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Mass Constraints on a Light Higgs Produced in η' Decays

Pablo Yepes

Physics Department
McGill University, Montreal, Quebec, Canada H3C 3J7

Present home institute: NIKHEF-H, P.O.Box 41882, 1009 DB Amsterdam
Present address: EP Division, CERN, CH-1211 Geneva 23

Abstract

An estimate of the branching ratio BR($\eta' \rightarrow \eta$H) and data from a beam-dump experiment are used to establish limits on the mass of a scalar Higgs boson in the context of the Minimal Standard Model.

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1. Introduction

The Higgs neutral boson is a fundamental ingredient of the Standard Model and its detection is one of the most important issues in High Energy Physics at present. Its mass not being predicted by theory leaves a very wide range open for experimental search. Nevertheless in the Minimal Standard Model the Higgs must be heavier than around 7 GeV/c^2, but this limit disappears if the heaviest fermion has a mass close to 80 GeV/c^2. However in most extensions of the Standard Model this limit will not exist any more, and light Higgses will be allowed whatever the heaviest fermion mass is.

A variety of experimental limits have been published and recently several reviews have appeared on the subject [1,2,3,4,5]. Unfortunately most of the existing bounds on the Higgs mass are very sensitive to the theoretical assumptions and so it is desirable to get limits from as many processes as possible. In the present paper the production of a light Higgs ($M_H < 210$ MeV/c^2) through the process $\eta' \rightarrow \eta$ H is studied in the frame of the Minimal Standard Model and a limit on the branching ratio is obtained from the analysis of data from a beam-dump experiment.

2. Light Higgs from η' decays

If the neutral Higgs boson is lighter than around 400 MeV/c^2 it can be produced through the decay $\eta' \rightarrow \eta$H. The $\eta\eta'$H coupling can be found the same way one obtains the KπH coupling, used to set limits on the Higgs production in kaon decays [7,8]. The branching ratio for $\eta' \rightarrow \eta$H is [7]

$$Br(\eta' \rightarrow \eta\ H) \approx 7.2\ 10^{-5}\ B_H \qquad (1)$$

where $B_H = 2p_H/m_{\eta'}$, being p_H the Higgs momentum in the η' rest frame.

Because the Higgs couples to mass, it decays predominantly into the heaviest states that are kinematically allowed. The present study will be relevant for light Higgses ($M_H \leq 2\ m_\mu$) which have only two decay channels: H$\rightarrow$e$^+$e$^-$ and H$\rightarrow\gamma\gamma$. The expressions for the widths of both channels can be found in reference [5]. $BR(H \rightarrow e^+ e^-)$ ranges from $\approx$1 at $M_H = 10\,MeV/c^2$ to $\approx$0.75 at $M_H = 200\,MeV/c^2$. The lifetime, τ, of such a light Higgs is rather long, it decreases with mass, ranging from 3. 10^{-10} s at $M_H = 10\,MeV/c^2$ to 10^{-11} s at $M_H = 200\,MeV/c^2$. This means that a Higgs with an energy of a few GeV, and consequently with a gamma factor ($\gamma_H = E_H/M_H$) of the order of a hundred, has a non negligible probability of travelling several meters before it decays.

3. Analysis and results

Beam-dump experiments have been used to search for weakly interacting neutral particles (WINP). The dump placed downstream the target is used to absorb strong and electromagnetic interacting particles, produced in the primary collision, and only the WINPs manage to traverse it. A detector placed behind the dump is used to detect the collisions or decays of those weakly interacting particles. Since the Minimal Standard Model Higgs boson is a WINP, this technique may be used to establish limits on its production.

Data from a beam-dump experiment searching for neutral heavy leptons carried out in the M2 neutral-hyperon beam line at Fermilab [9] are used in the present study. The experiment was designed to detect WINPs decaying into two charged particles in a vacuum volume placed downstream from the dump. A 400 GeV/c proton beam was incident on an iron target with a total number of interacting projectiles on target $N_p = 2.8\ 10^{13}$. In the off-line data analysis after the subtraction of some conventional backgrounds, no candidates for WINPs decaying into two charged particles were found and a limit on neutral heavy lepton production was obtained. As it was already pointed out in reference [6], if a light Higgs was produced in the experiment mentioned through any kind of process, there is a non zero probability that such a Higgs would have decayed into e^+e^- in the vacuum volume and it would have been detected. Since no WINP candidate was observed, limits on the Higgs production can be extracted from the data. In that way bounds on a Higgs produced through a Bremsstrahlung process were obtained in reference [6]. In the present paper a similar analysis is performed to establish limits on Higgs production through η' decays.

A Monte Carlo program was implemented to generate η' particles according to the Bourquin-Gaillard (BG) formula [10]

$$E\frac{d^3\sigma}{d^3p} = A_{\eta'}\left(\frac{2}{E_T+2}\right)^{12.3} \exp(-5.13/Y^{0.38})\ f(p_T) \tag{2}$$

where

$$f(p_T) = \begin{cases} \exp(-p_T) & \text{for } p_T < 1\ GeV/c \\ \exp(-1-23(p_T-1)/\sqrt{s}) & \text{for } p_T > 1\ GeV/c \end{cases}$$

where $Y = y_{max} - y$, being y the rapidity, and E_T (p_T) the transverse energy (momentum) expressed in GeV. $A_{\eta'}$ is a normalization factor that is adjusted to get an η' inclusive cross section $\sigma_{\eta'} = 250 \pm 100$ mb, corresponding to the estimated value in the 400 GeV/c pFe collisions of the experiment. This $\sigma_{\eta'}$ value was extrapolated from the particle production ratio η'/π^0 measured at the ISR pp collider [11], using the BG parametrization according to reference [12] and assuming a linear dependence on the target atomic number. Figure 1 shows the η' rapidity distribution in 400 GeV/c pFe collisions generated by the Monte Carlo program.

The number of Higgses that would have been detected in the experiment is given by the expression

$$N_H = N_p\, n_{\eta'}\, \varepsilon\, BR(\eta' \to \eta\, H)\ D_H\, BR(H \to e^+e^-) \tag{3}$$

where $n_{\eta'}$ is the number of η' produced per collision, ε is a factor including the detector acceptance and Higgs reconstruction efficiency calculated in the same way as it was done in reference [6]. D_H is the probability that the Higgs disintegrates inside the vacuum decay volume of the experiment and it is given by

$$D_H = \exp\left(-\frac{L_1}{c\beta_H\tau_H\gamma_H}\right)\left[1 - \exp\left(-\frac{L_2-L_1}{c\beta_H\tau_H\gamma_H}\right)\right] \tag{4}$$

where $L_{1(2)}$ is the distance from the target to the front(back) edge of the vacuum volume along the Higgs trajectory. The second term in parenthesis reflects the finite length of the vacuum volume. D_H decreases exponentially with the target-to-detector distance, L_1, and increases with the Higgs gamma factor, γ_H. Since the actual number of WINP candidates was zero, $N_H = 0$, an upper limit on

$BR(\eta' \rightarrow \eta\, H)$ can be deduced from the data. This limit is inversely proportional to the number N_H of Higgses expected in the experiment, as given by equation (3). In the present analysis only Higgses with $M_H \leq 2m_\mu$ are considered. This is due to the fact that a heavier Higgs has a much shorter lifetime and consequently N_H is too low to obtain significant limits on the branching ratio.

Figure 2 shows the experimental 90% CL upper limit on BR($\eta' \rightarrow \eta$H) obtained from this analysis[1] along with the theoretical expectation from (1). The limit obtained ranges between $\approx 3.10^{-6}$ to $\approx 3.10^{-8}$ lying below the theoretical expectation ($\approx 4.10^{-5}$) throughout the whole region considered ($10 \leq M_H \leq 210\ MeV/c^2$). Therefore, under the theoretical assumptions used to estimate the branching ratio BR($\eta' \rightarrow \eta$H) [7], the present analysis excludes a Higgs boson lighter than 210 MeV/c^2.

4. Conclusions

Data from an experiment looking for neutral heavy leptons is used in combination with calculations on the production of a light Higgs through η' decay to exclude a neutral scalar Higgs boson with $M_h \leq 210\ MeV/c^2$ in the framework of the Minimal Standard Model.

5. Acknowledgements

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[1] It is to be noted that the large uncertainty on the η' inclusive cross section in pFe (See section 3) has been taken into account to derive the experimental limit

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Figure captions

1. Rapidity distribution of the η' in 400 GeV/c pFe collisions generated by the Monte Carlo program.

2. Branching ratio of the decay $\eta' \to \eta H$ versus the Higgs mass: a)theoretical prediction [7] b)90% CL experimental upper limit obtained from the analysis. A Higgs mass $M_H < 210$ MeV/c^2 is excluded by the data.

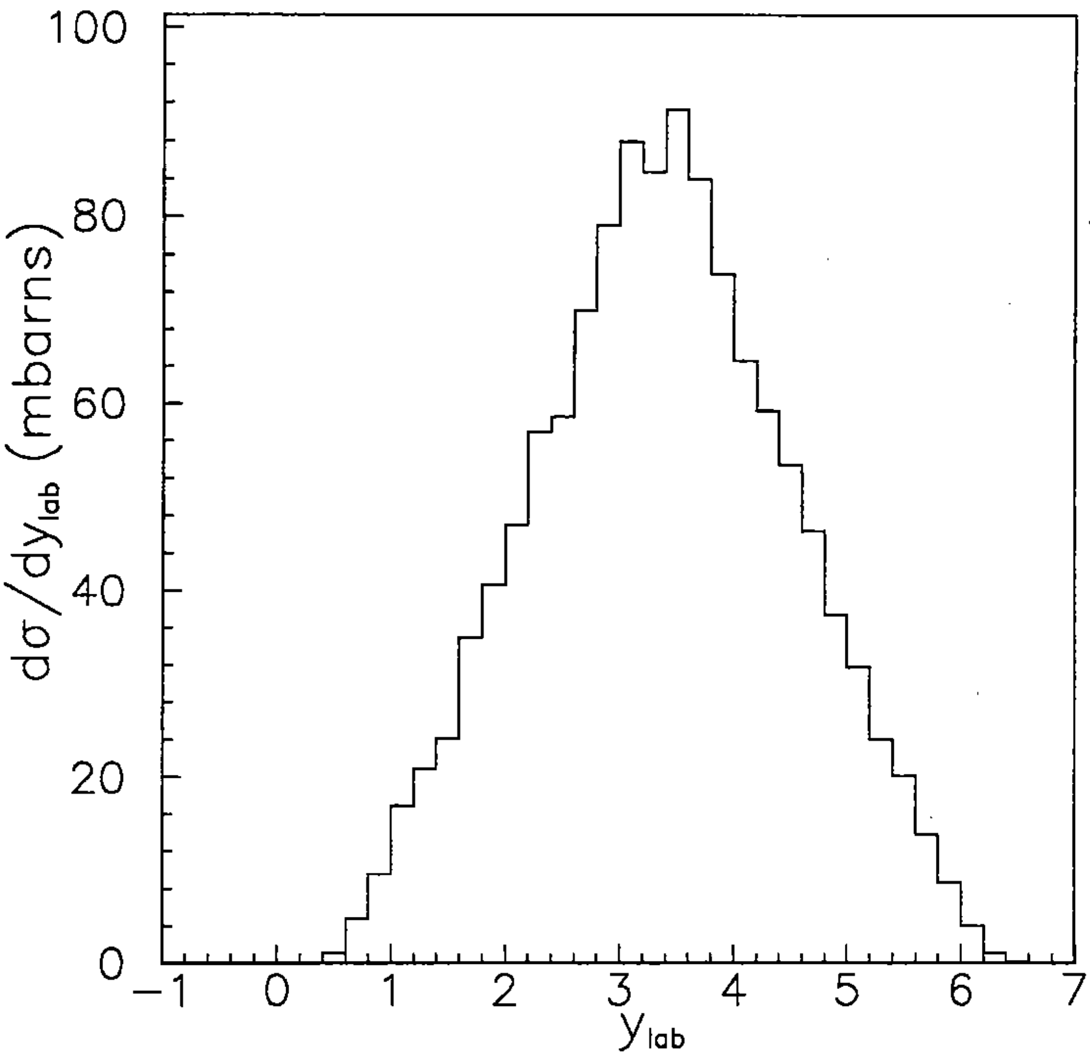
100
80
60
40
20
0
dσ/dy_{lab} (mbarns)
−1
0
1
2
3
4
5
6
7
y_{lab}

Figure 1

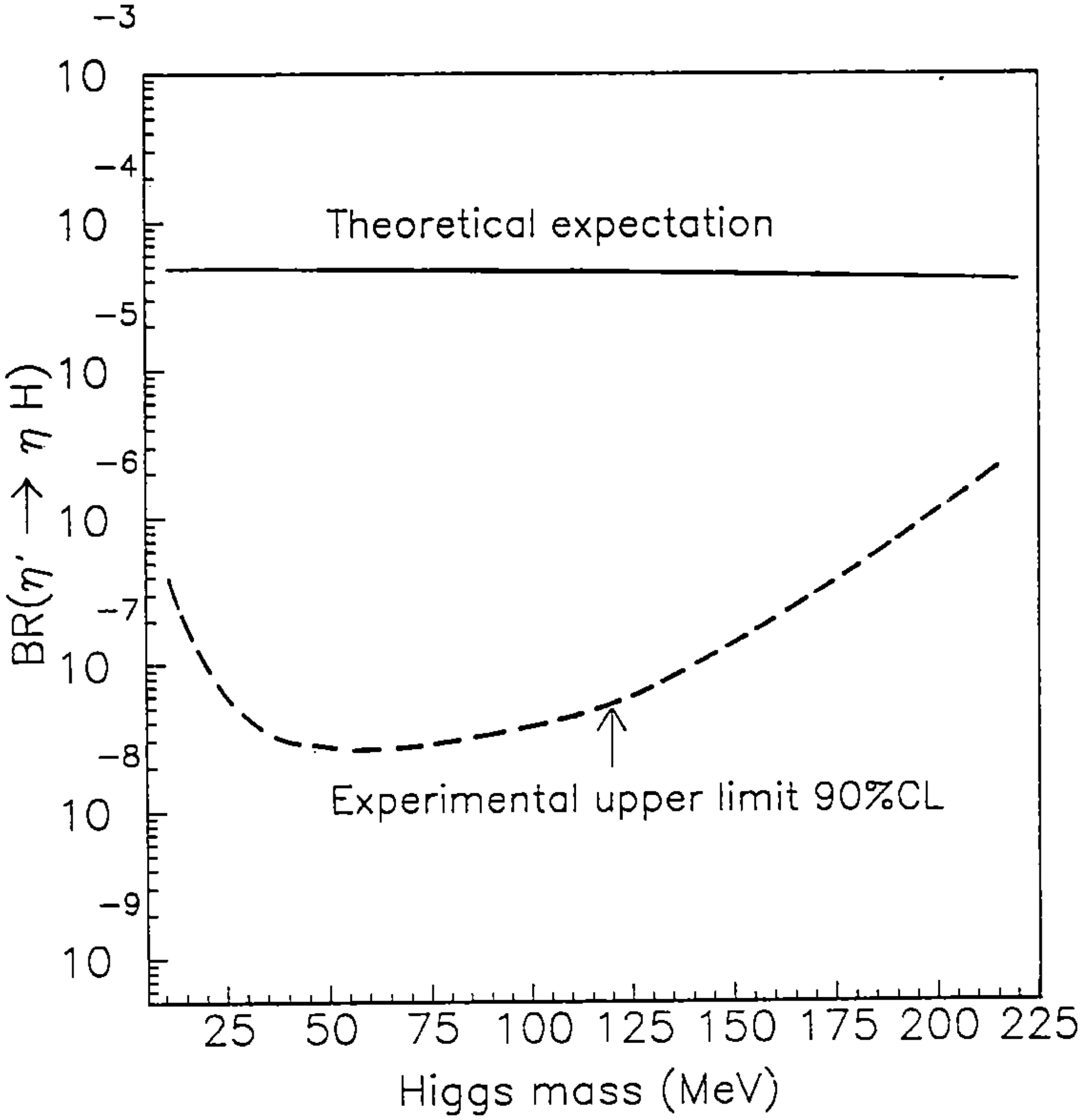
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
BR(η' → η H)
Theoretical expectation
Experimental upper limit 90%CL
25 50 75 100 125 150 175 200 225
Higgs mass (MeV)

Figure 2