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Higgs Searches at LEP2 : Present and Future

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SW9812

APR 10 1998

Invited talk at the International Workshop on Physics Beyond the Standard Model : from Theory to Experiment
Valencia, Spain, October 13-17, 1997

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Institut National
de Physique Nucléaire
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de Physique des Particules

Bâtiment 200 - 91405 ORSAY Cedex

LAL 98-04
February 1998

HIGGS SEARCHES AT LEP2 : PRESENT AND FUTURE

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Prospects of Higgs discovery at LEP2 are discussed in the framework of MSSM. Results obtained in 1996 on hZ, hA and H^+H^- are interpreted in the MSSM framework and in some possible extensions. Preliminary results of 1997 are indicated. Estimates for a discovery at 200 GeV energy are discussed.

1 Introduction

LEP has reached a crucial energy domain for searching the Higgs boson within supersymmetry. The minimal supersymmetric extension of the Standard Model (SM), known as MSSM, predicts an upper limit on the Higgs boson mass of 125 GeV. In section 2, I discuss in more detail a predictive scenario which gives an upper limit $\sim$ 103 GeV on the Higgs boson mass.

A Higgs boson mass below 103 GeV seems within LEP reach and, in section 3, I will discuss the requested machine performances for a discovery.

Present searches, in the SM (a limiting case of MSSM) and in the general MSSM scheme, will be presented in section 4 and 5. Results are based on published data from 1996.

Future prospects based on the first results at 183 GeV and on expectations at 200 GeV will be given in section 6.

Finally, some more general searches, beyond MSSM, are described in section 7.

2 MSSM predictions

One may recall that the SM, "stricto sensu" (i.e. no new physics appears up to the Planck scale), predicts a Higgs boson mass well above LEP2 reach.

Supersymmetry, in its general version that is allowing for more than 2 Higgs doublets and/or with some singlets, gives an upper limit of about 150 GeV. The minimal version, called MSSM, gives a limit[1] at 125 GeV. More precisely, one has :

$$m_h < M_Z|cos2\beta| \bigoplus 48.5GeV\sqrt{ln\frac{m_{\tilde{t}_1}m_{\tilde{t}_2}}{m_t^2}} \bigoplus Mixing \qquad (1)$$

where the top mass $m_t \sim$175 GeV and where $m_{\tilde{t}_{1,2}}$ are the stop masses. The first term is the tree level result, the second and third one are due to loop

corrections.

The critical dependence on tanβ comes from the tree level term of formula (1), which can be written :

$$(m_h)_{Tree} = \frac{tan^2\beta - 1}{tan^2\beta + 1} M_Z$$

Mixing effects, not explicitly written, can also provide extra contributions.

This upper limit is reached when m_A, the mass of the CP odd boson A, is above the upper bound on m_h. When A is lighter, one should consider the two complementary channels :
$e^+e^- \to Z^* \to hZ$ proportional to $\sin^2(\alpha - \beta)$ and $e^+e^- \to Z^* \to hA$ proportional to $\cos^2(\alpha - \beta)$, where α is the mixing angle between the two CP even bosons H_u and H_d appearing in the two doublets (the resulting physical states being h and H).

The SUGRA scheme, with mass unification for sfermions and Higgs bosons, leads to very definite predictions. Two solutions can be distinguished which give different masses for the Higgs boson h.

2.1 a/Low tanβ scenario

At low tanβ, well below m_t/m_b, renormalization group equations (RGE[2]) are influenced by the top Yukawa coupling. In particular electroweak symmetry breaking (EWSB) is triggered in the SUGRA scheme by the top Yukawa coupling term. To see this, one can write the EWSB solution as :

$$\frac{M_Z^2}{2} = -\mu^2 + \frac{m_{H_d}^2 - m_{H_u}^2 tan^2\beta}{tan^2\beta - 1} \tag{2}$$

where μ is the Higgs mixing term appearing in the SUSY superpotential.

At GUT scale $m_{H_d}^2$ and $m_{H_u}^2$ get a common value m_0^2. Provided that the top Yukawa coupling is not too small, the $m_{H_u}^2$ term can become negative and cancel the $-\mu^2$ term to generate M_Z^2 with the correct sign.

In this scenario, given the RGE, the top Yukawa coupling converges to a fixed quantity at M_Z scale , irrespective of it's value at the GUT scale (the so-called infra-red-fixed-point solution IRFP). This solution, m_t ~200 GeVsinβ, gives tanβ ~ 1.6-2 and therefore a tight upper bound[1] on $m_h < 103 GeV$. Adding one s.d. on the measured top mass increases the bound to 110 GeV.

It has been argued[6] that the generation of M_Z^2 in (2) results from a "fine-tuned" cancellation between large quadratic terms. To see this, one can compute M_Z^2 in terms of m_0 and $M_{1/2}$, the common gaugino mass at GUT. For

tanβ=2, one approximately gets :

$$\frac{M_Z^2}{2} \sim -\mu^2 + m_0^2 + 5M_{1/2}^2$$

Searches on right handed sleptons, which give a mass limit[4] approaching 80 GeV, together with searches on charginos[5], allow to set combined lower limits on m_0 and $M_{1/2}$. From these, one finds that μ reaches 270 GeV. It is therefore a matter of personal taste to decide if this value is too large compared to $M_Z^2/2$.

In the numerical example given above, one expects a Higgs boson h at 80 GeV and a heavy A with $m_A \sim \mu$. Note that μ is taken positive since the negative solution would lead to a Higgs boson mass (mixing term effect) below present limits from LEP. One could alternatively assume a small top Yukawa coupling at GUT scale and depart from the IRFP solution. This would imply m_t <200 GeVsinβ and therefore a larger tanβ. A heavier Higgs mass is therefore possible.

This IRFP scenario has two degrees of freedom ($M_{1/2}$ and m_0) and can therefore be well tested experimentally. It provides[7] a solution compatible with :

- Grand unification including b-τ mass unification
- Electro-weak symmetry breaking
- Heavy dark matter for cosmology
- Precision measurements

2.2 *b/Large tanβ scenario :*

When tan$\beta \sim m_t/m_b$, one can no longer neglect the impact of bottom and τ Yukawa coupling constants in the RGE. IRFP solutions also occur in this scenario but it seems that Yukawa coupling constants cannot be easily unified at the GUT scale.

Recently[7] this problem has received renewed attention and it seems that there is some mismatch between the resulting bottom mass value at the M_Z scale and the need to control the contributions to b$\rightarrow$ sγ. The solution would be to increase to $\sim$1 TeV level the masses of charginos and charged Higgs, which grossly fails the requirement of no "fine tuning". In this scenario, the Higgs gets heavy and escapes detection at LEP.

As usual, there are ways out which again consist in relaxing[8] some of the unification criteria. Some "fine tuning" cannot be however avoided.

To summarize, scenario a/ with an IRFP solution can fulfill all requirements (unification, dark matter, precision measurements). It predicts a light Higgs boson and therefore LEP2, as discussed in the next section, can provide a decisive test of this model.

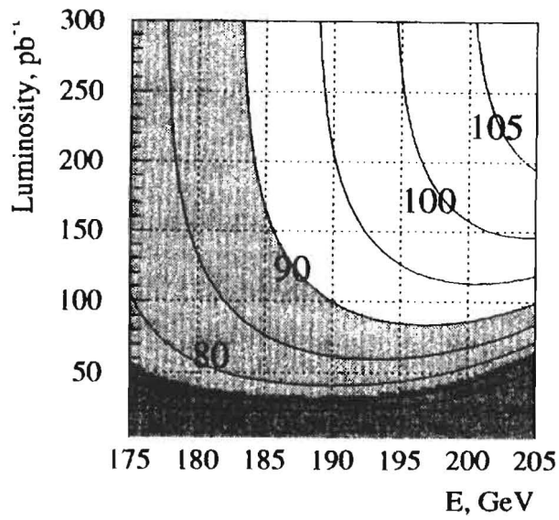

Figure 1: Iso-mass discovery curves of a SM Higgs boson in terms of energy and integrated luminosity/experiment.

3 How to reach m_h up to 103 GeV ?

During 1997, LEP has reached an energy of 184 GeV and provided up to 2 pb^{-1} per day to each of the four experiments. The integrated luminosity reaches only 60 pb^{-1} due to a late start-up (the fire) and to some low energy runs (Z data for calibration, 130-136 GeV run). Next year more than 100 pb^{-1} should be delivered per experiment.

The maximal energy of LEP depends primarily on the field gradient of the supraconductive cavities. 98 % of the cavities are able to reach 7 MV/m, while the nominal field is at at 6 MV/m. With some reconditioning of the bad cavities, it seems therefore possible to reach 200 GeV (recall that the radiative losses go like the 4th power of the beam energy). Cooling problems seem also under control, while the choice of beam optics is still under investigation.

Figure 1 shows the discovery potential (i.e. more than 5σ effect) of LEP2 for the Higgs boson in terms of energy and luminosity delivered per experiment. One clearly sees that about 250 pb^{-1} per experiment are needed to reach 103 GeV. Since the 200 GeV energy would not be reached before 1999 (upgrade

of cryoplants and reconditioning of bad cavities), this means that LEP should run in year 2000 to collect the 250 pb^{-1}. While technically feasible, this run is not yet funded financially.

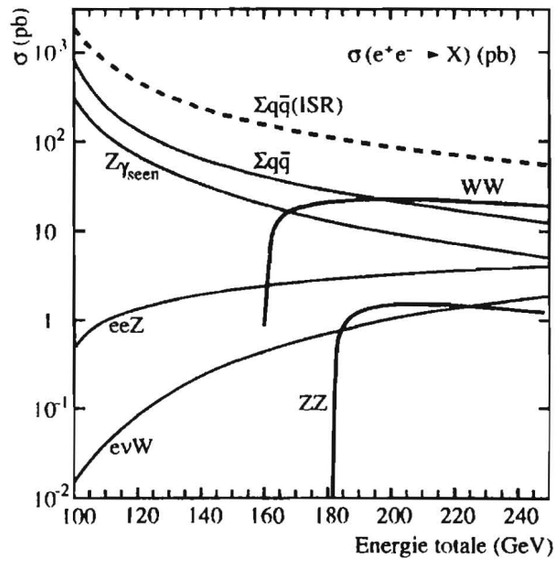

Figure 2: Typical cross-sections at LEP2.

4 SM Search

In 1996, $\sim$ 10 pb^{-1} has been collected at 161 GeV and about the same at 172 GeV. In 1997, as already mentioned, more than 50 pb^{-1} was collected at 183-184 GeV. An update of the Higgs searches was presented at the Jerusalem conference based on 5 pb^{-1}, while recently[5] the 4 experiments have given very preliminary results based on the 1997 data (see section 6). As stated in section 2, the so-called SM search described here can be considered as a limiting case of the MSSM search when A is heavy. hZ becomes accordingly the only relevant channel with the same cross-section than in the SM case.

Figure 2 illustrates the hierarchy of processes involved in this type of search. The hZ cross-section varies typically between 0.2 and 1 pb. h decays in about 90 % cases into $b\bar{b}$. b-tagging therefore allows the necessary rejection of W channels. In the recent years, LEP experiments have achieved

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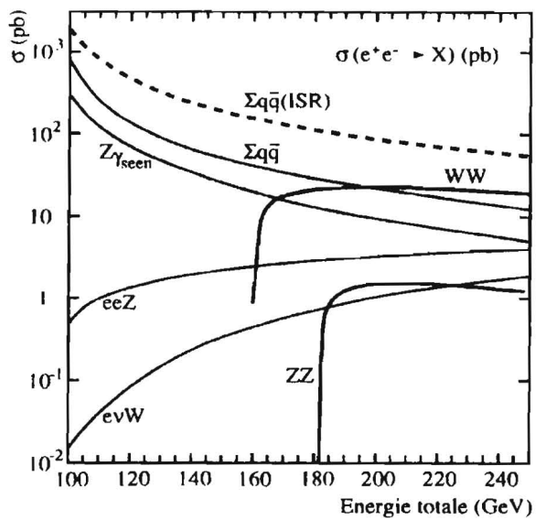

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impressive performances in the field, mainly driven by the measurement of R_b^0. The net result is a ~1.5 increase in efficiency as compared to the expectations given during the LEP2 workshop.

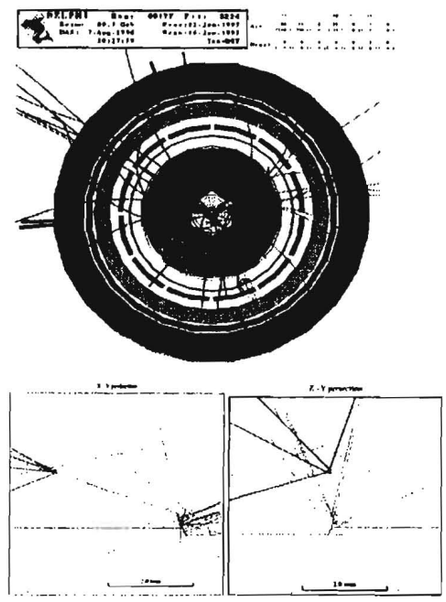


Figure 3: $H\nu\bar{\nu}$ candidate at 161 GeV with evidence for b-type secondary vertex. Estimated h mass : 65^{+5}_{-2}.

The results of the 4 analyses[10] are given in table 1. One can see that there are very few candidates with the noticeable exception of L3 for which one considers the candidates as "weighted" by their probabilities of being signal-like . An example of candidate is given in figure 3 showing a striking evidence for a secondary vertex with large mass and large multiplicity incompatible with a charm decay. This event is assigned to the H $\nu\bar{\nu}$ category since it has a missing mass compatible with a Z. The best SM explanation would be a ZZ* with Z into $\nu\bar{\nu}$ and Z* into $b\bar{b}$.

The 1996 data have been combined[11] giving the limit :

$$m_h > 77.1 \text{ GeV at } 95\ \%\ \text{C.L.}$$

Table 1: Results on SM searches

Expt	Eff	Expect	Seen	Mass Limit	5 pb-1 183 GeV
ALEPH	29%	0.9	0	70.7 GeV	74.0 GeV
DELPHI	29%	4.3	2	66.2 GeV	73.0 GeV
L3	40%	38.3	33	69.5 GeV	72.0 GeV
OPAL	31%	3.6	2	69.4 GeV	-

Table 2: Results on hA searches at high tanβ

Expt	Eff	Expect	Seen	Mass Limit	5 pb-1 183 GeV
ALEPH	54%	0.8	0	62.5 GeV	64.5 GeV
DELPHI	43%	2.4	0	59.5 GeV	62.0 GeV
L3	50%		5	58.4 GeV	-
OPAL	38%	7.4	8	56.1 GeV	-

for an expected limit of 75 GeV.

5 MSSM Search

5.1 *hA Search*

For large tanβ, h and A decay into $b\bar{b}$ in 92% of the cases and the rest into $\tau^+\tau^-$ (in fact the branching ratio for h depends also on the mixing angle α). The 4b final state can be analyzed with high efficiency and low background. $m_h \sim m_A$ in most of the relevant domain. The decay of h into 2A occurs for low tanβ, at the lower limit of the physical domain (see fig. 4). Taking into account the EWSB constraint which predicts a large m_A for these parameters, one may ignore this possibility. Note also that for tanβ<1, the charged Higgs search in top decays[12] allows to set a limit on m_A. The results obtained by the LEP collaborations[13] data are summarized in table 2 and 3 with preliminary updates based on 183 GeV data given at the Jerusalem conference.

5.2 *Interpretation*

MSSM results can be interpreted, at the tree level, in terms of two independent parameters, usually chosen as m_h and tanβ or m_A and tanβ. Loop correction modify this picture and introduce some dependence on SUSY parameters as can be seen in formula (1). The four LEP experiments have chosen the conventions of the LEP2 workshop[1] with 2 extreme cases :

Table 3: Results on hZ+hA searches

Expt	limit on m_h	limit on m_A
ALEPH	64.5 GeV	64.5 GeV
DELPHI	62.0 GeV	62.0 GeV
L3	58.4 GeV	58.4 GeV
OPAL	56.0 GeV	50.6 GeV

- Neglect mixing, and assume $M_S \sim 1$TeV, where M_S stands for the "average" stop mass.

- Maximal mixing, where the mixing coefficient is related to M_S such that the loop correction maximizes the Higgs mass.

Figure 4 gives an example of the region covered by the 1996 search.

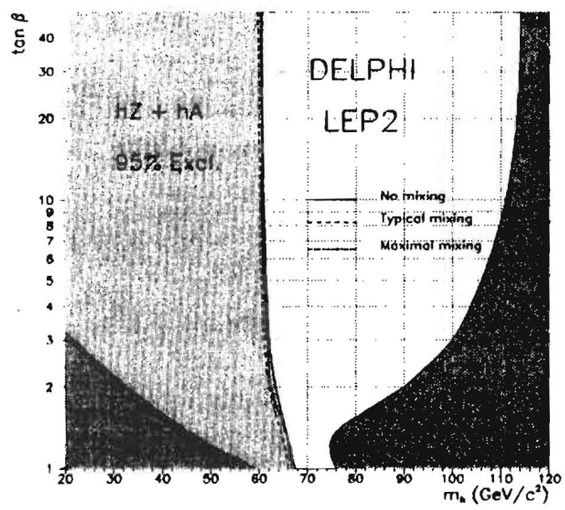


Figure 4: The light shaded region is 95% C.L. excluded based on 1996 Delphi data. The dark shaded regions are unphysical in MSSM.

It is not yet clear that this standard approach provides the correct limit on m_h and m_A and whether it would not be possible to produce "holes" by carefully choosing the SUSY parameters. From [14], it seems that there are

indeed such possibilities but it is fair to say that they disappear when sufficient luminosity (i.e. combining the 4 LEP results) is reached.

5.3 H^+H^- Search

In a strict MSSM model one has $m^2_{H^\pm} \sim m^2_A + m^2_W$ and therefore this channel is not yet relevant. Possible extensions of MSSM may however allow this channel.

Experimentally, the signature is difficult due to WW contamination which provides the same decay modes into $c\bar{s}$ and $\tau\bar{\nu}$.

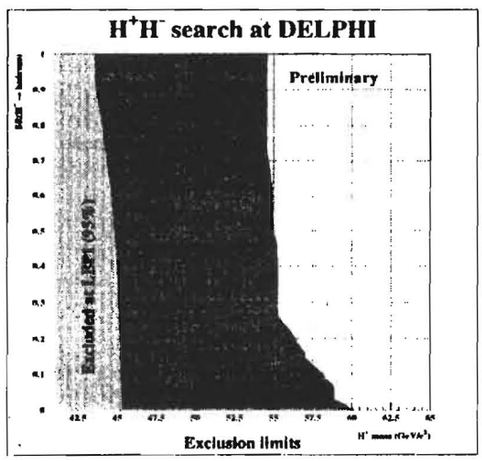


Figure 5: H^+H^- results based on 1996 data.

The present limit is given in figure 5 leading to :

$$m_{H^\pm} > 54.5 \text{ GeV at 95 \% C.L. limit from DELPHI}^{15}$$

This limit can be improved by the search[12] $t \to H^+b$, leading to $m_{H^\pm} > 160$ GeV for large $\tan\beta$ or when $\tan\beta < 1$.

6 Prospects at Higher Energies

With 183 GeV data one can expect an exclusion up to about 88 GeV with the four experiments. Preliminary limits were given at a LEPC, summarized in table 4 .

Table 4: Preliminary SM Higgs boson mass limits

Expt	limit	Luminosity(pb^{-1})
ALEPH	88.6 GeV	55
DELPHI	83.6 GeV	53.5
L3	82.2 GeV	36
OPAL	82 GeV	39

For MSSM, the exclusion limit from DELPHI is shown in figure 6. From these preliminary results one concludes that :

$$m_h > 73 \text{ GeV and } m_A > 75 \text{ GeV at } 95\ \% \text{ C.L.}$$

No update on the charged Higgs search was given, but one may expect a combined limit better than 65 GeV.

At 200 GeV, as mentioned in section 3, a discovery reach of 103 GeV is possible in the SM-like scenario. This would exclude the low $\tan\beta$ (see discussion of section 2) as shown in figure 7.

7 Beyond MSSM

Higgs bosons may decay invisibly into pairs of neutralinos. If this decay becomes dominant, one can still detect the hZ mode through the Z decays. The limits[10] are m_h >69.6 GeV for L3 and m_h >71.2 GeV for ALEPH.

One may also relax MSSM constraints and perform a general 2-doublet search involving h and A. One may even allow for CP violation and consider the interplay of 3 channels hZ,hA and AZ. As discussed in [16], the 3 couplings are related which allows a significant mass domain exclusion. Figure 8 shows results obtained by DELPHI in this scheme[17]. Note that the limits do not cover the scenario of a very light A which corresponds to a set of complicated detection possibilities. Note also that the effect of relaxing the dominance of the $b\bar{b}$ decays is also displayed.

8 Conclusion

Present Higgs limits are already tightly constraining the low $\tan\beta$ scenario of MSSM-GUT. Combining the 4 experiments, a complete coverage of this scenario can be reached provided LEP can run for 2 years at 200 GeV.

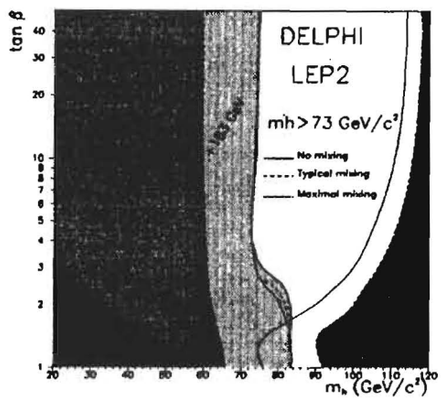


Figure 6: 95% C.L. exclusion contours based on 1997 DELPHI preliminary results.

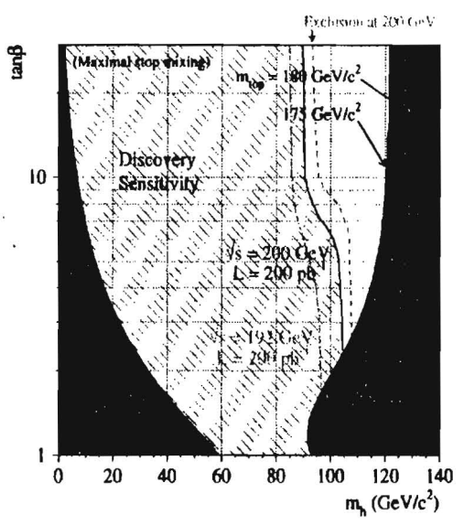
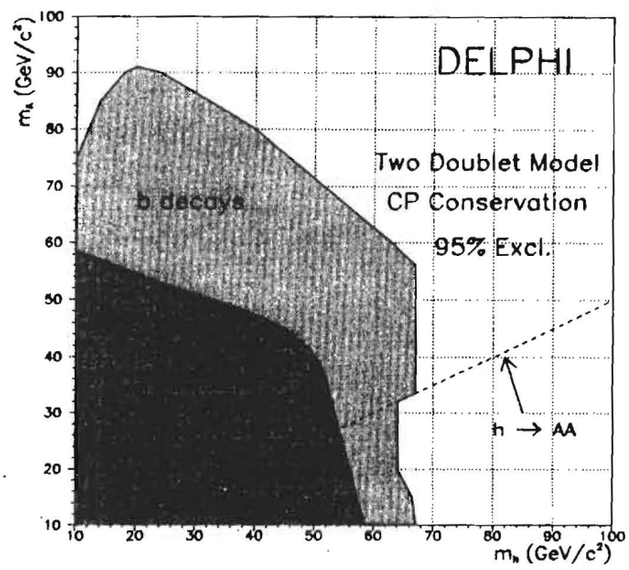


Figure 7: Discovery contours in MSSM with 200 pb^{-1} at 200 GeV.



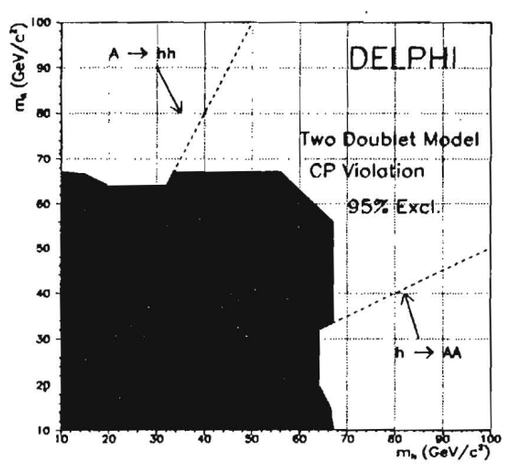


Figure 8: Upper plot gives exclusions contours obtained in a 2-doublet model with and without use of b-tagging. Plot below gives the corresponding contours when CP is not conserved.

Acknowledgements

Useful discussions with B. Murray, S. Pokorski, C. M. Rivero, and A. Sopczak are gratefully acknowledged.

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