In the Standard Model (SM), the weak gauge bosons and fermions acquire mass through the Higgs mechanism. A lower limit on the SM Higgs mass of 114.4 GeV was obtained from the direct search at LEP. Although a single Higgs doublet is sufficient to explain the non-zero particle masses while keeping the theory SU(2) gauge invariant, several extensions to this minimal model were proposed, to which this limit does not apply. Most of the models discussed here introduce one additional Higgs doublet and are therefore called Two Higgs doublet models (2HDM). Several signatures predicted by such models have been searched for at LEP using data collected at center-of-mass energies up to 209 GeV. All limits quoted in this report are at 95% confidence level.

1. Fermiophobic Higgs bosons

In some scenarios, the Higgs to fermion coupling can vanish at tree level [1]. At low masses, such a Higgs particle decays predominantly into photons while at higher masses (when it becomes kinematically possible), it decays preferably into a pair of W or Z bosons (where one of the bosons can be off-shell). All searches for bosonic Higgs decays reported here assume that the production mechanism is $e^+e^- \rightarrow HZ$.

1.1. Higgs decays into photons

Combining the two photons from the Higgs decay with the Z decay modes, one obtains three different final states: $\gamma\gammaq\bar{q}$, $\gamma\gamma\nu\bar{\nu}$ and $\gamma\gamma\ell\bar{\ell}$. All four LEP collaborations have eagerly searched for the corresponding signatures but no significant deviation from the SM backgrounds was observed. This non-observation is quantified as excluded region in the plane of the Higgs

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mass versus the production cross section times branching ratio into photons normalized to the SM Higgs production cross section \[2\], as shown in Fig. 1 (left). A (preliminary) lower limit is set on the Higgs mass at 109.7 GeV within the fermiophobic benchmark scenario \[2\].

![LEP Combined Excluded Region](image)

Figure 1. Left: Excluded regions of the Higgs mass versus the production cross section times branching ratio into photons normalized to the SM Higgs production cross section for the combination of the four LEP experiments’ Higgs to photon decay searches \[2\]. Right: The excluded Higgs production cross section (divided by the SM Higgs-Strahlung cross section) as function of the Higgs mass hypothesis for invisibly decaying Higgs bosons (LEP combination) \[4\].

1.2. **Higgs decays into W and Z bosons**

Because three gauge bosons are produced in this channel (WW*Z or ZZ*Z), one gets a variety of 6-fermion final states. Six categories of these final states have been analyzed by the L3 collaboration, covering 93% of the total branching ratio. Due to the absence of any indication for the existence of such a Higgs, a lower limit on its mass at 107 GeV is set \[3\].

2. **Invisibly decaying Higgs bosons**

Here we consider the possibility that Higgs boson decays fully or partially to invisible particles. As an example, some specific sets of the parameters of the Minimal Supersymmetric Standard Model (MSSM) predict Higgs decays into neutralinos. Again, searches at LEP assume that such a Higgs is produced in association with a Z boson, leading to the two experimental signatures “two jets plus missing energy” and “two charged leptons plus missing energy”. In neither of these two channels was any evidence for Higgs production observed \[4\]. The excluded Higgs production cross section
(divided by the SM Higgs-Strahlung cross section) as function of the Higgs mass hypothesis is shown in Fig. 1 (right). In models for which the Higgs production cross section is equal to the SM Higgs production cross section, Higgs masses below 114.4 GeV (preliminary) are excluded.

3. Charged Higgs bosons $H^\pm$

In the MSSM, the $H^\pm$ bosons are heavier than the $W$ (neglecting radiative corrections). Strict limits arise from $b \to s\gamma$ measurements [5], which, however, do not apply to so-called type I 2HDMs. The process $e^+e^-\to H^+H^-$ becomes kinematically possible at LEP center-of-mass energies. The experimental signatures depend strongly on the value of $\tan\beta$ (the ratio of the vacuum expectation values of the two Higgs doublets): For small values of $\tan\beta$, the main $H^\pm$ decay modes are into $cs$ and $\tau\nu$, while for large $\tan\beta$ so-called ‘three body decays’ ($H \to Aq\bar{q}, A\ell\nu$) via a virtual $W$ become dominant.

3.1. Small values of $\tan\beta$

All four LEP collaborations have searched for pair production of charged Higgs bosons, in the final states $cscs$, $c\tau\nu$ and $\tau\nu\tau\nu$. No significant excess was observed.

A preliminary lower limit on the Higgs mass is 78.6 GeV, independent of the branching ratio into $\tau\nu$ [6].

3.2. Large values of $\tan\beta$

Due to the nature of the three body decays of the charged Higgs bosons at high values of $\tan\beta$, the possible experimental signatures become more complicated. For example, OPAL performs a detailed analysis explicitly looking for the final states $(qqbb)(qqbb)$, $(\ell\nu bb)(qqbb)$ and $(\tau\nu)(qqbb)$. No indication of a signal has been found. The lower limit of these two analyses is at 76.6 GeV (preliminary) [7, 8].

4. Doubly charged Higgs bosons $H^{\pm\pm}$

Such Higgs particles can arise e.g. in Higgs triplet or left-right symmetric models. Charge conservation demands that doubly charged Higgs bosons only couple to charged leptons and other gauge and Higgs bosons at tree level.
One has to distinguish between three different experimental topologies which correspond to different ranges of the Higgs lifetime: Very short lifetimes lead to a four-lepton signature, intermediate lifetimes result in a Higgs decaying within the tracking chambers (i.e. tracks with kinks) while for longer lifetimes, two heavy doubly charged particles are seen in the detector. Three LEP experiments have searches for pair production of doubly charged Higgs bosons [9–11], without observing any evidence for such a signal. The lowest limit of these searches is set at 95.5 GeV.

5. Summary
Various models involving an extended Higgs sector have been probed at LEP. None of the searches has shown some evidence for such an extension of the SM. Limits have been set at 95% confidence level, by each collaboration and — where possible — for the combined LEP data. Most of the results are still preliminary, the LEP combination of final results will hopefully follow soon.

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