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Search for a low mass neutral Higgs boson in $Z^0$ decay

L3 Collaboration

We have searched for the neutral Higgs boson produced in the decays of the $Z^0$ through the process $Z^0\rightarrow H^0\gamma\nu\bar{\nu}$ in the mass range $M_{H^0} < 2$ GeV. From the analysis of a data sample corresponding to about 70,000 $Z^0\rightarrow\text{hadrons}$ 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 $Z^0\rightarrow\text{hadrons}$. 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 $4\pi$ with calorimeter...
tios 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°→hadrons and H°→μ±μ− event selection

We have searched for a low mass Higgs decaying into muons or hadrons in the reaction Z°→H°μ±μ∓, 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°*, recoiling against a low multiplicity jet coming from the H° 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⁻→γ⁺γ⁻(γ) 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 calorimetric cluster, besides the one associated with the lepton, is present in a cone of 30° around at least one lepton. This cut removes Z°→γ⁺γ⁻+hadrons events coming from the semileptonic decay of heavy quarks.

The Higgs decay products are identified requiring the presence of at least one charged track associated with the energy deposited in the calorimeters besides the ones associated with the leptons. This loose requirement ensures a high efficiency for detecting a low mass Higgs decaying into two charged particles and removes all e⁺e⁻→γ⁺γ⁻γ events.

Four events have been found which satisfy above requirements. One is an e⁺e⁻→μ⁺μ⁻μ⁺μ− event with the invariant mass of the two less energetic muons of about 300 MeV. Another two are identified as e⁺e⁻→μ⁺e⁻+hadrons events with the invariant mass of the two less energetic electrons smaller than 80 MeV. Both of them are compatible with photon conversion in the beam pipe. The fourth event is an e⁺e⁻→e⁺e⁻+hadrons. The hadron system consists of two charged tracks with measured invariant mass of about 1 GeV.

We have performed several Monte Carlo simulations of Z°→H°μ⁺μ⁻ events with the Higgs boson decaying into pairs of μ, π or K at various masses in the range 2Mμ < Mh < 2 GeV. The response of the detector has been simulated using the L3 detector simulation program 81. The simulation includes the effects of energy loss, multiple scattering, interactions and decays in the detector materials and the beam pipe. The resolution, the efficiency and the noise of the detector have also been taken into account.

The detection efficiencies range between ~28% for H°→μ⁺μ⁻ events and ~15% in the case of H°→ππ events where we assume that one third of the events consist of π⁺π⁻ final states which do not contain any charged tracks and thus are not selected. We have also simulated events with the Higgs boson decaying into a pair of resonances like η, ρ and K* obtaining similar detection efficiencies.

5. Event selection in the mass range Mh < 2Mμ

For masses of the Higgs boson below the μ⁺μ⁻ threshold the Higgs boson will decay predominantly into an e⁺e⁻ pair. The Higgs partial decay width is proportional to the square of the fermion mass in the final state. Due to the small of the electron the width of a Higgs with mass less than 2Mμ is such that its mean life time is of the order of several picoseconds. This implies that the Higgs will decay in the detector volume and, for very low masses, the Higgs will even decay outside the detector itself. For masses below the e⁺e⁻ threshold the Higgs boson decays into two photons and, in the minimal standard model, has a long life time [8].

81 The L3 detector simulation is based on GEANT Version 3.13 (September, 1989) [10]. The GHEISHA program [11] is used to simulate hadronic interactions.
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
efficient 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 bal­
cancing 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 re­
strictive 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 cal­
orimeters. 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 cross­
ing shows that this cut does not produce any ineffi­
ciency due to detector noise not modelled in the
simulation.
- The reconstructed missing momentum to the two
leptons has an angle greater than $8^\circ$ with respect to
the direction of any of the two leptons and greater
than $35^\circ$ with respect to the beam line. These cuts
remove collinear $\ell^+\ell^-\gamma$ events and $\ell^+\ell^-\gamma$ 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 simu­
lated signal for a Higgs of 0.04 GeV mass.

No events survive after applying the above selec­
tion criteria.

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

6. Interpretation of the results

Fig. 2 shows the number of events expected from the
reaction $e^+e^- \rightarrow Z^0 \rightarrow H^0\ell^+\ell^-$ in various decay
channels for $2M_{\ell\ell} < M_{H^0} < 2$ GeV. In order to be con­
servative, we have reduced the number of expected
events by 9% to account for systematic errors coming
from uncertainties in the Higgs production cross sec­
tion, in our event selection and in the trigger and de­
tector 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 $2M_{\ell\ell} < M_{H^0} < 2$ 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 $e^+e^- \rightarrow Z^0 \rightarrow H^0\ell^+\ell^-$ in the mass range
$M_{H^0} < 2M_{\ell\ell}$ is presented. Also in this case we have re­
duced the number of expected Higgs events by 9% to
account for systematic errors. Taking into account the
two $e^+e^- \rightarrow e^+e^-+\text{hadrons}$ events found we exclude the
7. Conclusion

We have searched for a neutral Higgs boson in the mass range \(M_{\text{lep}} > 2\) 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.

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References
