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Limits on the scale of compositeness from leptonic τ decays

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We study the effects of induced four-fermion contact interactions, which arise when leptons and quarks are considered as composite objects, on the leptonic decays of the τ. The current experimental values on the leptonic τ decays can be used to put limits on the scale of compositeness, which can be as high as $\Lambda_e > 8.1$ TeV and $\Lambda_\mu > 6.5$ TeV for the decay modes into an electron and muon, respectively.

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The recent values for the leptonic decays of the τ [1] have confirmed the validity of the standard model (SM) [2] as the theory of electroweak interactions at the current scales of energy. Moreover, the results have reached such precision that they have opened the possibility to constrain significantly some physics beyond the standard model, for instance, compositeness [3].

The family structure of the known fermions, among other regularities, has been considered as an indication to expect that the SM fermions and perhaps massive gauge bosons possess some kind of substructure. One consequence of compositeness will be the appearance of new effective contact interactions [4], such as four-fermion vertices, or modification to the SM interactions of fermions with gauge bosons, which would have to include form factors.

Current limits on the scale of compositeness (Λ) are of the order of 1–3 TeV [5], which are obtained mainly from the electron and muon properties. However, since it may happen that the third family (which is the heaviest) could be the most sensitive to effects from compositeness, one needs to obtain limits on Λ from properties of the third family. The limits obtained up to now from the τ lepton are not as good as the ones obtained from e and μ. For instance, the τ form factor can be tested with the reaction $e^+e^-\rightarrow\tau^+\tau^-$, giving the limit $\Lambda > 230$ GeV [6]. It is also possible to obtain limits on Λ from the anomalous magnetic moments (a_l), which in the case of the muon gives the limit $\Lambda > 1$ TeV [6]; however, there is not yet a precise measurement of the τ magnetic moment; thus, other methods have to be investigated to test its pointlike nature.

In this Rapid Communication, we study the effects of effective contact interactions on the leptonic decays of the τ as a possibility to put bounds on its scale of compositeness.

The SM prediction for the leptonic decay widths, including electroweak radiative corrections [7], is

$$\Gamma_{\rm SM}(\tau\rightarrow l\nu_l\nu_\tau)=\frac{G_F^2 m_\tau^5}{192\pi^3}f(m_l^2/m_\tau)r \quad (l=e,\mu) \tag{1}$$

where

$$f(x)=1-8x+8x^3-x^4-12x^2\ln(x)\ . \tag{2}$$

The factor r takes into account the radiative corrections that are not absorbed in the Fermi constant G_F, and is estimated to be 0.9960 [7].

The leptonic branching ratios can be calculated in terms of the observed τ lifetime, $\tau_\tau=(294.8\pm2.4)\times10^{-15}$ s, and the measured value for the mass of the τ lepton, $m_\tau=1777.0\pm0.3$ MeV, which are the values reported at the recent lepton-photon symposium [1]. This gives the theoretical (central) values $B_e^{\rm th}=0.1806\pm0.0015$ for the branching ratio of the electronic mode, and $B_\mu^{\rm th}=0.1757\pm0.0014$ for the muonic mode, which are now in good agreement with the experimental values, $B_e^{\rm expt}=0.1789\pm0.0013$ and $B_\mu^{\rm expt}=0.1741\pm0.0015$ [8], once the theoretical uncertainties are properly taken into account.

In order to study limits on the scale of compositeness, we shall consider the contribution to the decay width due to induced contact interactions, which arise in most models where the SM fermions are considered to be composite [4]. The effective Lagrangian that describes the charged current can be written as

$$L_{\tau\nu_\tau l\nu_l}=\left[\frac{g}{\Lambda_l}\right]^2[\eta_{LL}(\bar{n}_{\tau L}\gamma_\nu\tau_L)(\bar{l}_L\gamma^\nu\nu_{lL}) +\eta_{LR}(\bar{\nu}_{\tau L}\gamma_\nu\nu_{lL})(\bar{l}_R\gamma^\nu\tau_R)] \tag{3}$$

where the parameters η_{LL} and η_{LR} can take the values $0,+1,-1$, and we shall obtain limits on Λ_l ($l=e,\mu$) scales to the value $g^2=4\pi$. The dominant contribution from induced four-fermion interactions is given by the interference between the SM term and the new contribution. We find that the decay width can be written as

$$\Gamma=\Gamma_{\rm SM}+\Gamma_c\ , \tag{4}$$

where the SM part is given by Eq. (1), and the expression for the new part is

$$\Gamma_c=-\frac{G_F 2^{1/2} m_\tau^5}{192\pi^2\Lambda^2}[\eta_{LL}f_{LL}(z)+\eta_{LR}f_{LR}(z)] \tag{5}$$

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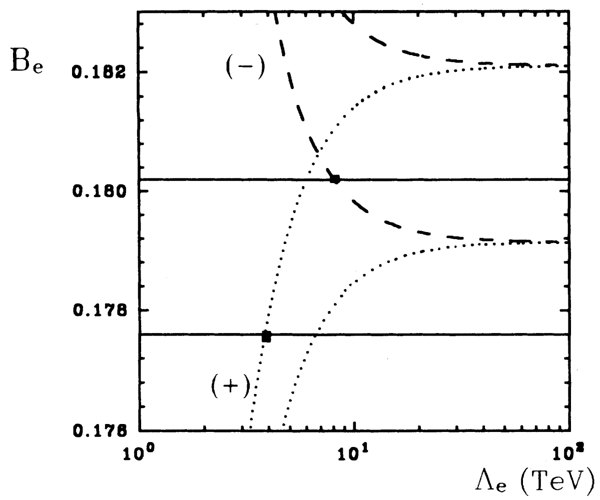

FIG. 1. The predicted band for $B(\tau\to\nu_\tau e\nu_e)$ as a function of the scale of compositeness. With dots: $\eta_{LL}=+1$; dashes: $\eta_{LL}=-1$. In Figs. 1–3 the horizontal solid lines correspond to the experimental band.

where $z=(m_l/m_\tau)^2$, and the function f_{LL} is the same as Eq. (2), whereas the function f_{LR} is given by

$$f_{LR}(z)=2z^{1/2}[1+9z-9z^2-z^3+6z(1+z)\ln(z)]\ . \tag{6}$$

In the following analysis we fix $\eta_{LR}=+1$, and allow η_{LL} to take both values ±1; changing the sign of η_{LR} for the e^- is not important because the number that appears in front of it is very small, whereas for the μ^- case, a change in sign can modify the results by a few percent only. Figures 1 and 2 show the predicted band for the branching ratios (BR's) as a function of the scale of compositeness (Λ_l), which result after propagating the experimental errors for the parameters that enter into the equations for BR's; it is interesting to notice that the main source of error comes from the lifetime, since the error that arises from the τ mass is smaller than the one from τ_τ by about one order of magnitude. The central values are not displayed to make the graphs more clear.[1]

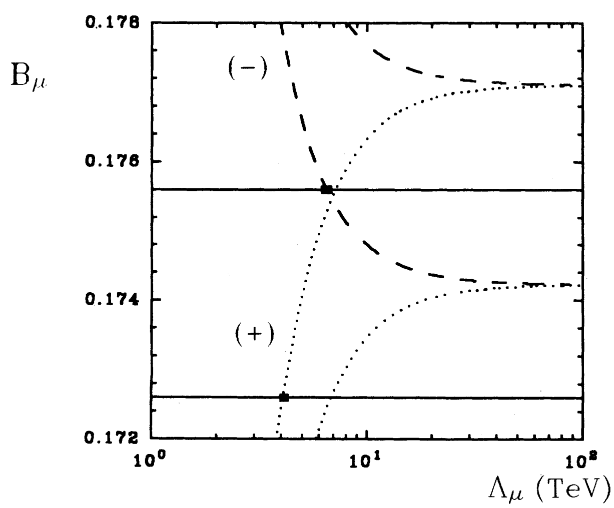

FIG. 2. The predicted band for $B(\tau\to\nu_\tau\mu\nu_\mu)$ as a function of the scale of compositeness. With dots: $\eta_{LL}=+1$; dashes: $\eta_{LL}=-1$.

One can see that it is possible to get an agreement with the experimental values of BR's, provided that $\Lambda_e>3.8$ TeV for $\eta=+1$, and $\Lambda_e>8.1$ TeV for $\eta=-1$; whereas for the muonic mode the limits are $\Lambda_\mu>4.1$ TeV for $\eta=+1$, and $\Lambda_\mu>6.5$ TeV for $\eta=-1$. It is important to realize that the previous limits are better than any previous bounds on the scale of compositeness obtained from the τ, and are also competitive with bounds obtained from the electron and muon properties [5].

Let us consider now the quantity R_τ, which is defined as

$$R_\tau=\frac{\Gamma_\tau-\Gamma_e-\Gamma_\mu}{\Gamma_e}\ . \tag{7}$$

Using the measured values of the leptonic branching ratios [8], one finds the value

$$R_\tau^{\mathrm{expt},B}=\frac{1-B_e-B_\mu}{B_e}=3.63\pm0.06\ . \tag{8}$$

If one includes in the leptonic widths the contributions from four-fermions interactions [Eq. (3)], considering the case $\Lambda_e=\Lambda_m$, then the value of R_τ gives bounds on Λ somehow lower than those obtained from the BR's, as Fig. 3 illustrates. On the other hand, if we consider the case $\Lambda_e\neq\Lambda_\mu$, then the bounds obtained from R_τ are similar to those obtained from the leptonic BR's.

In a previous work [10], we have studied if other prop-

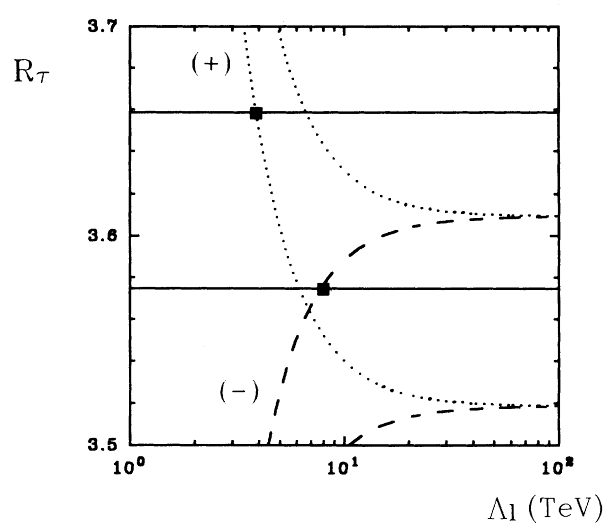

FIG. 3. The predicted band for R_τ as a function of the scale of compositeness. With dots: $\eta_{LL}=+1$; dashes: $\eta_{LL}=-1$.

[1]Radiative corrections are included only in Γ_{SM}. If one includes the r factor also in Γ_c, then the change in the bounds on Λ_l is less than about 0.2 percent, which is negligible. Moreover, the value of the r factor is not expected to be the same for both terms in Eq. (3).

erties of the τ can be modified by the presence of the four-fermion contact interactions, such as the Michael parameter (ρ), which is predicted to be $\frac{3}{4}$ in the SM, and whose measured value is 0.737 ± 0.029 [9], but we found that the contributions from Eq. (3) do not modify the SM result.

In summary, we find that the data on the properties of the τ can be used to constrain the scale of compositeness from an induced four-fermion contact interaction. The limits obtained from the leptonic branching ratios are $\Lambda_e > 3.8$ TeV ($\eta = +1$), and $\Lambda_e > 8.1$ TeV ($\eta = -1$) for the electronic mode, whereas for the muonic mode the limits are $\Lambda_\mu > 4.1$ TeV ($\eta = +1$), and $\Lambda_\mu > 6.5$ TeV ($\eta = -1$), which are better than previous bounds obtained from τ properties, and they are also competitive with previous bounds obtained from electron and muon properties [5].

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