arXiv:hep-ex/0108002 1 Aug 2001

THE SM HIGGS BOSON SEARCH at LEP: COMBINED RESULTS

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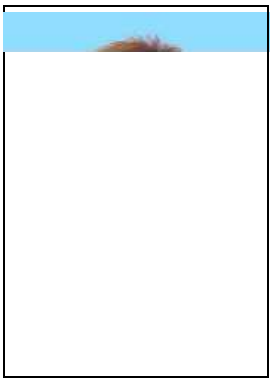

During the run in the year 2000, with data collected at collision energies up to 209 GeV, the LEP experiments have possibly unearthed the first evidence of a Higgs boson signal at $m_{\rm h} \approx 115\,{\rm GeV/c^2}$. The preliminary combined results prepared immediately after the end of the data-taking, in November 2000, are presented here. Overall, a 2.9 σ excess over the background is found, consistent with a Standard Model Higgs boson signal with $m_{\rm h} = 115.0\,{\rm GeV/c^2}$.

1 Introduction

During the year 2000, the LEP collider was pushed to the edge of its performance envelope in order to maximise the Standard Model (SM) Higgs discovery potential[1]. In total, the ALEPH, DELPHI, L3 and OPAL experiments have collected $\approx 870\,{\rm pb}^{-1}$ of data, mostly around centre-of-mass energies of $\sqrt{s} \approx 205$ GeV and $\sqrt{s} \approx 206.7$ GeV. Around 60% of the data was collected at $\sqrt{s} > 206$ GeV.

At 8h00 a.m., November 2nd, the LEP collider was shut down forever. On the 3rd of November the experiments presented their results at a special CERN seminar[2]. The combined results were also presented[3], including the quasi-totality ($\simeq 94\%$) of the data taken in 2000. The results presented here correspond to this combination. Having been prepared during the final days of data-taking, the results are clearly still preliminary. At the time of writing, the ALEPH and L3 collaborations are preparing their final publications, with DELPHI and OPAL to follow, before the end of 2001.

2 The combination method

The method for combining the results of the four experiments is described in detail elsewhere[4] and will only be succinctly introduced here. The combination relies on the extended likelihood ratio, between the signal+background hypothesis and the background-only hypothesis (see, e.g., elsewhere in these proceedings[5]):

$$Q = \frac{L_{s+b}}{L_b}, \qquad -2\ln Q(m_{\rm h}) = 2s_{tot} - 2\sum_i \ln(1+(s/b)_i)$$

where s_{tot} is the expected number of signal events in a given channel (search topology, $\sqrt{s}$, and experiment). Each of the data candidates i contributes a term with a weight $\ln(1+(s/b)_i)$ to $-2\ln Q$. $(s/b)_i$ is the local signal-to-background ratio for the given candidate, and is determined from the signal and background p.d.f.s for reconstructed mass as well as additional discriminant information (e.g., b-tagging, NN output). In order to combine the various channels one adds up the respective $-2\ln Q$ values.

3 The combined results

The distribution of the reconstructed mass of the candidates from the four experiments, compared with the expectation from the background and a potential signal with $m_{\rm h} = 115$ GeV/c^2, is shown in figure 1(a).

The signal-to-background ratio computed from the simulated samples, in the reconstructed mass region $m_{\rm rec} > 109\,{\rm GeV/c^2}$, is approximately 0.3.

It is worth pointing out again the oft-repeated shortcomings of such a mass plot: the calculation of the likelihood ratio is based on more than just this distribution. Also, in such a plot –where all events have equal weight independently of e.g., which search channel or centre-of-mass energy they originate from– it is impossible to convey the fact that different channels, centre-of-mass energies, can have widely different sensitivities to the signal hypothesis.

In order to partially overcome such criticism and glimpse which are the candidates that have more impact on the calculation, one can tighten the event selection without biasing the mass distribution. This is achieved by, for instance, tightening the selection cut on the b-flavour probability of the events. Figure 1(b) shows the high purity subset of candidates for which the signal-to-background ratio, in the reconstructed mass region $m_{\rm rec} > 109\,{\rm GeV/c^2}$, is 2.0. In the high mass region one can see an excess of candidates with respect to the SM background. The four most significant candidates, in terms of their

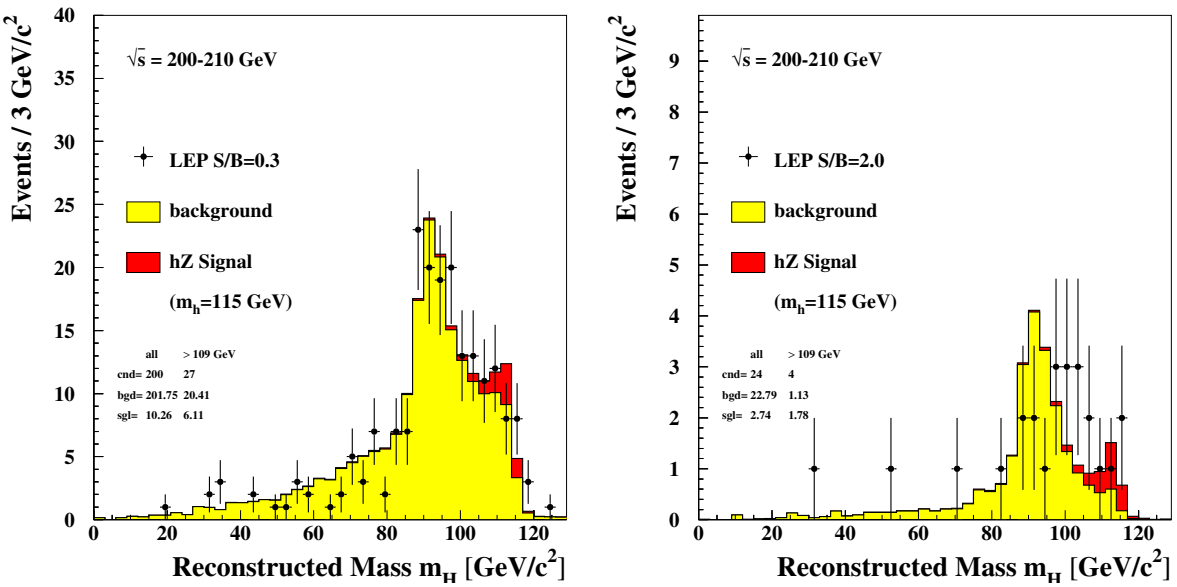

Figure 1: Reconstructed mass distributions for the candidate events selected by the four LEP experiments in the data collected in the year 2000. The distributions are shown at two different selection levels (see text): (a) loose event selection, low purity for $m_{\rm h} = 115\,{\rm GeV/c^2}$; (b) tight event selection, yielding a high-purity subsample of events for $m_{\rm h} = 115\,{\rm GeV/c^2}$.

weight, are three four-jet candidates from ALEPH[6] and one L3 candidate in the missing energy channel[7]. Table 1 lists the most significant candidates ordered by their contribution to the log-likelihood ratio[8].

The log-likelihood ratio curve is shown in Figure 2(a). It can be clearly seen that the data favour the signal+background hypothesis over the background only hypothesis, at $m_{\rm h} = 115\,{\rm GeV/c^2}$.

The probability at any given test mass $m_{\rm h}$, that a fluctuation of the background produces an event configuration at least as signal-like as the one observed is shown in Figure 2(b). For $m_{\rm h} = 115\,{\rm GeV/c^2}$ this probability is 4.2×10^{-3}, corresponding to a 2.9σ excess over the background.

Table 1: List of the most significant candidates from the four LEP experiments ordered by s/b at $m_{\mathrm{h}} = 115\,\mathrm{GeV/c^2}$.

Channel	Experiment	$\sqrt{s}$ (GeV)	Reconstructed mass ($\mathrm{GeV/c^2}$)	$(\frac{s}{b})_{115}$
$\mathrm{hq\bar{q}}$	A	206.7	114	4.7
$\mathrm{hq\bar{q}}$	A	206.7	112	2.3
$\mathrm{h}\nu\bar{\nu}$	L	206.6	114	2.05
$\mathrm{hq\bar{q}}$	A	206.7	110	0.90
$\mathrm{he^+e^-}$	A	205.3	118	0.60
$\mathrm{hq\bar{q}}$	O	205.4	113	0.52
$\mathrm{h}\tau^+\tau^-$	A	208.1	115	0.5
$\mathrm{hq\bar{q}}$	A	206.5	114	0.5
$\mathrm{h}\nu\bar{\nu}$	L	208.2	114	0.49
$\mathrm{hq\bar{q}}$	L	206.7	115	0.47
$\mathrm{hq\bar{q}}$	D	206.7	97	0.45
$\mathrm{hq\bar{q}}$	D	206.7	114	0.40

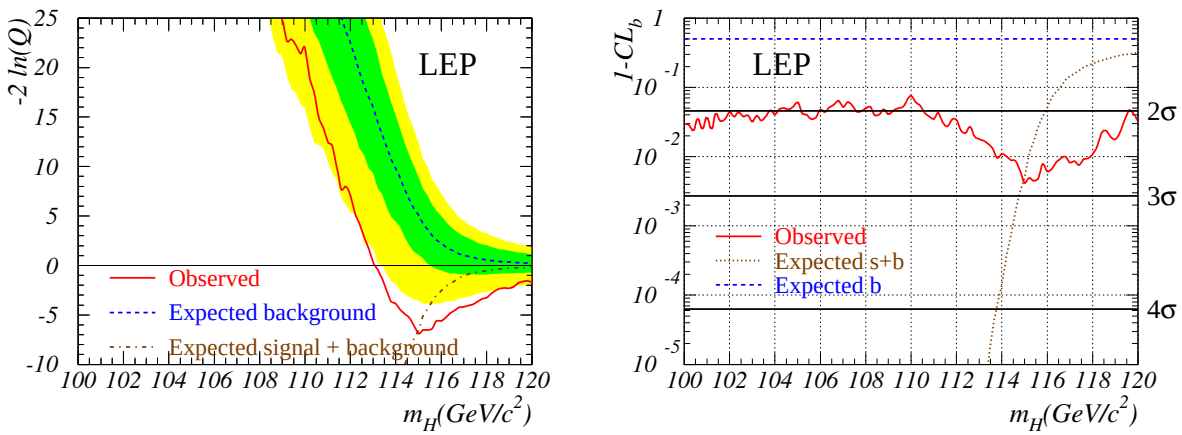

Figure 2: The combined results from LEP. (a) The log-likelihood ratio curve as a function of the test mass m_{h}. The solid line is the result obtained from the data. The dashed line is the expected median in the background-only scenario. The light- and dark-gray bands contain 68% and 95% of the simulated background-only experiments. The dot-dashed line is the expected position of the median log-likelihood when the latter is calculated at a mass m_{h} and includes a signal at that same mass. (b) The probability $1 - CL_b$ that a fluctuation of the background produces a result at least as signal-like as observed as a function m_{h}, for the data (solid line) and the expected background (dashed line). CL_b is the confidence level in the background hypothesis. The dotted line indicates the location of the median for a Higgs signal of mass m_{h}.

Note added (July 2001)

At the time of submitting these proceedings, a new preliminary LEP combined result has been released by the LEP Higgs working group[9]. The current combined result corresponds to an excess over the background at the 2σ level. The maximum consistency with an eventual signal occurs at $m_{\mathrm{h}} = 115.6\,\mathrm{GeV/c^2}$. In summary, the main differences in the inputs with respect to the combined result presented in these proceedings are:

- the L3 collaboration has released new search results[10] that supersede the earlier publication[7]. The overall L3 search sensitivity has improved by $1\,\mathrm{GeV/c^2}$, mostly due to improvements to the four-jet search. The missing energy search has been revised. As a consequence the highest weight candidate from L3, in the missing energy channel, saw its weight reduced by a factor ~ 2. The overall significance of the L3 observation with respect to the SM background processes was reduced from $\sim 1.7\sigma$ to $\sim 1\sigma$.

- the ALEPH collaboration updated its inputs to include a 2D correlation correction in the four-jet channel. The overall significance of the ALEPH excess over the background was reduced from $\sim 3.4\sigma$ to $\sim 3.2\sigma$.

- the data collected at $\sqrt{s}$ >206 GeV during the last days of LEP running, and which had not been included in the November 2000 result[3], has now been analysed by the four experiments and included in the combination. The extra data totals $\approx 55\,\mathrm{pb}^{-1}$.

The final combined result from LEP is expected towards the end of 2001, after the final publications of ALEPH, DELPHI and OPAL appear in print.

Acknowledgements

I would like to thank the conference organizers for inviting me to attend a memorable physics meeting. The skiing was also great. Most importantly, I thank all my colleagues in the LEP Higgs working group which were involved in the preparation of the results presented here, and which have assisted in the preparation of my talk.

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