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CONSTRAINTS ON THE CHARGED HIGGS SECTOR FROM B PHYSICS *

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Abstract

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ABSTRACT

We present the bounds that can be obtained on the charged Higgs sector in two-Higgs-Doublet Models from measurements at LEP of the decay $B \to D\tau\nu$, and from searches by CLEO for the inclusive decay $b \to s\gamma$.

Many extensions of the Standard Model (SM) predict the existence of an enlarged Higgs sector beyond the minimal one-doublet version[1]. The simplest extensions are models with two-Higgs-Doublets (2HDM), which predict a physical spectrum of three neutral Higgs scalars, two of which are CP-even (h^0, H^0) while one is CP-odd (A^0), and two charged Higgs scalars ($H^\pm$). We consider two distinct 2HDM which naturally avoid tree-level flavor changing neutral currents. In Model I, one doublet (ϕ_2) provides masses for all fermions and the other doublet (ϕ_1) decouples from the fermion sector. In a second model (Model II), ϕ_2 gives mass to the up-type quarks, while the down-type quarks and charged leptons receive their masses from ϕ_1. Supersymmetry and many axion theories predict couplings of the type present in Model II. Each doublet obtains a vacuum expectation value (vev) v_i, subject only to the constraint that $v_1^2 + v_2^2 = v^2$, where v is the usual vev present in the SM. In a general 2HDM, the charged Higgs mass $m_{H^\pm}$ and the ratio of vevs, $v_2/v_1 \equiv \tan\beta$, are *a priori* free parameters, as are the masses of all the neutral Higgs fields. However, in supersymmetric models, mass relationships exist between the various Higgs scalars. At tree-level, in such models, only two parameters are required to fix the masses and couplings of the entire scalar sector, but once radiative corrections are included[2], the values of the top-quark and squark masses also need to be specified.

The strongest direct search limits on charged Higgs bosons are from LEP[3], with $m_{H^\pm} \gtrsim M_Z/2$. These charged scalars may also reveal themselves through contributions to a variety of low-energy processes. Previous analyses[4] of the $H^\pm$ contributions to processes such as $B^0 - \bar{B}^0$, $D^0 - \bar{D}^0$, and $K^0 - \bar{K}^0$ mixing have found the approximate bound $\tan\beta \gtrsim m_t/600\,\text{GeV}$. $H^\pm$ bosons may also mediate the tree-level decay[5] $B \to D\tau\nu$. In Model I, enhancements over the SM rate for this process only occur for values of $\tan\beta$ which violate the above bound from meson anti-meson mixing. However, enhancements are found in Model II for large values of $\tan\beta$. In Fig. 1 we show the ratio of $B(B \to D\tau\nu)$ in Model II to that of the SM as a function of $\tan\beta$, for various values of $m_{H^\pm}$. The solid horizontal line represents the 90% C.L. upper bound on this ratio as obtained by ALEPH[3]. We see that for some range of the parameters, the value of this ratio exceeds the experimental bound, and that very large values of $\tan\beta$ are thus excluded. For example, $\tan\beta \lesssim 60$ for $m_{H^\pm} = 100\,\text{GeV}$.

Next we examine the radiative b-quark decay $b \to s\gamma$. A 90% C.L. upper bound on the branching fraction for this mode, $B(b \to s\gamma) < 8.4 \times 10^{-4}$, has been obtained by the CLEO Collaboration[6] via an examination of the inclusive photon spectrum in B-meson decays. Recent detector refinements coupled with increasing integrated luminosity leads us to anticipate that either the current limit will be strengthened, or the decay may actually be observed in the near future. The transition $b \to s\gamma$ proceeds through electromagnetic penguin diagrams, which involve the top-quark, together with a $H^\pm$ or SM $W^\pm$ boson in the loop. At the W scale the coefficients of the operators which mediate this transition take the generic form[4, 7]

$$c_i(M_W) = A_W(m_t^2/M_W^2) + \lambda A_H^1(m_t^2/m_{H^\pm}^2) + \frac{1}{\tan^2\beta} A_H^2(m_t^2/m_{H^\pm}^2)\,, \tag{1}$$

where $\lambda = -1/\tan^2\beta$, $+1$ in Models I and II, respectively, A_W corresponds to the SM amplitude, and $A_H^{1,2}$ represent the $H^\pm$ contributions; their analytic form is given for each contributing operator in Ref. 4,7. We employ the explicit form of the QCD corrections of Grinstein *et al.*[7], and use the 3-loop expression for α_s fitting the value of the QCD scale Λ to obtain consistency with measurements[3] of $\alpha_s(M_Z^2)$ at LEP.

Enhancements over the SM rate occur in Model I only for small values of $\tan\beta$. In Model II, large enhancements also appear for small values of $\tan\beta$, but more importantly, the branching fraction is found to *always* be larger than that of the SM. For certain ranges of the model parameters, the resulting value of $B(b \to s\gamma)$ exceeds the CLEO bound, and consistency with this limit thus excludes part of the $m_{H^\pm} - \tan\beta$ plane for a fixed value of m_t. This is shown in Fig. 2 for both models, where the excluded region lies to the left and beneath the curves. In Fig. 3a we present the branching fraction for Model II in the limit of large $\tan\beta$ as a function of m_t with $m_{H^\pm} = m_t - m_b$. If the actual value (or future upper bound) for the branching fraction were to lie below the solid curve, then the decay $t \to bH^\pm$ would be kinematically forbidden for a particular value of m_t. Here, we made use of the large $\tan\beta$ limit, since it minimizes the $H^\pm$ contributions to $b \to s\gamma$.

In the supersymmetric case, the bounds shown in Fig. 2b are more conventionally displayed as an allowed region in the $\tan\beta - m_A$ plane, where m_A is the mass of the CP-odd field. This is displayed in Fig. 3b for various values of m_t, where the radiative corrections to the SUSY mass relations have been employed assuming $M_{SUSY} = 1\,\mathrm{TeV}$. For $m_t = 150\,\mathrm{GeV}$, the excluded region is comparable to what can be explored by LEP I and II. We note that in supersymmetric theories, other super-particles can also contribute to the one-loop decay $b \to s\gamma$, and generally lead to a further enhancement in the rate[8].

In conclusion, we have shown that the decay $b \to s\gamma$ is by far the most restrictive process in constraining the parameters of the charged Higgs sector in 2HDM, yielding bounds which are stronger than those from other low-energy processes and from direct collider searches.

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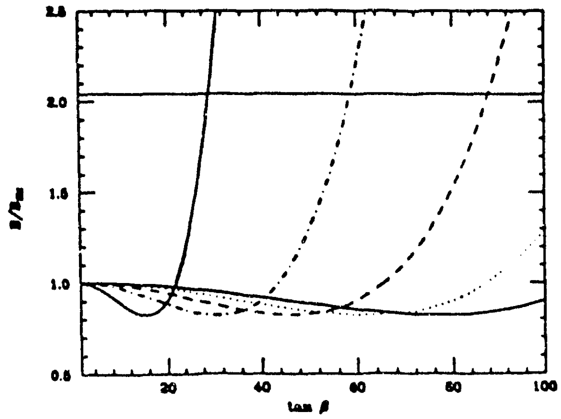

Fig. 1. The ratio of branching fractions for $B \to D\tau\nu$ in Model II to that of the SM. The solid horizontal line represents the ALEPH upper bound. From left to right the solid (dashed-dot, dashed, dotted, solid) curve represents $m_{H^\pm} = 50\,(100, 150, 200, 250)\,\text{GeV}$.

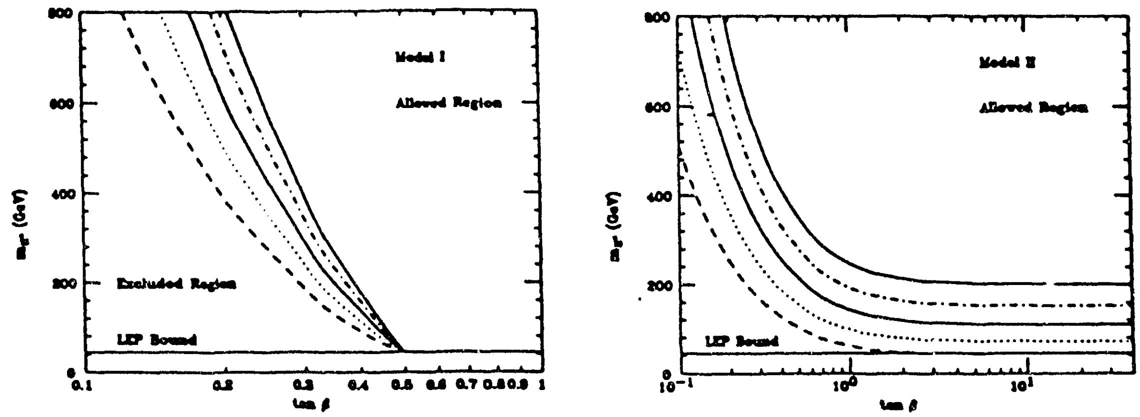

Fig. 2. The excluded regions in the $m_{H^\pm} - \tan\beta$ plane for various values of m_t, resulting from the present CLEO bound in (a) Model I and (b) Model II. In each case, from top to bottom, the solid (dashed dot, solid, dotted, and dashed) curve corresponds to $m_t = 210(180, 150, 120, \text{ and } 90)\,\text{GeV}$. The excluded region lies to the left and below each curve.

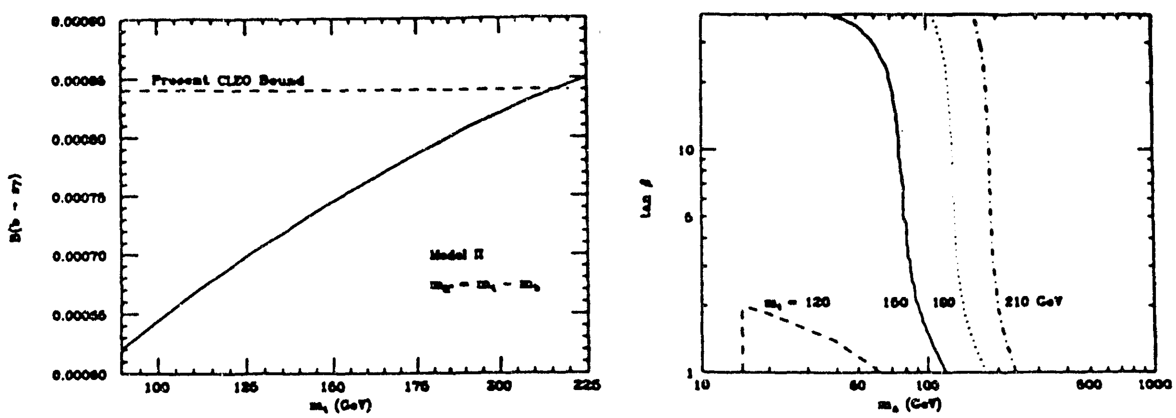

Fig. 3. (a) $B(b \to s\gamma)$ as a function of m_t, with $m_{H^\pm} = m_t - m_b$ in the large $\tan\beta$ limit in Model II. (b) The excluded region from the present CLEO limit in the $\tan\beta - m_A$ plane for various values of m_t as indicated.

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