From the Planck Scale to the Electroweak Scale,
La Londe-les-Maures, France, 11 - 16 May 2001

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Can the Higgs sector contribute significantly to the muon anomalous magnetic moment?

In collaboration with:

H. E. Haber, `hep-ph/0102297`, JHEP *to appear*

We show :

1. A light CP-even Higgs boson with $m_h \sim \mathcal{O}(10)$ GeV could explain the recent BNL measurement of the muon anomalous magnetic moment

2. Framework : General CP-conserving two-Higgs-doublet extension of the Standard Model with no tree-level flavor-changing neutral Higgs couplings

3. Significant contribution to muon $g-2$ *without violating known experimental constraints* only if the hZZ coupling (approximately) vanishes and $M_\Upsilon \lesssim m_h \lesssim 2m_B$.

• Based on Davier-Höcker calculation for the Hadronic contributions to the muon $g-2$, BNL reports a 2.6σ deviation from the SM

There are four possible interpretations of this discrepancy :

- a statistical fluctuation with 0.9% probability.
- something is "wrong" with the experiment
- something is "wrong" with the theoretical analysis of the hadronic contribution to the muon anomalous magnetic moment.
- the by far most exciting possibility:

there is "New Physics" BSM

$$215 \times 10^{-11} \lesssim \delta a_\mu^{NP} \lesssim 637 \times 10^{-11} \quad @90\% \text{ CL}$$

- δa_μ^{NP} is positive
- δa_μ^{NP} is of the same order of the EW contributions, $\delta a_\mu^{NP} \propto \frac{G_F m_\mu^2}{4\pi^2\sqrt{2}}$

• Why not from the Higgs sector ?

Standard model (SM)

$$\delta a_\mu^h \propto \frac{G_F m_\mu^2}{4\pi^2\sqrt{2}} \left(\frac{m_\mu^2}{m_h^2}\right)$$

suppressed since $m_h \gtrsim 113.5$ GeV

Two Higgs Doublet Model (II) [2HDM(II)] :

The enhancement from the Higgs sector to a_μ arises from two sources :

$$\{h, A\} - \mu^+ - \mu^- \ \propto \ \tan\beta \quad \Rightarrow \quad \delta a_\mu^{h,A} \propto \tan^2\beta$$

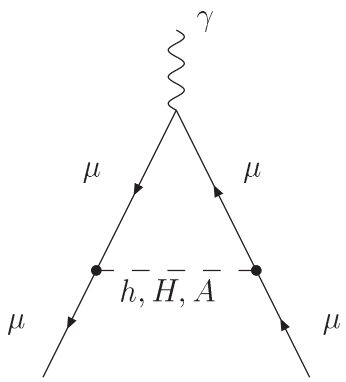
$$H^- - \mu^+ - \nu \ \propto \ \tan\beta \quad \Rightarrow \quad \delta a_\mu^{H^\pm} \propto \tan^2\beta$$

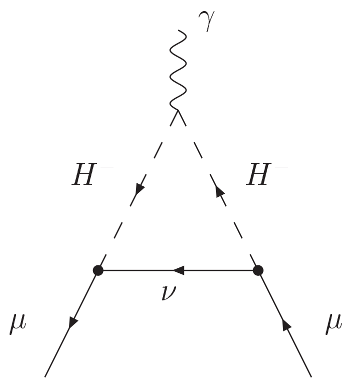
and

$$h - Z - Z \propto \sin(\beta - \alpha) \ \simeq 0$$

then m_h can be as small as ~ 10 GeV.

2HDM(II) Higgs boson corrections to a_μ





Non-decoupling limit: $\sin(\beta - \alpha) = 0$

$$\delta a_\mu^{\rm Higgs} = \delta a_\mu^h + \delta a_\mu^H + \delta a_\mu^A + \delta a_\mu^{H^\pm}$$

$$\simeq \frac{G_F m_\mu^2}{4\pi^2\sqrt{2}} \tan^2\beta \Big\{ \frac{m_\mu^2}{m_h^2}\Big[\ln\left(\frac{m_h^2}{m_\mu^2}\right) - \frac{7}{6}\Big] - \frac{m_\mu^2}{m_A^2}\Big[\ln\left(\frac{m_A^2}{m_\mu^2}\right) - \frac{11}{6}\Big] - \frac{m_\mu^2}{6 m_{H^\pm}^2}\Big\} .$$

√ δa_μ^H can be neglected since it does not give a contribution proportional to $\tan\beta$

√ A and $H^\pm$ exchange contribute a negative value to $\delta a_\mu^{\rm NP}$.

√ In order to explain the BNL $g-2$ we need positive corrections. We take m_A and $m_{H^\pm}$ large, $\gtrsim 100$ GeV.

√ If $\delta a_\mu^{\rm NP}$ is to be a consequence of the Higgs sector, it must be entirely due to the contribution of the light CP-even Higgs boson.

Therefore :

$$\delta a_\mu^{\rm Higgs} \simeq \delta a_\mu^h \simeq \frac{G_F m_\mu^2}{4\pi^2\sqrt{2}} \left(\frac{m_\mu^2}{m_h^2}\right) \tan^2\beta \Big[\ln\left(\frac{m_h^2}{m_\mu^2}\right) - \frac{7}{6}\Big] \, .$$

A light Higgs boson with a mass of around 10 GeV and with $\tan\beta = 35$ gives $\delta a_\mu^{\rm Higgs} \simeq 280 \times 10^{-11}$, which is within the 90% CL allowed range for $\delta a_\mu^{\rm NP}$.

<u>Decoupling limit: $\cos(\beta - \alpha) = 0$</u>

$\surd$ The couplings of the light Higgs boson, h, are (nearly) identical to those of the SM Higgs boson : $m_h \gtrsim 113.5$ GeV.

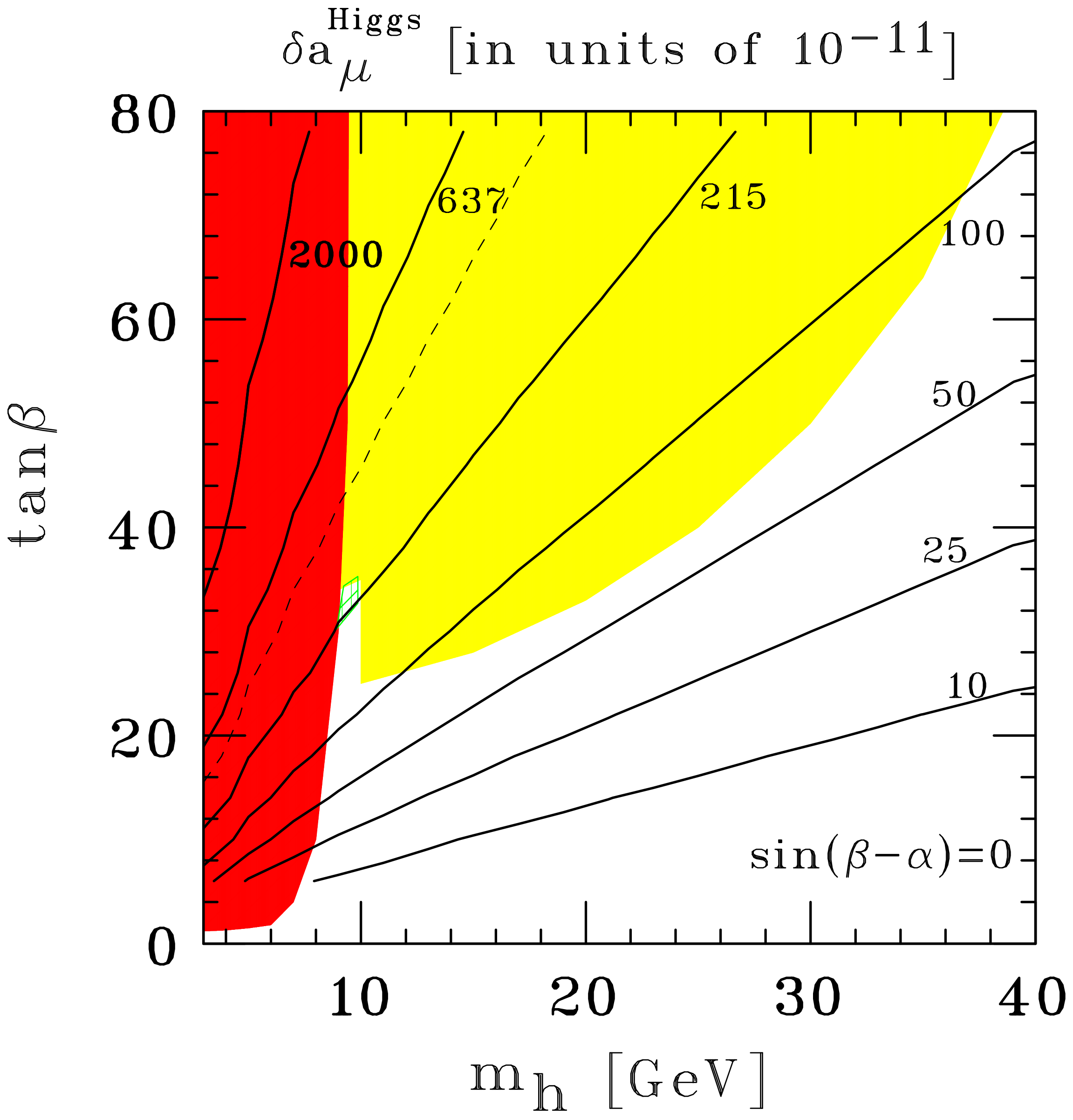
$\surd$ The H couplings to down-type fermion pairs are enhanced by $\tan\beta$

$\surd$ For : $\cos(\beta - \alpha) = 0$ and $m_H = m_A = m_{H^\pm}$

$$\delta a_\mu^{\rm Higgs} \simeq \frac{G_F m_\mu^2}{4\pi^2\sqrt{2}} \left(\frac{m_\mu^2}{m_A^2}\right) \tan^2\beta \Big[\frac{1}{2} - \left(\frac{2m_\mu^2}{m_A^2}\right) \ln\left(\frac{m_A^2}{m_\mu^2}\right)\Big] \, .$$

$\surd$ For 100 GeV $< m_A <$ 1000 GeV, and $30 < \tan\beta < 100$, the Higgs sector contribution to a_μ ranges from about 5×10^{-12} to 5×10^{-14}, which is three to five orders of magnitude below what is needed to explain the BNL measurement of a_μ.

Results



$m_\Upsilon \lesssim m_h \lesssim 2m_B$,

$\sin(\beta - \alpha) \simeq 0$,

$30 \lesssim \tan\beta \lesssim 35$.

CESR constraints on the light m_h

- An experimental search for $\Upsilon \to h\gamma$ by the CUSB Collaboration at CESR found no candidates.
- In addition to the non-relativistic, tree-level prediction there are :
  - $\mathcal{O}(\alpha_s)$ hard QCD corrections
  - relativistic corrections to the non-relativistic treatment of the $b\bar{b}$ bound state
  - bound state threshold corrections

Standard Model: $m_h \lesssim 5$—7 GeV can be ruled out at 95% CL but no precise upper limit due to the theoretical uncertainties

2HDM : $\Gamma(\Upsilon \to h\gamma)$ is enhanced by a factor of $\tan^2\beta$

$\surd$ For values of $\tan\beta \gtrsim 10$, the CUSB data can reliably rule out Higgs masses up to about 8 GeV.

$\surd$ For large $\tan\beta \simeq 30$ values, the $\tan^2\beta$ factor should dwarf the theoretical uncertainties!

$$m_h \gtrsim m_\Upsilon$$

[See red region in the previous figure]

LEP constraints on the light m_h

- A second bound on m_h can be derived from the non-observation of Higgs bosons at LEP via the process $e^+e^- \to hf\bar{f}$ $(f = b, \tau)$.

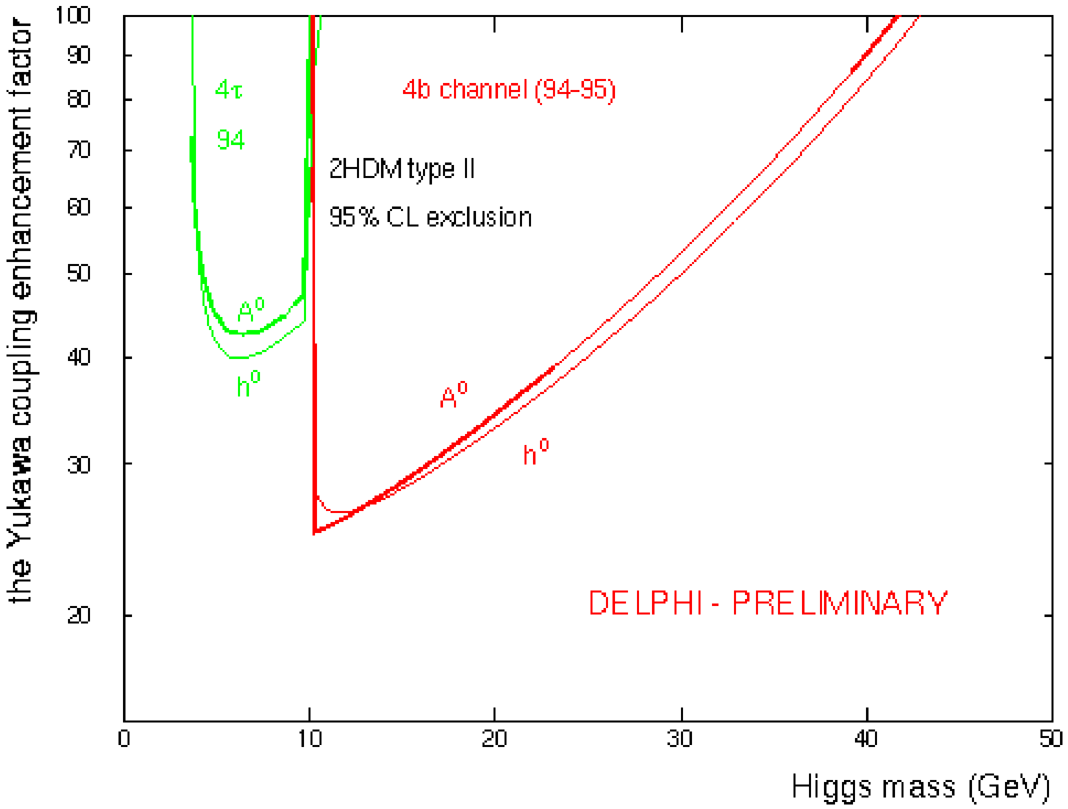
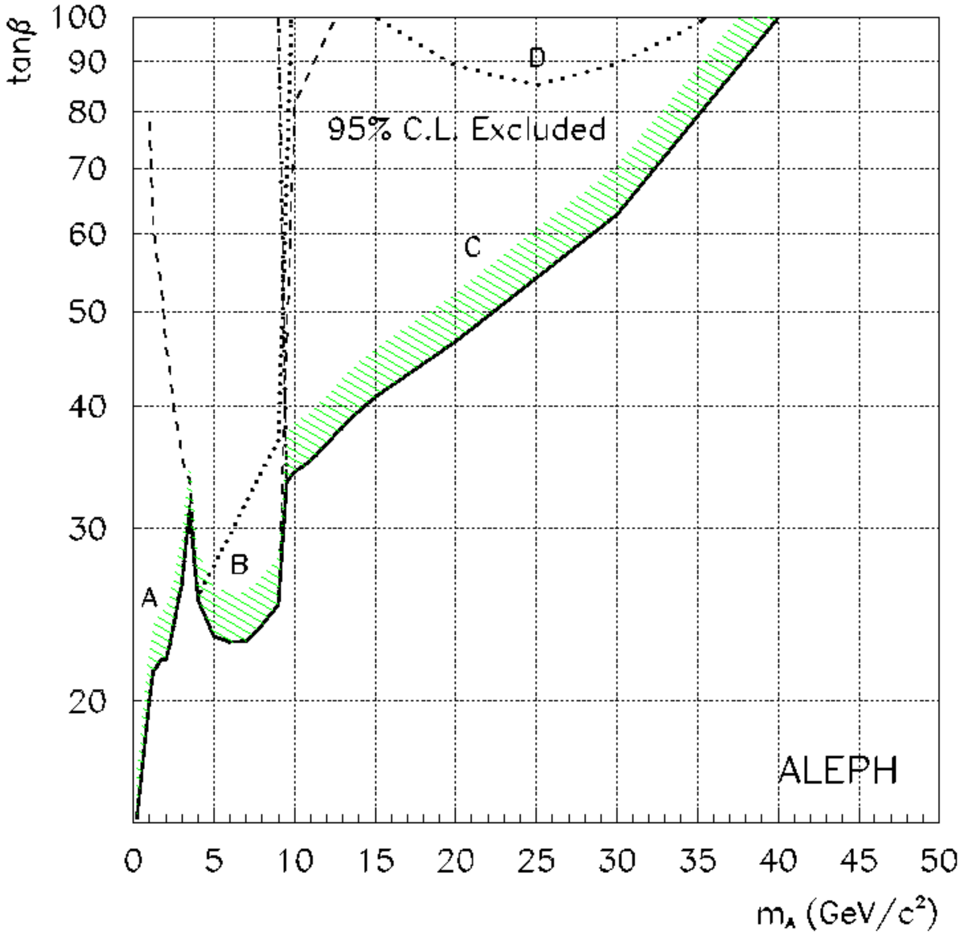


Figure 20: The exclusions within 2HDM type II.

From J. Kurowska, O. Grajek and P. Zalewski [DELPHI Collaboration], CERN-OPEN-99-385.



Similar for m_h

From J.B. de Vivie and P. Janot [ALEPH Collaboration], PA13-027 contribution to the International Conference on High Energy Physics, Warsaw, Poland, 25–31 July 1996.

- *Other constraints :*
  - *the one-loop process* $Z \to h\gamma$
  - *precision EW observables*

$\to$ *weaker bounds on* $m_h - \tan\beta$ *than CESR+LEP ones*

One noteworthy consequence of $m_h \sim 10$ *GeV*

- *the possibility of mixing between the* h *and the* 0^{++} $b\bar{b}$ *bound states* $\chi_{b0}(1P)$ *and* $\chi_{b0}(2P)$

$$\frac{\Gamma(\chi_{b0} \to \tau^+\tau^-)}{\Gamma(\chi_{b0} \to \ \text{hadrons})} \simeq \frac{2.5 \times 10^{-7}\ \text{GeV}^2}{(m_\chi - m_h)^2} \tan^4\beta$$

$\surd$ *Due to the large* $\tan^4\beta$ *enhancement, the predicted branching ratio for* $\chi_{b0} \to \tau^+\tau^-$ *can be substantial.*

$\surd$ *Particle Data Group provides no data on possible decay modes of the* χ_{b0} *other than the radiative decays,* $\chi_{b0} \to \Upsilon\gamma,\ \Upsilon'\gamma$.

Final Results and Conclusions

- Combined CESR+LEP+BNL(DH) in 2HDM(II):

  - $m_\Upsilon \lesssim m_h \lesssim 2m_B$,
  - $\sin(\beta - \alpha) \simeq 0$,
  - $30 \lesssim \tan\beta \lesssim 35$.

- In addition, H, A and $H^\pm$ must be sufficiently heavy to satisfy the LEP experimental constraints :

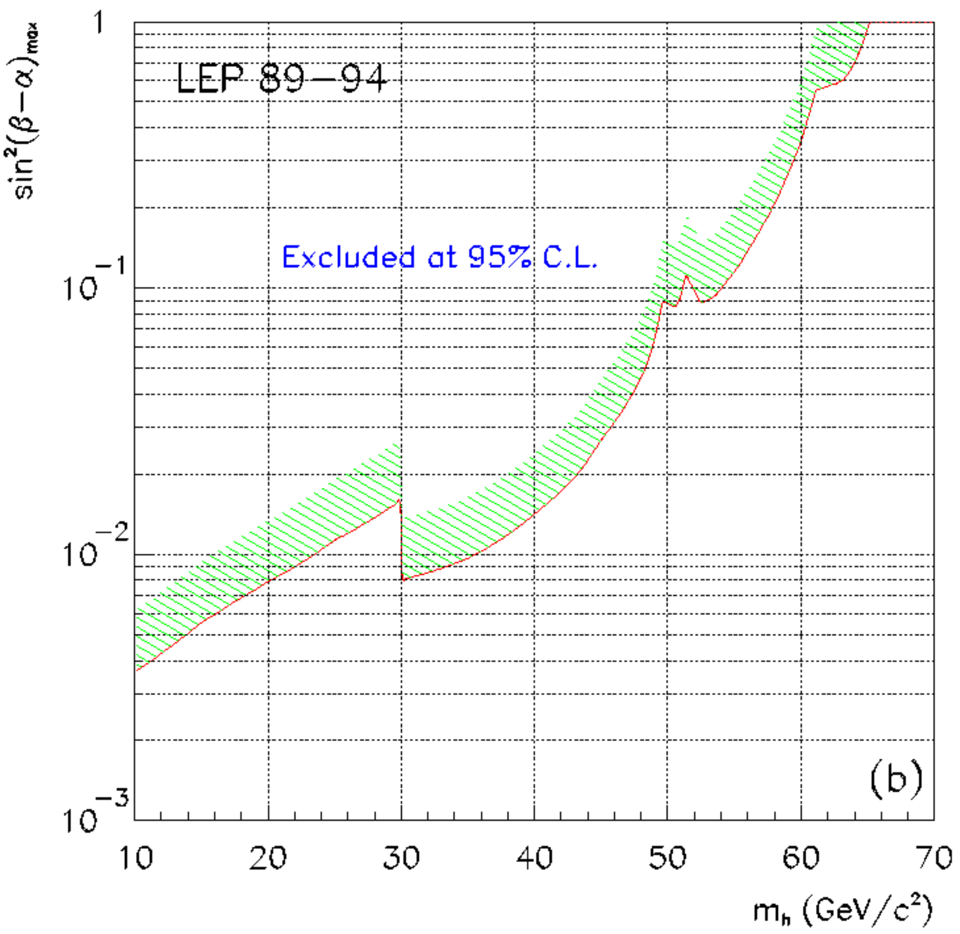
$$\begin{aligned} \surd\, m_H &\gtrsim 113.5 \text{ GeV} \\ \surd\, m_A &\gtrsim 80 \text{ GeV} \\ \surd\, m_{H^\pm} &\gtrsim 78.7 \text{ GeV} \end{aligned}$$

<u>These results can be confirmed or ruled out by :</u>

- a more complete analysis by the LEP Collaborations of their data in search of $e^+e^- \to hf\bar{f}$ ($f = b$ or τ)

- further improvement of the BNL measurement of the muon anomalous magnetic moment a_μ

- further improvement of the theoretical calculations on the hadronic contributions to the muon anomalous magnetic moment.



LEP 89−94
Excluded at 95% C.L.
(b)
$\sin^2(\beta-\alpha)_{max}$
1
10^{-1}
10^{-2}
10^{-3}
10
20
30
40
50
60
70
m_h (GeV/c^2)