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RARE KAON DECAYS WITH CHARGED HIGGS*

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ABSTRACT

We obtain the constraints on the CKM matrix elements and on the charged Higgs parameters in the two-Higgs-doublet model. Using these we find that the branching ratios for the CP violating rare decays $K_L \to \pi^0 e^+ e^-$ and $K_L \to \pi^0 \nu\bar{\nu}$ can be enhanced relative to the standard model.

The two-Higgs-doublet model is the simplest possible extension to the standard model (SM) yet it exhibits some of the characteristics of a more complicated scalar structure typical of most beyond the standard models. Here we explore the consequences of having a charged scalar in particular the phenomenological implications for rare Kaon decays. We will show that the CP violating rare decays $K_L \to \pi^0 \nu\bar{\nu}$ and $K_L \to \pi^0 e^+ e^-$ could be significantly larger than predicted by the SM, even reaching a measurable level.[1] On the contrary the CP conserving rare decays are unaffected by this new scalar.[1,2]

We consider a $SU(2) \times U(1)$ -invariant lagrangian with two Higgs doublets where one doublet ϕ_u couples to up-type quarks and the other, ϕ_d, to down-type quarks. The only non-standard feature of this Lagrangian is the appearance of extra terms arising from the new scalar fields. We consider only the effect of the charged Higgs. To completely describe this charged scalar two parameters need to be introduced. Here we take m_H, the mass of the charged Higgs, and $\xi \equiv v_d/v_u$, the ratio of the vacuum expectation values of ϕ_d and ϕ_u. In the two-Higgs-doublet model the fermion mass generation is similar to the standard model where the quark mixings and the CP violation is described by the Cabibbo-Kobayashi-Maskawa (CKM) matrix. However the values of the CKM matrix elements extracted from the data can be noticealy different from the standard ones as will be described in the following.

To find the allowed values for A, ρ, and η, the parameters of the CKM matrix in the Wolfenstein parametrization,[3] we perform a χ^2 fit to four measurements: ϵ, the CP violation parameter in $K \to \pi\pi$, x_d, the $B_d^0 - \bar{B}_d^0$ mixing, and the ratios $|V_{cb}/V_{us}^2|$ and $|V_{ub}/V_{cb}|$. Explicitly,[4-6]

$$\begin{aligned} \epsilon &= (2.272 \pm 0.022) \times 10^{-3}\,, \\ x_d &= 0.71 \pm 0.11\,, \\ A &= (0.044 \pm 0.007)/\lambda^2\,, \\ (\rho^2 + \eta^2)^{1/2} &= (0.11 \pm 0.04)/\lambda \end{aligned} \tag{1}$$

*talk presented by Paul Turcotte

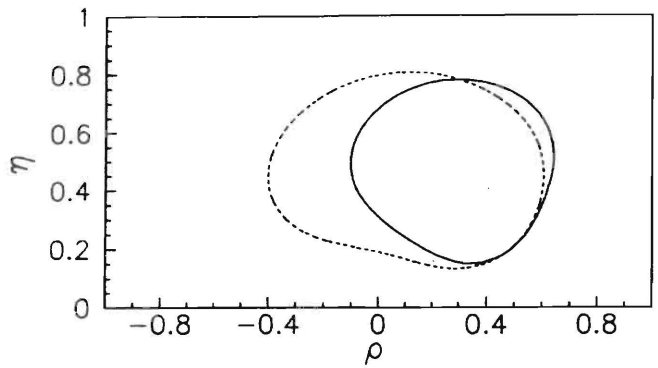

Fig. 1. Allowed range for ρ and η in the standard (solid) and two-Higgs-doublet model (dashed) at 90% C.L.

where $\lambda = 0.22$ is the Cabibbo angle. In the formulas given in refs 1 and 2 for ϵ and x_d for the two-Higgs-doublet model, we take $f_B = 220 \pm 30$ MeV, consistent with the recent lattice QCD calculations.[7] We assume $B_K = 0.8 \pm 0.2$ and $B_B = 1$, all uncertainties in B_B being hidden in f_B. The top quark mass is usually fixed to different values keeping in mind that one day it will be a well-measured parameter.

To give an idea of the effect of the charged Higgs on the CKM matrix elements, we compare, in Fig. 1, the results of the fits to the measurements given in (1) for the standard model and the two-Higgs-doublet model. These curves correspond, in the $\rho - \eta$ plane, to $\chi^2 = \chi^2_{min} + \delta$ with $\delta = 4.61$ (90% C.L.). For illustrative purposes, we have chosen $m_t = 120$ GeV, $m_H = 150$ GeV, $\xi = 1$ and kept A as a free parameter. We note that in both models very good fits to the data are found. This figure is typical in the sense that this model with a not too heavy charged Higgs and large f_B, prefers a positive value for ρ. We also see that η is approximately the same than in the standard model. For a very large m_H the standard results are recovered and in fact m_H must be lower than 500 GeV to have a significative impact.

For almost any values of m_t and m_H it is possible to find a very good fit to the data ($\chi^2 \simeq 0$), but this is not the case for the parameter ξ, which cannot be chosen arbitrarily large. In Fig. 2 we show the 90% C.L. upper limits for the parameter ξ in the $m_H - \xi$ plane for $m_t = 120$ and 200 GeV. For 45 $GeV < m_H < 500$ GeV, the upper limits on ξ can be set at 8 and 5 with $m_t = 120$ GeV and 200 GeV respectively.

With the allowed range for the parameters of the two-Higgs-doublet model, we can make predictions for rare kaon decays. The CP violating decays are the most interesting. For the decay $K_L \to \pi^0 e^+ e^-$, we focus on the direct CP violating contribution, although there is also a CP conserving part and an indirect CP violating part. This problem

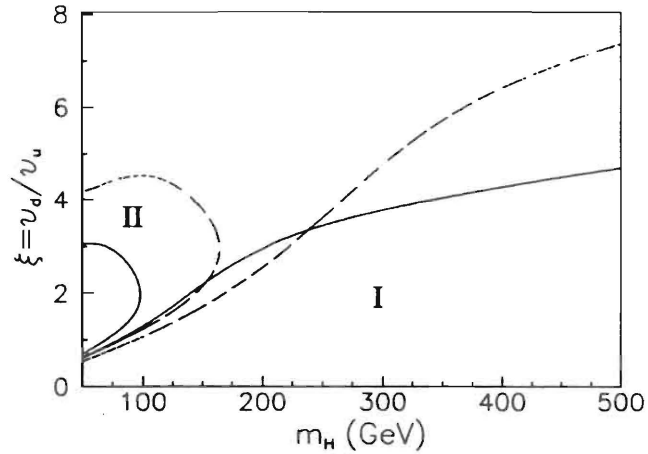

Fig. 2. 90% C.L. allowed values for ξ vs m_H for $m_t = 120$ (dotted) and 200 GeV (solid).

does not arise for $K_L \to \pi^0 \nu \bar{\nu}$ which is purely CP violating and furthermore dominated by the direct CP amplitude. The branching ratios for the direct CP violating part are given by[1,6]

$$Br(K_L \to \pi^0 e^+ e^-)_{dir} = 2.6 \times 10^{-14} A^4 \eta^2 (C_V^2 + C_A^2) \tag{2}$$

and

$$Br(K_L \to \pi^0 \nu \bar{\nu})_{dir} \;=\; 4.61 \times 10^{-11} A^4 \eta^2 |C_\nu(x_t) + C_\nu^{CH}(x_t, y_t)|^2 . \tag{3}$$

The calculation of the allowed range for the two branching ratios above (2) and (3) is performed with the use of a χ^2 fit to the four measurements mentioned in (1). Our strategy is to fix m_t (m_t, m_H and ξ) to different values and let the remaining variables A, ρ, η, m_H and ξ (A, ρ and η) vary in the whole range corresponding to a 90% C.L., i.e. $\chi^2 = \chi^2_{min} + 9.24$ (6.25). In this allowed parameter space we look for the upper and lower bounds for each branching ratio. In Fig. 3 we plot the branching ratios for $K_L \to \pi^0 e^+ e^-$ in the standard and charged Higgs models as a function of the top quark mass for $\xi = 1$ and $m_H = 150$ GeV. We can see that the upper bounds are enhanced due to the charged Higgs while the lower bounds are basically the same as the standard model.

For certain values of ξ and m_H this enhancement can be even larger. To see this, we calculate the upper bounds for the two processes of interest for any values of m_H

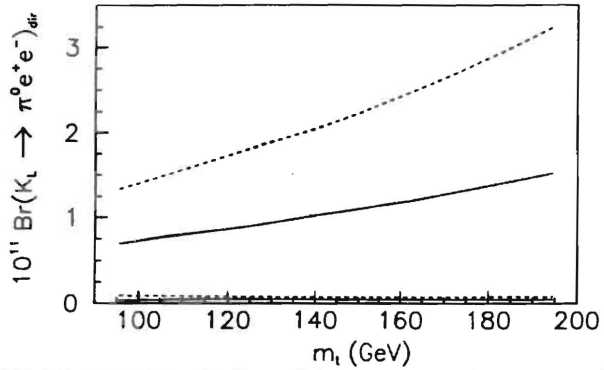

Fig. 3. Branching ratios for $K_L \to \pi^0 e^+ e^-$ as a function of m_t in the standard (solid) and charged Higgs (dashed) models; $\xi = 1$ and $m_H = 150\ GeV$.

and ξ. The contours of the upper values of $Br(K_L \to \pi^0 e^+ e^-)_{dir}$ in the $m_H - \xi$ plane are shown in Fig. 4. The given contours correspond to $Br(K_L \to \pi^0 e^+ e^-)_{dir} = 1.2$, 1.6 and 2.2×10^{-11} with $m_t = 120$ GeV. The contours for the decay $K_L \to \pi^0 \nu\bar{\nu}$ are very similar than for the charged lepton mode, only the branching ratios are about a factor of 8 larger. The maximum values for the branching ratios are located in the region within the inner contours, we get

$$\begin{aligned} Br(K_L \to \pi^0 e^+ e^-)_{dir} &\simeq 3\ (5) \times 10^{-11}\,; \\ Br(K_L \to \pi^0 \nu\bar{\nu})_{dir} &\simeq 2\ (4) \times 10^{-10} \end{aligned} \tag{4}$$

for $m_t = 120\ (200)\ GeV$, respectively. These values are about a factor 3.3 larger than in the standard model.

The same procedure described above can be used to study the CP conserving rare decays $K^+ \to \pi^+ \nu\bar{\nu}$ and $K_L \to \mu\bar{\mu}$, the rates for these decays are written as

$$\begin{aligned} Br(K_L \to \mu\bar{\mu})_{SD} &= 4.06 \times 10^{-10} A^4 (1-\rho)^2 |C_\mu(x_t) + C_\mu^{CH}(x_t, y_t)|^2\,, \\ Br(K^+ \to \pi^+ \nu\bar{\nu}) &= 10^{-6} [C_\nu(x_c) + 3.3 \times 10^{-3} A^2 (1-\rho)(C_\nu(x_t) + C_\nu^{CH}(x_t, y_t))]^2 \\ &\quad + 1.08 \times 10^{-11} [C_\nu(x_t) + C_\nu^{CH}(x_t, y_t)]^2 \end{aligned} \tag{5}$$

where $C_\nu^{CH}(x_t, y_t) = C_\mu^{CH}(x_t, y_t)$.

We find that for fixed values of ξ and m_H the upper limits on the two branching ratios are smaller than in the standard model.[5,6] This suppression occurs since the extra Higgs contribution to the rare Kaon decays enter also the x_d and ϵ constraints through loop diagrams, forcing the parameter ρ in the usual Wolfenstein parametrization of the

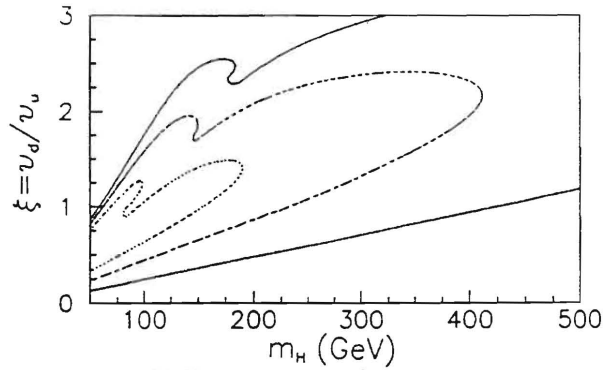

Fig. 4. Contour for upper bounds on $Br(K_L \to \pi^0 e^+ e^-)_{dir} = 1.2$ (solid), 1.6 (dashed) and 2.2×10^{-11} (dotted) in $m_H - \xi$ plane at 90% C.L. with $m_t = 120\ GeV$.

CKM matrix to be positive, reducing the branching ratio which depends mainly on $1 - \rho$.

In summary, we have shown that CP violating signals in rare Kaon decays could be significantly enhanced by the charged Higgs. For a large range of values of ξ and m_H, the branching ratios of the direct CP violating processes $K_L \to \pi^0 e^+ e^-$ and $K_L \to \pi^0 \nu\bar{\nu}$, could reach levels of 10^{-11} and 10^{-10} respectively, which are all accessible to future experiments.[8] The CP conserving decays on the others hand are insensitive to the presence of the charged Higgs.

References

1. G. Bélanger, C.Q. Geng, P. Turcotte, *Phys. Rev.* **D46** (1992) .
2. C. Q. Geng and J. N. Ng, *Phys. Rev.* **D38** (1988) 2858; A. J. Buras, *et al.*, *Nucl. Phys.* **B337** (1990) 284 ; V. Barger, J. L. Hewett and R. J. N. Phillips, *Phys. Rev.* **D41** (1990) 3421.
3. L. Wolfenstein, *Phys. Rev. Lett.* **51** (1983) 1945 .
4. Particle Data Group, *Phys. Lett.* **239B** (1990) 1 .
5. C. Q. Geng and P. Turcotte, *Phys. Lett.* **278B** (1992) 330 .
6. G. Bélanger and C. Q. Geng, *Phys. Rev.* **D43** (1991) 140.
7. C. Allton *et al.*, *Nucl. Phys.* **B349** (1991) 598 ; C. Alexandrou *et al.*, *Phys. Lett.* **256B** (1991) 60 .
8. Cf. K. Arisaka; Y. Hsiung; T. Inagaki; Y. Kuno; L. Littenberg; T. Numao; and B. Winstein, Talks presented at the KEK Workshop on Rare Kaon Decays Physics, KEK, Dec. 10-11, 1991.