

Searching for anomalous $\tau\nu W$ couplings

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The capability of current and future measurements at low and high energy e^+e^- colliders to probe for the existence of anomalous, CP -conserving, $\tau\nu W$ dipole moment-type couplings is examined. At present, constraints on the universality of the τ charged and neutral current interactions as well as the shape of the $\tau \rightarrow \ell$ energy spectrum provide the strongest bounds on such anomalous couplings. The presence of these dipole moments are shown to influence, e.g., the extraction of $\alpha_s(m_\tau^2)$ from τ decays and can lead to apparent violations of CVC expectations. [S0556-2821(97)04617-1]

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Although the standard model (SM) continues to do an excellent job of describing almost all experimental data [1], many believe that new physics must exist beyond the SM for a number of reasons and that it cannot be too far away. In addition to searches for new particle production or the observation of rare or forbidden decays of well-known particles at colliders, an alternative probe for new physics is that of precision measurements. One possibility is that the repetitive nature of the family structure in the SM may provide some insight into what form this new physics might take. In particular, the detailed properties of the third family of SM fermions may be the most sensitive probes of a new mass scale which is beyond the direct reach of current accelerators. To this end it is important to examine the nature of the b and t quarks as well as the τ lepton with as much precision as possible.

In the τ case one has a particularly clean laboratory in the hunt for new physics due to the added advantage associated with the fact that strong interaction effects can only arise at higher order, if at all, depending upon which τ property is being probed. For this reason we focus on the τ lepton in the following discussion. One possible form of new physics associated with the τ is a subtle modification of how the τ interacts with the gauge bosons of the SM, i.e., the Z , γ , and W . These new interactions, if their scale is sufficiently large, can be parametrized as a series of higher dimension, gauge invariant, though nonrenormalizable, operators involving the τ , the SM gauge fields, and perhaps the Higgs boson as well. Neglecting the possibility of leptonic CP violation, the new operators of lowest dimension that one can construct take the form of anomalous magnetic moment-type interactions. To explicitly construct these operators using only the SM particle content requires us to explicitly introduce the scalar Higgs field [2] in order to produce the required helicity flip while maintaining gauge invariance. Thus we find that anomalous dipole moment operators for the τ are necessarily of dimension six.

In the case of the Z and photon, our normalization for these operators take the conventional form

$$\mathcal{L}_Z = \frac{g}{2c_w} \bar{\tau} \left[\gamma_\mu (v_\tau - a_\tau \gamma_5) + \frac{i}{2m_\tau} \sigma_{\mu\nu} q^\nu (\kappa_\tau^Z - i \tilde{\kappa}_\tau^Z \gamma_5) \right] \tau Z^\mu, \quad (1)$$

where as usual $a_\tau = -1/2$ and $v_\tau = -1/2 + 2\sin^2\theta_w$. Similarly for the photon we can write an almost identical interaction structure:

$$\mathcal{L}_\gamma = e \bar{\tau} \left[Q_\tau \gamma_\mu + \frac{i}{2m_\tau} \sigma_{\mu\nu} q^\nu (\kappa_\tau^\gamma - i \tilde{\kappa}_\tau^\gamma \gamma_5) \right] \tau A^\mu, \quad (2)$$

where $Q_\tau = -1$. In both cases κ ($\tilde{\kappa}$) corresponds to an anomalous magnetic (electric) dipole complex *form factor*. Of course, as is well known, radiative corrections in the SM can easily induce dipole moment-type interactions. In this specific case, since the real part of the $\tilde{\kappa}$'s are intrinsically CP -violating, they remain zero to several loops whereas the κ 's receive complex, order α , contributions [3]. In both cases the imaginary parts of κ and $\tilde{\kappa}$ arise due to the absorptive parts of the loop diagrams. In the present paper we will be interested in anomalous magnetic dipole-type couplings that are over and above those of the SM and are comparable or perhaps somewhat larger in magnitude. We might expect that if very high mass scales are inducing these anomalous couplings then the parameters κ and $\tilde{\kappa}$ arising from this new physics will be real and not to be very scale dependent, i.e., their values at $q^2=0$ and M_Z^2 will be little different.

Experiments designed to directly probe the couplings $\kappa_\tau^{\gamma,Z}$ and $\tilde{\kappa}_\tau^{\gamma,Z}$ have been performed at the CERN e^+e^- collider LEP and elsewhere [4] with only negative results. In fact, in the Z boson case we can use the $Z \rightarrow \tau^+ \tau^-$ decay width, the τ forward-backward asymmetry, and the angular distribution of the τ polarization to constrain both κ_τ^Z , which we assume to be real, and $|\tilde{\kappa}_\tau^Z|$ through a ‘‘radiative corrections’’ analysis [5]. Using the data as presented at Moriond 1997 [1], a modified version of ZFITTER5.0 [6], and the input values of $\alpha_s(M_Z) = 0.118$ and $\alpha_{EM}^{-1} = 128.896$ [7] we obtain the 95% C.L. regions shown in Fig. 1. From this analysis we can conclude that if the anomalous couplings are the only source of new physics, the Z -pole data tell us that $|\kappa_\tau^Z, \tilde{\kappa}_\tau^Z| \leq 0.0023$. Note that this value $\sim \alpha/\pi$, the typical size of a SM loop correction. The direct search results yield comparable limits, particularly in the case of the CP -violating couplings. The corresponding bounds on κ_τ^γ and $\tilde{\kappa}_\tau^\gamma$ obtained through direct means are somewhat weaker.

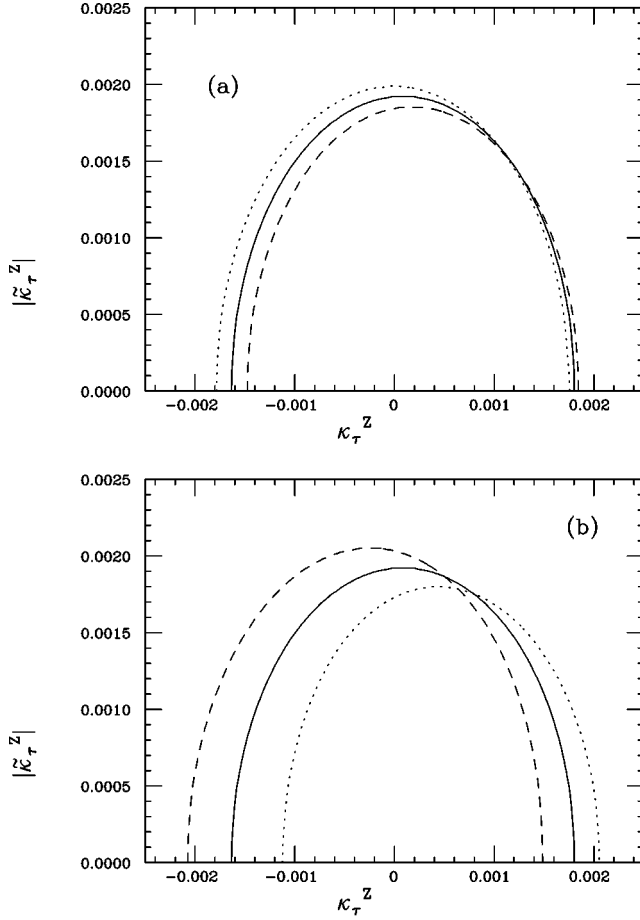


FIG. 1. 95% C.L. allowed regions for the $\tau\tau Z$ anomalous dipole moment couplings. In (a) $m_H = 300$ GeV has been assumed and the three curves correspond to $m_t = 169$ (dotted), 175 (solid), and 181 (dashed) GeV, respectively. In (b) $m_t = 175$ GeV is assumed for $m_H = 60$ (dotted), 300 (solid), or 1000 (dashed) GeV, respectively.

The purpose of this paper is to examine the analogous CP -conserving *charged current* dipole moment interactions of the τ which have not been as extensively discussed in the literature [8]. To this end, we modify the charged current $\tau\nu W$ interaction to now be of the form

$$\mathcal{L}_{\tau\nu W} = \frac{g}{\sqrt{2}} \bar{\tau} \left[\gamma_\mu + \frac{i}{2m_\tau} \kappa_\tau^W \sigma_{\mu\nu} q^\nu \right] P_L \nu_\tau W^\mu + \text{H.c.}, \quad (3)$$

which parallels the above coupling structures for the photon and Z . Here P_L is the left-handed projection operator and κ_τ^W is assumed to be real. If one allows for the possible existence of $\kappa_\tau^{Z,\gamma}$ then κ_τ^W must also exist with a comparable magnitude due to the demand that the original nonrenormalizable operators be gauge invariant. This is easily seen in a number of ways but perhaps the simplest is to examine a particular realization for these nonrenormalizable operators as presented in Ref. [2]:

$$\mathcal{L}_{\text{new}} = \frac{1}{\Lambda^2} \bar{L} \sigma_{\mu\nu} [\alpha_{\tau B} B^{\mu\nu} + \alpha_{\tau W} T_a W_a^{\mu\nu}] \tau_R \Phi + \text{H.c.}, \quad (4)$$

Here, L is the left-handed doublet containing the τ , Λ is a large mass scale, $\alpha_{\tau W}, \alpha_{\tau B}$ are a pair of parameters, $W_a^{\mu\nu}$ and

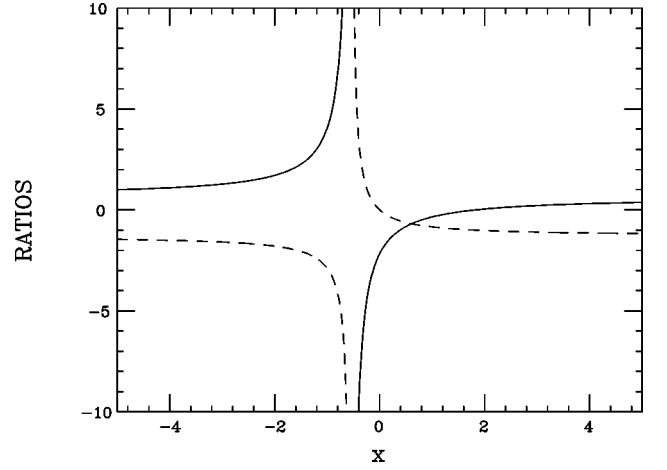


FIG. 2. The ratios $\kappa_\tau^W/\kappa_\tau^Z$ (dash) and $\kappa_\tau^\gamma/\kappa_\tau^Z$ (solid) as functions of the parameter x .

$B^{\mu\nu}$ are the $SU(2)_L$ and $U(1)$ field strength tensors, T_a are the $SU(2)_L$ generators, and Φ is the Higgs field which we can ultimately replace by its vacuum expectation value. Rewriting these operators in the mass eigenstate basis and employing the normalizations of Eqs. (1)–(3) we see that we can immediately write a pair of extremely simple relations amongst the three anomalous magnetic-moment-type couplings which do not depend upon the scale Λ :

$$\frac{\kappa_\tau^W}{\kappa_\tau^Z} = \frac{-1}{sc} \frac{tx}{t+x},$$

$$\frac{\kappa_\tau^\gamma}{\kappa_\tau^Z} = \frac{1}{2sc} \frac{tx+1}{t+x}, \quad (5)$$

where $t = \sin\theta_w/\cos\theta_w \equiv s/c$ and $x \equiv \alpha_{\tau W}/\alpha_{\tau B}$. A plot of these ratios is shown in Fig. 2 where we see that they are typically of order unity except near the points $x = -t$ and $x = 0$. These arguments possibly suggest that the relevant interesting range of $|\kappa_\tau^W|$ may not be much larger than about 0.001–0.01 since the corresponding anomalous κ_τ^Z couplings were found to be quite small. Again, this range is not much different than what we might expect from a typical loop correction of order α/π in the SM or simple extensions thereof. Since we will concentrate solely on κ_τ^W below, we will henceforth employ the simple notation $\kappa_\tau^W \equiv \kappa$.

The first point we need to address is what are the current direct limits on κ and how far are they away from the suggestive range of 0.001–0.01? The most obvious set of constraints arise from considerations of lepton universality since the τ now interacts with the W in a way that differs from the other leptons, which we treat as having only SM interactions. The two best places to test τ universality are the τ lifetime itself and the ratio of W decay widths $R = \Gamma(W \rightarrow \tau\nu)/\Gamma(W \rightarrow \mu\nu, e\nu)$. It is obvious that ratios such as $\Gamma(\tau \rightarrow P\nu)/\Gamma(P \rightarrow \mu\nu)$, where P is a pseudoscalar meson, will not yield additional constraints. Since the matrix element of the hadronic weak current between the pseudoscalar and the vacuum is proportional to the momentum of the virtual W , the $\sigma_{\mu\nu} q^\nu$ piece of the τ 's leptonic current will drop out, i.e., only the longitudinal part of the virtual W contrib-

utes. Any deviation from universality observed in such ratios *cannot* be attributed to an anomalous moment for the τ .

For the leptonic decay of the τ we find, neglecting the mass of the lepton in the final state,

$$\Gamma(\tau \rightarrow \ell \nu \bar{\nu}) = \Gamma_0 \left(1 + \frac{\kappa}{2} + \frac{\kappa^2}{10} \right), \quad (6)$$

where Γ_0 is the conventional SM result, while for the $W \rightarrow \tau \nu$ decay width we obtain

$$\Gamma(W \rightarrow \tau \nu) = \frac{G_F M_W^3}{6\sqrt{2}\pi} (1-r)^2 \left[1 + \frac{r}{2} - \frac{3\kappa}{4} + \frac{\kappa^2(1+2r)}{8r} \right], \quad (7)$$

where $r = (m_\tau/M_W)^2$. Here we see that in the W decay case the κ^2 term is dramatically enhanced kinematically. It is easy to include in these equations the effect of a CP -violating electric dipole moment type term, $\tilde{\kappa}$, by the replacement of the κ^2 in the last term of both expressions by the combination $\kappa^2 + \tilde{\kappa}^2$. $\tilde{\kappa}$ only appears quadratically since neither of these quantities are CP -violating observables. Using the most recent experimental data [9] we are able to obtain the following 95% C.L. bounds, neglecting potential $\tilde{\kappa}$ contributions:

$$\begin{aligned} B_{\ell/\tau_\tau/\tau_\mu}: \quad & -2.24 \times 10^{-2} \leq \kappa \leq 2.31 \times 10^{-2}, \\ R: \quad & -2.54 \times 10^{-2} \leq \kappa \leq 2.83 \times 10^{-2}. \end{aligned} \quad (8)$$

Note that the two constraints yield comparable limits implying that we must have $|\kappa| \leq 0.0283 = 0.03$, which is somewhat larger than the bounds we obtained for the Z case. We chose not to combine these two results since, in principle, $\kappa(0)$, which is probed by the τ width may differ from $\kappa(M_W^2)$, probed in W decays. Note that the W decay expressions can also be used to obtain a bound on $|\tilde{\kappa}|$ of a comparable size, but any limit obtainable from the τ lifetime will be rather poor. Clearly, we need to improve our sensitivity to nonzero values of κ by roughly a factor of a few to an order of magnitude. The statistics for doing so will be available at future runs of the Tevatron and at future B and τ/c factories.

Where else might we be able to probe values of κ of order 0.01 or less? In addition to modifying the total τ leptonic decay width, the presence of $\kappa \neq 0$ produces a distortion in the final state lepton spectrum which in general *cannot* be expressed as shifts in the Michel parameters. We recall that the general nature of the Michel spectrum assumes the absence of derivative couplings—something we now have due to the anomalous moment. We find that the invariant double differential decay distribution for τ leptonic decays in the absence of the polarization dependent terms is given by

$$\begin{aligned} \frac{d\Gamma}{dE_\ell d\cos\theta_{\ell\ell}} \sim & 3m_\tau^2(p \cdot k) - 4(p \cdot k)^2 \left(1 - \frac{\kappa}{2} \right) + \frac{3}{2} \frac{\kappa^2}{m_\tau^2} (p \cdot k) \\ & \times (m_\tau^2 - 2p \cdot k)^2, \end{aligned} \quad (9)$$

where $p(k)$ is the τ 's (final state lepton's) four-momentum and terms of order m_ℓ^2/m_τ^2 have been neglected. Note that in the κ^2 term cubic powers of $p \cdot k$ appear which are clearly

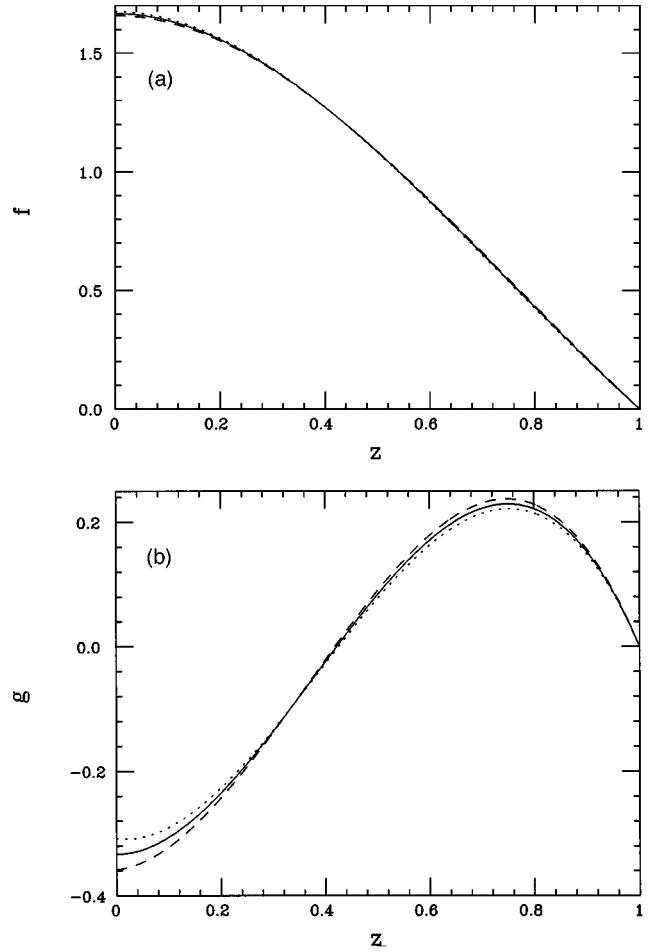


FIG. 3. The kinematic functions $f(z)$ and $g(z)$ for κ values of -0.05 (dotted), 0 (solid), or 0.05 (dashed).

incompatible with the standard Michel spectrum. As above, we can include the CP -violating electric dipole contribution by the standard replacement $\kappa^2 \rightarrow \kappa^2 + \tilde{\kappa}^2$, which implies that the lepton energy spectrum is not very sensitive to $\tilde{\kappa}$ nonzero as we might expect. There are two places where precision measurements of the τ lepton spectrum can be made: at high energies, sitting on the Z , or at low energies at a B or τ/c factory. On the Z an extra advantage is obtained due to the fact that the τ is naturally polarized. Beam polarization can greatly enhance this added sensitivity as has been exploited by the SLAC Large Detector (SLD) Collaboration [10]. At the Z , the *normalized* lepton energy spectrum for the τ to leading order in κ , which seems a reasonable approximation since κ is small, can be written in the absence of m_τ^2/M_Z^2 and m_τ^2/m_τ^2 corrections as

$$\frac{1}{N} \frac{dN}{dz} = f(z) + P_{\text{eff}}^\tau g(z), \quad (10)$$

where $z = E_\ell/E_\tau$, P_{eff}^τ is the production angular-dependent effective polarization of the τ including the effects of the initial e^- beam polarization as given in Ref. [10] and f, g are kinematic functions:

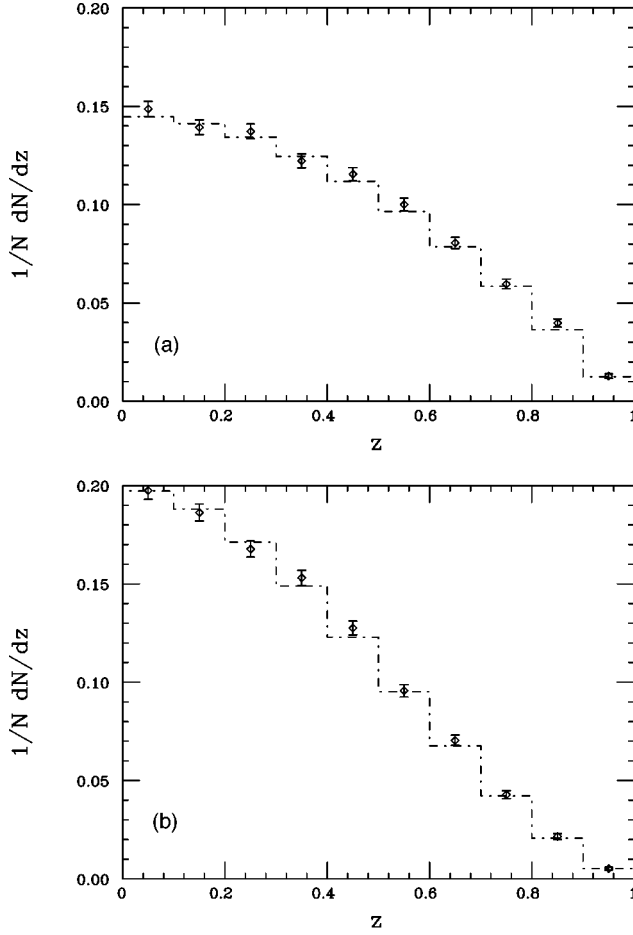


FIG. 4. Comparison of SM expectations and Monte Carlo data for the lepton energy spectrum in τ decays at the Z . The top figure corresponds to the sum of the two cases where the negative τ is forward and $P > 0$ and where the τ is backward and $P < 0$. The bottom plot shows the sum of the other two possibilities. In both figures the SM expectations are given by the dash-dotted histogram whereas the points represent the Monte Carlo data generated assuming the SM is correct.

$$f = \left(\frac{5}{3} - 3z^2 + \frac{4}{3}z^3 \right) + \kappa \left(-\frac{1}{6} + \frac{3}{2}z^2 - \frac{4}{3}z^3 \right),$$

$$g = \left(-\frac{1}{3} + 3z^2 - \frac{8}{3}z^3 \right) + \kappa \left(-\frac{1}{2} + 2z - \frac{3}{2}z^2 \right). \quad (11)$$

The behavior of both $f(z)$ and $g(z)$ due to variations in κ is shown in Fig. 3. There are several things to observe: first, g is more sensitive to variations in κ than is f so that having a handle on P_{eff}^τ through modifications of the beam polarization is very useful in obtaining a greater sensitivity. Second, the κ dependent term in f has the same structure as that due to a shift in $\frac{8}{3} \cdot \rho$, where ρ is one of the conventional Michel parameters [11]. The κ dependent term in g is *not* of the same form as a shift in the corresponding δ parameter.

The current bounds on κ from the SLD Collaboration are rather poor due to the low statistics available. To get an idea of what future constraints on κ might be obtainable, we perform a toy Monte Carlo study assuming a sample of

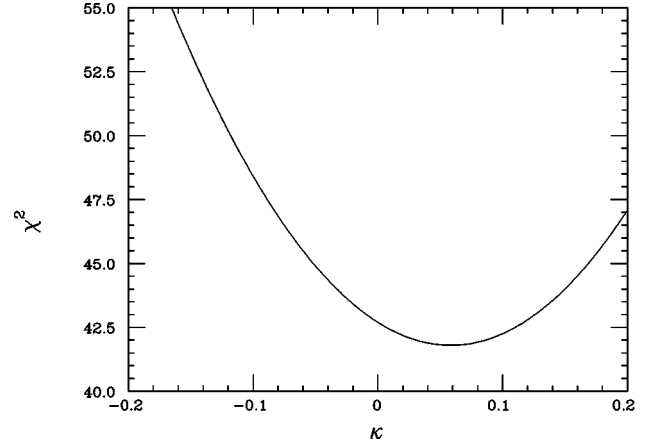


FIG. 5. χ^2 fit to the Monte Carlo data using the κ -dependent form of the leptonic energy spectrum in τ decays on the Z pole.

20 000 $\tau \rightarrow \ell$ decays, corresponding to about 1.5 million Z 's, assuming a beam polarization of $|P| = 77.2\%$ and a cut on the angular acceptance of $|\cos\theta_\ell| \leq 0.75$. We follow the same approach as SLD [10] and consider four distinct cases depending on whether P is positive or negative and whether the negatively charged τ goes into the forward or backward hemisphere of the detector. In each case, we divide the z range into 10 equal bins, generating data weighted by the statistical errors only. Figure 4 shows the resulting Monte Carlo generated distributions in comparison with the expectations of the SM.

In order to obtain our κ constraint, we perform a χ^2 fit to the above distributions, which were generated assuming $\kappa = 0$, by using the κ -dependent functional forms above. We obtain a best fit of $\kappa = 0.06 \pm 0.12$ at 95% C.L. with a χ^2/N_{DF} of 41.8/40; this result is explicitly shown in Fig. 5. It is clear from this analysis that Z pole measurements will never be able to achieve the level of sensitivity we require to probe $|\kappa|$ values below 0.03.

What happens at a B or τ - c factory? Here the τ is either at rest or is relatively slow and a pseudorest frame can be defined. In the τ rest frame, neglecting the ℓ mass and polarization dependent terms, one finds

$$\frac{d\Gamma(\tau \rightarrow \ell \nu \bar{\nu})}{dx} = \Gamma_0 x^2 [6 - 4x + 2\kappa x + 3\kappa^2(1-x)^2], \quad (12)$$

where $x = 2E_\ell/m_\tau$ and Γ_0 was introduced above. (As above, the contribution of $\tilde{\kappa}$ can be included by the replacement $\kappa^2 \rightarrow \kappa^2 + \tilde{\kappa}^2$.) Neglecting terms of order κ^2 again we see that the *normalized* lepton energy spectrum in the τ rest frame can be written as

$$\frac{1}{\Gamma} \frac{d\Gamma}{dx} = x^2 [6 - 4x + \kappa(4x - 3)]. \quad (13)$$

As in the Z case, we see that by comparing with the conventional Michel spectrum [9] the effect of κ on the normalized spectrum *to this order* is the same as $8/3\Delta\rho$ [11]. The current best single measurement of ρ using the final state lepton

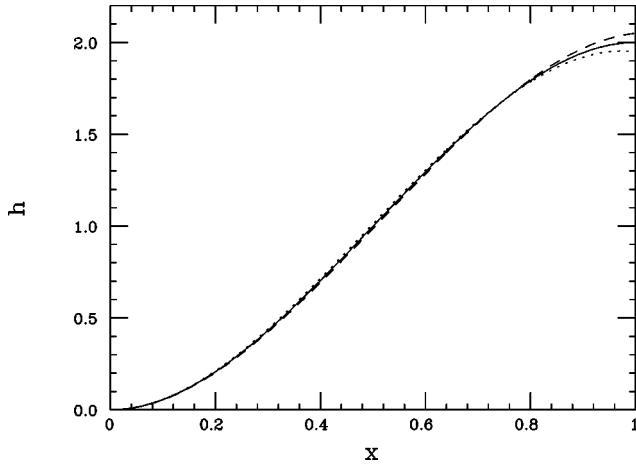


FIG. 6. $h(x)$ as defined in the text for $\kappa = -0.05$ (dotted), 0 (solid), and 0.05 (dashed).

spectrum comes from CLEO [12]; assuming $e - \mu$ universality they obtain $\Delta\rho = \rho - 0.750 = -0.015 \pm 0.015$ or $\kappa = -0.040 \pm 0.040$. This is already far better than what we obtained earlier on the Z peak using our toy Monte Carlo program. Using the current world average value $\Delta\rho = \rho - 0.750 = -0.009 \pm 0.014$ [13] gives a comparable result. It is clear that future B factories, with more than an order of magnitude increase in statistics should begin to probe κ values of order 0.01. Figure 6 shows a plot of the function $h(x) = (1/\Gamma)(d\Gamma/dx)$ for different values of κ . Note that the most significant deviation from the SM occurs at large values x where the most statistics are available.

In order to get an estimate of the future sensitivity of low energy measurements to nonzero values of κ , we return to our Monte Carlo approach assuming a sample of 10^8 τ pairs. Data on the τ 's lepton energy spectrum are then generated assuming the SM is correct and is put into 10 equal sized x bins as is shown in Fig. 7. Only statistical errors were included.

A κ -dependent fit is then performed with the results

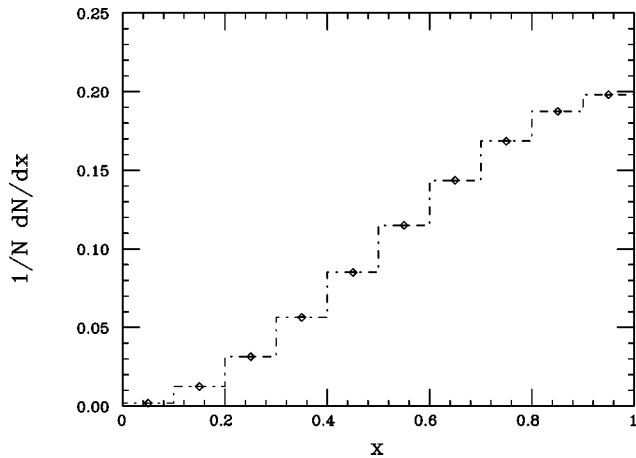


FIG. 7. Comparison of SM expectations and Monte Carlo data for the lepton energy spectrum in τ decays at a B or $\tau - c$ factory. As above, the SM expectations are given by the dash-dotted histogram whereas the points represent the Monte Carlo data generated assuming the SM is correct.

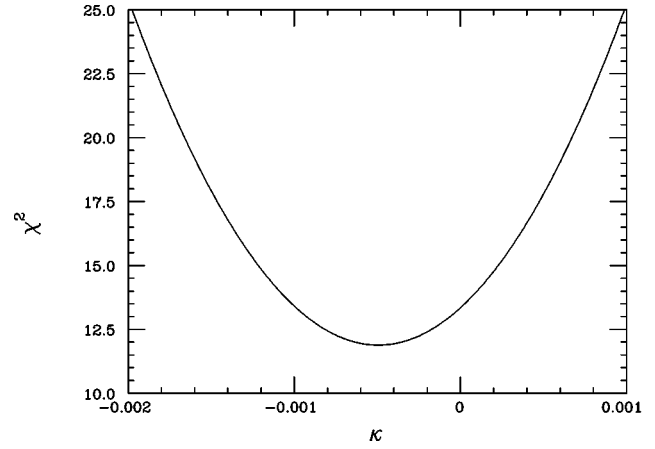


FIG. 8. χ^2 fit to the Monte Carlo data using the κ -dependent form of the leptonic energy spectrum in τ decays at a B or $\tau - c$ factory.

shown in Fig. 8. Here we see that the fitted value of κ is determined to be $\kappa = (-0.49^{+0.82}_{-0.81}) \cdot 10^{-3}$ at 95% C.L. with a χ^2/N_{DF} of 11.9/10. A parallel analysis using a data sample of the same size but with ten times as many bins obtained $\kappa = (-0.04 \pm 0.79) \cdot 10^{-3}$ at 95% C.L. with a χ^2/N_{DF} of 90.5/100. From this analysis it is clear that very large τ data samples of this magnitude will allow the probing κ 's in the 0.001–0.01 range even if significant systematic errors are present.

Are there additional constraints that we can obtain on κ from the semileptonic decay modes? As we saw above, τ decays to pseudoscalar mesons do not provide any additional sensitivity to $\kappa \neq 0$ since the purely transverse $\sigma_{\mu\nu} q^\nu$ terms decouple in this case. We thus turn to decays of the type $\tau \rightarrow V\nu$ where V is either a vector or axial-vector meson or where V represents the hadronic continuum at and above the two-pion threshold. As is well known, the ratio of the semileptonic to leptonic widths of the τ can be symbolically written as

$$R_\tau = \frac{\Gamma(\tau \rightarrow \text{hadrons})}{\Gamma(\tau \rightarrow \ell \nu \bar{\nu})} \sim \int_0^{m_\tau^2} R \left(\frac{s}{m_\tau^2} \right) \frac{\rho(s) ds}{m_\tau^2}, \quad (14)$$

where $\rho(s) = \text{Im}\Pi(s)/\pi$ is the spectral density defined in terms of the appropriate charged current correlator $\Pi(q^2)$ and R is the kinematic kernel which now depends on κ . Defining $x = s/m_\tau^2$ we find that $R(x)$ is given to all orders in κ by

$$R(x) = (1-x)^2 \frac{[1 + 2x + 3\kappa x + (1/4)\kappa^2 x(2+x)]}{[1 + (1/2)\kappa + (1/10)\kappa^2]}. \quad (15)$$

As usual, we can incorporate $\tilde{\kappa}$ contributions by the now standard replacement $\kappa^2 \rightarrow \kappa^2 + \tilde{\kappa}^2$ in this expression; again, the numerical contributions from the $\tilde{\kappa}$ terms cannot be large. The above expression for $R(x)$, expanded to linear

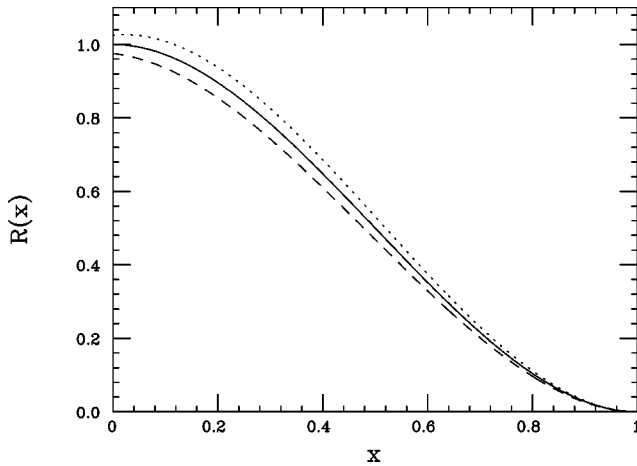


FIG. 9. The kinematic function $R(x)$ as defined in the text assuming $\kappa = -0.05$ (dotted), 0 (solid), and 0.05 (dashed).

order in κ and neglecting possible $\tilde{\kappa}$ contributions is shown in Fig. 9 and displays reasonable sensitivity to κ . In principle, a nonzero value of κ can be responsible for an apparent breakdown in the usual CVC (conserved vector current) predictions in that the τ 's weak coupling to the W is no longer solely a mixture of conventional vector and axial-vector currents. Of course, the matrix element of the weak hadronic charged current is still simply related to the corresponding electromagnetic current by an isospin rotation. However, when it is contracted with the τ 's charged current matrix element, new κ -dependent terms arise which are not present in $e^+e^- \rightarrow \text{hadrons}$. It is clear from Fig. 9 that positive (negative) values of κ will produce a decrease (increase) in the predicted value of the relative hadronic branching fraction of the τ , R_τ . As an estimate of the current sensitivity we compare the experimental rate for $\tau \rightarrow 2\pi\nu$ with that expected from CVC using the low-energy e^+e^- data as input [14] in the region of the ρ resonance allowing for κ to be nonzero; we find that $\kappa = -0.44 \pm 0.39$ at 1σ . Also, crudely, we find that a value of $\kappa = 0.03$ (-0.03) leads to *decrease* (*increase*) in the continuum τ hadronic width of roughly as large as -3 (3)%, a value not too much smaller than the leading inclusive QCD correction to the tree-level SM electroweak result of $\alpha_s(m_\tau^2)/\pi$. $\kappa \neq 0$ could thus have important implications to the problems associated with a clear understanding of the running of the QCD coupling [15] if the value extracted from hadronic τ decays [16] is indeed shifted due to these anomalous couplings.

Lastly, we note that a nonzero value for κ also leads to a modification of the transverse and longitudinal polarization fractions for the ‘‘V’’ in the final state of this semileptonic decay. (In what follows we loosely define the longitudinal component as that arising from the q_ν/M_V in V 's polarization vector; this reproduces the well-known SM results.) Unfortunately, the $\kappa \neq 0$ contribution is quite small particularly in the low invariant mass region. With x now denoting the ratio m_ν^2/m_τ^2 we find that, to lowest order in κ ,

$$F_T = \frac{(2+3\kappa)x}{1+(2+3\kappa)x},$$

$$F_L = \frac{1}{1+(2+3\kappa)x}, \quad (16)$$

where $F_{T(L)}$ is the transverse (longitudinal) fraction of ‘‘V.’’ For $|\kappa| \leq 0.03$ we see that this effect is below the 1% level; there is little sensitivity here to anomalous couplings.

In this paper we have considered how existing and future measurements can probe the CP -conserving anomalous magnetic dipole moment of the τ , κ , in charged current interactions. Searches for the corresponding coupling structure in electromagnetic and weak neutral current interactions of τ 's have been undertaken for some time and interesting limits have been obtained. We have argued that if γ and/or Z anomalous couplings are present for the τ at some level then the analogous charged current couplings must also be present with a comparable magnitude due to gauge invariance. In almost all cases, except for the decay $W \rightarrow \tau\nu$, the contributions to the observables that we consider from potential CP -violating terms arising from the electric dipole moment $\tilde{\kappa}$, if they are at all present, are shown to be small.

We observed that the current best limits on κ are indirect and arise from universality tests, specifically, considerations of the τ lifetime and the $W \rightarrow \tau\nu$ branching fraction. These two independent measurements tell us that $|\kappa| \leq 0.028$ at 95% C.L. Clearly, at both B and τ - c factories, universality tests involving the τ should improve these indirect limits by factors of order a few to as much as an order of magnitude depending on the size of systematic errors. More interestingly, direct experiment sensitivity to nonzero values of κ arise from a number of sources, in particular, the shape of final state lepton energy spectrum in $\tau \rightarrow \ell \nu \bar{\nu}$. We showed that the shift in the *unnormalized* spectrum cannot be accommodated through variations in the Michel parameters. However, to first order in κ , the normalized spectrum modification was found to be proportional to $\delta\rho$. A toy Monte Carlo study showed that the sensitivity obtainable from future data on a sample of more than 10^6 polarized Z 's at SLD cannot probe κ values at the requisite 0.01 level. A measurement of the same spectrum at B and/or τ - c factories where 10^8 τ pairs are available was shown by the same toy Monte Carlo approach to be sensitive to κ at the 0.001 level.

Hadronic τ decays were shown to display somewhat more subtle sensitivity to finite κ and, in particular, decays to a single pseudoscalar were shown to have no sensitivity whatsoever since only the couplings of the virtual longitudinal W are being probed there. Decays to ‘‘vector’’ or ‘‘axial-vector’’ meson final states (i.e., the hadronic continuum above the 2π threshold) were shown to display threefold κ sensitivity via modifications in the overall decay rates as well as in the associated invariant mass distributions and the polarization of the final state. In particular we showed that the deviations in the value of R_τ due to a nonzero κ can lead to an incorrect extraction of the strong coupling constant, $\alpha_s(m_\tau^2)$, with the obvious implications elsewhere. We also found that the anomalous moment terms can lead to potentially large apparent violations of CVC.

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