The $(g-2)_\mu$ data and the lightest Higgs boson in 2HDM(II)

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The present limits on the lightest Higgs boson in 2HDM (II) in light of the new E821 measurement of $g-2$ for the muon are discussed.

The precision measurement of $g-2$ for the muon is expected to shed light on "new physics". Here [1] we discuss constraints on the lightest neutral Higgs boson in 2HDM (II) which can be drived from the new E821 measurement based on 1999 data [2]. A current mean of experimental results for $(g-2)_\mu$ is (from [2])

$$a_\mu^{exp} \equiv (g-2)_\mu^{exp}/2 = 11\ 659\ 203\ (15) \cdot 10^{-10},$$

where the accuracy of this result (in parentheses) approaches the size of electro-weak contribution, a_μ^{EW}. The ultimate accuracy of the E821 experiment is $4 \cdot 10^{-10}$. The Standard Model prediction for a_μ consists of the QED, hadronic and EW contributions:

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

Both the QED and EW contributions to a_μ^{SM} are well under control. The predictions for the hadronic contribution, a_μ^{had}, differ considerably among themselves. Its uncertainty is presently of order $(7-10)\cdot 10^{-10}$, with the dominant error coming from the leading vacuum polarization contribution (see discussions in [3], also [4]). A new controversy of the light-by-light scattering contribution (a sign !) has appeared recently [7].

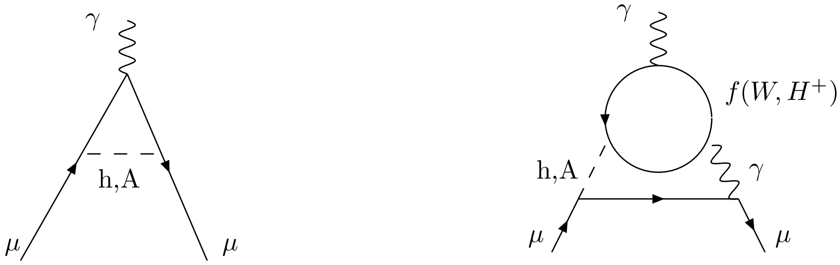
The difference between the experimental data, a_μ^{exp}, and the Standard Model (SM) prediction, a_μ^{SM}, defines the room for "new physics". Obviously the uncertainties of the hadronic contributions influence the estimation of a size of new effects. To illustrate the present situation we calculate 95% CL intervals ($lim(95\%)$) for an allowed new contribution, δa_μ, using two representative SM predictions [3]: one based on the calculation of leading vacuum polarization diagrams by Davier and Höcker (DH)[5] and the other by Jegerlehner (J2000)[6], with a smaller and larger a_μ^{had} (and its uncertainty), respectively.

The obtained intervals we apply to constrain the parameters of the non-supersymmetric, CP conserving 2HDM ('Model II') [8]. This model, based on the two doublets of complex scalar fields, predicts existence of five Higgs particles: two neutral Higgs scalars h and H, one neutral pseudoscalar A, and a pair of charged Higgses $H^\pm$. In this model *one* light neutral Higgs boson, h or A, with mass even below 20 GeV is still allowed by the LEP [10, 11] and low energy experiments [12, 13] in contrast to the SM Higgs boson which should be heavier than 114.1 GeV (95 % CL) [9]. Previous (CERN) data and the SM prediction(s) for a_μ were used by us to derive the constraints (based on the one-loop calculation [14]) for h or A in 2HDM (II) [15]. A very small improvement with comparison to the LEP limits were obtained. In this paper we use new E821 data and apply the two-loop approach [17] to derive tight constraints on the Yukawa couplings to muon of h and A (similar results are in [17], see also [1, 16] for one-loop results). Next we combine these constraints with other limits to derive current constraints for the lightest Higgs boson in 2HDM(II).

We study separately case A and case B based on the DH and J2000 calculation of the leading vacuum polarization diagram, respectively. The contributions due to higher order hadronic corrections and the light-on-light scattering are taken from [18] and [20], respectively. In the table below we collect, following [3], the corresponding SM contributions (and their uncertainties). From Δa_μ, the difference of the central values $a_\mu^{exp} - a_\mu^{SM} \equiv \Delta a_\mu$, and the error for this quantity, σ, one can calculate an allowed at chosen confidence level (CL) interval of an additional contribution. We estimate σ by adding in quadrature σ_{exp} and σ_{tot}. Assuming a Gaussian distribution we calculate in both cases, A and B, the allowed at 95% CL δa_μ regions, symmetric around Δa_μ (see table below).

case	A [in 10^{-11}]	B [in 10^{-11}]
QED	116 584 706 (3)	116 584 706 (3)
had	6 739 (67)	6 803 (114)
EW	152 (4)	152 (4)
tot	116 591 597 (67)	116 591 661 (114)
$\Delta a_\mu(\sigma)$	426(165)	362(189)
$lim(95\%)$	$102 \leq \delta a_\mu \leq 750$	$-8.65 \leq \delta a_\mu \leq 733$

We see that at 95 %CL the more conservative estimation of the hadronic contribution to a_μ^{SM} (case B) leads to both the negative and positive δa_μ, while in case A δa_μ is of a positive sign only. As a consequence, the 95 %CL interval leads in case A to an *allowed positive* contribution (*an allowed band*) and at the same time to the *exclusion* of the negative contribution. For the case B, the positive (negative) contribution is only bounded from above (below) (*upper limits* for the absolute value of the new contribution). This reflects the fact that the SM prediction lies within the 95% CL interval for case B, while for case A it is outside the corresponding interval.



One- and two-loop diagrams. The W^+ and H^+ loops contribute only for a h exchange.

We apply the obtained intervals δa_μ to constrain parameters of the 2HDM (II) using a simple approach, where only one neutral Higgs boson, h or A, contributes. In the one-loop calculation (based on the one-loop diagram, see above) a light scalar scenario leads to the positive, whereas the one with a light pseudoscalar to the negative contribution to a_μ, independently of mass. In the two-loop analysis, based on a sum of the one- and two-loop (fermionic and bosonic) diagram contributions, the situation changes drastically. Now the positive (negative) contribution can be ascribed to a scalar h with mass below (above) 5 GeV or a pseudoscalar A with mass above (below) 3 GeV. For h we assumed χ_V^h=0, so the W-loop does not contribute. A H^+ loop, for M_{H^+} = 400, 800 GeV and infinity (and with parameter $\mu = 0$ in the hH^+H^- coupling), is included in the analysis.

Our results are presented in Fig.1 and Fig. 2 (tick lines) together with current upper limits from the Yukawa process (ALEPH, DELPHI and OPAL results) and lower limits from the $Z \to h(A)\gamma$ [10]. In addition the upper 90% CL limits from the Υ decay (K,N), rescaled by a factor 2, and from the TEVATRON [21] are presented. Constraints based on case B lead to an improvement of the existing upper limits for h for mass above 10 GeV (Fig.1(left)) and for A above 50 GeV (Fig. 2(left)). For case A our results are in form of allowed regions for mass below 5 GeV for h (Fig.1(right)) and for mass above 3 GeV for A (Fig.2(right)) (see also [17]).

This two-loop analysis based on new $(g-2)_\mu$ data and on the DH estimation of a_μ^{had} (case A) if combined with constraints from other experiments allows in the 2HDM (II) for an existance of a pseudoscalar with mass between $\sim$ 25 GeV and 70 GeV, and $\tan\beta$ above 30. A light scalar is excluded. This latter result is in agreement with a conclusion of theoretical analysis [22].

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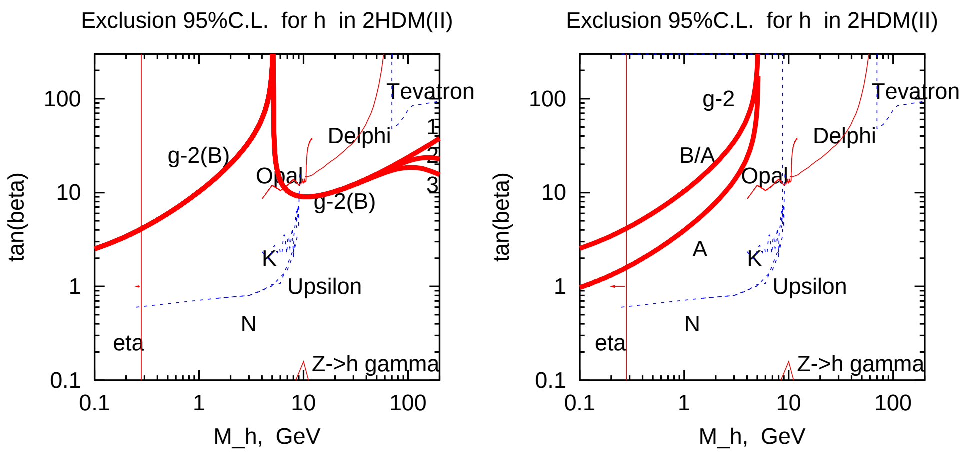

FIG. 1: The 95% CL upper and lower limits for the Yukawa coupling χ_d^h for a scalar h ($\chi_d^h = \tan\beta$ for vanishing coupling to gauge bosons $\chi_V^h = 0$) as a function of mass. Left: The tick lines "$g-2(B)$" give upper limits in case B. Line 1 (2,3) is obtained for mass of H^+ equal to infinity (800, 400 GeV). Right: Similar results for case A, allowed region between upper tick line B/A (which coincides with case B) and lower tick line A.

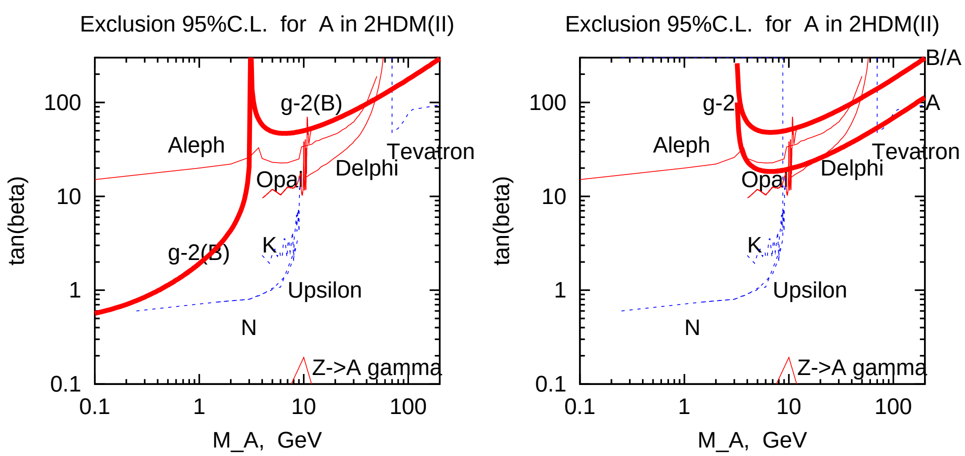

FIG. 2: As in Fig.1 for a pseudoscalar A ($\chi_d^A = \tan\beta$).