

τ weak dipole moments from azimuthal asymmetries *

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We show that transverse and normal single- τ polarization of τ pairs produced at $e^+ e^-$ unpolarized collisions, at the Z peak, are sensitive to weak (magnetic and electric) dipole moments of the τ . We also show how these components of the τ polarization are accessible by measuring appropriate azimuthal asymmetries in the angular distribution of its decay products. Sensitivities of the order of $10^{-18} e \cdot cm$, for the weak-electric dipole moment, and 10^{-4} (10^{-3}), for the real (imaginary) part of the weak-magnetic dipole moment of τ , may be achieved. Compatible bounds are also presented from spin-spin correlated asymmetries.

1. INTRODUCTION

Electron and muon dipole moments provide very precise tests of quantum field theories. The agreement between the predicted (first obtained by Schwinger [1] in first order) and the measured electron anomalous magnetic moment is one of the most spectacular achievements of quantum field theory. Electric and weak-electric dipole moments have been exhaustively investigated to look for signals of CP -violation in both the quark and the leptonic sector[2]. Low energy, LEP1 and SLC, experiments result in an enormous variety of measurements that lead, up to now, to the confirmation of the quantum corrections given by the Standard Model (SM).

The theoretical and experimental situation for the electro-magnetic (*i.e.* the ones related to the γ -coupling) dipole moments of light fermions is firmly established[3]: experiments are sensitive to an impressive number of decimal places and theoretical predictions of higher orders have been computed. For heavy fermions (τ, b, t), the magnetic DM are much poorly measured, and

also their theoretical significance is more involved. The anomalous weak magnetic dipole moments have been calculated for heavy fermions [4,5] in the Standard Model. For τ 's, weak dipole moments have been tested at LEP1 and SLC in recent years [6] by means of the angular distribution of the τ decay products acting as spin analyzers.

In this contribution we first show how, for $e^+ e^- \rightarrow \tau^+ \tau^-$ unpolarized scattering at the Z -peak, the transverse (within the collision plane) and normal (to the collision plane) single τ polarizations are very sensitive to the anomalous weak-magnetic ($a_\tau^w(M_Z^2)$) and weak-electric ($d_\tau^w(M_Z^2)$) dipole form factors. We construct azimuthal asymmetries, for single τ decay products, sensitive to each effective coupling in order to separate this signal in the search for new physics. Finally we present how some azimuthal asymmetries coming from spin-spin correlations can help in the search for signals of the weak dipole moments.

2. DIPOLE MOMENTS

The most general Lorentz invariant structure describing the interaction of a vector boson V with two fermions $f\bar{f}$ can be written in terms

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of ten form factors:

$$\begin{aligned} & \langle f(p_-)\bar{f}(p_+)|J^\mu(0)|0\rangle = \\ & e\bar{u}(p_-)[\gamma^\mu(f_1 - f_2\gamma_5) + (if_3 - f_4\gamma_5)\sigma^{\mu\nu}q_\nu \\ & + (f_5 + if_6\gamma_5)(q_-)^\mu + \sigma^{\mu\nu}(q_-)_\nu(f_7 + if_8\gamma_5) \\ & + (if_9 + f_{10}\gamma_5)q^\mu]v(p_+) \end{aligned} \quad (1)$$

with $q = p_+ + p_-$ and $q_- = p_+ - p_-$. For all particles on-shell, these ten form factors may be reduced to the first four: f_1 and f_2 parameterize the vector and vector-axial sector of the current; f_3 and f_4 are proportional to the anomalous magnetic (a_f^V) and electric (d_f^V) dipole moment, respectively:

$$f_3(q^2) = \frac{a_f^V(q^2)}{2m_f}, \quad f_4(q^2) = \frac{d_f^V(q^2)}{e} \quad (2)$$

Dipole moment couplings can be also seen as the coefficients of the corresponding vector boson-fermion-fermion ($V\psi\psi$) interaction terms of an $U(1)$ -invariant effective lagrangean

$$\begin{aligned} \mathcal{L} = \mathcal{L}_{SM} & - \frac{i}{2} d_f^V \bar{\psi}\sigma^{\mu\nu}\gamma_5\psi \mathcal{F}_{\mu\nu} \\ & + \frac{1}{2} \frac{ea_f^V}{2m_f} \bar{\psi}\sigma^{\mu\nu}\psi \mathcal{F}_{\mu\nu} \end{aligned} \quad (3)$$

where \mathcal{L}_{SM} is the tree-level Standard Model lagrangean and

$$\mathcal{F}_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu, \quad V = \gamma, Z \quad (4)$$

For on-shell photons ($V = \gamma$), we find the usual definition for the anomalous magnetic dipole moment (AMDM) $a_f^\gamma(q^2 = 0)$ and electric dipole moment (EDM) $d_f^\gamma(q^2 = 0)$. For on-shell Z -bosons ($V = Z$) we *define*, by analogy, the anomalous weak magnetic and weak electric dipole moments (AWMDM and WEDM) of the fermion f as the corresponding factors $a_f^w(q^2 = M_Z^2)$ and $d_f^w(q^2 = M_Z^2)$ in Eq.(3).

2.1. C , P and T transformation properties

As can be seen from Eq.(3), the dipole moment form factors are related with chirality-flipping operators of the theory. Under discrete C , P , and T symmetries the term with a_f^V is $C(+)$, $P(+)$

and $T(+)$; the one with d_f^V transforms as $C(+)$, $P(-)$ and $T(-)$. For the $V = Z$ case, the dipole moments may get an imaginary (absorptive) part which, contrary to the real part, is $T(-)$ for the A(W)MDM (a_f), and $T(+)$ for the (W)EDM (d_f).

2.2. Theoretical predictions

From the theoretical point of view, as it is already well known, only the on-shell definition of the AWMDM is electroweak gauge invariant and free of uncertainties. The AWMDM may receive contributions from both new physics and electroweak radiative correction to the SM.

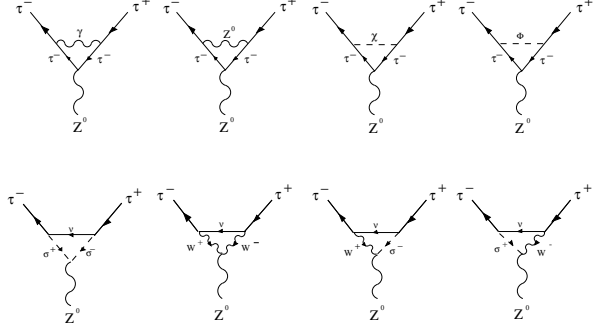


Figure 1. Contributing Feynman diagrams to a_τ^w that are also present for the AMDM (photon vertex).

The leading Standard Model contribution to a_τ^w has been computed [4] in the t 'Hooft-Feynman gauge, where no ambiguities in the finite parts are present [7]. There are 14 diagrams to consider, 6 of which are not present in the photon vertex case. The eight diagrams that have a photon analogue are shown in figure 1, and the new ones are shown in figure 2. One-loop contributions are formally of order α , but the magnitude of each diagram is in fact also governed by the weak-boson or Higgs mass-factors like m_τ^2/M_Z^2 or m_τ^2/M_Φ^2 , so that the Higgs contribution only modifies the real part of the result in less than a 1%. The main contributions come from the diagram with νWW and $W\nu\nu$ in the loop. The final result is [4]:

$$a_\tau^w(M_Z^2) = - (2.10 + 0.61 i) \times 10^{-6} \quad (5)$$

Notice the presence of an absorptive part of the same order as the dispersive part due to the fact that particles in the loop can be on-shell.

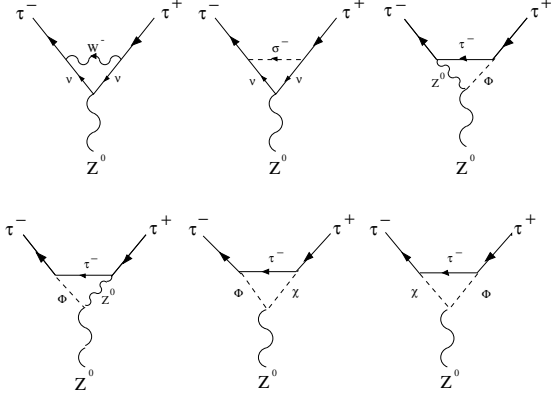


Figure 2. Contributing Feynman diagrams to a_τ^w that are not present for the AMDM (photon vertex).

On the other hand, from a very general argument, it was established [8] that for a fermion of mass m_f , contributions from new physics to the AWMDM at Λ -scale, must enter with a factor $\equiv m_f^2/\Lambda^2$, then it is clear that precise experiments in the measurement of the AWMDM may provide bounds for compositeness and also for the scale of new physics [9–11].

For the (W)EDM, d_τ , the theoretical predictions are much less precise. In the SM the Kobayashi-Maskawa phase is the only source of CP -violation and it is not possible to generate a non vanishing (W)EDM at one-loop level; one has to go up to three-loops [12] to get a non vanishing contribution. In extended models the situation changes and one can get a contribution to the WEDM moment already at one-loop [13–15], so that a CP -violating signal coming from an appreciable (weak) electric dipole moment will unambiguously lead to new physics.

3. SINGLE TAU POLARIZATION AT LEP1

Using the lagrangean (3), the tree level cross section for the process $e^+ e^- \rightarrow \tau^+ \tau^-$ unpolar-

ized scattering, at the Z -peak, can be written as:

$$\frac{d\sigma}{d\Omega_{\tau^-}} = \frac{d\sigma^0}{d\Omega_{\tau^-}} + \frac{d\sigma^S}{d\Omega_{\tau^-}} + \frac{d\sigma^{SS}}{d\Omega_{\tau^-}} \quad (6)$$

where the first term collects the spin independent terms,

$$\frac{d\sigma^0}{d\Omega_{\tau^-}} = \frac{\alpha^2 \beta}{(4s_w c_w)^4 \Gamma_Z^2} \times [A_0 + A_1 \cos^2 \theta_{\tau^-} + A_2 \cos \theta_{\tau^-}] \quad (7)$$

with

$$A_0 = (v^2 + a^2) \frac{2v^2 + \beta^2(a^2 - v^2)}{2s_w c_w} \quad (8)$$

$$A_1 = (v^2 + a^2)^2 \beta^2 \frac{1}{2s_w c_w} \quad (9)$$

$$A_2 = 4a^2 v^2 \beta \frac{1}{s_w c_w} \quad (10)$$

The second one takes into account the linear terms in the spin [4,16],

$$\frac{d\sigma^S}{d\Omega_{\tau^-}} = \frac{\alpha^2 \beta}{128 s_w^3 c_w^3 \Gamma_Z^2} [(s_- + s_+)_x X_+ + (s_- + s_+)_y Y_+ + (s_- + s_+)_z Z_+ + (s_- - s_+)_y Y_-] \quad (11)$$

with

$$X_+ = a \sin \theta_{\tau^-} \left\{ \frac{-v [2v^2 + (v^2 + a^2)\beta \cos \theta_{\tau^-}]}{\gamma s_w c_w} + 2\gamma [2v^2(2 - \beta^2) + (v^2 + a^2)\beta \cos \theta_{\tau^-}] \operatorname{Re}(a_\tau^w) \right\} \quad (12)$$

$$Y_+ = -2v\gamma\beta \sin \theta_{\tau^-} [2a^2 + (v^2 + a^2)\beta \cos \theta_{\tau^-}] \operatorname{Im}(a_\tau^w) \quad (13)$$

$$Y_- = 2a\gamma\beta \sin \theta_{\tau^-} [2v^2 + (v^2 + a^2)\beta \cos \theta_{\tau^-}] (2m_\tau d_\tau^w/e) \quad (14)$$

$$Z_+ = -\frac{va}{s_w c_w} [(v^2 + a^2)\beta(1 + \cos^2 \theta_{\tau^-}) + 2(v^2 + \beta^2 a^2) \cos \theta_{\tau^-}] + 2a [4v^2 \cos \theta_{\tau^-} + (v^2 + a^2)\beta(1 + \cos^2 \theta_{\tau^-})] \operatorname{Re}(a_\tau^w) \quad (15)$$

where α is the fine structure constant, Γ_Z is the Z -width and $\gamma = M_Z/(2m_\tau)$, $\beta = (1 - 1/\gamma^2)^{1/2}$ are the dilation factor and τ velocity, respectively. s_\pm are the polarization vectors of τ^\pm in the proper reference frame and $v = -1/2 + 2s_w^2$ and $a = -1/2$ are the SM vector and axial vector $Z\tau^-\tau^+$ couplings. We have neglected terms proportional to the electron mass and kept up to linear terms in the weak dipole moments. The reference frame is chosen such that the outgoing τ^- momenta is along the z axis and the incoming e^- momenta is in the $x - z$ plane, with θ_{τ^-} the angle determined by these two momenta. Terms with $(s_- - s_+)_{x,y,z}$ factors in Eq.(11) carry all the information about the CP -violating pieces of the lagrangean. Normal and transverse τ polarizations are zero at tree level in the SM, in the zero mass limit, due to helicity arguments.

The spin-spin term, $\frac{d\sigma^{SS}}{d\Omega_{\tau^-}}$, of Eq.(6), is not relevant in this calculation due to the fact that we are going to consider polarization asymmetries of a single *tau* only. By summing up over the polarization states of the other *tau*, it results in erasing this contribution.

3.1. Normal polarization (P_N)

The normal polarization (along y -axis) of a single *tau* (Y_\pm terms of Eq.(11)) is even under parity. Then, considering the transformation properties of the dipole moments described in section 2.1, only $a \cdot v^2 \cdot d_\tau^w$ or $a^3 \cdot d_\tau^w$ (no v suppression, in this case) terms are allowed in Y_- (see Eq.(14)), in contrast to the case in the spin-spin correlation observables, where the leading term is $a^2 \cdot v \cdot d_\tau^w$. The Y_+ term is CP -conserving and time reversal-odd; it is an observable generated by a T -odd absorptive part of the magnetic moment, $\text{Im}(a_\tau^w)$. The dependence with $a^2 \cdot v \cdot \text{Im}(a_\tau^w)$ or $v^3 \cdot \text{Im}(a_\tau^w)$ is associated with the fact that the normal polarization is even under parity.

3.2. Transverse polarization (P_T)

The transverse polarization (along the x -axis) of a single τ (X_+ term of Eq.(11)) is parity-odd and time reversal-even. It can only arise from the interference of both helicity conserving and helicity flipping amplitudes. The first term of X_+ in Eq.(12) comes from helicity flipping sup-

pressed ($1/\gamma \equiv 2m_\tau/M_Z$) amplitudes in the Standard Model and the second one comes from the γ -enhanced chirality flipping weak-magnetic tensorial a_τ^w vertex. Both contributions must be proportional to an odd number of axial-vector couplings a (av^3 or a^3).

If one allows the WEDM d_τ^w to have an (absorptive) imaginary part, then there is also a term (let us say X_-) proportional to this $T(+)$ imaginary part [11]. We are not going to take into account this contribution because sizeable contributions coming from new physics at a high Λ scale can not give any absorptive part at the M_Z scale, so that such terms must be obtained at higher orders and, in principle, must be much smaller.

4. AZIMUTHAL ASYMMETRIES

At LEP1 τ pairs decay before reaching the detectors and the energies and momenta of their hadronic decay products can be measured. In channels where both τ 's decay semileptonically, the τ direction can only be reconstructed up to a two fold ambiguity [17] if no high precision measurement of both charged hadron tracks is made. It is this ambiguity that destroys the information coming from polarization when looking at the decay products. However, with the help of micro-vertex detectors, a high resolution reconstruction of these hadron-tracks is possible, then the τ direction can be completely reconstructed [18]. This opens new possibilities to measure the transverse and normal component of the polarization from the angular distribution of single τ decay products. Therefore we will only consider semileptonic decay channels for both *taus*.

From Eq.(6) and Eq.(11), and following standard procedures [19], it is straightforward to get the expression for the $e^+e^- \rightarrow \tau^+ \tau^- \rightarrow h_1^+ X h_2^- \nu_\tau$ and $h_1^+ \nu_\tau h_2^- X$ cross sections:

$$\begin{aligned} & \frac{d\sigma(e^+e^- \rightarrow \tau^+\tau^- \rightarrow h_1^+ X h_2^- \nu_\tau)}{d(\cos\theta_{\tau^-}) d\phi_{h_2^-}} \\ &= Br(\tau^- \rightarrow h_2^- \nu_\tau) Br(\tau^+ \rightarrow h_1^+ X) \\ & \times \left[4 \frac{d\sigma^0}{d\Omega_{\tau^-}} + \frac{\alpha^2 \beta \pi}{128 s_w^3 c_w^3 \Gamma_Z^2} \alpha_{h_2^-} (X_+ \cos\phi_{h_2^-} \right. \end{aligned}$$

$$\begin{aligned}
& \left. \begin{aligned} & + (Y_- + Y_+) \sin \phi_{h_2^-} \end{aligned} \right] & (16) \\
& \frac{d\sigma(e^+e^- \rightarrow \tau^+\tau^- \rightarrow h_1^+\bar{\nu}_\tau h_2^- X)}{d(\cos \theta_{\tau^-}) d\phi_{h_1^+}} \\
& = Br(\tau^- \rightarrow h_2^- X) Br(\tau^+ \rightarrow h_1^+ \bar{\nu}_\tau) \\
& \times \left[4 \frac{d\sigma^0}{d\Omega_{\tau^-}} + \frac{\alpha^2 \beta \pi}{128 s_w^3 c_w^3 \Gamma_Z^2} \alpha_{h_1^+} (-X_+ \cos \phi_{h_1^+} \right. \\
& \left. + (Y_- - Y_+) \sin \phi_{h_1^+} \right] & (17)
\end{aligned}$$

where the angle ϕ_h is the azimuthal hadron angle in the frame we have already defined. All other angles have been integrated out. The longitudinal polarization term (Z_+) disappears when the polar angle θ_h of the hadron is integrated out. For π and ρ mesons the magnitude of the parameter α_h is $\alpha_\pi = 0.97$ and $\alpha_\rho = 0.46$.

4.1. Observables for the AWMDM

With the τ direction fully reconstructed in semileptonic decays, we can get information about the real part of the AWMDM, by defining the following asymmetry of the τ -decay products [4,16]:

$$A_{cc}^\mp = \frac{\sigma_{cc}^\mp(+)-\sigma_{cc}^\mp(-)}{\sigma_{cc}^\mp(+)+\sigma_{cc}^\mp(-)} \quad (18)$$

where

$$\sigma_{cc}^\mp(+)=\left(\int_0^1 d(\cos \theta_{\tau^-}) \int_{-\pi/2}^{\pi/2} d\phi_{h^\mp+}\right) \quad (19)$$

$$\int_{-1}^0 d(\cos \theta_{\tau^-}) \int_{\pi/2}^{3\pi/2} d\phi_{h^\mp+} \left) \frac{d\sigma}{d(\cos \theta_{\tau^-}) d\phi_{h^\mp+}}$$

$$\sigma_{cc}^\mp(-)=\left(\int_0^1 d(\cos \theta_{\tau^-}) \int_{\pi/2}^{3\pi/2} d\phi_{h^\mp+}\right) \quad (20)$$

$$\int_{-1}^0 d(\cos \theta_{\tau^-}) \int_{-\pi/2}^{\pi/2} d\phi_{h^\mp+} \left) \frac{d\sigma}{d(\cos \theta_{\tau^-}) d\phi_{h^\mp+}}$$

This asymmetry selects the $\cos \theta_{\tau^-} \cos \phi_{h^\mp}$ term of the cross section given in Eq.(16) and Eq.(17), which is the leading one in the anomalous weak-magnetic moment a_τ^w (it comes with the couplings a^3),

$$\begin{aligned}
A_{cc}^\mp &= \mp \alpha_h \frac{s_w c_w (v^2 + a^2)}{4 \beta a^3} \\
&\times \left[\frac{-v}{\gamma s_w c_w} + 2 \gamma \operatorname{Re}(a_\tau^w) \right] & (21)
\end{aligned}$$

Notice that it changes sign for τ^- and τ^+ .

Similarly, for the imaginary (absorptive) part of the AWMDM, one can define an asymmetry that selects the $\sin \phi_{h^\mp}$ term from Y_+ [4]:

$$\begin{aligned}
A_s^\mp &= \frac{\int_0^\pi d\phi_h^\mp \frac{d\sigma}{d\phi_h^\mp} - \int_\pi^{2\pi} d\phi_h^\mp \frac{d\sigma}{d\phi_h^\mp}}{\int_0^\pi d\phi_h^\mp \frac{d\sigma}{d\phi_h^\mp} + \int_\pi^{2\pi} d\phi_h^\mp \frac{d\sigma}{d\phi_h^\mp}} \\
&= \mp \alpha_h \frac{3\pi\gamma}{4} c_w s_w \frac{v}{a^2} \operatorname{Im}(a_\tau^w) & (22)
\end{aligned}$$

For numerical results we consider $10^7 Z$ events and one τ decaying into $\pi \nu_\tau$ or $\rho \nu_\tau$ (*i.e.* $h_1, h_2 = \pi$ or ρ in (16) and (17) respectively), while summing up over the $\pi \nu_\tau, \rho \nu_\tau$ and $a_1 \nu_\tau$ semileptonic decay channels of the τ for which the angular distribution is not observed (this amounts to about 52% of the total decay rate). Collecting events from the decay of both *taus*, one gets a sensitivity (within 1 s.d.) [4]:

$$|\operatorname{Re}(a_\tau^w)| \leq 4 \cdot 10^{-4} \quad (23)$$

$$|\operatorname{Im}(a_\tau^w)| \leq 1.1 \times 10^{-3} \quad (24)$$

Comparing these values with the SM predicted ones (5) it is clear that, if a large signal related to these observables is found, it should be attributed to physics beyond the SM.

4.2. Observables for the WEDM

The analysis of the *tau*-decay products allows us to select the terms of the cross sections (16) and (17) which carry the relevant information about the CP -violating effective coupling d_τ^w . The leading term (the one with a^3) is extracted by the asymmetry:

$$A_{sc}^\mp = \frac{\sigma_{sc}^\mp(+)-\sigma_{sc}^\mp(-)}{\sigma_{sc}^\mp(+)+\sigma_{sc}^\mp(-)} \quad (25)$$

where $\sigma_{sc}^\mp(\pm)$ are defined similarly as in Eqs. (19–20) but changing the ϕ_{h^\mp} angular integration to:

$$\sigma_{sc}^\mp(+)=\sigma(\cos\theta_{\tau^-}\cdot\sin\phi_{h^\mp}>0) \quad (26)$$

$$\sigma_{sc}^\mp(-)=\sigma(\cos\theta_{\tau^-}\cdot\sin\phi_{h^\mp}<0) \quad (27)$$

From Eqs. (16–17) we finally obtain:

$$A_{sc}^- = A_{sc}^+ = \alpha_h \frac{\gamma}{2} s_w c_w \frac{v^2 + a^2}{a^3} (2m_\tau d_\tau^w / e) \quad (28)$$

without any background from the Standard Model. It has the same sign for both τ^+ and τ^- .

Under the same hypothesis as for the AWMDM one can get, from this asymmetry, the following bound to the WEDM [16]:

$$|d_\tau^w| \leq 2.3 \cdot 10^{-18} e \cdot cm \quad (29)$$

The analysis made so far assumes there is no mixing among the weak dipole moments in the defined asymmetries. Then, the bounds presented here are the best one can get from azimuthal asymmetries. If one takes the complete set of dipole moments in the calculation of the asymmetries one has to either make a complete analysis with all the asymmetries [20] or construct genuine CP -conserving (-violating) observables to disentangle the different contributions. For example, a genuine CP -violating observable is the asymmetry A_{sc} as compared for the particle and its antiparticle

$$A_{sc}^{CP} \equiv \frac{1}{2}(A_{sc}^- + A_{sc}^+) \quad (30)$$

What is tested from the A_{sc}^{CP} -asymmetry is whether the normal polarizations of both τ ’s are different. Within the contributions considered in this paper, they are opposite. This implies the equality of the decay-product asymmetries (25), so $A_{sc}^{CP} = A_{sc}^+ = A_{sc}^-$ and the observable is given only by the CP -violating term d_τ^w , eliminating the contribution from a (v/a) suppressed $\text{Im}(a_\tau^w)$ term, coming from the Y_+ sector of the normal polarization (13). A similar CP -even observable can be obtained [11] for the A_s^\mp asymmetry, $A_s = (A_s^- - A_s^+)/2$, which cancels the CP -odd (again v/a suppressed) d_τ^w contribution from the Y_- sector (14) of P_N .

5. SPIN-SPIN CORRELATIONS

Bounds on the τ AWMDM can be also obtained by measuring spin correlation asymmetries in the decay of a Z to $\tau^+ \tau^-$. The CP -violating weak electric dipole moment (WEDM) has been considered in Ref. [22] by means of momentum correlations of the decay products of the τ pair. For the CP -conserving sector of the interaction described by lagrangean (3), the spin-spin term of the $e^+ e^- \rightarrow \tau^+ \tau^-$ cross section, at the Z -peak, can be written as:

$$\begin{aligned} \frac{d\sigma^{SS}}{d\Omega_{\tau^-}} &= \frac{\alpha^2}{128s_w^3c_w^3} \frac{1}{\Gamma_Z^2} [(s_x^+ s_x^-) \mathcal{X}\mathcal{X} \\ &+ (s_y^+ s_y^-) \mathcal{Y}\mathcal{Y} + (s_z^+ s_z^-) \mathcal{Z}\mathcal{Z} \\ &+ (s_x^+ s_y^- + s_y^+ s_x^-) \mathcal{X}\mathcal{Y} \\ &+ (s_x^+ s_z^- + s_z^+ s_x^-) \mathcal{Z}\mathcal{X} \\ &+ (s_y^+ s_z^- + s_z^+ s_y^-) \mathcal{Z}\mathcal{Y}] \end{aligned} \quad (31)$$

where the coefficients XX , XY , ZX ... carry all the information about the Transverse-Transverse, Transverse-Normal, Longitudinal-Transverse ... spin correlations.

Let us fix our attention on the spin correlation involving the transverse (within the production plane) and normal (to the production plane) components, relevant for the AWMDM:

$$\mathcal{X}\mathcal{X} \equiv (\mathcal{X}\mathcal{X})_0 \sin^2 \theta_{\tau^-} \quad (32)$$

$$\mathcal{X}\mathcal{Y} \equiv (\mathcal{X}\mathcal{Y})_0 \sin^2 \theta_{\tau^-} \quad (33)$$

$$\mathcal{Z}\mathcal{X} \equiv (\mathcal{Z}\mathcal{X})_0 \sin \theta_{\tau^-} + (\mathcal{Z}\mathcal{X})_1 \sin 2\theta_{\tau^-} \quad (34)$$

$$\mathcal{Z}\mathcal{Y} \equiv (\mathcal{Z}\mathcal{Y})_0 \sin \theta_{\tau^-} + (\mathcal{Z}\mathcal{Y})_1 \sin 2\theta_{\tau^-} \quad (35)$$

with

$$\begin{aligned} (\mathcal{X}\mathcal{X})_0 &= (a^2 + v^2) \\ &\times \left[\frac{(2v^2 - \beta^2(v^2 + a^2))}{2s_w c_w} - 4v \text{Re}(a_\tau^w) \right] \end{aligned} \quad (36)$$

$$(\mathcal{X}\mathcal{Y})_0 = 2a(a^2 + v^2)\beta \text{Im}(a_\tau^w) \quad (37)$$

$$(\mathcal{Z}\mathcal{X})_0 = 2a^2 v \beta \left[\frac{v}{s_w c_w \gamma} - 2\gamma \text{Re}(a_\tau^w) \right]$$

$$(\mathcal{Z}\mathcal{X})_1 = v(a^2 + v^2) \times \left[\frac{v}{2s_w c_w \gamma} - \gamma(2 - \beta^2)\text{Re}(\mathbf{a}_\tau^w) \right] \quad (38)$$

$$(\mathcal{Z}\mathcal{Y})_0 = 4\gamma a v^2 \beta^2 \text{Im}(\mathbf{a}_\tau^w) \quad (39)$$

$$(\mathcal{Z}\mathcal{Y})_1 = \gamma \beta a (v^2 + a^2) \text{Im}(\mathbf{a}_\tau^w) \quad (40)$$

These equations show that Transverse-Normal, C_{TN} (XY term), and Longitudinal-Normal, C_{LN} (ZY terms), spin correlations are directly proportional to the T -odd imaginary part of the τ weak magnetic dipole moment, while the Longitudinal-Transverse C_{LT} (ZX terms) is proportional (except for a small tree level contribution) to the real part of the dipole moment (note that $\gamma \gg 1$). Transverse-Transverse C_{TT} (XX term) are also sensible to the real part of the AWMDM but its contribution is not enhanced by the γ -factor.

In particular the XY spin correlation, C_{TN} , associated with the Transverse-Normal component of the τ polarizations

$$\langle P_T P_N \rangle = \frac{(XY)_0 \sin^2 \theta_\tau}{A_0 + A_1 \cos^2 \theta_{\tau^-} + A_2 \cos \theta_{\tau^-}} \quad (41)$$

(with A_0 , A_1 and A_2 defined in Eqs. (8–10)) is a parity-odd and time reversal-odd observable which, being generated by absorptive parts of the amplitude, must be proportional to the imaginary part of the AWMM. In the SM it also receives small contributions from the interference of γ exchange with the imaginary Z exchange amplitude [21]. When this contribution is subtracted from the definition of C_{TN} , the measured value, from data collected in 1992-1994 running period, by ALEPH [23] is:

$$C_{TN} = -0.08 \pm 0.14(\text{stat}) \pm 0.02(\text{syst}) \quad (42)$$

Using this data and the expression (41), in the $\beta \rightarrow 1$ limit,

$$C_{TN} \approx \frac{(XY)_0}{A_0} = \frac{4A}{(V^2 + A^2)} c_w s_w \text{Im}(\mathbf{a}_\tau^w) \quad (43)$$

one gets the following bound on the imaginary part of the AWMM:

$$|\text{Im}(\mathbf{a}_\tau^w)| < 0.04 \quad (44)$$

Up to now there is no measurement of the C_{LT} and C_{LN} correlations, that are sensitive to the real and imaginary part of the AWMDM.

6. CONCLUSIONS

We have studied the physical content of the normal and transverse τ polarizations for $\tau^+ \tau^-$ pairs produced from unpolarized $e^+ e^-$ collisions at the Z -peak, and shown how their measurement offers an opportunity to put bounds on the weak dipole moments induced by models beyond the standard theory. For semileptonic decays, where the τ direction can be reconstructed, we have defined appropriate asymmetries in the azimuthal distribution of the hadron from which one can measure the weak dipole moments. We have shown that the best sensitivity one can expect in the measurement of these observables is of the order of 10^{-4} (10^{-3}), for the real (imaginary) part of the anomalous weak magnetic dipole moment, and $10^{-18} e \cdot \text{cm}$ for the weak electric dipole moment. We have also shown an analysis of the spin-spin correlation terms that may also provide competitive independent bounds to the AWMDM. Nowadays sensitivities are below those required in order to measure the values predicted from the Standard Model.

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