

**Searches for Invisible Higgs bosons: Preliminary
combined results using LEP data collected at energies
up to 209 GeV**

ALEPH, DELPHI, L3 and OPAL Collaborations

The LEP working group for Higgs boson searches

Abstract

In the year 2000 the four LEP experiments have collected data at energies between 200 and 209 GeV, for approximately 868 pb^{-1} integrated luminosity. The LEP working group for Higgs boson searches has combined these data with earlier data sets collected at lower centre-of-mass energies to search for a neutral CP-even Higgs boson, produced at the Standard Model rate, decaying into “invisible” particles. No statistically significant excess has been observed when compared to the Standard Model background prediction, and assuming that the Higgs boson decays only into such states a lower bound has been set on its mass at 95% confidence level of $114.4 \text{ GeV}/c^2$.

To be submitted to EPS'01 in Budapest and LP'01 in Rome

ALL RESULTS QUOTED IN THIS NOTE ARE PRELIMINARY

1 Introduction

We present combined results from the ALEPH, DELPHI, L3 and OPAL Collaborations on searches for the neutral Higgs bosons decaying into “invisible” particles such as neutralinos or majorons. The results are obtained by combining the data collected in the year 2000 at centre-of-mass energies between 202 and 209 GeV with earlier data collected at lower energies [1]. The new data represent an integrated luminosity of approximately 868 pb^{-1} in total.

Unless explicitly specified, all cross-sections, branching ratios and many other physics quantities which are used in this combination of data, are calculated within HZHA [2].

Each experiment has generated Monte Carlo event samples for the Higgs boson signal and the various background processes, typically, at 202, 204, 206, 208 and 210 GeV energies. Cross-sections, branching ratios, distributions of the reconstructed mass and other discriminating variables relevant to the combination have been interpolated to energies which correspond to the data sets. In this procedure special care has been taken to the regions of kinematic cutoff where the signal and background distributions vary rapidly. It has been established that the interpolation procedure does not add significantly to the final systematic uncertainties.

The statistical procedure adopted for the combination of the data and the precise definition of the confidence levels CL_b , CL_{s+b} , CL_s by which the search results are expressed, follow our usual definitions[1, 3].

2 Combined search for ‘invisible’ Higgs boson decays

At LEP the SM Higgs boson is expected to be produced mainly via the Higgs-strahlung process $e^+e^- \rightarrow HZ$, while contributions from the $WW \rightarrow H$ fusion channel, $e^+e^- \rightarrow H\nu_e\bar{\nu}_e$, are typically below 10%. The Higgs boson may not make its presence obvious. For instance, in supersymmetric theories, depending upon the parameters, the decay of a Higgs boson into neutralinos might dominate. The Higgs boson could then be invisible at LEP. Majoron models can also produce dominantly invisible decay modes. However, if the Higgs boson is produced through the Higgs-strahlung process, the Z can be detected, and the presence of the Higgs boson inferred. This production process is assumed here.

The four LEP collaborations performed searches for acoplanar jets ($H \rightarrow \text{invisible}$)($Z \rightarrow q\bar{q}$) or leptons ($H \rightarrow \text{invisible}$)($Z \rightarrow ll$).

The analysis procedures of the four LEP experiments producing the inputs for the present combination are described in individual documents [4, 5, 6, 7]; we merely summarise the results in Table 1. For DELPHI, the channel ($Z \rightarrow ll$) includes the $\tau\tau$ decay mode of the Z boson, which is not used by the other experiments.

The large spread in the numbers of selected candidates reflects substantial differences in

Experiment:	ALEPH	DELPHI	L3	OPAL
Integrated luminosity in 2000 (pb^{-1}):	215.6	225.1	217.3	210
Backg. predicted / Evts. observed				
Acoplanar jets:	8.17 / 8	35.9 / 30	56.2 / 50	61.8 / 47
Acoplanar leptons:	6.7 / 7	21.7 / 13	5.9 / 9	–
Events in all channels	14.9 / 15	57.6 / 43	62.1 / 59	61.8 / 47
Median 95% CL Limit (GeV/c^2) :	112.6/111.8	110.7/110.7	110.2/110.1	107.4*/108.5
Observed 95% CL Limit (GeV/c^2) :	114.1/113.1	113.0/113.0	107.6/107.5	107.0/107.4

Table 1: *Information related to the searches of the four LEP experiments for ‘invisible’ Higgs boson decays at energies between 200 and 209 GeV (year 2000 data), with a Higgs boson mass at 110 GeV/c², if relevant. All limits include the previous years’ data. The ALEPH confidence level estimator is different from that employed here. Using the same technique we find an observed upper limit of 114.0 for the ALEPH data, which is close to the 114.1 GeV/c² which ALEPH report. (*) OPAL quotes the average instead of the median expected limit*

the selection methods and optimisation procedures. For instance, ALEPH and L3 use a sliding analysis technique. Only the relevant candidates for a Higgs mass hypothesis are reported. For table 1 the Higgs boson mass was taken as 110 GeV/c².

The test-statistic as a function of the mass m_H , computed for the observed results, is shown in Figure 1. In the presence of a signal it should have a minimum near the true Higgs boson mass. A negative value would indicate a preference for the signal hypothesis and the more negative the value the more significant the signal. The full-line curve representing the observation is in agreement with the dashed line representing the background hypothesis, and deviates from the dotted curves which represent the most likely signal + background situation. In fact, in the region 112 to 115 GeV/c² there is a deficit of events corresponding to around 1.5 standard deviations from the background expectation, which means that the observed limit will be somewhat stronger than expected.

The compatibility with background of the result is given by $1 - CL_b$, which is plotted as a function of m_H in Figure 2. The dotted line shows the expectation in the presence of a signal; its crossing with the 5σ line at 109.5 GeV/c² indicates the range of sensitivity of the data to a discovery. As expected, there is no suggestion of any signal.

A 95% confidence level lower limit on the Higgs boson mass may be set by identifying the mass region where $CL_s < 0.05$, as shown in Figure 3. The CL_s curve shown gives the limit on m_H assuming a 100% branching ratio into invisible modes. The median limit expected in the absence of a signal is 113.5 GeV/c² and the limit observed by combining the LEP data is 114.4 GeV/c². The inclusion of systematic errors, which have been neglected, is expected to reduce this lower bound by approximately 100 MeV/c².

The upper limit on the rate of $H \rightarrow invisible$ as a function of m_H is shown in Figure 4. The

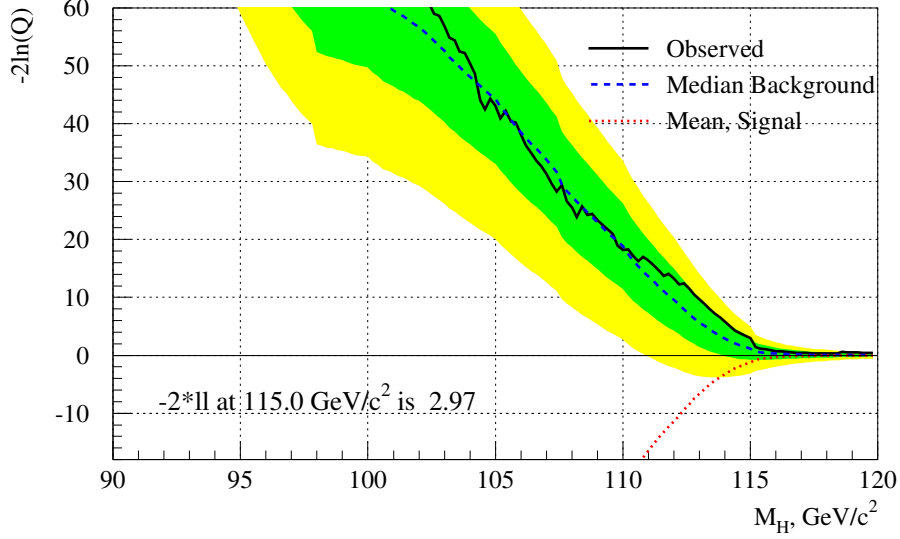


Figure 1: *The distribution of $-2*\ln(Q)$ for the combined search for $h^0 \rightarrow invisible$ by LEP.*

scale is:

$$\xi^2 = \frac{\sigma_{HZ}}{\sigma_{HZ}^{StandardModel}} Br(H \rightarrow invisible) \quad (1)$$

as a fraction of the rate expected from a Standard Model H decaying 100% invisibly. The same information is shown in figure 5 but as a limit on the cross-section at 206 GeV. There is a somewhat stronger exclusion than expected around the Z region, due to a deficit of candidates.

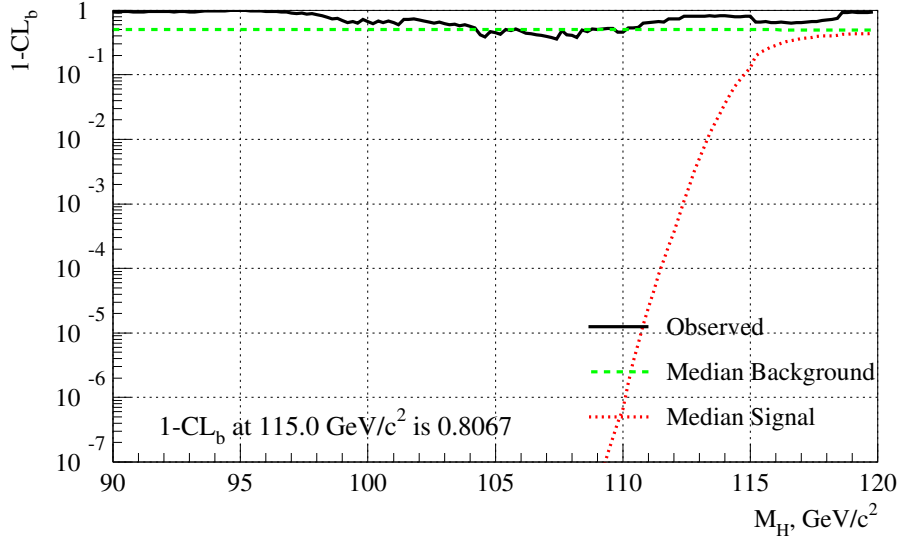


Figure 2: The value of $1 - CL_b$ for the LEP combined data in the $h^0 \rightarrow$ invisible search. There is a no suggestion of any signal-like excess.

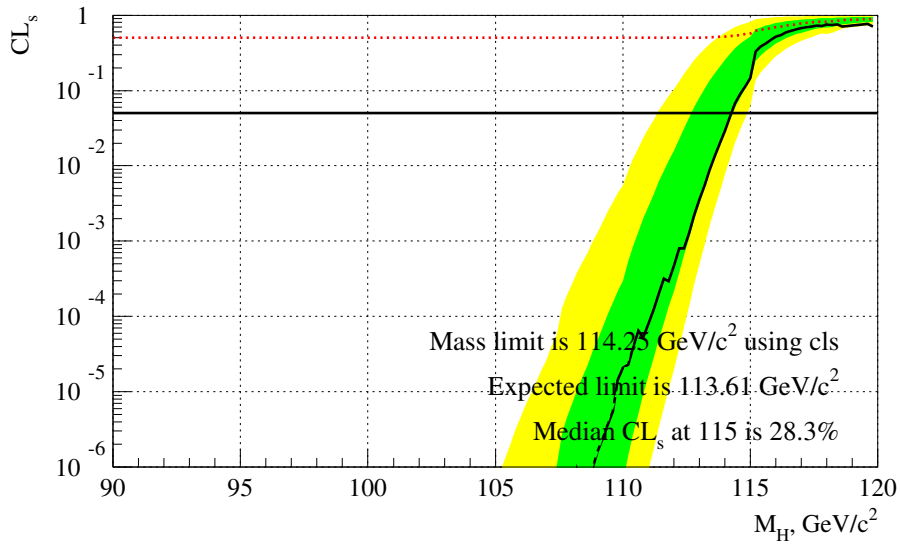


Figure 3: The value of CL_s for the LEP combined data in the $h^0 \rightarrow$ invisible search. The observed limit of $114.4 \text{ GeV}/c^2$ for a 100% branching ratio into invisible modes exceeds somewhat the expected limit of $113.6 \text{ GeV}/c^2$.

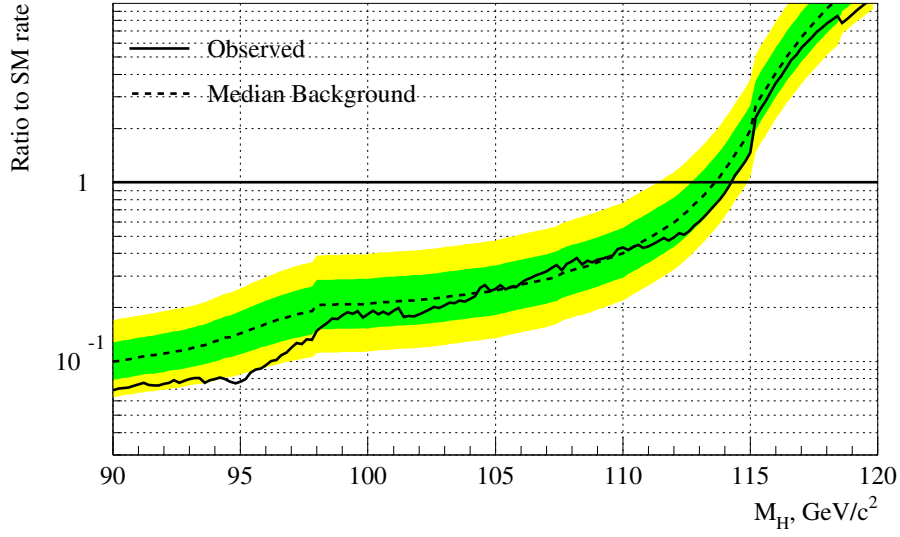


Figure 4: The region excluded by the combined LEP results in the $h^0 \rightarrow$ invisible search. The 95% CL upper limit on, ξ^2 , the production rate as a fraction of the Standard Model total rate, is shown, together with the expected range assuming there is no signal.

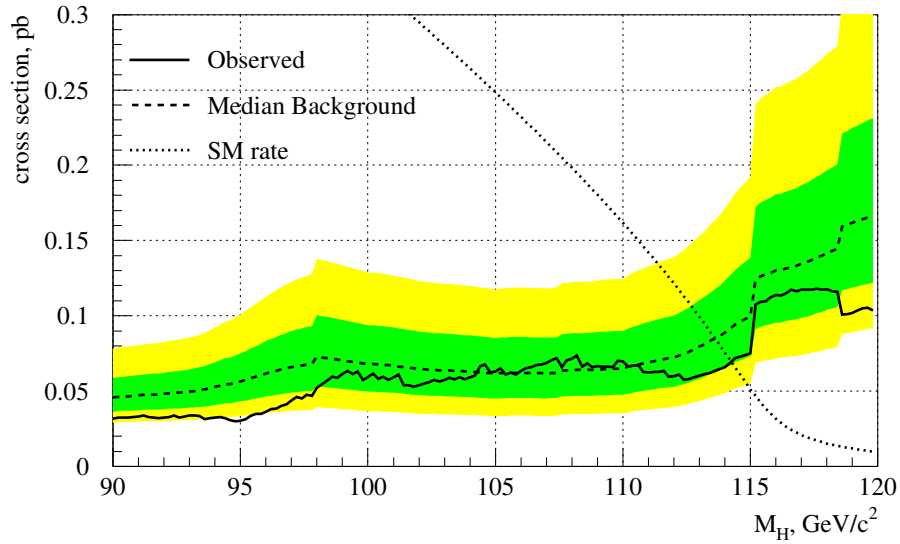


Figure 5: The upper limit on the invisible Higgs boson production cross-section. The cross-section is quoted at 206.0 GeV; data at other energies are scaled to that value using the Standard Model relative cross-sections.

3 Summary

The LEP working group for Higgs boson searches has updated its previous combined limit for the mass of a Higgs boson decaying invisibly, including the data collected in the year 2000 at energies between 200 and 209 GeV, for a total integrated luminosity of approximately 868 pb⁻¹. In the absence of a statistically significant excess in the data, a new lower bound of 114.4 GeV/c² has been obtained at the 95% confidence level and assuming the Standard Model production cross-section and that the Higgs boson exclusively decays invisibly.

ALL THE RESULTS QUOTED IN THIS NOTE ARE PRELIMINARY.

References

- [1] ALEPH, DELPHI, L3 and OPAL Collab., The LEP working group for Higgs boson searches, *Searches for Higgs bosons: Preliminary combined results using LEP data collected at energies up to 202 GeV*, CERN-EP/2000-055.
- [2] HZHA: P. Janot, in CERN Report 96-01, Vol. 2, p. 309 (1996); Version 3, released in December 1999, <http://alephwww.cern.ch/janot/Generators.html>.
- [3] ALEPH, DELPHI, L3 and OPAL Collab., The LEP working group for Higgs boson searches, CERN EP 98-046 (1998).
- [4] ALEPH Collab., *Search for an invisibly decaying Higgs boson at LEP at centre-of-mass energies up to 209 GeV*, ALEPH 2001-008 (2001);
- [5] DELPHI Collab., *Searches for invisibly decaying Higgs bosons*, Contribution to the summer conferences, DELPHI 2001-079 CONF 507.
- [6] P. Lebrun, S. Muanza and D. Teyssier for the L3 Collab., Search for invisible Higgs boson decays in e^+e^- collisions at $\sqrt{s} = 200$ to 209 GeV, L3 note 2690, July 2 2001.
- [7] OPAL Collab., *Searches for Higgs Bosons in Extensions to the Standard Model in e^+e^- collisions at the Highest LEP energies*, OPAL PN472 (2001).