PROCEEDINGS

SEARCHES FOR THE NEUTRAL HIGGS BOSONS PREDICTED BY THE MSSM USING LEP DATA

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ABSTRACT: Results from 870 pb^{-1} collected by each of the four LEP experiments have been derived for the Higgs bosons predicted by the MSSM. Limits on the masses of the neutral Higgs bosons h^0, A^0, H^0, and $\tan\beta$, have been obtained by the LEP Higgs working group.

1. Introduction

The Minimal Supersymmetric extensions of the Standard Model predict two complex scalar field doublets, with a total of eight degrees of freedom. As in the Standard Model, three of them appear as the longitudinal polarization states of the gauge bosons $W^{\pm}$ and Z^0. The remaining five degrees of freedom are manifested in five physical scalar Higgs states. Assuming that the Higgs sector of the MSSM conserves CP, the physical Higgs bosons are The CP-even h^0 and H^0, the CP-odd A^0, and the charged Higgs bosons $H^{\pm}$. Results are expressed in terms of two parameters which are generally chosen as m_A and $\tan\beta$, the ratio of vacuum expectation values of the two Higgs fields.

A total of 870 pb^{-1} has been collected per LEP experiment at center-of-mass energies larger than 200 GeV. These data have been combined with the data collected previously at lower energies.

2. The neutral Higgs bosons

At the tree level, the mass of the lighter of the two CP-even Higgs bosons is limited to be less than the mass of the Z^0. Radiative corrections, particularly from loops containing the top quark, allow the lightest Higgs boson mass limit to go up to 135 GeV/c^2 [1]. In the MSSM, the Higgsstrahlung process $e^+e^- \rightarrow h^0Z^0$ proceeds as it does in the Standard

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Model, but its rate is suppressed by the factor $\sin^2(\beta-\alpha)$; $e^+e^- \to H^0Z^0$ is suppressed by the factor $\cos^2(\beta-\alpha)$ when kinematically possible. The cross-section for $e^+e^- \to h^0A^0$ is proportional to $\cos^2(\beta-\alpha)$. The searches for the Standard Model Higgs boson [2] are interpreted in the context of the MSSM identifying the SM Higgs boson H^0 with the lightest CP-even Higgs boson h^0. This paper will describe the searches for the neutral Higgs bosons through the processes $e^+e^- \to h^0A^0$ and $e^+e^- \to h^0Z^0$.

Over much of the parameter space considered, h^0 and H^0 decay predominantly into $b\bar{b}$ and $\tau^+\tau^-$, although for various choices of the parameters, the decays $h^0 \to A^0A^0$, $c\bar{c}$, gg, W^+W^- can become important.

Searches for $e^+e^- \to h^0A^0$ have been conducted in the 4b and $b\bar{b}$ $\tau^+\tau^-$ channels [3]. The main contributions to background come from four-fermions and $q\bar{q}$.

We test for the presence of a MSSM Higgs boson signal using a constrained model with seven parameters: M_{SUSY}, M_2, μ, A, $\tan\beta$, m_A and $m_{\tilde{g}}$. At the electroweak scale all of the soft SUSY-breaking parameters in the sfermion sector are set to M_{SUSY}. M_2 is the SU(2) gaugino mass parameter, μ is the supersymmetric Higgs boson mass parameter, A is the common trilinear Higgs-squark coupling parameter. Three benchmark scenarios have been considered [4].

2.1 The no-mixing scenario

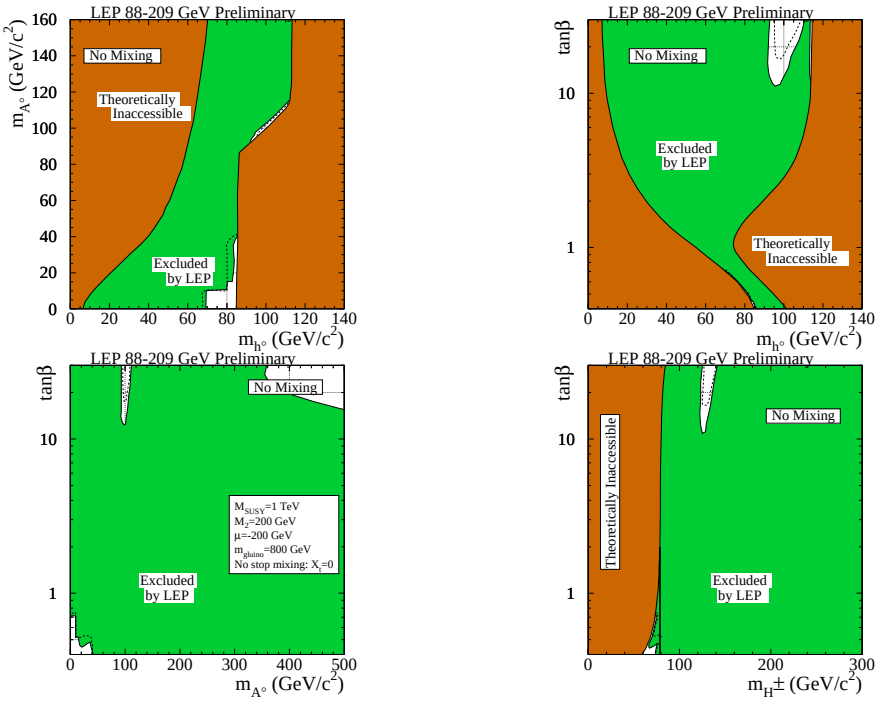

Figure 1: The MSSM exclusion for the no-mixing scenario. This figure shows the excluded and theoretically inaccessible regions as functions of the MSSM parameters in four projections: upper left for the (m_{h^0},m_A) plane, upper right for the (m_{h^0},$\tan\beta$) plane, lower left for the (m_A,$\tan\beta$) plane and lower right for the ($m_{H^\pm}$,$\tan\beta$) plane.

In the so-called no-mixing scenario, it is assumed that there is no mixing between the scalar partners of the left-handed and the right-handed top quarks. The following values and ranges for the parameters have been chosen: M_{SUSY} = 1 TeV/c^2, M_2 = 200 GeV/c^2, μ = -200 GeV/c^2, $X_t = A - \mu \cot\beta = 0$, $0.4 \leq \tan\beta \leq 50$, 4 GeV/$c^2$ $\leq m_A \leq$ 1 TeV/c^2, $m_{\tilde{g}}$ = 800 GeV/c^2. Most of the Monte Carlo samples assume that the h^0 and the A^0 have decay widths which are small compared to the resolutions of the reconstructed masses. This assumption is only valid for $\tan\beta \leq 30$, hence higher values of $\tan\beta$ are not considered.

The 95% CL exclusion contours are shown in Figure 1 for the no-mixing scenario. For $\tan\beta \leq 0.7$, there is an unexcluded region with m_A below 40 GeV/c^2 and m_{h^0} above 65 GeV/c^2. In this region the decay $h^0 \to A^0A^0$ opens and it dominates over $h^0 \to b\bar{b}$ decays and exclusion using b-tagged channels becomes impossible. For unexcluded models in the no-mixing scenario, with $\tan\beta \leq 0.7$, the mass of the charged Higgs bosons is less than 74 GeV/c^2. The lower bound obtained by the combination of direct searches at LEP [5] is 78.6 GeV/c^2 assuming that charged Higgs boson decays exclusively into cs or $\tau\nu$. This assumption is broken by decays to W^*A^0 with a branching ratio which can be as large as 0.6 for $\tan\beta \leq 0.7$ and a charged Higgs mass of 74 GeV/c^2. For $\tan\beta \geq 0.7$ the observed (expected median) lower bounds on m_{h^0} and m_A are respectively 91.5 (95.0) and 92.2 (95.3) GeV/c^2. Values of $\tan\beta$ between 0.7 and 10.5 are excluded (expected bounds are 0.8 and 16.0).

2.2 The m_{h^0}-max scenario

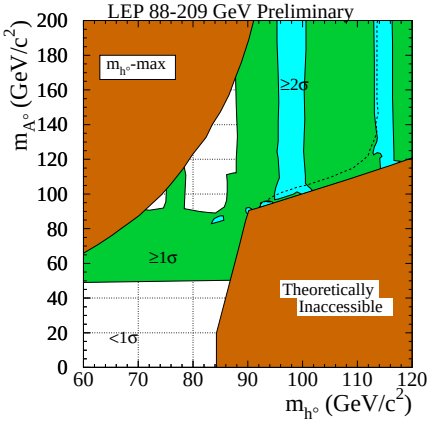

Figure 2: The distribution of the confidence level CL_b for the m_{h^0}-max scenario. Results from the h^0Z^0 searches are combined with the results of the h^0A^0 searches.

The m_{h^0}-max scenario, is designed to yield the maximal value of m_{h^0}. This scenario differs from the no-mixing scenario only by the value of the stop mixing parameter X_t which is now set to 2 M_{SUSY}. In the white domain of Figure 2, the observation either shows a deficit or is less than 1σ over the background prediction. Structures on the $m_{h^0} = m_A$ line could arise from $e^+e^- \to h^0A^0$ and vertical structures could be due to the features of $e^+e^- \to h^0Z^0$. Effects larger than 2 σ are consistent with the expectation for H^0Z^0, h^0Z^0 and h^0A^0 production for some MSSM parameter combination [6]. As shown in Figure 3, the observed (expected median) lower bounds on m_{h^0} and m_A are respectively 91.0 (94.6)

and 91.9 (95.0) GeV/c^2. Values of $\tan\beta$ between 0.5 and 2.4 are excluded (expected bounds are 0.5 and 2.6).

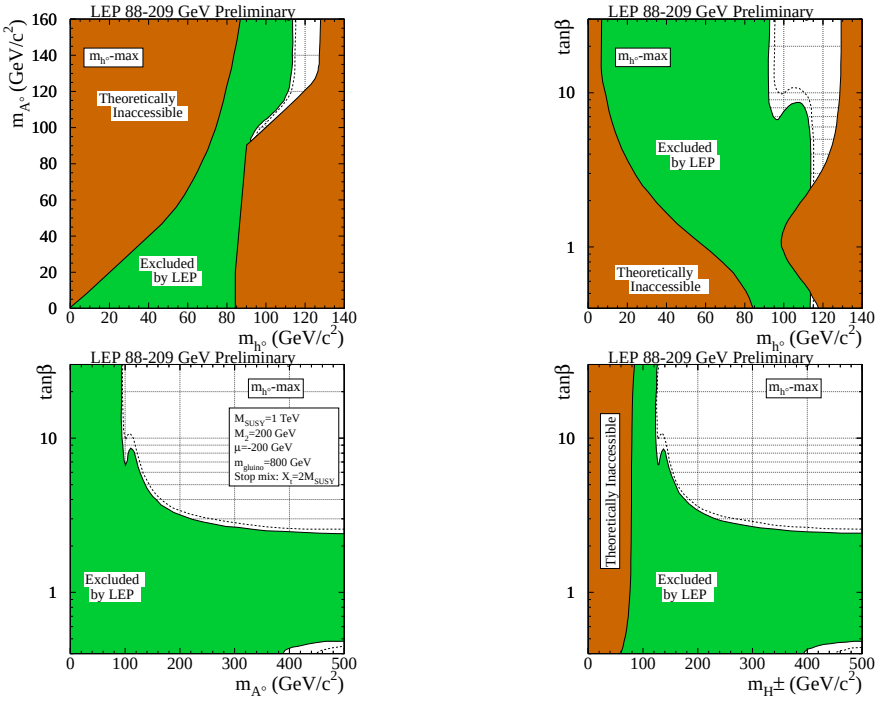

Figure 3: The MSSM exclusion for the m_{h^0}-max scenario. This figure shows the excluded and theoretically inaccessible regions as functions of the MSSM parameters in four projections: upper left for the (m_{h^0},m_A) plane, upper right for the (m_{h^0},tan β) plane, lower left for the (m_A,tan β) plane and lower right for the ($m_{H^\pm}$,tan β) plane.

These results can also be expressed in terms of coupling strength limits as shown in Figure 4.

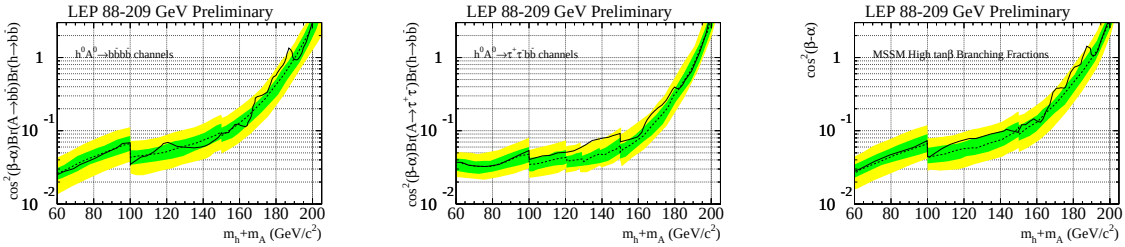

Figure 4: The first two figures from left show the limit on $\cos^2(\beta-\alpha)\mathrm{BR}(h^0\to b\bar{b})\mathrm{BR}(A^0\to b\bar{b})$ and on $\cos^2(\beta-\alpha)\mathrm{BR}(h^0\to b\bar{b})\mathrm{BR}(A^0\to\tau^+\tau^-)$ respectively, assuming $m_{h^0}\approx m_A$ and the energy dependence of the m_{h^0}-max scenario. The third figure shows the limit on $\cos^2(\beta-\alpha)$ assuming $m_{h^0}\approx m_A$, and the fixed branching fractions $\mathrm{BR}(h^0\to b\bar{b})$=0.94, $\mathrm{BR}(A^0\to b\bar{b})$=0.92, $\mathrm{BR}(h^0\to\tau^+\tau^-)$=0.06 and $\mathrm{BR}(A^0\to\tau^+\tau^-)$=0.08, typical of the m_{h^0}-max scenario for values of $\tan\beta$ larger then 10. The solid line is the observed limit, and the dashed line is the median expected limit in an ensemble of hypothetical experiments in the absence of signal. Contours indicating the 68% and the 95% probability bands centered on the median expectation show the expected variation of the limit in an ensemble of background-only experiments.

2.3 The large-μ scenario

The third scenario, called the large-μ scenario, is designed to illustrate choices of the MSSM parameters for which h^0 does not decay into a pair of b quarks. The inclusion of the flavour-independent searches in this scenario adds enough sensitivity to exclude it at the 95% CL.

3. Summary

Searches for the Higgs bosons predicted by the extensions of the Standard Model with 2 Higgs-field doublets have been carried out by the four LEP experiments and results have been combined by the LEP Higgs working group. No evidence of Higgs boson production was found and in the absence of signal, limits on masses, $\tan\beta$ and branching fractions have been set at 95% CL. All results are still preliminary. Individual experiments have updated the results used for the presented combination : year 2000 data samples have been fully reprocessed, the precise knowledge of the LEP centre-of-mass energy has been propagated to final results, additional simulated event samples have been generated and some selection algorithms have been improved. Only small changes to the presented combined results are expected.

Acknowledgments

I wish to express my gratitude to all my colleagues from the four LEP experiments for their help in the preparation of this contribution.

References

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[5] The ALEPH, DELPHI, L3, and OPAL Collaborations, and the LEP Higgs Working Group, LHWG Note 2001-05.

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