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# Limits on the electromagnetic and weak dipole moments of the tau-lepton in a 331 model

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**Abstract**

Using as an input the data obtained by the L3 and OPAL Collaborations for the reaction $e^+e^- \to \tau^+\tau^-\gamma$ at the $Z_1$-pole, we obtained bounds on the electromagnetic and weak dipole moments of the tau-lepton in the context of a 331 model. Our bounds on the electromagnetic moments are consistent with the bounds obtained by the L3 and OPAL Collaborations for the reaction $e^+e^- \to \tau^+\tau^-\gamma$. We also obtained bounds on the tau weak dipole moments which are consistent with the bounds obtained recently by the DELPHI, ALEPH and BELLE Collaborations from the reaction $e^+e^- \to \tau^+\tau^-$. Our work complements other studies on the electromagnetic and weak dipole moments of the tau-lepton.

*Keywords:*
Electric and magnetic moments, taus, neutral currents, models beyond the standard model.

## 1. Introduction

The production of tau-lepton pairs in high energy $e^+e^-$ collisions has been used to set bounds on its electromagnetic and weak dipole moments [1]. In the Standard Model (SM), the $\tau$ anomalous magnetic moment (MM) $a_\tau = (g_\tau - 2)/2$ is predicted to be $(a_\tau)_{SM} = 0.0011773(3)$ [2] and the respective electric dipole moment (EDM) $d_\tau$ is generated by the GIM mechanism only at very high order in the coupling constant. Similarly, the weak MM and EDM are induced in the SM at the loop level giving $a^W_\tau = -(2.10 + 0.61i) \times 10^{-6}$ and $d^W_\tau \leq 8 \times 10^{-34}e$cm. Since the current bounds on these dipole moments are well above the SM predictions, it has been pointed out that these quantities are excellent candidates to look for physics beyond the SM [3]. The couplings of the photon and $Z$ gauge boson to charged leptons may be parameterized in the following form:

$$\Gamma^\alpha_V = eF_1(q^2)\gamma^\alpha + \frac{ie}{2m_l}F_2(q^2)\sigma^{\alpha\mu}q_\mu + eF_3(q^2)\gamma_5\sigma^{\alpha\mu}q_\mu, \quad (1)$$

where $V = \gamma, Z$, $m_l$ is the lepton mass and $q = p' - p$ is the momentum transfer. The $q^2$-dependent form-factors $F_i(q^2)$ have familiar interpretations for $q^2 = 0$: $F_1(0) \equiv Q_l$ is the electric charge; $F_2(0) \equiv a_l$; and $F_3 \equiv d_l/Q_l$. The weak dipole moments are defined in a similar way: $F^Z_2(q^2 = m^2_Z) = a^W_\tau$ and $F^Z_3(q^2 = m^2_Z) = d^W_\tau/e$. The latest bounds obtained for the electromagnetic and weak dipole moments from the DELPHI, ALEPH and BELLE Collaborations at the 95% C.L. are: $-0.052 < a_\tau < 0.013$, $-0.22 < d_\tau(10^{-16}\ e\text{cm}) < 0.45$ and $a^W_\tau < 1.1 \times 10^{-3}$, $d^W_\tau < 0.50 \times 10^{-17}e$cm.
Our aim in this work is to analyze the reaction $e^+e^- \to \tau^+\tau^-\gamma$ in the $Z_1$ boson resonance [4, 5, 6]. The analysis is carried out in the context of a 331 model [7] and we

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attribute electromagnetic and weak dipole moments to the tau-lepton.

## 2. The total cross section for $e^+e^- \to \tau^+\tau^-\gamma$

The total cross section for the reaction $e^+e^- \to \tau^+\tau^-\gamma$ using the neutral current lagrangian given in Eq. (9) of Ref. [7] for the 331 model is given in Eq. (2).

The MM, EDM and the mixing angle $\phi$ give a contribution to the total cross section for the process $e^+e^- \to \tau^+\tau^-\gamma$ of the form:

$$\sigma(e^+e^- \to \tau^+\tau^-\gamma) = \int \frac{\alpha^2}{48\pi}\left[\frac{e^2 a_\tau^2}{4m_\tau^2} + d_\tau^2\right]\left[\frac{1-4x_W+8x_W^2}{x_W^2(1-x_W)^2}\right]$$
$$\cdot\left[\frac{(1-4x_W+x_W^2)(s-2\sqrt{s}E_\gamma)+\frac{1}{2}E_\gamma^2\sin^2\theta_\gamma}{(s-M_{Z_1}^2)^2+M_{Z_1}^2\Gamma_{Z_1}^2}\right]$$
$$+\int \frac{\alpha^2 e}{256\pi}\left[\frac{ea_\tau}{2m_\tau}+d_\tau\right]\left[\frac{(1-4x_W+8x_W^2)^2}{x_W^2(1-x_W)^2}\right]$$
$$\cdot\left[\frac{9E_\gamma^2\sin^2\theta_\gamma+12\sqrt{s}E_\gamma-9s-4\sqrt{s}E_\gamma\sin^2\theta_\gamma}{\sqrt{s}E_\gamma\sin^2\theta_\gamma[(s-M_{Z_1}^2)^2+M_{Z_1}^2\Gamma_{Z_1}^2]}\right] \quad (2)$$
$$+\int \frac{\alpha^3}{16}\left[\frac{(1-4x_W+8x_W^2)^2}{x_W^2(1-x_W)^2}\right]$$
$$\cdot\left[\frac{-s^2+3s\sqrt{s}E_\gamma-2sE_\gamma^2+\frac{1}{2}sE_\gamma^2\sin^2\theta_\gamma-\frac{3}{4}\sqrt{s}E_\gamma^3\sin^2\theta_\gamma}{sE_\gamma^2\sin^2\theta_\gamma[(s-M_{Z_1}^2)^2+M_{Z_1}^2\Gamma_{Z_1}^2]}\right]$$
$$\times\left(\cos\phi-\frac{\sin\phi}{\sqrt{3-4x_W}}\right)^4 E_\gamma dE_\gamma d\cos\theta_\gamma.$$

The expression given for the first term corresponds to the cross-section previously reported by Grifols and Mendez [8], while the second and third terms comes from the contribution of the 331 model, of the interference and the SM contribution due to bremsstrahlung in which the photon is radiated to the final tau or antitau. Evaluating the limit when the mixing angle is $\phi = 0$, the terms that depend of $\phi$ in (2) are zero and Eq. (2) is reduced to the expression (4) given in Ref. [8], more the contribution of the interference and the contribution of the SM, respectively.

## 3. Results and Conclusions

In order to evaluate the integral of the total cross section as a function of the mixing angle $\phi$ of the 331 model, we require cuts on the photon angle and energy to avoid divergences when the integral is evaluated at the important intervals of each experiment. We integrate over $\cos\theta_\gamma$ from $-0.74$ to $0.74$ and $E_\gamma$ from 5 $GeV$ to 45.5 $GeV$.

Table 1: Table 1. Limits on the $a_\tau$ magnetic moment and $d_\tau$ electric dipole moment at 90% C. L..

| $\phi$ | $a_\tau$ | $d_\tau(10^{-16}\ e\,\mathrm{cm})$ |
|---|---|---|
| $-3.979\times10^{-3}$ | [-0.049, 0.025] | [-2.72, 1.38] |
| 0 | [-0.052, 0.028] | [-2.88, 1.55] |
| $1.309\times10^{-4}$ | [-0.053, 0.029] | [-2.94, 1.61] |

Table 2: Limits on the $a_\tau^W$ weak magnetic moment and $d_\tau^W$ weak electric dipole moment at 90% C. L..

| $\phi$ | $a_\tau^W(10^{-3})$ | $d_\tau^W(10^{-17}\ e\,\mathrm{cm})$ |
|---|---|---|
| $-3.979\times10^{-3}$ | [-2.166, 2.086] | [-1.202, 1.158] |
| 0 | [-2.193, 2.113] | [-1.217, 1.173] |
| $1.309\times10^{-4}$ | [-2.194, 2.114] | [-1.218, 1.174] |

The total number of events is given by $N \approx \sigma(\phi, a_\tau, d_\tau)\mathcal{L}$, where $N = 1559$ and $\mathcal{L} = 100\ pb^{-1}$ for the process $e^+e^- \to \tau^+\tau^-\gamma$. Taking this into consideration, we can get a bound for the tau magnetic moment as a function of $\phi$ with $-3.979\times10^{-3} \le \phi \le 1.309\times10^{-4}$ [7] and $d_\tau = 0$. The values obtained for this bound for several values of the $\phi$ parameter are show in Table 1.

The bounds for the weak dipole moments of the tau-lepton according to the data from the L3 Collaboration [1] are given in the Table 2.

In conclusion, we determined bounds on the electromagnetic and weak dipole moments of the tau-lepton using the data published by the L3 and OPAL Collaborations for the process $e^+e^- \to \tau^+\tau^-\gamma$. In addition, we obtained bounds for the weak dipole moments similar to those obtained recently by the DELPHI, ALEPH and BELLE Collaborations from the process $e^+e^- \to \tau^+\tau^-$. In the limit $\phi = 0$, our bound take the value previously reported in Ref. [8] for the SM. In addition, the analytical and numerical results for the total cross section have never been reported in the literature before and could be of relevance for the scientific community.

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