LOOKING FOR A LIGHT HIGGS
PARTICLE AT PRESENT AND FUTURE
COLLIDERS *

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Abstract

Present data do not rule out the light neutral Higgs particle $h$ or $A$ with mass below 40–50 GeV in the framework of the general 2HDM ("Model II"). The recent limits from LEP I on the parameters of the model, based on the Bjorken process $Z \to Zh$, Higgs pair production $Z \to Ah$ and the Yukawa process $Z \to f\bar{f}A$ ($f = b$ quark or $\tau$ lepton) are presented. Including limits on Higgs bosons masses from LEP I data additional constraints on the allowed value of $\tan \beta$ for mass below 2 GeV, can be obtained from the existing ($g-2)_\mu$ data. The improvement in the accuracy by factor 20 in the forthcoming ($g-2)_\mu$ experiment E821 may lead to more stringent limits on mass of neutral Higgs boson up to 30 GeV, or even higher if the mass difference between $h$ and $A$ is larger than $M_Z$. The exclusion/discovery potential

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of the gluon-gluon fusion in $ep$ collision at HERA is also discussed. Already for a luminosity $L_{ep} = 25 \text{ pb}^{-1}$ this measurement may lead to more stringent limits on $\tan \beta$ for the mass range 5-15 GeV, especially for the pseudoscalar case. In addition the possible search for very light Higgs particle in $\gamma \gamma$ fusion at low energy (10 GeV) LC is described. It may improve bounds considerably compared to the present limits for mass around between 1.5 and 8 GeV assuming the luminosity 10 fb$^{-1}$.

1  Status of 2HDM.

1.1  Introduction.

The mechanism of spontaneous symmetry breaking proposed as the source of mass for the gauge and fermion fields in the Standard Model (SM) leads to a neutral scalar particle, the minimal Higgs boson. According to the LEP I data, based on the Bjorken process $e^+e^- \rightarrow HZ^*$, it should be heavier than 66 GeV[1], also the MSSM neutral Higgs particles have been constrained by LEP1 data to be heavier than $\sim 45$ GeV [2, 3, 4]. The general two Higgs doublet model (2HDM) may yet accommodate a very light ($\lesssim 45$ GeV) neutral scalar $h$ or a pseudoscalar $A$ as long as $M_h + M_A \gtrsim M_Z$[2].

The minimal extension of the Standard Model is to include a second Higgs doublet to the symmetry breaking mechanism. In two Higgs doublet models the observed Higgs sector is enlarged to five scalars: two neutral Higgs scalars (with masses $M_H$ and $M_h$ for heavier and lighter particle, respectively), one neutral pseudoscalar ($M_A$), and a pair of charged Higgses ($M_{H^+}$ and $M_{H^-}$). The neutral Higgs scalar couplings to quarks, charged leptons and gauge bosons are modified with respect to analogous couplings in SM by factors that depend on additional parameters: $\tan \beta$, which is the ratio of the vacuum expectation values of the Higgs doublets $v_2/v_1$, and the mixing angle in the neutral Higgs sector $\alpha$. Further, new couplings appear, e.g. $Zh(H)A$ and $ZH^+H^-$. 

In this paper we will focus on the appealing version of the models with two doublets ("Model II") where one Higgs doublet with vacuum expectation value $v_2$ couples only to the "up" components of fermion doublets while the other one couples to the "down" components [5]. In particular, fermions couple to the pseudoscalar $A$ with a strength proportional to $(\tan \beta)^{\pm 1}$ whereas
the coupling of the fermions to the scalar $h$ goes as $\pm (\sin \alpha / \cos \beta)^{\pm 1}$, where
the sign $\pm$ corresponds to isospin $\mp 1/2$ components. In such model FCNC processes are absent and the $\rho$ parameter retains its SM value at the tree level. Note that in such scenario the large ratio $v_2/v_1 \sim m_{top}/m_b \gg 1$ is naturally expected.

The well known supersymmetric model (MSSM) belongs to this class. In MSSM the relations among the parameters required by the supersymmetry appear, leaving only two parameters free (at the tree level) e.g. $M_A$ and $\tan \beta$. In general case, which we call the general 2 Higgs Doublet Model (2HDM), masses and parameters $\alpha$ and $\beta$ are not constrained by the model. Therefore the same experimental data may lead to very distinct consequences depending on which version of two Higgs doublet extension of SM, supersymmetric or nonsupersymmetric, is considered.

### 1.2 Present constraints on 2HDM from LEP I.

Important constraints on the parameters of two Higgs doublet extensions of SM were obtained in the precision measurements at LEP I. The current mass limit on charged Higgs boson $M_{H^\pm} = 44$ GeV/c was obtained at LEP I \cite{4} from process $Z \to H^+H^-$, which is independent on the parameters $\alpha$ and $\beta$. (Note that in the MSSM version one expect $M_{H^\pm} > M_W$). For neutral Higgs particles $h$ and $A$ there are two main and complementary sources of information at LEP I. One is the Bjorken processes $Z \to Z^*h$ which constrains $g_{hZZ}^2 \sim \sin^2(\alpha - \beta)$, for $M_h$ below 50-60 GeV.. The second process is $Z \to hA$, constraining the $g_{ZhA}^2 \sim \cos^2(\alpha - \beta)$ for $M_h + M_A \leq M_Z$. This Higgs pair production contribution depends also on the masses $M_h$, $M_A$ and $M_Z$.

Results on $\sin^2(\alpha - \beta)$ and $\cos^2(\alpha - \beta)$ can be translated into the limits on neutral Higgs bosons masses $M_h$ and $M_A$. In the MSSM, due to relations among parameters, the above data allow to draw limits for the masses of individual particles: $M_h \geq 45$ GeV for any $\tan \beta$ and $M_A \geq 45$ GeV for $\tan \beta \geq 1$ \cite{3, 4}. In the general 2HDM the implications are quite different, here the large portion of the $(M_h, M_A)$ plane, where both masses are in the range between 0 and $\sim 50$ GeV, is excluded \cite{4}.

The third basic process in search of a neutral Higgs particle at LEP I

\footnote{The off shell production could also be included, e.g. as in \cite{5}.}
is the Yukawa process, \(i.e.\) the bremsstrahlung production of the neutral Higgs boson \(h(A)\) from the heavy fermion, \(e^+e^- \rightarrow f\bar{f}h(A)\), where \(f\) means here \(b\) quark or \(\tau\) lepton. This process plays a very important role since it constrains the production of a very light pseudoscalar even if the pair production is forbidden kinematically, \(i.e.\) for \(M_h + M_A > M_Z\). It allows also to look for a light scalar, being an additional, and in case of \(\alpha = \beta\) the most important, source of information. The importance of this process was stressed in many papers\([6, 17]\), the recent discussion of the potential of the Yukawa process is presented in Ref.\([7]\).

New analysis of the Yukawa process by ALEPH collaboration\([8]\) led to the exclusion plot (95\%) on the \(\tan \beta\) versus the pseudoscalar mass, \(M_A\). (Analysis by L3 collaboration is also in progress\([7]\)). It happened that obtained limits are rather weak\([1]\) allowing for the existence of a light \(A\) with mass below 10 GeV with \(\tan \beta = 20\)–30, for \(M_A=40\) GeV \(\tan \beta\) till 100 is allowed! For mass range above 10 GeV, similar exclusion limits should in principle hold also for a scalar \(h\) with the replacement in coupling \(\tan \beta \rightarrow \sin \alpha / \cos \beta\). Larger differences one would expect however in region of lower mass, where the production rate at the same value of coupling for the scalar is considerably larger than for the pseudoscalar and therefore more stringent limits should be obtained\([1]\).

1.3 The 2HDM with a light Higgs particle.

In light of the above results from precision experiments at LEP I there is still the possibility of the existence of one light neutral Higgs particle with mass below \(\sim 40\)–50 GeV. As far as other experimental data, especially from low energy measurements, are concerned they do not contradict this possibility as they cover only part of the parameter space of 2HDM, moreover some of them like the Wilczek process have large theoretical uncertainties both due to the QCD and relativistic corrections\([10, 13]\) (see also discussion in\([12, 13]\)).

In following we will study the 2HDM assuming that one light Higgs particle may exist. Moreover we will assume according to LEP I data the following mass relation between the lightest neutral Higgs particles: \(M_h + M_A \geq M_Z\). We specify the model further by choosing particular values for the param-

\(^2\) neglecting the off shell production

\(^3\) Note, that the obtained limits are much weaker than the limits estimated in Ref.\([8]\).
eters $\alpha$ and $\beta$ within the present limits from LEP I. Since $\sin(\alpha - \beta)^2$ was found \[4, 5]\ to be smaller than 0.1 for the $0 \lesssim M_h \lesssim 50$ GeV, and even below 0.01 for a lighter scalar, we simply take $\alpha = \beta$. It leads to equal in strengths of the coupling of fermions to scalars and pseudoscalars. For the scenario with large $\tan \beta \sim O(m_t/m_b)$ large enhancement in the coupling of both $h$ and $A$ bosons to the down-type quarks and leptons is expected.

As we described above the existing limits from LEP I for a light neutral Higgs scalar/pseudoscalar boson in 2HDM are rather weak. Therefore it is extremely important to check if more stringent limits can be obtained from other measurements.

In Sec.2 we present how one can obtained the limits on the parameters of the 2HDM from current precision $(g - 2)$ for muon data\[13\], also the potential of the future E821 experiment \[19\] with the accuracy expected to be more than 20 times better is discussed. (See Ref.\[15\] for details.) Note that in \[19\] we took into account the full contribution from 2HDM, i.e. exchanges of $h$, $A$ and $H^\pm$ bosons incorporating the present constraints on Higgs bosons masses from LEP I. In this talk we present limits on $\tan \beta$ which can be obtained in a simple approach (Ref.\[13, 14\] and also \[17\]), i.e. from the individual $h$ or $A$ terms. This approach reproduces the full 2HDM prediction up to say 30 GeV if the mass difference between $h$ and $A$ is $\sim M_Z$, in wider range mass if this difference is larger.

The possible exclusion/discovery potential of the gluon-gluon fusion at $ep$ collider HERA \[12, 13\](Sec.3) and of the $\gamma\gamma$ collision at the suggested low energy LC (Sec.4) will also be discussed \[14\]. In Sec.5 the combined exclusion plot (95 % C.L.) is presented. The search of a light neutral Higgs particle in heavy ion collisions at HERA and LHC are discussed elsewhere\[16\].

### 2 Constraints on the parameters of 2HDM from $(g - 2)$.

#### 2.1 Present limits.

The present experimental data limits on $(g - 2)$ for muon, averaged over the sign of the muon electric charge, is given by \[21\]:

$$a^\text{exp}_\mu = \frac{(g - 2)_\mu}{2} = 1.165923 \times (8.4) \cdot 10^{-9}.$$
The quantity within parenthesis, $\sigma_{\text{exp}}$, refers to the uncertainty in the last digit. The expected new high-precision E821 Brookhaven experiment has design sensitivity of $\sigma_{\text{exp}}^{\text{new}} = 4 \cdot 10^{-10}$ (later even $1-2 \cdot 10^{-10}$, see Ref.[23]) instead of the above $84 \cdot 10^{-10}$. It is of great importance to reach similar accuracy in the theoretical analysis.

The theoretical prediction of the Standard Model for this quantity consists of the QED, hadronic and EW contribution:

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

The recent SM calculations of $a_{\mu}$ are based on the QED results from [24], hadronic contribution obtained in [29, 25, 21, 30, 31] and [22] and the EW results from [23, 22]. The uncertainties of these contributions differ among themselves considerably (see below and in Ref.[20, 23, 26, 15]). The main discrepancy is observed for the hadronic contribution, therefore we will mainly consider case A, based on Refs.[24, 25, 29, 28, 31, 23], with relatively small error in the hadronic part. For comparison the results for case B (Refs. [25, 24, 22, 23]) with the 2 times larger error in the hadronic part is also displayed. (We adopt here the notation from [20].)

| case | A [in 10^{-9}] | B [in 10^{-9}] |
|------|----------------|----------------|
| QED  | 1 165 847.06 (0.02) | 1 165 847.06 (0.02) |
| had  | 69.70 (0.76) | 68.82 (1.54) |
| EW   | 1.51 (0.04) | 1.51 (0.04) |
| tot  | 1 165 918.27 (0.76) | 1 165 917.39 (1.54) |

The room for a new physics is given basically by the difference between the experimental data and theoretical SM prediction: $a_{\mu}^{\text{exp}} - a_{\mu}^{\text{SM}} \equiv \delta a_{\mu}$.  

Below the difference $\delta a_{\mu}$ for these two cases, A and B, is presented together with the error $\sigma$, obtained by adding the experimental and theoretical errors in quadrature:

| case | A [in 10^{-9}] | B [in 10^{-9}] |
|------|----------------|----------------|
| $\delta a_{\mu}(\sigma)$ | 4.73(8.43) | 5.61(8.54) |
| $\lim(95\%)$ | $-11.79 \leq \delta a_{\mu} \leq 21.25$ | $-11.13 \leq \delta a_{\mu} \leq 22.35$ |
| $\lim_{\pm}(95\%)$ | $-13.46 \leq \delta a_{\mu} \leq 19.94$ | $-13.71 \leq \delta a_{\mu} \leq 20.84$ |

\[4\text{However in the calculation of } a_{\mu}^{\text{EW}} \text{ the (SM) Higgs scalar contribution is included(see discussion in [15]).}\]
One can see that at 1 $\sigma$ level the difference $\delta a_{\mu}$ can be of positive and negative negative sign. For that beyond SM scenarios in which both positive and negative $\delta a_{\mu}$ may appear, the 95% C.L. bound can be calculated straightforward (above denoted by $\lim(95\%)$). For the model where the contribution of only one sign is physically accessible (i.e. positive or negative $\delta a_{\mu}$), the other sign being unphysical, the 95%C.L. limits should be calculated in different way \[^{[21]}\]. These limits calculated separately for the positive and for the negative contributions ($\lim_{\pm}(95\%)$), lead to the shift in the lower and upper bounds by $-1.3 \cdot 10^{-9}$ up to $-2.6 \cdot 10^{-9}$ with respect to the standard (95%) limits.

2.2 Forthcoming data.

Since the dominate uncertainty in $\delta a_{\mu}$ is due to the experimental error, the role of the forthcoming E821 experiment is crucial in testing the SM or probing a new physics.

The future accuracy of the $(g - 2)_{\mu}$ experiment is expected to be $\sigma_{exp}^{new} \sim 0.4 \cdot 10^{-9}$ or better. One expects also the improvement in the calculation of the hadronic contribution \[^{[5]}\] such that the total uncertainty will be basically due to the experimental error. Below we will assume that the accessible range for the beyond SM contribution, in particular 2HDM with a light scalar or pseudoscalar, would be smaller by factor 20 as compared with the present $\lim_{\pm}95\%$ bounds. So, we consider the following option for future measurement (in $10^{-9}$):

$$\delta a_{\mu}^{new} = 0.24, \quad \text{and} \quad \lim_{\pm}^{new}(95\%): -0.69 \leq \delta a_{\mu} \leq 1.00.$$  

Assuming above bounds, we discuss below the potential of future $(g - 2)$ measurement for the constraining the 2HDM.

2.3 2HDM contribution to $(g - 2)_{\mu}$.

As we mentioned above the difference between experimental and theoretical value for the anomalous magnetic moment for muon we ascribe to the 2HDM contribution, so we take $\delta a_{\mu} = a_{\mu}^{(2HDM)}$ and $\delta a_{\mu}^{new} = a_{\mu}^{(2HDM)}$ for present and future $(g - 2)$ data, respectively.

\[^{[5]}\]The improvement in the ongoing experiments at low energy in expected as well.
To $a^{(2HDM)}_{\mu}$ contributes a scalar $h$ ($a^h_{\mu}$), pseudoscalar $A$ ($a^A_{\mu}$) and the charged Higgs boson $H^\pm$ ($a^{\pm}_{\mu}$). The relevant formulae can be found in the Appendix in Ref.[13]. Each term $a^\Lambda_{\mu}$ ($\Lambda = h, A$ or $H^\pm$) disappears in the limit of large mass, at small mass the contribution reaches its maximum (or minimum if negative) value. The scalar contribution $a^h_{\mu}(M_h)$ is positive whereas the pseudoscalar boson $a^A_{\mu}(M_A)$ gives negative contribution, also the charged Higgs boson contribution is negative. Note that since the mass of $H^\pm$ is above 44 GeV (LEP I limit), its small contribution can show up only if the sum of $h$ and $A$ contributions is small (see Ref.[13] for details).

Here we present results based on a simple calculation of the $a^{(2HDM)}_{\mu}$ in two scenarios:

- a) pseudoscalar $A$ is light, and
  \[ a^{(2HDM)}_{\mu}(M_A) = a^A_{\mu}(M_A) \]  
  \[ (1a) \]

- b) scalar $h$ is light, and
  \[ a^{(2HDM)}_{\mu}(M_h) = a^h_{\mu}(M_h) \]  
  \[ (1b) \]

This simple approach is based on the LEP I mass limits for charged and neutral Higgs particles and it means that $h(A)$ and $H^\pm$ are heavy enough in order to neglect their contributions in (1a(b)). The full 2HDM predictions for these two scenarios are studied in Ref.[13], and differences between two approaches start to be significant above mass, say 30 GeV.

Note that the contribution is for the scenario b) positive, whereas for the scenario a) – negative. Therefore we have to include this fact when the 95% C.L. bounds of $a^{(2HDM)}_{\mu}$ are calculated (limits $\lim_{\mu}(95\%)$ introduced in Sec.2.1). Since the case A gives more stringent $\lim_{\mu}(95\%)$ constraints, this case was used in constraining parameters of the 2HDM.

The obtained 95%C.L. exclusion plots for $\tan \beta$ for light $h$ or $A$ is presented in Fig.1, together with others limits. The discussion of these results will be given in Sec.5.

3 Gluon-gluon fusion at HERA

The gluon-gluon fusion via a quark loop, $gg \rightarrow h(A)$, can be a significant source of light non-minimal neutral Higgs bosons at HERA collider due to
the hadronic interaction of quasi-real photons with protons\[12\]. In addition the production of the neutral Higgs boson via $\gamma g \rightarrow b\bar{b}h(A)$ may also be substantial\[11, 12\]. Note that the latter process also includes the lowest order contributions due to the resolved photon, like $\gamma b \rightarrow bh(A)$, $b\bar{b} \rightarrow h(A)b$ etc. We study the potential of both $gg$ and $\gamma g$ fusions at HERA collider. It was found that for mass below $\sim 30$ GeV the $gg$ fusion via a quark loop clearly dominates the cross section. In order to detect the Higgs particle it is useful to study the rapidity distribution $d\sigma/dy$ of the Higgs bosons in the $\gamma p$ centre of mass system. Note that $y = -\frac{1}{2} \log \frac{E_h - p_h}{E_h + p_h} = -\frac{1}{2} \log \frac{x_p}{x_\gamma}$, where $x_p(x_\gamma)$ are the ratio of energy of gluon to the energy of the proton (photon), respectively. The (almost) symmetric shape of the rapidity distribution found for the signal is extremely useful to reduce the background and to separate the $gg \rightarrow h(A)$ contribution.

The main background for the Higgs mass range between $\tau\tau$ and $bb$ thresholds is due to $\gamma\gamma \rightarrow \tau^+\tau^-$. In the region of negative rapidity the cross section $d\sigma/dy$ is very large, e.g. for the $\gamma p$ energy equal to 170 GeV $\sim 800$ pb at the edge of phase space $y \sim -4$, then it falls down rapidly approaching $y = 0$. At the same time signal reaches at most 10 pb (for $M_h=5$ GeV). The region of positive rapidity is not allowed kinematically for this process since here one photon interacts directly with $x_\gamma = 1$, and therefore $y_{\tau^+\tau^-} = -\frac{1}{2} \log \frac{1}{x_p} \leq 0$. Moreover, there is a relation between rapidity and invariant mass: $M_{\tau^+\tau^-}^2 = e^{2y_{\tau^+\tau^-}} S_{\gamma p}$. Significantly different topology found for $\gamma\gamma \rightarrow \tau^+\tau^-$ events than for the signal allows to get rid of this background. The other sources of background are $q\bar{q} \rightarrow \tau^+\tau^-$ processes. These processes contribute to positive and negative rapidity $y_{\tau^+\tau^-}$, with a flat and relatively low cross sections in the central region (see \[12\]).

Assuming that the luminosity $\mathcal{L}_{ep}=250$ pb$^{-1}/y$ we predict that $gg$ fusion will produce approximately thousand events per annum for $M_h = 5$ GeV (of the order of 10 events for $M_h = 30$ GeV). A clear signature for the tagged case with $\tau^+\tau^-$ final state at positive centre-of-mass rapidities of the Higgs particle should be seen, even for the mass of Higgs particle above the $bb$ threshold (more details can be found in Ref.\[12\]).

To show the potential of HERA collider the exclusion plot based on the $gg$ fusion via a quark loop can be obtained. In this case, as we mentioned above, it is easy to find the part of the phase space where the background is negligible. To calculate the 95% C.L. for allowed value of $\tan \beta$ we take into
account signal events corresponding only to the positive rapidity region (in
the $\gamma p$ CM system). Neglecting here the background the number of events
were taken to be equal to 3. The results for the $ep$ luminosity $L_{ep} = 25$ pb$^{-1}$
and 500 pb$^{-1}$ are presented in Fig. 1 and will be discussed in Sec.5.

4 Photon-photon fusion at NLC

The possible search for a very light Higgs particle may in principle be per-
formed at low energy option of LC suggested in the literature. In the papers
[14] we addressed this problem and find that the exclusion based on the $\gamma\gamma$
fusion into Higgs particle decaying into $\mu\mu$ pair, at energy $\sqrt{s_{ee}} = 10$ GeV,
may be very efficient in probing the value of $\tan \beta$ down to 5 at $M_h \sim 3.5$
GeV and below 15 for $2 \lesssim M_h \lesssim 8$ GeV provided that the luminosity is equal
to $10$ fb$^{-1}$/y (See Fig. 1).

5 Exclusion plots for 2HDM and conclusion

In Fig.1 the 95% C.L. exclusion curves for the $\tan \beta$ in the general 2HDM
("Model II") obtained by us for a light scalar (solid lines) and for a light pseu-
doscalar (dashed lines) are presented in mass range below 40 GeV. For compar-
ison results from LEP I analysis presented recently by ALEPH collabora-
tion for pseudoscalar is also shown (dotted line). The region of ($\tan \beta, M_{h(A)}$)
above curves is excluded.

Constraints on $\tan \beta$ were obtained from the existing $(g-2)_\mu$ data includ-
ing LEP I mass limits. We applied here a simple approach, which reproduces
the full 2HDM contributions studied in Ref.[15] below mass of 30 GeV. We see
that already the present $(g-2)_\mu$ data improve limits obtained recently
by ALEPH collaboration on $\tan \beta$ for low mass of the pseudoscalar: $M_A \leq 2$
GeV. Similar situation should hold for a 2HDM with a light scalar, although
here the Yukawa process may be more restrictive for $M_h \leq 10$ GeV[7].

The future improvement in the accuracy by factor 20 in the forthcoming
$(g-2)_\mu$ experiment may lead to more stringent limits than provided by LEP
I up to mass of a neutral Higgs boson $h$ or $A$ equal to 30 GeV, if the mass
difference between scalar and pseudoscalar is $\sim M_Z$, or to higher mass for a
larger mass difference. Note however that there is some arbitrariness in the
deriving the expected bounds for the $\delta a^\mu_{\mu}$. The search at HERA in the gluon-gluon fusion via a quark loop search at HERA may lead to even more stringent limits (see Fig.1) for the mass range 5–15 (5–25) GeV, provided the luminosity will reach 25 (500) pb$^{-1}$ and the efficiency for $\tau^+\tau^-$ final state will be high enough. The other production mechanisms like the $\gamma g$ fusion and processes with the resolved photon are expected to improve farther these limits.

In the very low mass range the additional limits can be obtained from the low energy NL $\gamma\gamma$ collider. In Fig.1 the at luminosity 100 pb$^{-1}$ and 10 fb$^{-1}$. To conclude, in the framework of 2HDM a light neutral Higgs scalar or pseudoscalar, in mass range below 40 GeV, is not ruled out by the present data. The future experiments may clarify the status of the general 2HDM with the light neutral Higgs particle.

The role of the forthcoming g-2 measurement seems to be crucial in clarifying which scenario of 2HDM is allowed: with light scalar or with light pseudoscalar. If the $\delta a_\mu$ is positive/negative then the light pseudoscalar/scalar is no more allowed. Then farther constraints on the coupling of the allowed light Higgs particle one can obtained from the HERA collider, which is very well suitable for this. The simple estimation based on one particular production mechanism namely gluon-gluon fusion is already promising, when adding more of them the situation may improve further. It suggests that the discovery/exclusion potential of HERA collider is very large.

The very low energy region of mass may be studied in addition in LC machines. We found that the exclusion based on the $\gamma\gamma$ fusion into Higgs particle decaying into $\mu\mu$ pair, at energy $\sqrt{s_{ee}}=10$ GeV, may be very efficient in probing the Higgs sector of 2HDM even for luminosity 100 pb$^{-1}$. It is not clear however if these low energy options will come into operation.

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6 In this analysis the 100% efficiency has been assumed. If the efficiency will be 10 % the corresponding limits will be larger by factor 3.3
with D. Choudhury and J. Żochowski. Some of them are updated according
to the reports presented during the conference ICHEP’96, July 1996, Warsaw.

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Figure 1: The 95% exclusion plots for light scalar (solid lines) or light pseudoscalar (dashed lines) in 2HDM. The limits derivable from present $(g-2)\mu$ measurement and from existing LEP I results (Yukawa process) for the pseudoscalar (dotted line) are shown. The possible exclusions from HERA measurement (the gluon-gluon fusion via a quark loop with the $\tau^+\tau^-$ final state) for luminosity 25 pb$^{-1}$ and 500 pb$^{-1}$ as well from $\gamma\gamma \rightarrow \mu^+\mu^-$ at low energy NLC (10 fb$^{-1}$) are also presented. Parameter space above the curves can be ruled out.