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LOOKING FOR A FERMIOPHOBIC HIGGS BOSON AT LEP2 IN THE WW CHANNEL USING THE ALEPH DETECTOR

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A feasibility study concerning the search for WW decay of a Higgs boson produced in association with a fermion pair via the Higgs-strahlung or boson-fusion diagrams is presented. An expected upper limit is derived, as a function of the Higgs boson mass, on the product of the $e^+e^- \to Hf\bar{f}$ cross section and the $H \to WW$ branching ratio.

1 Introduction

A Higgs model incorporating two doublets of complex scalar fields [1] generates five scalar Higgs bosons, three of which are neutral. For certain choices of the model parameters, one of these neutral scalars provides mass only to the fermions and the other couples exclusively to the bosons, i.e. is a "fermiophobic" Higgs boson.

In the ALEPH experiment at LEP, the search for a fermiophobic Higgs boson has been primarily carried out in the $H \to \gamma\gamma$ channel, in which the Higgs boson couples to photons via a W loop [2]. For fermiophobic Higgs bosons heavier than 90 GeV, the predicted $H \to \gamma\gamma$ branching ratio becomes small relative to the predicted $H \to WW$ branching ratio (Fig. 1) motivating a search in this new channel[3].

The study is normalized to a luminosity of 453.3 pb^{-1} corresponding to the data taken in the years 1999 and 2000 at center-of-mass energies ranging from 191 to 209 GeV.

2 The ALEPH detector

The ALEPH detector is described in detail in Ref. [4]. An account of its performance and a description of the standard analysis algorithms can be found in Ref. [5].

In ALEPH, the trajectories of charged particles are measured with a silicon vertex detector, a cylindrical wire chamber, and a large time projection chamber (TPC). These detector components are immersed in a 1.5 T axial magnetic field provided by a superconducting solenoidal coil. The electromagnetic calorimeter, placed between the TPC and the coil, is a highly-segmented, 22-radiation-length-thick sandwich of lead planes and proportional wire chambers. It is used to identify electrons and photons. The hadron calorimeter consists of a iron return yoke of the magnet instrumented with streamer tubes. It provides a measurement of

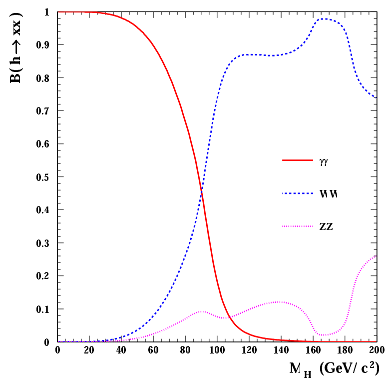

Figure 1. Branching fraction of benchmark fermiophobic Higgs boson into boson pairs as calculated by HDECAY2 [3].

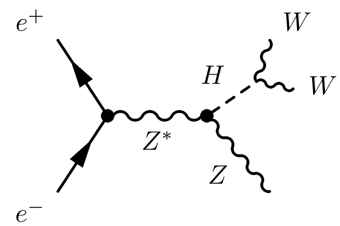

Figure 2. "Higgs-strahlung" diagram contributing dominantly to the WWff production at LEP.

the hadronic energy and, together with the external muon chambers, an efficient identification of muons by their characteristic penetration pattern. Global event quantities (such as total energy and missing momentum) are determined with an energy-flow algorithm which combines all the above measurements into electrons, photons, muons, as well as charged and neutral hadrons.

3 Final state selection

The processes considered in this works are characterized by two W bosons and two fermions, originating from a Z boson in the dominating Higgs-strahlung diagram (Fig.2). In the Higgs boson mass range kinematically accessible at LEP, one of the virtual W's is expected to be near on-shell, and the other to have a much smaller mass and energy.

The full spectrum of HZ $\rightarrow$ WWff contains a total of 96 different topologies depending on the decays of the W's and the Z. These final states were pooled in 13 exclusive selections depending on the number of jets, hard leptons and soft leptons in the final state.

All the selection cuts are optimized in order to minimize the expected confidence level $\langle \mathrm{CL_s} \rangle$, defined as the ratio of the likelihood functions for the signal and background only hypothesis. For the signal, a Higgs boson mass hypothesis of 110 $\mathrm{GeV/c^2}$ is chosen for the optimization process.

In order to illustrate this process, the selection procedure will be sketched for the most sensitive channel, namely the one characterized by two jets from the Z decay, a "hard" ($>$ 25 GeV) lepton and two softer jets from the off-shell W boson.

A first set of quantities is used to distinguish the signal from the $\gamma\gamma$, $\mathrm{l^+l^-}$ and $\mathrm{q\bar{q}}$ backgrounds. These are the angle between the hard lepton and the total momentum, which must be lower than 41°, the number of charged particle tracks ($N_{ch} > 20$), and the mass of the hard W boson that can be reconstructed as the

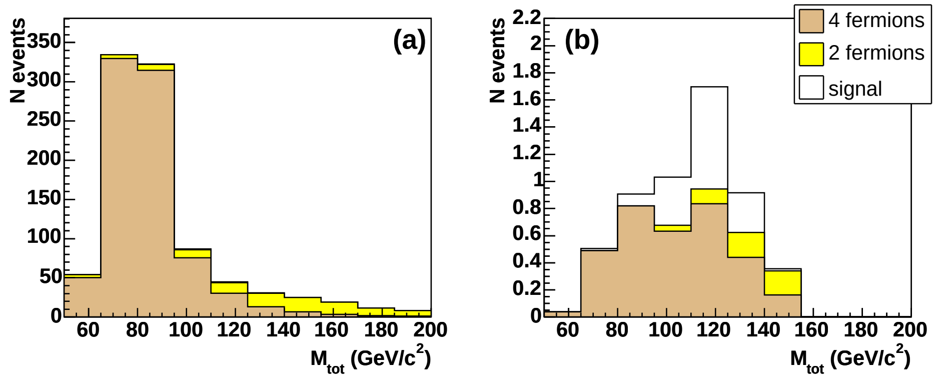

Figure 3. Distributions of the total hadronic mass $M_{tot\ (hadr)}$ plotted for the sensitive channel after the preselection (a) and after the final selection cuts (b).

invariant mass of the hard lepton and the missing momentum ($M_W > 55\mathrm{GeV/c^2}$). By this way, events are selected that are compatible with a lepton-neutrino system resulting from the decay of a on-shell W boson at rest.

To suppress the remaining backgrounds, mainly WW events, the energy of the leading lepton is asked to be less than 55 GeV, the hadronic acollinearity must be larger than 137°, and the event thrust lower than 0.93 since it is reduced by the soft hadronic activity from the off-shell W.

Figure 3 gives the distributions of the discriminant variable, the total hadronic mass, after the preselection and after all cuts.

4 Results

The thirteen analysis are combined and the log-likelihood ratio is computed as a function of the Higgs boson mass (Fig. 4).

The main contribution to the systematic error comes from the Monte Carlo statistics. The uncertainties from the cross-section productions, from the simulation of the calorimeter energy scale and from hadronization processes are also taken into account.

The systematic errors related to the simulation of the calorimeter are evaluated by modifying the calorimeter calibration and lead to an mean uncertainty of the order of 3% on the remaining background level. The uncertainties on the hadronization process are evaluated by comparing WW events produced with the JETSET[6] Monte Carlo and WW events from the ARIADNE[7] Monte Carlo. The associated mean systematic error is 6%.

An expected upper limit on $\xi^2 = B(H \to WW)\sigma(e^+e^- \to Hff)/\sigma^{SM}(e^+e^- \to Hff)$ is derived as a function of the Higgs boson mass. If the branching of the Higgs boson to WW is taken to be one, the expected limit is 107.5 GeV/c^2. In the fermiophobic Higgs boson scenario, one expects to exclude a Higgs boson in a mass range from 97.5 GeV/c^2 to 104 GeV/c^2(Fig. 5).

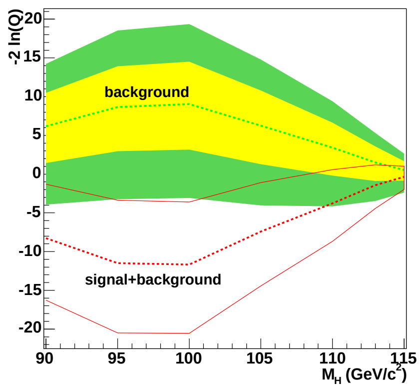

Figure 4. Log-likelihood ratio as a function of the mass. The one- and two-sigmas bands for the background-only hypothesis and the one-sigma band for the signal hypothesis are shown.

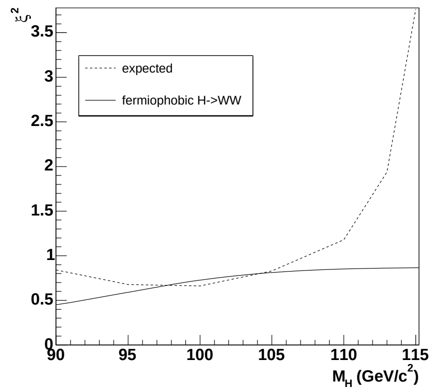

Figure 5. Limit on ξ^2 as a function of the Higgs boson mass. The dotted line corresponds to the expected limit. The benchmark Higgs model is depicted by the full line.

The present study extends the reach of the analysis performed by the ALEPH collaboration in the $\gamma\gamma$ channel [2]. More generally, this analysis could complement existing searches for new physics beyond the standard model and constraints models introducing anomalous couplings in the Higgs sector.

Acknowledgments

It is a pleasure to congratulate my colleagues from the accelerator divisions for the outstanding operation of LEP 2, especially in its last year of running during which the accelerator performance was pushed beyond expectation. We are indebted to the engineers and technicians for their contributions to the excellent performance of ALEPH. The author would like to thank the Belgian FNRS for supporting him as research fellow.

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