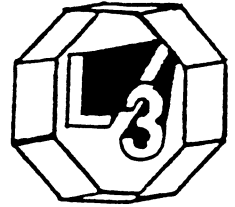CERN-L3 019

Search for a Low Mass Neutral Higgs Boson in Z° Decay

The L3 Collaboration

ABSTRACT

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

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 $M_{H^\circ} < 2$ GeV. This new search is based on a data sample corresponding to about 70,000 $Z^\circ \to$ hadrons. Results from previous searches for the Higgs boson in this mass range at LEP can be found in [3].

The L3 Detector

The L3 detector covers 99% of 4π with calorimetry. The detector consists of a central vertex chamber, a high resolution electromagnetic calorimeter composed of BGO crystals, 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 Tesla along the beam axis. The detector and its performance are described in detail elsewhere [4,5].

H° production and decay

The $e^+e^- \to Z^\circ \to H^\circ + Z^{\circ *}$ 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 mass of the H° greater than 2 GeV [8]. Below 2 GeV non-perturbative effects make the prediction of the branching ratios 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.

$H^\circ \to$ hadrons and $H^\circ \to \mu^+\mu^-$ event selection

We have searched for a low mass Higgs decaying into muons or hadrons in the reaction $Z^\circ \to H^\circ \ell^+ \ell^-$, 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 $Z^{\circ *}$, 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 $e^+e^- \to \ell^+\ell^-(\gamma)$ 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 calorimetric cluster, besides the one associated with the lepton, is present in a cone of 30° around at least one lepton. This cut removes $Z^° \rightarrow \ell^+\ell^- + hadrons$ 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 $e^+e^- \rightarrow \ell^+\ell^-\gamma$ events.

Four events have been found which satisfy above requirements. One is an $e^+e^- \rightarrow \mu^+\mu^-\mu^+\mu^-$ event with the invariant mass of the two less energetic muons of about 300 MeV. Another two are identified as $e^+e^- \rightarrow e^+e^-e^+e^-$ 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 $e^+e^- \rightarrow e^+e^- + hadrons$. The hadron system consists of two charged tracks with measured invariant mass of about 1 GeV.

We have performed several Monte Carlo simulations of $Z^° \rightarrow H^°\ell^+\ell^-$ events with the Higgs boson decaying into pairs of μ, π or K at various masses in the range $2M_\mu < M_{H^°} < 2$ GeV. The response of the detector has been simulated using the L3 detector simulation program [10]. 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 $\sim 28\%$ for $H^° \rightarrow \mu^+\mu^-$ events and $\sim 15\%$ in the case of $H^° \rightarrow \pi\pi$ events where we assume that one third of the events consist of $\pi^°\pi^°$ 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.

Event selection in the mass range $M_{H^°} < 2M_\mu$

For masses of the Higgs boson below the $\mu^+\mu^-$ 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 mass of the electron the width of a Higgs with mass less than $2M_\mu$ 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].

We have used the selection method described in the previous section also to search for $H^° \rightarrow e^+e^-$ events, but, for Higgs masses below ~ 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

decay 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 lenghts 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 $\ell^+\ell^-$ 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. Figure 1 shows the acoplanarity distribution of the events surviving all other cuts for the $\mu^+\mu^-$ final state compared with the expectation from the $\mu^+\mu^-(\gamma)$ Monte Carlo [11] 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 ~13% at $M_{H^\circ} \approx$ 0.1 GeV and ~18% at $M_{H^\circ} \approx 0$ and $M_{H^\circ} \approx 0.2$ GeV.

Interpretation of the results

Figure 2 shows the number of events expected from the reaction $e^+e^- \rightarrow Z^\circ \rightarrow H^\circ\ell^+\ell^-$ in various decay channels for $2M_\mu < M_{H^\circ} < 2$ 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 $e^+e^- \rightarrow e^+e^- + hadrons$) as possible Higgs candidates we exclude the presence of a Higgs boson in the mass range $2M_\mu < M_{H^\circ} < 2$ 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 figure 3 the number of events expected from the reaction $e^+e^- \rightarrow Z^\circ \rightarrow H^\circ\ell^+\ell^-$ in the mass range $M_{H^\circ} < 2M_\mu$ is presented. Also in this case we have reduced the number of expected Higgs events by 9% to account for systematic

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errors. Taking into account the two $e^+e^- \to e^+e^-e^+e^-$ events found we exclude the presence of a Higgs boson in this mass range at the 99% confidence level.

Conclusion

We have searched for a neutral Higgs boson in the mass range $M_{H^\circ} < 2$ 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.

Acknowledgments

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FIGURE CAPTIONS:

Fig.1 Acoplanarity angle $(\Delta\varphi)$ distribution for:

$Z^\circ \rightarrow \mu^+\mu^-$ data (full points);

$Z^\circ \rightarrow \mu^+\mu^-(\gamma)$ Monte Carlo (hollow histogram) normalized to the luminosity;

$Z^\circ \rightarrow H^\circ\mu^+\mu^-$ Monte Carlo for $M_{H^\circ} = 0.04$ GeV (hatched histogram) normalized to twenty times the luminosity.

The arrow indicates the $\Delta\varphi > 0.05$ cut described in the text.

Fig.2 Number of expected events from the process $Z^\circ \rightarrow H^\circ\ell^+\ell^-$ as a function of the Higgs boson mass for three decay channels: $H^\circ \rightarrow \mu^+\mu^-$, $H^\circ \rightarrow \pi\pi$ and $H^\circ \rightarrow KK$.

Fig.3 Number of expected events from the process $Z^\circ \rightarrow H^\circ\ell^+\ell^-$ as a function of the Higgs boson mass in the range $M_{H^\circ} < 2M_\mu$.

Curve A is for the case of detected Higgs decay products;

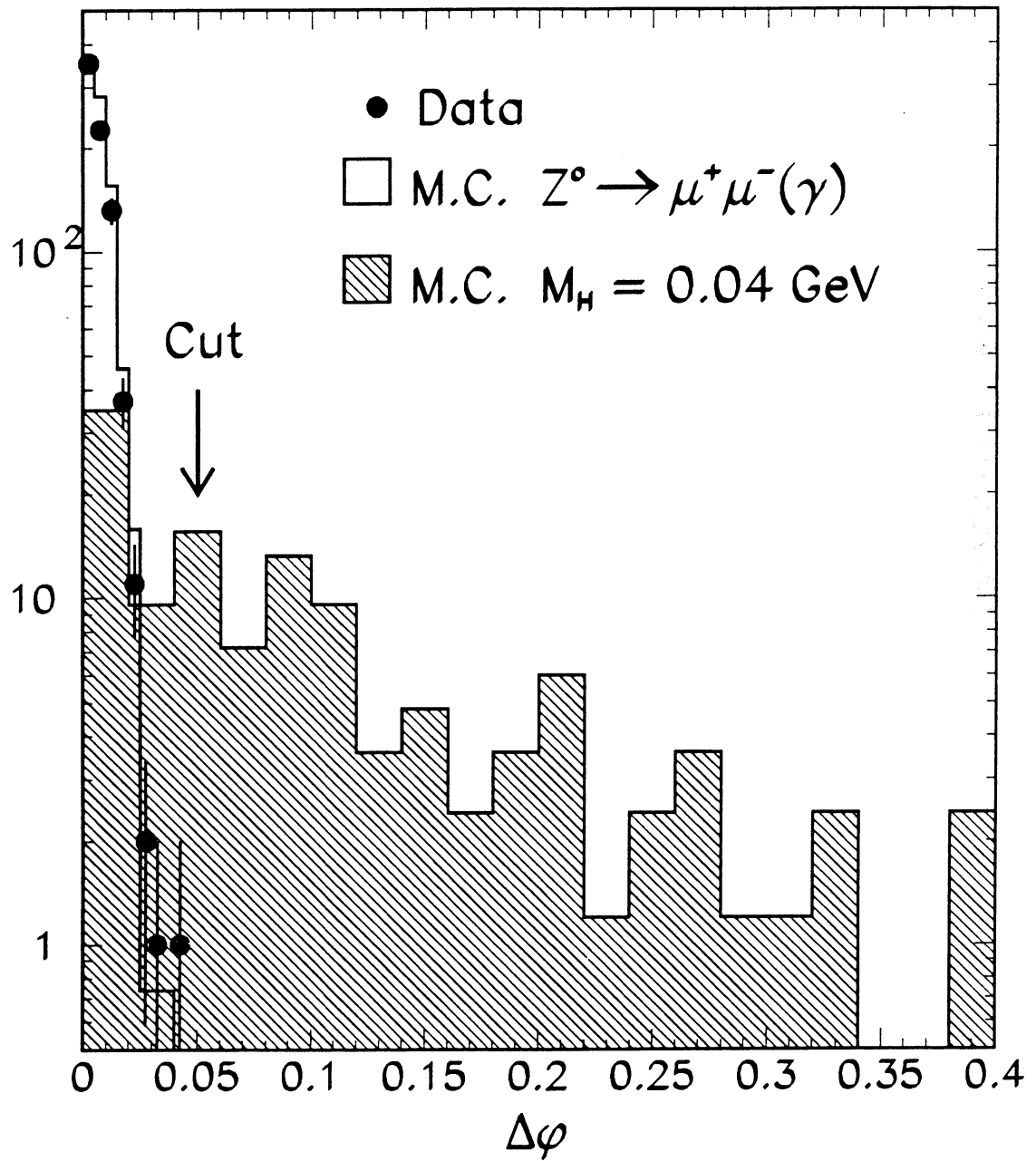curve B is for the search of an Higgs decaying outside the volume of the electromagnetic calorimeter;

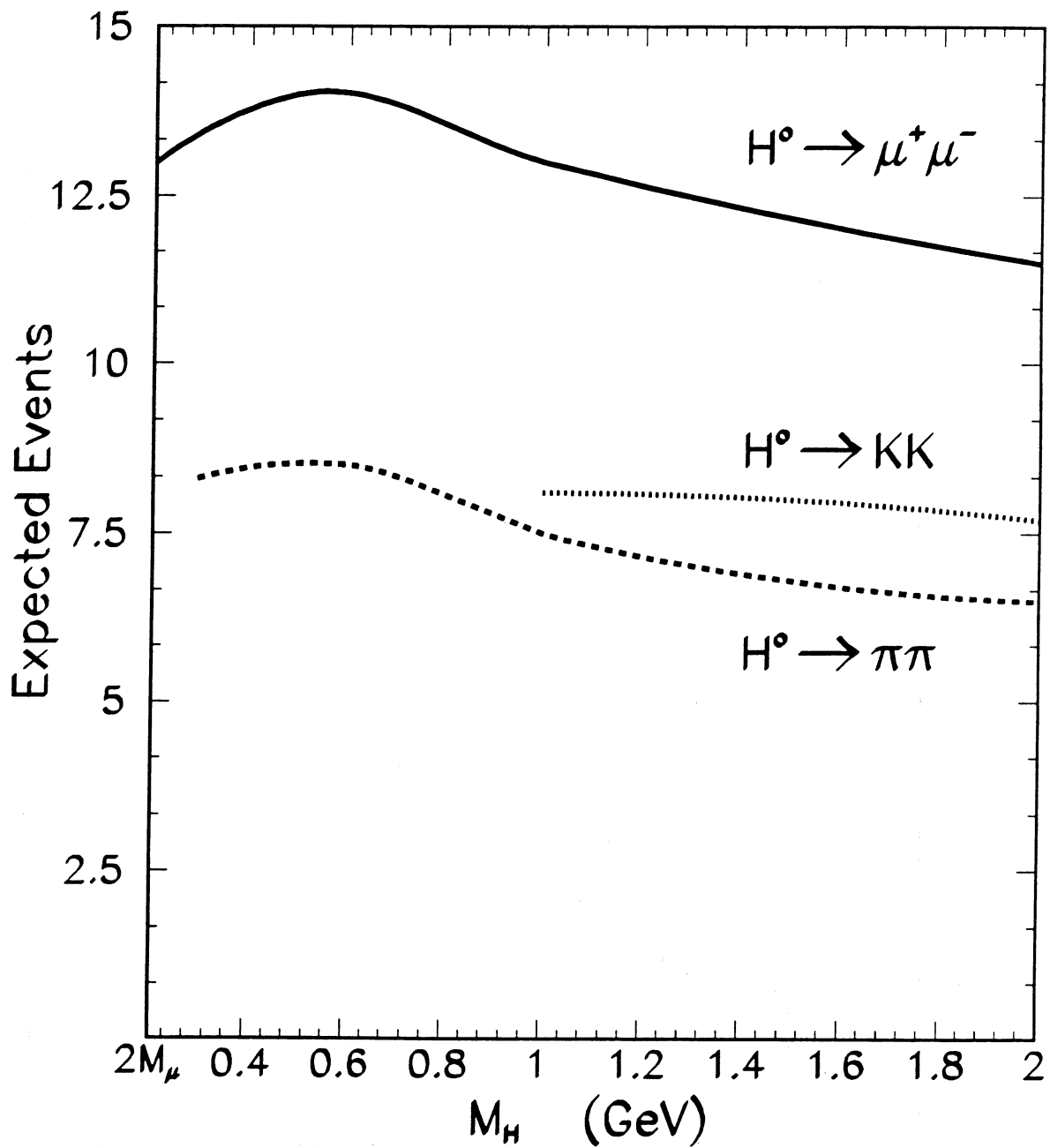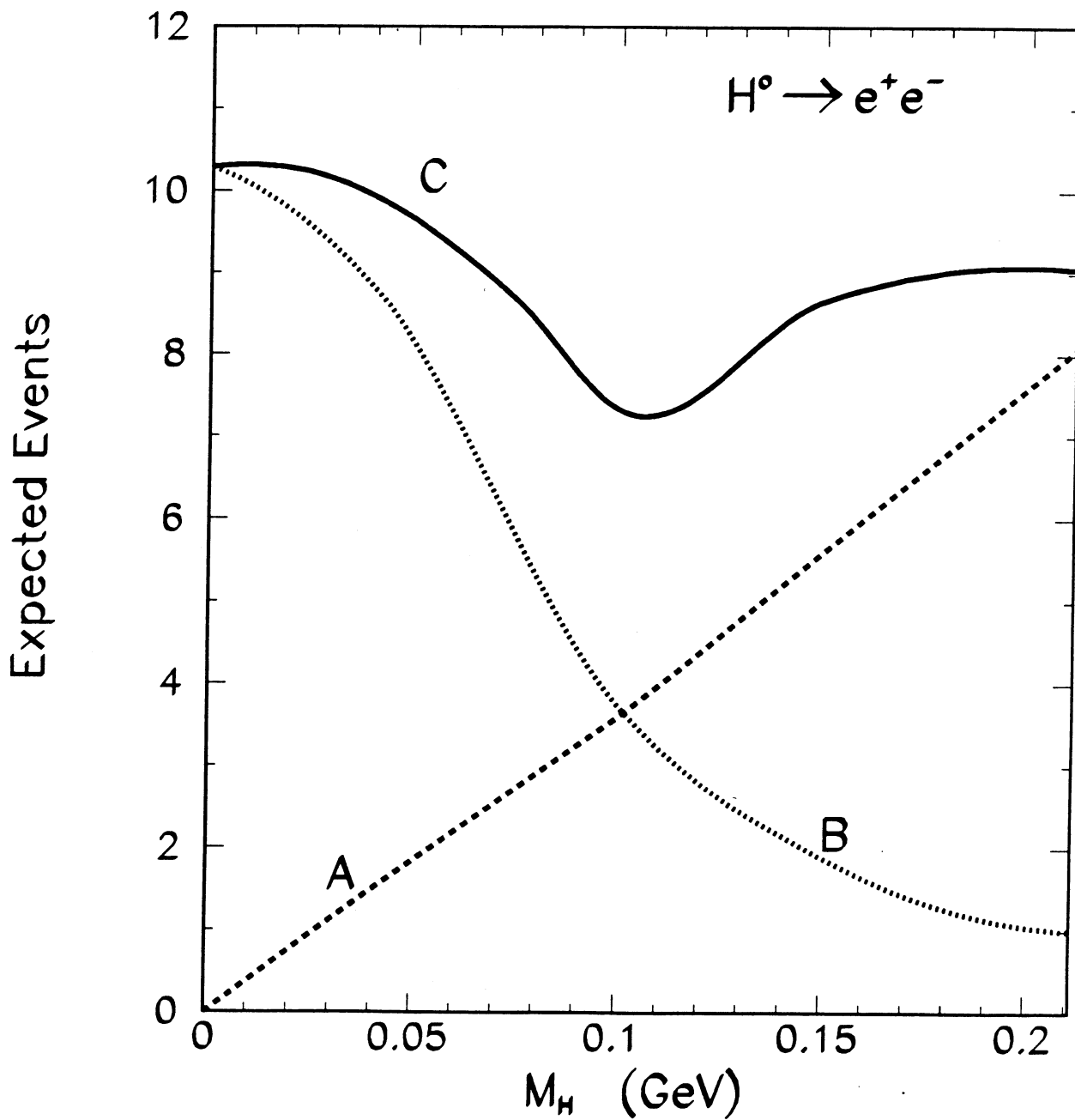curve C is the sum of A and B.

Figure 1

Figure 2

Figure 3