The charged Higgs boson at LEP Towards the final combination

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The four LEP collaborations have searched for charged Higgs bosons in the framework of Two Higgs Doublet Models (2HDM). The data of the four experiments (still preliminary for OPAL) have been statistically combined. The results are interpreted within the 2HDM for Type I and Type II benchmark scenarios. No statistically significant excess has been observed when compared to the Standard Model background prediction, and the combined LEP data exclude large domains of the parameter space.

1 Introduction

The full presentation may be found in [1]. The four LEP collaborations have searched for charged Higgs bosons in the framework of Two Higgs Doublet Models (2HDM). Since the preliminary combination prepared for the summer 2001 conferences, three experiments have published their final results [2, 3, 4] and OPAL will soon do so. Thus the LEP working group for Higgs bosons searches has performed a preliminary statistical combination of the data taken at centre-of-mass energies from 183 GeV to 209 GeV.

The existence of a pair of charged Higgs bosons is predicted by several extensions of the Standard Model. In Two Higgs Doublet Models, the couplings are completely specified in terms of the electric charge and the weak mixing angle, θ_W, and therefore, at tree level, the production cross-section depends only on the charged Higgs boson mass. Higgs bosons couple to mass and therefore decay preferentially to heavy particles, but the precise branching ratios may vary significantly depending on the model. Two scenarios have been considered. The first one allows charged Higgs decays to fermions only, which is the case in the 2HDM of type II [5] for not too small m_{A} (section 2). The second scenario allows in addition the charged Higgs boson to decay into gauge and Higgs bosons (possibly off-shell). This situation is realized in the 2HDM of type I [6] over large parts of the $\tan\beta$ parameter space (section 3).

Pair-production of charged Higgs bosons occurs mainly via s-channel exchange of a photon or a Z^0 boson. The tree-level decay amplitude is independent of the model assumptions and depends only on the mass of the charged Higgs boson. Furthermore, the (electroweak) radiative corrections (which depend on the model) are small.

Each experiment has produced analyses for various decay channels which, combined with the different centre-of-mass energies, amounts to 122 samples of data.

The statistical procedure adopted for the combination of the data and the precise definitions of the confidence levels CL_b, CL_{s+b}, CL_s by which the search results are expressed, have been previously described [7]. The main sources of systematic error affecting the signal and background predictions are included, using an extension of the method of Cousins and Highland [8] where the confidence levels are the averages of a large ensemble of Monte Carlo experiments.

*On behalf of the LEP Higgs Working Group.

2 Combined searches in the 2HDM of type II

In type II 2HDM [5], one Higgs doublet couples to up-type fermions and the other to down-type fermions. The Higgs sector of the Minimal Supersymmetric Standard Model (MSSM) is a particular case of such models, where the $H^{\pm}$ is constrained to be heavier than the W boson at tree level. For the masses accessible at LEP energies, the $\tau^{-}\bar{\nu}_{\tau}$ and $\bar{c}s$ decays (and their charge conjugates) are expected to dominate, as can be seen on Figure 1 (left).

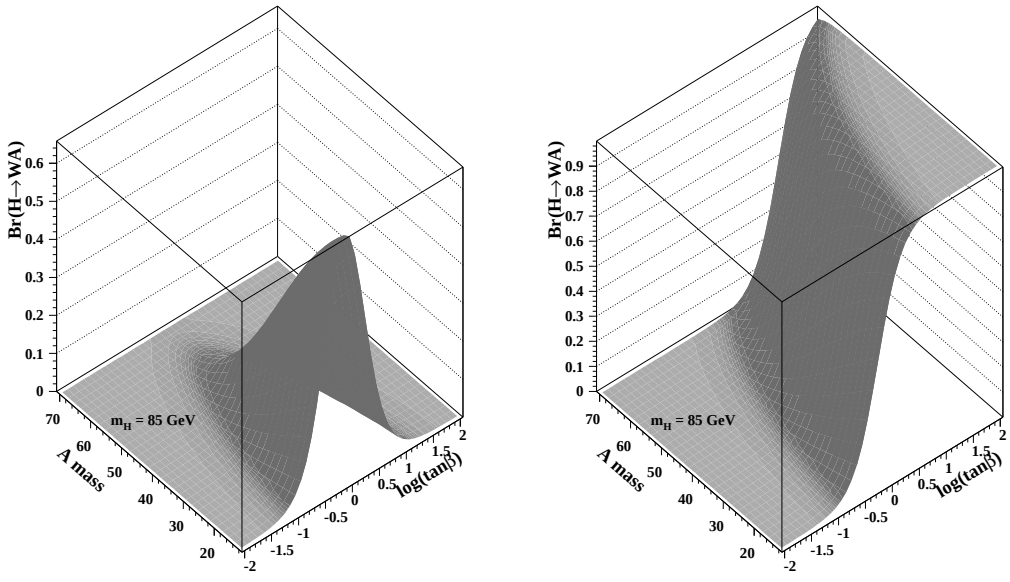

Figure 1: Bosonic Branching fraction in 2HDM Type II (left) and Type I (right)

The searches are carried out under the assumption that the two decays $H^{+} \to c\bar{s}$ and $H^{+} \to \tau^{+}\nu$ exhaust the H^{+} decay width, but the relative branching ratio is free. This historical assumption is valid for the MSSM since the A mass is expected to be large. Combining the results from the four experiments, a scan has been done, in the plane Br = $B(H^{+} \to \tau^{+}\nu)$ versus $m_{H^{\pm}}$. Figure 2 (left) shows the observed background confidence level CL_b. This observed confidence level is everywhere within the $\pm 2\sigma$ region of the background prediction, except for some small regions at low mass and high mass that slightly exceed the 2 σ level. All three such regions are the superposition of small excesses compared to the expectation seen by two or three of the experiments, and are far from the expected limit. The expected median and observed mass limits are shown in Figure 2 (right).

3 Combined searches in the 2HDM of type I

An alternative set of models, type I models [6], assume that all fermions couple to the same Higgs doublet. In this case and if the neutral pseudo-scalar A is light enough (which is not excluded by direct searches for the general 2HDM [9]) the decay to $W^{*}A$ can be predominant even in the range of masses of interest at LEP (W^{*} is an off-shell W boson).

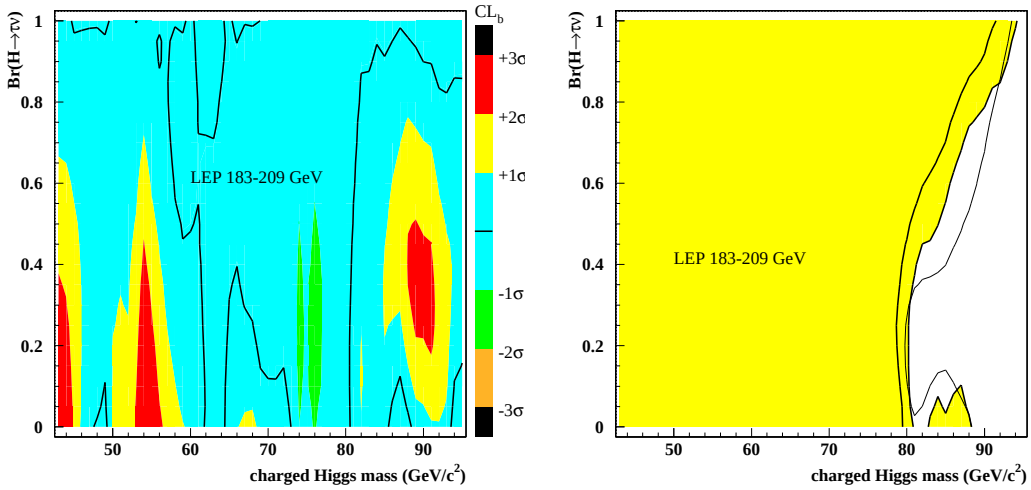

Figure 2: Type II 2HDM : Left : contours based on the observed p-values CL_b as a function of $m_{\mathrm{H}^\pm}$ and Br, indicating the statistical significance of local departures from the expectation. Right : the bounds on $m_{\mathrm{H}^\pm}$ as a function of Br. The shaded area is excluded at the 95% CL. The expected exclusion limit (at the 95% CL) is indicated by the thin solid line and the thick solid line inside the shaded area is the observed limit at the 99.7% CL.

Figure 1 (right) shows the branching ratio for this decay. Basically, for all boson masses, the possible charged Higgs boson decays are purely fermionic for low $\tan\beta$ (the ratio of the Higgs vacuum expectation values) and purely bosonic for high $\tan\beta$. Between these two extreme cases, the change is rapid in $\tan\beta$ (between typically 0.1 and 10.) and slower in A boson mass. Type I models are explored through the combination of all decay channels. The combination is performed according to the branching ratios predicted by the model as a function of $\tan\beta$ and the boson masses. When there was a possible overlap between two channels, the one providing less sensitivity was ignored to avoid double counting. This is the case in the intermediate region in $\tan\beta$ for purely hadronic channels (W*AW*A and $\mathrm{c\bar{s}\bar{c}s}$) on one hand and the semi-leptonic channels ($\mathrm{W^*A\tau^-\bar{\nu}_\tau}$ and $\mathrm{c\bar{s}\tau^-\bar{\nu}}$) on the other hand. Furthermore, the scan is restricted to m_{A} above 12 GeV since the search was done only through its decay into two b-jets.

Figure 3 shows the observed confidence level in the backgound hypothesis CL_b, for three values of m_{A}, which exhibits a slight (always below the 3 σ level) excess for low and intermediate A masses in the region where the bosonic decays dominate (high $\tan\beta$). When proceeding to the limit computation, it happens that these limits are everywhere found in a region where an excess is observed, resulting in a shift of the order of 3 GeV between observed and expected limits, as can be seen on Figure 4. It is worth noting that the valley visible on Figure 4 corresponds to regions where the conservative approach of keeping only one channel when both contribute but may induce double counting is applied.

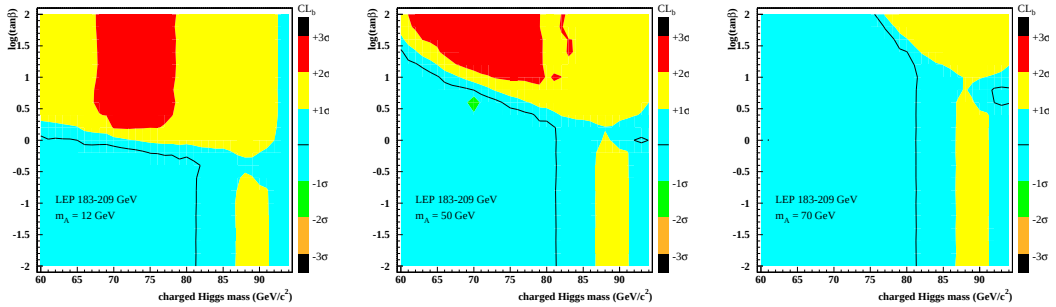

Figure 3: Type I 2HDM : Contours based on the observed p-values CL_b as a function of $m_{\mathrm{H}^\pm}$ and $\tan\beta$, indicating the statistical significance of local departures from the expectation, for 3 values of m_{A} (resp. 12, 50 and 70 GeV).

4 Conclusions

All results are still preliminary. In the scenario with fermionic decay channels alone, adapted for most of the 2HDM type II, the mass of the charged Higgs boson is greater than 80.1 GeV (95% CL), limited mainly by the WW background in that region. A new scenario has been explored, for 2HDM type 1, thanks to analyses by DELPHI and OPAL in the bosonic decay channels. In this case, the mass of the charged Higgs boson is greater than 76.0 GeV (95% CL), due mainly to a slight excess of observed events with respect to the expectation (79 GeV).

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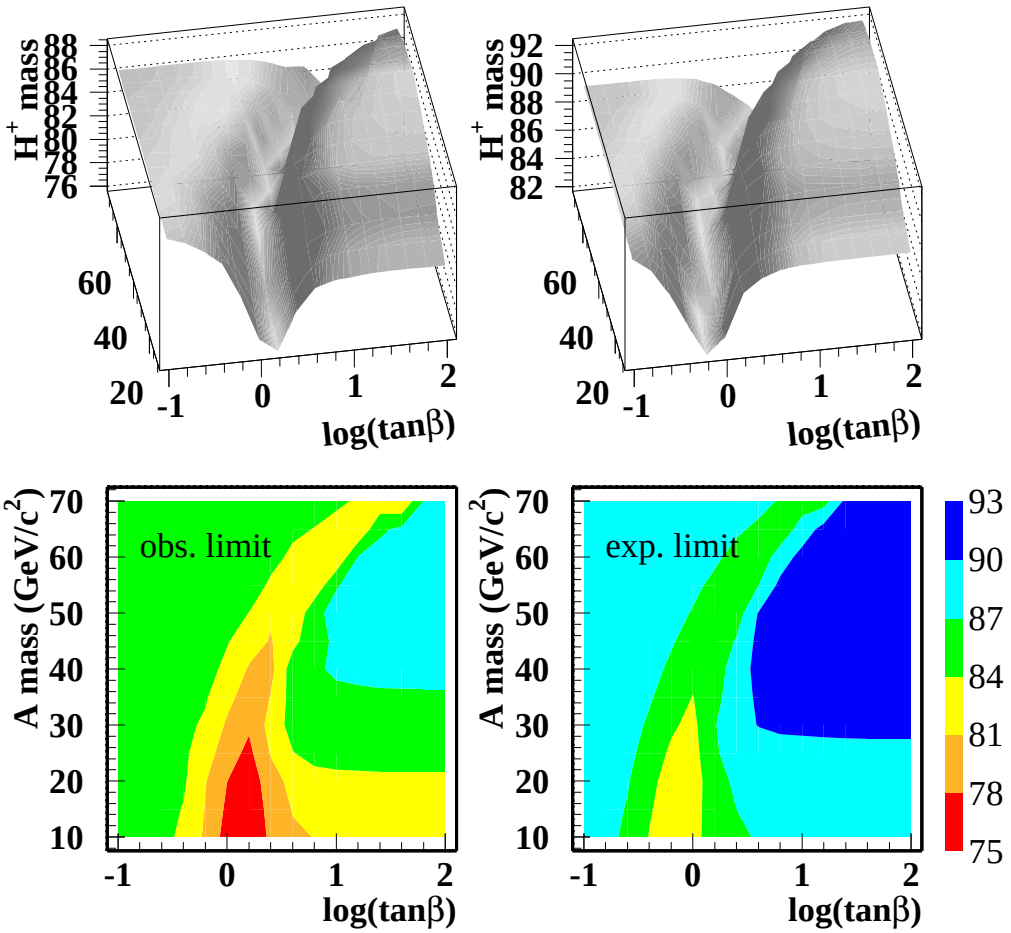

Figure 4: Type I 2HDM : Observed (left) and expected (right) 95% CL limits on the mass of the charged Higgs boson.