

STANDARD MODEL HIGGS SEARCH STRATEGY AT LEP

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The Standard Model Higgs boson has been searched for by the four LEP experiments in the last twelve years. The data collected at LEP in the year 2000 suggest the first observation of a Higgs boson. In this letter, I describe the basic concepts of the Higgs search at LEP, with emphasis in the statistical method used to combine the results from the LEP experiments.

1 Introduction

In 12 years of running, the LEP collider at CERN has produced e^+e^- collisions in the interaction region of the four detectors ALEPH, DELPHI, L3 and OPAL. The centre-of-mass energy of the interactions varied from about 90 to 210 GeV. The large amount of data collected at these energies has allowed the experiments to measure the most relevant parameters of the Standard Model¹ with very high accuracy, establishing the success of the model.

However, the Standard Model does not provide an answer to a fundamental problem: in a gauge invariant theory all fundamental particles should be massless, in contradiction with the observation of the heavy W and Z bosons. Currently, there is no direct evidence of electroweak symmetry breaking and the generation of masses of the gauge bosons. The Higgs mechanism is introduced in the model to let particles acquire mass by interaction with the Higgs field. As a result, there should be a new particle of a completely new kind, the Higgs boson, whose mass is not predicted by the theory.

2 Higgs Production at LEP

The dominant Higgs production mode at LEP is the Higgsstrahlung process, $e^+e^- \rightarrow Z^* \rightarrow HZ$ (Figure 1 (left)). The processes W^+W^- and ZZ fusion, giving rise to the $H\nu\bar{\nu}$ and $H e^+e^-$

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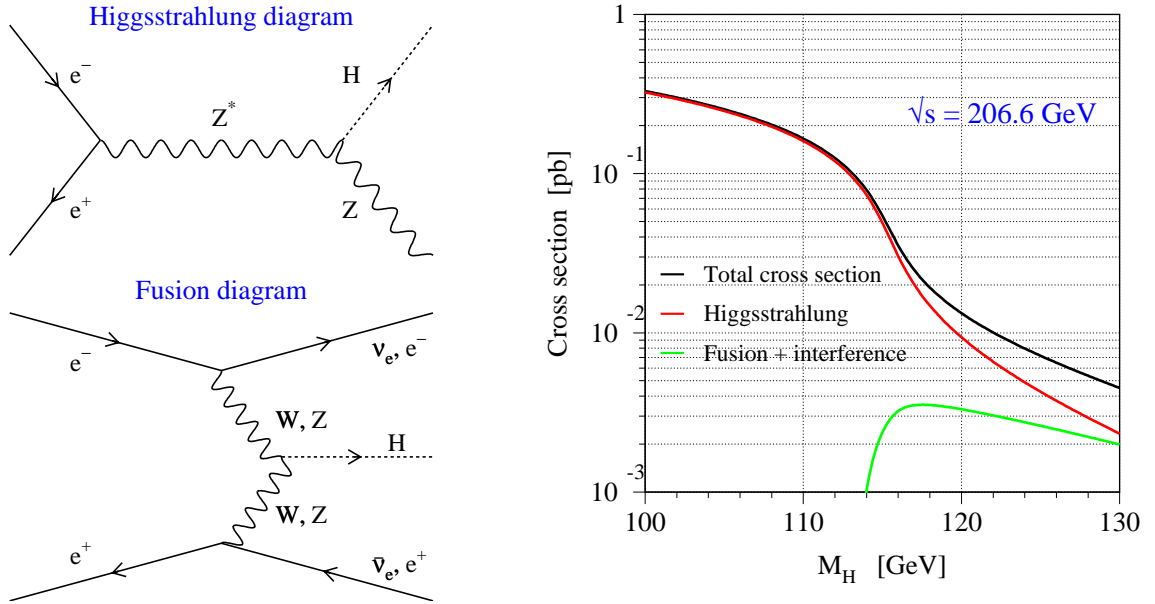


Figure 1: Higgs production modes (left) and cross section as function of the Higgs mass (right).

channels, contribute with smaller rate to the Higgs production cross section (Figure 1 (right)).

The integrated luminosity collected by the four experiments at LEP in the year 2000 amounts to 870 pb^{-1} , at centre-of-mass energy between 200 and 209 GeV. At these energies, Higgs bosons of 116 GeV mass or heavier are difficult to be detected, as they would be produced beyond the kinematic limit. As an example, assuming a Higgs of 115 GeV mass, a luminosity of 500 pb^{-1} collected at $\sqrt{s} \sim 207 \text{ GeV}$ and a detection efficiency of 50 %, the number of expected signal events is 12.5.

The Higgs boson is predicted to decay mainly in b-quark pairs for masses below 120 GeV. The Z boson decays into hadrons, neutrinos and leptons with branching fractions 69.6%, 20% and 10.1%, respectively. The search for the Higgs boson is based on the study of four distinct event topologies representing approximately 80% of the HZ decay modes in the mass range of interest: $b\bar{b}q\bar{q}$ (4-jet channel), $b\bar{b}\nu\bar{\nu}$ (missing energy channel), $q\bar{q}\ell^+\ell^-$ ($\ell = e, \mu, \tau$) and $\tau^+\tau^-q\bar{q}$ (lepton and tau channels, respectively). With the exception of the $HZ \rightarrow \tau^+\tau^-q\bar{q}$ decay mode, all the analyses are optimised for $H \rightarrow b\bar{b}$ decay.

Figure 2 (left) displays the topology of the four search channels, together with their branching ratios. The expected signal events for a 115 GeV mass Higgs are: 6.5 from the 4-jet channel, 1.9 from the missing energy channel, 1 from taus and 0.6 from leptons ($e+\mu$), that is 10 events in total.

The main backgrounds are events from $e^+e^- \rightarrow q\bar{q}(\gamma)$, W^+W^- and ZZ processes (Figure 2 (right)). The tagging of jets originating from b-quarks plays a crucial role in the identification of signal events. After the final selections, typically few hundred events are expected from background processes. The detailed description of the analyses of the different channels can be found elsewhere in these proceedings^{2,3}.

3 The Statistical Method: $-2 \ln(Q)$

Each of the four LEP experiments performs the Higgs search in four analysis channels, with data collected at several centre-of-mass energies. A simple statistical method⁴ has been developed by the experiments in order to treat LEP as a single search analysis.

The results of the individual analyses are expressed in terms of one (or more) final variable,

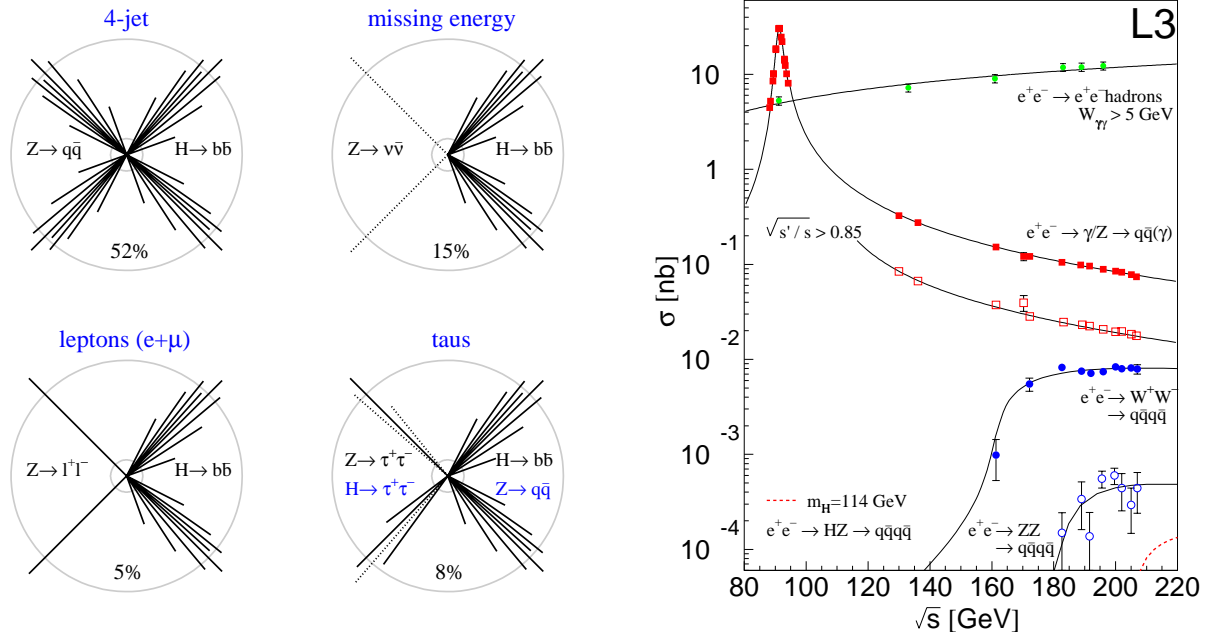


Figure 2: Left, topology of the four search channels, together with the branching ratio and the conventional name of the channel. Right, cross section of the background processes.

also called *discriminant*, which is calculated for the signal and background expectations as well as for the data. How this final variable is calculated for each channel is explained elsewhere^{2,3}. The shape of the distributions depends on the Higgs mass hypothesis.

The ratio between the expected number of signal and background events (the so called s/b ratio) for a given value of the final variable reflects the likelihood for an event being signal or background-like. Events from different experiments and channels with the same value of the s/b ratio are combined together, as they have the same sensitivity (discriminating power) to a possible Higgs signal. As an example, Figure 3 shows typical distributions of a discriminant variable (left) and the s/b ratio (right) for data, signal and background events. Events at high values of s/b are more signal-like.

In order to quantify the signal-likeness of the data, the *Likelihood Ratio*⁴ test-statistic is defined as the ratio of the Poisson probabilities of data to be consistent with either the signal

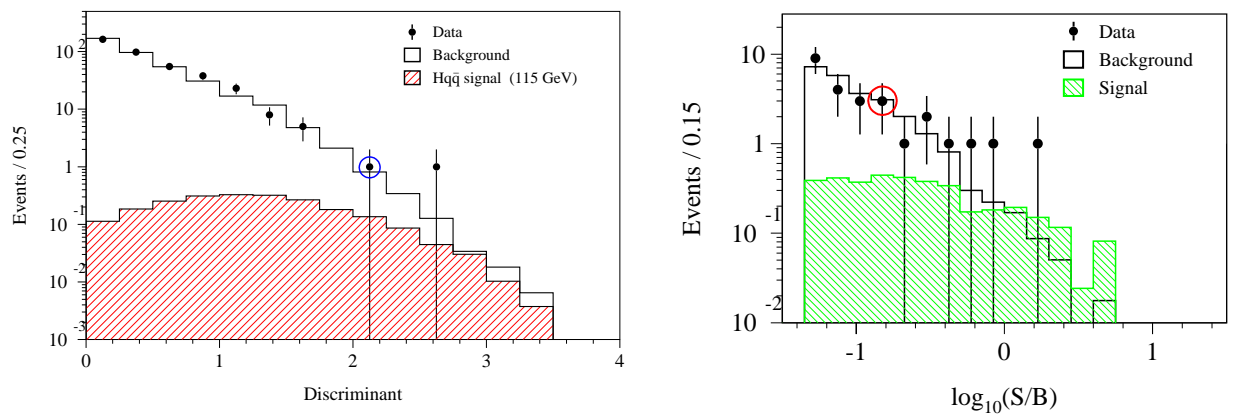


Figure 3: Typical distributions of a discriminant variable (left) and the s/b ratio (right) for data, signal and background events.

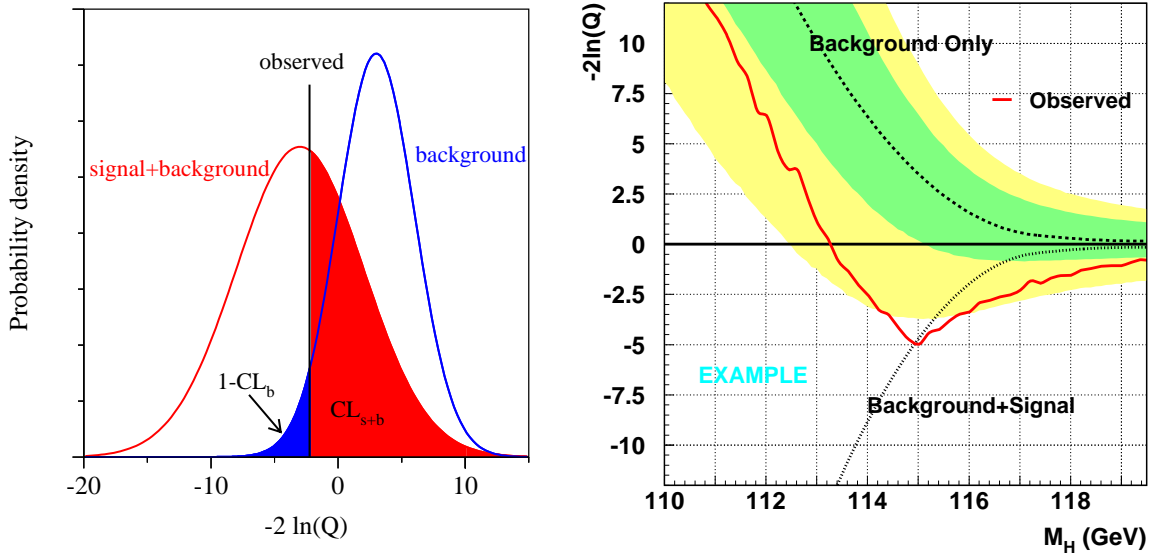


Figure 4: Left, example distributions of $-2 \ln(Q)$ for the background and signal plus background hypotheses, as well as for the data, for a given Higgs mass. The definition of the confidence levels of the background (CL_b) and the signal plus background (CL_{s+b}) are also shown. Right, example distribution of $-2 \ln(Q)$ as function of the Higgs mass. The colour bands are the 1σ and 2σ bands for the background expectation.

plus background hypothesis or the background only hypothesis:

$$Q = \frac{\mathcal{L}(s + b)}{\mathcal{L}(b)}$$

Each bin in the s/b ratio distribution (i) is treated as a Poisson counting experiment:

$$\ln(Q) = -s_{tot} + \sum_{i=1}^N n_i \ln \left(1 + \frac{s_i}{b_i} \right)$$

where n_i is the number of observed events, s_i the expected signal and b_i the expected background in a given bin. The sum runs over all the bins in the s/b distribution, *i.e.* all the observed events enter the likelihood calculation. The value of Q , and hence its discrimination power, depends on the Higgs mass hypothesis and on the Higgs production cross section (s_{tot}). In the high statistics limit $-2 \ln(Q)$ approaches the difference in χ^2 of the two hypotheses, that is why this convention is adopted.

The results of the LEP combination using this statistical method are presented in detail elsewhere in these proceedings⁵.

References

1. S.L. Glashow, *Nucl. Phys.* **22**, 579 (1961), S. Weinberg, *Phys. Rev. Lett.* **19**, 1264 (1967), A. Salam, "Weak and Electromagnetic Interactions", in *Elementary Particle Theory*, edited by N. Svartholm, page 367, Stockholm, 1969, Almqvist and Wiksell.
2. G. Davies, "Selecting Standard Model Higgs candidates in the 4-jet channel at LEP", these proceedings.
3. E. Piotto, "Selecting Standard Model Higgs candidates in other channels at LEP", these proceedings.
4. ALEPH, DELPHI, L3 and OPAL Collab., The LEP Working Group for Higgs Boson Searches, Preprint CERN-EP/2000-055.
5. A. Okpara, "Standard Model Higgs at LEP: combined results", these proceedings.