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SEARCH FOR HIGGS BOSONS AT LEP

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SEARCH FOR HIGGS BOSONS AT LEP

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ABSTRACT

Searches of Standard Model Higgs bosons at LEP are reviewed discussing the effects of irreducible background. Limits from the four LEP experiments are presented. The status of SUSY Higgs searches will be updated.

1. Introduction

In the Standard Model (SM)[1] the spontaneous symmetry breaking is assumed to give masses to vector bosons and to fermions. To prove experimentally this hypothesis the Higgs particle has to be found with the predicted properties. In the SM it is possible to compute the couplings of the Higgs particle to fermions and bosons but the mass remains a free parameter of the theory. In the past the search for this particle has been performed for all the accessible masses. After a very short review of the theoretical properties of the Higgs boson, the experimental status before LEP will be summarized. The main part of the talk will be dedicated to present the search at LEP, and the results from the four experiments will be presented. Finally the status of the Higgs searches within the SUSY model will be discussed.

2. Theoretical Motivation

In the Standard Model Lagrangian the addition of explicit mass terms would destroy the renormalizability of the theory, so mass can be introduced only through the mechanism of the spontaneous symmetry breaking. To build this mechanism a doublet of complex scalar fields is added to the lagrangian for a total of four degree of freedom, three of them are then used to gives masses to W^+, W^- and Z^0, the last one remains as physical state: the Higgs Boson. The coupling to Z^0 in Eq.(1) comes from the gauge invariance, while the coupling to fermions is fixed by Yukawa interactions.

$$\alpha_{HZZ} = \frac{gM_Z}{cos\theta_W} = \frac{gM_z^2}{M_W}$$
$$\alpha_{hff} = \frac{gm_f}{2M_W} \tag{1}$$

In this scheme the Higgs boson violates the universality of the weak interaction because is coupled to the fermions proportionally with their mass, in this scheme the model cannot predict the mass of the Higgs Boson which remains free parameter.

1.1. Theoretical Limits on the Mass

No limit can be inferred by the contribution of the Higgs to the radiative corrections (like for quark top) because at one loop level the contribution is logarithmic and at second level is screened by a factor g^2.

The Higgs mass within the Standard Model is expressed as:

$$m_H^2 = 2\lambda v^2 \tag{2}$$

where λ can vary from 0 to ∞.

The lower limit is given by the request that vacuum is well behaved when λ get small. This limit [2] is usually expressed as a function of m_t and looses its validity for $m_t \approx 80GeV$:

$$M_H^2 > \frac{3}{16\pi^2 v^2}[2M_w^4 + M_Z^4 - 4m_t^4] \tag{3}$$

To work out the limit for $m_t > 80GeV$ it is necessary to impose the vacuum stability in a different way.

An upper limit can be derived from unitarity. When $\lambda \geq 1$ a strong self-interaction starts and new terms would appear in the potential. The pertubative unitarity bound requires[3]:

$$M_H^2 \leq \frac{8\sqrt{2}\pi}{3G_f} = (1.01TeV)^2 \tag{4}$$

A stronger limit,$m_H \leq 200GeV$, can be derived in Grand Unified scenario using renormalization group equation.

3. Experimental status before LEP

Since the mass of the Higgs boson is not predicted by the theory the experimental search before LEP has been performed in the full mass range from very low to the highest available mass. Different reactions has been used and the excluded mass region goes from 0 up to few GeV. All these limits suffer from theoretical uncertainties due to the unknown QCD correction to the branching ratio . Only one experiment, performed in Orsay, is safe because it is based on the decay of Higgs into electrons, but the region excluded is only between 1.2 and 52 MeV. In Table 1 a summary of all these results can be found.

MASS RANGE	REACTION	EXPERIMENT	REF
$M_H < 2m_e$	Muonic atom		[4]
$M_H < 10 - 20 MeV$	$K \rightarrow \pi H$	BNL exp.	[5]
$2m_e < M_H < 10 MeV$	$O^+ - O^+$		[6]
$1.2 < M_H < 52 MeV$	$H \rightarrow e^+e^-$	Orsay	[7]
$10 < M_H < 100 MeV$	$\pi \rightarrow e\nu$	SINDRUM	[8]
$15 < M_H < 300 MeV$	$K \rightarrow \pi H$	NA31	[9]
$70 MeV < M_H < 3.6 GeV$	$B \rightarrow HX$	MARKII	[10]
$210 Mev < M_H < 5 GeV$	$K \rightarrow v\gamma$	CUSB	[11]

Table 1: Summary of Higgs searches before LEP.

4. Searches at LEP

The great advantage of the Higgs search at LEP is the possibility to use the reaction $Z^0 \rightarrow Z^{0*}H^0$ where the coupling constant is proportional to squared mass of the intermediated boson and is theoretically computable. At LEP the Higgs Boson can be produced through the two processes , in the second order process, shown in Fig1b, the Higgs Boson is emitted with a monochromatic photon. In the loop you can have fermions and bosons, the signature is very clear but the cross section is too low and with a large background due to radiative events ($q\bar{q}\gamma$).

The Bjorken process is shown in Fig1a, in this reaction the Higgs is emitted by the real Z, its signature is given by the decay products of the virtual Z which remain after emission. The cross sections for the two processes are shown in Fig2, up to $70 GeV$ the second one wins, above this energy the cross section becomes so small that will be anyway very difficult to perform the Higgs search at LEP I. The decay mode of the Z^0 and H^0 are shown in Table 2, the channel having the highest rate is Z^0H^0 to 4jets but is not used because of the huge background due to decays of Z^0 into multijet events. To study the Higgs production the LEP experiments have used the channel in which the Z^0 decays in charged or neutral leptons. The search in the two leptonic channels shows complementary features: the neutral one

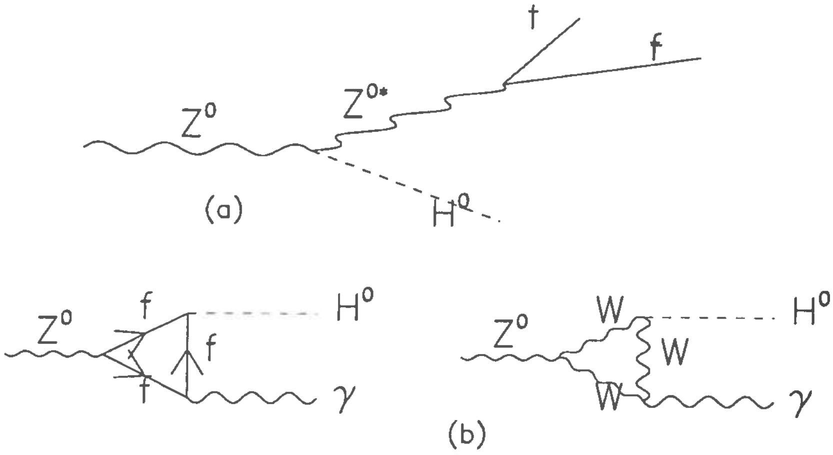


Figure 1: Higgs Production: a)Bjorken process, b)1-loop process

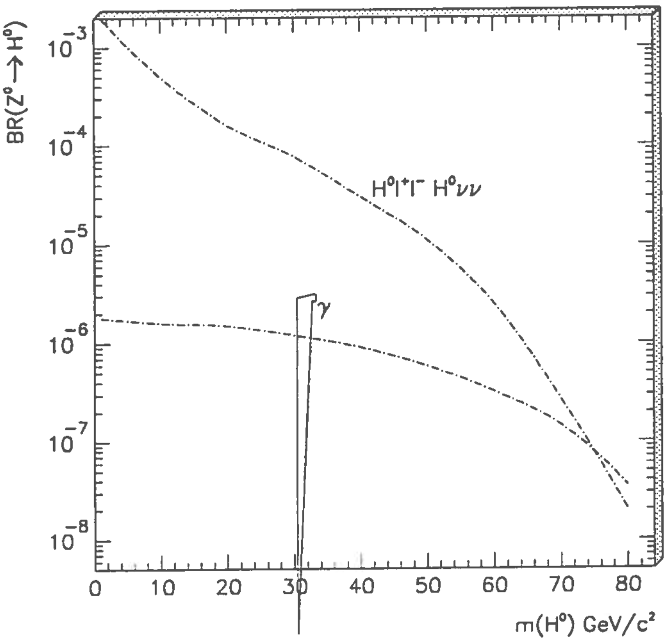


Figure 2: The cross section for the Higgs Boson production at LEPI

	$q\overline{q}$	$\nu\overline{\nu}$	e^+e^-	$\mu^+\mu^-$	$\tau^+\tau^-$
Z^0	70%	20%	3%	3%	3%
H^0	95%				5%

Table 2: Branching ratio of Z^0 and $H^0(m_H > m_{bb})$.

is very important to increase the statistic but its signature (missing energy and momentum) is poor, the charged channels are less important from the statistical point of view, but have a very clear signal (two isolated and energetic leptons). So it is worthwhile to use both channels.

As previously said the Higgs couples with the mass, so it will decay in the heaviest available particle, for this reason in different mass regions it gives different signatures. A very light Higgs Boson has a long life time given by:

$$\tau(m) \approx \frac{0.120}{m_{H^0}(GeV/c^2)} \tag{5}$$

Below the μ threshold the Higgs particle can be considered a long lifetime particle and we can distinguish the case of a decay outside the detector ("invisible Higgs ") or inside as an isolated V^0. In this region the coupling is to electrons and photons.

The second region to be studied in the Higgs search is the so called "intermediate region" between the $2m_\mu$ threshold and the region where the Higgs can decay in heavy quarks. In this mass region the Higgs Boson couples to muons and to all different light quarks, the branching ratios are not very well known (non perturbative QCD effects) and for this region the analysis is model dependent.

The last region considered (above the charm threshold) is the one mainly investigated by the present analysis at LEP. At this energy the cross section is strongly decreasing with the Higgs mass, while the background increases with the statistics. So particular cure has been used to account for very rare background sources like second order electromagnetic processes.

4.1 Low Mass Region

For m_H below $40 MeV$ the Higgs is not visible inside the detector, so the search in concentrated on events with two high energy acolliear or acoplanar leptons; no activity in the electromagnetic calorimeter is required to reject background due to radiative Z^0 events . For m_{H^0} above $40 MeV$ the Higgs can be seen in the detector as an isolated V^0, the main background is due to pair conversion and long lived particles. All experiments have excluded Higgs Boson production with mass below $2m_\mu$ already with the '90 data [12, 13, 14, 15].

4.2 Intermediate Mass Region

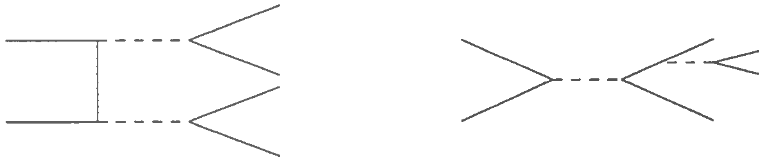
This region is difficult due to theoretical uncertainties; the DELPHI analysis[16] is based on topological requirement and it uses the most pessimistic branching ratio, so it is quite model independent. To achieve model independent analysis the experiment OPAL[17] uses two complementary analysis with only electromagnetic final states. All experiments exclude Higgs boson in this mass range[12].

4.3 Second Order Electromagnetic Processes

As we said previously, an important source of background in the Higgs search at high mass is due to the electromagnetic processes with four fermions in the final state because they can give exactly the same final state as the signal. On the other side one should consider that their cross section is very small in the kinematical region of interest since they are second order processes so they become important only when high statistics data are considered. In Fig3 the Feynman diagrams of this process are shown , the most relevant for the Higgs search is the annihilation one. The main features of these events have been studied using a Montecarlo program[18]

Multiperipheral

Bremsstrahlung



Conversion

Annihilation

Figure 3: Feynman diagrams for four fermion processes

A dedicated search was performed to find four fermions events and to compare with MonteCarlo predictions. The results for DELPHI are shown in Table 3, similar results have been obtained by the other LEP experiments.

As example the plot of the recoil mass against the two electrons in the channel $ee q\bar{q}$ selected at the level of generation, and after some cuts are applied to the analysis is shown in Fig4 . After the cuts the distribution is quite flat in the mass region considered, while for the signal one should expect an accumulation of events at a fixed mass. The most effective cut to reject this background is a cut on the hadronic visible energy at 10 GeV.

4.4 High Mass Region

The main problem in the search of the Standard Model Higgs Boson at high mass is the behaviour of the cross section, since it is strongly decreasing with the mass as can be seen in Fig2. The high luminosity, already achieved by the LEP machine, allows to study this mass range but with an increased level of backgrounds due to $q\bar{q}$ events and to the processes described in previous section. Three channels are used , the decay of Z^0 in neutrinos, in electrons and in muons; the τ channel has been studied only at the beginning but now is no more used since it gives very low efficiency.

LL	'90 data	'91 data	tot.data	MC
e^+e^-	0	11	11	$7.2 \pm .7$
$\mu^+\mu^-$	3	6	9	$9.3 \pm .9$
$\tau^+\tau^-$	3	5	8	$3.9 \pm .4$
total	6	22	28	20.4 ± 1.2

Table 3: DELPHI: events found in llV^0 search.

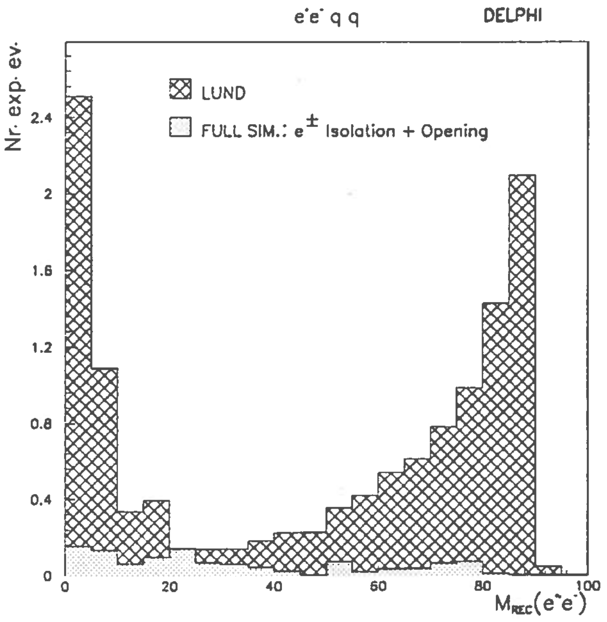


Figure 4: Recoil mass of four fermions events after selection cuts

In the neutrino channel the main signature is the missing energy and the missing momentum due to the neutrinos. A very important feature of the detector for this channel is its hermeticity since the undetected energy can simulate the neutrinos. Other physical background are the semileptonic decays of the heavy quarks where neutrinos are also produced. All the processes with part of the particles going in the forward region (like two photon physics events or beam gas interactions) are also very dangerous because all the detectors are less efficient in this region. The main cuts used by the experiments to analyse the data are the cuts on acollinearity and acoplanarity defined using the jet axis, to reject hadronic events which tend to be back-to-back. To fight against semileptonic decay of heavy quarks is important to select events with missing momentum isolated with respect to the direction of the jets. Another important variable used is the sum of the three angles between jets when the event is forced to be a three jet event. For background this variable is peaked at 360° while the signal shows a more flat distribution.

This is only a very short summary of the selections used, many of them depending on the characteristics of the experiment. Only one candidate event has been observed by the OPAL experiment in their preliminary analysis(see Table4).

In the charged channels two energetic and isolated leptons are requested. The background from semileptonic decay of heavy quarks is eliminated by the cut on isolation. Important background can be produced by misidentified leptons, like punch-through in hadron calorimeter for muon or superposition of π^0 and $\pi^\pm$ in the electromagnetic calorimeter for electrons, these backgrounds can be strongly reduced by a severe lepton identification. The last process that can simulate the signal is the four fermion production described in section 4.3. This background cannot be completely suppressed because the final state is completely equivalent to our signal, but it can be reduced efficiently with a cut on visible mass. Up to now, since its cross section is small, no many events have been observed in this channel, but for the next year, with a big jump in luminosity expected from LEP, events will be found and the only way to separate the background from signal will be to look at the mass distribution of the events.

In charged leptonic channel 4 events have been observed at LEP (see Table 4), which are compatible with the expected background.

4.5 Conclusions about S.M. Higgs

The analysis presented is based on the statistics collected by the four LEP experiments up to the end of 1991 (see Table 5). With the cuts described in previous section the efficiencies obtained in the different channels are shown in Table 5. Many sources of errors are present, Higgs cross section and its branching ratios, luminosity, fragmentation function and the statistics of Monte Carlo events used; all these sources have been combined and the expected number of events is decreased by one sigma to take them into account. Accounting for the observed events each experiment can exclude the Higgs Boson production up to the value shown in Table 5 [19, 20, 21, 22].

In principle it should be possible to combine the limits of the different experiments to reach a better result; this procedure, used in the past, can be criticized from two points of view: first because to reach higher limit more statistics must be analyzed and this means more background events; second because when the mass

EXPERIMENT	Channel	Mass(GeV/c^2)	Exp. 4f back.
DELPHI	e^+e^-qq	35.0 ± 5.0	0.33 ± 0.05
L3	$\mu^+\mu^-qq$	70.4 ± 0.7	1.7 ± 0.2
L3	e^+e^-qq	31.4 ± 1.5	1.6 ± 0.3
OPAL	e^+e^-qq	37.4 ± 4.4	< 1.0
OPAL	$\nu\nu qq$	40.7 ± 4.9	< 1.0

Table 4: Summary of events observed in the Higgs search

EXPERIMENT	Z^0_{had}	$H\nu^+\nu^-$	He^+e^-	$H\mu^+\mu^-$	LIMIT
ALEPH	488000	59%	63%	68%	53.0
DELPHI	330000	42%	41%	50%	47.0
L3	408000	59%	52%	62%	52.0
OPAL	494000	45%	49%	49%	51.0

Table 5: Analysis efficiency in different channels (for a $m_H = 50GeV$)

range changes also the analysis changes and in general the efficiency decreases. If these procedure is applied anyway[23] a limit of 60 GeV/c^2 can be quoted.

From precise measurements at LEP combined with results from previous low energy experiment[24] it is possible to derive a limit on the Top mass and an indication of a low Higgs mass (below $160GeV/c^2$), which is encouraging for the search at LEP.

5. MSSM Neutral Higgs Boson Searches

The search for Higgs Bosons in SuperSymmetric Standard Model[25] has been reviewed very recently after the introduction of the radiative corrections to the calculation of the masses[26]. The new effect can be summarized in a dependence of the mass of the light Higgs h on the mass of the quark top given in Eq(6):

$$\epsilon \equiv \frac{3\alpha_W}{2\pi}\frac{m_{top}^4}{m_W^2 m_Z^2} ln(\frac{m_{stop}^2}{m_{top}^2}) \qquad (6)$$

Using this correction the tree level inequalities are no more valid and the h boson can decay into two A bosons. The experiments developed a new analysis to explore this channel taking into account the rich phenomenology of the Higgs particles. At the time of the conference only ALEPH and DELPHI have concluded their work and their results are shown in Fig5. The kinematical limit has been reached only by the ALEPH experiment.

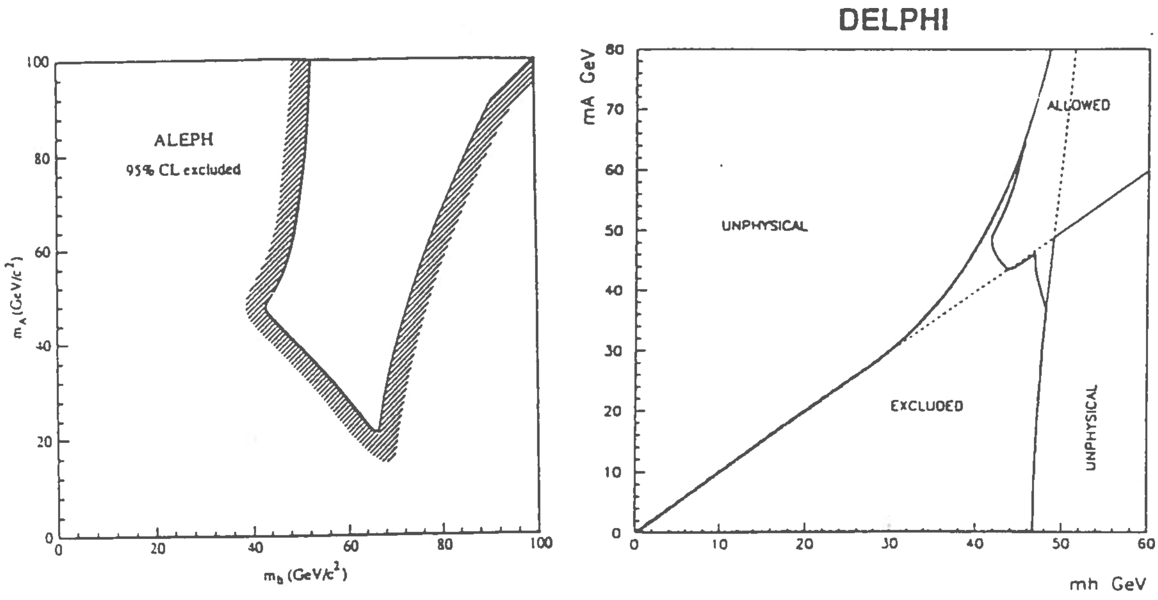


Figure 5: ALEPH and DELPHI excluded region at 95%CL.

6. Conclusion

In the search of the Standard Model Higgs Boson LEP has played a crucial role confirming previuos results and pushing the limit down to 0 GeV/c^2 and up to almost the sensitivity limit. After the present limit (60 GeV/c^2) the work of Higgs hunters will be more difficult due to the presence of irriducible backgrounds. Only at LEP II the search will continue thank to an improved signal over background ratio up to a limit which will depend on the energy of the machine, and I hope it will be the highest possible.

Also the SUSY Higgs need the new accelerator to extend the excluded region of the parameter space, but the final word on this theory will be said only by a future e^+e^- linear accelerator at high energy.

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