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Physique subatomique/*Subatomic physics*

AVANCÉES EN PHYSIQUE DES PARTICULES : LA CONTRIBUTION DU LEP

ADVANCES IN PARTICLE PHYSICS: THE LEP CONTRIBUTION

Direct search for the Standard Model Higgs boson

Patrick Janot [a]*, Marumi Kado [b]

[a] CERN, EP Division, CH-1211 Geneva 23, Switzerland

[b] Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

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Abstract For twelve years, LEP revolutionized the knowledge of electroweak symmetry breaking within the standard model, and the direct discovery of the Higgs boson would have been the crowning achievement. Searches at the Z resonance and above the W^+W^- threshold allowed an unambiguous lower limit on the mass of the standard model Higgs boson to set be at 114.1 GeV$\cdot c^{-2}$. After years of efforts to push the LEP performance far beyond the design limits, hints of what could be the first signs of the existence of a 115 GeV$\cdot c^{-2}$ Higgs boson appeared in June 2000, were confirmed in September, and were then confirmed again in November. An additional six-month period of LEP operation was enough to provide a definite answer, with an opportunity to make a fundamental discovery of prime importance. ***To cite this article: P. Janot, M. Kado, C. R. Physique 3 (2002) 1193–1202.***

Higgs boson / search / limit / 115 GeV$\cdot c^{-2}$ / LEP / CERN

La recherche du boson de Higgs

Résumé Au cours de ses douze années de fonctionnement, LEP a revolutionné la connaissance de la brisure de symétrie électrofaible dans le cadre du modèle standard. La découverte directe du boson de Higgs en aurait été le couronnement. Les recherches au pic du Z et au-delà du seuil de production de paires de W ont permis d'exclure de manière non ambiguë toute masse en dessous de 114.1 GeV$\cdot c^{-2}$. Après des années d'efforts, les performances de LEP ont fini par dépasser les limites de ce que l'on croyait possible. Alors, les premiers signes de ce qui pourrait bien être un boson de Higgs de 115 GeV$\cdot c^{-2}$ commencèrent à apparaître en juin 2000, furent confirmés en septembre, et confirmés à nouveau en novembre. Le cas échéant, six mois de plus auraient suffi pour transformer ces indices en une découverte d'importance fondamentale. ***Pour citer cet article : P. Janot, M. Kado, C. R. Physique 3 (2002) 1193–1202.***

boson de Higgs / recherche / limite / 115 GeV$\cdot c^{-2}$ / LEP / CERN

* Corresponding author.
E-mail address: Patrick.Janot@cern.ch (P. Janot).

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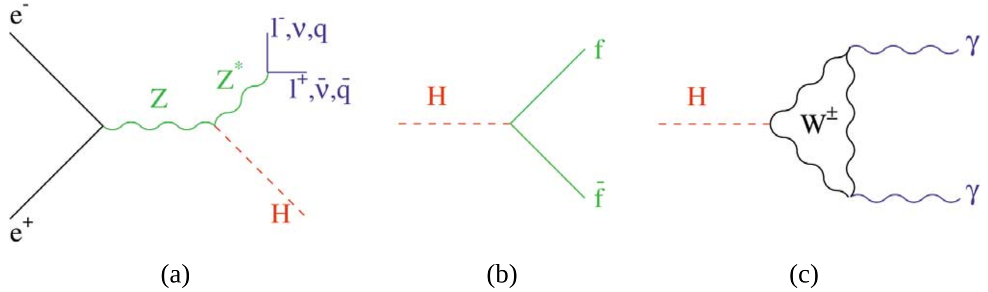


Figure 1. Feynman diagrams for: (a) the standard model Higgs boson production at LEP 1; (b) the standard model Higgs boson decay into a pair of fermions; and (c) into a pair of photons.

1. Introduction

The precision measurements made at LEP and SLD [1], combined with the top quark mass measured at the Tevatron, allowed the mass of the Higgs boson to be predicted in the framework of the standard model,

$$\mathrm{m_H} = \left(80^{+44}_{-28}\right)\ \mathrm{GeV}{\cdot}c^{-2},$$

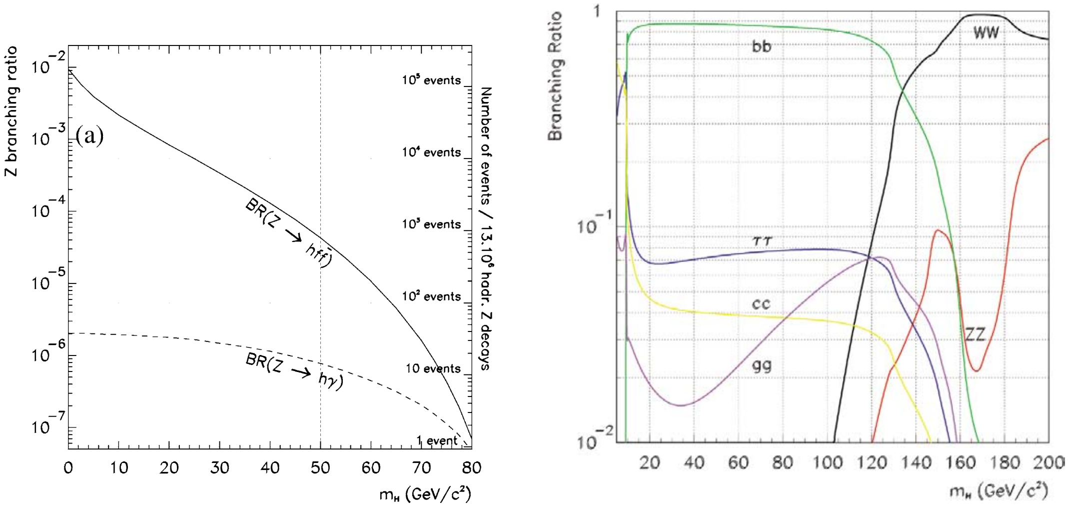
as obtained with the as-yet most precise determination of the fine structure constant [2] when evaluated at the Z mass. (The value of $\Delta\alpha^{(5)}_{\mathrm{had}}(\mathrm{M_Z})$ reported in [2] is 0.02767 ± 0.00016.) The prediction of such a light Higgs boson – between 0 and 200 $\mathrm{GeV}{\cdot}c^{-2}$ in the standard model at 95% C.L. – greatly emphasized the interest of its direct search at LEP. The motivation was further enhanced by the popular supersymmetric theories, which generally predict an even lighter standard-model-like Higgs boson (below $\sim$130 $\mathrm{GeV}{\cdot}c^{-2}$ [3]) without spoiling the internal consistency of the precision measurements.

Before LEP started in summer 1989, searches for a very light standard model Higgs boson had already been carried out (for detailed reviews, see for instance [4,5], and references therein) in decays of light mesons: $\pi^+ \to \mathrm{He}^+\nu_{\mathrm{e}}$ [6], $\mathrm{K}^0 \to \mathrm{H}\pi^0$ [7], $\mathrm{B}^0 \to \mathrm{HX}$ [8], $\mathrm{J}/\psi \to \mathrm{H}\gamma$ and $\Upsilon \to \mathrm{H}\gamma$ [9], followed by the decay $\mathrm{H} \to \mu^+\mu^-$. Although affected by potentially large QCD corrections to the decay rate [10], the negative result of the latter was believed to exclude the entire range $2m_\mu < \mathrm{m_H} \lesssim 5\ \mathrm{GeV}{\cdot}c^{-2}$ at 95% C.L. In July 1989, an original electron beam dump experiment [11] unambiguously covered the range $2m_{\mathrm{e}} < \mathrm{m_H} < 52\ \mathrm{MeV}{\cdot}c^{-2}$.

In the twelve years that followed, because of its large and unambiguously known coupling to the Z [12], direct searches for the standard model Higgs boson between 0 and 115 $\mathrm{GeV}{\cdot}c^{-2}$ became the monopoly of LEP. Their results drastically modified the experimental knowledge in the field. They will remain with no competition for a least five more years, when either the Tevatron or the LHC may have produced sufficient luminosity to become sensitive to a heavier Higgs boson.

2. The LEP 1 era

The operation of LEP at and around the Z resonance between 1989 and 1995 (LEP 1) allowed the four detectors to collect a total of about 20 million Z decays. The dominant Z decay leading to Higgs boson production at LEP 1 is called the Higgs-strahlung process, $\mathrm{Z} \to \mathrm{Hf\bar{f}}$ where f is a neutrino, a lepton or a quark, and is sketched in the diagram of Fig. 1(a). The corresponding Z branching fraction is displayed in Fig. 2(a) as a function of the Higgs boson mass, together with the number of events expected to be produced in the LEP 1 data sample: over 10 000 to 100 000 events were expected to be produced for a very light Higgs boson down to about 20 events for a 70 $\mathrm{GeV}{\cdot}c^{-2}$ Higgs boson.



(a) (b)

Figure 2. (a) Branching ratio of the Z decay into $\mathrm{Hf\bar{f}}$ (left axis), and corresponding number of events expected in the LEP 1 data sample (right axis); and (b) decay branching fractions of the Higgs boson as a function of its mass. (The very low mass region is not represented.)

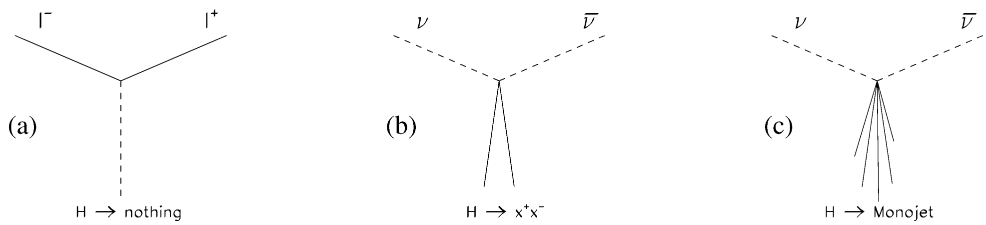


Figure 3. Final state topologies for the search for a light standard model Higgs boson: (a) acoplanar lepton pair with an invisible Higgs boson; (b) acoplanar charged particle pair; and (c) monojet.

Beside the production rate, the decay modes of the Z (Fig. 1(a)) and the Higgs boson (Figs. 1(b) and 1(c)) determine the final state topologies and therefore the search strategy. Because the Higgs boson is expected to couple to particles proportionally to their mass [12], it tends to preferentially decay into the pair of heaviest particles kinematically accessible. In Fig. 2(b), the decay branching fractions of the Higgs boson are shown as a function of its mass. Above the $\mathrm{b\bar{b}}$ threshold and in the region of interest at LEP, the Higgs boson mostly decays into $\mathrm{b\bar{b}}$, in 85% of the cases. Below this threshold, the Higgs boson may decay into $\mathrm{c\bar{c}}$, $\tau^+\tau^-$, $\mu^+\mu^-$, $\mathrm{e^+e^-}$, or into a gluon or a photon pair, leading to a variety of final states with a lower multiplicity than for higher masses.

The high production rate of a light Higgs boson renders the search very easy at LEP 1. As sketched in Fig. 3, three topologies were mainly looked for, (i) acoplanar lepton pairs $\ell^+\ell^-$ from the Z decay, recoiling against missing energy and momentum, to investigate the case in which the Higgs boson is so light (around or below $2m_\mathrm{e}$) that its lifetime makes it undetectable [13–16]; (ii) acoplanar pairs (see, for instance, [17, 18]) of charged particles $\mathrm{x^+x^-}$, recoiling against missing energy and momentum due to $\mathrm{Z}^* \to \nu\bar{\nu}$, to deal with the $\mathrm{H} \to \mathrm{e^+e^-}$, $\mu^+\mu^-$, $\tau^+\tau^-$, $\pi^+\pi^-$, ... decays (for $\mathrm{m_H}$ between $2m_\mathrm{e}$ and 1 $\mathrm{GeV}{\cdot}c^{-2}$); and (iii) low-multiplicity monojets [17,18], recoiling against missing energy and momentum due to $\mathrm{Z}^* \to \nu\bar{\nu}$, to take care of the Higgs boson hadronic decays (for $\mathrm{m_H}$ up to 20 $\mathrm{GeV}{\cdot}c^{-2}$). The absence of signal observed in

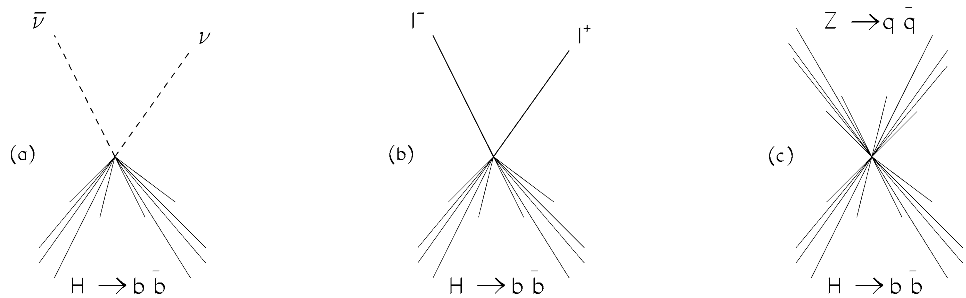


Figure 4. (a) The acoplanar jets and (b) the energetic lepton pair topologies, are searched for when $m_H \gtrsim 20$ GeV·c^{-2}; (c) the four-jet topology is overwhelmed by background at LEP 1.

these essentially background-free topologies allowed any Higgs boson mass below $\sim$20 GeV·c^{-2}, including the case in which m_H is exactly zero, to be excluded at much more than 95% C.L.

For higher Higgs boson masses, the expected final states are different and are mainly made of a Z recoiling against an acoplanar pair of hadronic jets from the Higgs boson decay. Most of these final states are purely hadronic when $Z^* \to q\bar{q}$, and are overwhelmed with the huge background from hadronic Z decays. Only 24% of the final states, leading to the well identifiable topologies displayed in Figs. 4(a) and 4(b), were therefore used in the search for the Higgs boson by the four experiments, (i) the $(H \to \text{hadrons})(Z^* \to \nu\bar{\nu})$ final state, with two acoplanar jets accompanied with missing energy, called the $h\nu\bar{\nu}$ channel; and (ii) the $(H \to \text{hadrons})(Z^* \to \ell^+\ell^-)$ final state, with $\ell = e$ or μ, with two energetic leptons isolated from the accompanying hadronic system, called the $H\ell^+\ell^-$ channel.

This left only ten (three) events produced for $m_H = 65$ (70) GeV·c^{-2}, to be found within 13 million hadronic Z decays, rendering quite sophisticated the analysis techniques developed for this search [19–22]. In total, four events were observed in the $H\nu\bar{\nu}$ topology and nine events in the $H\ell^+\ell^-$ topology, well compatible with the 6.0 and 14.6 events expected from standard background processes, mainly from $e^+e^- \to b\bar{b}$ in the $h\nu\bar{\nu}$ channel, and from four-fermion process $e^+e^- \to \ell^+\ell^- q\bar{q}$ in the $H\ell^+\ell^-$ topology.

This agreement between the observation and the standard model expectation allowed each of the four experiments to extract lower limits on the Higgs boson mass: 55.4 (DELPHI), 59.6 (OPAL), 60.2 (L3) and 63.9 GeV·c^{-2} (ALEPH). In 1995, a combined 95% C.L. lower limit of 65.6 GeV·c^{-2} was obtained for the standard model Higgs boson mass [23].

3. From LEP 1 to LEP 2: getting more energy

To go beyond this result, the only efficient solution was to increase the LEP energy above the HZ threshold, $\sqrt{s} > m_H + M_Z$, so as to produce a Z on mass shell and a Higgs boson via the Higgs-strahlung process (Fig. 5(a)). As shown in Fig. 5(b), a centre-of-mass energy in excess of 160 GeV is required to become sensitive to a 70 GeV·c^{-2} Higgs boson, and $\sqrt{s} = 192$ GeV is needed to reach $m_H = 100$ GeV·c^{-2}.

For this reason, a total of 288 Nb/Cu superconducting cavities was progressively installed in the LEP tunnel between 1995 and 1999 (144 in 1995, 176 in 1996, 240 in 1997, 272 in 1998 and 288 in 1999). The design accelerating gradient of 6 MV·m^{-1} was aimed at compensating the energy lost by e^+'s and e^-'s at $\sqrt{s} = 192$ GeV, i.e., about 3 GeV per turn. It is worth noting that 372 cavities, i.e., as many as could possibly be installed in the LEP tunnel, would have allowed a large integrated luminosity to be produced at centre-of-mass energies in excess of 220 GeV.

The corresponding increase of the sensitivity (in terms of mass) of the standard model Higgs boson searches (Section 4), which follows closely the successive increase of centre-of-mass energy, is displayed in Fig. 6(a). Although no additional accelerating hardware had been foreseen in 1999 and 2000, the sensitivity continued to increase significantly, from about 100 to 115 GeV·c^{-2}, thanks to the large integrated

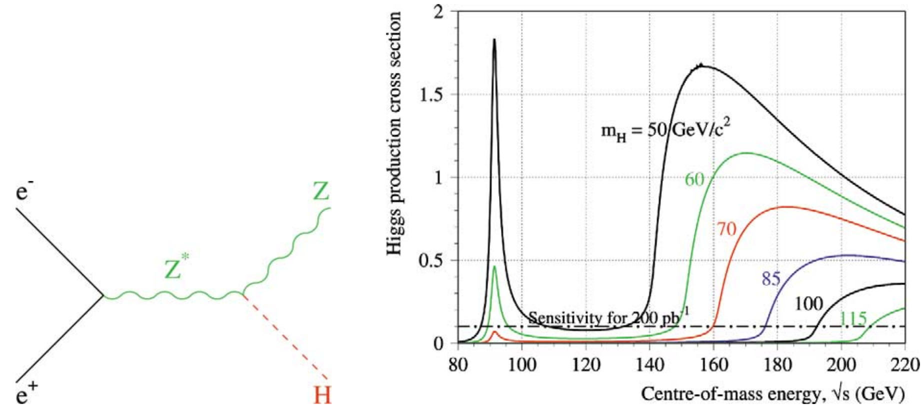
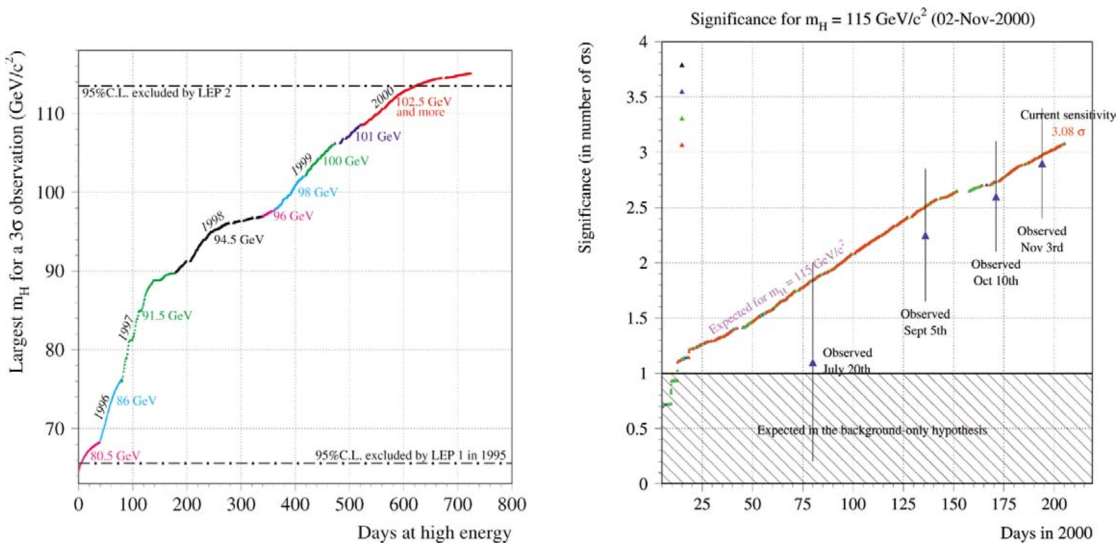


Figure 5. (a) Higgs boson production process at LEP 2; and (b) the cross section as a function of the centre-of-mass energy for several Higgs boson mass values. Also indicated (dash-dotted line) is the 5σ-sensitivity reached with an integrated luminosity of 200 pb^{-1}.



(a) (b)

Figure 6. (a) Evolution of the 3σ-sensitivity on m_{H} from 1996 to 2000. (b) Online determination of the expected significance, in standard deviations, as a function of time in the year 2000 for $m_{\mathrm{H}} = 115\ \mathrm{GeV}\cdot c^{-2}$. The four dots with error bars correspond to the observation of an excess of events in the 2000 data.

luminosity produced up to $\sqrt{s} = 209.2$ GeV. Such high centre-of-mass energies would not have been reached if it were not for the great ingenuity and utmost efforts to take advantage of all possible resources of the collider, especially in the year 2000 [24] and, to a lesser extent, in 1999.

1. The cryogenic installation was upgraded (as foreseen for the LHC) to allow the accelerating gradient of the superconducting cavities to be gradually increased from 6 $\mathrm{MV}\cdot\mathrm{m}^{-1}$ to 7.5 $\mathrm{MV}\cdot\mathrm{m}^{-1}$, for a global gain of 650 MV. The overall stability of the cryogenic system was also greatly improved with this upgrade.

Table 1. Effect on $\sqrt{s}$ and on the 3σ-sensitivity on m_H of the 1999–2000 LEP improvements.

Improvement	Effect on $\sqrt{s}$ (GeV)	m_H sensitivity (GeV$\cdot c^{-2}$)
(1) Cryogenics upgrade	$192 \to 204$	$100 \to 112$
(2) One klystron margin	$204 \to 205.5$	$112 \to 113$
(3) Mini-ramps to no margin	$205.5 \to 207$	$113 \to 114$
(4) Eight Cu cavities	$207 \to 207.4$	$114 \to 114.25$
(5) Orbit correctors	$207.4 \to 207.8$	$114.25 \to 114.5$
(6) Smaller RF frequency	$207.8 \to 209.2$	$114.5 \to 115.1$

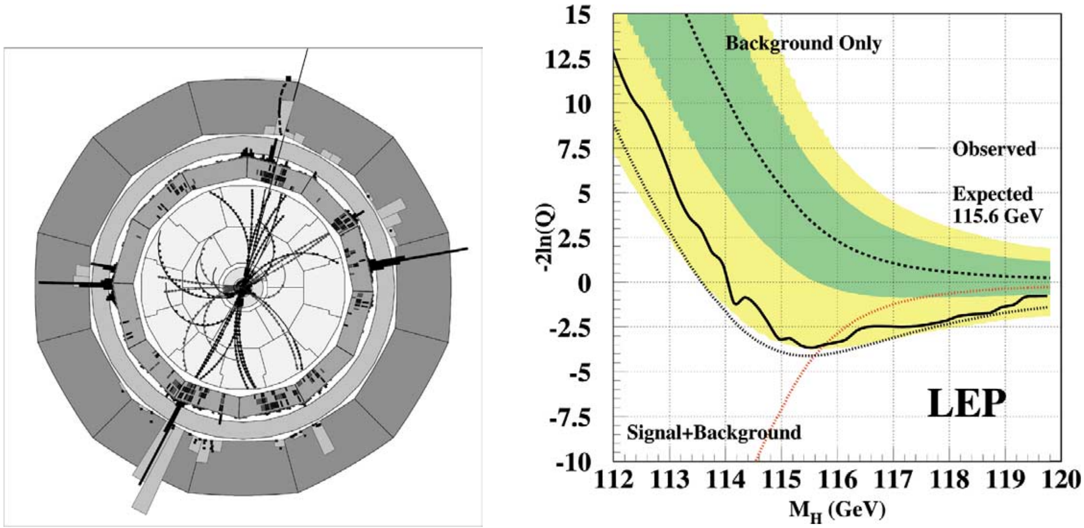
2. With this gain in stability, the RF margin was reduced from 200 MV (corresponding to two klystrons allowed to trip without losing the beams) to 100 MV (a one-klystron margin) with only moderate a reduction of the average fill duration.
3. At the end of each fill, mini-ramps to a no-margin situation were performed, allowing another 100 MV to be gained for a duration of approximately fifteen minutes (the average time between two klystron trips).
4. Eight warm Cu cavities (from LEP 1) were re-installed for a gain of 30 MV.
5. Unused (mostly uncabled) orbit correctors were powered in series to act as magnetic dipoles, thus increasing the bending length of LEP and allowing the beam energy to be increased while keeping constant the energy loss by synchrotron radiation.
6. The radio-frequency was slightly reduced (by 100 Hz out of 350 MHz), so that the beam in its modified orbit sees more dipolar magnetic field from the focusing quadrupoles, and so as to benefit from the additional margin brought by the resulting shortening of the bunches.

The successive effects on the centre-of-mass energy and the Higgs-boson-mass 3σ sensitivity are displayed in Table 1. Altogether, these improvements allowed the maximum centre-of-mass energy to be raised from 192 to 209.2 GeV, and the 3σ-sensitivity on the standard model Higgs boson mass to be increased from 100 to 115.1 GeV$\cdot c^{-2}$.

4. LEP 2: First hints at $m_H = 115$ GeV$\cdot c^{-2}$?

The three final state topologies (leptons, acoplanar jets with missing energy, or four jets) arising from HZ production with a Higgs decay in $b\bar{b}$ and Z decays into $\ell^+\ell^-$, $\nu\bar{\nu}$ or $q\bar{q}$, as displayed in Fig. 4, were simultaneously searched for at LEP 2. Unlike at LEP 1, the fully-hadronic final state does not suffer from the huge background from hadronic Z decays. Moreover, the final state Z boson, produced on-shell at LEP 2, provides an additional kinematic constraint, which allows the Higgs boson mass to be reconstructed for each event with a good accuracy, thus further reducing the background from $q\bar{q}$, W^+W^- or ZZ production. Because of its dominant rate ($\sim$70%), the search in the four-jet channel was even found to have a sensitivity to the Higgs boson higher than that of the combination of the missing energy and the leptonic final states.

These clear signatures were selected with efficiencies ranging from 40% for the four-jet final state to 80% for the leptonic case. However clear, these signatures have contributions from the aforementioned standard model background processes, some of which are hardly distinguishable from signal events. To fully take advantage of the topological, kinematical or b-quark content event characteristics allowing signal to be discriminated from backgrounds, likelihood methods or neural networks were used to construct a single combined variable x reflecting the ‘signal-ness’ of an event. The distributions of this combined variable were used to assess, with large simulated event samples of signal and background, an m_H-dependent signal-to-noise ratio $s(x)/b(x)$, and thus a weight $w(x, m_H) = 1 + s(x)/b(x)$, to each candidate event. The comprehensive negative log-likelihood $\mathcal{L}(m_H)$ resulting from the product of the weights of the N selected



(a) (b)

Figure 7. (a) Event display of the first, most significant Higgs boson candidate event. (b) Distribution of the negative log-likelihood (full curve) as a function of the hypothesized Higgs boson mass, compared to the prediction for a 115.6 GeV$\cdot c^{-2}$ Higgs boson (dotted curve) and the background-only hypothesis (dashed curve). The shaded areas correspond to the 68% and 95% C.L. bands around the latter.

candidate events

$$\mathcal{L}(\mathrm{m_H}) = -2\ln Q \quad \text{with } Q = \prod_{i=1}^{N}\left[1 + w_i(x_i, \mathrm{m_H})\right]$$

accounts not only for the number of events observed compared to those expected in the signal and background-only hypotheses, but also for the distribution of the combined variable in the selected data sample.

This log-likelihood is expected to be smaller in the presence of signal than with background events only, and a possible minimum would point to the most likely value for the Higgs boson mass. However, because the signal cross section decreases rapidly when $\mathrm{m_H}$ increases, the separation between a signal-like and a background-only experiment is expected to vanish as $\mathrm{m_H}$ reaches the HZ kinematic threshold, $\mathrm{m_H} \sim \sqrt{s} - \mathrm{M_Z}$. With the 200 pb^{-1} collected by each of the four experiments in the year 2000, their combined likelihood was expected to be sensitive to a signal cross section of 40 fb, corresponding to eight (less than four) signal events produced in (detected by) each experiment.

Because, until June 2000, no noticeable excess of signal-like candidate events had been seen in the LEP data [25–29], the whole $\mathrm{m_H}$ range below 114.1 GeV$\cdot c^{-2}$ could be excluded. In June 2000, sizeable luminosity at centre-of-mass energies above 206 GeV (i.e., above the kinematic threshold for a Higgs boson of 115 GeV$\cdot c^{-2}$) started to be steadily delivered. From this moment onwards, signal-like events compatible with the production of a Higgs boson with mass 115 GeV$\cdot c^{-2}$ were regularly recorded by the LEP experiments.

The increase with time of the significance of the observed excess of such events, compared with the expectation from a 115 GeV$\cdot c^{-2}$ Higgs boson, can be followed in Fig. 6(b). The first significant candidate event [30], displayed in Fig. 7(a), was collected at the end of June 2000, when only 30 pb^{-1} had been delivered at $\sqrt{s} = 206.6$ GeV. This event, with a reconstructed mass of 114 GeV$\cdot c^{-2}$ when interpreted in

Table 2. Characteristics of the highest purity candidate events.

Exp.	Channel	$\sqrt{s}$	M_{rec} (GeV$\cdot c^{-2}$)	$(s/b)_{115}$
ALEPH	Four Jets	206.7	114.3	4.6
ALEPH	Four Jets	206.7	112.9	2.3
ALEPH	Four Jets	206.7	110.0	0.9
L3	$H\nu\bar{\nu}$	206.4	115.0	0.7
OPAL	Four Jets	206.7	110.7	0.7
DELPHI	Four Jets	206.7	114.3	0.6
ALEPH	$H\ell^+\ell^-$	205.0	118.1	0.6
ALEPH	$H\ell^+\ell^-$	208.1	115.4	0.5
ALEPH	Four Jets	206.5	114.5	0.5
OPAL	Four Jets	205.4	112.6	0.5
DELPHI	Four Jets	206.7	97.2	0.4
L3	Four Jets	206.4	106.3	0.4

the Higgs boson hypothesis, was observed in the four-jet channel by the ALEPH experiment and turned out later to be the purest event ever, with a signal-to-noise ratio of 4.6. If, in the coming decade, the discovery of the Higgs boson is indeed confirmed at $m_H = 115$ GeV$\cdot c^{-2}$, it is not before a linear e^+e^- collider is built that such pure events will again be observed.

By the beginning of September, several additional events had been observed with a Higgs boson mass best estimate of 114.9 GeV$\cdot c^{-2}$, setting the excess at a significance level of 2.3σ, in agreement with the 2.5σ expected from a 115 GeV$\cdot c^{-2}$ Higgs boson. With this result, the LEP experiments won one additional month of LEP operation by a hard-fought struggle with CERN management, although two months had been firmly requested to double the integrated luminosity above 206 GeV. The result was anyhow astonishing. More events had been observed, and the significance of the excess had increased following closely the expectation, as illustrated in Fig. 6. It reached, on 2 November 2000, a level of almost 3σ in agreement with the expectation from a 115 GeV$\cdot c^{-2}$ Higgs boson signal.

The observed excess is in all respects in agreement with the production of a Higgs boson signal, as is explained in details in [31,32]. It is largely observed in the four-jet channel, as expected from signal events, but receives small contributions from the other two final states. Given the small number of significant events observed at high mass (listed in Table 2), their distribution among the four experiments is statistically compatible with being democratic. The excess is not the result of only a few, very significant, events, but actually affects smaller signal-to-noise ratio values, as expected from signal events. Finally, the excess was observed with selection algorithms optimized in 1999 and frozen before the start of the 2000 data taking period, thus excluding always possible data-driven biases.

In 2001, the data were fully reprocessed by three experiments, some analyses were re-optimized and numerous systematic studies were carried out [33–37]. Whereas the reprocessing did not significantly change the result, the a posteriori analysis re-optimization and, to a lesser extent, the more complete assessment of systematic uncertainties, led to a conservative re-evaluation of the significance of the excess to 2.1σ [29]. The excess is still in perfect agreement with the production of a Higgs boson with mass 115.6 ± 1 GeV$\cdot c^{-2}$, as is visible from the distribution of the re-evaluated negative log-likelihood (Fig. 7(b)).

With six more months of LEP operation in 2001, i.e., with an integrated luminosity of 200 pb^{-1} and an upgraded centre-of-mass energy above 208.5 GeV (made possible with a few available additional cavities and few accelerator tricks), this excess could have turned into an unambiguous $(5.5^{+0.6}_{-0.9})\sigma$ discovery [31]. This extension would have led to the reconstructed mass spectrum displayed in Fig. 8, should the Higgs

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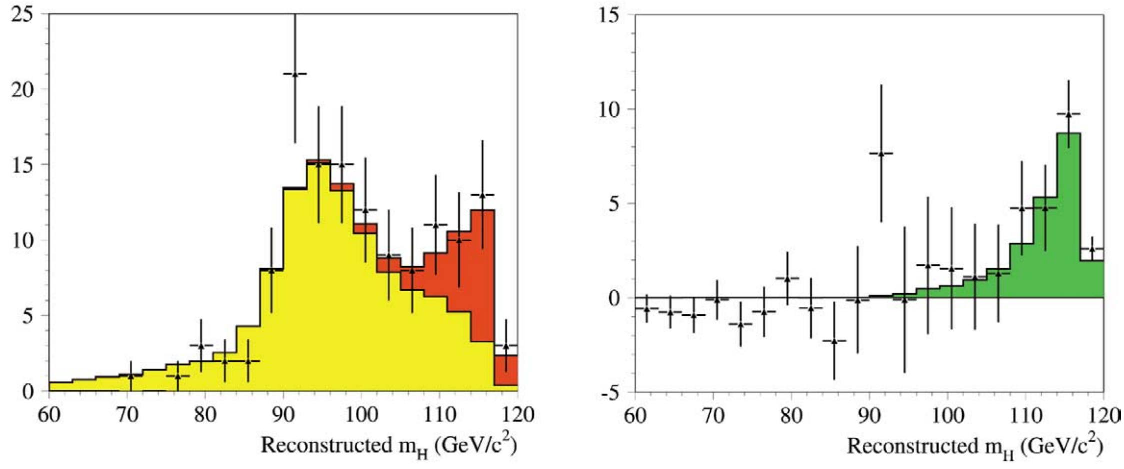

(a) (b)

Figure 8. Expected reconstructed mass spectrum of the most significant events (with an s/b value in excess of 0.5) after a six-month run of LEP in 2001, should the Higgs boson mass indeed be around 115 GeV$\cdot c^{-2}$: (a) raw spectrum; (b) background-subtracted spectrum, with an expected excess of 28 events. In (a), the error bars correspond to the square root of the number of event counted in each bin; in (b), the error bars correspond to the expected statistical uncertainty of the background, to give an idea of the expected significance of the excess.

boson mass indeed be around 115.6 GeV$\cdot c^{-2}$. Similarly, in the null hypothesis, the new data would have allowed us to demonstrate that the excess seen in 2000 was due to a statistical fluctuation.

However, after a long but uneven battle between science and politics, CERN's Director General decided to shut down LEP for ever on 17 November 2000, at 16:15.

5. Conclusion

After twelve years of outstanding Physics at LEP, the precision electroweak measurements led to a prediction of the Higgs boson mass in the framework of the standard model,

$$m_{\mathrm{H}} = \left(80^{+44}_{-28}\right)\ \mathrm{GeV}\cdot c^{-2}, \tag{1}$$

thus excluding all masses in excess of $\sim$200 GeV$\cdot c^{-2}$ at 95% C.L.

Direct searches for the HZ process carried out at LEP 1 and LEP 2 allowed the entire mass range between 0.0 and 114.1 GeV$\cdot c^{-2}$ to be excluded at 95% C.L. In the last year of LEP 2 running, these searches unveiled an excess of signal-like events, compatible in every aspects with the production of a standard model Higgs boson of mass

$$m_{\mathrm{H}} = (115.6 \pm 1)\ \mathrm{GeV}\cdot c^{-2}, \tag{2}$$

and in remarkable agreement with Eq. (1). Six more months of LEP running in 2001 could have confirmed the hints and turn them into a 5σ discovery.

Instead, at least five years are now needed for a possible confirmation, and probably many more before a detailed study becomes available. Who is going to confirm first is not yet clear. The end of the decade may be thrilling.

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