Profile of Two-Higgs-Doublet-Model Parameter Space

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We review recent work on constraining the parameter space of the Two-Higgs-Doublet Model by theoretical and experimental results. Some characteristics of the model, in particular the distribution of masses in the surviving parameter space, are discussed.

1 Introduction

We report on recent work on constraining the multi-dimensional parameter space of the Two-Higgs-Doublet Model by theoretical and experimental results [1, 2].

As compared with the Standard Model (SM), the Two-Higgs-Doublet Model (2HDM) allows for an additional mechanism for CP violation [3]. This is one of the main reasons for continued strong interest in the model [4].

Several experimental constraints restrict its parameter space. The $B \to X_s\gamma$ rate excludes low values of the charged-Higgs mass, $M_{H^\pm}$ [5], whereas $B-\bar{B}$ oscillations and the branching ratio R_b for $Z \to b\bar{b}$ exclude low values of $\tan\beta$. The precise measurements at LEP of the ρ parameter constrain the mass splitting in the Higgs sector, and force the masses to be not far from the Z mass scale [6].

From the theoretical point of view, there are also consistency conditions. The potential has to be positive for large values of the fields [7, 8]. Furthermore, we require the tree-level Higgs–Higgs scattering amplitudes to be unitary [9]. Together, these constraints dramatically reduce the allowed parameter space of the model. In particular, the unitarity constrain excludes large values of $\tan\beta$, *unless* μ is reasonably large. This limit is basically the decoupling limit [10].

Our recent study [2], restricted to the so-called "Type II" version, where up-type and down-type quarks couple to different Higgs doublets, uses rather complete and up-to-date experimental results, as well as accurate theoretical predictions for the above quantities. We consider a model with the Z_2 symmetry respected by the quartic couplings, i.e., no λ_6 and λ_7 couplings. Otherwise, we allow for full generality. In particular, we allow for CP violation, taking λ_5 complex. (For a definition of the potential, see [2].) The neutral Higgs boson sector will thus contain three bosons, described by a 3×3 mixing matrix R. These three neutral Higgs bosons will in general all have CP-violating Yukawa couplings. A related study, focused more on large values of $\tan\beta$, was also presented at this Workshop [11].

2 Results

We parametrize the model in terms of the masses of the two lightest neutral Higgs bosons, together with the charged Higgs boson mass, $\tan\beta$, the soft parameter μ^2, and the rotation matrix R of the neutral sector. The third (heaviest) neutral mass is then calculable, as well as the quartic couplings, λ_i (see [12, 13]).

We establish allowed regions in the $\tan\beta$–$M_{H^\pm}$ plane by the following procedure: For each point in this plane, we scan over the parameters $\boldsymbol{\alpha} = \{\alpha_1, \alpha_2, \alpha_3\}$, defining the mixing matrix R in the neutral-Higgs sector, imposing the absolute theory constraints of positivity and unitarity. At each point, we evaluate a χ^2 penalty corresponding to the experimental constraints, adopting the "best" point (lowest χ^2) in $\boldsymbol{\alpha}$.

For two values of μ (200 and 500 GeV), we show in Fig. 1 the allowed regions in the $\tan\beta$–$M_{H^\pm}$ plane, taking into account the theoretical constraints mentioned above, the LEP2 non-discovery, the very precise $\Delta\rho$ measurements at LEP, as well as the B-physics constraints ($B \to X_s\gamma$, mainly), and R_b. The masses of the two lightest neutral Higgs bosons are here kept fixed, at $M_1 = 100$ GeV and $M_2 = 300$ GeV or 500 GeV.

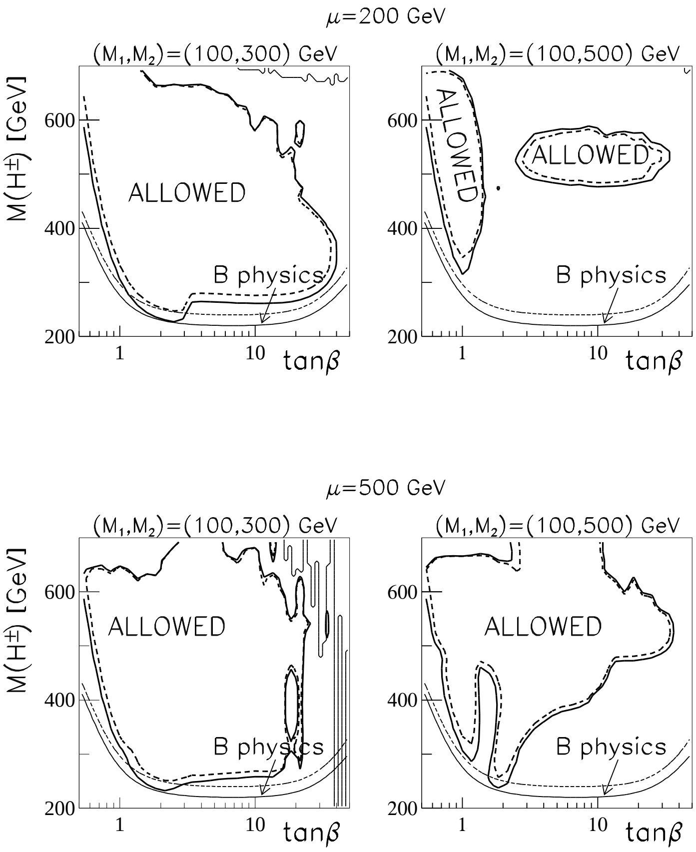

Figure 1: Allowed regions in the $\tan\beta$–$M_{H^\pm}$ plane, taking into account theoretical and experimental constraints.

The over-all surviving regions of parameter space depend significantly on the "soft" parameter μ^2. At low or negative values, the unitarity constraint will cut off the allowed region already at moderate values of $\tan\beta$. We have therefore shown results for a couple of positive values of μ^2, the higher one approaching the so-called decoupling limit.

3 Distribution of Higgs masses

It turns out that, if μ is comparable with M_2, or smaller, the distribution of M_3-values will be very narrow, especially at large values of $\tan\beta$. This is illustrated in Fig. 2, for $M_1 = 100$ GeV, and two sets of (M_2, μ) values: $(300, 200)$ GeV and $(500, 500)$ GeV. Also, we note that for $M_2 = 500$ GeV and $\mu = 500$ GeV (lower panels), low values of $M_{H^\pm}$ are excluded. This is basically because of the $\Delta\rho$ constraint.

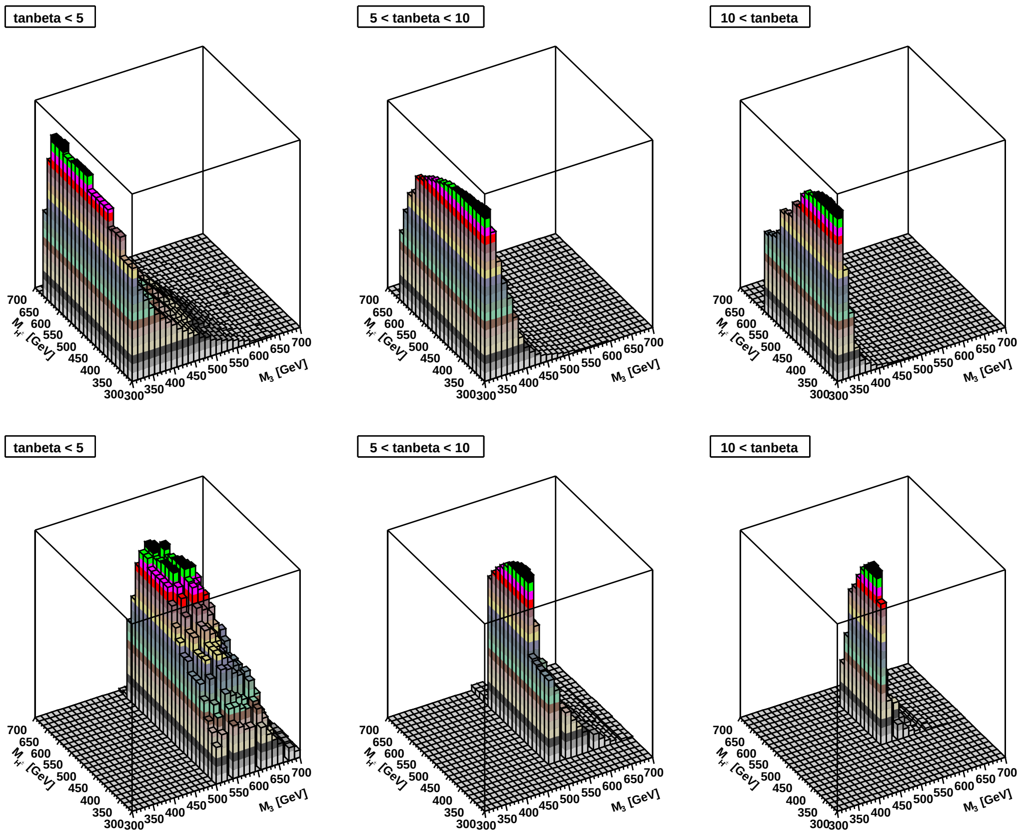

Figure 2: Distribution of M_3-values for fixed $M_1 = 100$ GeV. Top: $M_2 = 300$ GeV and $\mu = 200$ GeV; bottom: $M_2 = 500$ GeV and $\mu = 500$ GeV. Three slices of $\tan\beta$-values are shown.

On the other hand, if μ is larger than M_2, the distribution can be considerably wider, as is seen in Fig. 3.

4 Summary

We have shown that the constraints of positivity and tree-level unitarity of Higgs–Higgs scattering, B-physics results, together with the precise LEP measurements, in particular of the ρ-parameter at LEP, exclude large regions of the 2HDM (II) parameter space. High values of $\tan\beta$ are excluded unless μ is large, allowing M_2 and M_3 both to be heavy. Furthermore, M_2 and M_3 should be reasonably close to each other. Improved precision of the $\bar{B} \to X_s\gamma$ measurement could significantly reduce the remaining part of the parameter space, but it appears unlikely that the model could be excluded other than by a negative search at the LHC.

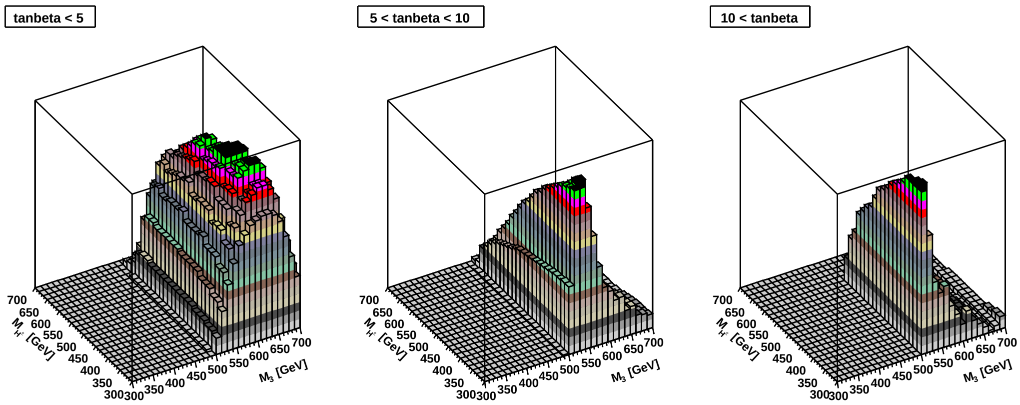

Figure 3: Distribution of M_3-values for $M_1 = 100$ GeV, $M_2 = 300$ GeV and $\mu = 500$ GeV. Three slices of $\tan\beta$-values are shown, increasing to the right.

Acknowledgments

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