Dipole moments of the \( \tau \)-neutrino

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Abstract. Bounds on the anomalous magnetic moment and the electric dipole moment of the \( \tau \)-neutrino are calculated through the reaction \( e^+e^- \rightarrow \nu \bar{\nu}\gamma \) at the \( Z_1 \)-pole, and in the framework of a left-right symmetric model. The results are based on the recent data reported by the L3 Collaboration at CERN LEP. We find that the bounds are almost independent of the mixing angle \( \phi \) of the model in the allowed experimental range for this parameter.

1. Introduction

In many extensions of the Standard Model (SM) the neutrino acquires a nonzero mass, a magnetic moment and an electric dipole moment \([1]\). In this manner the neutrinos seem to be likely candidates for carrying features of physics beyond the Standard Model \([2]\). Apart from masses and mixings, magnetic moments and electric dipole moments are also signs of new physics and are of relevance in terrestrial experiments, in the solar neutrino problem, in astrophysics and in cosmology \([3]\).

At the present time, all of the available experimental data for electroweak processes can be understood in the context of the Standard Model of the electroweak interactions (SM), with the exception of the results of the SUPER-KAMIOKANDE experiment on the neutrino-oscillations \([4]\), as well as the GALLEX, SAGE, GNO, HOMESTAKE and LSND \([5]\) experiments.

Our aim in this work is to analyze the reaction \( e^+e^- \rightarrow \nu \bar{\nu}\gamma \). We use recent data collected with the L3 detector at CERN LEP \([6-9]\) near the \( Z_1 \) boson resonance in the framework of a left-right symmetric model and we attribute an anomalous magnetic moment and an electric dipole moment to a massive tau neutrino. Processes measured near the resonance serve to set limits on the tau neutrino magnetic moment and electric dipole moment. In this paper, we take advantage of this fact to set bounds for \( \mu_\nu \) and \( d_\nu \) for different values of the mixing angle \( \phi \) \([10-12]\), which is consistent with other constraints previously reported \([9,13,14,15,18]\) and \([16,17]\).

2. The Total Cross Section

We calculate the total cross section of the process \( e^+e^- \rightarrow \nu \bar{\nu}\gamma \) using the Breit-Wigner resonance form \([19]\)
Table 1. Bounds on the $\mu_{\nu_{\tau}}$ magnetic moment and $d_{\nu_{\tau}}$ electric dipole moment for different values of the mixing angle $\phi$ in the $Z_1$ resonance, i.e., $s = M_{Z_1}^2$.

| $\phi$ | $\mu_{\nu_{\tau}} \times 10^{-6} \mu_B$ | $d_{\nu_{\tau}} \times 10^{-17} \text{cm}$ |
|--------|---------------------------------|---------------------------------|
| -0.009 | 3.37                            | 6.50                            |
| -0.005 | 3.34                            | 6.44                            |
| 0      | 3.31                            | 6.38                            |
| 0.004  | 3.28                            | 6.32                            |

\[
\sigma (e^+e^- \rightarrow \nu \bar{\nu} \gamma) = \frac{4\pi(2J + 1)\Gamma_{e^+e^-} \Gamma_{\nu \bar{\nu} \gamma}}{(s - M_{Z_1}^2)^2 + M_{Z_1}^2 \Gamma_{Z_1}^2},
\]

(1)

where $\Gamma_{e^+e^-}$ is the decay rate of $Z_1$ to the channel $Z_1 \rightarrow e^+e^-$ and $\Gamma_{\nu \bar{\nu} \gamma}$ is the decay rate of $Z_1$ to the channel $Z_1 \rightarrow \nu \bar{\nu} \gamma$.

The total cross section is given by

\[
\sigma (e^+e^- \rightarrow \nu \bar{\nu} \gamma) = \int \frac{\alpha^2(\mu_{\nu_{\tau}}^2 + d_{\nu_{\tau}}^2)}{192\pi} \left[ \frac{1}{2}(a^2 + b^2) - 4a^2x_W + 8a^2x_W^2 \right]
\]

\[
\times \frac{x_W^2(1 - x_W)^2}{(s - M_{Z_1}^2)^2 + M_{Z_1}^2 \Gamma_{Z_1}^2} \frac{E_{\gamma}dE_{\gamma}d\cos \theta_{\gamma}}{(s - M_{Z_1}^2)^2 + M_{Z_1}^2 \Gamma_{Z_1}^2},
\]

(2)

where $x_W \equiv \sin^2 \theta_W$.

Evaluating the limit when the mixing angle is $\phi = 0$, the expression for $a$ and $b$ is reduced to $a = b$ and Eq. (2) is reduced to the expression (3) given in Ref. [13].

3. Results

As was discussed in Ref. [13], $N \approx \sigma(\phi, \mu_{\nu_{\tau}}, d_{\nu_{\tau}}) \mathcal{L}$. Using the Poisson statistic [9,20], we require that $N \approx \sigma(\phi, \mu_{\nu_{\tau}}, d_{\nu_{\tau}}) \mathcal{L}$ be less than 14, with $\mathcal{L} = 137 \text{ pb}^{-1}$, according to the data reported by the L3 Collaboration Ref. [9] and references therein. Taking this into consideration, we put a bound for the tau neutrino magnetic moment and the electric dipole moment as a function of the $\phi$ mixing parameter. We show the value of this bound for values of the $\phi$ parameter in Table 1.

4. Conclusions

We have determined a bound on the magnetic moment and the electric dipole moment of a massive tau neutrino in the framework of a left-right symmetric model as a function of the mixing angle $\phi$, as shown in Table 1.

In summary, we conclude that the estimated bound for the tau neutrino magnetic moment and the electric dipole moment are almost independent of the experimental allowed values of the $\phi$ parameter of the model. In the limit $\phi = 0$, our bound takes the value previously reported in the Ref. [9].
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