THE SEARCH FOR HIGGS

The L3 Collaboration

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ABSTRACT

We searched for the production of the Standard Model Higgs H° and the Minimum Supersymmetric Standard Model Higgs h° and A° in ~65,000 Z° decays observed by the L3 detector at LEP. No signature was found. We obtained the mass limit of $M_{H^\circ} > 36.2$ GeV and $M_{h^\circ}, M_{A^\circ} > 41.5$ GeV at the 95% confidence level.

Introduction

The Higgs particle, associated with the electroweak symmetry breaking mechanism of the Standard Model (SM), has been elusive. Theoretically, only the upper limit placed at ~1 TeV seems robust. The previous experimental limits for the low mass Higgs obtained by K^+ and Υ decays have been plagued by the theoretical ambiguities [1,2]. It is important to search for the Higgs particle in an experimentally clean and theoretically unambiguous process and extend its search to as high a mass as possible.

At the e^+e^- collider LEP, the Higgs H° can be searched at the Z° peak in the process

$$e^+e^- \rightarrow Z^\circ \rightarrow H^\circ + f^+f^-$$

where f^+f^- is a fermion pair originating from the decay of off-shell Z°. For f^+f^- being $\nu\bar{\nu}, e^+e^-$ and $\mu^+\mu^-$, the event has a clean signature and can be detected unambiguously. In the framework of the Standard Model, the rate can be calculated precisely [2].

In the Minimal Supersymmetric extention of the Standard Model (MSSM), the symmetry beaking is achieved by two Higgs doublets, each doublet being coupled exclusively to up-type or down-type quarks (leptons). The model has 5 physical Higgs particles, of which h° (CP-even) and A° (CP-odd) may be observed at LEP in the following processes;

$$e^+e^- \rightarrow Z^\circ \rightarrow h^\circ + A^\circ$$
$$e^+e^- \rightarrow Z^\circ \rightarrow h^\circ + f^+f^-$$

In this paper, we report a search of H° and h°/A° by using the L3 detector [3].

The L3 Detector

The L3 detector consists of a time expansion chamber (TEC) for the charged particle detection, a high resolution electromagnetic calorimeter composed of BGO crystals, an array of plastic scintillation counters, a uranium hadron calorimeter with proportional chamber readout and a high precision muon chamber system. The calorimeters cover 99% of 4π. The BGO and the muon chamber covers approximately $|\cos(\theta)| < 0.7$.

These detectors are installed in a 12 m diameter solenoidal magnet of 0.5 tesla. The beam pipe is made of two layers of beryllium, each 1.4 mm thick, constituting less than 0.01 radiation lengths of materials in front of the TEC. The detector and its performance are reported in detail in [4].

Event Selection for H°

$e^+e^- \rightarrow H^\circ + \nu\bar{\nu}$, $M_{H^\circ} > 2$ GeV

For M_{H° above 2 GeV, H° predominantly decays into a pair of heavy quarks or τ's. The final state $H^\circ + \nu\bar{\nu}$ will be detected as a 1 or 2 jet event with large missing energy and energy imbalance due to the undetected $\nu\bar{\nu}$. The separation of H° from the main background, Z° → hadrons, is shown in Fig.1.

To achieve an optimum separation of H°, we define a variable P_H from the following observables X_i.
X_1=Total Energy
X_2=Transverse Energy Imbalance
X_3=Acollinearity Angle of 2 Most Energetic Jets
X_4=Acoplanarity Angle of 2 Most Eenergetic Jets
X_5=Recoil Energy of 2 Most Energetic Jets
X_6=Number of Calorimetric Clusters

X_7=Number of Charged Tracks
X_8=Polar Angle of Thrust Axis

After applying loose preselection criteria, we calculate the variable $P_H = N^{sel}/N^{tot}$ for each preseleted event by using H° Monte Carlo events, where N^{tot} is the total number of generated events and N^{sel} is the number of selected H° Monte Carlo events satisfying the conditions

$$X_i^{ev} - 2\sigma_{X_i} < X_i < X_i^{ev} + 2\sigma_{X_i}$$

for i=1,8.

The value X_i^{ev} is calculated for each candidate and σ_{X_i} is pre-calculated as the r.m.s. width of the variable X_i in the H° Monte Carlo.

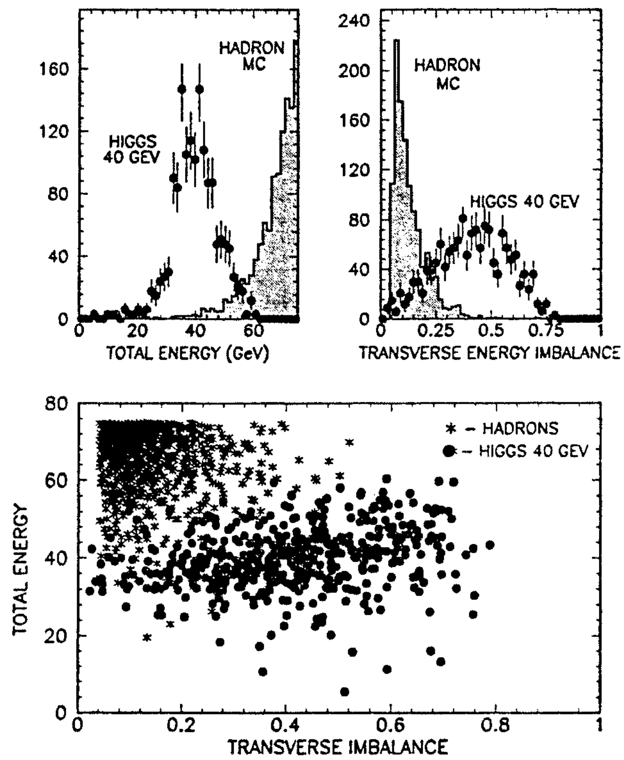

Figure.1 Separation of H° Event

The variable P_H serves for an effective single variable for the separation of H°. By construction, P_H has a large value for H° and is concentrated near 0 for the background events. After applying the cut $P_H > 0.07$, we are left with no H° candidate out of 65,000 Z° hadronic decays. The detection efficiency of this method has been calculated by the Monte Carlo and is shown in Fig.2.

$e^+e^- \to H^\circ + (e^+e^-, \mu^+\mu^-)$, $M_{H^\circ} < 2$ GeV

Below the mass of 2 GeV, we expect H° to decay predominantly into a pair of hadrons or muons. The decay mechanism is dominated by the non perturbative effects and theoretical estimates of the branching ratios are highly model dependent [2]. As the signature of leptons is very clean, we only require very loose constraints on Higgs decay products; one charged track in TEC associated with the energy deposit in BGO.

We select events with high energy and non-collinear lepton pairs. We first require two leptons with E_1 and E_2 greater than 30 GeV for e^+e^- and $P_1 + P_2$ greater than 30 GeV for $\mu^+\mu^-$, where E_1 and E_2 are the electron energies measured in BGO and P_1 and P_2 are the muon momenta measured in the muon chamber. The acollinearity angle ξ of the two leptons must be $\xi > 4^\circ$. Moreover, we require that there should be no additional energy deposit in the calorimeter besides the one by the muon itself in a 30° cone around the muon. This is to remove the background $Z^\circ \to \mu^+\mu^- +$ hadrons originating from the semileptonic decays of heavy quarks.

The detection efficiency for each decay channel, $H^\circ \to \mu^+\mu^-, KK$ and $\pi\pi$ can be reliably calculated by the Monte Carlo since our requirement on the Higgs decay products is simple. It ranges between ~28% for the most efficient channel of $H^\circ \to \mu^+\mu^-$ and ~15% for $H^\circ \to \pi\pi$ where the decay into $\pi^0\pi^0$ is not detected.

We observed 4 candidates satisfying the above criteria from the data sample corresponding to 70,000 hadronic decays of Z°.

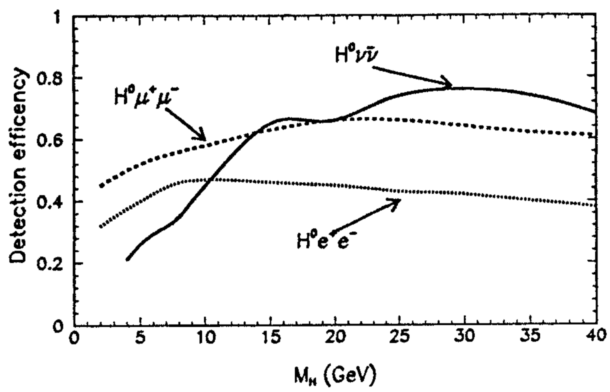

Figure.2 Detection Efficiency of $H^\circ + f^+f^-$

$e^+e^- \to H^\circ + (\mu^+\mu^-, e^+e^-)$, $M_{H^\circ} < 2M_\mu$

When the Higgs mass is below $2M_\mu$, the fermion decay channel is limited to $H^\circ \to e^+e^-$. Due to the quadratic mass dependence of the decay width, H° becomes long-lived and a significant fraction of the produced H°'s decays only outside of the BGO calorimeter. As the interaction of H° with ordinary matter particles is very weak, this leads to an event with energetic and non-collinear leptons where the corresponding missing energy is not detected in the BGO. The search of H° in this mass region, therefore, must be done for l^+l^- + "nothing" in addition to the l^+l^- + "one charged track".

We require two energetic leptons with E_1 and E_2 greater than 30 GeV for e^+e^- and $P_1 > 10$ GeV and $P_2 > 30$ GeV for $\mu^+\mu^-$. The acoplanarity angle Δ_ϕ must be greater than 2.9°. There should be no energy detected besides the one associated with leptons in the first 22 radiation lengths of the calorimeters. To remove the contamination of $l^+l^-(\gamma)$ events, we also require the missing momentum vector reconstructed from l^+l^- to be more than 8° away from any two leptons and greater than 35° from the beam line.

With the above cuts, we saw no events for the data sample corresponding to 70,000 hadronic Z° decays. The detection efficiency calculated by the Monte Carlo is 13-18% depending on M_{H°.

Limits on H° Mass

M_{H° above 2 GeV; The number of expected H° events satisfying above selection criteria is shown in Fig.3 for Z° → H° + $\nu\bar{\nu}$ and Z° → H° + l^+l^- [5]. We have reduced the expected number by 9% to take into account the systematic error mainly due to the uncertainty in estimating the detection efficiency. We found no candidate in this mass region and exclude 2.0 GeV < M_{H° < 36.2 GeV at 95% c.l..

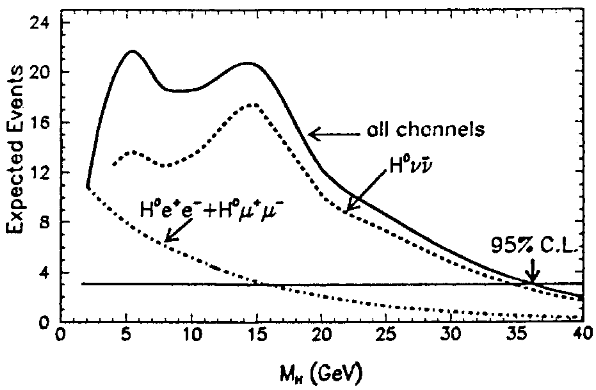

Figure.3 Number of Expected Events

$2M_\mu < M_{H^\circ} < 2$ GeV; We found 2 candidates; one $e^+e^- \to \mu^+\mu^-\mu^+\mu^-$ event with an invariant mass of ~0.6 GeV and another event of $e^+e^- \to e^+e^-$ + two charged hadrons forming an invariant mass of ~1.0 GeV. The probability to observe these two events from the expected number of H° events shown in Fig.4 is less than 1% for any combination of the branching ratios into $\mu^+\mu^-$, $\pi\pi$ and KK. We exclude the region $2M_\mu < M_{H^\circ} < 2$ GeV at 99% c.l.. Both candidate events are consistent with the 4 fermion decay of Z°.

M_{H° below $2M_\mu$; We found two $e^+e^- \to e^+e^-e^+e^-$ events with invariant mass of ~80 MeV. From the expected number of H° events shown in Fig.5, we exclude the region of 0< $M_{H^\circ} < 2M_\mu$ at the 99% c.l.. The observed two candidates are consistent with $e^+e^- \to e^+e^-\gamma$ events with the photon conversion in the beam pipe.

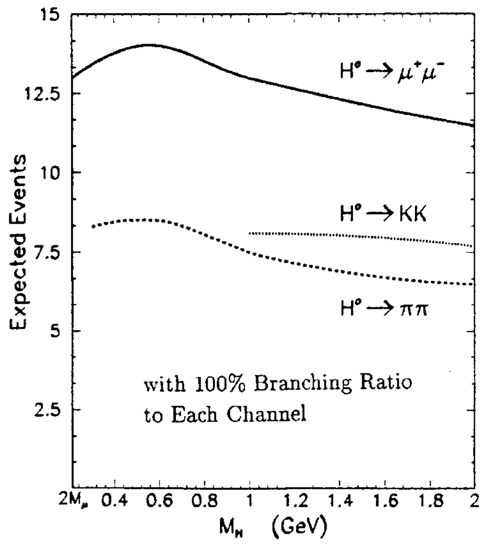

Figure.4 Number of Expected Events

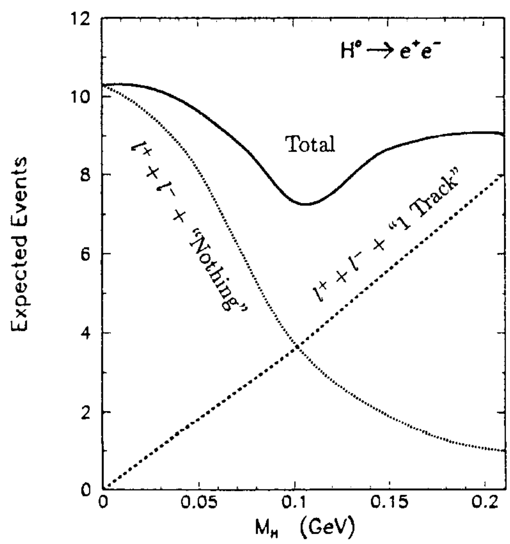

Figure.5 Number of Expected Events

Search for h° and A°

The decay branching ratio of $Z^\circ \to h^\circ + A^\circ$ is determined by the parameter $\tan\beta = v2/v1$, where v1 and v2 are the vacuum expectation values of the two Higgs doublets. For a large value of the top quark mass, $\tan\beta \gg 1$ is theoretically favoured. The h° and A° decay predominantly into $b\bar{b}$ or $\tau^+\tau^-$ in this case.

We search for the h° + A° events in the following 4 categories;

A. The hadronic 4-jet events where the invariant masses of 2 jets fall in the search region of M_{h° and M_{A°. ($b\bar{b}b\bar{b}$)

B. The low thrust hadronic events associated with 2 muons from the semileptonic decay of the b quarks. ($b\bar{b}b\bar{b}$)

C. The events with two narrow jets in one hemisphere recoiling against low thrust hadronic jets. ($b\bar{b}\tau^+\tau^-$)

D. The low energy hadronic events composed of 4 narrow jets. ($\tau^+\tau^-\tau^+\tau^-$)

In the data sample corresponding to 71,000 hadronic decays of Z°, we have observed no signatures of the h° and A° production. The excluded mass regions of M_{h° and M_{A° are shown as contours A-D in Fig.6.

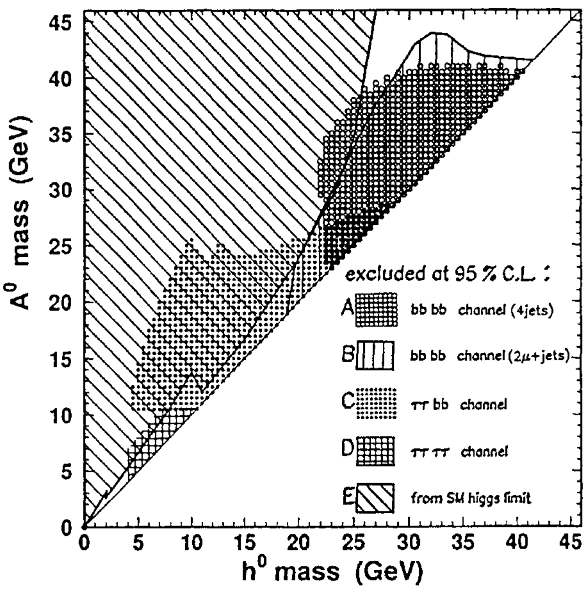

Figure.6 Excluded Region of M_{h° and M_{A°

The event signature of h° (MSSM) production in $Z^\circ \to h^\circ + f^+f^-$ is almost identical to the corresponding process of H° (SM) production. The limit obtained from $Z^\circ \to H^\circ + l^+l^-$ and $Z^\circ \to H^\circ + \nu\bar{\nu}$ can be translated into the limit of M_{h° by correcting for the difference in branching ratios [2,3]. The detection efficiencies of the h° and H° are almost identical except for the $h^\circ + \nu\bar{\nu}$ for $M_{h^\circ} < 11$ GeV, where the event is identified by detecting the Higgs decays into $\tau^+\tau^-$ and hadrons. The different admixture of $\tau^+\tau^-$ and hadron decays of h° compared to H° requires a correction in the detection efficiency.

The excluded region from this analysis is shown as contour E in Fig.6.

Conclusions

We have searched for the production of H° (SM) and h°/A° (MSSM) Higgs particles from the Z° decay. No signature was found. We have obtained the mass limit of $M_{H^\circ} > 36.2$ GeV and $M_{h^\circ}, M_{A^\circ} > 41.5$ GeV at the 95% confidence level. The results of M_{H° is free from the theoretical ambiguity of the Higgs decay branching ratios in the low mass region.

References

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3. Some of the results are finalized after the conference and submitted for publication.
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