HIGGS SEARCHES AND PROSPECTS FROM LEP2

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The status of the search at LEP2 for the Higgs in the standard model (SM) and in the minimal supersymmetric extension of the standard model (MSSM) is reviewed. A preliminary lower limit of 95.5 GeV/c^2 at 95% C.L. on the SM Higgs is obtained after a preliminary analysis of the data collected at $\sqrt{s} = 189$ GeV. For standard choices of MSSM parameter sets, the search for the neutral Higgs bosons h and A leads to preliminary 95% C.L. exclusion lower limits of 83.5 GeV/c^2 and 84.5 GeV/c^2 , respectively.

1 Introduction

After reviewing the indirect information on the Higgs mass based on precise electroweak measurements performed at LEP1, SLD and at the TEVATRON, I will discuss the mechanisms of Higgs production and decay and the strategy adopted to search for the neutral Higgs boson (in the SM and in the MSSM) at LEP2 [1]. I will summarise the results based on the analysis of approximately 170 pb^{-1} collected by each LEP experiment at $\sqrt{s} = 189$ GeV updated to the more recent Winter Conferences numbers [2]. In the end I will briefly discuss the prospects for Higgs discovery at LEP2.

2 Higgs mass from precision electroweak measurements and from theoretical arguments

The aim of precision electroweak tests is to prove the SM beyond the tree level plus pure QED and QCD corrections and to derive constraints on its fundamental parameters. Through loop corrections, the SM predictions for the electroweak observables depend on the top mass via terms of order $\mathrm{G_F/M_t^2}$ and on the Higgs mass via logarithmic terms. Therefore from a comparison of the theoretical predictions [3], computed to a sufficient precision to match the experimental capabilities and the data for the numerous observables which have been measured, the consistency of the theory is checked and constraints on M_H are placed, once the measurement of M_t from the TEVATRON is input. The present 95% C.L. upper limit on the Higgs mass in the SM is [4,2]

$$M_\mathrm{H} < 220\,\mathrm{GeV}/c^2\,, \tag{1}$$

if one makes due allowance for unknown higher loop uncertainties in the analysis. The corresponding central value is still rather imprecise:

$$M_{\mathrm{H}} = 71^{+75}_{-42} \pm 5\,\mathrm{GeV}/c^2\,. \tag{2}$$

The range given by Eq.1 may be compared with the one derived from theoretical arguments [5]. It is well known that in the SM with only one Higgs doublet a lower limit on the Higgs mass M_{H} can be derived from the requirement of vacuum stability. This limit is a function of the energy scale Λ where the model breaks down and new physics appears. Similarly an upper bound on M_{H} is obtained from the requirement that up to the scale Λ no Landau pole appears. If, for example, the SM has to remain valid up to the scale $\Lambda \simeq \mathrm{M_{GUT}}$, then it is required that $135 < M_{\mathrm{H}} < 180$ GeV/c^2.

In the MSSM two Higgs doublets are introduced, in order to give masses to the up-type quarks on the one hand and to the down-type quarks and charged leptons on the other. The Higgs particle spectrum therefore consists of five physical states: two CP-even neutral scalars (h,A), one CP-odd neutral pseudo-scalar (A) and a charged Higgs boson pair ($\mathrm{H}^{\pm}$). Of these, h and A could be detectable at LEP2 [6]. In fact, at tree-level h is predicted to be lighter than the Z. However, radiative corrections to M_{h} [7], which are proportional to the fourth power of the top mass, shift the upper limit of M_{h} to approximately 135 GeV/c^2 , depending on the MSSM parameters.

3 Higgs production and decay

At LEP2, the dominant mechanism for producing the standard model Higgs boson is the so-called Higgs-strahlung process $\mathrm{e^+e^-} \to \mathrm{HZ}$ [8,9], with smaller contributions from the WW and ZZ fusion processes leading to $\mathrm{H}\nu_{\mathrm{e}}\bar{\nu}_{\mathrm{e}}$ and $\mathrm{He^+e^-}$ final states, respectively. A sizeable cross section (few 0.1 pb) is obtained up to $M_{\mathrm{H}} \sim \sqrt{s} - M_{\mathrm{Z}}$, so that an energy larger than 190 GeV is needed to extend the search above $M_{\mathrm{H}} \simeq M_{\mathrm{Z}}$. For example the production cross section at $\sqrt{s} = 189$ GeV for $M_{\mathrm{H}} = 95$ GeV/c^2 is 0.18 pb, which for an integrated luminosity $\mathcal{L}$=170 pb^{-1}/exp. gives 30 signal events per experiment.

For the MSSM Higgs the main production mechanisms are the Higgs-strahlung process $\mathrm{e^+e^-} \to \mathrm{hZ}$, as for the SM Higgs, and the associated pair production $\mathrm{e^+e^-} \to \mathrm{hA}$ [10]. The corresponding cross sections may be written in terms of the SM Higgs-strahlung cross section, σ^{SM}, and of the cross section $\sigma^{\mathrm{SM}}_{\nu\overline{\nu}}$ for the process $\mathrm{Z}^* \to \nu\overline{\nu}$ as

$$\begin{aligned} \sigma(\mathrm{e^+e^-} \to \mathrm{Zh}) &= \sin^2(\beta-\alpha)\,\sigma^{\mathrm{SM}} \\ \sigma(\mathrm{e^+e^-} \to \mathrm{hA}) &\propto \cos^2(\beta-\alpha)\,\sigma^{\mathrm{SM}}_{\nu\overline{\nu}}\,. \end{aligned} \tag{3}$$

The parameter tanβ gives the ratio of the vacuum expectation values of the two Higgs doublets and α is a mixing angle in the CP-even sector.

The Higgs-strahlung hZ process occurs at large $\sin^2(\beta-\alpha)$, i.e., at small tanβ. Conversely, at small $\sin^2(\beta-\alpha)$, i.e., at large tanβ, when hZ production dies out, the associated hA production becomes the dominant mechanism with rates similar to the previous case. In this region the masses of h and A are approximately equal.

For masses below ~ 110 GeV/c^2 , the SM Higgs decays into $\mathrm{b\overline{b}}$ in approximately 85% of the cases and into $\tau^+\tau^-$ in approximately 8% of the cases. Similar branching ratios (BR) are expected for the MSSM Higgs bosons. Above $M_{\mathrm{H}} \sim 135$ GeV/c^2 , the BR into W and Z pairs becomes dominant.

4 Searches at LEP2

While at LEP1 energies the signal to noise ratio was as small as 10^{-6} due to the very high $\mathrm{q\overline{q}}$ cross section, at LEP2 the signal to noise ratio is much more favourable, increasing to $\simeq$ 1%. In order to reduce this background, mainly due to W pair production, $\mathrm{q\overline{q}}$ (with two gluons or two additional photons in the final state) and ZZ events, use is made of b-tagging techniques which exploit the large BR of the Higgs into $\mathrm{b\overline{b}}$. For $M_{\mathrm{H}} \simeq M_{\mathrm{Z}}$, as is the case for the expected experimental sensitivity, ZZ production represents an irreducible source of background since the Z decays into $\mathrm{b\overline{b}}$ in 15% of the cases.

The following event topologies are studied:

i) The leptonic channel (Z→ $\mathrm{e^+e^-}, \mu^+\mu^-$, H→ $\mathrm{b\overline{b}}$) which represents 7% of the Higgs-strahlung cross section. These events are characterised by two energetic leptons with an invariant mass close to M_{Z} and a recoil mass equal to M_{H}. Because of the clear experimental signature, no b-tag is necessary and therefore the signal efficiency is high, typically $\sim$ 75%.

ii) The missing energy channel (Z→ $\nu\overline{\nu}$, H→ $\mathrm{b\overline{b}}$) comprising $\simeq$ 20% of the Higgs-strahlung cross section. This channel is characterised by a missing mass consistent with M_{Z} and two b-jets. The selection efficiency is $\simeq$ 35%.

iii) The four jet channel (Z→ $\mathrm{q\overline{q}}$, H→ $\mathrm{b\overline{b}}$) which is not as distinctive as the two previous topologies but compensates for this drawback with its large BR of $\simeq$ 64%. The efficiency for this channel is typically $\simeq$ 40%.

iv) The $\tau^+\tau^-\mathrm{q\overline{q}}$ channel (Z→ $\tau^+\tau^-$, H→ $\mathrm{q\overline{q}}$ and vice-versa) with a $\simeq$ 9% BR. The event topology includes two hadronic jets and two oppositelycharged, low multiplicity jets due to neutrinos from the τ decays. The signal efficiency is of the order of 25%.

The b-tagging algorithms are based on the long lifetime of weakly decaying b-hadrons, on jet shape variables such as charged multiplicity or boosted sphericity and on high p_t leptons from semileptonic b decays. The b-jet identification is improved by combining information from the different b-tagging algorithms with tools like neural-networks and likelihoods. Typically, for a 60% signal efficiency, the WW background, which has no b-content, is suppressed by a factor over 100, and the $\mathrm{q\overline{q}}$ and ZZ backgrounds by approximately a factor 10. With respect to the b-tagging algorithms developed for the measurement at LEP1 of $\mathrm{R_b}$, the b fraction of Z hadronic decays, the performances at LEP2 have improved by almost a factor of 2, due to vertex detectors with an extended solid angle coverage and to more efficient b-tagging techniques.

All the analyses developed for the standard model Higgs produced via the Higgs-strahlung mechanism can be used with no modification for the supersymmetric case, provided that the Higgs decays to standard model particles ($\mathrm{b\overline{b}}$, $\tau^+\tau^-$). The results can then be reinterpreted in the MSSM context, by simply rescaling the number of expected events by the factor $\sin^2(\beta - \alpha)$.

For the pair production process, the signal consists of events with four b-quark jets or a $\tau^+\tau^-$ pair recoiling against a pair of b-quark jets.

5 Results and prospects

Table 1 shows the number of selected events in the data for the SM Higgs search, the expected number of background events and the expected numbers of signal events assuming $M_\mathrm{H} = 95$ GeV/c^2 [2,11,12,13,14].

Table 1. Standard Model Higgs search. Number of observed events in the data n_obs, expected number of background events n_back and expected numbers of signal events n_sig assuming $M_\mathrm{H} = 95$ GeV/c^2 for the four LEP experiments and for their combination. Also shown are the number of events observed and expected by the four experiments combined in the mass window $\Delta M_\mathrm{H} = 92 - 96$ GeV/c^2 .

	n_obs	n_back	n_sig
ALEPH	53	44.8	13.8
DELPHI	26	31.3	10.1
L3	30	30.3	9.9
OPAL	50	43.9	12.6
Total	159	150	46.4
$\Delta M_\mathrm{H} = 92 - 96$ GeV/c^2	47	37.5	24.6

As can be observed from Table 1, an excess of events is observed by

Table 2. Observed 95% C.L. lower limits on M_{H}. Also shown are the limits predicted by the simulation if no signal were present.

	Observed limit (GeV/c^2)	Expected limit(GeV/c^2)
ALEPH	90.2	95.7
DELPHI	95.2	94.8
L3	95.2	94.4
OPAL	91.0	94.9

ALEPH [11] and OPAL [14] which, in the case of OPAL, is concentrated in the mass region around $M_{\mathrm{H}} \simeq M_{\mathrm{Z}}$, while for ALEPH it is distributed over higher masses, typically ≥ 95 GeV/c^2 . These results translate into the lower limits shown in Table 2, together with the sensitivity (expected limit) of each experiment.

Table 3 shows the preliminary 95% C.L. lower limits on M_{h} and M_{A} for the four LEP experiments [2,11,12,13,14], as well as the derived excluded ranges of $\tan\beta$ for both no mixing and maximal mixing in the scalar-top sector.

In the years 1999 to 2000 LEP2 is expected to deliver a luminosity larger than 200 pb^{-1} per experiment at a centre-of-mass energy eventually as high as $\sim$ 200 GeV. These data should allow to discover a SM Higgs of 107 GeV/c^2 or to exclude a Higgs lighter than $\sim$108 GeV/c^2 [15,16]. This is a particularly interesting region to explore, given the present indication for a light Higgs from the standard model fit of the electroweak precision data. The sensitivity to the Higgs in the MSSM will reach $\sim$ 90 GeV/c^2 for the high $\tan\beta$ region and $\sim$ 108 GeV/c^2 for $\tan\beta \simeq 1$, therefore allowing good coverage of the MSSM plane.

Table 3. Observed 95% C.L. lower limits on M_{h} and M_{A}. Also shown are the derived excluded ranges of $\tan\beta$. The mass limits are given for $\tan\beta > 1$, except for those of DELPHI, given for $\tan\beta > 0.5$.

	M_{h} (GeV/c^2)	M_{A} (GeV/c^2)	$\tan\beta$ max. mixing	$\tan\beta$ no mixing
ALEPH	80.8	81.2	-	$1 < \tan\beta < 2.2$
DELPHI	83.5	84.5	$0.9 < \tan\beta < 1.5$	$0.6 < \tan\beta < 2.6$
L3	77.0	78.0	$1. < \tan\beta < 1.5$	$1. < \tan\beta < 2.6$
OPAL	74.8	76.5	-	$0.81 < \tan\beta < 2.19$

Acknowledgments

I would like to thank Cesareo Dominguez and Raul Viollier for their great hospitality and excellent organization of the Workshop and “Maestro” Patrick Janot for his precious advice and for carefully reading this manuscript.

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