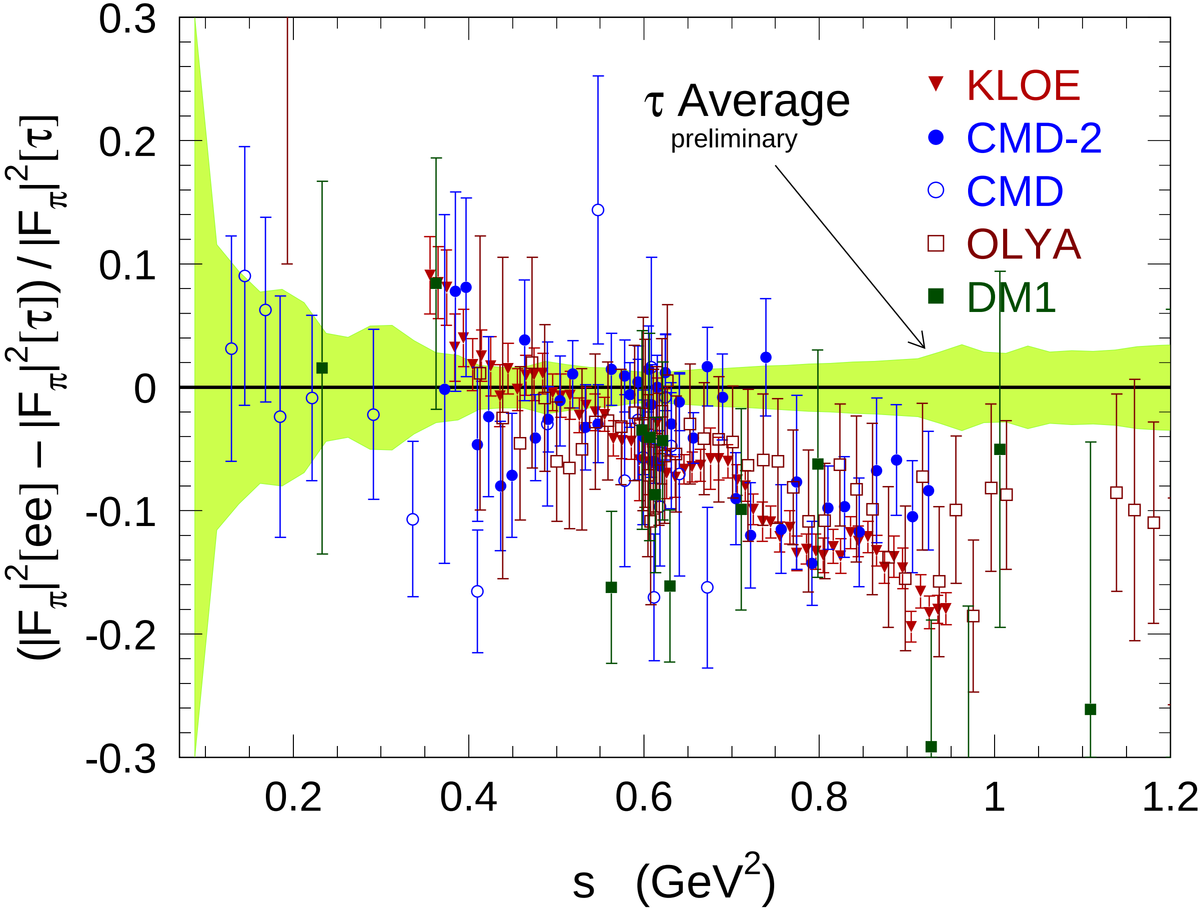
Hadronic contribution to the muon magnetic anomaly - a new estimate using precise results on the pi^+pi^- spectral function from the KLOE Confirmation of the previous e^+e^- annihilation data in this channel, Disagreement with the isospin-breaking-corrected spectral function from tau $\rightarrow$ pi-pi0 nu decays.

2.7 standard deviations from the BNL measurement !

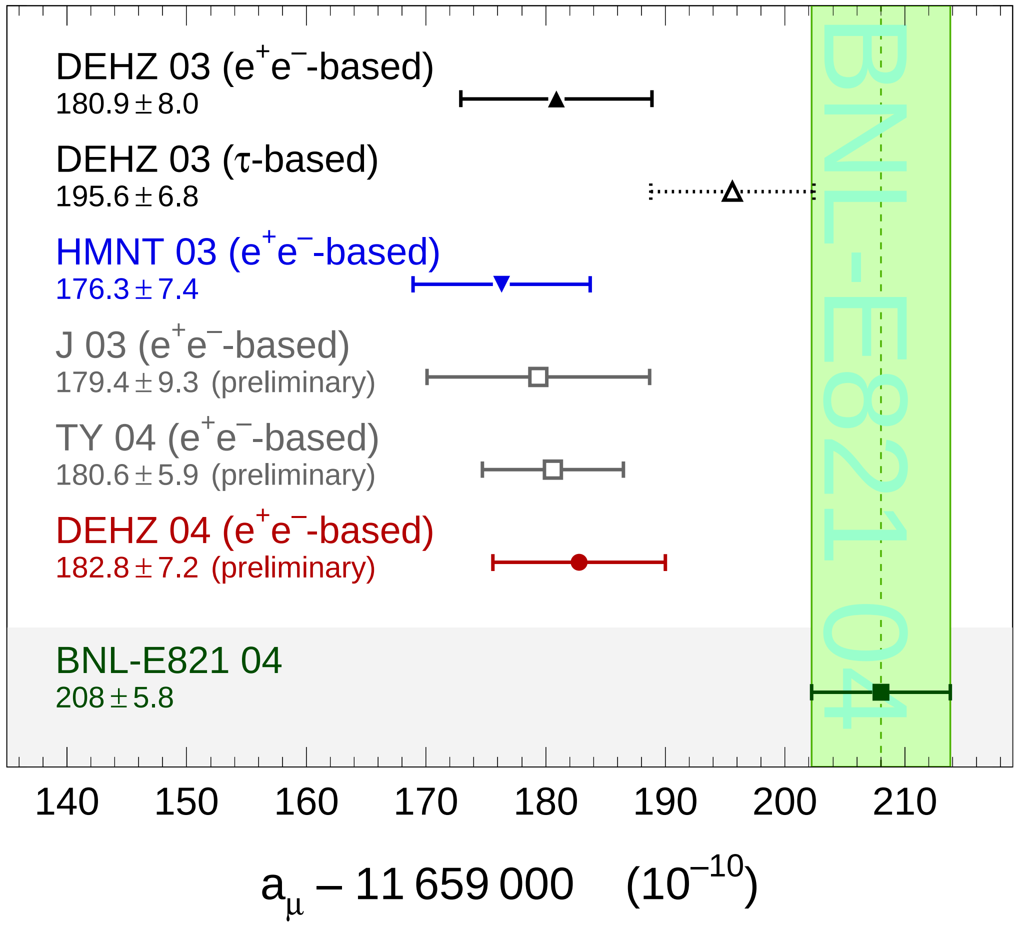
When compared to the world average of the muon magnetic anomaly measurements, dominated by the results from the BNL experiment,

$$a_\mu = (11\,659\,208.0 \pm 5.8)10^{-10} \ ,$$

Respective e^+e^- and τ-based predictions disagreed at the level of 2.5 and 1.3 standard deviations, when adding exp. and th. errors in quadrat



Summary



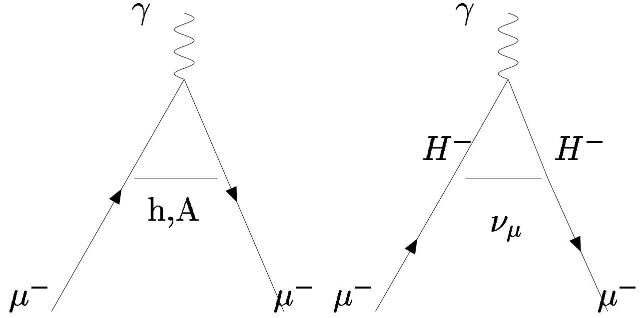
DEHZ 03 (e+e−-based)
180.9 ± 8.0
DEHZ 03 (τ-based)
195.6 ± 6.8
HMNT 03 (e+e−-based)
176.3 ± 7.4
J 03 (e+e−-based)
179.4 ± 9.3 (preliminary)
TY 04 (e+e−-based)
180.6 ± 5.9 (preliminary)
DEHZ 04 (e+e−-based)
182.8 ± 7.2 (preliminary)
BNL-E821 04
208 ± 5.8
BNL-E821 04
140 150 160 170 180 190 200 210
a_μ – 11 659 000 (10^−10)

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

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

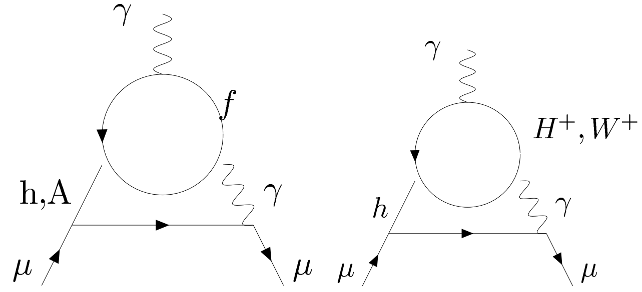
•light A scenario : $a_\mu^{2HDM} \approx a_\mu^A$

one loop



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

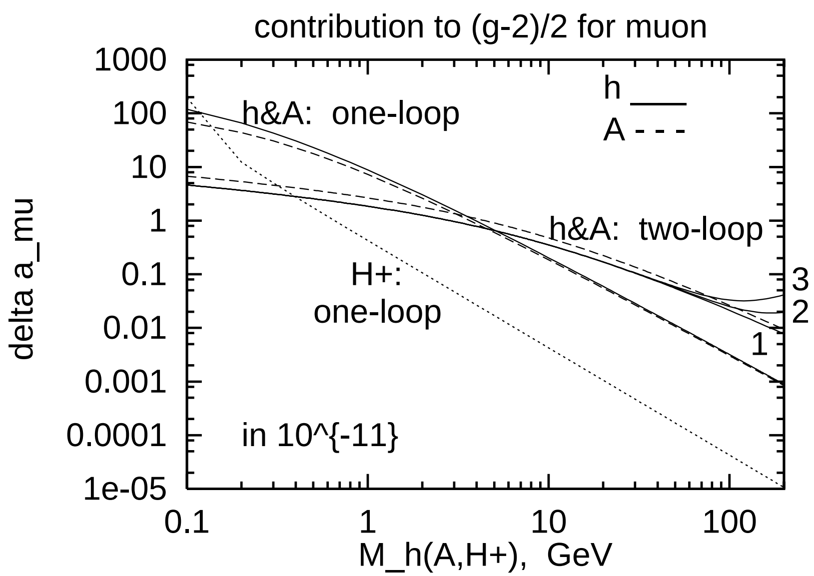
two loop



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

Two loop contributions larger than one-loop for mass ∼ few GeV!

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



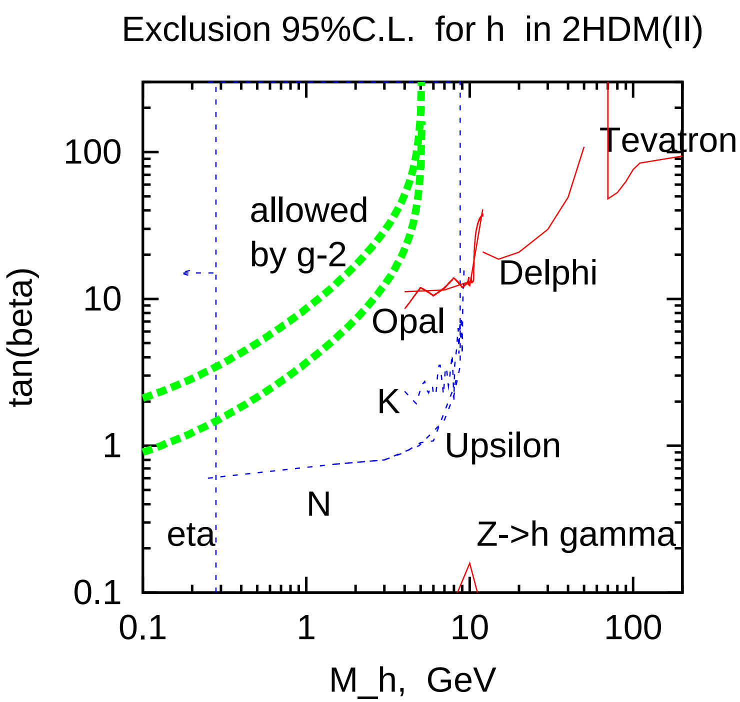
1–
no H^+
2–
$M_{H^\pm}$=800GeV
3–
$M_{H^\pm}$=400GeV

light A
contr. positive
for mass above 5 GeV

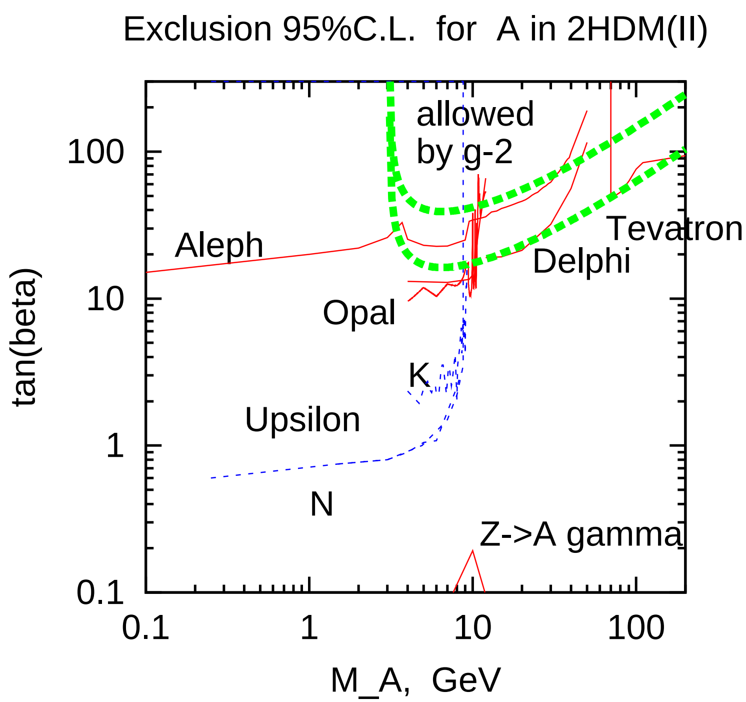
light h
contr. positive
for mass below 3 GeV
$\beta - \alpha = 0$, $\mu^2 = 0$

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

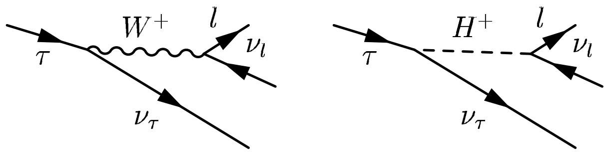
plus LEP data, etc

New estimations $\Rightarrow$ allowed regions for A only if all existing data are taken into account

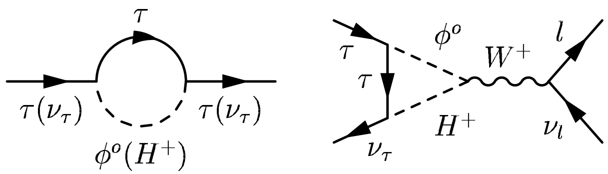
A with mass 25-70 GeV and 25 $<$ tan β $<$ 115 in agreement with all data

Leptonic tau decays

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



Loop corrections involve neutral Higgs bosons
dominant contributions at large tan beta



The partial decay widths and branching ratios:

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

The '04 world averaged data for the leptonic τ decay modes and τ lifetime:

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

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

Note that the relative errors of the above measured quantities are of the 0.34-0.38 %, the biggest being for the lifetime.

The SM prediction for these branching ratios can be defined as the ratios of the SM predicted decay widths to the total width as measured in the lifetime experiments, namely $Br^l|_{SM} = \Gamma^l|_{SM}/\Gamma^{tot}_{exp} = \Gamma^l|_{SM}\tau_\tau$. Therefore, one can parametrise a possible beyond the SM contribution by a quantity Δ^l, defined as

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

In the lowest order of SM

$$Br^e|_{SM} = (17.80 \pm 0.07)\%, \;\; Br^\mu|_{SM} = (17.32 \pm 0.07)\%. \tag{2}$$

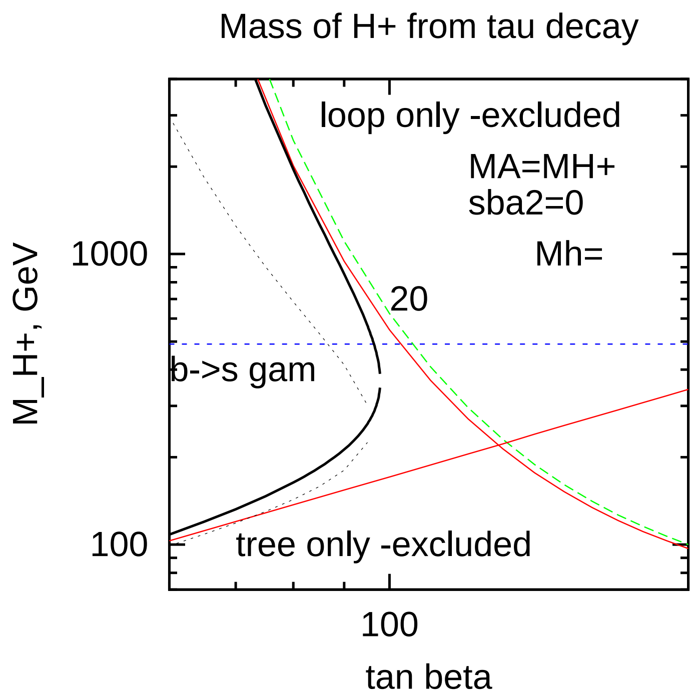
Together with the experimental data this leads to the following estimations for the possible beyond SM contributions to the considered branching ratios,

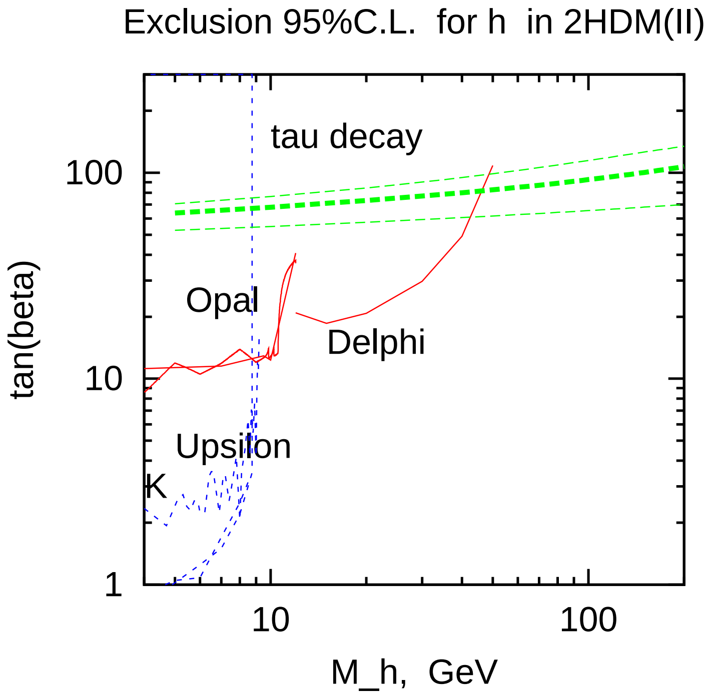
$$\Delta^e = (0.20 \pm 0.51)\%, \quad \Delta^\mu = (0.26 \pm 0.52)\%.$$

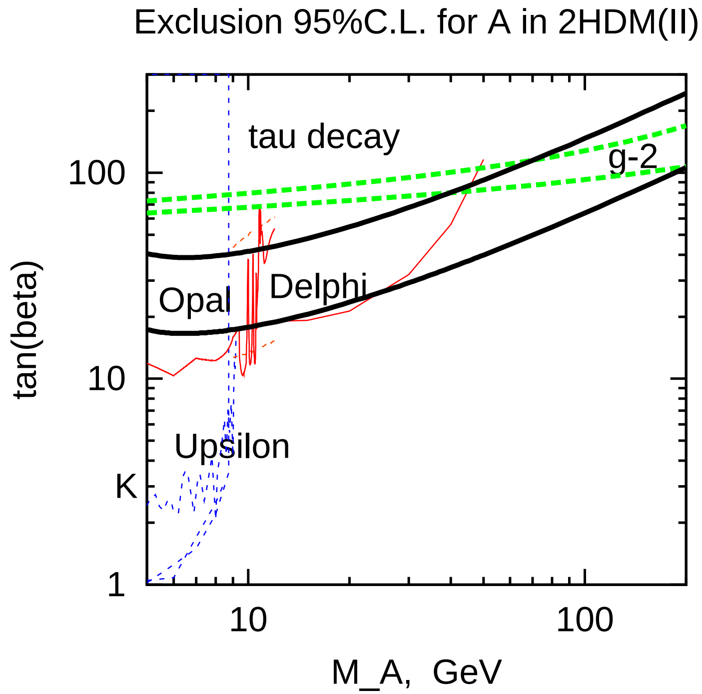
Using them we derive the 95% C.L. bounds on Δ^l, for the electron and muon decay mode, respectively:

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

One can see that the negative contributions are constrained more strongly that the positive ones.


Mass of H+ from tau decay
loop only -excluded
MA=MH+
sba2=0
Mh=
20
b->s gam
tree only -excluded
1000
100
M_H+, GeV
100
tan beta


Exclusion 95%C.L. for h in 2HDM(II)
tau decay
Opal
Delphi
Upsilon
K
tan(beta)
100
10
1
10
100
M_h, GeV


Exclusion 95%C.L. for A in 2HDM(II)
tau decay
g-2
Opal
Delphi
Upsilon
K
tan(beta)
100
10
1
10
100
M_A, GeV

Conclusions

- In 2HDM - various potentials possible

- Large masses of Higgs particle can be obtained in two different ways:

  $\rightarrow$ by large μ parameter related to the soft term in the potential

  $\rightarrow$ by large (but not too large) couplings λ_i

- The selfcoupling of Higgs particles, like $g_{hH^+H^-}$, if expressed in terms of masses, depends on μ

- The $H \rightarrow \gamma\gamma$ process, due to loop with H^+, is sensitive to this coupling. It can be used to distinguish between SM and SM-like 2HDM(II)

- Light h ot A even with mass $\sim$ 10 GeV in agreement with data

What that means: SM in agreement with data?

2HDM (II) - in agreement with data even in such extreme cases:

with the lightest Higgs boson

- very light, with mass eg. few GeV,
  and with very weak (or no) coupling to Z/W

- SM-like, with mass eg. 115 GeV, couplings as for H_{SM}
  (relative couplings $\chi_V, \chi_u, \chi_d = 1$)

Challenge $\rightarrow$ SM-like scenarios in the extensions of the SM

Light or Little Higgs?