Search for a low mass neutral Higgs boson in Z⁰ decay

L3 Collaboration

We have searched for the neutral Higgs boson produced in the decays of the Z° through the process Z°→H°±± in the mass range $M_{H^0} < 2$ GeV. From the analysis of a data sample corresponding to about 70 000 $Z^0\rightarrow$hadrons we exclude a minimal standard model Higgs boson in the mass range $0 < M_{H^0} < 2$ GeV at the 99% confidence level independent of the Higgs decay channels.

1. Introduction

There have been many searches for the neutral Higgs boson [1] for masses above 2 GeV [2,3]. Since the Higgs mass is not fixed by the theory it can only be found by an exhaustive experimental search. In this letter we report on our search for a low mass Higgs in the mass range $M_{H^0} < 2$ GeV. This new search is based on a data sample corresponding to about 70 000 $Z^0\rightarrow$hadrons. Results from previous searches for the Higgs boson in this mass range at LEP can be found in ref. [3].

2. The L3 detector

The L3 detector covers 99% of 4π with calorimeter. The detector consists of a central vertex chamber, a high resolution electromagnetic calorimeter composed of BGO crystal, a ring of scintillation counters, a uranium and brass hadron calorimeter with proportional wire chamber readout, and a very accurate muon chamber system. These detectors are installed in a 12 m diameter magnet which provides a uniform field of 0.5 T along the beam axis. The detector and its performance are described in detail elsewhere [4,5].

3. $H^0$ production and decay

The $e^+e^-\rightarrow Z^0\rightarrow H^0+Z^0\star$ cross section is predicted by the standard model [6] and depends on the Higgs mass [7]. The Higgs decay partial widths into fermions are also well established for a mass of the $H^0$ greater than 2 GeV [8]. Below 2 GeV nonperturbative effects make the prediction of the branching ra-
tions of the Higgs boson decaying into hadrons and leptons less firm \[8,9\], leading to large uncertainties in the detection efficiency of light Higgs. For this reason, instead of following a specific model, we have made an independent search for each Higgs decay channel.

4. $H^0 \rightarrow \text{hadrons and } H^0 \rightarrow \mu^+\mu^-$ event selection

We have searched for a low mass Higgs decaying into muons or hadrons in the reaction $Z^0 \rightarrow H^0 \pi^+\pi^-$, where the leptons can be two muons or two electrons. These events are characterized by the presence of two high momentum isolated leptons coming from the off shell $Z^0$, recoiling against a low multiplicity jet coming from the $H^0$ decay.

The two muons are identified requiring two tracks in the muon chambers with momentum greater than 3 GeV coming from the interaction vertex and associated with at least one hit in the scintillator ring in time with the beam crossing. In addition the sum of the two muon momenta is required to be greater than 30 GeV.

The two electrons are identified requiring two electromagnetic clusters in the BGO calorimeter each with energy greater than 30 GeV. At least one of them should have a track in the vertex chamber associated with it.

In order to remove most of the $e^+e^-\rightarrow \pi^+\pi^-(\gamma)$ events the angle between the two leptons is required to be smaller than 176°.

The isolation of one of the two leptons is ensured by requiring that no other calorimeter each with energy greater than 30 GeV. At least one of them should have a track in the vertex chamber associated with it. In order to remove most of the $e^+e^-\rightarrow \pi^+\pi^-(\gamma)$ events the angle between the two leptons is required to be smaller than 176°.

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We have used the selection method described in the previous section also to search for $H^0 \rightarrow e^+ e^-$ events, but, for Higgs masses below $\sim 100$ MeV, it becomes inefficient due to the absence of tracks in the 50 cm radius vertex chamber. In this case a complementary method can be used. It relies on the fact that, if the Higgs decays outside the volume of the electromagnetic calorimeter, the event will contain only two acoplanar leptons with no other detected particle balancing the missing momentum.

To select these events we require the two leptons to be identified with the same criteria as in the previous method. The two muons must also satisfy more restrictive momentum cuts: the least energetic muon should have a momentum greater than 10 GeV and the most energetic one should have a momentum greater than 30 GeV.

In addition we require that:
- No energy clusters (besides the one associated with the leptons) with energy greater than 0.5 GeV should be present in the first 22 radiation lengths of our calorimeters. In the end-cap region ($|\cos \theta| > 0.75$) this energy cut is 1.5 GeV since this region is covered only by the hadron calorimeter. A study of events from a random trigger in coincidence with the beam crossing shows that this cut does not produce any inefficiency due to detector noise not modelled in the simulation.
- The reconstructed missing momentum to the two leptons has an angle greater than 8° with respect to the direction of any of the two leptons and greater than 35° with respect to the beam line. These cuts remove collinear $\ell \bar{\ell} \gamma$ events and $\ell \bar{\ell} \gamma$ events where the photon escapes along the beam direction.
- The acoplanarity angle between the two leptons is larger than 0.05 rad. Fig. 1 shows the acoplanarity distribution of the events surviving all other cuts for the $\mu^+ \mu^-$ final state compared with the expectation from the $\mu^+ \mu^-$ Monte Carlo [12] and the simulated signal for a Higgs of 0.04 GeV mass.

No events survive after applying the above selection criteria.

The detection efficiency obtained combining the two methods is $\sim 13\%$ at $M_{H^0} \sim 0.1$ GeV and $\sim 8\%$ at $M_{H^0} \sim 0.2$ GeV.

6. Interpretation of the results

Fig. 2 shows the number of events expected from the reaction $e^+ e^- \rightarrow Z^0 \rightarrow H^0 \mu^+ \mu^-$ in various decay channels for $2M_{\mu} < M_{H^0} < 2$ GeV. In order to be conservative, we have reduced the number of expected events by 9% to account for systematic errors coming from uncertainties in the Higgs production cross section, in our event selection and in the trigger and detector efficiencies. We also ignore any contribution to the signal from background sources. Taking into account the two events seen (the $e^+ e^- \rightarrow \mu^+ \mu^- \mu^+ \mu^-$ and the $e^+ e^- \rightarrow e^+ e^- + \text{hadrons}$) as possible Higgs candidates we exclude the presence of a Higgs boson in the mass range $2M_{\mu} < M_{H^0} < 2$ GeV at the 99% confidence level for any value of the branching ratio of the Higgs into muons, pions, kaons or higher mass resonances.

In fig. 3 the number of events expected from the reaction $e^+ e^- \rightarrow Z^0 \rightarrow H^0 \mu^+ \mu^-$ in the mass range $M_{H^0} < 2M_{\mu}$ is presented. Also in this case we have reduced the number of expected Higgs events by 9% to account for systematic errors. Taking into account the two $e^+ e^- \rightarrow e^+ e^- e^+ e^-$ events found we exclude the
7. Conclusion

We have searched for a neutral Higgs boson in the mass range $M_{1\ell^+\ell^-} > 2$ GeV looking for its decays into a pair of electrons, muons, pions or kaons. We have also searched for a long living Higgs boson decaying outside the volume of our electromagnetic calorimeter. Combining the results of all these searches we exclude the presence of a minimal standard model Higgs boson with mass lower than 2 GeV at the 99% confidence level.

Acknowledgement

We wish to thank CERN for its hospitality and help. We particularly want to express our gratitude to the LEP division: it is their excellent achievements which made this experiment possible. We acknowledge the effort of all engineers and technicians who have participated in the construction and maintenance of this experiment. We acknowledge the support of all the funding agencies which contributed to this experiment.

References


