SEARCH FOR HIGGS BOSONS AT LEP*

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Searches for the Standard Model Higgs and SUSY Higgses have been performed in the data collected by the four LEP experiments ALEPH, DELPHI, L3 and OPAL in the year 2000 at a centre-of-mass energies between 200 and 209 GeV corresponding to a total integrated luminosity of around 220 pb^{-1} per experiment. An excess of data above background predictions indicates a possible production of a Higgs boson with mass in the vicinity of 115 GeV/c^2.

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1. Introduction

The Higgs mechanism plays a central role in the unification of the electromagnetic and weak interactions by providing mass to the intermediate vector bosons, W and Z, without violating local gauge invariance. Within the Standard Model (SM), the Higgs mechanism predicts a single neutral scalar particle, the Higgs boson. This prediction is extended to five physical Higgs particles in the frame of the Minimal Supersymmetric Standard Model (MSSM), three of them neutral and two charged.

In this note the combined results from the searches for the SM Higgs boson by the four LEP experiments is presented. These searches include data collected since 1998 (data at 189 GeV) till 2000 (data up to 209 GeV). The total integrated luminosity exceeds 2.4 fb^{-1}.

2. Decay channels

At LEP energies, the SM Higgs boson is expected to be produced in association with a Z boson through the Higgsstrahlung process $e^+e^- \to HZ$. Small additional contributions are expected from t-channel W and Z bosons fusion processes, which result in a final production of a pair of electron or

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neutrinos, respectively, together with the Higgs boson. For the mass range kinematically accessible, the Higgs particle decays mainly into a pair of b quarks (with branching ratio between 74–85%) while decays to τ lepton pairs, WW^* and gluon pairs are less important ($\sim 7\%$ each). The final topologies are determined by these decays as well as the Z boson decays. Searches are thus performed in the four jet final state $(H \to b\bar{b})\, q\bar{q}$, the missing energy channel $(H \to b\bar{b})\, \nu\bar{\nu}$, the leptonic final state $(H \to b\bar{b})\, l\bar{l}$ where l denotes electron or muon and finally in the τ lepton final states $(H \to b\bar{b})\, \tau\bar{\tau}$ or $(H \to \tau\bar{\tau})(Z \to q\bar{q})$.

2.1. Four jet channel

Higgs boson searches in fully hadronic events usually start with a four-jet preselection which eliminates radiative events and reduces the $q\bar{q}(\gamma)$ and $Z\gamma^*$ background, forcing the selected events into a four jet topology.

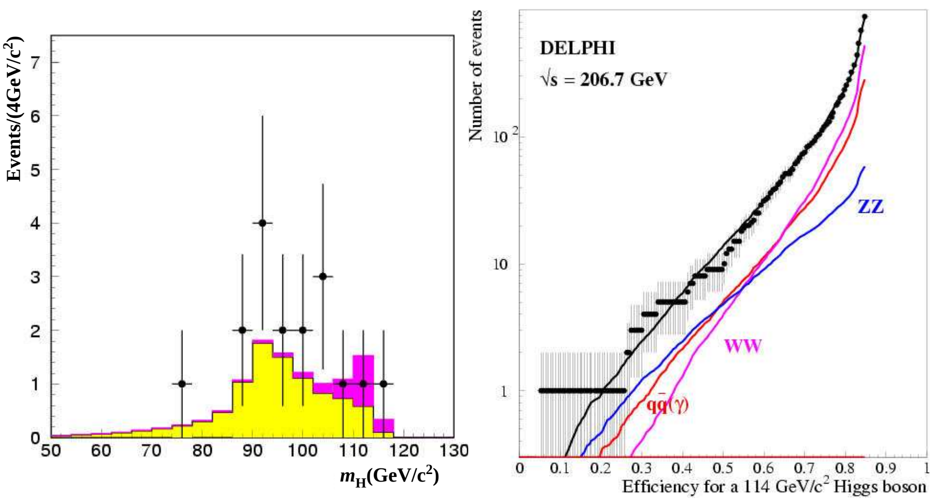

Fig. 1. Higgs mass distribution for the ALEPH experiment (left) and observed number of data and background events as function of the efficiency over a Higgs signal with $m_{\mathrm{H}} = 114\,\mathrm{GeV}/c^2$ for DELPHI (right).

Although different experiments perform different analysis (cut based, likelihood based or by means of an Artificial Neural Network (ANN) construction) the basic ingredients are common, namely the presence of two b-tagged jets together with a recoiling dijet with invariant mass compatible with m_Z.

The Higgs mass estimator is chosen as the dijet mass recoiling against m_Z. Amongst the three possible pairings the "right" one is chosen using kinematical information (χ^2 of the 5C fit) and jet b-tag content. Fig. 1 shows the

Higgs mass distribution for the ALEPH experiment at the final selection level. One can also see for the DELPHI analysis the observed data and expected number of background events as function of the efficiency over a Higgs signal with $m_{\rm H} = 114$ GeV$/c^2$.

2.2. Missing energy channel

Two b-tagged acoplanar jets — acoplanarity reduced next to the kinematical limit — are characteristic of this channel where the missing energy should be compatible with m_Z in which the Z boson decayed into neutrinos.

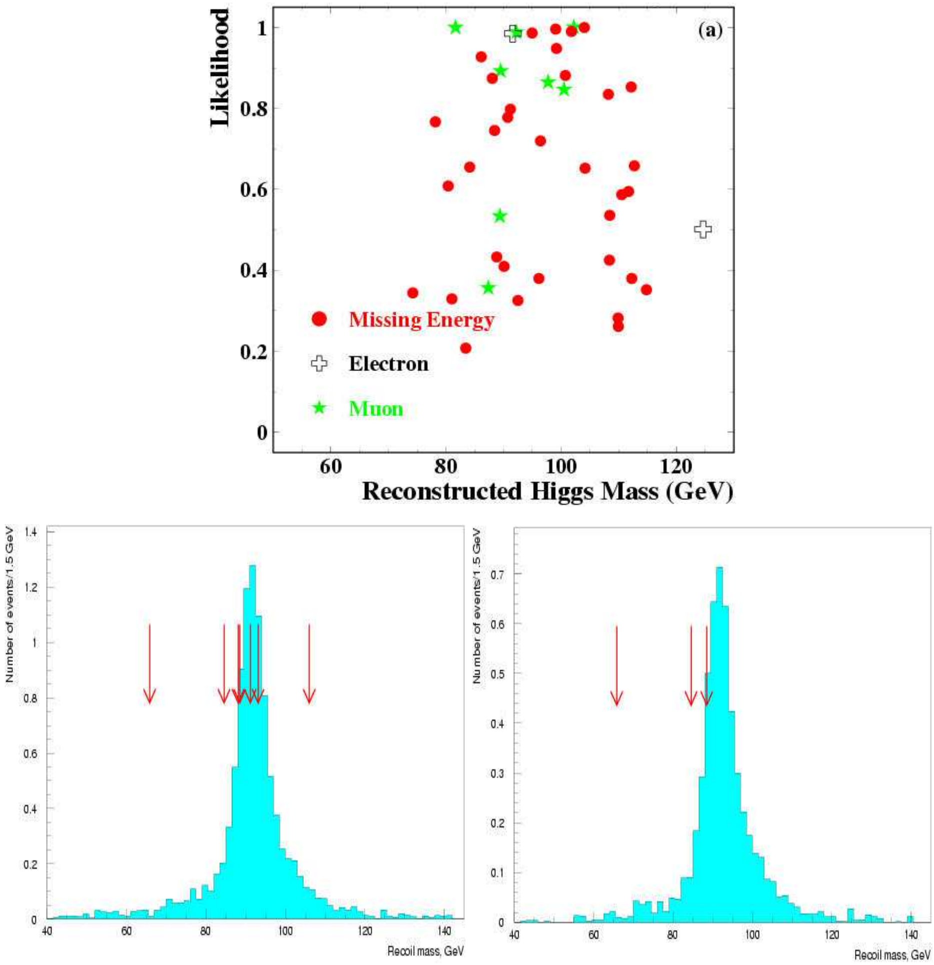

Fig. 2. Multidimensional variable *versus* reconstructed Higgs mass for the OPAL missing energy channel (top) and background mass distributions at two different cut levels for DELPHI $h\mu\mu$ analsysis (bottom).

This channel happens to be one of the most complicated to study due to the needed high level knowledge about hermeticity and energy reconstruction in the detector. Techniques employed in this channel are normally multidimensional variables such as likelihood or ANN outputs. Bidimensional distributions are used in which the discriminant variable is plotted against the reconstructed Higgs mass as can be seen for example in Fig. 2 (top) for the OPAL experiment.

2.3. Leptonic channels

Two isolated leptons together with two b-tagged jets are the distinctive signature of these channels. They are basically very clean channels and cut analysis are distinctive enough. A slight complication appears in the case of the τ lepton in which either the Higgs boson or the Z boson may decay. Fig. 2 (bottom) shows the data and background mass distributions at two different cut levels for the DELPHI experiment.

3. Statistical techniques

The statistical method used is the likelihood test where "signal + background" and "background only" hypothesis are tested.

It is defined: $Q(m_{\rm H}) = L(s+b)/L(b)$. The normalised distributions are integrated to create the confidence levels $CL_b(m_{\rm H})$ and $CL_{s+b}(m_{\rm H})$. The lower limit in the Higgs boson mass would be the value corresponding to $CL_s(m_{\rm H}) = 0.05$ (having defined $CL_s(m_{\rm H}) = CL_{s+b}(m_{\rm H})/CL_b(m_{\rm H})$) being discovery $1 - CL_b(m_{\rm H}) < 5.710^{-7}$. Fig. 3 (left) shows the graphical

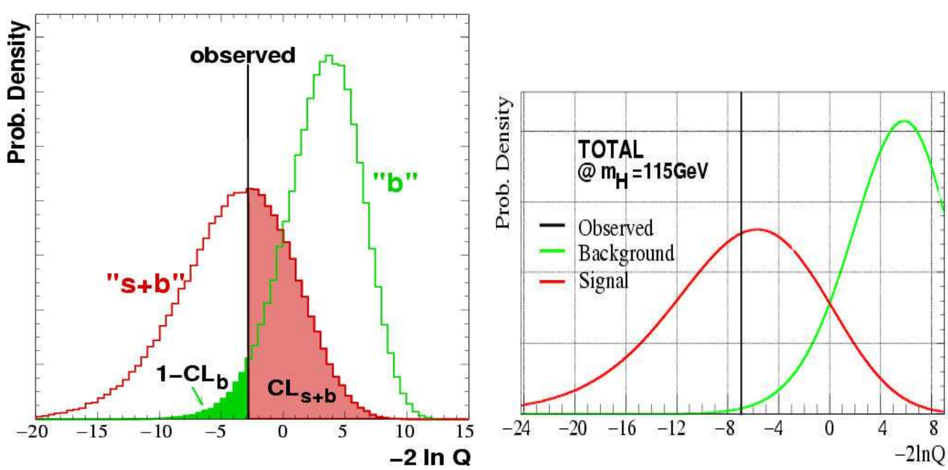

Fig. 3. Description of the statistical variables used (left) and actual observation value (right).

description of these quantities while in the right part one can see the actual observation of the four experiments combined for the hypothetical Higgs mass of 115 GeV/c^2. Real data shows clearly a preference for the "signal +background" hypothesis rather than the "background" alone.

In order to look deeply into individual contributions of each of the four LEP experiments the same kind of plot is given in Fig. 4 for each of them. It can be noticed how, except DELPHI, the rest of the experiments see real data compatible with the "signal+background" hypothesis.

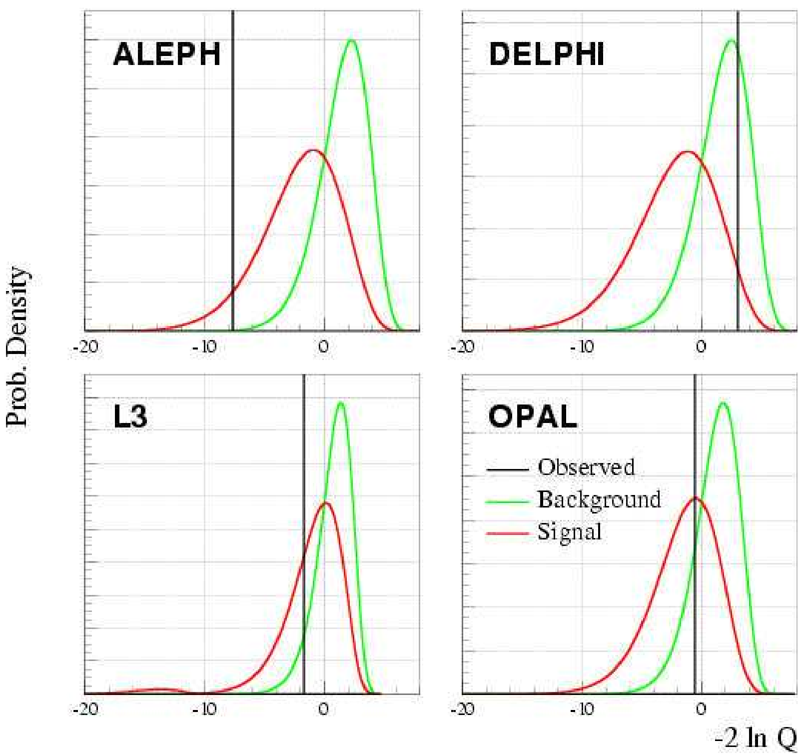

Fig. 4. Observed value of $-2\ln Q$ for each of the four LEP experiments.

Similar results but shown as a funtion of m_{H} can be seen in Fig. 5 where the plot gives the distribution of the χ^2 fit to the hipothetical Higgs mass. Fig. 6 shows the value of $1-CL_b$. From this last figures one can see the clear minimum at a value of $m_{\mathrm{H}} \sim 115$ GeV/c^2 with a statistical significance of around $2.8\,\sigma$

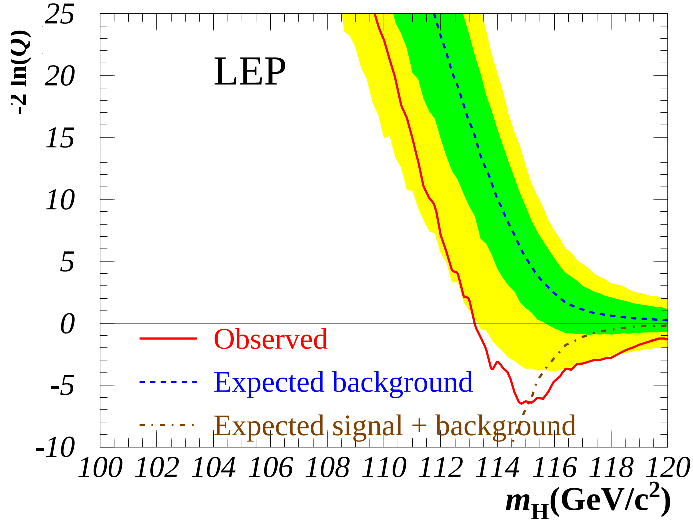

Fig. 5. Distribution of the χ^2 fit for combined results.

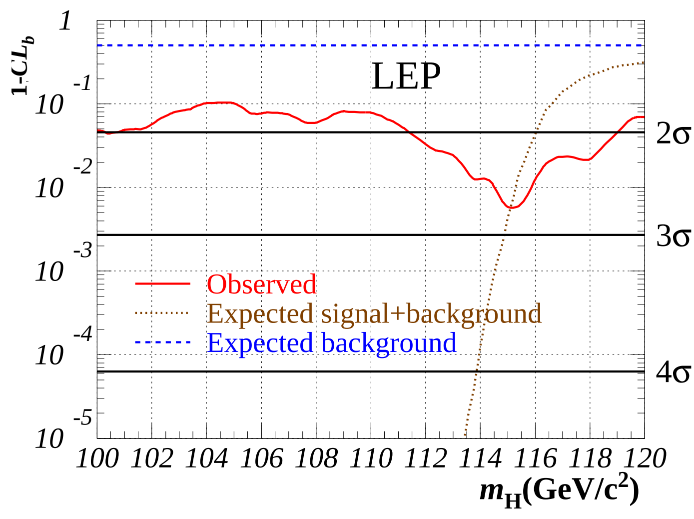

Fig. 6. $1 - CL_b$ for combined results.

4. Conclusions

Combining the data from the four LEP experiments in the search for SM Higgs boson, an excess is observed compatible with the presence of such a particle with $m_{\rm H} \sim 115\,{\rm GeV}/c^2$. Three out of four experiments have positive contributions to this excess.