

PDF hosted at the Radboud Repository of the Radboud University Nijmegen

The following full text is a publisher's version.

For additional information about this publication click this link.

<http://hdl.handle.net/2066/27571>

Please be advised that this information was generated on 2017-12-05 and may be subject to change.

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

L3 Collaboration

B. Adeva^a, O. Adriani^b, M. Aguilar-Benitez^c, H. Akbari^d, J. Alcaraz^c, A. Aloisio^e,
 G. Alverson^f, M.G. Alviggi^e, Q. An^g, H. Anderhub^h, A.L. Andersonⁱ, V.P. Andreev^j,
 T. Angelovⁱ, L. Antonov^k, D. Antreasyan^l, P. Arce^c, A. Arefiev^m, T. Azemoonⁿ, T. Aziz^o,
 P.V.K.S. Baba^g, P. Bagnaia^p, J.A. Bakken^q, L. Baksay^r, R.C. Ballⁿ, S. Banerjee^{o,g}, J. Bao^d,
 L. Barone^p, A. Bay^s, U. Beckerⁱ, J. Behrens^h, S. Beingessner^t, Gy.L. Bencze^u, J. Berdugo^c,
 P. Bergesⁱ, B. Bertucci^p, B.L. Betev^k, A. Biland^h, R. Bizzarri^p, J.J. Blaising^t, P. Blömeke^v,
 B. Blumenfeld^d, G.J. Bobbink^w, M. Bocciolini^b, W. Böhlen^x, A. Böhm^v, T. Böhringer^y,
 B. Borgia^p, D. Bourilkov^k, M. Bourquin^s, D. Boutigny^t, B. Bouwens^w, J.G. Branson^z,
 I.C. Brock^{aa}, F. Bruyant^a, C. Buisson^{ab}, A. Bujak^{ac}, J.D. Burgerⁱ, J.P. Burq^{ab}, J. Busenitz^{ad},
 X.D. Cai^g, C. Camps^v, M. Capellⁿ, F. Carbonara^e, F. Carminati^b, A.M. Cartacci^b,
 M. Cerrada^c, F. Cesaroni^p, Y.H. Changⁱ, U.K. Chaturvedi^g, M. Chemarin^{ab}, A. Chen^{ae},
 C. Chen^{af}, G.M. Chen^{af}, H.F. Chen^{ag}, H.S. Chen^{af}, M. Chenⁱ, M.C. Chen^{ah}, M.L. Chenⁿ,
 G. Chiefari^e, C.Y. Chien^d, F. Chollet^t, C. Civinini^b, I. Clareⁱ, R. Clareⁱ, G. Coignet^t,
 N. Colino^a, V. Commichau^v, G. Conforto^b, A. Contin^a, F. Crijns^w, X.Y. Cui^g, T.S. Daiⁱ,
 R. D'Alessandro^b, R. de Asmundis^e, A. Degré^{at}, K. Deiters^{aa,ai}, E. Dénes^u, P. Denes^q,
 F. DeNotaristefani^p, M. Dhina^h, D. DiBitonto^{ad}, M. Diemoz^p, F. Diez-Hedo^a,
 H.R. Dimitrov^k, C. Dionisi^p, F. Dittus^{ah}, R. Dolinⁱ, E. Drago^e, T. Driever^w,
 D. Duchesneau^s, P. Duinker^{wa}, I. Duran^{ac}, H. El Mamouni^{ab}, A. Engler^{aa}, F.J. Epplingⁱ,
 F.C. Erné^w, P. Extermann^s, R. Fabbretti^h, G. Faberⁱ, S. Falciano^p, Q. Fan^{g,af}, S.J. Fan^{aj},
 M. Fabre^h, J. Fay^{ab}, J. Fehlmann^h, H. Fenker^f, T. Ferguson^{aa}, G. Fernandez^c, F. Ferroni^{pa},
 H. Fesefeldt^v, J. Field^s, F. Filthaut^w, G. Finocchiaro^p, P.H. Fisher^d, G. Forconi^s,
 T. Foreman^w, K. Freudenreich^h, W. Friebel^{ai}, M. Fukushimaⁱ, M. Gailloud^y,
 Yu. Galaktionov^m, E. Gallo^b, S.N. Ganguli^o, P. Garcia-Abia^c, S.S. Gau^{ae}, S. Gentile^p,
 M. Glaubman^f, S. Goldfarbⁿ, Z.F. Gong^{g,ag}, E. Gonzalez^c, A. Gordeev^m, P. Göttlicher^v,
 D. Goujon^s, G. Gratta^{ah}, C. Grinnellⁱ, M. Gruenewald^{ah}, M. Guanziroli^g, A. Gurtu^o,
 H.R. Gustafsonⁿ, L.J. Gutay^{ac}, H. Haan^v, S. Hancke^v, K. Hangarter^v, M. Harris^a,
 A. Hasan^g, D. Hauschildt^w, C.F. He^{aj}, T. Hebbeker^v, M. Hebert^z, G. Hertenⁱ, U. Herten^v,
 A. Hervé^a, K. Hilgers^v, H. Hofer^h, H. Hoorani^g, L.S. Hsu^{ae}, G. Hu^g, G.Q. Hu^{aj}, B. Ille^{ab},
 M.M. Ilyas^g, V. Innocente^{ca}, E. Isiksal^h, E. Jagel^g, B.N. Jin^{af}, L.W. Jonesⁿ, R.A. Khan^g,
 Yu. Kamyshkov^m, Y. Karyotakis^{ta}, M. Kaur^g, S. Khokhar^g, V. Khoze^j, D. Kirkby^{ah},
 W. Kittel^w, A. Klimentov^m, A.C. König^w, O. Kornadt^v, V. Koutsenko^m, R.W. Kraemer^{aa},
 T. Kramerⁱ, V.R. Krastev^k, W. Krenz^v, J. Krizmanic^d, A. Kuhn^x, K.S. Kumar^{ak}, V. Kumar^g,
 A. Kunin^m, A. van Laak^v, V. Laliou^s, G. Landi^b, K. Lanus^a, D. Lanske^v, S. Lanzano^e,
 P. Lebrun^{ab}, P. Lecomte^h, P. Lecoq^a, P. Le Coultre^h, I. Leedom^f, J.M. Le Goff^a, L. Leistam^a,
 R. Leiste^{ai}, M. Lenti^b, J. Lettry^h, P.M. Levchenko^j, X. Leytens^w, C. Li^{ag}, H.T. Li^{af}, J.F. Li^g,
 L. Li^h, P.J. Li^{aj}, Q. Li^g, X.G. Li^{af}, J.Y. Liao^{aj}, Z.Y. Lin^{ag}, F.L. Linde^{aa}, D. Linnhofer^a,
 R. Liu^g, Y. Liu^g, W. Lohmann^{ai}, S. Lökös^r, E. Longo^p, Y.S. Lu^{af}, J.M. Lubbers^w,
 K. Lübelmeyer^v, C. Luci^a, D. Luckey^{li}, L. Ludovici^p, X. Lue^h, L. Luminari^p, W.G. Ma^{ag},
 M. MacDermott^h, R. Magahiz^r, M. Maire^t, P.K. Malhotra^o, R. Malik^g, A. Malinin^m,
 C. Maña^c, D.N. Maoⁿ, Y.F. Mao^{af}, M. Maolinbay^h, P. Marchesini^g, A. Marchionni^b,

J.P. Martin ^{ab}, L. Martinez ^a, F. Marzano ^p, G.G.G. Massaro ^w, T. Matsuda ⁱ, K. Mazumdar ^o, P. McBride ^{ak}, T. McMahon ^{ac}, D. McNally ^h, Th. Meinholz ^v, M. Merk ^w, L. Merola ^e, M. Meschini ^b, W.J. Metzger ^w, Y. Mi ^g, M. Micke ^v, U. Micke ^v, G.B. Mills ⁿ, Y. Mir ^g, G. Mirabelli ^p, J. Mnich ^v, M. Möller ^v, B. Monteleoni ^b, G. Morand ^s, R. Morand ^l, S. Morganti ^p, V. Morgunov ^m, R. Mount ^{ah}, E. Nagy ^u, M. Napolitano ^e, H. Newman ^{ah}, M.A. Niaz ^g, L. Niessen ^v, D. Pandoulas ^v, G. Passaleva ^b, G. Paternoster ^e, S. Patricelli ^e, Y.J. Pei ^v, D. Perret-Gallix ^l, J. Perrier ^s, A. Pevsner ^d, M. Pieri ^b, P.A. Piroué ^q, V. Plyaskin ^m, M. Pohl ^h, V. Pojidaev ^m, N. Produit ^s, J.M. Qian ^{i,g}, K.N. Qureshi ^g, R. Raghavan ^o, G. Rahal-Callot ^h, P. Razis ^h, K. Read ^q, D. Ren ^h, Z. Ren ^g, S. Reucroft ^f, O. Rind ⁿ, C. Rippich ^{aa}, H.A. Rizvi ^g, B.P. Roe ⁿ, M. Röhner ^v, S. Röhner ^v, U. Roeser ^{ai}, Th. Rombach ^v, L. Romero ^c, J. Rose ^v, S. Rosier-Lees ^l, R. Rosmalen ^w, Ph. Rosselet ^y, J.A. Rubio ^{a,c}, W. Ruckstuhl ^s, H. Rykaczewski ^h, M. Sachwitz ^{ai}, J. Salicio ^{a,c}, J.M. Salicio ^c, G. Sartorelli ^{l,g}, G. Sauvage ^l, A. Savin ^m, V. Schegelsky ^j, D. Schmitz ^v, P. Schmitz ^v, M. Schneegans ^l, M. Schöntag ^v, H. Schopper ^{al}, D.J. Schotanus ^w, H.J. Schreiber ^{ai}, R. Schulte ^v, S. Schulte ^v, K. Schultze ^v, J. Schütte ^{ak}, J. Schwenke ^v, G. Schwering ^v, C. Sciacca ^e, I. Scott ^{ak}, R. Sehgal ^g, P.G. Seiler ^h, J.C. Sens ^w, I. Sheer ^z, V. Shevchenko ^m, S. Shevchenko ^m, X.R. Shi ^{aa}, K. Shmakov ^m, V. Shoutko ^m, E. Shumilov ^m, N. Smirnov ^j, A. Sopczak ^{ah,z}, C. Spartiotis ^d, T. Spickermann ^v, B. Spiess ^x, P. Spillantini ^b, R. Starosta ^v, M. Steuer ^{l,i}, D.P. Stickland ^q, B. Stöhr ^h, H. Stone ^s, K. Strauch ^{ak}, B.C. Stringfellow ^{ac}, K. Sudhakar ^{o,v}, G. Sultanov ^a, R.L. Sumner ^q, L.Z. Sun ^{ag}, H. Suter ^h, R.B. Sutton ^{aa}, J.D. Swain ^g, A.A. Syed ^g, X.W. Tang ^{af}, E. Tarkovsky ^m, L. Taylor ^f, E. Thomas ^g, C. Timmermans ^w, Samuel C.C. Ting ⁱ, S.M. Ting ⁱ, Y.P. Tong ^{ae}, F. Tonisch ^{ai}, M. Tonutti ^v, S.C. Tonwar ^o, J. Tòth ^u, G. Trowitzsch ^{ai}, K.L. Tung ^{af}, J. Ulbricht ^x, L. Urbàn ^u, U. Uwer ^v, E. Valente ^p, R.T. Van de Walle ^w, H. van der Graaf ^w, I. Vetlitsky ^m, G. Viertel ^h, P. Vikas ^g, U. Vikas ^g, M. Vivargent ^{l,i}, H. Vogel ^{aa}, H. Vogt ^{ai}, M. Vollmar ^v, G. Von Dardel ^a, I. Vorobiev ^m, A.A. Vorobyov ^j, An.A. Vorobyov ^j, L. Vuilleumier ^y, M. Wadhwa ^g, W. Wallraff ^v, C.R. Wang ^{ag}, G.H. Wang ^{aa}, J.H. Wang ^{af}, Q.F. Wang ^{ak}, X.L. Wang ^{ag}, Y.F. Wang ^b, Z. Wang ^g, Z.M. Wang ^{g,ag}, J. Weber ^h, R. Weill ^y, T.J. Wenaus ⁱ, J. Wenninger ^s, M. White ⁱ, R. Wilhelm ^w, C. Willmott ^c, F. Wittgenstein ^a, D. Wright ^q, R.J. Wu ^{af}, S.L. Wu ^g, S.X. Wu ^g, Y.G. Wu ^{af}, B. Wysłouch ⁱ, Y.D. Xu ^{af}, Z.Z. Xu ^{ag}, Z.L. Xue ^{aj}, D.S. Yan ^{aj}, B.Z. Yang ^{ag}, C.G. Yang ^{af}, G. Yang ^g, K.S. Yang ^{af}, Q.Y. Yang ^{af}, Z.Q. Yang ^{aj}, C.H. Ye ^g, J.B. Ye ^h, Q. Ye ^g, S.C. Yeh ^{ae}, Z.W. Yin ^{aj}, J.M. You ^g, M. Yzerman ^w, C. Zaccardelli ^{ah}, L. Zehnder ^h, M. Zeng ^g, Y. Zeng ^v, D. Zhang ^z, D.H. Zhang ^w, Z.P. Zhang ^{ag}, J.F. Zhou ^v, R.Y. Zhu ^{ah}, H.L. Zhuang ^{af} and A. Zichichi ^{a,g}

^a European Laboratory for Particle Physics, CERN, CH-1211 Geneva 23, Switzerland

^b INFN – Sezione di Firenze and University of Florence, I-50125 Florence, Italy

^c Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas, CIEMAT, E-28040 Madrid, Spain

^d Johns Hopkins University, Baltimore, MD 21218, USA

^e INFN – Sezione di Napoli and University of Naples, I-80125 Naples, Italy

^f Northeastern University, Boston, MA 02115, USA

^g World Laboratory, FBLJA Project, CH-1211 Geneva, Switzerland

^h Eidgenössische Technische Hochschule, ETH Zürich, CH-8093 Zurich, Switzerland

ⁱ Massachusetts Institute of Technology, Cambridge, MA 02139, USA

^j Leningrad Nuclear Physics Institute, SU-188 350 Gatchina, USSR

^k Central Laboratory of Automation and Instrumentation, CLANP, Sofia, Bulgaria

^l INFN – Sezione di Bologna, I-40126 Bologna, Italy

^m Institute of Theoretical and Experimental Physics, ITEP, SU-117 259 Moscow, USSR

ⁿ University of Michigan, Ann Arbor, MI 48109, USA

^o Tata Institute of Fundamental Research, Bombay 400 005, India

^p INFN – Sezione di Roma and University of Rome “La Sapienza”, I-00185 Rome, Italy

^q Princeton University, Princeton, NJ 08544, USA

- ^r Union College, Schenectady, NY 12308, USA
^s University of Geneva, CH-1211 Geneva 4, Switzerland
^t Laboratoire de Physique des Particules, LAPP, F-74519 Annecy-le-Vieux, France
^u Central Research Institute for Physics of the Hungarian Academy of Sciences, H-1525 Budapest 114, Hungary
^v I. Physikalisches Institut, RWTH, W-5100 Aachen, FRG¹
 and III. Physikalisches Institut, RWTH, W-5100 Aachen, FRG¹
^w National Institute for High Energy Physics, NIKHEF, NL-1009 DB Amsterdam, The Netherlands
 and NIKHEF-H and University of Nijmegen, NL-6525 ED Nijmegen, The Netherlands
^x Paul Scherrer Institut (PSI), Würenlingen, Switzerland
^y University of Lausanne, CH-1015 Lausanne, Switzerland
^z University of California, San Diego, CA 92182, USA
^{aa} Carnegie Mellon University, Pittsburgh, PA 15213, USA
^{ab} Institut de Physique Nucléaire de Lyon, IN2P3-CNRS/Université Claude Bernard, F-69622 Villeurbanne Cedex, France
^{ac} Purdue University, West Lafayette, IN 47907, USA
^{ad} University of Alabama, Tuscaloosa, AL 35486, USA
^{ae} High Energy Physics Group, Taiwan, ROC
^{af} Institute of High Energy Physics, IHEP, Beijing, P.R. China
^{ag} Chinese University of Science and Technology, USTC, Hefei, Anhui 230 029, P.R. China
^{ah} California Institute of Technology, Pasadena, CA 91125, USA
^{ai} High Energy Physics Institute, O-1615 Zeuthen-Berlin, FRG
^{aj} Shanghai Institute of Ceramics, SIC, Shanghai, P.R. China
^{ak} Harvard University, Cambridge, MA 02139, USA
^{al} University of Hamburg, W-2000 Hamburg, FRG

Received 28 September 1990

We have searched for the neutral Higgs boson produced in the decays of the Z^0 through the process $Z^0 \rightarrow H^0 \ell^+ \ell^-$ 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 calorime-

try. 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 $e^+e^- \rightarrow Z^0 \rightarrow H^0 + Z^{0*}$ 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-

¹ Supported by the German Bundesministerium für Forschung und Technologie.

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

We have searched for a low mass Higgs decaying into muons or hadrons in the reaction $Z^0 \rightarrow H^0 \ell^+ \ell^-$, 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^{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 $e^+e^- \rightarrow \ell^+ \ell^- (\gamma)$ 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 $Z^0 \rightarrow \ell^+ \ell^- + \text{hadrons}$ 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 $e^+e^- \rightarrow e^+e^- + \text{hadrons}$. The hadron system consists of two charged tracks with measured invariant mass of about 1 GeV.

We have performed several Monte Carlo simulations of $Z^0 \rightarrow H^0 \ell^+ \ell^-$ events with the Higgs boson decaying into pairs of μ , π or K at various masses in the range $2M_\mu < M_{H^0} < 2 \text{ GeV}$. The response of the detector has been simulated using the L3 detector simulation program ^{#1}. 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 $H^0 \rightarrow \mu^+ \mu^-$ events and $\sim 15\%$ in the case of $H^0 \rightarrow \pi\pi$ events where we assume that one third of the events consist of $\pi^0\pi^0$ 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 $M_{H^0} < 2M_\mu$

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 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].

^{#1} 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 ~ 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 $\ell^+\ell^-$ 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. 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 $\mu^+\mu^-(\gamma)$ 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 $M_{H^0} \approx 0.1$ GeV and $\sim 18\%$ 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 $2M_\mu < M_{H^0} < 2$ 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 $e^+e^- \rightarrow Z^0 \rightarrow H^0 \ell^+\ell^-$ 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

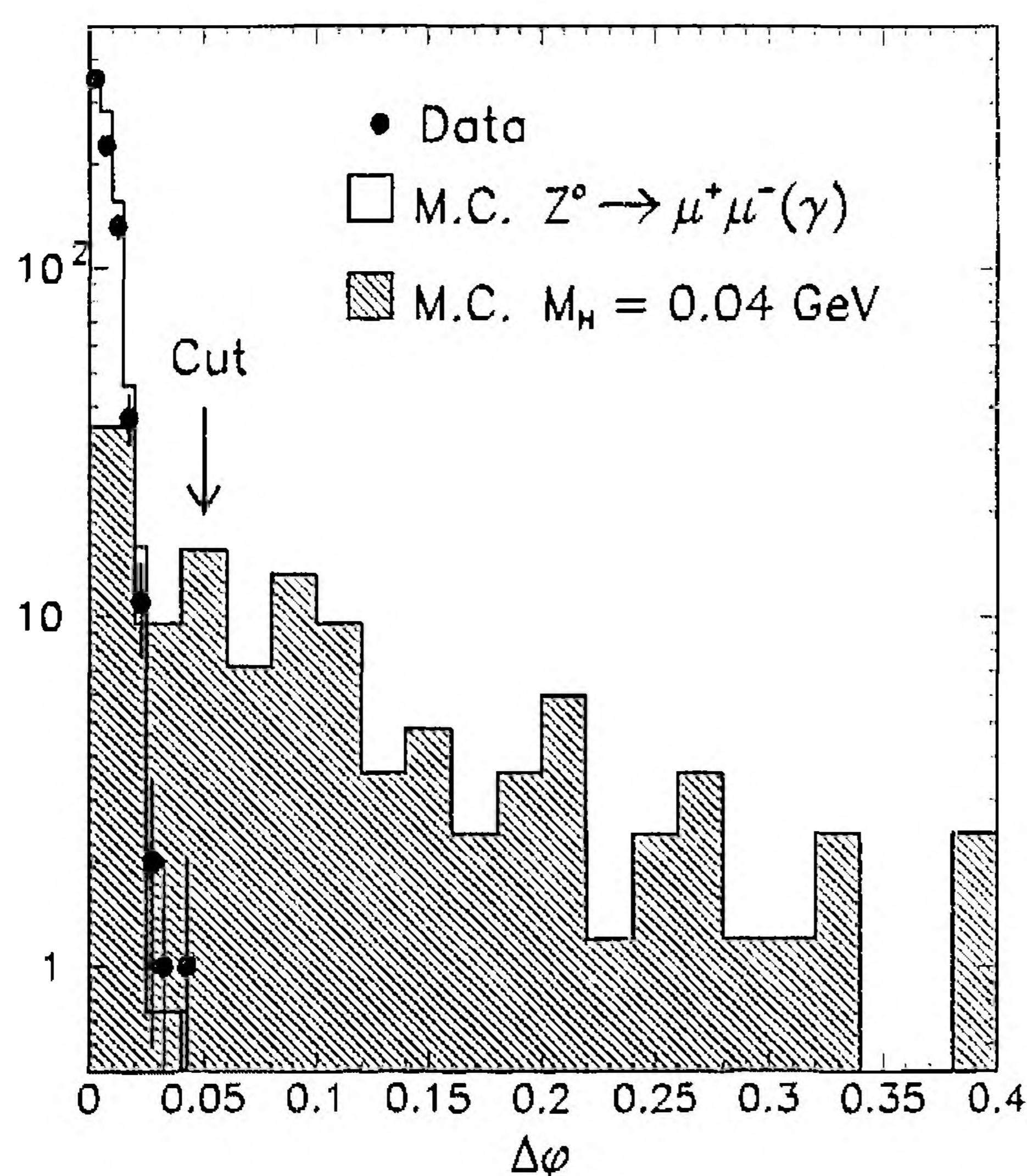


Fig. 1. Acoplanarity angle ($\Delta\phi$) distribution for: $Z^0 \rightarrow \mu^+\mu^-$ data (full points); $Z^0 \rightarrow \mu^+\mu^-(\gamma)$ Monte Carlo (hollow histogram) normalized to the luminosity; $Z^0 \rightarrow H^0\mu^+\mu^-$ Monte Carlo for $M_{H^0} = 0.04$ GeV (hatched histogram) normalized to twenty times the luminosity. The arrow indicates the $\Delta\phi > 0.05$ cut described in the text.

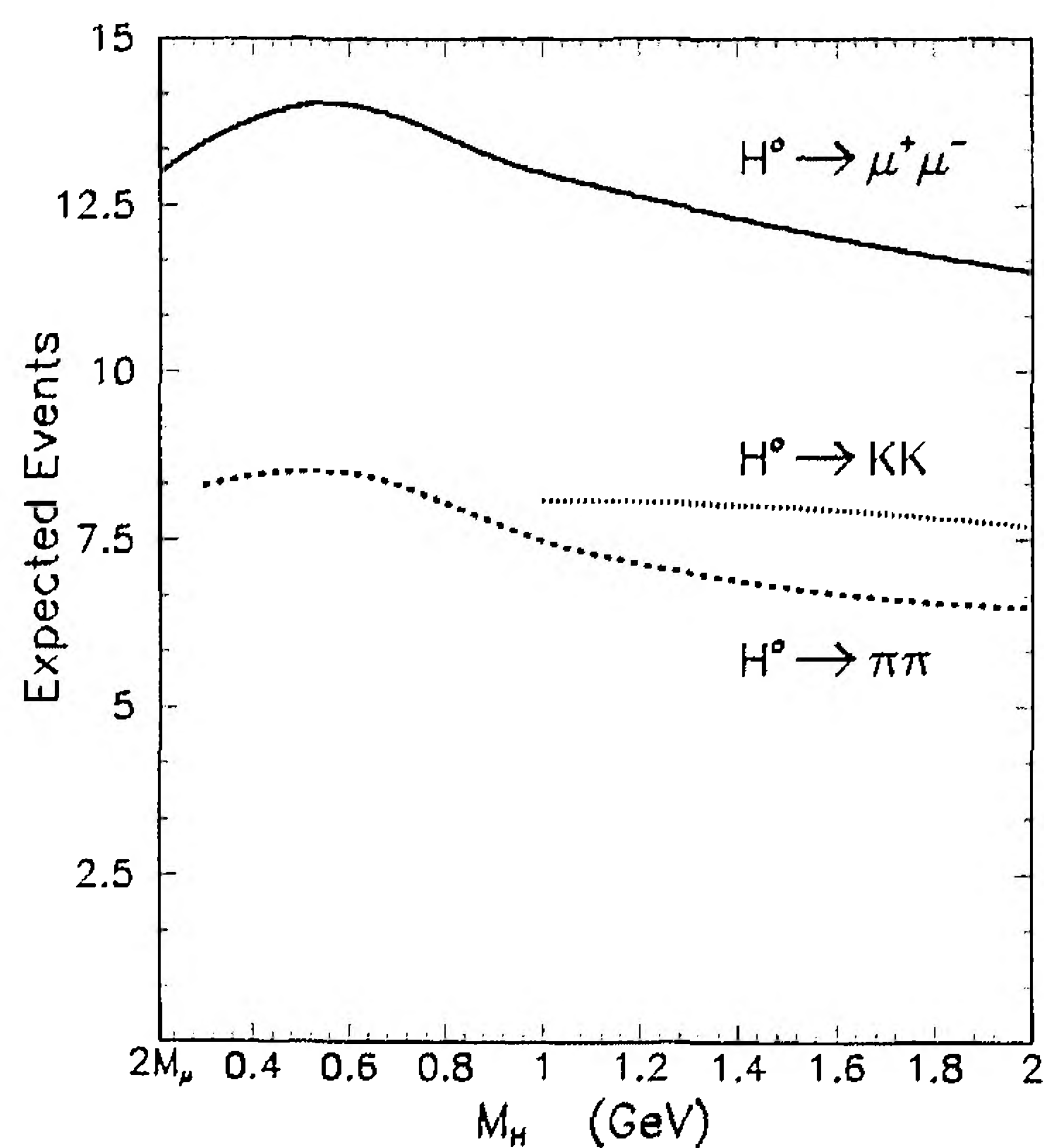


Fig. 2. Number of expected events from the process $Z^0 \rightarrow H^0 q^+ q^-$ as a function of the Higgs boson mass for three decay channels: $H^0 \rightarrow \mu^+ \mu^-$, $H^0 \rightarrow \pi\pi$ and $H^0 \rightarrow KK$.

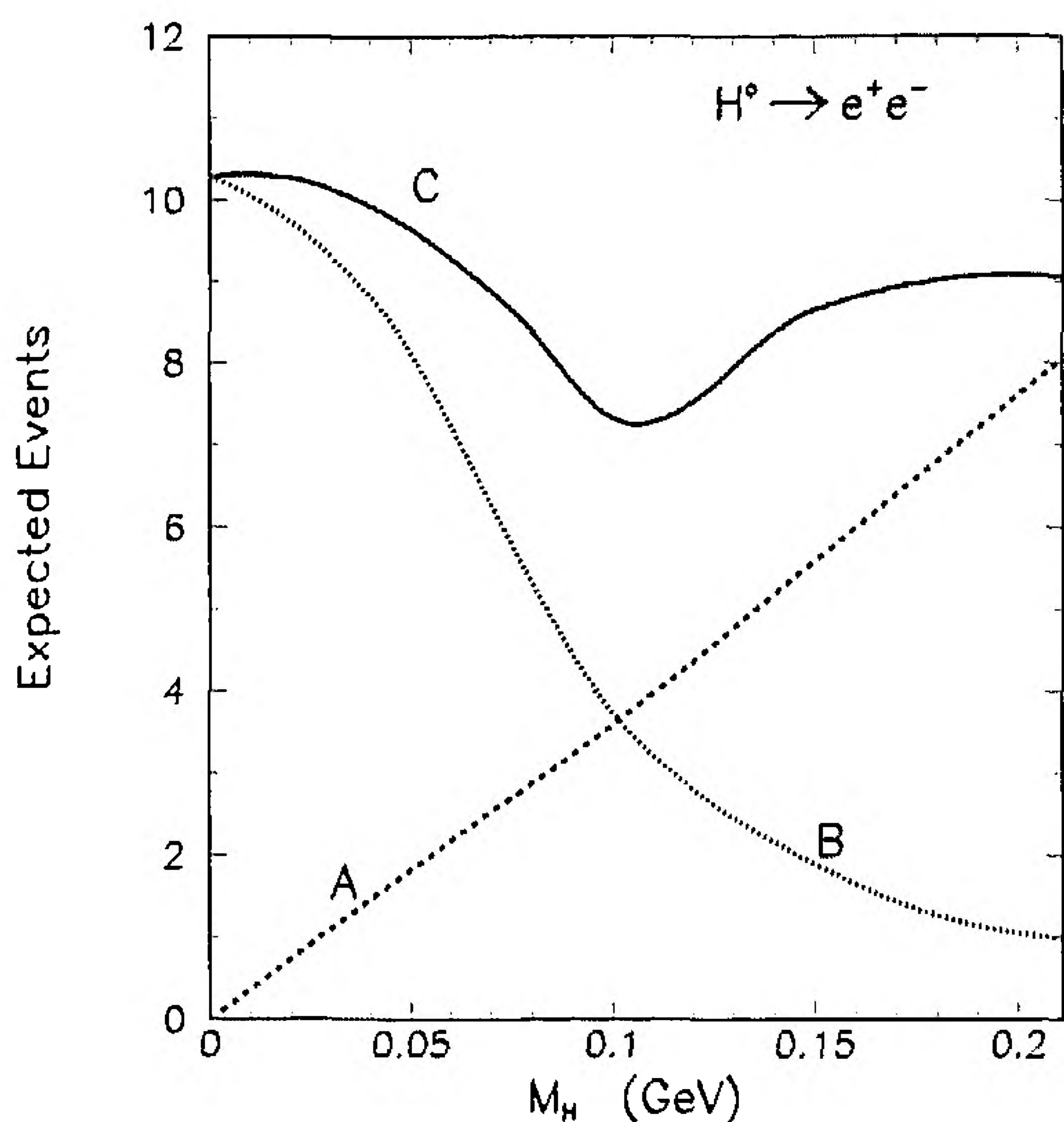


Fig. 3. Number of expected events from process $Z^0 \rightarrow H^0 q^+ q^-$ as a function of the Higgs boson mass in the range $M_{H^0} < 2M_\mu$. Curve A is for the case of detected Higgs decay products; curve B is for the search of an Higgs decaying outside the volume of the electromagnetic calorimeter; curve C is the sum of A and B.

presence of a Higgs boson in this mass range at the 99% confidence level.

7. Conclusion

We have searched for a neutral Higgs boson in the mass range $M_{H^0} > 2$ 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

- [1] P.W. Higgs, Phys. Lett. 12 (1964) 132; Phys. Rev. Lett. 13 (1964) 508; Phys. Rev. 145 (1966) 1156; F. Englert and R. Brout, Phys. Rev. Lett. 13 (1964) 321.
- [2] L3 Collab., B. Adeva et al., Phys. Lett. B 248 (1990) 203.
- [3] ALEPH Collab., D. Decamp et al., Phys. Lett. B 236 (1990) 233; B 245 (1990) 289; B 246 (1990) 306; OPAL Collab., M.Z. Akrawy et al., Phys. Lett. B 236 (1990) 224; B 251 (1990) 211; DELPHI Collab. P. Abreu et al., Nucl. Phys. B 342 (1990) 1.
- [4] L3 Collab., B. Adeva et al., Nucl. Instrum. Methods A 289 (1990) 35.
- [5] L3 Collab., B. Adeva et al., Phys. Lett. B 249 (1990) 341.
- [6] S.L. Glashow, Nucl. Phys. 22 (1961) 579; S. Weinberg, Phys. Rev. Lett. 19 (1967) 1264; A. Salam, Elementary particle theory, ed. N. Svartholm (Almqvist and Wiksell, Stockholm, 1968) p. 367.
- [7] F.A. Berends and R. Kleiss, Nucl. Phys. B 260 (1985) 32.
- [8] P.J. Franzini et al. in: Z Physics at LEP, CERN report CERN-89-08, eds. G. Altarelli, R. Kleiss and C. Verzegnassi, Vol. II (CERN, Geneva, 1989) p. 59, and references therein.

- [9] M. Voloshin and V. Zakharov, Phys. Rev. Lett. 45 (1980) 688;
M. Voloshin, Sov. J. Phys. 44 (1986) 478;
S. Raby and G.B. West, Phys. Rev. D 38 (1988) 3488.
- [10] See R. Brun et al., GEANT 3, CERN report CERN DD/EE/84-1 (Revised) (September 1987).
- [11] H. Fesefeldt, RWTH Aachen preprint PITHA 85/02 (1985).
- [12] S. Jadach et al., KORALZ, in: Proc. Workshop on Z physics at LEP, eds. G. Altarelli, R. Kleiss and C. Verzegnassi, CERN report CERN-89-08, Vol. III (CERN, Geneva, 1989) p. 69, Comput. Phys. Commun., to be published.