

Anomalous magnetic moment of the muon and Higgs-mediated flavor changing neutral currents

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In the two-Higgs doublet extension of the standard model, flavor-changing neutral couplings arise naturally. In the lepton sector, the largest such coupling is expected to be $\mu - \tau - \phi$. We consider the effects of this coupling on the anomalous magnetic moment of the muon. The resulting bound on the coupling, unlike previous bounds, is independent of the value of other unknown couplings. It will be significantly improved by the upcoming E821 experiment at Brookhaven National Laboratory. [S0556-2821(98)02521-1]

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The simplest extension of the standard model involves the addition of an extra Higgs doublet. In general, such a model will generate tree level flavor changing neutral currents (FCNC). The Higgs doublet of the standard model does not generate tree level FCNC because the mass matrix is directly proportional to the Yukawa coupling matrix, so diagonalization of the former automatically diagonalizes the latter. However, in a two-doublet model, the mass matrix is the sum of two Yukawa coupling matrices (each times the appropriate vacuum expectation value), and since the Yukawa coupling matrices are generally not simultaneously diagonalizable, diagonalization of the mass matrix will *not*, in general, diagonalize the Yukawa coupling matrices, leading to tree-level FCNC.

These tree-level FCNC are dangerous, leading to potentially large contributions to processes such as $K^0 - \bar{K}^0$ mixing. This led Glashow and Weinberg [1] to propose a discrete symmetry, which either couples one Higgs doublet to all of the fermions (model I) or else couples one doublet to the $Q=2/3$ quarks and the other to the $Q=-1/3$ quarks (model II).

However, it was pointed out by Cheng and Sher [2] that, for many models, the coupling was the geometric mean of the Yukawa couplings of the two fermions. As a result, FCNC involving the first generation fields are very small, and the bounds are not as severe. Thus, one can also consider model III, in which no discrete symmetry is imposed, and the flavor-changing neutral couplings are simply constrained by experiment.

This has led to a number of calculations involving model III [3–11]. The most extensive analyses were those of Refs. [10, 12]. In Ref. [10], the implications of tree-level FCNC for many processes were considered, including $K^0 - \bar{K}^0$, $D^0 - \bar{D}^0$, $B^0 - \bar{B}^0$ and $B_s^0 - \bar{B}_s^0$ mixing, $e^+ e^- (\mu^+ \mu^-) \rightarrow t \bar{c} + c \bar{t}$, $Z \rightarrow b \bar{b}$, $t \rightarrow c \gamma$ and the ρ parameter. In Ref. [12], the effects on $\tau \rightarrow \mu \gamma$, $\tau \rightarrow e \gamma$ and $\mu \rightarrow e \gamma$, other lepton-flavor violating decays of the τ and μ , and a number of rare B-decays were determined. In all of these papers, the results were given as upper bounds on the neutral flavor changing scalar couplings. In most of these calculations, the results were given in terms of the product of various Yukawa couplings. For example, the bound from $\tau^- \rightarrow \mu^- \mu^+ \mu^-$ is dependent on $h_{\tau \mu} h_{\mu \mu}$, where h_{ij} is the coupling of the scalar to fermions i and j .

In this Brief Report, we point out that a bound on leptonic flavor changing couplings can be obtained from the anomalous magnetic moment of the muon. This bound has several advantages over previous bounds: it depends only on a single Yukawa coupling, rather than a product; it is stronger than previous bounds, using reasonable assumptions about the ratio of couplings; it could be improved significantly in the near future at the upcoming experiment E821 [13] at Brookhaven National Laboratory.

As shown in the above references, one can choose a basis for the two Higgs doublets such that only one doublet, H , obtains a vacuum expectation value. That doublet will then have flavor-diagonal couplings, while the couplings of the other, ϕ , will be unconstrained. The relevant term in the Lagrangian is

$$m_e \bar{e}_L e_R (\sqrt{2} H/v) + m_\mu \bar{\mu}_L \mu_R (\sqrt{2} H/v) + m_\tau \bar{\tau}_L \tau_R (\sqrt{2} H/v) + h_{ij} \bar{l}_i l_j R \phi + \text{H.c.} \quad (1)$$

The ϕ field is composed of a scalar ϕ_s and a pseudoscalar ϕ_p . Since one expects [2] the heavier generations to have larger flavor-changing couplings, we will look at the bound on the $h_{\mu \tau}$ arising from the magnetic moment of the muon.

The diagram is given in Fig. 1. The diagrams in which the photon couples to the external lines do not give a contribu-

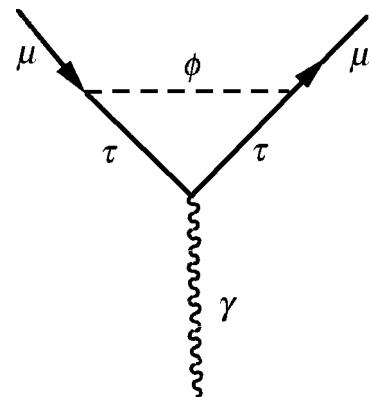


FIG. 1. Contribution to the anomalous magnetic moment of the muon from the exchange of flavor-changing scalars. The scalar can be either a scalar or a pseudoscalar.

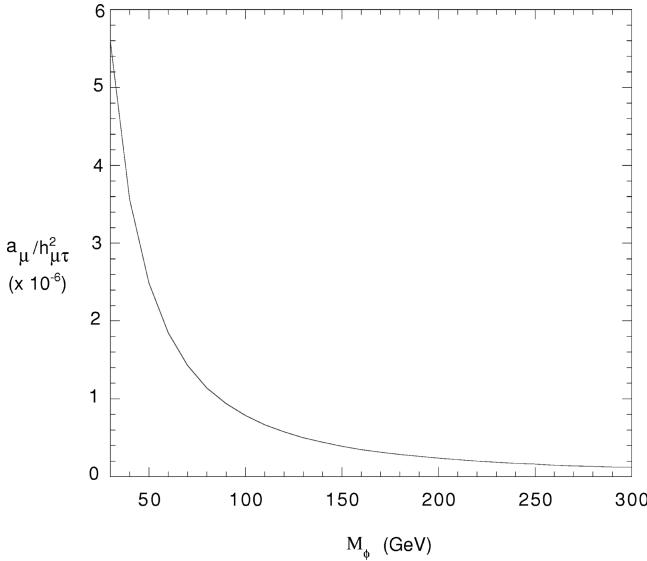


FIG. 2. The contribution of the diagram of Fig. 1 to the anomalous magnetic moment of the muon. The contribution of the scalar is shown; that of the pseudoscalar is within a few percent of that of the scalar, but of opposite sign.

tion to the magnetic moment of the muon. The calculation is straightforward, and we find that the contribution to $a_\mu \equiv (g_\mu - 2)/2$ is given by

$$a_\mu = \frac{h_{\mu\tau}^2}{16\pi^2} \int_0^1 \frac{z^2(1-z) \pm z^2(m_\tau/m_\mu)}{z(z-1) + z(m_\tau^2/m_\mu^2) + (1-z)m_\phi^2/m_\mu^2} dz \quad (2)$$

where m_ϕ is the mass of the scalar or pseudoscalar, and the $(+/-)$ sign is chosen for the scalar (pseudoscalar). In the expected limit $m_\mu \ll m_\tau \ll m_\phi$, the integral becomes

$$\mp \frac{m_\mu m_\tau}{m_\phi^2} \left(\log \frac{m_\tau^2}{m_\phi^2} + \frac{3}{2} \right). \quad (3)$$

The resulting contribution is given in Fig. 2. The scalar and pseudoscalar have contributions which are almost identical (within a few percent), but of opposite sign; the scalar contribution is shown. Since there is no reason that the masses should be similar, and since the result is so sharply dependent on the mass, we expect the lighter of the two to make the dominant contribution.

Consider the case in which the lighter scalar is 80 GeV (current CERN e^+e^- collider LEP bounds apply to a standard model Higgs boson, and are generally weaker for two doublet models). We see that this gives a value of a_μ which is $1.14 \times 10^{-6} h_{\mu\tau}^2$. The current value of a_μ is in agreement with expectations, and the uncertainty [11] is 7.4×10^{-9} . Thus, the contribution of the flavor-changing coupling must be less than this uncertainty, or $h_{\mu\tau}$ must be less than 0.11. More importantly, the experimental uncertainty in the anomalous magnetic moment will shortly decrease by up to a factor of 20, so that a bound on $h_{\mu\tau}$ of 0.027 can be obtained.

How does this bound compare with other bounds? As noted above, *all* other bounds depend on the product of $h_{\mu\tau}$ times other unknown Yukawa couplings. Thus, the bound is unique. However, one can make reasonable assumptions about these other couplings. For example, in Ref. [12], it was argued that grand unified theories will give a relationship between h_{bs} and $h_{\mu\tau}$; from this, they looked at the process $B \rightarrow K\mu\tau$ to get the bound $h_{\mu\tau} < 0.024$. Unfortunately, there are no experimental limits listed for $B \rightarrow K\mu\tau$; their bound was obtained by noting that 17% of τ 's decay into μ 's, and using the bound on $B \rightarrow \mu^+ \mu^- X$. Since the experimental cuts would be quite different, this result is very uncertain, and thus the bound on $h_{\mu\tau}$ could be considerably higher (and also requires the assumption of grand unification). In addition, one can assume that the ratio of $h_{\tau\tau}$ to $h_{\mu\tau}$ is $\sqrt{m_\tau/m_\mu}$, in which case the bound on $h_{\mu\tau}$ from $\tau \rightarrow 3\mu$ gives 0.2, which is also much weaker [14]. It should be pointed out that a similar diagram could bound the flavor-changing $h_{\mu e}$ coupling, but much stronger bounds on that can be obtained from bounds on radiative muon decay.

In the absence of any solid theoretical understandings of Yukawa couplings, one must rely on experiment to bound such couplings. In the simplest extension of the standard model, a flavor changing coupling of the μ and τ to a neutral scalar can, in general, exist. In this work, we have shown that the strongest bound on such a coupling (independent of assumptions about other couplings) arises from the contribution to the anomalous magnetic moment of the muon. Should the E821 experiment find a value which is in conflict with the standard model, this may provide one of the simpler explanations.

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value for $h_{\mu\tau}$ is the geometric mean of the Yukawa couplings of the muon and tau, or 0.0025. Our bound is still above that value. However, the symmetry arguments in that work apply only to the ratio of the couplings, not their overall scale, and thus higher couplings are certainly possible.