Eur Phys J C **33**, s01, s720–s722 (2004)
Digital Object Identifier (DOI) 10.1140/epjcd/s2003-03-801-1

EPJ C direct
electronic only

Flavour and model-independent Higgs boson searches at LEP

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Received: 17 November 2003 / Accepted: 19 November 2003 /
Published Online: 3 December 2003 –

Abstract. Now the LEP experiments have finalized their results on the Standard-Model Higgs boson, and are finalizing results on the most common Supersymmetric scenari, a wealth of results are being released that do not rely on explicit model assumptions, but rather on particular final states. In the absence of any convincing excess in the data, results are then extracted in a quasi model-independent way, most often in the form of excluded signal cross-sections, normalized to Standard Model cross-sections. The aim of the experiments is to provide a catalog of results that can be used in a straightforward way for future studies of models of electroweak symmetry breaking.

PACS. 13.66.Fg Gauge and Higgs boson production in e^+e^- intteractions – 13.66.Hk Production of non-standard model particles in e^+e^- interactions

1 Introduction

From 1989 to 2000, the LEP experiments have accumulated an unprecedented data set at e^+e^- centre-of-mass energies up to 209 GeV. The first seven years were dedicated to the study of the Z boson, with about 4.5 million Z boson decays recorded per experiment, while from 1996, a gradual increase of the centre-of-mass energy and machine luminosity lead to a total set of about 2.5 fb^{-1}, collected between 130 and 209 GeV.

After the end of data-taking, the Standard Model Higgs boson search was the focus of attention, even more so in the context of a possible hint of its presence. Final, LEP combined results on this search have been submitted to this Conference [1]. The MSSM, as most popular extension to the Standard Model Higgs sector, was next in line, with results being finalized currently.

The current trend in LEP searches for Higgs bosons is based on the exploitation of specific final states, rather than models. As soon as the Standard Model is extended by at least one Higgs doublet, one expects production of the lightest Higgs bosons (denoted h and A) in association with a Z boson ($e^+e^- \to hZ$), in pairs ($e^+e^- \to hA$), or through radiation off a heavy final fermion ($e^+e^- \to$ bbh or bbA). When kinematically open, cascade decays in the final state (like h→AA, or A→hZ) also occur. Furthermore, the Higgs boson decays to fermions are much less contrained than in the Standard Model or its supersymmetric extensions; decays to c-quarks, gluons, or τ-leptons can easily become dominant.

For every process, one can write the Higgs boson mediated cross-section into a given final state, like the product of a purely electroweak factor (i.e. function only of the weak angle and the weak boson masses, and of the involved Higgs boson masses through a phase space factor), and of a term that contains all terms arising from Higgs boson mixing, CP violation in the Higgs sector, or other effects:

$$\sigma_{Z(h\to X)} = \sigma^{ew}_{Zh} \times C^2_{Z(h\to X)}$$
$$\sigma_{hA\to X)} = \sigma^{ew}_{hA} \times C^2_{hA\to X}$$
$$\sigma_{ff(h/A\to X)} = \sigma^{ew}_{ffh/A} \times C^2_{h/A\to X}$$

In the above, the σ^{ew} factors are "model-independent", while the model-dependent C^2 factors include and hide all terms related to the dilution of the Higgs boson couplings to the vector bosons, to the non-standard Higgs boson branching fractions, etc.

It is thus possible, for a given final state, to perform a search, and in absence of a signal, set an upper bound on the corresponding C^2 factor (in practice, this bound is a function of the masses of the involved Higgs bosons). Such a bound is very general, and can then be compared to the prediction of any specific model of the Higgs sector. I give examples of such applications in the following.

2 Recent results from DELPHI, L3, OPAL

I consider in turn final states where the Higgs bosons decay into b-quarks or τ-leptons; hadrons, without specifying which parton species (quark or gluon) initiates the jets; and finally an analysis fully independent of the Higgs boson decay-mode. The three LEP experiments quoted above contribute to these analyses.

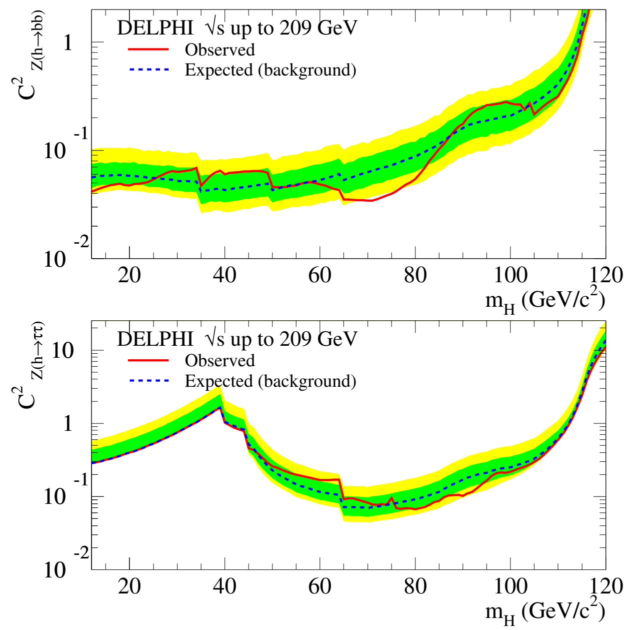

Fig. 1. Excluded values of C^2 in the Z(h→bb) and Z(h→ $\tau\tau$) channels, as a function of m_h [2]

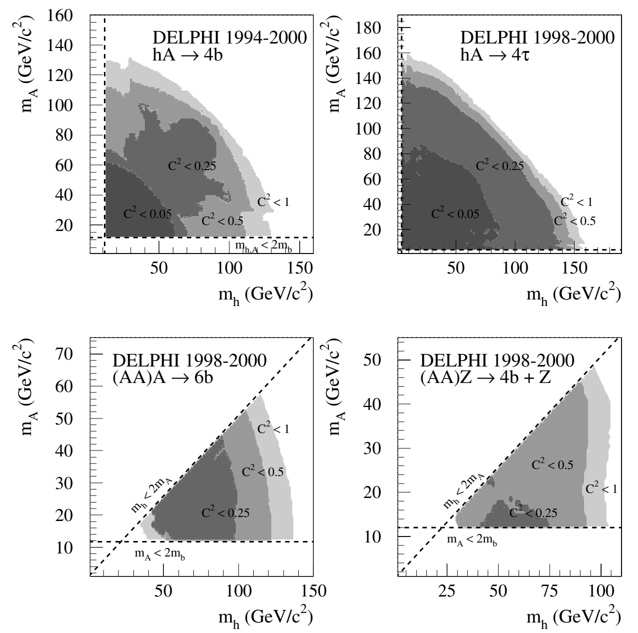

Fig. 2. Excluded values of C^2 in the hA→4b, hA→4τ, hA→AAA→6b and hZ→AAZ→4b+Z channels, as a function of m_h and m_A [2]. The different coloured regions indicate domains in the (m_h, m_A) plane where the excluded C^2 is smaller than the corresponding value given on the figure

2.1 Final states with b-quarks or τ-leptons

The Standard Model and MSSM searches for Higgs bosons decaying into b-quarks or τ-leptons can be reinterpreted in a model-independent way by considering the h→bb and h→ $\tau\tau$ modes in turn, and varying their cross-section, to determine for each decay-mode which value of C^2 is exactly excluded at 95%CL. This study has been performed by all LEP experiments, and statistical combinations are being performed [1]. The DELPHI results on hZ production [2] are displayed in Fig. 1, for two Higgs boson decay modes. The same approach, but when two Higgs bosons are involved, leads to the excluded regions of Fig. 2. Finally, Higgs boson production through their Yukawa coupling to heavy fermions, was considered by DELPHI [2] and OPAL [3] in various channels. Figures 3 illustrates the OPAL results on bb(h/A→ $\tau\tau$).

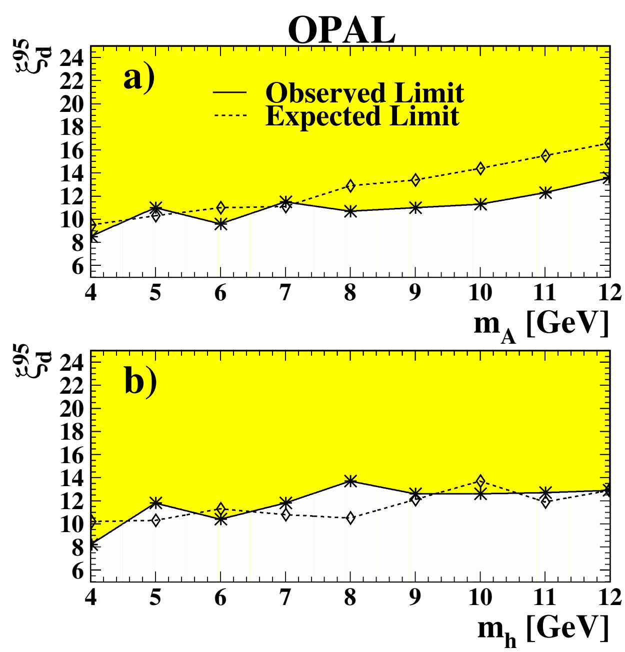

Fig. 3. Excluded values of C in the bb(h→ $\tau\tau$) and bb(A→ $\tau\tau$) channels, as a function of the Higgs boson mass [3]

2.2 Flavour-blind analyses

In this analysis, all hadronic Higgs boson decay modes are treated on an equal footing, thus releasing the usual assumptions on b-quark dominance in Higgs boson decays. In the hZ production mode, a pair of well-separated jets from the Higgs boson, recoiling against a pair of charged leptons or neutrinos from the Z, constitute a well defined signal. When the Z boson decays to jets as well, the analysis is more complicated because of the large purely hadronic backgrounds from W-pair and quark-pair production. The full kinematic event structure is then exploited (event shape variables, and dijet mass information); due to its large cross-section (since the Z boson decays into hadrons constitute 70% of its total width), this last channel contributes significant sensitivity. The OPAL results, combining all channels, are displayed in Fig. 4. The same approach can be applied to the hA production mode, when both Higgs bosons are assumed to decay into jets. The results provided by the L3 experiment are displayed in Fig. 5.

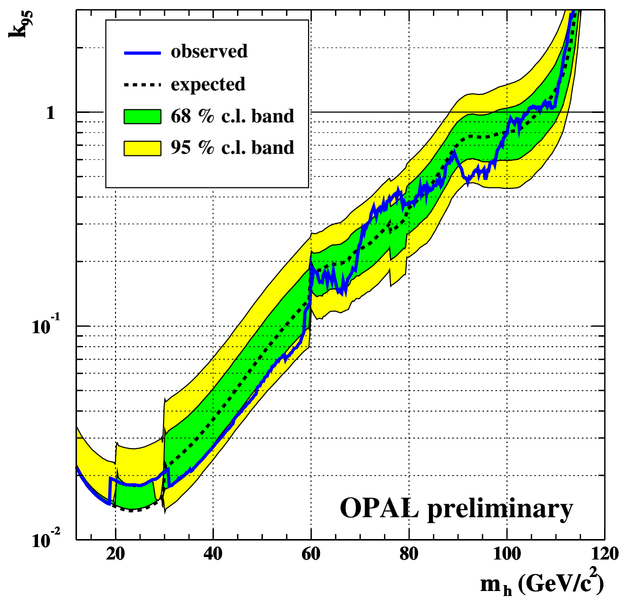

Fig. 4. Excluded values of C^2 (denoted k_{95} on the figure) in the Z(h→hadrons) channel, as a function of $\mathrm{m_h}$ [4]

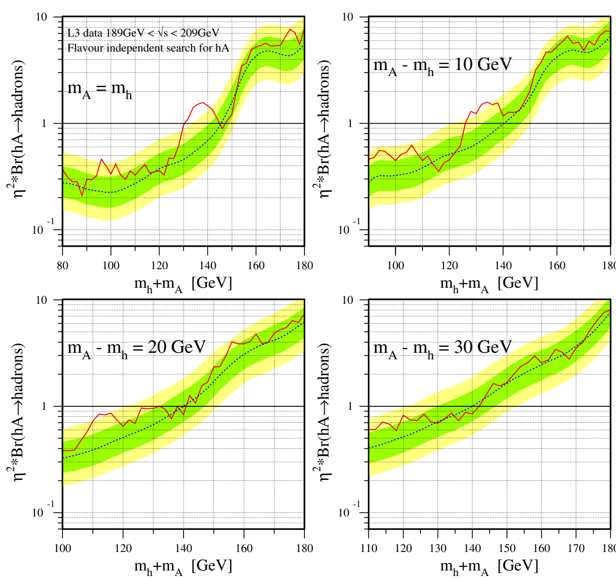

Fig. 5. Excluded values of C^2 (denoted $\eta^2 \times \mathrm{BR(hA \to hadrons)}$ on the figure) in the hA→hadrons channel, as a function of $\mathrm{m_h + m_A}$, for various values of $\mathrm{m_A - m_h}$ [5]

2.3 Decay-mode independent results

This search exploits OPAL data taken at the Z peak, and between 183 and 209 GeV. The hZ process is considered. Events are selected with Z decays into electron or muon pairs, and the mass spectrum of the system recoiling against it is analysed irrespective of its particle content. Z decays into neutrinos are also considered, when the scalar particle decays into electrons or photons. Higgs boson decays into an arbitrary combination of hadrons, photons, leptons or invisible particles, as well as the possibility that it may be stable, are covered in this way. The results in terms of excluded C^2 values are displayed in Fig. 6.

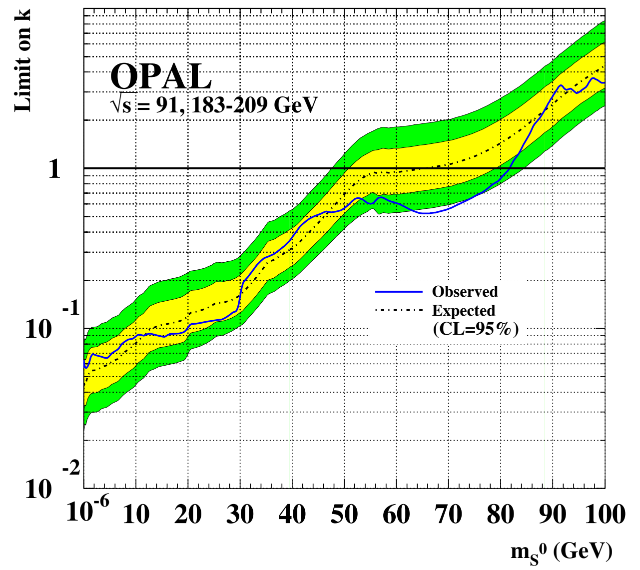

Fig. 6. Excluded values of C^2 (denoted k on the figure) in the Z(h→X) channel, as a function of the scalar mass [6]

3 Conclusions and perspectives

I hope I have given some insights on how the LEP experiments proceed to an exhaustive exploration of the possibilities provided by extensions to the Standard Model in the Higgs sector. Some of the final states described here were never considered earlier; still, no signal was observed. Hence, upper bounds were set on the corresponding cross-sections (normalized to reference ones), providing a catalog of limits that can be compared to specific model predictions.

The excluded values of the C^2 factors are typically of the order $10^{-2} - 10^{-1}$, for hA or hZ production. The explored range of Higgs boson masses covers most of the available domain at LEP2. In this range, the current and future hadron colliders most often have no sensitivity, thus still increasing the relevance of these searches.

Finally, the searches presented here that are covered by more than one LEP experiment (notably the flavour-independent hZ and hA searches) will be statistically combined, with the perspective of a significant increase in sensitivity.

References

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2. The DELPHI Collaboration: paper 211 submitted to this Conference, to be submitted to Eur. Phys. J. C
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