PoS PROCEEDINGS OF SCIENCE

Electromagnetic dipole moments of the τ-lepton at the ILC and CLIC

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We quantify the anomalous magnetic moment and electric dipole moment of the τ-lepton through the process $e^+e^- \to \tau^+\tau^-\gamma$, within the ranges of energies and luminosities affordable at the future International Linear Collider (ILC) and the Compact Linear Collider (CLIC). The tau-lepton is a key particle in various Beyond the Standard Model (BSM) models and is considered a laboratory for many experimental or simulation aspects in searches for new physics. In particular, the tau-lepton anomalous couplings to bosons in the $\tau^+\tau^-\gamma$ and $\tau^+\tau^-Z$ vertices, have made the tau-lepton one of the most attractive particles for new physics searches.

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1. Introduction

The anomalous electromagnetic dipole moments of charged leptons provide very precise tests of quantum electrodynamics. In addition, the Standard Model (SM) predictions can also be confronted with these properties; that is these particles can help both to test the SM and to find new physics. The study of the magnetic and electric dipole moments of the tau-lepton gains special interest due to a hint of possible new physics BSM. The main purpose is to quantify the Anomalous Magnetic Moment (AMM) and the Electric Dipole Moment (EDM) of the τ-lepton through the process $e^+e^- \to \tau^+\tau^-\gamma$, framed in the $SU(4)_L \times U(1)_X$ electroweak model [1–4], within the ranges of energies and luminosities affordable at the ILC and CLIC linear colliders. The $SU(4)_L \times U(1)_X$ symmetry is a natural extension of the $SU(3)_C \times SU(3)_L \times U(1)_X$ symmetry, also known as the 3-3-1 model.

2. Cross-section for the reaction $e^+e^- \to \tau^+\tau^-\gamma$

We estimates the prediction for the AMM and the EDM of the tau-lepton through the process $e^+e^- \to (Z_i) \to \tau^+\tau^-\gamma$, $Z_i = 1, 2, 3$ at the ILC and CLIC. The Feynman diagrams which give the most important contribution to the cross-section from $e^+e^- \to \tau^+\tau^-\gamma$ at the Z_i resonance are shown in Fig. 1. This process allows us to determine phenomenological limits for the AMM and the EDM of the τ. As a result we find that contributions of the a_τ and d_τ increase the total cross-section of the process $e^+e^- \to (Z_i) \to \tau^+\tau^-\gamma$, $Z_i = 1, 2, 3$. The sensitivity bounds on the magnetic and electric dipole moments of the τ-lepton are sensitivity to the parameters of the future ILC and CLIC. Limits can be set on the dipole moments a_τ and d_τ of the tau-lepton according to the ratio of the $SU(4)_L \times U(1)_X$ scale versus $SU(3)_C \times SU(2)_L \times U(1)_Y$ scale.

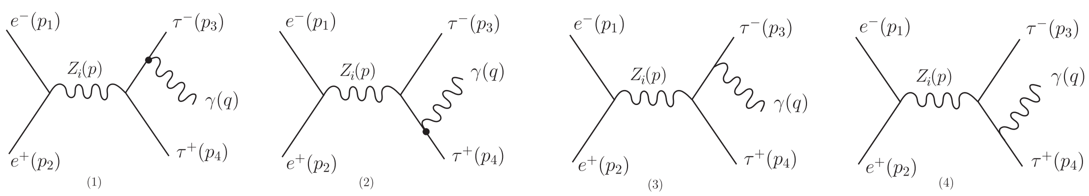

Fig. 1: The Feynman diagrams contributing to the signal process $e^+e^- \to \tau^+\tau^-\gamma$ when the Z_i vector bosons are produced on mass-shell. New physics (represented by a black circle) in the electroweak sector can modify the $\tau^+\tau^-\gamma$ couplings.

We calculate the cross-section for the reaction $e^-(p_1)e^+(p_2) \to \tau^-(p_3)\tau^+(p_4)\gamma(q)$ using the neutral current lagrangian for the $SU(4)_L \times U(1)_X$ model for the Feynman diagrams of Fig. 1. The model predicts the existence of two new neutral gauge bosons Z_2 and Z_3.

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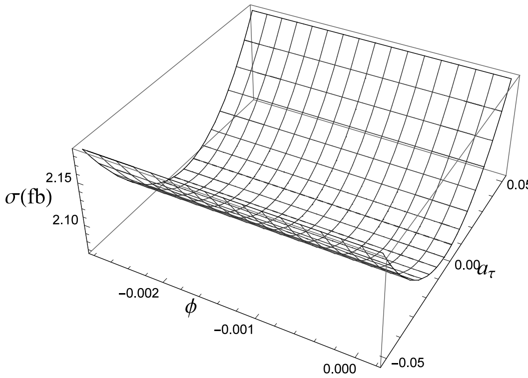

Fig. 2: The surface shows the shape for the cross-section of the process $e^+e^- \to \tau^+\tau^-\gamma$ as a function of AMM a_τ and the mixing angle ϕ with $\sqrt{s} = 3000$ GeV.

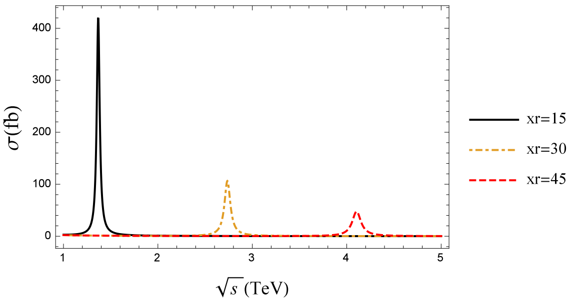

Fig. 3: The total cross-section of the production process $e^+e^- \to \tau^+\tau^-\gamma$ as a function of $\sqrt{s}$ for $x_r = 15$ (solid line), $x_r = 30$ (dot-dashed line) and $x_r = 45$ (dashed line).

3. Results and Conclusion

We consider the following pertinent approximations, (1) we approximate the mass of the two new neutral gauge bosons are of the same order, $M_{Z_2} \approx M_{Z_3}$. In this way, their decay rate is approximately of the same order $\Gamma_{Z_2} \approx \Gamma_{Z_3}$. (2) The mass of Z_2, Z_3 bosons can be approximated as $M_{Z_{2,3}} = x_r M_{Z_1}$ with $x_r = \frac{M_{Z_2}}{M_{Z_1}}$, and the decay width of the Z_2, Z_3 bosons are approximated as: $\Gamma_{Z_{2,3}} = x_r \Gamma_{Z_1}$. The mass range of the new neutral gauge bosons investigated is $\mathcal{O}(1.3 - 3.9)$ TeV [5, 6], which is equivalent to $x_r\ \epsilon$.

TABLE 1: Benchmark parameters of the ILC and CLIC based e^+e^- colliders [7–10].

ILC	$\sqrt{s}$ (TeV)	$\mathcal{L}(\text{fb}^{-1})$
Phase I	0.250	10, 100, 250, 500, 1000
Phase II	0.5	10, 100, 250, 500, 1000
Phase III	1	10, 100, 250, 500, 1000
CLIC	$\sqrt{s}$ (TeV)	$\mathcal{L}(\text{fb}^{-1})$
Phase I	0.380	100, 250, 500, 800, 1000
Phase II	1.5	100, 500, 1000, 2000, 3000
Phase III	3	100, 500, 1000, 3000, 5000

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In our numerical analysis, we obtain the total cross-section for the $e^+e^- \to \tau^+\tau^-\gamma$ signal, that is $\sigma_{Tot} = \sigma_{Tot}(a_\tau, d_\tau, \sqrt{s}, x_r, \phi)$. Thus, in our numerical computation, we will assume that $\sqrt{s}$, x_r and ϕ are free parameters, with the benchmark parameters for the ILC and CLIC, the best-expected sensitivity limits for the a_τ magnetic moment and the d_τ electric dipole moment of the tau-lepton with $\sqrt{s} = 250$ GeV, $\mathcal{L} = 250, 500, 1000$ fb^{-1} and $x_r = 15$ are:

$$|a_\tau| = [0.0147;\ 0.0104;\ 0.0073], \tag{1}$$

$$|d_\tau(\text{ecm})| = [8.198;\ 5.797;\ 4.099] \times 10^{-17}. \tag{2}$$

These bounds are competitive with respect to the experimental results reported by the DELPHI and BELLE Collaborations, as well as with others limits reported in the literature.

3.1 Conclusion

We have studied the phenomenology of the cross-section of the $e^+e^- \to \tau^+\tau^-\gamma$ signal, as well as the sensitivity on the AMM a_τ and the EDM d_τ of the tau-lepton in the model based on the $SU(4)_L \times U(1)_X$ symmetry. The sensitivity limits on the electromagnetic dipole moments were estimated for future e^+e^- linear colliders ILC and CLIC with center-of-mass energies of $\sqrt{s} = 250 - 3000$ GeV and integrated luminosities of $\mathcal{L} = 250 - 5000$ fb^{-1}. We find that the sensitivity bounds on the a_τ and d_τ at the ILC and CLIC at high energy and high luminosity can reach a sensitivity of the order of $\mathcal{O}(10^{-3} - 10^{-1})$ and $\mathcal{O}(10^{-17})$(ecm) at 95% C.L., respectively.

Our results do not appear outside the realm of detection in future experiments with improved sensitivity. In addition, a fiducial contribution is that our analytical and numerical results for the total cross-section have not been reported before in the literature and could be of relevance for the scientific community.

Acknowledgments

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