Higgs search at HERA

Maria Krawczyk

Institute of Theoretical Physics, Warsaw University, Hoża 69, 00 681 Warsaw, Poland

Abstract: Present data do not rule out a light neutral Higgs particle with mass below 40–50 GeV in the framework of 2HDM with $\tan \beta \sim 20-30$. The promising possibility of searching for a light Higgs particle in such a scenario in photoproduction at HERA collider is discussed. For the MSSM there is only a very small chance to observe the Higgs sector, and only for limited mass range $\sim 45-50$ GeV and with large $\tan \beta$.

1 Introduction

The possibilities of Higgs searches at the HERA collider have been studied in the first HERA Workshop in 1987 [1]. It was found that it ‘is (almost) impossible’ to observe the Standard Model (SM) Higgs. A similar conclusion for the SM scalar Higgs search at HERA, even with an upgraded luminosity and/or proton energy, can be found in the contribution to this Workshop [2].

Non-minimal Higgs boson production at HERA has also been investigated during the HERA Workshop’87 as well as in other papers [13, 14, 15]. It was found that photon-gluon fusion into $b\bar{b}h(A)$ may be an important production mechanism of Higgs bosons in the two Higgs doublet extension of the SM at HERA. Also other subprocesses with Higgs boson bremsstrahlung, namely those with the resolved photon in the initial state, are important at HERA [14]. Another production mechanism is gluon-gluon fusion via a quark loop, where the Higgs particle is produced in resonance. For large $\tan \beta$ and Higgs masses below 30 GeV this process dominates the production cross section over $\gamma g$ fusion [15].

According to LEP I data, Higgs bosons in the MSSM have to be heavier than 45 GeV, therefore their production rate at the HERA collider is rather small. For the mass of $h$ and $A$ equal to 45 GeV both the $\gamma g$ and the $gg$ cross sections for $\tan \beta=30$ are $\sim 5$ fb. When adding the similar contribution from WW fusion into $h$ [4], one may expect 20-30 events to be produced at HERA with an integrated luminosity of 1 fb$^{-1}$.

The situation is quite different in the non-supersymmetric version of the two Higgs doublet extension of the SM (the so called general two Higgs doublet model - 2HDM) since in this model

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one light neutral Higgs boson with mass below 40-50 GeV may still exist, moreover with large
coupling to $\tau$ and $b$-quark. In this case there is a good chance to study the Higgs sector at
HERA, with one thousand events expected for a Higgs mass of 5 GeV and $\tan \beta=30$, assuming
$\mathcal{L}_{ep}=250 \, \text{pb}^{-1}$.

Below we present the status of this model, i.e., the 2HDM with a light Higgs boson,
and in the next section we discuss the possibility to perform a Higgs boson search at HERA,
focusing mainly on the gluon-gluon fusion production via a quark loop. Existing limits from
LEP I for the coupling of a light neutral Higgs boson in the 2HDM are rather weak. Also
present data on $(g-2)$ for the muon improve only slightly the limits on $\tan \beta$ for a Higgs
mass below 2 GeV. Therefore it is extremely important to check if more stringent limits can
be obtained from HERA measurements. The combined exclusion plot showing the potential of
HERA measurement is presented in Sec.4. Sec.5 contains our conclusion.

2 Status of the 2HDM with a Light Neutral Higgs

The mechanism of spontaneous symmetry breaking proposed as the source of mass for the
gauge and fermion fields in the 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 $\square$. A possible extension of the SM is to include a second Higgs doublet to the
symmetry breaking mechanism. In the 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 the heavier and
lighter particle, respectively), one neutral pseudoscalar ($M_A$), and a pair of charged Higgses
($M_{H\pm}$). 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 $\alpha$. Also further new couplings appear,
e.g. $Z h(H) A$ and $Z H^+ H^-$. In the following 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 only to the "down" compo-
ments $\square$. (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 the isospin $\mp 1/2$ components). In such a model FCNC processes are
absent and the $\rho$ parameter retains its SM value at the tree level. Note that in such a 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 the MSSM there
are additional relations among the parameters required by supersymmetry, leaving only two
free parameters (at the tree level) e.g. $M_A$ and $\tan \beta$. In the general case, denoted 2HDM,
masses and parameters $\alpha$ and $\beta$ are not constrained. Therefore the same experimental data
may lead to very distinct consequences depending on which version of the two Higgs doublet
extension of the SM, supersymmetric or nonsupersymmetric, is considered.
2.1 Present constraints on the 2HDM from LEP I.

Important constraints on the parameters of the two Higgs doublet extensions of the SM were obtained in the precision measurements at LEP I. The current mass limit on the charged Higgs boson $M_{H^\pm}$=44 GeV was obtained at LEP I\(^3\) from the process $Z \rightarrow H^+H^-$, which is independent of the parameters $\alpha$ and $\beta$. (Note that in the MSSM version one expects $M_{H^\pm} > M_W$). For the neutral Higgs particles $h$ and $A$ there are two main and complementary sources of information at LEP I. One is the Bjorken process $Z \rightarrow Z^* h$ which constrains $g_{hZZ}^2 \approx \sin^2(\alpha - \beta)$, for $M_h$ below 50-60 GeV. The second process is $Z \rightarrow hA$, constraining $g_{ZhA}^2 \approx \cos^2(\alpha - \beta)$ for $M_h + M_A \lesssim M_Z$. Results on $\sin^2(\alpha - \beta)$ and $\cos^2(\alpha - \beta)$ can be translated into limits on the neutral Higgs bosons masses $M_h$ and $M_A$. In the MSSM, due to additional relations among the 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 $\tan \beta \geq 1$\(^3\),\(^4\). In the general 2HDM the implications are quite different, here only the large portion of the $(M_h,M_A)$ plane, where both masses are in the range between 0 and ~50 GeV, is excluded\(^4\).

The third basic process to search for a neutral Higgs particle at LEP I is the Yukawa process, *i.e.* the bremsstrahlung production of a neutral Higgs boson $h(A)$ from a heavy fermion: $e^+e^- \rightarrow f\bar{f}h(A)$, where $f$ means here $b$ quark or $\tau$ lepton \(^2\).\(^5\). A new analysis of the Yukawa process by the ALEPH collaboration \(^10\) led to an exclusion plot on $\tan \beta$ versus the pseudoscalar mass, $M_A$. (The analysis by the L3 collaboration is also in progress \(^11\).). However, the obtained limits are rather weak 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 the mass range above 10 GeV, similar exclusion limits should in principle hold also for a scalar $h$ when replacing the coupling $\tan \beta \rightarrow \sin \alpha / \cos \beta$. However, one would expect larger differences in the lower mass region, where the production rate at the same value of coupling for the scalar is considerably larger than for the pseudoscalar. More stringent limits should be obtained there\(^1\).

In the 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: $M_h + M_A \lesssim M_Z$. We specify the model further by choosing particular values for the parameters $\alpha$ and $\beta$ within the present limits from LEP I. Since $\sin^2(\alpha - \beta)$ was found \(^1\),\(^4\) to be smaller than 0.1 for $10 \lesssim M_h \lesssim 50$ GeV, and even below 0.01 for a lighter scalar, we simply take $\alpha = \beta$. This leads to equal strengths of the coupling of fermions to scalars and pseudoscalars. Note that then the EW gauge boson couplings to the Higgs scalar $h$ disappear \(^4\). For the scenario with large $\tan \beta \sim O(m_t/m_b)$ a large enhancement in the coupling of both $h$ and $A$ bosons to the down-type quarks and leptons is expected.

Below we present how one obtains limits on the parameters of the 2HDM from current muon $(g - 2)$ data \(^2\), also the potential of the forthcoming E821 experiment \(^2\) is discussed. (See Ref.\(^2\) for details.)

2.2 Constraints on the 2HDM from $(g - 2)_\mu$

The present experimental limit on $(g - 2)$ for the muon, averaged over the sign of the muon electric charge, is given by \(^2\):\(^\text{2}

$$e^\text{exp}_{\mu} = \frac{(g-2)_\mu}{2} = 1 \, 165 \, 923 \, (8.4) \cdot 10^{-9}.$$\(^\text{2}

\(^2\) A does not couple to W and Z \(^3\).
The quantity within parenthesis, \( \sigma_{\text{exp}} \), refers to the uncertainty in the last digit.

The theoretical prediction of the SM for this quantity consists of the QED, hadronic and EW contributions:

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

The recent SM calculations of \( a_{\mu} \) are based on the QED results from [29], the hadronic contributions obtained in [34, 33, 31, 35, 36] and [37] and the EW results from [28, 27]. The uncertainties in these contributions differ among themselves considerably (see below and in Refs.[25, 28, 31, 20]). The main discrepancy is observed for the hadronic contribution, therefore we will here consider case A, based on Refs.[29, 30, 34, 33, 36, 28], with relatively small error in the hadronic part. It corresponds to:

\[
a_{\mu}^{\text{SM}} = 1165.918.27 (0.76) \cdot 10^{-9}.
\]

(The results for case B (Refs. [30, 31, 37, 28]) with the 2 times larger error in the hadronic part is discussed in [28, 20].)

The room for new physics, like the 2HDM with a light scalar or a light pseudoscalar, is basically given by the difference between the experimental data and the theoretical SM prediction:

\[
a_{\mu}^{\text{exp}} - a_{\mu}^{\text{SM}} \equiv \delta a_{\mu}.
\]

Below, the difference \( \delta a_{\mu} \) for the considered case, A, is presented together with the error \( \sigma \), obtained by adding the experimental and theoretical errors in quadrature (in \( 10^{-9} \)):

\[
\delta a_{\mu}(\sigma) = 4.73(8.43) \quad \text{and} \quad \lim_{\pm}(95\%) : -13.46 \leq \delta a_{\mu} \leq 19.94
\]

One can see that at the 1 \( \sigma \) level the difference \( \delta a_{\mu} \) can be positive or negative. For the beyond the SM scenario 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 separately for the positive and for the negative contributions (\( \lim_{\pm}(95\%) \) above).

The future accuracy of the \((g-2)_{\mu}\) experiments is expected to be \( \sigma_{\text{exp}}^{\text{new}} \sim 0.4 \cdot 10^{-9} \) or better [24, 23]. One also expects an improvement in the calculation of the hadronic contribution [4] 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 will be smaller by a factor of 20 compared to the present \( \lim_{\pm}(95\%) \) bounds. So, we consider the following option for future measurements (in \( 10^{-9} \)):

\[
\lim_{\pm}^{\text{new}}(95\%) : -0.69 \leq \delta a_{\mu}^{\text{new}} \leq 1.00.
\]

The difference \( \delta a_{\mu}^{\text{new}} \) we now ascribe to the 2HDM contribution, so we take \( \delta a_{\mu} = a_{\mu}^{(2HDM)} \) and \( \delta a_{\mu}^{\text{new}} = a_{\mu}^{(2HDM)} \) for present and future \((g-2)_{\mu}\) data, respectively. We will consider two scenarios:

- **a) pseudoscalar** \( A \) is light
- **b) scalar** \( h \) is light.

Here we calculate the 2HDM contribution assuming for case **a)** \( a_{\mu}^{(2HDM)}(M_{A}) = a_{\mu}^{A}(M_{A}) \), whereas for **b)** : \( a_{\mu}^{(2HDM)}(M_{h}) = a_{\mu}^{h}(M_{h}) \). This simple approach is based on the LEP I mass limits for charged and neutral Higgs particles and differs from the full 2HDM predictions, studied in Ref.[20], significantly for a Higgs mass above about 30 GeV. Note that the contribution for the scenario **b)** is positive, whereas for the scenario **a)** it is negative.

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3However in the calculation of \( a_{\mu}^{\text{EW}} \) the (SM) Higgs scalar contribution is included (see discussion in [20]).

4An improvement in the ongoing experiments at low energy is expected as well.
The exclusion plots for $\tan \beta$ obtained from present $(g - 2)_\mu$ data at 95% C.L. for a light $h$ or $A$, go beyond those from LEP I for Higgs masses below 2 GeV. $\tan \beta \sim 15$ is still allowed for the mass of the Higgs particle as low as 1 GeV, above 2 GeV $\tan \beta$ is limited to 20. These results together with others will be presented later in Sec. 4.

It is worth pointing out the unique role of the forthcoming $(g - 2)_\mu$ measurement in clarifying which scenario of the 2HDM is allowed: the model with a light scalar or with a light pseudoscalar. If the $\delta a^\mu_{\text{ew}}$ is positive (negative) then the light pseudoscalar (scalar) is excluded. Further constraints on the coupling of the allowed light Higgs particle can be obtained from HERA, which is very well suited for this task.

### 3 Search for a Higgs particle at HERA

We now study the possibility of light neutral Higgs scalar and/or pseudoscalar production in a 2HDM at HERA \cite{14,15,16}. We limit ourselves to the mass range above 5 GeV, in order to apply the LO approach. Next order results are in preparation \cite{18}, but we expect that even a K-factor $\sim 1.5-2$ will not change the results drastically. The results obtained for 2HDM hold also for MSSM, provided the proper range of mass is considered, i.e., above 45 GeV. The results relevant for SM can also be obtained from the 2HDM predictions for $h$ production with $\tan \beta=1$.

Photon-gluon and gluon-gluon fusions in photoproduction at HERA are expected to be basic sources of a light Higgs bosons in 2HDM \cite{15}. Note that the $ZZ$ and $WW$ fusions are not relevant since the pseudoscalar, $A$, does not couple to EW gauge bosons, and the scalar couplings, which are proportional to $\sin(\alpha - \beta)$, are put to zero by the assumed by us condition: $\alpha = \beta$. (Even if the upper experimental limits for $\sin(\alpha - \beta)$ are used (Sec. 2.1), light Higgs boson production in $ZZ/WW$ fusion is still effectively suppressed.)

The total cross section for on-shell neutral Higgs boson production is calculated, along with the rates for the particular final states $\rightarrow \tau^+\tau^-$ or $bb$. These decay channels are the most important since in 2HDM with large $\tan \beta$ $h$ and $A$ decay mainly to the heaviest available fermionic "down-type" states. (Details can be found elsewhere, e.g., in \cite{8,17}).

#### 3.1 Bremsstrahlung of the Higgs boson: $\gamma g \rightarrow b\bar{b}h(A)$ and other related processes.

At HERA, the photoproduction of neutral Higgs boson in a 2HDM via

$$\gamma g \rightarrow b\bar{b}h(A)$$

may be substantial \cite{13,15}. The total $h$ cross section (integrated over the $b\bar{b}$ final state) is presented in Fig.1a. Note that this process also includes $\gamma b \rightarrow bh(A)$, as well the lowest order contributions due to the resolved photon, i.e., $b\bar{b} \rightarrow h(A)b$, $bg \rightarrow h(A)b$, etc. These subprocesses were studied in Ref. \cite{14}, in Fig.2a we present obtained results. Each of these processes needs an independent analysis of the background \cite{18}. As this work is not yet completed, we will not use these processes for the derivation of the exclusion plot in Sec.4.
3.2 Gluon-gluon fusion via a quark loop

A Higgs boson photoproduction in gluon-gluon fusion via a quark loop,

\[ gg \rightarrow h(A), \]

(2)

can be even more significant \cite{14, 15}. The results for HERA with upgraded energy are also presented in Fig. 1a. A comparison of (2) with \( \gamma g \) fusion (1) shows that, for large \( \tan \beta \) and for mass below \( \sim 30 \) GeV, the \( gg \) fusion clearly dominates the total cross section. Note that the total \( gg \) cross section for \( \tan \beta = 30 \) is large: \( \sigma \sim 10^5 \) fb for a Higgs mass of 5 GeV, falling to 5 fb at mass \( \sim 45 \) GeV (where the \( \sigma_{gg} \) meets the \( \sigma_{\gamma g} \)).

A mass of 45 GeV corresponds to the lowest currently allowed mass for MSSM Higgs bosons. (Note that in MSSM, \( h \) and \( A \) tend to be degenerated in mass for large \( \tan \beta \)). Adding the contribution for \( \tan \beta = 30 \) from processes (1) and (2) for both scalar and pseudoscalar as well as that due to WW fusion into \( h \) \cite{2} which are of the same order, we estimate that HERA will produce 20-30 events of this sort with luminosity 1 fb\(^{-1}\).

In Fig.1a the \( \tan \beta = 1 \) case corresponds to the prediction for SM Higgs production in \( \gamma g \) and \( gg \) fusion. Applying the current limit for the SM Higgs mass, \( M_{Higgs} \geq 66 \) GeV \cite{3}, we see how small the corresponding \( \gamma g \) and \( gg \) cross sections are, more than three orders of magnitude smaller than the rate found in WW fusion into \( h \) \cite{2}.

Comparing the scalar production in Fig.1a with corresponding production in Fig.1b, in which the nominal HERA beam energy was used, we see an extremely weak dependence on
beam energy for scalar production. In Fig.1b we also consider pseudoscalar production via gluon-gluon fusion (2) for $\tan \beta=30$. The total cross sections ($h(A) \rightarrow \text{all}$) and the cross sections for the $\tau^+\tau^-$ final state are shown. It is interesting to notice the large difference, in the mass range below 10 GeV, between scalar and pseudoscalar production seen both in the total cross section $\sigma$ as well as in the $\sigma \cdot \text{Br}(\rightarrow \tau^+\tau^-)$. Note that the difference almost disappears for the $\tau^+\tau^-$ cross section above the $bb$ threshold.

Figure 2: In the $\gamma p$ CM system at $\sqrt{s_{\gamma p}}=170$ GeV a) the cross section for scalar production in various subprocesses (tan $\beta=20$, from Ref.[14]) and b) the rapidity distribution for $\tau^+\tau^-$ pair are presented. The background ($\gamma\gamma \rightarrow \tau^+\tau^-$) and the signal (the scalar Higgs boson contribution, integrated over $\Delta M_h=1$ GeV) are shown (from Ref.[13]).

For detection, 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 $y = -\frac{1}{2} \log \frac{E_h-p_h}{E_h+p_h} = -\frac{1}{2} \log \frac{x}{x_p}$, where $x_p(x_γ)$ are the ratio of the energy of the gluon to the energy of the proton and 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, which we will discuss now for the $\tau^+\tau^-$ final state.

The main background in the mass range between $\tau^+\tau^-$ and $bb$ thresholds is due to $\gamma\gamma \rightarrow \tau^+\tau^-$. In the region of negative rapidity $d\sigma/dy_{\tau^+\tau^-}$ is very large, e.g. for $\gamma p$ energy equal to 170 GeV the cross section $\sim 800$ pb at the edge of phase space ($y_{\tau^+\tau^-} \sim -4$), and it then falls rapidly when $y_{\tau^+\tau^-}$ approaches 0. At the same time, the signal reaches at most 10 pb (for $M_h=5$ GeV). The results for a scalar are shown in Fig.2b. The region of positive rapidity is not allowed kinematically for this process since one photon interacts directly with $x_γ = 1$, and therefore $y_{\tau^+\tau^-} = -\frac{1}{2} \log \frac{1}{x_p} \leq 0$. A significantly different topology found for $\gamma\gamma \rightarrow \tau^+\tau^-$ events than for the signal should allow a reduction of this background.

The other sources of background are $q\bar{q} \rightarrow \tau^+\tau^-$ processes (not shown here). These processes contribute to positive and negative rapidity $y_{\tau^+\tau^-}$, with a flat and relatively low cross-section (below 0.5 pb) in the central region.
Note that Higgs decaying into $b$-quarks has a much more severe background, and we will not discussed it here (see Ref.\[14][13]).

Assuming a luminosity $L_{ep}=250 \text{ pb}^{-1}/\text{y}$ we predict that $gg$ fusion will produce around one thousand events per annum for $M_h = 5 \text{ GeV}$ (and roughly 10 events for $M_h = 30 \text{ GeV}$). A clear signature for the tagged case with a $\tau^+\tau^-$ final state at positive centre-of-mass rapidities of the Higgs scalar should be seen, even for a Higgs mass above the $bb$ threshold (more details can be found in Ref.\[14\]). For the pseudoscalar case even more events are expected in the mass region below 10 GeV.

To show the potential of HERA, the exclusion plot based on $gg$ fusion via a quark loop with the $\tau^+\tau^-$ final state can be drawn. In this case, as we mentioned above, it is easy to find the part of phase space where the background is hopefully 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). The results for the $ep$ luminosity $L_{ep} = 25 \text{ pb}^{-1}$ and 500 pb$^{-1}$ are presented in Fig. 3 and will be discussed in the following section.

4 Exclusion plot for 2HDM

In Fig.3 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 pseudoscalar (dashed lines) are presented in mass range below 40 GeV. For comparison results from LEP I analysis presented recently by ALEPH collaboration for pseudoscalar \[11\] 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, including LEP I mass limits (Sec.2.2). We see that already the present $(g-2)_\mu$ data improve LEP I limits on $\tan \beta$ for $M_A \lesssim 2 \text{ GeV}$. A similar situation should hold for a 2HDM with a light scalar, although here the Yukawa process may be more restrictive for $M_h \leq 10 \text{ GeV}$ \[3\].

The future improvement in the accuracy by a factor of 20 in the forthcoming $(g-2)_\mu$ experiment may lead to more stringent limits than provided by LEP I up to a mass of $h$ or $A$ equal to 30 GeV, if the mass difference between scalar and pseudoscalar is $\sim M_Z$, or to even higher mass for a larger mass difference $\[20\]$. 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 may lead to even more stringent limits (see Fig.3) for the mass range 5–15 (5–25) GeV, provided the luminosity will reach 25 (500) pb$^{-1}$ and the efficiency for the $\tau^+\tau^-$ final state will be high enough \[11\]. The other production mechanisms, such as $\gamma g$ fusion and other subprocesses with the resolved photon, are expected to improve these limits further \[14, 15, 18\].

In the very low mass range, additional limits can be obtained from the low energy NL $\gamma\gamma$ collider with $\sqrt{s_{ee}}=10 \text{ GeV}$. In Ref.\[17\] we found that the exclusion based on $\gamma\gamma$ fusion into Higgs, decaying into $\mu^+\mu^-$, may be very efficient. In Fig.3 the results corresponding to a luminosity 10 fb$^{-1}$ are presented.

\footnote{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 (a simple scaling) for fixed luminosity.}
The 95% C.L. exclusion plot for a light scalar (solid lines) or light pseudoscalar (dashed lines) in 2HDM. The limits derivable from present \((g - 2)_\mu\) measurements and from existing LEP I results (pseudoscalar production in the Yukawa process) (dotted line) are shown. The possible exclusions from HERA (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 (from [17]). Possible limits from future data for \((g - 2)_\mu\) are also shown. The parameter space above the curves can be ruled out.

5 Conclusion

In the framework of 2HDM, a light neutral Higgs scalar or pseudoscalar in the mass range below 40-50 GeV is not ruled out by the present LEP I and \((g - 2)_\mu\) data. The other low energy experiments cover only part of parameter space of 2HDM; some, such as the Wilczek process, have large theoretical uncertainties both due to the QCD and relativistic corrections([12, 6])(see also discussion in [15, 16]).

The role of the forthcoming \((g - 2)_\mu\) measurement seems to be crucial in clarifying which scenario of 2HDM is allowed: with light scalar or with a light pseudoscalar. If the \(\delta a^\text{new}_\mu\) is positive(negative) then the light pseudoscalar(scalar) is excluded. Then, further constraints on the coupling of the allowed light Higgs particle can be obtained from HERA, which is very well suited for this. The simple estimation performed at luminosity 500 pb\(^{-1}\) for one particular production mechanism, namely gluon-gluon fusion, is already promising; adding more processes may further improve the situation significantly. The most important experimental handle is a good efficiency for the \(\tau^+\tau^-\) channel.

All this suggests the large discovery/exclusion potential of HERA for the mass range 5–20 GeV [15]. It is unlikely that the LEP/LHC experiments will have a larger potential in such a mass region [14].

The very low mass region may also be studied at low energy NLC machines. We found that the exclusion based on \(\gamma\gamma\) fusion into Higgs, decaying into \(\mu^+\mu^-\), 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.
Future experiments will clarify the status of the general 2HDM with a light neutral Higgs particle – the role of HERA in such a study may be very important.

By contrast, for the MSSM the potential of HERA even with luminosity 1 fb$^{-1}$ is relatively poor, producing only 20-30 events of $h$ and $A$, if the mass is in the 45-50 GeV range for $\tan\beta=30$.

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