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TAU-SPIN CORRELATIONS AT THE Z PEAK: APLANARITIES OF THE DECAY PRODUCTS

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ABSTRACT

The production of τ pairs at the Z-peak leads to interesting dynamical information contained in their spin density matrix. Besides the longitudinal polarization of each τ-lepton, there are two independent spin-spin correlations associated with the transverse (within the production plane) and normal (to the production plane) polarization components. The transverse-normal spin correlation is both a parity-odd and time reversal-odd observable. We analyze the correlated angular distribution of the decay products as polarization analyzers of the $\tau^+\tau^-$ system. We find two azimuthal asymmetries of the decay products and the incoming beam, which are able to disentangle these spin correlation observables without reconstructing the τ-direction.

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1. Introduction

The LEP experiments make it possible to study a variety of processes with high precision and in extremely clean conditions [1], [2], including the production of $\tau^-\tau^+$ events. When the production mechanism is restricted to chirality conserving interactions, such as those associated with gauge theories, the non-vanishing observables at high energy are limited by helicity conservation. Besides the production cross section one finds, for unpolarized e^-e^+ collisions, the forward-backward asymmetry [3], the longitudinal polarization [4], the longitudinal spin correlation (equal to unity), the transverse spin correlation and the T-odd transverse (within the production plane) - normal (to the production plane) spin correlation [5]. Around the Z-peak, all these observables get non-vanishing values at tree level from the Z-exchange amplitude, except the T-odd correlation which, in the standard model, only gets contributions from the absorptive parts generated at one-loop level as unitarity corrections [5]. In models with chirality-flipping couplings to fermions [6], [7], [8] one finds more possibilities of building non-vanishing observables.

The use of τ-decays as polarization analyzers of the τ-spin state has been considered in the preparation of LEP, following the principles discussed in the pioneering work of Tsai [9]. The energy spectrum of the decay product (either a charged lepton or a hadron) in the laboratory frame, i.e. the Z rest frame, carries information about the longitudinal polarization of the τ. The sensitivity of a given decay channel to this longitudinal τ-polarization depends on the spin of the decay product whose spectrum is measured. For the ρ and a_1 channels, the sensitivity can be increased by measuring the helicity of these particles [10], [11]. First experimental results on the mean longitudinal τ- polarization at LEP measuring the energy spectrum of the decay product have been presented recently [12]. Up to now, particular emphasis has been placed on the measurement of the longitudinal τ-polarization, due to its sensitivity to the value of the electroweak mixing angle $\sin^2\theta_W$ ($\equiv s_W^2$) of the standard model. However, it is important to carry out a more general test of the coupling structure of the theory beyond the mere determination of its parameters. In this respect, the measurement of the energy correlation function has been considered in the literature [13], [14].

The direct measurable quantities are the momenta of hadrons and charged leptons coming from the decay of the taus. In this paper we analyze the angular distributions of the decay products of both taus, to look for the manifestations of the τ-spin correlations. We find two azimuthal asymmetries of the plane defined by the two final charged particles

with respect to the beam direction, able to measure independently the transverse spin correlation and the T-odd transverse-normal spin correlation. It is crucial to notice that the information is not lost when the τ-direction is integrated out. The experimental determination of these asymmetries would be of great interest.

2. τ Production at the Z Peak

Let us consider the process

$$e^-(k_1) + e^+(k_2) \to \tau^-(p_1, s_1) + \tau^+(p_2, s_2) \tag{2.1}$$

around the Z-peak. The momenta of the particles are as indicated and s_1^μ (s_2^μ) is the covariant spin vector of the τ^- (τ^+). When the incoming helicity states are averaged, the transition probability is given by the general structure

$$\overline{\sum}|M(s_1,s_2)|^2 = \frac{1}{4}\,|P(q^2)|^2\{A + B_{1\mu}s_1^\mu + B_{2\mu}s_2^\mu + C_{\mu\nu}s_1^\mu s_2^\nu\}\ , \tag{2.2}$$

where $q = k_1 + k_2$ and

$$P(q^2) = \frac{e^2}{16 s_W^2 c_W^2}\,\frac{q^2}{q^2 - M_Z^2 + iq^2\Gamma_Z/M_Z} \tag{2.3}$$

contains the Z-coupling normalization and the Z-propagator. The terms A, ..., $C_{\mu\nu}$ depend on the theory used to describe the transition. We include the Z-exchange amplitude, with effective (complex) vector and axial-vector couplings, and, when needed, its interference with the γ-exchange amplitude. In fact, this interference is of some importance only for the T-odd spin correlation [5]. In the standard model, its magnitude is comparable to that induced by the absorptive parts of the electroweak radiative corrections to the $Z \to \tau^-\tau^+$ decay amplitude.

A straightforward calculation of the right-hand side of eq. (2.2) allows the identification of the spin-independent term,

$$A = C_0(1+\cos^2\theta) + 2C_1\cos\theta\ . \tag{2.4}$$

Here θ is the τ^--polar angle with respect to the e^--direction, and the coefficients C_0 and C_1 contain the information on the Z-couplings:

$$C_0 = (|v_e|^2 + |a_e|^2)(|v_\tau|^2 + |a_\tau|^2)\ , \tag{2.5a}$$

$$C_1 = 4Re(v_e a_e^*)Re(v_\tau a_\tau^*)\ . \tag{2.5b}$$

One recognizes in eqs. (2.4) and (2.5a,b) the well-known terms associated with the integrated cross section, $\sigma = \frac{|P(q^2)|^2}{12\pi q^2} C_0$, and the forward-backward asymmetry, $A_{FB} = \frac{3}{4}\frac{C_1}{C_0}$.

In order to discuss the dependence on the τ-spin vectors, we decompose s_1^μ and s_2^μ in their longitudinal, transverse (within the collision plane) and normal (to the collision plane) components, $s_i^\mu = s_i^L l_i^\mu + s_i^T t^\mu + s_i^N n^\mu$ (i=1,2). To leading order in the tau-lepton mass m_τ, the terms linear in s_i^μ (i=1,2) are given by

$$B_{1\mu} s_1^\mu + B_{2\mu} s_2^\mu = W_\tau + W_e \; , \tag{2.6}$$

where

$$W_\tau = -D_0 (s_1^L - s_2^L)(1 + \cos^2\theta) \; , \tag{2.7a}$$
$$W_e = -D_1 (s_1^L - s_2^L) 2\cos\theta \; . \tag{2.7b}$$

Within our theoretical framework, other possible terms associated with transverse and/or normal polarizations of single taus are suppressed by lepton mass factors. W_τ contains the longitudinal polarization of the taus for unpolarized Z's, $P_\tau = -D_0/C_0$, whereas W_e is related to the angular asymmetry of the longitudinal polarization of the taus induced by the polarized Z's, $P_Z = -D_1/C_0$. The information provided by W_e is the same as that of the left-right asymmetry for longitudinally polarized beams. The explicit expressions for the coefficients D_0 and D_1, in terms of the Z-couplings, are

$$D_0 = 2(|v_e|^2 + |a_e|^2) Re(v_\tau a_\tau^*) \; , \tag{2.8a}$$
$$D_1 = 2 Re(v_e a_e^*)(|v_\tau|^2 + |a_\tau|^2) \; . \tag{2.8b}$$

Note that due to the factorization induced by single Z-exchange $A_{FB} = \frac{3}{4} P_Z P_\tau$.

The quadratic terms in the polarization of both taus contain interesting spin correlations, which introduce additional dependences on the vector and axial-vector Z-couplings besides those already present in the rate, the forward-backward asymmetry and the longitudinal polarization of the tau. We find

$$C_{\mu\nu} s_1^\mu s_2^\nu = C_0 h_0 + C_1 h_1 + C_2 h_2 + D_2 h_3 \; , \tag{2.9}$$

where

$$h_0 = -s_1^L s_2^L (1 + \cos^2\theta) \; , \tag{2.10a}$$
$$h_1 = -s_1^L s_2^L 2\cos\theta \; , \tag{2.10b}$$
$$h_2 = (s_1^N s_2^N - s_1^T s_2^T)\sin^2\theta \; , \tag{2.10c}$$
$$h_3 = (s_1^N s_2^T + s_1^T s_2^N)\sin^2\theta \; . \tag{2.10d}$$

The fact that both h_0 and h_1 have the same couplings, C_0 and C_1 respectively, as those of the spin independent term A (eq. (2.4)) leads to a longitudinal spin correlation equal to unity. This is nothing but a consequence of helicity conservation.

C_2 and D_2 are the τ-spin correlations associated with the transverse-transverse and transverse-normal components of both polarizations,

$$C_{TT} \equiv \frac{C_2}{C_0} = \frac{|a_\tau|^2 - |v_\tau|^2}{|a_\tau|^2 + v_\tau|^2} \; , \tag{2.11a}$$
$$C_{TN} \equiv \frac{D_2}{C_0} = -\frac{2Im(v_\tau a_\tau^*)}{|v_\tau|^2 + |a_\tau|^2} - \frac{2 s_W^2 c_W^2 Re(v_e a_\tau)\Gamma_Z/M_Z}{(|v_e|^2 + |a_e|^2)(|v_\tau|^2 + |a_\tau|^2)} \; . \tag{2.11b}$$

The first is a parity-even observable which measures the interference between the left- and right-handed amplitudes in the Z-decay: it gives the difference in the probability for the decays from the charge conjugation state with $C = +1$ or $C = -1$. The C_{TN} correlation is both a parity-odd and time reversal-odd observable which, as shown in eq. (2.11b), can be generated from absorptive parts in the electroweak amplitudes. The second term of eq. (2.11b) comes from the interference of γ-exchange with the imaginary part of the Z-exchange amplitude. In some extended models C_{TN} could get a contribution from CP-violating amplitudes. The purpose of this paper is to find a method to measure these spin correlations.

3. τ - Decays as Polarization Analyzers

To look for the signal of the spin correlations, we let both taus decay to a charged particle, which will be detected, plus missing neutrinos. This will translate the spin correlations into angular correlations of the decay products. The momenta of the two decay products X_1 from τ^- and X_2 from τ^+ are indicated by q_1 and q_2 respectively. The angular distribution of X_1 (X_2) from an arbitrary polarized τ^- (τ^+) can be written in the rest frame of the tau as

$$\frac{d\Gamma^{(s_i)}}{\Gamma_{X_i}}(\tau \to X_i + \ldots) = \frac{1}{4\pi}\left[1 - \alpha_i m_\tau \frac{(q_i \cdot s_i)}{(q_i \cdot p_i)}\right] d\Omega_i^* \; , \tag{3.1}$$

where α_i is the polarization analyzer of the spin s_i^μ, $i = 1, 2$.

We have calculated the values of α_i for the dominant decay channels of the τ, assuming general vector and axial vector couplings for the τ decay. In the leptonic decay mode, we find

$$\alpha_{l^\pm} = \pm\, \xi/3 \; , \tag{3.2}$$

where ξ is the Michel polarization parameter for $\tau \to l + \nu_\tau + \nu_l$ [15]. For the hadronic decays, we introduce the covariant amplitudes

$$M = \frac{G}{\sqrt{2}} \bar{\nu}_\tau \gamma_\mu (g_V - g_A \gamma_5) \tau J_H^\mu , \tag{3.3}$$

with G the Fermi constant and J_H^μ the weak hadronic current, and define the chiral polarization parameter

$$\xi_H = \frac{2Re(g_V g_A^*)}{|g_V|^2 + |g_A|^2} . \tag{3.4}$$

The polarization analyzer in the decay mode $\tau \to \pi + \nu_\tau$ is then simply given by:

$$\alpha_{\pi^\pm} = \mp \xi_\pi . \tag{3.5}$$

The ρ channel is slightly more complicated. If the angular distribution of eq. (3.1) refers to the ρ direction, [1] it is straightforward to obtain the following result in the narrow width approximation,

$$\alpha_{\rho^\pm} = \mp \xi_\rho \, \frac{m_\tau^2 - 2m_\rho^2}{m_\tau^2 + 2m_\rho^2} \, \frac{m_\tau^2 + m_\rho^2}{m_\tau^2 - m_\rho^2} = \mp 0.67 \, \xi_\rho . \tag{3.6}$$

For the $\tau \to a_1 + \nu_\tau$ channel, the value of the corresponding $\alpha_{a_1^\pm}$ is also given by eq. (3.6) with the appropriate mass changes (m_{a_1} instead of m_ρ); the result is however smaller and very sensitive to the value of the a_1-mass (4×10^{-3} for m_{a_1} = 1260 MeV and 0.13 for m_{a_1} = 1200 MeV), so we will not consider this decay mode any further.

The angular distribution of the sequential process $e^- e^+ \to \tau^- \tau^+ \to X_1 X_2 + ...$ in the laboratory frame, where the taus move with velocity $\beta = |\vec{p}|/E$, may be written in the following way [9], [16]:

$$d\sigma(e^- e^+ \to X_1 X_2 + ...) = Br(\tau^- \to X_1 + ...) Br(\tau^+ \to X_2 + ...) \frac{|P(q^2)|^2}{64\pi^2 q^2 (4\pi)^2}$$
$$\times \{A + B_{1\mu} n_1^\mu + B_{2\mu} n_2^\mu + C_{\mu\nu} n_1^\mu n_2^\nu\} \frac{d\Omega \; d\Omega_1 \; d\Omega_2}{\gamma^4 (1 - \beta \cos\chi_1)^2 (1 + \beta \cos\chi_2)^2} . \tag{3.7}$$

[1] Since the ρ decays before being detected, one may think that it would be cleaner to use the angular distribution of the final charged pion in the decay chain: $\tau^\mp \to \rho^\mp + \nu_\tau \to \pi^\mp + \pi^0 + \nu_\tau$. Unfortunately, this procedure washes out the sensitivity to the τ - polarization, as we find $\alpha_{\rho^\pm \to \pi^\pm} = \mp \xi_\rho f(m_\rho)$, where $f(m_\rho) \sim 6 \times 10^{-2}$. As a consequence, we will use the ρ - direction as analyzer of the τ-polarization, although experimentally the direction of the charged pion can be measured more accurately.

In the result (3.7), the Jacobian of the transformation for the angular variables from the rest system of the taus to the laboratory frame has been obtained in the limit of vanishing final masses. The dilation factor $\gamma = E/m_\tau$ controls the range of the opening angle χ_1 of the decay product X_1 with respect to τ^-, and similarly for $(\pi - \chi_2)$. The bracket {...} is obtained from eq. (2.2) under the recipe [16]:

$$s_i^\mu \to n_i^\mu = -\alpha_i \frac{m_\tau}{(p_i \cdot q_i)} \eta_i^{\mu\nu} q_{i\nu} \qquad (i = 1, 2) , \tag{3.8}$$

where $\eta_i^{\mu\nu} = -g^{\mu\nu} + p_i^\mu p_i^\nu / m_\tau^2$.

4. Angular Correlations

To proceed further, we choose the following coordinate system in the laboratory frame, as indicated in fig. 1,

$$\begin{aligned} \hat{q}_1 &= (0, 0, 1) \\ \hat{q}_2 &= (\sin\theta_{12}, 0, \cos\theta_{12}) \\ \hat{k} &= (\sin\theta_1 \cos\phi_1, \sin\theta_1 \sin\phi_1, \cos\theta_1) \\ \hat{p} &= (\sin\chi_1 \cos\psi, \sin\chi_1 \sin\psi, \cos\chi_1) . \end{aligned} \tag{4.1}$$

In terms of these angles, one can write the other directional variables θ [angle between $\hat{k}$ and $\hat{p}$], χ_2 [angle between $\hat{p}$ and $\hat{q}_2$] and θ_2 [angle between $\hat{k}$ and $\hat{q}_2$]. Our choice of angular variables is adequate, as we shall see, to discuss angular correlations between the decay products. The aim is to analyze the resulting correlations when the tau direction $\Omega(\chi_1, \psi)$ is integrated out in eq. (3.7). A different strategy to study energy correlations between the decay products was discussed by Nelson [14].

We can expand the resulting expression for eq. (3.7) to the dominant order in the dilation factor γ, taking into account that due to the boost one has $\chi_1 \sim \gamma^{-1}$ and $\theta_{12} \equiv \pi - \epsilon$ with $\epsilon \sim \gamma^{-1}$. To leading order in χ_1 and ϵ, the bracket involved in the cross section (3.7) is given by

$$A + B_{1\mu} n_1^\mu + B_{2\mu} n_2^\mu + C_{\mu\nu} n_1^\mu n_2^\nu = G_0 (1 + \cos^2\theta_1) + G_1 2\cos\theta_1 + G_2(\phi_1) \sin^2\theta_1 . \tag{4.2}$$

As seen, the angular distribution in θ_1 (the direction of one daughter product with respect to the electron beam) reproduces the form in θ that the parent tau had with respect to the beam (see eqs. (2.4), (2.7)and (2.10)). Besides the angular dependences explicitly indicated, G_0, G_1 and $G_2(\phi_1)$ are functions of the three angular variables (χ_1, ψ , ϵ). G_0

gets contributions from the C_0 term of A and $C_{\mu\nu}$ and the D_0 term of B_μ; its information on the parent process corresponds to the decay rate and the longitudinal polarization of the tau, P_τ. G_1 gets contributions from the C_1 term of A and $C_{\mu\nu}$ and the D_1 term of B_μ; its information on the tau production process corresponds to the forward-backward asymmetry, A_{FB}, and the polarization of the Z, P_Z, for unpolarized beams. $G_2(\phi_1)$ is the function which contains the information on the spin correlations C_{TT} and C_{TN}, discussed in eq. (2.11a,b).

When the azimuth ψ between the tau and the plane defined by both decay products is integrated out, the θ_1-distribution has the same form as in eq. (4.2), with new functions

$$g_i \equiv \int_0^{2\pi} d\psi \, \frac{G_i}{(1+\beta\cos\chi_2)^2} \qquad (i=0,1,2)\,. \tag{4.3}$$

We find

$$\begin{aligned} g_i = \frac{8\pi\gamma^4}{R^{3/2}} \Big\{ & C_i \Big[(1+x+\gamma^2\epsilon^2)[1-\alpha_1\alpha_2(1-\frac{2}{1+x})] \\ & + \frac{2\alpha_1\alpha_2}{R}(1-\frac{2}{1+x})[(1+x+\gamma^2\epsilon^2)^2+2\gamma^2\epsilon^2 x] \Big] \\ & + D_i \Big[(\alpha_1-\alpha_2)(1+x+\gamma^2\epsilon^2) - \alpha_1 \frac{2(1+x+\gamma^2\epsilon^2)}{1+x} \\ & + \alpha_2 \frac{2}{R}[(1+x+\gamma^2\epsilon^2)^2+2\gamma^2\epsilon^2 x] \Big] \Big\} \qquad (i=0,1), \end{aligned} \tag{4.4a}$$

$$g_2(\phi_1) = 8\pi\gamma^4\alpha_1\alpha_2[C_2\cos 2\phi_1 + D_2\sin 2\phi_1] 12\gamma^2\epsilon^2 \frac{x(x-1-\gamma^2\epsilon^2)}{(1+x)R^{5/2}}\,, \tag{4.4b}$$

where $x \equiv (\gamma\chi_1)^2$ and $R \equiv x^2 + 2(1-\gamma^2\epsilon^2)x + (1+\gamma^2\epsilon^2)^2$.

As seen in eq. (4.4b), the two spin correlations C_2, D_2 of interest can be separated out, by looking at the azimuthal distribution of the two decay products with respect to the electron beam. We can integrate over x without losing the information on C_2, D_2; so the reconstruction of the tau direction is unnecessary.

When $d\sigma$ is integrated over the tau-direction χ_1, the correlated angular distribution for the decay products X_1 and X_2 is obtained, to leading order in $\epsilon \equiv \pi - \theta_{12}$, as

$$d\sigma = K(q^2)\, F(\theta_1,\phi_1;\theta_{12})\, d\Omega_1 d\Omega_2\,, \tag{4.5}$$

where

$$K(q^2) = Br(\tau^- \to X_1 + ...) Br(\tau^+ \to X_2 + ...) \frac{|P(q^2)|^2\gamma^2}{(4\pi)^3 q^2}\,, \tag{4.6}$$

and

$$F(\theta_1,\phi_1;\theta_{12}) = F_0(\epsilon)(1+\cos^2\theta_1) + F_1(\epsilon)2\cos\theta_1 + F_2(\epsilon,\phi_1)\sin^2\theta_1\,. \tag{4.7}$$

The three functions $F_i(\epsilon)$ ($i=0,1,2$) of eq. (4.7) are given by

$$F_i(\epsilon) \equiv \frac{1}{8\pi\gamma^4}\int dx\, \frac{g_i}{(1+x)^2} \qquad (i=0,1,2)\,. \tag{4.8}$$

These functions have the following interesting dependences on the polarization analyzers α_1, α_2 of the channels X_1,X_2:

$$F_i(\epsilon) = C_i[Q_1(\epsilon) + \alpha_1\alpha_2 Q_2(\epsilon)] + D_i(\alpha_1-\alpha_2)Q_3(\epsilon) \qquad (i=0,1)\,, \tag{4.9a}$$

$$F_2(\epsilon,\phi_1) = \alpha_1\alpha_2[C_2\cos 2\phi_1 + D_2\sin 2\phi_1]Q_4(\epsilon)\,. \tag{4.9b}$$

The four functions Q_i (i=1,2,3,4) are represented in fig. 2. We reproduce that the characteristic width of the ϵ -distribution is $\sim \gamma^{-1}$.

To single out the spin-correlation terms associated with C_2 and D_2, we define the following aplanarities for fixed values of (θ_1,ϵ):

$$A_c(\theta_1,\epsilon) = \frac{\int_{\cos 2\phi_1>0} d\sigma - \int_{\cos 2\phi_1<0} d\sigma}{\int_{\cos 2\phi_1>0} d\sigma + \int_{\cos 2\phi_1<0} d\sigma}\,, \tag{4.10a}$$

$$A_s(\theta_1,\epsilon) = \frac{\int_{\sin 2\phi_1>0} d\sigma - \int_{\sin 2\phi_1<0} d\sigma}{\int_{\sin 2\phi_1>0} d\sigma + \int_{\sin 2\phi_1<0} d\sigma}\,. \tag{4.10b}$$

In particular, for $\theta_1 = \pi/2$ we present in fig. 3 the results of

$$A_c(\pi/2,\epsilon) = \frac{2}{\pi}\frac{\alpha_1\alpha_2 C_2 Q_4(\epsilon)}{F_0(\epsilon)} \tag{4.11}$$

for the dominant decay modes of the tau. The coefficients C_2, C_0 and D_0 have been fixed to the values expected in the standard theory, as well as the τ decay parameters, $\xi = \xi_\pi = \xi_\rho = 1$. Similarly, these results can be translated into values of $A_s(\pi/2,\epsilon)$ by the substitution $C_2 \to D_2$. The highest sensitivity of the method to determine the correlations C_{TT} and C_{TN} appears for values of $\gamma\epsilon \sim 2$, although the width of the ϵ - distribution of events is typically $\gamma\epsilon \sim 1$.

One can consider aplanarities integrated over ϵ, keeping in each case the whole set of events within the plane defined by the azimuth ϕ_1. Some sensitivity is lost in these ϵ - integrated aplanarities, which are presented in Table 1 for all the channels we have analyzed.

channel	$A_c(\pi/2)$	$A_s(\pi/2)$
$\pi^+\pi^-$	2.1×10^{-1}	2.6×10^{-3}
π^+l^-	-7.0×10^{-2}	-8.6×10^{-4}
$\pi^+\rho^-$	1.4×10^{-1}	1.7×10^{-3}
$\rho^+\rho^-$	9.4×10^{-2}	1.2×10^{-3}
ρ^+l^-	-4.7×10^{-2}	-5.7×10^{-4}
l^+l^-	2.3×10^{-2}	2.9×10^{-4}

Table 1: Integrated azimuthal asymmetries.

5. Discussion

The correlated angular distribution of the decay products of the tau-pairs produced at the Z peak in e^+e^- collisions contains interesting information about the spin density matrix of both taus. A convenient choice of the angular variables for the decay product and beam three-momenta, without any reference to the tau direction, is shown in Fig. 1. We have found that the two aplanarities A_c and A_s defined in eqs. (4.10)are able to measure the tau spin correlations C_{TT} and C_{TN}, associated with the transverse and normal polarizations of both taus.

The first observable is parity even and it gives the relative magnitude between the vector and the axial probabilities for the $Z \to \tau^+ + \tau^-$ decay. The signal of A_c in the standard theory, either as a function of the acollinearity angle ϵ between both decay products or in its ϵ-integrated version, is given in Fig. 3 and Table 1, respectively. It appears to be big enough to be detected in forthcoming analyses of LEP experiments.

The spin correlation C_{TN}, as well as the corresponding observable aplanarity A_s, are of great interest because of their T-odd character. In the standard theory, the small non-vanishing value of A_s is due [5] to the generation of absorptive parts from the electroweak radiative corrections to the Z-decay amplitude and to the interference between the Z-exchange and γ-exchange amplitudes. This prediction for A_s, shown in Table 1 for the ϵ-integrated version, should be considered as the standard reference to look for manifestations of new physics related to CP-violation. The observation of a value for A_s above the standard prediction would be of major interest.

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Figure Captions

Fig. 1. Coordinate system in the LAB frame used in the calculation of the angular distribution for $e^+ + e^- \to \tau^+ + \tau^- \to X_1 + X_2 + \ldots$

Fig. 2. Functions which appear in the angular distribution of $e^+ + e^- \to \tau^+ + \tau^- \to X_1 + X_2 + \ldots$ after integrating out the τ solid angle (eq. $(4.9a, b)$). Dash-dotted line: Q_1; continuous line: Q_2; dotted line: Q_3; dashed line: Q_4.

Fig. 3. Results of the azimuthal asymmetry $A_c(\pi/2, \epsilon)$ for the dominant τ decay modes.

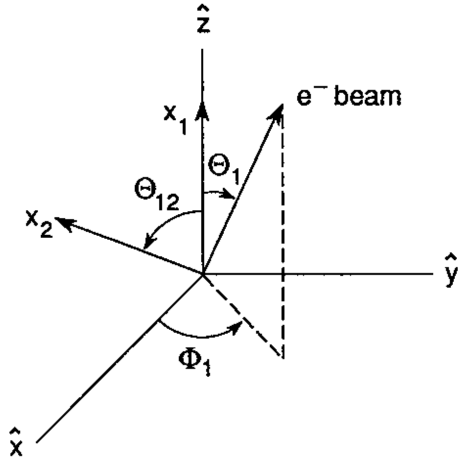

Fig. 1.

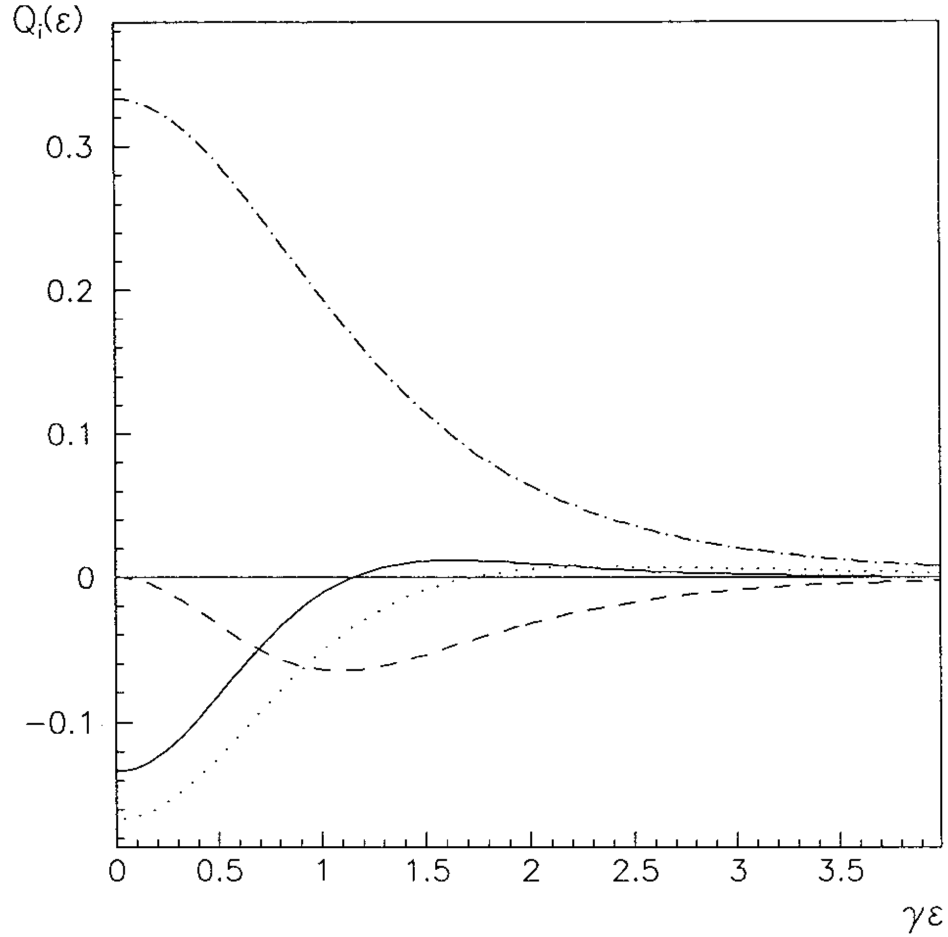

Fig. 2.

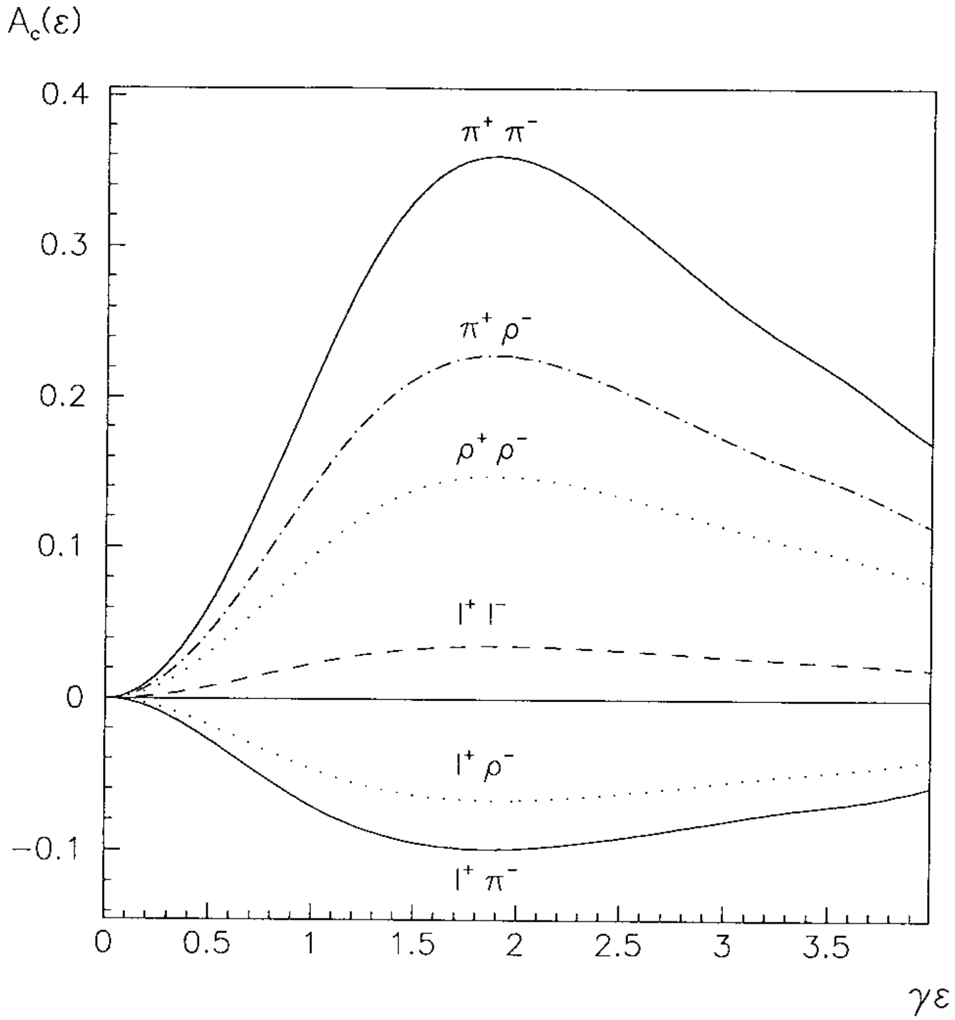

Fig. 3.

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