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HIGGS AT LEP*

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The search for standard, supersymmetric and non-standard Higgs bosons at LEP is shortly reviewed.

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1. Introduction

The Higgs mechanism is one of the basic ingredients of the standard theory of fundamental interactions. It allows for the unification of the electromagnetic and weak interactions without violating local gauge invariance. Within the Standard Model, it predicts a single neutral scalar fundamental particle of arbitrary mass (self-consistency of the model imposes an upper bound of about 1 TeV). Precision electroweak measurements indicate that the mass of the standard model Higgs boson should be 85^{+54}_{-34} GeV and the 95% CL upper bound is set at 196 GeV [1]. But this fundamental scalar need not exist. One of the main goals of the contemporary accelerator particle physics is to find the Higgs boson or exclude its existence.

In the years 1998-2000 the four LEP collaborations, ALEPH, DELPHI L3 and OPAL, have collected 2465/pb of e^+e^- collision data at $\sqrt{s}$ between 189 and 209 GeV. This amount of experimental data, complemented when necessary by LEP 1 data, was used for search of the Standard Model (SM) Higgs boson, Minimal Supersymmetric Standard Model (MSSM) and non-standard Higgs bosons.

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2. Search for SM Higgs boson [2]

The Higgs boson properties are well determined within SM. If exists, it is produced via Higgs-strahlung or vector boson fusion and decays mainly (74%) into $b\bar{b}$. The searches at LEP encompass the four following topologies:

(i) fully hadronic: $(H \to b\bar{b})(Z \to q\bar{q})$,
(ii) missing energy: $(H \to b\bar{b})(Z \to \nu\bar{\nu})$,
(iii) semileptonic: $(H \to b\bar{b})(Z \to \ell\bar{\ell})$ and
(iv) tau channel: $(H \to b\bar{b})(Z \to \tau^+\tau^-)$, $(H \to \tau^+\tau^-)(Z \to q\bar{q})$.

The fully hadronic channel has the greatest cross-section. The performance is dominated by b-tagging capabilities of the detectors. For the missing energy channel the mass resolution is the main challenge, but it is the only channel "to go beyond the kinematic limit" via vector boson fusion. Semileptonic channels give excellent mass resolution but suffer from the low cross-section. The tau channels requires challenging reconstruction of τ decays.

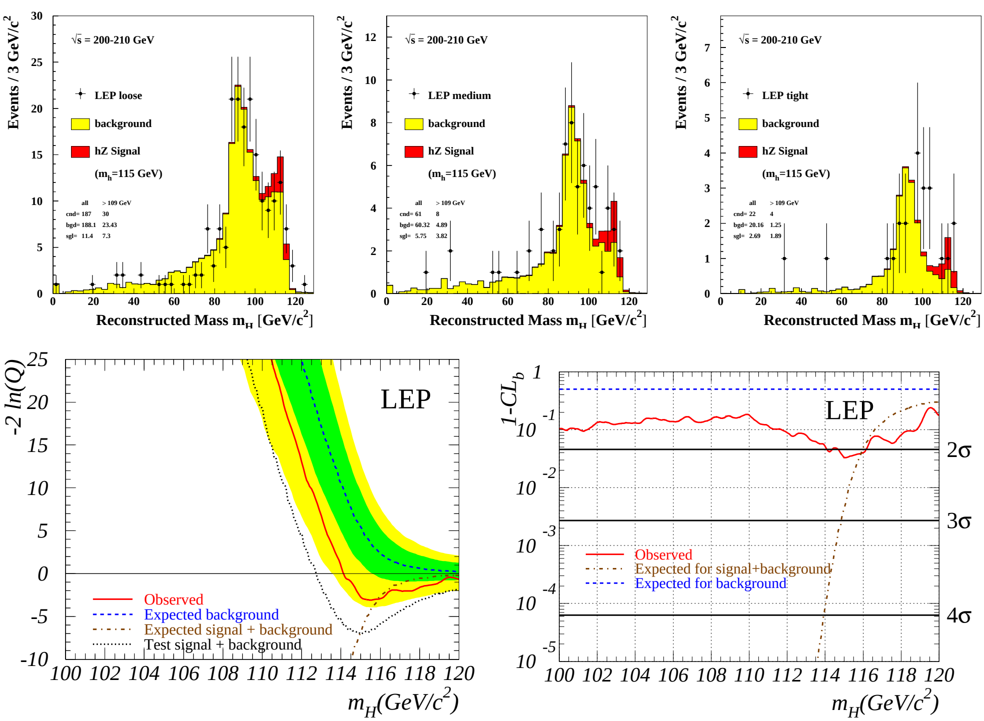

Fig. 1. Distributions of the reconstructed Higgs boson mass for selections of increasing purity (upper plots) and their statistical interpretation (lower plots). For details see the reference [2].

During the last year (2000) of taking data by LEP the ALEPH collaboration reported an excess of events suggesting production of SM Higgs boson with mass in the vicinity of 115 GeV. Because of that the LEP shutdown was postponed by one month. The excess was not confirmed by other LEP collaborations (Fig. 1). Finally the 95% CL exclusion was set at $m_H > 114.1$ GeV.

3. Search for MSSM neutral Higgs bosons [3]

The MSSM requires the existence of five physical Higgs bosons out of eight degrees of freedom of the Higgs sector. They are CP-even h^0 and H^0, CP-odd A^0 and charged H^+ and H^-. Supersymmetry constraints the mass of the lighter CP-even neutral states to be less than Z^0 mass at tree level and less than 135 GeV after taking into account radiative corrections. MSSM neutral Higgs bosons are searched at LEP in the Higgs-strahlung $e^+e^- \to Z^0 h^0$ and pair production $e^+e^- \to A^0 h^0$ processes. In the later case, the MSSM prediction that if pair production channel is open at LEP then $m_{h^0} \approx m_{A^0}$ is used in the analysis. For most of the parameter space both h^0 and A^0 are expected to decay into $b\bar{b}$ and $\tau^+\tau^-$ pairs, but for special choice of parameters these decays could be suppressed.

The search comes out to be negative. The result could be presented via three specific scenarios. The "m_{h^0}–max" scenario is designed to yield the maximal value of m_{h^0} in the model whereas the "no-mixing" scenario assumes that there is no mixing between the scalar partners of the left- and right-handed t. The exclusions in the plane m_{A^0}, m_{h^0} for these scenarios are shown in figure 2.

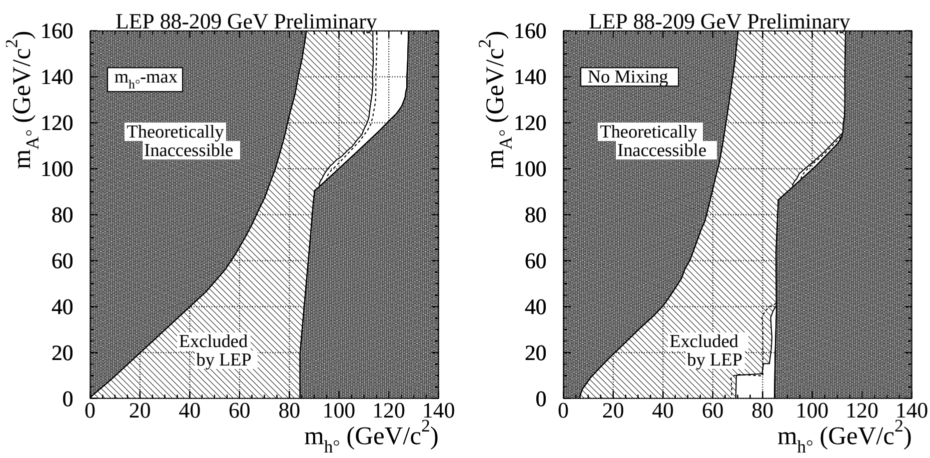

Fig. 2. The MSSM exclusions. See the reference [3] for details.

The third, "large μ" scenario is designed to illustrate choices of MSSM parameters for which h^0 does not decay into $b\bar{b}$. A careful scan over the model space indicates that the addition of so called flavor-blind search [4] excludes this scenario.

4. Search for charged Higgs bosons [5]

Charged Higgs bosons are predicted by Two Higgs Doublet Models (2HDM). The possible dominant decay channel is $H^+ \to c\bar{s}$ or $H^+ \tau^+ \nu_\tau$. In the search it is assumed that other decay channels can be neglected. One of the LEP experiments L3 sees an excess of 4 jet events corresponding to the signal of 68 GeV charged Higgs boson. Such signal, however, is excluded by the other three LEP collaborations. Finally the lower mass bound is set at 78.6 GeV at 95% CL.

5. Search for fermiophobic Higgs bosons [6]

In the SM BR($h^0 \to \gamma\gamma$) is very small. However, in particular formulations of *e.g.* some versions of the Two Higgs Doublet Model (2HDM), Higgs boson coupling to fermions can be very small and consequently decay into photons may dominate. Search for excess of $Z^0\gamma\gamma$ events comes out to be negative. Assuming SM cross-section, the 95% CL lower bound on the mass of fermiophobic Higgs boson is set at 108.2 GeV.

6. Search for invisible Higgs bosons [7]

The Higgs boson could decay into invisible particles. For example in some versions of MSSM decays into neutralinos might dominate. In absence of statistically significant excess in the data, the bound is set at 114.4 GeV assuming SM cross-section and 100% BR.

7. General 2HDM search [8]

One of the simplest extensions of the SM Higgs sector, the Two Higgs Doublet Model type II, 2HDM(II), fits very well electroweak precision measurements while providing room for one light CP-even or CP-odd Higgs [9].

For such Higgs boson, the Yukawa process could be the only production mechanism at LEP. Significant cross-section is predicted only for large $\tan\beta$ at LEP 1 energies.

If the heavier of h^0, A^0 can be produced at LEP than channels with decays $h^0 \to A^0 A^0$, $h^0 \to Z^0 A^0$ or $A^0 \to Z^0 h^0$ might dominate.

Description of preliminary DELPHI analysis in these channels can be found in the reference [8]. In figure 3 some preliminary exclusions are shown.

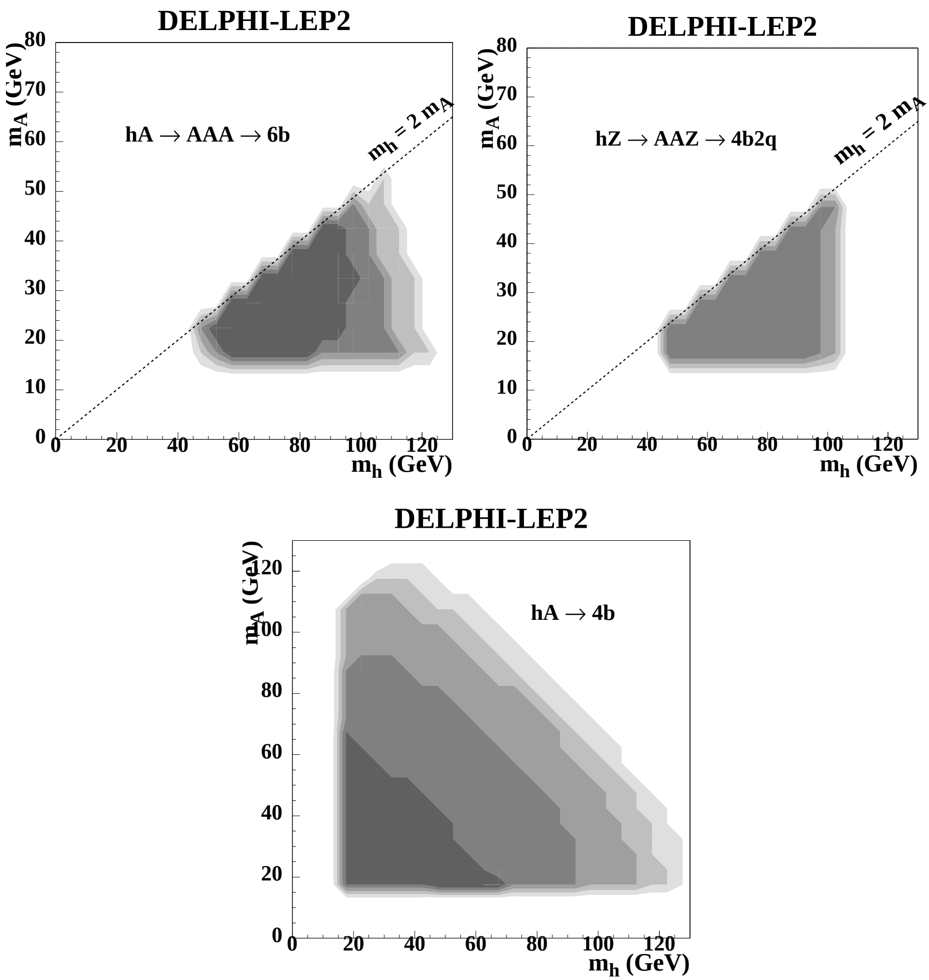

Fig. 3. Region in the m_{A^0}, m_{h^0} plane excluded by the analysis [8] using LEP 1 and LEP 2 data. In the figures below different levels of shadow correspond to exclusions of maximal cross-sections suppressed be the factors 0.1, 0.3, 0.5, 0.75 and 1.0 from darker to lighter gray respectively.

8. Conclusions

Despite excellent performance of LEP, sophisticated methods of statistical inference of data, searching all possible topologies, the Higgs boson was not found at LEP.

The question "Why we have not yet seen the Higgs boson, specially the MSSM h^0?" is open. May be it does not exists? May be it is in one of the corners of weak sensitivity? But may be it is because we have not forced LEP to run at ultimate energy? With 80 superconducting cavities more, the MSSM parameter space could be almost fully exploited [10]. Unfortunately we have lose that chance.

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