HINTS OF HIGGS BOSON PRODUCTION AT LEP

MARUMI KADO

European Organization for Nuclear Research (CERN),
1211 Geneva 23, Switzerland.

Abstract

An excess of signal-like events above the expected background, corresponding to approximately three standard deviations, was observed in the search for the standard model Higgs boson at LEP in 2000. This excess is consistent with the existence of a 115 GeV/c^2 Higgs particle.

The LEP run in 2000 at centre-of-mass energies up to 209 GeV allowed the standard model Higgs boson search sensitivity at three standard deviations (σ) to extend up to a mass of 115 GeV/c^2. Around this limit of sensitivity, an excess of 2.9σ was observed [1]. Its characteristics are consistent with those expected from the signal: the distributions of the events among the experiments, among the decay channels, as a function of time, and as a function of signal purity match the signal hypothesis [2]. A complete introduction on the generalities of Higgs boson searches at LEP will not be given here and can be found in [3, 4, 5, 6]. The results given herein are based on the ∼810 pb^{-1} of data used for the latest LEP wide combination [1], among which ∼490 pb^{-1} were taken at energies above 206 GeV. This data sample is lacking ∼30 pb^{-1} of data collected in the last week before the final shutdown of LEP. However all collaborations have published results on their entire data sample.

Results of the Individual Experiments

To quantify the result of a search channel, the full discriminating power of certain event characteristics, such as reconstructed mass, b-tagging or a final discriminating

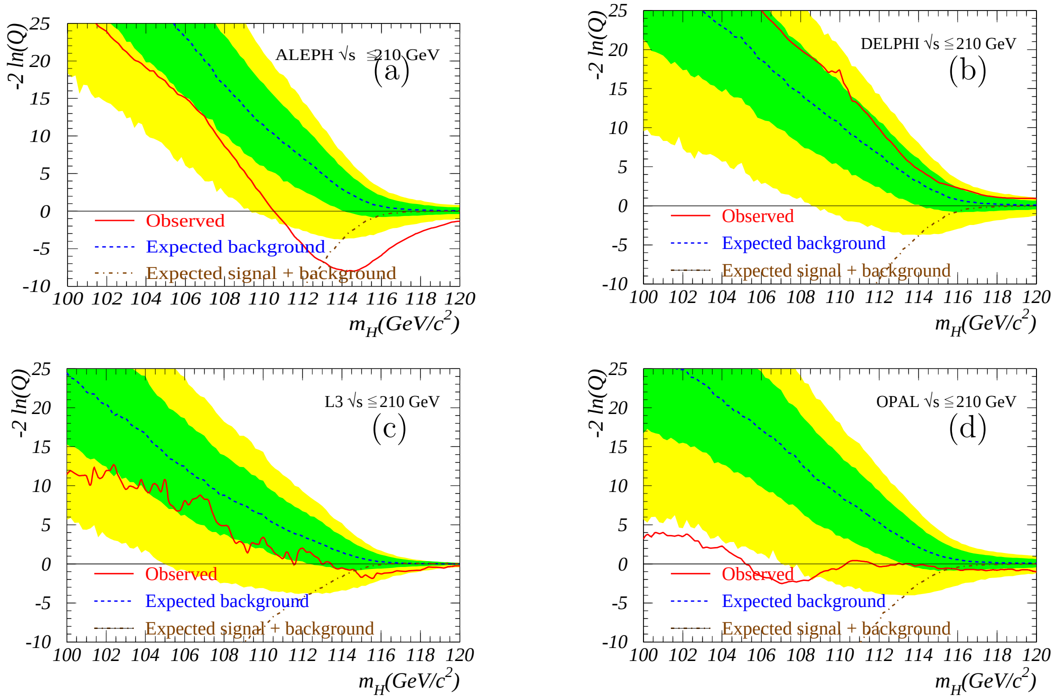

Figure 1: The log-likelihood estimator for the (a) ALEPH, (b) DELPHI, (c) L3 and (d) OPAL experiments as a function of the Higgs boson mass hypothesis, for the observation (solid), background only (dashed) and signal (dashed dotted) expectations. The dark and light gray regions around the background only expectation illustrate the one and two sigma bands respectively.

variable (*e.g.* obtained with neural network or likelihood techniques), are all taken into account in a log-likelihood estimator $-2\ln Q$ of a Higgs boson mass hypothesis ($m_{\rm H}$). The latter is defined as:

$$-2\ln Q(m_{\rm H}) = 2s_{tot}(m_{\rm H}) - 2\sum_i \ln(1+\frac{s_i}{b_i}(m_{\rm H}))$$

where s_{tot} is the total amount of signal expected in the channel and s_i/b_i is the ratio of the signal and the background values of the distribution of the discriminant quantities used for the $i^{\rm th}$ candidate event observed; this ratio will be referred to as event weight. Independent channels and experiments are simply combined by adding their estimators. The distribution of the estimator for each individual experiment is shown in Fig. 1 as a function of the Higgs boson mass hypothesis. The result obtained by the ALEPH search shows a clear minimum at high signal mass hypotheses, mostly due to an excess of four jet events with reconstructed masses near the kinematic threshold. The most likely signal mass hypothesis is 114 GeV/c^2. The probability (1-$\rm CL_b$) for this excess to be due to a fluctuation of the background when testing a mass hypothesis of 114 GeV/c^2 is 0.15%. The mass hypothesis for which the excess is most unlikely to result from a background fluctuation is 116 GeV/c^2 with 1-$\rm CL_b$$\sim$0.05%. This hint of the existence of a Higgs boson with mass around 115 GeV/c^2 is further supported by the observations of

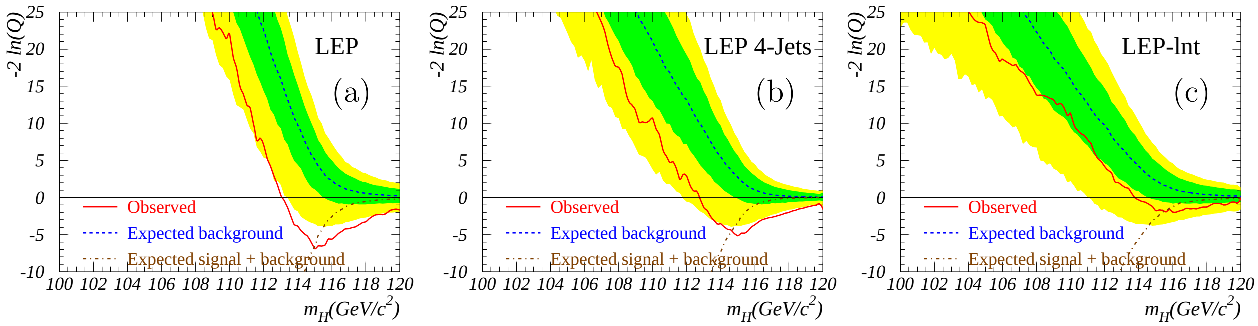

Figure 2: The log-likelihood estimator for the (a) combination of all channels and experiments, (b) the combination of the four jet channels and (c) of all channels except the four jet of all experiments as a function of the Higgs boson mass hypothesis, for the observation (solid), background only (dashed) and signal (dashed dotted) expectations.

L3 and OPAL. Though less significantly, both experiments observe an excess of events at high reconstructed masses with respective probabilities of 6.8% and 19%. DELPHI observes a deficit of events which is compatible with the background only hypothesis for a signal mass hypothesis of 115 GeV/c^2 (1-CL$_\mathrm{b}$=67%) but not incompatible with the signal hypothesis. The probability (CL$_\mathrm{s}$) that this deficit is due to a downward fluctuation of a 115 GeV/c^2 signal is $\sim$14%. Although most of the effect is seen in ALEPH, the distribution of the excess among the four experiments is consistent with the expectation in the presence of a $\sim$115 GeV/c^2 Higgs boson.

Combined Result

This consistency is reflected in the combination of the four experiments where the most likely Higgs boson mass hypothesis is 115 GeV/c^2, in agreement with the signal expectation, as seen in Fig. 2-a. The combined probability that the excess be due to a background fluctuation is 0.042%, corresponding to a significance of 2.9σ. Selecting the most signal like events by requiring that their event weight for a Higgs boson mass hypothesis of 115 GeV/c^2 be larger than 0.3, 14 event are observed in the data, 7 events are expected from all background processes and 7 are expected from a 115 GeV/c^2 signal. These candidate events are well distributed among experiments (6 are selected in ALEPH, 3 in L3, 3 in OPAL and 2 in DELPHI) and among the search channels (9 are selected in the four jet channel, 3 in the missing energy channel and two in the charged lepton channels). These numbers are consistent with the signal hypothesis.

Consistency and Robustness

Many systematic studies were performed to substantiate the compatibility of the observation with the signal hypothesis. Three relevant examples are given here.

The four quark final state is considerably more sensitive to the signal than the leptonic (electron, muon, tau or neutrino) final states. However, the combination of all leptonic channels performs nearly as well as the four quark channel. The results of

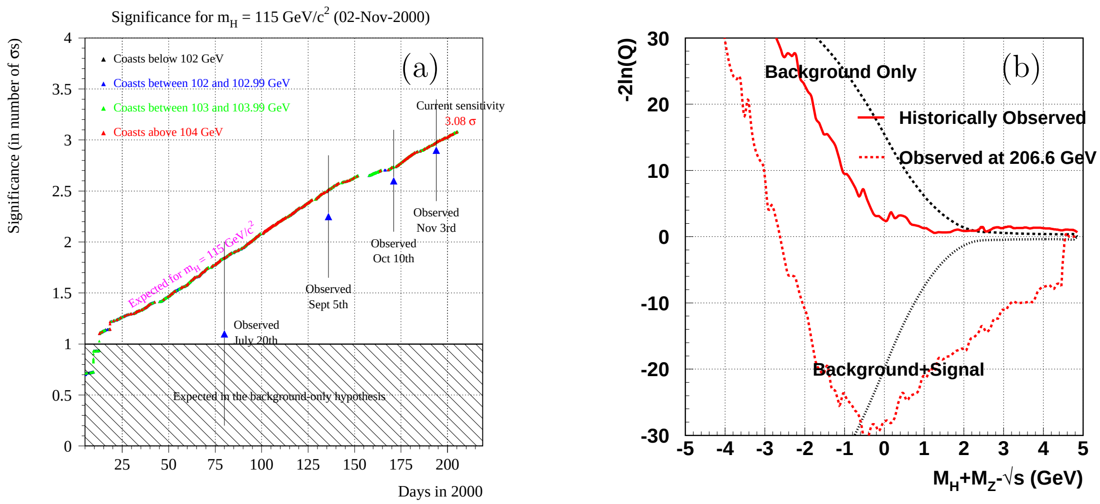

Figure 3: (a) Evolution of the observed significance at $m_{\rm H} = 115$ GeV/c^2 in 2000, compared to the expected increase in the signal hypothesis. The error bars are statistical only, with large point-to-point correlation. The expectation in the background only hypothesis is also indicated in the slanted region. (b) Observed estimators for the combination of all experiments and all data with $\sqrt{\rm s}$ <206.5 GeV (full curve) and what it would have been had the excess observed above $\sqrt{\rm s}$ >206.5 GeV been seen at all centre-of-mass energies (dashed curve) as a function of the distance of the Higgs boson mass hypothesis to the threshold. The expectation in absence and presence (dotted curves) of signal are also shown.

these combinations are illustrated in Fig. 2-b and c. In both cases an excess is observed with a minimum of the estimator at masses around ~115 GeV/c^2, showing that the effect is shared between channels. The probabilities for these excesses to be due to background fluctuations are, in terms of standard deviations, 2.3σ and 1.9σ respectively for the combinations of the four jet channel at 115 GeV/c^2 and the leptonic channels at 116 GeV/c^2. This check confirms the consistency of the excess amongst channels.

To check the compatibility of the effect in different data samples with various signal purities, the development of the excess is compared to its expected evolution in the hypothesis of a 115 GeV/c^2 signal. As shown in Fig. 3-a, the constant growth of the excess in time is consistent with the signal hypothesis.

To exclude the possibility of a systematic bias near the kinematic threshold, a combination of the searches with the 500 pb^{-1} of data taken at centre-of-mass energies ranging from 189 to 206 GeV is compared to what it would have been had the excess observed above 206 GeV been due to systematic bias close to the kinematic threshold. The estimators, for both cases, are displayed in Fig. 3-b [7] as a function of the distance to threshold ($m_{\rm H} + m_{\rm Z} - \sqrt{s}$). This comparison shows how dramatic the effect of a systematic bias would have been. Its absence in the data taken at centre-of-mass energies below 206 GeV therefore illustrates the robustness of the analyses near the kinematic threshold.

Latest Updates

In the remaining $\sim$30 pb^{-1} of the last week of data taking, only one significant event has been collected in OPAL in the four jet channel. The significance for $m_{\mathrm{H}} = 115$ GeV/c^2 is therefore decreased by approximately 5% in ALEPH and is unchanged in OPAL. The significance of the DELPHI deficit is also unchanged. The L3 collaboration has not updated the significance of its excess. Therefore, the conclusions with respect to those which can be drawn from the combined results [1] are unchanged.

Conclusion

In view of its consistency in all regards and its robustness, the evidence for a 115 GeV/c^2 Higgs boson is as strong as could be expected from the amount of data collected at centre-of-mass energies above 206 GeV at LEP.

Acknowledgements

It is a pleasure to thank the organisers and the secretariat of the LEP3 conference in Rome for their wonderful hospitality. I am very grateful Jean-Baptiste de Vivie for his careful reading of these proceedings.

References

[1] P. Igo-Kemenes, *"Status of Higgs boson searches"*, LEPC, november 2000.

[2] LEP Higgs Working Group, *"Standard Model Higgs Boson at LEP: Results with the 2000 data, Request for running in 2001"*, http://alephwww.cern.ch/~janot/LEPCO/lephwg.ps

[3] ALEPH Collaboration, *"Observation of an excess in the search for the standard model Higgs boson at ALEPH"*, Phys. Lett. B **495**, 1 (2000).

[4] DELPHI Collaboration, *"Search for the standard model Higgs boson at LEP in the year 2000"*, Phys. Lett. B **499**, 23 (2001).

[5] L3 Collaboration, *"Higgs candidates in e^+e^- interactions at $\sqrt{\mathrm{s}}$=206.6 GeV"*, Phys. Lett. B **495**, 18 (2000).

[6] OPAL Collaboration, *"Search for the standard model Higgs boson in e^+e^- collisions at $\sqrt{\mathrm{s}}$=192 to 209 GeV"*, Phys. Lett. B **499**, 38 (2001).

[7] LEP Higgs Working Group, *"A Hint of the Standard Model Higgs Boson at LEP: Frequently Asked Questions and Their Answers"*, http://alephwww.cern.ch/~janot/LEPCO/qanda.ps